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The Effective Technological Processes for PGM Recovery from Dunites of Urals Platinum Belt, Russia

[1]A.P. Kozlov and [2]T.N. Matveeva

[1] Vernadsky State Geological Museum, Russian Academy of Sciences, Russia.
[2]Institute of Comprehensive Exploitation of Mineral Resources, Russian Academy of Sciences, Russia.

[1]Orcid: 0000-0002-5146-8194, [2]orcid: 0000-0002-5658-9948

Abstract

The results of mineralogical and technological studies of platiniferous dunites from Svetloborsky zonal massif (Urals platinum belt) are presented and the basic typomorphic signs of productive mineral assemblages are substantiated. The characteristic features of platinum ore mineralization are revealed: a wide range of iron-platinum alloys, enrichment of ore-formed system by the elements Os, Ir, Rh and activity of the S and As in it, intrusion of Fe-Ni sulphides in platinum and its fusion with magnetite.

More than 80% of PGM mineral grains has size less than 100 microns, that determines the possibility of significant losses of platinum in the process of gravity separation and the need for additional recovery processes for small and fine fractions of platinum tailings and sludge products.

Summarized results of laboratory tests of small-volume sample processing of platiniferous dunites are presented and the processing flow sheet is developed and tested. The flow sheet incorporates several stages, including stage-wise grinding and gravity separation of ore using the centrifugal concentrator Knelson KS-MD for differently sized material and flotation treatment of tailing products using new classes of reagents for additional recovery of PGM fines.

Keywords: Dunites, PGM mineralization, Mineralogical and Technological Research, Technological Processes, Gravity Separation, Flotation

INTRODUCTION

Since the 19th century, Russia has been a leading producer of platinum group metals (PGM), primarily platinum [1]. The only resource of this valuable minerals then have been unique platinum placers of Nizhny Tagil and Isovsky areas in the Middle Urals, from which more than 520 tons of platinum has been mined historically. By the middle of the last century, the main reserves of platinum placer deposits in the Urals were exhausted [2]. It was believed that the remaining primary resources presented by disparate strands and schlieren of chromite ore, had no independent commercial value due to the small volume and a high degree of erosion. However, current estimates by specialists dealing with metallogeny of PGM suggest that Ural Platinum Belt retains its unique potential for platinum ore. The main expectations are associated with the Nizhny Tagil dunites and mafic-ultramafic Svetloborsky arrays, which are now confined space waste deposits of alluvial platinum [3]. The average content of platinum in dunites is low (0.3 – 1.7 ppm), so the potential of industrial mining of these platinum ore will be determined by achieving a technological solutions to their processing with low production cost and high recovery of valuable components could [4-6].

METHODOLOGY

The study has integrated the research from three main directions: mineralogical and mineral processing research of platinum-hosting dunites, study of platinum extraction by gravity methods and additional recovery of platinum from the tailings after gravity separation by flotation.

Mineralogical and Technological Research

The main task of mineralogical and mineral processing research was to study the productive mineral associations of PGM in dunites of Svetloborsky array. It was aimed at identifying the assemblages of platinum mineralization and rock-forming minerals and ore dunites, the size and shape of the localization of mineral grains of PGM major technological properties of productive PGM mineralization. For the purposes of the studies seven mineralogical and metallurgical samples (15 – 20 kg) of dunites were selected, as well as samples from exploration wells and ditches.

To isolate the platinum mineralization on the first stage of the study the samples were crushed to less than -2.0 mm particle size, washed in water and then separated in a heavy liquid (bromoform). All grains similar to platinum were selected visually from gravity concentrates under a binocular microscope. Secondly, tails were subjected to additional grinding to a particle size less than -0.6 mm followed by obtaining a concentrate of heavy minerals and selection of individual grains of PGM. Thirdly, each fraction was separated into magnetic and nonmagnetic sub-fractions. Totally from the concentrates obtained on the first stage of gravity separation (-2.0 mm) of the samples of Svetloborsky array 638 grains were determined and separated. After grinding (-0.6 mm) and concentration 524 grains were additionally found in the concentrates.

After fabrication of thin polished sections and blocks a complex mineralogical studies was performed, integrating: the study of relationships between the PGM minerals and host rock-forming and ore minerals by optical microscopy and scanning electron microscopy, determination of platinum mineral forms by X-ray microanalysis; photographing of individual grains and productive microparageneses .

