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To the question about prospects (upcycle) of abandoned copper-sulphide pits in the Urals

Sfen Stepanovich KARAGODIN[1, *], Vladimir Sfenovich KARAGODIN[2, **], Yuriy Petrovich MOROZOV[2, *], Ivan Vasil'evich ZAUZOLKOV[3, ****]**

[1]Nedra group Ltd., Ekaterinburg, Russia
[2]Ural State Mining University, Ekaterinburg, Russia
[3]CJSC "NPK Ekologia", Ekaterinburg, Russia

Relevance of the topic is due to concern of modern civilized society about the negative impact on the ecology of man-made mineral formations of the mining activity.
Technogenic ores are represented by sludges, which are removed by groundwater from abandoned pits and rock dumps. They are deposited in surface watercourse and serve as a source of environmental disasters. They overfill natural and artificial sedimentation basin, and the mine waters carrying them threaten to increase acidity in protected reservoirs that serve as a source for drinking water for big cities. At the same time, in recent years, the industrial value of these sludges has been determined, and the technology has been developed for extracting non-ferrous metals and useful associated components from them. It is revealing that this ore sludge occur directly in alluvial and deluvial deposits of river valleys and ponds, which are also of industrial interest as a source of surface gold and industrial minerals – sand gravel mixes. The need for the extraction of large volumes of the latter is particularly relevant, since an extensive construction program is planned and implemented here.
The purpose of this paper is to attract attention of business and the public to an economically advantageous project for the development of man-made copper-zinc ores from the abandoned pits of the Urals with a simultaneous solution of environmental problems.
Methodology. The work was done by the authors using the results of their own research and materials in collaboration with the team of Nedra group Ltd.
The result of the work. The authors have shown the presence of technogenic copper-zinc deposit within the territory of the Degtyarsky pit and predicted gold-bearing placers in addition to it.
Conclusions. The main task of the study in the territory of the Degtyarsky pit is granting the licenses for the sites of Istok and Elchyovka; the estimated cost of engineering design and geological exploration with an evaluation of reserves of non-ferrous, noble metals and associated raw materials in sludge and alluvium-deluvium, as well as with the solution of environmental problems, ranges from 50–60 to 80 million rubles.

Keywords: technogenic and complex deposit, copper-zinc ores, alluvial gold, industrial minerals, economics, ecology.

Introduction

Mining activity generates a large amount of mine waste, which accumulates in unwanted artificial man-made waste heaps and sludge storages [1, 2, etc.]. One of the most extensive mining activities is copper mining. Copper is a metal that has been important to humanity since ancient times and is the third largest metal in the world after iron and aluminum. The undesirable effect of such mining operations is especially enhanced in the case of mining by the shaft method since the minerals that make up copper ore contain sulfur in large quantities, which forms an acid when dissolving in water. Therefore, acidic mine waters, adversely affecting plants and the animal world, engender one of the most significant environmental problems and are the main source of water pollution worldwide [3–5].

Sludges of abandoned copper-pyrite pits of the Urals (Degtyarsky, Levikhinsky, Gumeshevsky, Verkhne-Pyshminsky, Zyuzelsky and other smaller ones – 14 pits in the Middle Urals in total) that carried out by underground and surface waters from idle mines and dumps accumulate in the surface watercourse overflowing them and threatening the environmental safety of adjacent territories (Fig. 1) [6–8, https://uraloved.ru/ goroda-i-sela/sverdlovskaya-obl/gorod-degtyarsk].

Technogenic lead-zinc deposit of the Degtyarsky pit

At the same time, in recent years, some sources exploring sludge of the Degtyarsky copper-sulphide pit, one of the largest in the world [9, 10, etc.], show the commercial value of the marketable output produced from sludge: copper, zinc, ferrum and oxide coloring agent and quartz-sulphide cake containing gold, silver and rare earth metals, as well as industrial mineral – gypsum (Bukharov A. N. 2013, *Tekhniko-ekonomicheskoye obosnovaniye investitsionnogo proyekta «Opytno-promyshlennoye predpriyatiye po kompleksnoy pererabotke ilov pruda-otstoynika otrabotannogo Degtyarskogo mednogo rudnika s polucheniyem tovarnoy produktsii* [Feasibility study of the investment project "Experimental-industrial enterprise for integrated processing of sludge from the treatment pond of the abandoned Degtyarsky copper pit to produce marketable products". Ekaterinburg, 22 p.) (Table 1).

