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A Tailing Dump as Industrial Deposit; Study of the Mineralogical Composition of Tailing Dump of the Southern Urals and the Possibility of Tailings Re-Development

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Abstract: It is found that regions with depleted, or on the verge of depletion, of mineral resources are subject to additional pressures due to intensifying social and environmental problems. This paper proposes the development of the mining industry, reducing the dependence of the economy on the sharp volatility of the raw materials market in a period of global shocks by addressing social and environmental problems in regions with a depleting mineral resource base. It is assumed that the geotechnology development from simple mineral extraction to technologies providing a full cycle of georesources development with industrial waste recycling contributes to the resource provision of sustainable development. The material and mineralogical composition of the four tailing dumps (Uchalinskiy, Buribayskiy, Sibayskiy and Gaiskiy Ore-Processing plants have been studied) united with the similarity of the processed raw materials, and as a consequence, the similar enrichment technology has been studied and established. An approximate estimate of valuable components left in industrial wastes was made. The possibility of valuable component extraction (e.g., gold) from tailings using double agitation cyanidation was substantiated. There is no necessity of obligatory grinding of tailings to increase the recovery rate of valuable components. It was experimentally determined that the extraction of gold from tailings is 75.9–82.14% and depends on the investigated technogenic raw material. It has been proved that industrial waste can be recycled for the purpose of the resource provision of sustainable development. The need for further, more detailed studies of industrial formations has been identified. This will help to identify patterns of valuable component distribution in the industrial mass and to study its extraction possibilities in more details.

Keywords: testing; ore processing plant; tailings of ore-processing; recycling of industrial waste; resource provision; industrial formations; industrial waste; sustainable development; tailings storage facilities

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1. Introduction

In the global community, there is a trend towards integration, development of a unified complex of the world economy functioning, joint solution of most economic problems and creation of a single market space [1]. This trend is complemented by another development, the regionalization of the world and its multipolarity, which manifests in a redistribution of regulation and the role of individual countries and groups of countries in the world economy [2].

Achieving a stable and balanced state of the world mineral resource base implies meeting the demand for mineral raw materials in the basic sectors of the world economy:

the fuel and energy complex, nuclear energy, ferrous and non-ferrous metallurgy, and agrochemical and non-metallic industries [3,4]. In general, the current provision of the basic economic sectors with explored mineral resources seems to be rather satisfactory [5]. At the same time, the problems with provision have emerged or been aggravated for almost each group of minerals [6,7].

Therefore, a rather acute problem of mining regions is the depletion of the deposit resource base [8,9], which leads to the closure of mining and processing plants [10,11]. Such regions are characterized by social and environmental problems. Firstly, the closure or liquidation of mining and processing facilities leaves a large number of skilled personnel, who had previously supported their work. Secondly, at mining and processing sites, large areas of degraded land in the form of industry-related masses occur [12–14].

There is a need for a new perspective on solving the current issue: providing the world market with available resources in order to ensure sustainable development [15] and increase financial sustainability in times of global shocks [10]. The problem of mineral scarcity makes it urgent to find additional sources of raw materials, while simultaneously addressing the issue of minimizing or completely eliminating the impact of the mining industry on the environment [16,17].

One of these directions is the involvement of industry-related raw materials in recycling [18]. Industry-related masses formed in mining areas are, in fact, industrial deposits. They represent waste rock or substandard ore dumps of mining enterprises, slag and ash dumps of the fuel and energy complex, tailing dumps of ore-processing plants, slags and slimes of metallurgical production and so on [19]. Often, in terms of the quality and quantity of the contained minerals, the formed industry-related masses are suitable for industrial use [16,18–20]. They are a potential source of valuable components extraction, in particular non-ferrous, precious and rare metals, which becomes possible with the development of processing technology and changes in economic conditions [20].

The issue of the recycling of industrial formations is quite topical at the moment. Waste rock dumps and low-grade ores of mining enterprises, as well as tailings of ore-processing plants and metallurgical slag dumps, are a promising source of raw materials. In advanced countries, these resources are used for secondary extraction of non-ferrous, rare and precious metals, which can improve the existing economic efficiency of enterprises and improve the ecology of the region [21].

