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Ore Minerals in Technogenic Wastes of the Levikhinsky Mine (Middle Urals)

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Abstract. Technogenic waste from non-ferrous metal mines can be a potential raw material for precious metals. The work carried out research on the material composition of overburden and enclosing rock dumps of such mines - Levikhinsky (Middle Urals). The contents of non-ferrous metals (Cu, Zn), gold and silver were determined on an atomic emission spectrometer with inductively coupled plasma, the mineral composition was determined on an X-ray diffractometer, and ore minerals were examined under a scanning electron microscope. High gold and silver contents were established, comparable to ore content (0.5-3.5 g/t and 2.7-33 g/t, respectively). Gold is mainly found in a microdispersed form, there are single grains up to 4 mm in size. Silver is found in the form of impurities and small precipitates in sulfides. The contents of copper and zinc are quite low (0.01-0.16 wt% and 0.01-0.035 wt%, respectively), which are concentrated in chalcopyrite and sphalerite. With gravity concentration, it was possible to obtain concentrates with a copper content of up to 0.5 wt%, gold up to 46 g/t and silver up to 621 g/t. The data indicate that the use of dumps is promising as a raw material for precious metals and copper.

1. Introduction

A significant share of the world's gold reserves is concentrated in technogenic waste from the extraction and production of non-ferrous metals [1]. In Russia, the resource potential of technogenic gold-bearing objects is estimated at many hundreds of tons of Au, which corresponds to 55-60% of the volume of gold mined in the country [2]. One of the types of technogenic gold deposits is mining waste, which are overburden and enclosing rock dumps. They are characterized by an uneven distribution of the gold content (0.1–1.0 g/t), the predominance of microdispersed particles of a noble metal in the raw material, and a heterogeneous composition of the crushed material (from dusty particles to meter-long blocks) [1, 3]. This type of technogenic raw material is rather poor in gold content, is often used for laying mine workings, reclamation of disturbed lands and even for glass production [4-6].

However, there are a number of exceptions, and in some technogenic deposits (overburden dumps and enclosing rocks), gold content are comparable to those of ores. One of these deposits is the mining dumps of the Levikhinsky Cu-Zn mine (Middle Urals): according to our data, high contents of gold (0.5 - 3.5 g/t) and silver (2.7 - 33 g/t) are noted. The mine carried out the extraction of Cu-Zn sulfide ores from the Levikhinskoye deposit, which was developed from the 1920s to the early 2000s [7].

During this time, a huge amount of technogenic waste has accumulated, which may well be a potential raw material for gold and silver.

In this work, an analysis of the material composition of the dumps of the Levikhinsky Cu-Zn mine is carried out to assess the possible prospects of their use as a raw material for gold and silver.

2. Materials and methods

The samples taken from the dumps of the Levikhinsky mine are loose material, mainly psammitic (0.5-2 mm) and psephite (up to 50 mm), to a lesser extent, siltstone fractions (less than 0.1 mm). The chemical composition of the studied samples (with the exception of lumps and sulfide ores) is shown in Table 1.

Table 1. The average chemical composition of the studied samples, wt.%.

Component	Content	Component	Content	Component	Content	Component	Content
SiO_2	59.6	TiO_2	0.88	MnO	0.035	Cu	0.042
Al_2O_3	14.0	FeO	0.79	K_2O	2.53	Sum	94.4
CaO	0.33	Fe_2O_3	13.3	Na_2O	1.10		
MgO	0.95	$Fe_{общ}$	8.95	S	0.83		

The mineral composition was determined under an Axio Image optical microscope and by X-ray phase analysis on an XRD 7000C X-ray diffractometer. Ore minerals were examined under an SNE4500M scanning electron microscope equipped with an XFlash Detector 630M energy dispersive attachment. The content of gold, silver, copper, zinc and sulfur was determined on an atomic emission spectrometer with inductively coupled plasma Spectroflame Modula S.