* sfen80k@mail.ru
https://orcid.org/0000-0002-5882-821X
** karagodinDEC@yandex.ru
*** tails2002@inbox.ru
**** ecolnpk@mail.ru

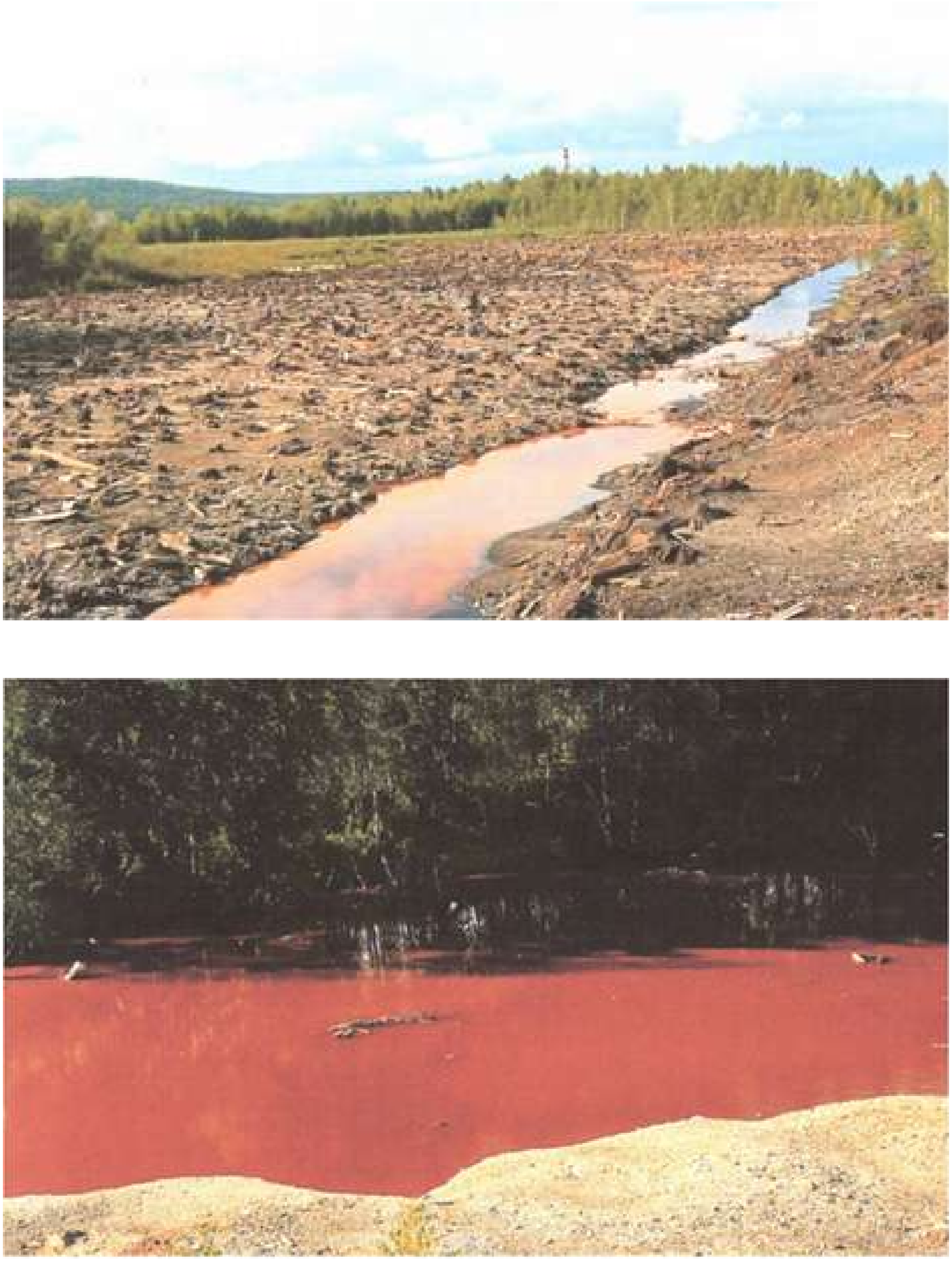


Figure 1. Woeful spectacle of the valley of the Istok river containing slimes of the Degtyarsky pit (source: uralmines.ru).
Рисунок 1. Удручающие виды современного состояния долины р. Исток, вмещающей шламы Дегтярского рудника (источник: uralmines.ru).