For the recycling of industrial deposits, conditions are required that implement new technological principles and solutions that have been developed at the level of scientific discovery, laboratory or industrial research [22]. Many studies have been carried out on the recycling of industrial geomaterials [18–22] and proposed methods for extracting a valuable component from industrial georesources: by cyanidation [19], agitation leaching method [18,20] or the heap leaching method [16,21,22].

Unfortunately, these technologies are rarely brought to industrial production. This is due to the fact that new construction or reconstruction with consecutive replacement of existing technological lines is very capital intensive.

However, there are advantages to recycling industrial raw materials:

1. Introducing innovative technologies that increase the competitiveness of the enterprise and its financial sustainability;
2. Providing additional workplaces;
3. Improving the life quality and health of the region's population;
4. Reducing the cost of prospecting for new fields and further exploration of exploited fields;
5. Extending the life of the field and the life of the plant;
6. Extraction of a valuable component or/and production of additional goods;
7. Transition to a resource-renewable deposit exploitation model;
8. Minimization up to the exclusion of rent payments for land retirement;
9. Recultivation and return of land previously occupied for industrial waste storage into production turnover;

10. Minimization up to elimination of sources polluting the environment.

All this helps to solve social problems and increase economic efficiency and the financial sustainability of the enterprise, as well as minimize the impact of mining and processing enterprises on the environment of the region [23].

As it has been mentioned before, the development of deposits all over the world is accompanied by a depletion of the resource base. The copper and sulfide deposits located in the Southern Urals of Russia are no exception. The Southern Urals is a geographical region located in the central part of Russia; it is the southern and widest mountain system of the Ural Mountains. In the north, the border is drawn along the latitudinal section of the Ufa River, and in the south, it extends to the border with Kazakhstan. In the west and east, it is limited by the East European and West Siberian plains, respectively. One solution to increase saleable metals while reducing environmental damage is to involve past industrial formations and safely dispose of them in isolated landfills or in the mined-out stopes of underground mines.

The economic efficiency, together with the environmental safety of the development of deposits characterized by mineral resource base depletion, is achieved through the use of industrial waste for the backfill production, with the preliminary extraction of the valuable component from them [24]. This circular economy model [25] is opposed to traditional technologies characterized by the disposal (storage) of industrial waste into the environment or its simple (without additional processing) use in backfill [26,27]. The innovative direction of modern technologies for obtaining raw materials includes the following stages:

1. Extraction of commercial ores for further processing;
2. The involvement of industrial raw materials in the recycling process to further extract the valuable components remaining in them using innovative technologies;
3. Extraction of out-of-balance, low-value or complex ores for further processing, using a hardening backfill mining system that minimizes losses and dilution;
4. The use of industrial waste after technological treatment (process of additional extraction of valuable component) in the backfill or for civil engineering production when using activated fine fraction as a binder and coarse fraction as an aggregate.

It should be noted that the most attractive, for priority development of industrial geo-mineral resources from an economic point of view, are the industrial mineral formations formed on the basis of ore processing of wastes. In comparison with waste rock dumps, they are rather compactly concentrated, are more homogeneous in terms of grain-size distribution, and more often represent fine-grained fractionated sands, which are already prepared for further technological processing and extraction of metals. The priority development of tailing mass from the point of view of technosphere safety is caused by the fact that most of these wastes are in the form of suspensions, which determines their increased mobility, and as a consequence, a higher danger to the environment.

To address the issue of the resource provision of sustainable development in the context of a reducing mineral resource base, it is necessary to carry out evaluation work with the study of the technological properties of stockpiled tailings. In this regard, the priority tasks are:

1. Study and generalization of experience in the development of industrial waste storage facilities for non-ferrous and noble metal ores;
2. Performing evaluation work on tailing facilities;
3. Study of the material composition and enrichability of flotation tailings;
4. Study of regularities in the distribution of the quality and technological properties of tailings stored in industrial formations;
5. Determination of promising technological solutions corresponding to the current level of technology development in this area;
6. Development of technological recommendations for the involvement of ore-processing waste in commercial operation.