3. Results and discussions

Outwardly, three groups of materials can be distinguished. The first group is yellow color and is composed of fragments of quartz-sericite schists, quartz sand, and a small amount of clay material. It is often located in the upper part of dumps and in the channels of temporary streams. Mineral composition: quartz up to 90 wt%, muscovite up to 10 wt%, hematite and goethite up to 4 wt%, less than 1 wt% feldspars, clinochlore and sulfides. The content of ore components is low: sulfur up to 0.1 wt%, copper up to 0.01 wt%, zinc up to 0.01 wt%, gold up to 1.6 g/t and silver up to 6.1 g/t (samples L-2-9, L-K). All of them are concentrated in sulfides, represented by pyrite, single grains of chalcopyrite and sphalerite, the size of which does not exceed 4-5 mm. The second group is crushed stone and sand of orange and brown colors with a high content of goethite, hematite and magnetite (in total from 10 to 25 wt.%). The group consists of quartz-sericite and quartz-chlorite schists, limonite, chalcedony, fragments of quartz veins and other rocks (basic metasomatites and volcanics). The proportion of quartz in the mineral composition reaches 50-70 wt%, the amount of layered aluminosilicates and feldspars increases (an increase in Al_2O_3 to 20 wt% is noted) and the amount of sulfides (up to 5 wt%, S proper is up to 2.5 wt%). The amount of copper is 0.01 - 0.1 wt%, zinc 0.035 wt%, gold 0.5 - 2.2 g/t, silver 2.7 - 33 g/t. There are large gold particles up to 4 mm in size. The third group is observed in the form of separate small dumps of gray color, consisting of sulfide sands and fragments of pyrite ores up to 1 m in size. They are located throughout the territory of the dumps. The content of sulfides in them reaches 65 wt.% And they are represented by pyrite, in small amounts by chalcopyrite, sphalerite. The size of grains and crystals of pyrite is from hundredths of a mm to 1 cm. All sulfur is concentrated in sulfides. Here, copper and gold reach their maximum grades - 0.16 wt.% And 3.5 g/t, respectively.

The contents of copper, zinc, sulfur, gold and silver in the studied samples are shown in Table 1. Ore minerals are shown in Figure 1.

Table 2. The content of Au, Ag, Cu, Zn, S in the studied samples, wt.%.

	L-2-1	L-2-2	L-2-3	L-2-4	L-2-6	L-2-9	L-K
Cu	0.10	0.0098	0.08	0.16	0.03	0.01	0.005
Zn	n/a	n|/a	0.035	0.015	n/a	n/a	0.01
S	1.37	1.27	0.4	32.6	2.5	0.03	0.09
Au	$1.5{\cdot}10^{-4}$	$0.5{\cdot}10^{-4}$	$2.2{\cdot}10^{-4}$	$3.5{\cdot}10^{-4}$	$1.0{\cdot}10^{-4}$	$1.6{\cdot}10^{-4}$	$0.72{\cdot}10^{-4}$
Ag	$7.7{\cdot}10^{-4}$	$2.7{\cdot}10^{-4}$	$33{\cdot}10^{-4}$	$6.2{\cdot}10^{-4}$	$3.7{\cdot}10^{-4}$	$4.1{\cdot}10^{-4}$	$6.1{\cdot}10^{-4}$