The concentrations in these man-made ores of copper – 1.5% and zinc – 5.5% are illustratory (whereas the copper content was 0.9–1.26%, and zinc, 1.38–2.7 % [9] in ledge ores using shaft method), as well as the presence of a highly profitable technology for extracting valuable elements from sludge developed by CISC "NPK Ekologia".

Within the territory of the Degtyarsky pit, the predicted resources of technogenic ore (sludge) of category P_2 in the valley of the Istok river can be expertly taken in the amount of 1.3 million tons; category P_1 in the Elchevsky teatment pond – 1.1 million tons. In general, the estimated resources of sludge in the Degtyarsky pit of categories $P_1 + P_2$ will amount to 2.4 million tons. In

Table 1. The chemical composition and volume of sludge in the licensed areas of the Degtyarsky pit.
Таблица 1. Химический состав и объемы шлама на лицензионных участках Дегтярского рудника.

No	Element	Average grade in dry ore, %	Reserves, tons
1	Copper	1.5	6000
2	Zink	5.5	22 000
3	Ferrum	20	80 000
4	Manganese	2.9	1100
5	Cementitious residue (gypsum)	70	280 000

Table 2. The volume and cost of stocks of the main raw materials extracted at the licensed sites of the Degtyarsky pit according to the technology developed by CJSC "NPK Ekologia".
Таблица 2. Объем и стоимость запасов основного сырья, извлекаемых на лицензионных участках Дегтярского рудника по разработанной «НПК Экология» технологии.

Elements	Recoverable quantities, tons	Price, 1 ton	Sales, million $	Sales, million €	Sales, billion rubles
Copper	4200	$ 6100	25.62	23.37	1.6
Zink	15 400	$ 2600	40.04	162.56	2.52
Ferrum	56 000	2000 rubles	2.24	2.04	0.11
Cementitious residue (SiO_2, $CaCO_3$, $CaSO_4$)	196 000	1000 rubles	3.92	3.56	0.96
Total	–	–	71.82	191.53	4.44

1 € = 73 rubles, 1 $ = 63 rubles.

this case, estimated reserves of copper of the category $C_1 + C_2$ in the sludge of the valley of the Istok river and the Elchevsky teatment pond can be estimated at 14250 tons (6000 tons + 8250 tons).

According to the data of PJSC Uraltsvetmetrazvedka for 2003, silver reserves in the sludges of the Elchevsky pond amounted to 0.736 tons with an average grade of 1.6 ppm. The gold content in the sludge was not determined. At the same time, according to CJSC "NPK Ekologia", in the sludge (silt) sample taken from the Elchevsky pond, gold was determined in the amount of 1.1 ppm. However, the absence of geological description of the material of this sample does not allow determining its genesis and classifying it as sludge or alluvium-deluvium. The mineral assemblage and distribution of noble metal contents by area and thickness of deposits of sludge from the Degtyarsky pit has not been studied.

Predicted resources of ore sludge from another largest copper mine, Levikhinsky, are estimated at 5 million tons. The conditional predicted reserves of copper of $C_1 + C_2$ category with a content of 1.5% in its sludge will be more than 18 750 tons.

CJSC "NPK Ekologia" together with Nedra group of companies has formed a promising business plan for extraction and processing of ore sludge in the licensed site of the Istok river. In particular, it provides information on the volume and cost of non-ferrous metals and related raw materials that can be extracted in the site of the valley of the Istok river[1] (Table 2, with the author's amendment of rough prices for July 2018).