In Russia, as elsewhere in the world, there is limited experience in reliable geological exploration of industrial formations from tailings [28]. During the exploitation of a deposit, it is necessary to estimate the generated industrial waste from the point of view of its reuse for recycling. This estimation of industrial resources should be based on actual data, including the selection of parameters for characterizing resources and methods for assessing their recoverability [29]. The main purpose of the evaluation work may be to identify the resource potential of the industry-related mass.

Based on the above, it can be determined that it is a very topical issue to study and systematize the industrial waste of the mining sector in order to recycle it in the future. In order to solve this task, it is necessary to identify industrial deposits, study their mineralogical composition and determine the recycling possibility to obtain an environmental and economic effect.

2. Materials and Methods

For the research, a large mining and industrial region of Russia was chosen, the Southern Urals, where a large amount of mining, ore processing and metallurgical enterprises are concentrated. This leads to the formation of industrial formations near such enterprises (Figure 1).

Figure 1. Industrial accumulation sites (scale 1:20,000,000): 1—Cherepovets; 2—Novolipetsk; 3—Chusovoy; 4—Nizhny Tagil; 5—Chelyabinsk; 6—Uchalinsk; 7—Sibay; 8—Buribay; 9—Mednogorsk; 10—Gai; 11—Orsk Khalilovo; 12—West Siberia.

In the course of research work in the Ural region, the industrial formations of tailings from the Uchalinskiy, Buribayskiy, Sibayskiy and Gaiskiy ore-processing plants were studied. Table 1 shows the characteristics of the studied tailings.

The studied industrial sites are concentrated in traditional mining and processing areas and are in central Russia in two regions: the Orenburg region (site 10 in Figure 1) and the Republic of Bashkortostan (sites 6, 7 and 8 in Figure 1).

The fact that all the deposits are part of the Urals copper belt is the reason for combining these sites in a single study. This predetermined approximately the same material and mineralogical composition of the mined ores, and as a result, the same ore-processing scheme with little variability. All the ore-processing plants under consideration are part of the Ural Mining and Metallurgical Company (UMMC), a Russian metallurgical company that occupies a leading position in Russia and is ninth in the world in the production of copper.

Table 1. The characteristics of the tailings facilities in the Southern Urals (completed by the authors).

Parameter	Unit of Measure	Sibaiskiy Ore-Processing Plant		Uchalinskiy Ore-Processing Plant	Buribayskiy Ore-Processing Plant	Gaiskiy Ore-Processing Plant
		New	Old			
Land size	Hectare	146.2	23.5	113	31	190
Thickness	Meter	Up to 25	Up to 22	Up to 21	Up to 18	Up to 40
Length	Meter	1560	740	1700	600	-
Width	Meter	600	350	750	600	-
Operation period	Year	1966–2005	1959–1966	1969–2010	1942–1970, 1971–present	Up to 2010
Approximate reserves	Million Tonnes	14	4.5	40.8	5.5	40

The Gaiskiy Ore-Processing Plant is a part of the Gaisky Mining and Processing Combine. The current capacity of the plant is about 9.5 million tonnes of raw material per year. The Gaiskiy Ore-Processing Plant processes pyrite, copper and copper-zinc ores, and the end product is copper and zinc concentrates.

Sibaiskiy Ore-Processing Plant was formed as part of the Bashkirian Copper-Sulphur Combine and produces copper, zinc and pyrite concentrates.

Uchalinskiy Ore-Processing Plant is a part of the Uchalinskiy Mining and Processing Combine. The plant processes copper-pyrite ores and produces copper and zinc concentrates, as well as sulfur flotation pyrites.

At the Uchalinskiy Ore-Processing Plant, to obtain saleable zinc concentrate, a technological scheme has been introduced of bulk-preferential flotation, with cyanide-free separation of the bulk copper-zinc concentrate. This scheme is unique and is not used at other deposits of the holding. This scheme, with certain improvements, especially in terms of obtaining saleable zinc concentrate, is currently used.

Buribayskiy Ore-Processing Plant is a part of the Buribayskiy Mining and Processing Combine. The final product is copper and zinc concentrates.

As already mentioned, the technological ore-processing scheme at the holding's factories is approximately the same and provides for three-stage crushing and three-stage grinding to a fineness of 92–93% of the class -0.074 mm. For ore processing, a direct preferential flotation scheme is used, with the sequential rejection of copper and zinc concentrates. The pyritic concentrate is sent to the tailings dump, although it was previously shipped to customers.

