Useful Component Recovery from Saranovskaya Mine Rudnaya Wastes

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Abstract

This study presents experimental results on beneficiation of tailings from the Saranovskaya Mine Rudnaya (SMR) at the Main Saranovskoe deposit, Perm region. The goal of this study was to analyze the composition of tailings and to determine the degree of their suitability for upgrading using a spiral classifier. Laboratory studies show that the proposed upgrading flow chart was correct. The experiments yielded a chrome concentrate of economic importance. In addition, this study presents new quantitative data on the platinum-group elements (PGE) concentrations in the chrome ores from the central ore body (COB), microphotographs of mineral forms of platinum-group metals recovered from tailings and data on their chemical composition.

Keywords: chromite, tailings, beneficiation, platinum-group minerals, spiral classifier

Introduction

Chrome ores are the most important raw materials for iron and steel industry. Global chromite consumption is steadily increasing, amounting to 12 - 13 million tons per year. The main chrome ore deposits in Russia are Saranovskoe and Southern Saranovskoe (Perm Region), Aganozerskoe (Karelia), Sopcheozerskoe (Murmansk region). Of these deposits, only the Main Saranovskoe deposit with the estimated reserves of 4.7 million tons, which are about 11% of the above-mentioned deposits, is currently mined (State Report 2017). Nevertheless, Saranovskaya Mine Rudnaya is the largest and most important enterprise in Russia for chromite ore extraction and beneficiation. At present, the Main Saranovskoe deposit is currently mined. The thickest beds, containing ores with a similar chemical composition and known as the Western, Central and Eastern ore bodies are under exploitation. The mined ore is beneficiated at the beneficiation plant, which is located directly on the industrial site of the mine and is incorporated in a single process flow chart.

Many publications are devoted to the characteristics of the geological structure. The main Saranovskoe Deposit has attracted the attention of geo-log immediately after opening in the 30-ies of the XIX century (Zaitseva, 2009), thanks to the discovery of a new chromium-containing minerals: uvarovite (Hess, 1832). As the field of chrome ores it has begun to be developed since 1889 the Characteristics of its geological structure is the subject of numerous publications (Vakhromeev and others, 1936; Zimin, 1938; Volchenko and others, 1979). The monographic description of the Saranovsky magmatic complex with the detailed characteristic of its petrographic structure, and also the field is executed by O. K. Ivanov (1990). Later (2016) he compiled a description of the Mineralogy of the Deposit.

Description of the structure and composition of ore bodies of the Main Saranovskoye Deposit, the methods of their testing was made by V. F. Myagkov and V. L. Batalov in 1966. R. G. Iblaminov (2002) reconstructed the history of the formation of the Deposit.

The Deposit was studied in detail in the course of numerous geological exploration works, as well as various scientific and case studies. The most detailed information about the structure and composition of ore bodies was obtained as a result of geological surveying, which ensured the operation of the Deposit.

In view of the current trend of raw materials import dependence and the lack of domestically mined raw materials, the active use of beneficiation tailings of chromite ores appears to be of great importance.

We analyzed the composition of tailings generated at the Saranovskaya Mine Rudnaya (SMR) and performed experiments on tailings beneficiation to obtain an additional source of chromium, improve the ecological situation in the area and assess the possibility of the recovery of platinum-group metals.

Object of Study and Analytical Methods

The Main Saranovskoe deposit, located on the western slope of the Middle Ural Mountains in the Perm region (Russia), has been mined since the 1930s. Mining and beneficiation activities on the northern flank of the Main Saranovskoe deposit generated a large dump of solid wastes (tailings), 50 m in length, 8 m in width, and 6 m in height which are stored as a pile on the mine site (fig. 1).

Figure 1 shows sampling localities and Table 1 presents sampling data.