When the main categories of the studied platinum parageneses in dunites of Svetloborsky array were compared with other zonal arrays of Platinum Belt of the Urals (Nizhny Tagil and Kamenushinsky arrays) and Koryak-Kamchatka Platinum Belt (Gal'moenan zoned massif) it was established that they all possessed the following common (typomorphic) features [7, 8]: the significant predominance of the iron-platinum alloys over the other PGM minerals in their composition; development of two magmatic parageneses - early platinum-osmium and later platinum-iridium in equilibrium with magmatic sulfides of variable composition [(Ru, Os)S_2]; manifestation of superimposed sulfide-arsenide platinum mineralization integrated with iridium or rhodium specializations; post magmatic evolution of assemblages forwarding to increasing copper in the system; the development of redox processes in the final stages of formation of mineral assemblages: platinum oxides and multi-component alloys reduced from the sulfide PGM (Ir-Rh-Fe).

The characteristic features of the mineral association of Svetloborsky array were determined to be the following: a wide range of iron-platinum alloys; enrichment of ore-forming system by the elements Os, Ir, Rh and activity of the S and As in it; intrusion of Fe-Ni sulfides in platinum minerals and close fusion with secondary magnetite.

The contrast technological properties of platinum group elements (PGM) mineralization in Svetloborsky array should be characterized as: occurrence of more than 80 % of the grains of platinum-containing minerals in the size classes of less than -100 microns; association of tulameenite, sulfides and PGM sulfur-arsenides inside productive platinum mineralization that have low micro-hardness (less than 170 kg/mm^2); comprising platinum productive parageneses of PGM minerals having expressed magnetic properties (tetraferroplatinum, oxidized platinum), as well as secondary magnetite and various Fe-containing alloys.

Concentration of Platinum by Gravity Methods

Complex laboratory tests were perfomed using technological sample of dunites weighing 84 kg selected on Svetloborsky array, Vysotsky deposit, ore zone number 1. The sample was selected on the canvas applying trench method of surface mining. Ore material was presented by serpentinized dunites with numerous veins and intrusions of serpentine, pyroxene, and chlorite. According to the probe passport platinum content in the sample estimated 0.7-0.9 ppm, but the results of chemical analysis and subsequent determination by atomic emission spectrometry with inductively coupled plasma (ICP AES) determined 0.28 ppm Pt.

Scheme of laboratory tests on samples of technological gravitational scheme incorporated 4 main stages: preparation of samples for research, including crushing and grinding operations, stage-wise processing of ore by the centrifugal concentrator; cleaning of gravity concentrates on the concentration table, magnetic separation of gravity concentrations and tailings.

The survey was conducted based on the GRG (gravity recoverable gold) test, which provides 3-stage processing of ore by the centrifugal concentrator "Knelson KC- MD". In accordance with the procedure feed size in the first stage was -2.0 (1.7) mm, the second - roughly 80 % -250 microns (0.5 mm) and the third - 80 % -75 microns (- 0 1 mm).

When processing the sample of platinum dunite the following gravity concentrates were obtained: the first stage concentrate weight was 428 g with a yield of 0.67 %, the second stage concentrate weight was 484 g with a yield of 0.76 %, and a third - 522 g with a yield of 0.82 %. The total mass of the gravitational concentrate was 1434 g with a yield of 2.26 % of the original sample. Tailings yield was 97.7 %.

The KC-MD concentrates obtained in each stage were subjected to cleaning on the concentration table "TCO". In the process of reduction of probe mass (4.4 times) three samples of 115 g, 92 g and 118 g were obtained.

Based on the results of the mineralogical analysis of platinum minerals that possess definite magnetic properties (tetraferroplatinum, oxidized platinum), as well as adhesions with platinum magnetite, magnetic separation of gravity concentrates and tailing products was carried out in a constant magnetic field.

Results of Pt distribution in the products obtained under the dressing operations using lead smelting method followed by atomic emission spectroscopy using an inductively coupled plasma (ICP-AES) are shown in Table 1.