To improve the quality, zinc concentrates are subjected to copper and iron removal by copper-pyrite flotation. The extraction of the main useful components in single-name concentrates is copper—75–85% and zinc—60–75%. Copper concentrate contains 15–20% copper, and zinc concentrate contains 45–55% zinc. Total copper extraction is 80–87%, and total zinc extraction is 75–84%.

The volume of industrial waste accumulated in the tailing dumps during the ore-processing plants operation is shown in Table 1. In addition, this table shows the areas of land taken out of economic turnover and allocated for the creation of tailing dumps. All this indicates a high ecological load on the environment.

The study of the tailing dumps was carried out according to a pre-formed grid of pits, with the removal of the near-surface depleted layer. The pitting method was chosen because of its simplicity and minimal financial capacity. The near-surface layer was removed with a wheel loader (Figure 2), and the pits were driven by an excavator.

Figure 2. Results of near-surface layer removal on the tailings dump using a wheel loader.

The pits were driven on the tailings pond beaches (drained areas) on a 60 m × 60 m grid to a depth of 6 m. After removal of the near-surface layer to a depth of 0.5 m, three spot samples were taken with a wheel loader. A deepening was then performed with an excavator, and three spot samples were taken every 0.5 m to increase the depth of the pit to 6 m.

The number of pits for each tailings dump was determined by the beach square, the object under study, which predetermined the free access and safe conduct of the study.

Thus, 4 pits were completed in the old tailing dump (Figure 3a) and 6 pits in the new tailing dump of Sibaiskiy Ore-Processing Plant (Figure 3b), 8 pits in the tailing dump of Gaiskiy plant (Figure 3c), 5 pits in the tailing dump of Buribayevskiy Ore-Processing Plant and 6 pits in the Uchalinskiy Ore-Processing Plant (Figure 3d).

The methodology of the tailings investigation included representative sampling, determination of the main and associated components content, and forms of gold presence in the studied material. Methods of rational (phase) analysis for the presence of valuable components, assay tests and mass-spectrometer analysis with Inductively Coupled Plasma were applied. Optical methods (spectral (luminescent) analysis) were used to estimate the mineral composition, as well as an optical-geometric method to estimate the granular composition of the grains and aggregates present in the raw material under study.

The evaluation sampling consisted of interval-by-interval extraction of tailings material from the pits at each half-meter interval.

It was established that in the structure of all tailings, horizontal bedding is traced in all pits (Supplementary Materials, Figure S1) due to reclamation and the chemical migrations of elements, which has resulted in the formation of areas with higher concentrations of valuable components.

Considering the non-uniform structure of the strata, two fractions were selectively extracted (Supplementary Materials, Figure S2). The composition of each fraction was subsequently studied, and the increased content of non-ferrous or noble metals in each fraction was established.

The patterns of the composition change were revealed. At all the tailing dumps, industry-related sulfates were found in the upper part of the cut. The material is represented by loose sandy fractions.