Shovels and 10 L metallic bins were used to collect samples. Samples were placed in plastic bags and labeled with a sample identification number and sample location. All of the samples were delivered to the laboratory for analysis, the <2 mm fraction was separated by sieving and the percentage of this fraction was determined along the pile contour. The 4 and 2 mm mesh hand sieves were used to obtain three fractions. The mineral composition of the >2 mm fractions not upgraded without using an additional preparation technique was studied using a Leica EZ4 stereomicroscope to determine the percentage of the ore component in the >2 mm fraction.

Table 1 The weight of collected samples

Sample no.	Sampling locality	Weight, kg
SR-1	center	30
SR-2	base	30
SR-3	center	30
SR-4	top	30
SR-5	base	30
SR-6	center	30
SR-7	top	30
SR-8	top	30
SR-9	center	30
SR-10	base	30
SR-11	center	30
SR-12	base	30
SR-13	top	30
Total weight, kg		390

Figure 1 Photo of tailings pile with sampling localities (Google Earth Pro).

Because of its high specific gravity (4.2-4.8), chromite can be easily upgraded using a spiral classifier (Polkin 1987). The <2 mm fraction was subjected to upgrading, because of the large volume of samples not requiring additional preparation. The next step was the selection of a spiral classifier, depending on its specifications. It was found practically that the SVM-250 spiral classifier is best suited for our purposes, but has substantial drawbacks, namely insufficient water flow inside a table. This disadvantage was overcome by using additional perforated hose.

Mineralogical and geochemical studies of samples were performed in the laboratories of the Nanomineralogy Sector and Department of Mineralogy and Petrography of the Perm State University. The chemical composition of rocks and ores was determined on Bruker's S8 Tiger (Bruker, USA) X-ray fluorescence spectrometer. The total mineral composition was determined by X-ray powder diffraction using a D2 Phaser (Bruker, USA)diffractometer. The identification of mineral phases was based on the PDF-2 database (2010) The composition of the chromite grains was studied using a scanning electron microscope JSM-6390LV (Jeol, Japan) equipped with an EDS system (INCA 350 Oxford Instruments, UK). The contents of the platinum group elements (PGEs) were determined by ICP-MS with an ELAN-9000 instrument at the Institute of Geology and Geochemistry of the Ural Branch, Russian Academy of Sciences The content of PGEs was analyzed in the <2 mm fraction concentrates in the laboratory of the Nanomineralogy Sector of the Perm State University using an AURORA M90 (Bruker, USA) inductively coupled plasma--mass spectrometer.

Results

The results of sieve analysis showed that the <2 mm particles prevail in the dump and account for two thirds of the dump tailings. The average value for all samples taken is 71% of the fraction less than 2 mm and 29% of the fraction greater than 2 mm. Table 2 shows the average mineral composition of the >2 mm fraction, which was not subjected to upgrading without preliminary preparation.

Table 2 *Mineral composition of the 2-4 mm and > 4 mm fractions.*

Sample	Weight, g	%
Chromite	145.7	33.5
Serpentine	277.7	64.7
Uvarovite+ calcite	6.8	1.8
Total	429.2	100

Table 2 shows that > 2 mm fractions are not of particular interest due to the low proportion of this fraction in the dumped tailings. Secondly, nearly 65% of this fraction is represented by silicate rocks. The next step involves upgrading the <2 mm fraction to obtain two concentrates. Concentrate I is the lighter fraction represented by low density grains, while the concentrate II is the heavier fraction. The final concentrates were dried and weighed. The averaged data of gravimetric analysis for all samples were 67% of the heavy fraction concentrate and 33% of the light fraction concentrate. Both qualitative and quantitative analyses of the concentrates and the starting tailing samples were performed using various analytical techniques. Such methods as electron microscopy with a microprobe analyzer, X-ray structural analysis, X-ray fluorescence analysis, ICP-MS method, sieve analysis, mineralogical analysis under a microscope, which were discussed in the Methods Chapter. XRD analysis showed changes in the mineral composition of tailings, before and after upgrading (Table 3).

X-ray diffraction analysis confirmed that the upgrading resulted in the increase in the proportion of chromite and decrease in the proportion of impurities in the heavier fraction. XRF data also confirms the high-grade characteristics of the final product (Table 4).