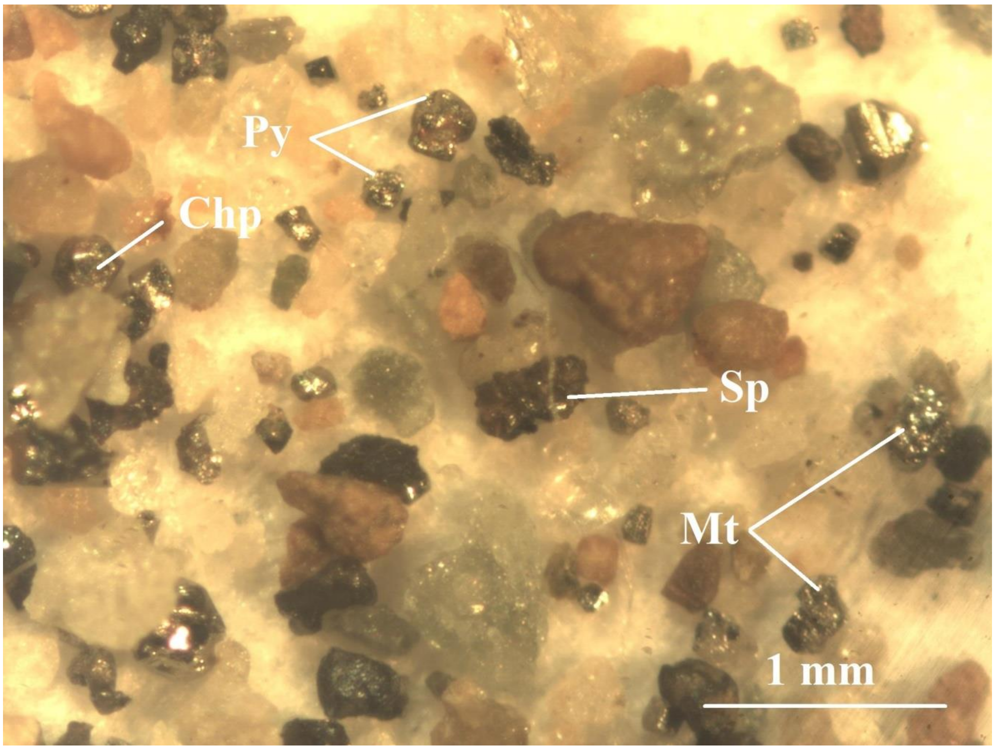

Figure 1. Ore minerals from the Levikhinsky mine dumps: Py - pyrite, Chp – Chalcopyrite, Sp - sphalerite, Mt - magnetite.

3.1. Pyrite

The mineral occupies up to 95 wt% among sulfides. Its content in the studied samples (with the exception of sulfide ores) usually ranges from 0.2 to 5 wt%. The grain size ranges from 5 microns to 5 mm, the predominant size is 50-100 microns. The mineral is often represented by fragments and intergrowths of crystals, as well as inclusions in quartz. There are crystals of a cubic shape, many of them have combination shading on their faces, traces of dissolution and traces of crystals of other minerals. Less common are pentagondodecahedral forms of crystals and their intergrowths. Usually the crystal size is on average 50 µm. Pyrite contains small admixtures of copper (up to 2 wt%), cobalt (up to 4 wt%), and silver (less than 1 wt%). In sulfide dumps, fragments of ore are easily crumbled, traces of dissolution, small crusts of iron oxides and hydroxides, and very fine silver precipitates (micron sizes) are clearly visible on the grains.

3.2. Sphalerite and Chalcopyrite

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Minerals are quite rare, in the form of single grains of tenths of a millimeter in size and intergrowths with pyrite. The most widespread is chalcopyrite. It forms pseudo-tetrahedral and pseudo-dodecahedral crystals, the maximum size of which reaches 200 microns. Just as in pyrite, on the faces of chalcopyrite crystals, traces of dissolution, thin crusts of oxides and hydroxides of iron and copper are often observed. Sphalerite mainly forms lamellar and isometric grains, and there are intergrowths of ruby-colored crystals (Fig. 1). Their size reaches 300 microns. Most often, the mineral is found in materials with a high content of hematite, goethite and magnetite, which is confirmed by chemical analysis (sample L-2-3, table 2).

3.3. Gold

Gold is represented mainly by microdispersed particles (less than 10 microns in size), often associated with pyrite grains. There are single large grains up to 4 mm in size, having a plate-like shape. These plates are twisted into tubes (Fig. 2). The thickness of the plates does not exceed 5-10 microns. The tubes contain iron oxides and nonmetallic minerals (mainly aluminosilicates, micas, and quartz). The plates themselves are polycrystalline aggregates with a layered structure. Sliding bands, traces of dissolution, films and crusts of iron oxides and hydroxides are visible on the surface. One grain of gold taken from the sample, presumably, one can judge that the noble metal was redeposited on artificial metal fragments (such as nails). This is evidenced by the thin-layered structure of the grain, its unnatural clear shape of a rectangular parallelepiped, one of the ends of which passes into a flat unfolded plate. Large grains of gold contain very few impurities: mainly copper, silver and iron (the first percent).