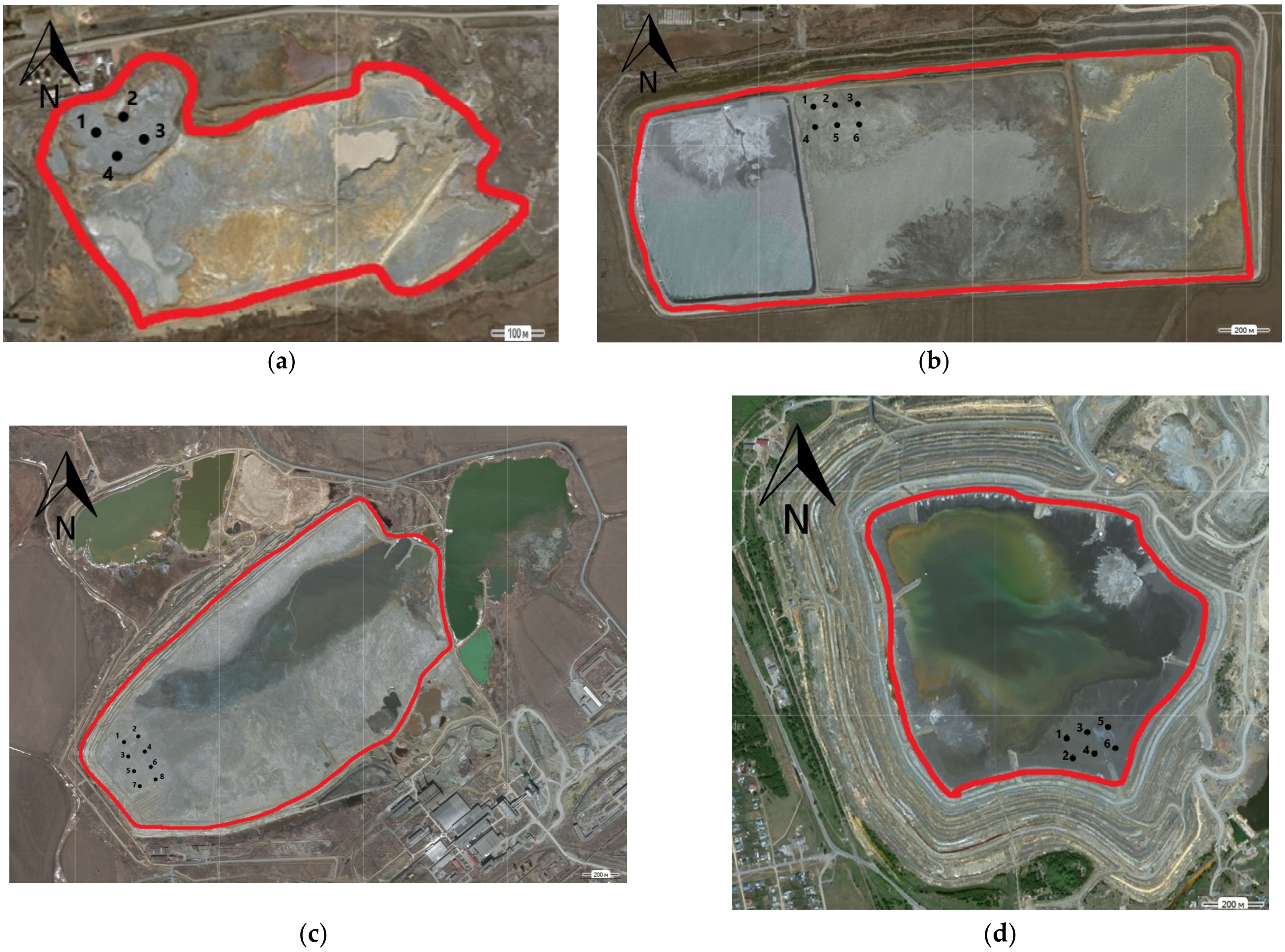

Figure 3. Plan of location of exploration pits.

Industry-related sulfates were found in all the tailings of the holding and in each pit. Active processes of sulfate formation can be traced to a depth of 1–2 m (Supplementary Materials, Figure S3). Very large inclusions of minerals are observed, and the color of the crystals is from white to blue. In the open air and when heated, these unstable compounds quickly decompose.

Technogenic sulfates are extremely unstable in an acidic environment and undergo staged transformations during storage. In this regard, some samples were not dried, but immediately packed in opaque and moisture-proof bags in order to preserve the natural environment and humidity.

The mine tailings water is always processed (in varying degrees) with the ions Fe^{2+}, Fe^{3+}, Cu^{2+}, Zn^{2+}, Cd^{2+}, $SO_4{}^{2-}$, etc. Heavy metals in soluble form migrate to the environment and settle in the tailing pond column. Due to the distance to the laboratory and the consequent logistical difficulties, it was necessary to reduce the volume and weight of the samples, while at the same time maintaining the validity of the results. To this end, the following methods had to be applied: drying, fine crushing and homogenizing.

Samples were dried on a specially prepared site, while retaining their unique sample number. Loose samples were dried within one day and water-bearing samples within three days. After drying, samples were crushed in a DESI-11 disintegrator to produce fragments up to 7–8 mm in size, and then homogenizing of samples in the field on metal substrates was carried out. Sample reduction was carried out with quartering.