Auriferous alluvials of the river valleys Istok and Elchyovka

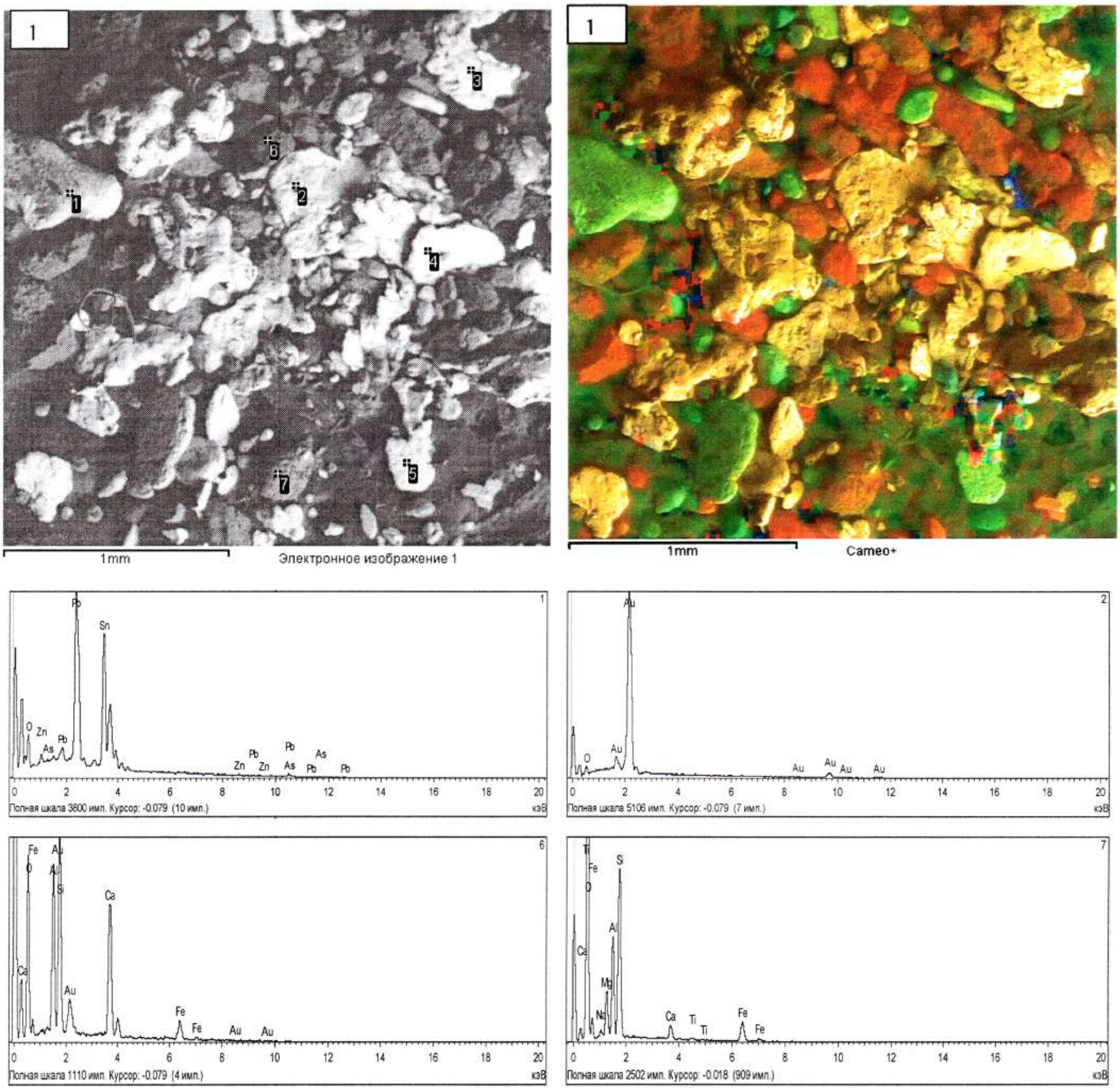
Further, special attention should be paid to the fact that areas occupied by river valleys Istok and Elchyovka are located in the area of distribution of alluvial placers with an average industrial gold content of 180–235 mg/m^3. The geological structure of the Degtyarsky pit indicates the presence of the latter within the territory under consideration. Along the valley of the Elchyovka river (its affluents and ravines are located within the territory of tectonically disturbed eastern exocontact of the Revdinsky gabbro massif, which serves as the alimentation zone of the robbed-out gold alluvial deposits) there are often traces of old mining. There is the Elchyovskoye occurrence of surface gold at the mouth of the Istok river. The orebody of gold can be the intrusive body of the medium acidic composition of the fourth phase of the Revda complex.