Table 1: Distribution of platinum between the products of gravity concentration

Product	Fraction	Mass, g	Yield, %	Content of Pt, ppm	Recovery of Pt, %
Initial probe		63470	100,0	0.28 (0.422)	
1 stage of concentration					
Concentrate TCO1	Magnetic fraction	49	0.08	54.81	10.0
	Non-magnetic fraction	66	0.10	23.17	5.7
	Total	115	0.18	(36.65)	15.7
Tails TCO 1	Magnetic fraction	39	0.06	н/о	
	Non-magnetic fraction	274	0.43	н/о	
	Total	313	0.49	0.57	0.7
Concentrate КС-MD 1		428	0.67	(10.26)	16.4
Tails КС-MD 1		63042	99.33		
2 stage of concentration					
Concentrate TCO2	Magnetic fraction	69	0.11	46.69	12.0
	Non-magnetic fraction	23	0.04	54.58	4.7
	Total	92	0.14	(48.66)	16.7
Tails TCO 2	Magnetic fraction	115	0.18	3.16	1.4
	Non-magnetic fraction	277	0.44	0.73	0.7
	Total	392	0.62	(1.44)	2.1
Concentrate КС-MD 2		484	0.76	(10.41)	18.8
Tails КС-MD 2		62558	98.56		
3 stage of concentration					
Concentrate TCO 3	Magnetic fraction	89	0.14	23,1	7.7
	Non-magnetic fraction	29	0.05	17,3	1.9
	Total	118	0.19	(21.69)	9.6
Tails TCO 3	Magnetic fraction	89	0.14	4,34	1.4
	Non-magnetic fraction	315	0.50	0,51	0.6
	Total	404	0.64	(1.35)	2.0
Concentrate КС-MD 3		522	0.82	(5.94)	11.6
Total concentrate КС-MD		**1434**	**2.26**	**(8.73)**	**46.8**
- Total concentrate TCO		**325**	**0.51**	**(34.62)**	**42.0**
- Tails TCO (magnetic fraction)		**204**	**0.32**	**(3.67)**	**2.8**
- Tails TCO (non-magnetic fraction)		**905**	**1.43**	**(0.59)**	**2.0**
Dump tails		**62036**	**97.74**	**0.23**	**53.2**

Note: In parentheses are the calculated values Pt content.

Flotation Recovery of Platinum from the Tails of Gravity

Laboratory experiments on the flotation recovery of fine fractions of platinum mineralization using conventional butyl xanthate, modified diethyldithiocarbamate (reagent DEDTCm) and reagent Hostaflot M -91 (manufactured by "Clariant") were performed on re-grinding to a particle size 80% -0.071 mm tails finishing products of concentrates obtained after centrifugal concentration “TCO 1, TCO 2, TCO 3”.

Modified diethyldithiocarbamate (reagent DEDTCm) has been used as an additional collector of platinum minerals, based on its ability to form a coordination bond with platinum and selective adsorption on the surface of platinum-bearing sulfides [9, 10]. High selectivity of reagent Hostaflot M-91 with respect to the platinum-bearing copper and nickel minerals has been reached in flotation of copper-nickel sulfide ores [11, 12].

Based on the results of mineralogical studies, productive platinum mineral association of Svetloborsky array was exposed to oxidation, leading to the replacement of primary minerals of PGM by platinum oxides phases with varying degree of oxidation. The occurrence of oxidized platinum compounds apparently leads to a lower flotation ability of the minerals, so with the aim to dissolve oxidized films on the surface of Pt and to update mineral surface properties we proposed to use an ultrasonic washing of the ore sample prior to flotation.

In addition, the characteristic feature of the platinum minerals in dunites of Svetloborsky array is platinum mineralization association with secondary magnetite, which forms a close fusion with PGE and PGM grains on the periphery and fills cracks and pores in the altered and oxidized platinum. An additional collector of oxidized minerals - oxihydryl collector (OC) was tested.

The first series of experiments was carried out on samples of the magnetic fraction of gravity tails with advanced ultrasonic washing of the sample. A sample by mass of 15 g was tested in the flotation camera 100 ml. Reagent mode: the collector dosage - xanthate + OC – (150 +150) g/t, the regulator of medium to pH 8.5; frother MIBC - 60 g/t , flotation time 5 min. As a result of the flotation concentrate yield was 27.7 - 36.4%. The combined flotation products, respectively, concentrates and tailings were assayed for platinum content. Flotation results are shown in Table 2.

Table 2: Flotation results of combined magnetic fractions after gravity concentration

Product	Yield, %	Content of Pt, ppm	Recovery of Pt, %
Concentrate	34.47	4.09	56.01
Tails	65.53	1.69	43.99
Feed sample	100	2.52	100

Extraction of platinum into the concentrate was 56.01 % with a concentration of 4.09 ppm Pt. The selected mode when the reagent combination of collectors in conjunction with pre-washing of the original sample has a concentration of platinum in the froth flotation product.