Considering the fact that three-point samples were taken at each interval, and the interval was 0.5 m, 36 samples were initially taken for each pit. Thus, 144 samples were taken for the old Sibaiskiy tailing dump, and 216 samples for the new one. In total, 288 samples were taken at the Gaiskiy tailing dump, 180 at the Buribaevskiy tailing dump and 216 at the Uchalinskiy tailing dump. To average the testing, the pits were divided into layers: upper, middle and lower. Each layer was 2 m, and 12 samples corresponded to it. Initially, averaging was carried out at each interval. As a result of averaging, one sample out of three was obtained. Then the averaging was carried out at the layers in each pit. Accordingly, after averaging, there were 3 samples per pit. The total number of samples decreased by 12 times. Thus, the number of samples transferred to the laboratory for each tailing dump corresponded to: old Sibaiskiy—12, new Sibaiskiy—18, Gaiskiy—24, Buribaevskiy—15 and Uchalinskiy—18.

In addition, as previously noted, wet samples with industrial sulfates from a depth of 1–2 m were collected for each pit of each tailing dump. The number of samples corresponded to the number of pits in the tailing dump.

Then, the collected samples were transferred to the laboratory for physical examination of ores and minerals. Samples were supplied for particle size distribution and material composition analysis, which was carried out in the laboratory of the Platov South, Russian State Polytechnic University.

In the laboratory, wet samples with industrial sulfates were dried in ventilated ovens at 40 °C for 48 h to avoid volatilization of volatile elements. Further, the studies were carried out in the same way for all samples. All samples were re-homogenized to form a representative sample.

The samples were examined with X-ray analysis. Particle-Induced X-ray Emission (PIXE) and X-ray diffraction (XRD) analyses were conducted, and samples were ground at <212 μm and <100 μm [30]. This contributes to a more accurate determination of the trace chemical elements that are able to assess the morphology of the sample, taking into account the proportion of chemical elements in the collected samples [31].

The survey was carried out on the DRON-3M device, on Co-radiation using a Fe-filter. Processing of the received spectra was carried out according to the X-ray fluorescence analysis, with application of the Joint Committee on Powder Diffraction Standards (JCPDS). The smoothed results of processing the obtained X-ray patterns of the tails mineral composition are shown in Table 2. It was found that the main phase of the samples is represented with ink-stone, and rosenite is present in a subordinate amount.

Table 2. Elemental and material composition of tailing dumps.

Tailing Dumps of the Ore-Processing Plant	Element Content					
	Copper	**Zinc**	**Sulfur**	**Iron**	**Gold**	**Silver**
	%				**g/t**	
Sibayskiy	0.21	0.50	22.7	32.7	0.85	18.5
Uchaly	0.22	0.63	23.1	29.5	0.6	8.5
Buribai	0.45	0.21	25.6	23.1	1.2	10.3
Gaiskiy	0.3	0.23	26.6	13.9	0.7	4.0

3. Results and Discussions

Based on the laboratory tests and the results obtained, it is possible to establish the approximate amount of useful components present in the industry-related formations (Table 3) and their suitability for extraction.

Table 3. Total volume of useful components in tailing dumps.

Tailing Dumps of the Ore-Processing Plant	Element Content					
	Copper	Zinc	Sulfur	Iron	Gold	Silver
	Thousand Tons				Tons	
Sibayskiy	34.5	90.0	3650.0	5900.0	13.9	344.0
Uchalinskiy	90.0	257.0	6300.0	8050.0	16.5	232.0
Buribayskiy	25.0	11.6	1410.0	1280.0	6.60	56.8
Gaiskiy	120.0	92.0	10,600.0	5550.0	32.0	160.0
Total:	269.5	450.6	21,960.0	20,780.0	69.0	792.8

Based on the results obtained, it is possible to conduct a simplified economic assessment of the studied industrial objects.

Considering world metal prices (at the date of the article writing on 8 June 2022) and the research results, it is possible to estimate an approximate cost of the valuable components contained in the investigated formations (Table 4).

Table 4. Cost of valuable components in tailings.