The swampy area of the Istok site is composed of alluvial sediments, which are overlapped by silts and sludge supplied by waters from the abandoned Degtyarsky pit. Since the valley of the Istok river is known for the previously worked-out prospecting gold-bearing alluvial Pre-Quaternary and modern placers, one should expect to have the richest industrial placer of gold in the alluvium of the Elchyovsky pond. Although the Elchyovsky teatment pond is a water protection object, technogenic sludges covering the alluvial-deluvial sediments of its water area have overflowed the pond. There is only one way to avoid the disaster: to have the project for construction of dike embankment which cost exceeds 2 billion rubles. One more cost-effective option is cleaning the treatment pond from the sludge with excavation and washing of gold-bearing alluvial-deluvial sediments of the pond.

Table 3. The results of the samples studying by CJSC "NPK Ekologia".
Таблица 3. Результаты исследований проб ООО НПК «Экология».

Sample's name	Weight of initial sample, kg	Mass fraction, grain-size class – 1.4+0 mm, %	Weight of extractable Au in the sample, g	Au mass fraction in the initial sample, ppm	Au mass fraction in the initial sample, g/m^3
C31	35.40	50.56	0.0033	0.093	0.167
C32	38.00	50.61	0.0110	0.289	**0.520**
C33	40.00	61.68	0.0188	0.470	**0.846**
C34	38.00	61.79	0.0110	0.289	**0.520**
C35	36.60	50.22	0.0055	0.150	**0.270**
C36	37.42	53.89	0.0338	0.903	**1.625**
C37	33.84	69.21	0.0055	0.162	**0.291**
C38	35.22	62.86	0.0011	0.031	0.056
C39	34.30	66.66	0.0031	0.090	0.162
Total	328.78	–	0.0931	2.477	4.457

[1]Karagodin S. S., Mazur S. V., Shinkaryuk I. E. 2015, *Biznes-plan investitsionnogo proyekta «Opytno-promyshlennoye predpriyatiye po kompleksnoy pererabotke shlamov otrabotannogo Degtyarskogo mednogo rudnika s polucheniyem tovarnoy produktsii»* [The business plan of the investment project called "Experimental-industrial enterprise for complex processing of waste sludge from the Degtyarsky copper pit for production marketable output"]. Ekaterinburg, 80 p.