The percentage of recovery of the useful component (chrome) was calculated for combined sample weighing 51kg and is presented below in Table 5.

The mineralogical and geochemical data by Volchenko in 2011 were used to estimate the average content of PGEs in the western (WOB), central (COB) and eastern (EOB) ore bodies (mg/t, respectively): Os – 108, 110, 88; Ir – 140, 117, 50; Ru – 100, 110, 82; Rh – 8, 22, 10; Pt – 50, 70, 40; Pd – 6, 3, 10. This

***Table 3** The mineral composition of tailings before and after upgrading (average value for all samples, in %)*

Sample	Chromite	Serpentine	Calcite	Dolomite	Quartz	Albite	Magnetite	Actinolite	Total
Starting tailings*	51.4	28	3.8	3.6	2.1	2.8	1.8	0.5	100
Heavy fraction	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
Light fraction	31.1	32.8	6.8	6.8	8.6	4.6	6.2	3.1	100

* - tailings from a dump

***Table 4** The results of x-ray fluorescence analysis (average value for all samples), wt.%*

Sample	MgO	SiO_2	CaO	TiO_2	Cr_2O_3	Fe_2O_3	Al_2O_3	MnO	SO3	LOI***	Total
Starting tailings *	13.72	3.81	0.73	0.62	31.43	23.81	18.24	0.16	0.07	1.34	101.2
Heavy fraction	12.9	1.51	0.33	0.64	43.01	25.08	19.49	0.17	0.06	0.45	101.8
Light fraction	24.21	34.64	5.74	0.54	10.32	8.24	5.28	0.25	0.08	11.96	102.1

* - tailings from a dump

***Table 5** Percentage of recovery of the useful component Cr_2O_3,%*

Sample no. (tailings)	Weight of sample, kg	Cr_2O_3, wt.%	Cr_2O_3, kg	Recovery,%
heavier fraction	30	43.01	12.7	79.0
light fraction	21	10.3	2.1	21.0

study showed the presence of laurite RuS_2 - erlichmanite OsS_2 series platinum-group minerals (PGM) in all ore bodies, which occur as idiomorphic grains, 5-50 micrometers in size, and the presence of braggit (Pt, Ni) S - vysotskite (Pd, Ni) S series occurring as small inclusions (1-10 micrometers in size) in the COB Cr-spinels. The authors revealed a trend of increasing concentrations of Os, Rh, and Pd upward the section (from west to east). Despite the complex nature of the ores, these authors showed that the recovery of precious metals is not economically feasible due to the lack of acceptable technology for PGM recovery and the use of chrome ores in refractory manufacturing. The form of occurrence and localization of PGM in the tailings was studied to identify the possibility of PGM recovery and ore upgrading. Since the PGMs are characterized by a small grain size (up to 50 μm), beneficiation tailings with a < 4 mm particle size, which are mostly Cr-spinel and serpentine in composition were collected. The <2 mm fraction was upgraded using a spiral classifier to obtain a high-grade Cr-spinel concentrate (95-100%). The 0.5-0.125 mm and <0.125 mm fractions were sieved out and upgraded with bromoform to ultra-fine concentrates and studied under the electron microscope. The 0.5-0.125 mm fraction was mounted into epoxy resin and polished twice to different depths of grains, and the <0.125 mm fraction was dusted as a thin layer directly onto a carbon tape. The study of these samples showed the presence of PGMs only in the <0.125 mm fraction. The PGMs (Fig. 2, table 6) are represented by laurite (8 grains) and erlichmanite (1 grain).

Fragments of films of the irarsite composition (IrAsS) were found on two laurite grains. They are represented by isolated grains, while no intergrowths with other minerals or inclusions in Cr-spinel grains are found. The concentrations of PGE were determined by mass spectrometry in the chrome ore from the central ore body (Table 7).