Tailing Dumps of the Ore-Processing Plant	Element Content					
	Copper	Zinc	Sulfur	Iron	Gold	Silver
	Million USD					
Sibay	336.72	344.97	38.325	867.30	748.10	243.311
Uchalinskiy	878.40	985.08	66.15	1183.35	888.00	164.1
Buribaiskiy	244.00	44.62	14.80	188.16	355.21	40.17
Guyskiy	1171.20	352.63	111.30	816.59	1722.24	113.17

The cost per ton of metals contained in the studied industry-related formations on the London Metal Exchange is the following: copper—USD 9760; zinc—USD 3833; iron—USD 147; and sulfur—USD 10.5; and per troy ounce of raw material: silver—USD 22.0 and gold—USD 1674.

The investigated industry-related objects (tailing dumps) can actually be classified as industry-related deposits in terms of the volume of reserves and their approximate value. This approach to understanding industry-related objects increases the possibility of replenishing the mineral resource base of the mining enterprise during the operational period or replenishing it during the final stage of deposit development.

Studies have demonstrated a sufficient volume of valuable components in industrial sites. At the same time, it should be noted that there are a number of advantages of industrial storage facilities:

1. Geographical prominence, i.e., the lack of prospecting and research work;
2. Extracted resources, i.e., resources are on the surface;
3. Preparedness, i.e., raw materials do not need additional crushing;
4. Accessibility, i.e., all the infrastructure is already in place;
5. Replenishability, i.e., the continuous inflow of industrial waste into storage facilities as a result of mineral extraction and processing.

The relatively high content of valuable components in tailings often reflects only a quantitative aspect. It was, therefore, necessary to establish its recoverability. A rational analysis of industrial raw materials was carried out in the research laboratory of the Platov South, Russian State Polytechnic University.

The possibility of valuable components extraction from the ore-processing tailings was considered on the example of industrial raw materials of the Gaiskiy and Buribayevskiy processing plants, using gold as an example. The experiment on the phase composition of gold in the tailings included sequential gold extraction with cyanidation, cyanidation of tailings after treatment with $SnCI_2$ and leaching with aqua regia (HCl + HNO3 mixture). When performing cyanidation of homogenized Gaiskiy processing plant's wastes—which have in their composition 95.2% of particles of the class −0.074 mm, and cyanide concentration was 0.105%—the agitation time was 48 h, with Liquid:Solid ratio = 2:1. It has been established that for a full leaching cycle with 95.2% of class −0.074 mm, gold recovery is 65.12%.

The tails of the first cyanidation were subjected to secondary cyanidation after their treatment with $SnCI_2$. Tailings leaching in NaCN solutions with a concentration of 0.105% was carried out for 24 h. The gold recovery rate was 21.05%. The tails of the second cyanidation after dissolution in aqua regia (HCl + HNO_3 mixture) were analyzed for gold content in the residue. The gold content in the tailings after treatment with aqua regia was 0.09 g/t, while its initial content was 0.7 g/t.

The data obtained indicate that 50.88% of the gold in the tailings of the Gaiskiy plant is in refractory form. There was no free gold found for extraction. The easily cyanitable gold in the minerals' aggregates amounted to 49.12%. The refractoriness of tailings to cyanide leaching is mainly due to the close association of gold with sulfide minerals (29.82%) and its association with minerals soluble in hydrochloric acid-iron oxides and hydroxides, carbonates (14.04%) and thin dissemination in rock-forming minerals (7.02%). The results obtained indicate the need for mandatory tailings regrinding if a decision is made to involve them in commercial operation.

In technological tests on gold extraction from the tailings of the Buribayevskiy plant using the same methodology, it was found that during cyanidation at 94% of class −0.074 mm, the gold extraction was 53.3% at its initial content of 1.2 g/t. Secondary cyanidation was carried out on the Buribayevskiy plant tailings of the first cyanidation after treatment with $SnCI_2$. The recovery of gold from the Buribayevskiy plant after secondary cyanidation was 75.9%.

The results indicate that 40.31% of the gold in the industrial storage site is in refractory form for processing. There was no free gold found for extraction. The easily cyanitable gold in the minerals aggregates amounted to 59.7%. The refractoriness of gold-bearing tailings to leaching is primarily due to its association with iron oxides and hydroxides, carbonates (32.84%), close association of gold with sulfide minerals (4.48%) and thin dissemination in rock-forming minerals (2.99%). The absence of free gold in the ore-processing waste is confirmed with the results of the mineral composition study for materials sampled from the tailings of the Buribayevskiy and Gaiskiy processing plants.