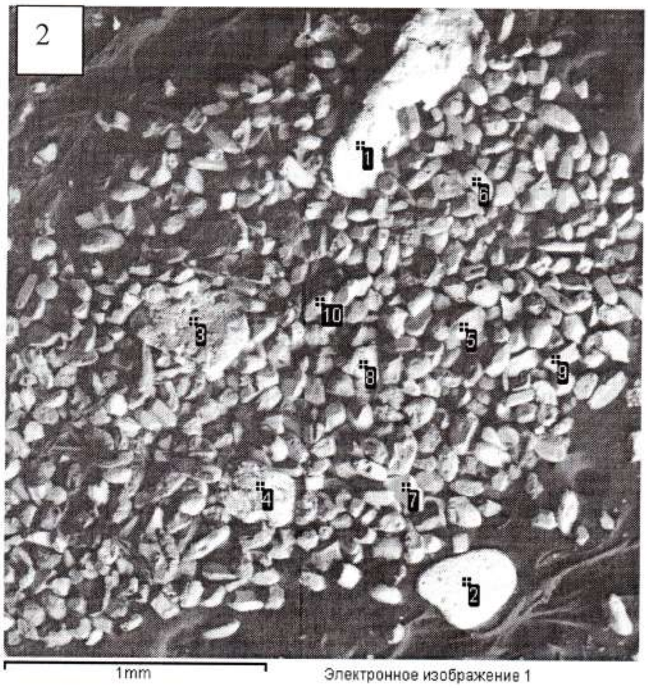


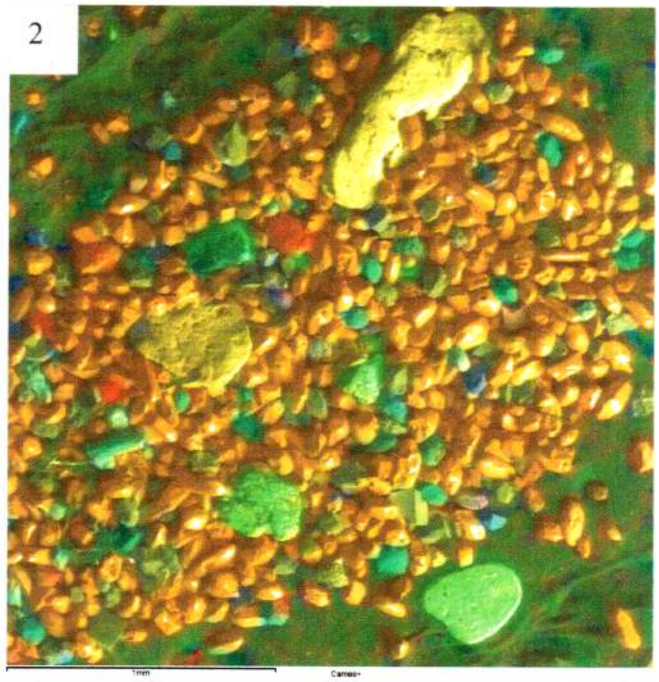
Параметры обработки: выполнен анализ всех элементов (нормализован); все результаты в весовых процентах.

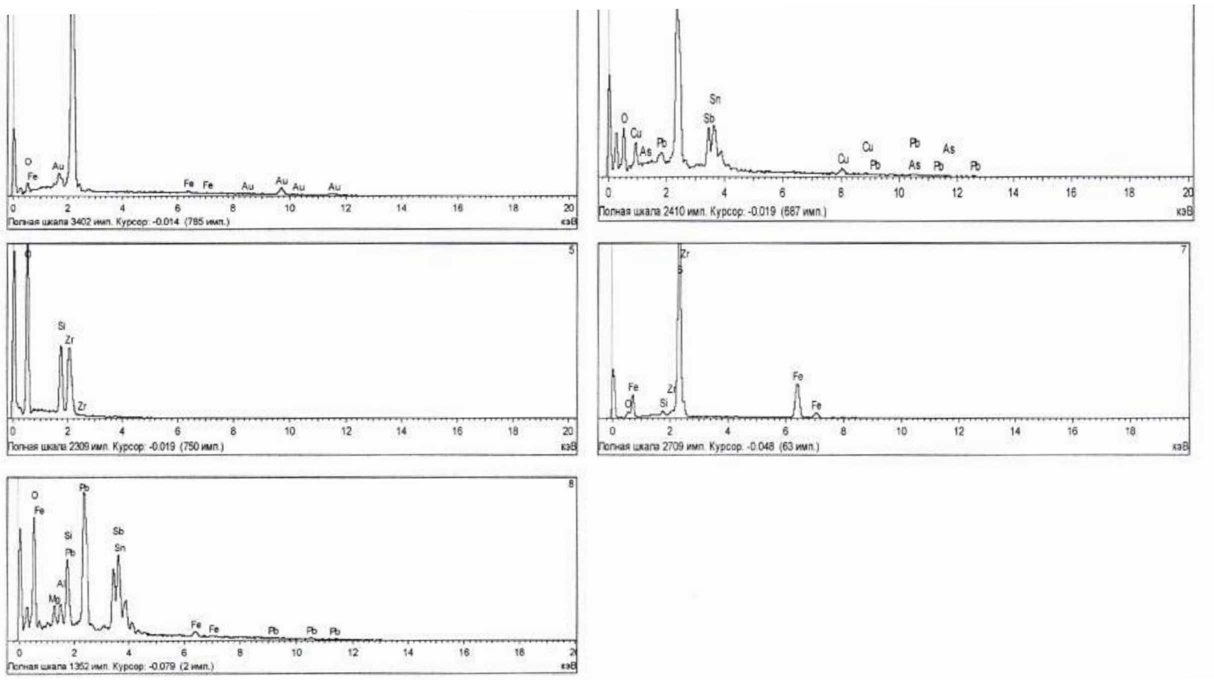
Спектр	O	Na	Mg	Al	Si	Ca	Ti	Fe	Zn	As	Sn	Sb	Au	Pb	Итог
1	10,1								1,5	0,0	46,9			41,5	100,0
2	3,7												96,3		100,0
3	4,3							1,3					94,4		100,0
4	3,1			0,3									96,6		100,0
5	10,8			0,5	0,9					0,0	22,1	22,9		42,9	100,0
6	37,3			10,2	13,7	21,3	.	9,3					8,3		100,0
7	46,7	0,7	4,5	9,9	19,0	3,2	0,8	15,1							100,0