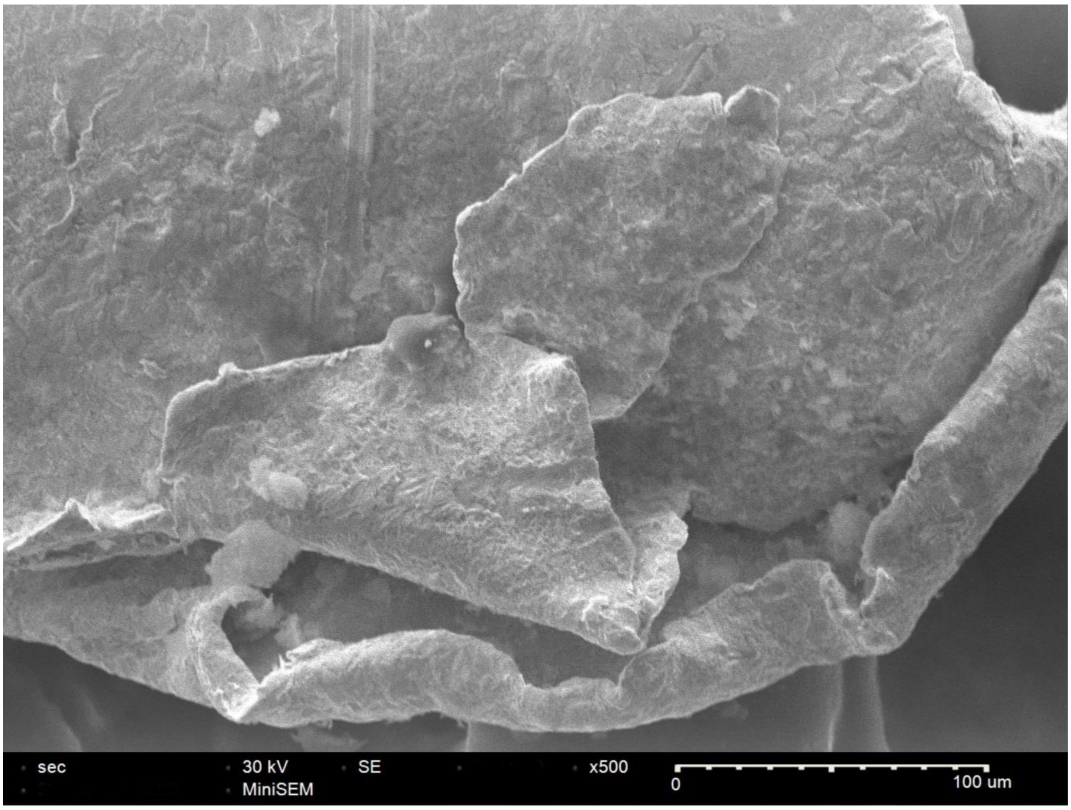

Figure 2. The surface of the gold particle extracted from the concentrate: a - the boundaries of the gold particle, on which its original thin-lamellar shape is visible; b - traces of sliding on the surface of the particle and its inhomogeneous structure. Pictures were taken in SE mode.

For the materials under study, gravity concentration was carried out in order to obtain concentrates rich in noble and non-ferrous metals. Enrichment was carried out on a K-200vl centrifugal separator. Data on the contents of gold, silver and copper are shown in Table 3.

Table 3. The content of Au, Ag, Cu, in the products of benefication, wt.%.

	Concentrate	Intermediate product	Sludge
Mass fraction of the product, %	0.1	60.0	39.9
Au	$46 \cdot 10^{-4}$	$2.3 \cdot 10^{-4}$	$2.7 \cdot 10^{-4}$
Ag	$621 \cdot 10^{-4}$	$22.5 \cdot 10^{-4}$	$66 \cdot 10^{-4}$
Cu	0.5	0.09	0.08
For sulphide dumps, %	7.2	67.9	24.9
Au	$4 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	$1.6 \cdot 10^{-4}$
Ag	$12.1 \cdot 10^{-4}$	$4.2 \cdot 10^{-4}$	$3.1 \cdot 10^{-4}$
Cu	0.15	0.16	0.08

From table 2, we see that it is possible to obtain rather rich concentrates from the dumps of the Levikhinsky mine, containing up to 46 g/t gold, 621 g/t silver and 0.5 wt% copper. However, a significant portion of these metals goes to the tailings, in particular to the fine fraction (sludge). One of the main reasons for this may be the fact that a significant proportion of metals is represented by microdispersed particles that cannot be extracted by gravity separation.

4. Conclusions

Thus, the paper gives a brief description of the fine and medium fractions (up to 5 cm) of dumps of enclosing and overburden rocks of the Levikhinsky mine (Middle Urals). Quite high contents of gold and silver were established, comparable to ore content (0.5-3.5 g/t and 2.7-33 g/t, respectively). Gold is mainly found in a microdispersed form; there are single grains of up to 4 mm in size, which are thin-lamellar tubular aggregates. Silver is found in the form of impurities and small precipitates in sulfides. The contents of copper and zinc are quite low (0.01-0.16 wt% and 0.01-0.035 wt%, respectively), which are concentrated in chalcopyrite and sphalerite. With gravity concentration, it was possible to obtain concentrates with a copper content of up to 0.5 wt%, gold up to 46 g/t and silver up to 621 g/t. However, a significant part of microdispersed gold and other metals (silver, copper and zinc) goes into the intermediate product and sludge. In the future, it is planned to conduct a more detailed study on the mineralogy of valuable metals in dumps, to consider possible options for their more complete extraction into concentrate and the use of further waste products in the construction industry.

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