The industrial raw material is composed of minerals from ores and host rocks typical for copper-pyrite deposits of the Southern Urals. In a homogenized sample from the tailings of the Gaiskiy processing plant for the investigated fineness range −1 + 0.25 mm, the presence of ore minerals pyrite, chalcopyrite and sphalerite, both as separate grains and intergrown pieces with non-metallic host mass, was established. It has been found that pyrite is the most common ore mineral in the studied wastes—13.9 wt%. The predominant form is grains and granular aggregates, and less often isomorphic crystals, such as cubes and octahedrons, which are cross-sections of polyhedrons. The form of the chalcopyrite precipitate is allotriomorphic grains, xenomorphic precipitates between pyrite grains and a non-metallic component, which act as cement for the scattered pyrite grains. Chalcopyrite forms individual phenocrysts in the non-metallic mass or irregularly shaped aggregates with sphalerite. Tin-white arsenopyrite is present in the tails as long prismatic and rhombic grains with distinct facets. The intergrowths of pyrite and rock-forming minerals are predominantly irregular and sinuous (Supplementary Materials, Figure S4a). Chalcopyrite forms microscopic inclusions in pyrite. Chalcopyrite grains are represented in a subordinate amount of 0.3 wt.% (Supplementary Materials, Figure S4b).

Sphalerite in the samples analyzed is present both as solitary elongated aggregates and as inclusions in pyrite, developing through cracks in pyrite and between grains of non-metallic minerals. Individual grains are irregularly shaped and have irregular boundaries. Sphalerite inclusions in pyrite are characterized by rounded outlines. In general, all of the samples analyzed show a reasonably good opening of the aggregates. This has a positive effect on the leaching of ore-processing waste and does not require additional grinding, which minimizes costs. However, in some cases, regrinding of tailings is mandatory, which was found in the rational analysis.

4. Conclusions

The conducted studies have established: The availability of valuable components in industrial formations (tailings) of the Southern Urals of Russia sufficient for extraction in terms of economic feasibility and technical possibility; the possibility of extraction of valuable components from industrial formations (tailings) of the Southern Urals of Russia with the double agitation cyanidation method.

The conducted research allows judging the prospects of the re-development of industrial wastes located in the tailings of the Southern Urals of Russia. It is necessary to justify, develop and implement an innovative technology for the processing of low-grade, industrial, raw materials for the purpose of additional extraction of the remaining components. A preliminary assessment of the potential use of industrial raw materials as an initial source of information for the estimation of specific industrial deposits and subsequent extraction of materials has been obtained. The results of the tailings study necessitate further, more detailed survey of the tailings to identify the distribution of the valuable components in the industrial formation and to study in more detail the possibility of extraction.

A progressive direction in the subsoil development is the creation of industrial deposits—the purposeful formation of industrial mineral objects with specified parameters in the subsoil and on the Earth's surface. The creation of industrial deposits and their incorporation into the mineral resource complex of the future will ensure the ecologically balanced development of mineral deposits and promote the design of mining and processing enterprises on the principles of sustainable development.

Involvement of industrial deposits in the re-development will increase the life of the enterprise and will solve the issue of creating additional jobs for qualified workers of the closing mines.

The study of potential future recovery or reuse of industrial resources is an integral task that must be realized at the time of mine operation. The problems of industrial waste accumulation and the social problems associated with mine closure can be solved. The solution is simple enough—extraction from industrial deposits. It is possible to make a profit by solving environmental and social problems.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/resources12020028/s1, Figure S1: Horizontal bedding (tailings dump of the Buribaevskiy Ore-Processing Plant), Figure S2: Identified two separate fractions with different content of non-ferrous and noble metals (old tailings of the Sibayskiy Ore-Processing Plant), Figure S3: Sulfates of the Gaiskiy tailing dump from pit № 2., Figure S4. Ore minerals in tailings samples of the Gaiskiy processing plant (−1 + 0.25): (a) Arsenopyrite grains in mass; (b) Pyrite with small drop-shaped inclusions and xenomorphic chalcopyrite grains.

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