Изображение поверхности образца № 1 в режимах BSE, <Cameo>, спектры и таблица результатов анализа в выделенных точках.

Figure 2. Electronic photographs and graphics of the study of gold washings using the micrologging sonde (sample no. 1).
Рисунок 2. Электронные фотографии и графики исследования шлиха на микрозонде (образец № 1).







Параметры обработки: выполнен анализ всех элементов (нормализован); все результаты в весовых процентах.

Спектр	O	Mg	Al	Si	S	Ti	Fe	Cu	As	Zr	Sn	Sb	Au	Pb	Итог
1	4,0						1,2						94,8		100,0
2	11,7							6,6	0,0		17,8	13,4		50,5	100,0
3	6,1		0,4	2,7									90,7		100,0
4	10,4							3,9	0,2		19,9	23,3		42,3	100,0
5	59,5			10,4						30,1					100,0
6	38,5			14,8						46,7					100,0
7	2,7			0,7	46,4		48,2			2,0					100,0
8	19,6	1,4	1,2	4,0			2,1				18,6	22,2		30,8	100,0
9	59,0			8,8						27,1					100,0
10	57,0		2,6	10,9		5,5				24,0					100,0

Изображение поверхности образца № 2 в режимах BSE, <Cameo>, спектры и таблица результатов анализа в выделенных точках.

Figure 3. Electronic photographs and graphics of the study of gold washings using the micrologging sonde (sample no. 2).
Рисунок 3. Электронные фотографии и графики исследования шлиха на микрозонде (образец № 2).

These considerations are practically confirmed by new findings (prior to prospecting and evaluation works). So, when sinking in the valley of the Istok river, the team of CJSC "NPK Ekologia" discovered a previously unknown industrial alluvial gold deposit (Table 3).

As one can determine from the data in the table, the average gold content in this placer was 495 mg/m^3 with a sample weight of 328.78 kg, which is composed of nine particular samples weighing from 34 to 40 kg. At the same time the industrial gold content are found in 8 samples: from 162 mg/m^3; in four samples, it is especially high: from 520 mg/m^3 to 1.625 g/m^3.

The samples were taken from the surface dump borders of the pit without a geological description of the test material characterized as "soil". The material composition of the "soil" has not been studied. However, there are some electronic photographs and graphs of the study of gold washings from the "soil" using the micrologging sonde, in which the magnitude of fine (up to one-third micron) placer gold and fineness of gold is visible (Fig. 2, 3).

Since the samples were taken from the surface dumps of the pit without fixation, it is not known from what depth this dump was selected, and it is not possible to judge the thickness of the gold-bearing reservoir. However, the above information undoubtedly indicates the industrial scale of this deposit and the need for its exploration. In addition, in three separate samples of the "soil" (sandy and slimy precipitate) from the valleys of the Istok river, the team of CJSC "NPK Ekologia" have determined: gold in the amount of 0.224 ppm; 0.422 ppm and 3.48 ppm, as well as silver, respectively, – 8.4 ppm; 9.6 ppm and 12.6 ppm.

It is known that sludge from abandoned copper-sulphide fields form industrial technogenic deposits [6, 11, 12, etc.]. The sludges of the Degtyarsky pit are not an exception. It is clear from the above information that they are a remarkable copper-zinc polymetallic ore and form an industrial technogenic deposit.

Geologically, sludge is deposited directly in alluvial and deluvial deposits of the river valleys and ponds, which are of industrial interest as a source of placer gold and industrial minerals – sand gravel mixes [13–15].

Conclusion

Thus, the field in the valley of the Istok river located in a 4.5 km long site (from Degtyarsk to the Elchyovsky pond) and in the Elchyovsky pond itself is complex and promising field for further development. The high economic effect of exploiting such deposits is particularly clearly defined when it is calculated using the methodology proposed by V. A. Dushin and V. S. Karagodin [16].