A second series of experiments was carried out on the combined product of the magnetic and nonmagnetic fractions of size -0.5 mm (61% of -0.071 mm) and -0.1 mm (80% of -0.071 mm) through re-grinding of fraction -0.5 mm up to 80 % -0.071 mm, ultrasonic washing and magnetic separation of flotation tailings. Flotation conditions: ore weighed 100 g, flotation cell volume 750 ml, the collectors - xanthate, DEDTKm, Hostaflot M -91, OC (150-300 g/t), depressor of gangue minerals (300 g/t), MIBC as frother - 60 g/t , 5 min flotation time . The results of the experiments are shown in Table 3**.**

Table 3: Results of flotation of combined tailings after gravity concentration

No	Product	Yield, %	Content of Pt, ppm	Recovery of Pt, %
1.	Concentrate	15.94	2.17	47.48
	Magnetic fraction of tails	7.8	2.95	31.58
	Concentrate + Magnetic fraction of tails	23.74	2.43	79.06
	Tails	76.26	0.2	20.94
	Feed sample	100	0.73	100
2.	Concentrate	31.68	1.31	62.8
	Magnetic fraction of tails	8.01	1.94	23.51
	Concentrate + Magnetic fraction of tails	39.69	1.45	86.31
	Tails	60.31	0.15	13.69
	Feed sample	100	0.66	100

No	Product	Yield, %	Content of Pt, ppm	Recovery of Pt, %
3.	Concentrate	24.1	1.96	64.83
	Magnetic fraction of tails	9.21	1.48	18.7
	Concentrate + Magnetic fraction of tails	33.31	1.826	83.53
	Tails	66.7	0.18	16.47
	Feed sample	100	0.73	100

RESULTS AND DISCUSSION

As a result of the mineralogical and technological research, the presence of significant amounts of platinum in small size classes (less than 100 microns) in Svetloborsky array ore has been established. This fact explains the probability of significant losses of platinum in the process of gravity separation of these type of dunites, while gravitational methods demonstrated high results in the concentration processing of platinum dunites ores from Galmoenansky array [13]. Keeping in mind this fact we came to a conclusion that for the complete extraction of platinum from dunites of Svetloborsky array processing by stage-by-stage grinding operations and consistent gravitational extraction of platinum mineralization in the large and middle classes would be not sufficient. Additional treatment of fines and platinum-containing tailing slurry products by means of flotation and magnetic separation would be highly demanded [14, 15].

In the result of laboratory tests of flowsheet incorporated staged grinding of the sample material and gravity concentration on centrifugal concentrator “Knelson KC- MD" a total concentrate containing 8.73 ppm Pt was obtained with a recovery estimated 46.8%. After additional concentration of Pt at the concentration table TCO its content increased up to 34.62 ppm at 42.0% extraction. It should be noted fairly uniform recovery of Pt in gravity separation stages: in the first stage - 16.4%, the second - 18.8 %, and the third - 11.6%. At a relatively high content of platinum in tailings 0.23 ppm, the losses of valuable component in gravitational flowsheet tailing has been comprised of 53.2%.

Separation of gravity concentrates TCO according to their magnetic properties has shown higher recovery of platinum in the magnetic fraction at all stages of enrichment. At the first step the recovery of Pt into magnetic fraction was 63.7 % from the operation, at the second and third - 71.8 % and 80.2 %, respectively. A significant increase in the quality of the concentrate was obtained at the first step of treatment: platinum content in the magnetic fraction of TCO 1 concentrate was 54.81 ppm, in nonmagnetic fraction - 23.17 ppm. More effective separation according to magnetic properties has been obtained under magnetic separation of tailing products of TCO. At the second and third stages of enrichment there were isolated magnetic fractions with the content of Pt 3.67 ppm, managed to additional extraction of 2.8 % of platinum.

Analysis of the results of flotation in a combination with magnetic separation of mixed tailings of gravitational concentration in size -0.1 mm (-0.071 mm 80 %) has shown that the usage of new reagents, in addition to traditional collector xanthate helped to recover up to 64.83 % of platinum into the flotation concentrate and up to 18-20 % of platinum into the magnetic product after magnetic separation of flotation tailings, thus producing the total extraction of Pt about 85 %. Re-cleaning of the concentrate is expected to improve its quality concerning to the platinum content. The platinum content in the tailings is 0.15-0.2 %.

CONCLUSIONS

Complex of technological processes that determine the completeness of extraction of platinum from dunites of zoned mafic–ultramafic complexes of the Middle Urals has been scientifically substantiated and experimentally verified. A detailed study of the technological properties of productive platinum mineralization has shown the necessity of a combined flowsheet application, which in addition to stage-by-stage grinding and consistent gravitational concentration of platinum in coarse and medium classes should include selective concentration of small and thin tail classes of platinum and sludge products by flotation and magnetic separation. The prospective application of modified diethyldithiocarbamate (reagent DEDTCm) as an additional collector in flotation recovery of fine fractions of the slurry platinum-containing products of dunites dressing has been demonstrated.

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