The PGE contents of chrome ores from the central ore body in table 7 are of no economic importance. Table 8 shows the results of quantitative measurements of PGE

Table 6 The composition of platinum-group metals, wt.%

Element	1	2	3	4	5	6	7	8	9	10	11
S	33.51	37.48	35.35	32.94	31.52	36.63	36.74	35.25	25.81	27.34	30.46
Ni	0.00	0.18	0.22	0.00	0.00	0.43	0.00	0.00	0.00	0.00	0.41
As	0.00	0.00	0.23	0.00	0.24	0.00	0.00	0.00	0.00	8.94	8.70
Ru	30.59	44.06	42.94	32.27	26.30	46.07	47.74	45.59	3.22	20.38	32.40
Os	21.79	11.14	16.36	28.45	27.73	10.45	7.38	14.99	49.07	13.58	10.77
Ir	14.10	7.13	4.89	6.33	14.21	6.41	8.15	4.17	21.89	29.76	17.27
Σ	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Note. The columns show the average compositions (out of 2 analyses): 1-8 - laurite, 9 - erlichmanite, 10 and 11 - irarsite film on the laurite grains 1 and 3, respectively

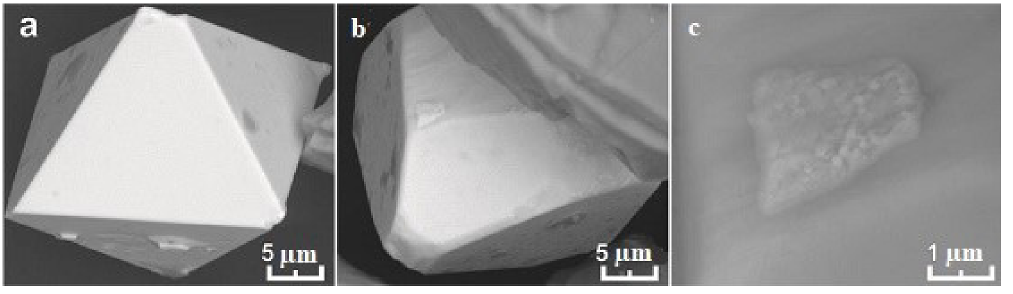

Figure 2 Os-Ru sulfides (BSE): a, b - laurite crystals of various forms; c - a fragment of an irarsite film on laurite (b)

Table 7 Platinum-group elements (PGE) concentrations, ppm

Element	Chromite	Chromite	Chromite	Chromite
Re	0.002	0.000	0.005	0.001
Ir	0.023	0.016	0.021	0.022
Pt	0.003	0.003	0.002	0.003
Ru	0.322	0.224	0.086	0.023
Rh	0.039	0.030	0.012	0.008
Pd	0.162	0.218	0.122	0.047
Au	0.000	0.000	0.001	0.000
Subtotal	0.551	0.491	0.249	0.103
Total	1.0415	ppm		

Table 8 PGE contents of tailings, ppm

	Ru	Rh	Pd	Os	Ir	Pt	Au	Total
1	0.30	0.00	0.77	0.42	0.09	0.06	0.23	1.87
2	0.05	0.00	0.73	0.06	0.03	0.08	0.14	1.10

1 – heavier fraction obtained from tailings upgrading using a spiral classifier, 2 – lighter fraction of obtained from tailings upgrading using a spiral classifier.

contents in the light and heavy fractions, obtained from beneficiation of tailings from the Saranovskoe chromite deposit using a spiral classifier.

The following conclusions can be made: although no economic concentrations were identified, the contents in Tables 7 and 8 are close to them. However, Volchenko Yu.A. reported that the PGE contents may reach economic concentrations, but he emphasized the impossibility of PGM recovery due to the need to crush lumpy chrome ore, which is the main industrial type in the enterprise. Also, there is an assumption that the PGMs might have migrated into tailings together with the associated silicate rocks. Moreover, additional upgrading tests using magnetic and electromagnetic separators proved to be ineffective. The results of this study allowed the enterprise to install an additional beneficiation line using spiral classifiers to obtain the final product in the form of the <2 mm chrome concentrate.

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