Considerable profitability of mining such a complex field is a good opportunity to direct funds to artificial revegetation of the territory of the Degtyarsky pit involved in the ecological incident [6–8, https://uraloved.ru/goroda-i-sela/sverdlovskaya-obl/gorod-degtyarsk]; this territory is the part of a beautiful mountainous area defined as Ural Switzerland by some experts.

When addressing environmental issues, first of all, a geoecological assessment should be carried out due to the development of the mine's field transformation [17]. Moreover, one should pay attention to the introduction of modern geotechnological methods of mining, such as biotechnology – metal extraction using bacteria and fungi. In recent decades, biotechnology has been increasingly used both in the operation of primary deposits, and in the elimination of geo-ecological stress, as well as in artificial revegetation [18, 19].

Summary

The immediate task of research within the territory of the Degtyarsky pit is to receive licenses for the Istok and Elchyovka sites, to design a project for geological exploration, to solve environmental problems and to conduct geological exploration with an assessment of reserves of non-ferrous, noble metals and associated raw materials in sludge and alluvium-deluvial mining. The estimated cost of these works ranges from 50–60 to 80 million rubles.

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К вопросу о перспективах (второй жизни) заброшенных медноколчеданных рудников Урала

Сфен Степанович КАРАГОДИН[1, *],
Владимир Сфенович КАРАГОДИН[2, **],
Юрий Петрович МОРОЗОВ[2, ***],
Иван Васильевич ЗАУЗОЛКОВ[3, ****]

[1]ООО Концерн «Недра», Россия, Екатеринбург
[2]Уральский государственный горный университет, Россия, Екатеринбург
[3]ООО НПК «Экология», Россия, Екатеринбург

Актуальность рассматриваемой темы обусловлена обеспокоенностью современного цивилизованного общества негативным влиянием на экологию техногенных образований горнодобывающей деятельности.
Техногенные руды заброшенных медноколчеданных рудников представлены шламами, которые выносятся подземными водами из заброшенных шахт и горных отвалов, отлагаются в поверхностных водоемах и служат источником экологических бедствий. Они переполняют естественные и искусственно создаваемые отстойники, а несущие их шахтные воды угрожающе повышают кислотность в охраняемых водоемах, которые служат резервуарами питьевого водоснабжения миллионных городов.
Вместе с тем в последние годы установлена промышленная ценность этих шламов, разработана технология извлечения из них цветных металлов и полезных сопутствующих компонентов. Показательно, что шламы обычно залегают на аллювиальных и делювиальных отложениях речных долин и прудов, которые представляют промышленный интерес как источник россыпного золота и строительных материалов – песчано-гравийных смесей. Потребность в добыче больших объемов последних особенно актуальна, так как здесь запланирована и реализуется обширная программа строительства.
Целью настоящей публикации является привлечение внимания бизнеса и общественности к экономически привлекательному проекту разработки техногенных медно-цинковых руд заброшенных рудников Урала с одновременным решением экологических проблем.
Методология. Работа выполнена авторами с использованием результатов собственных исследований и привлечением и анализом фондовых материалов в содружестве с коллективом ООО Концерн «Недра».
В результате работы показано наличие на территории заброшенного Дегтярского рудника промышленного техногенного медно-цинкового месторождения и спрогнозировано присутствие в комплексе с ним золотоносных россыпей.
Выводы. Ближайшей задачей исследований на территории Дегтярского рудника является получение лицензий на участки «Исток» и «Ельчёвка», составление проекта геологоразведочных работ, решение экологических проблем и проведение геологоразведочных работ с оценкой запасов цветных, благородных металлов и сопутствующего сырья в шламах и аллюво-делювии. Ориентировочная стоимость этих работ составляет от 50–60 до 80 млн руб.

Ключевые слова: техногенное месторождение, комплексное месторождение, медно-цинковые руды, аллювиальное золото, строительные материалы, экологические проблемы.

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* ✉ sfen80k@mail.ru
https://orcid.org/0000-0002-5882-821X
** karagodinDEC@yandex.ru
*** tails2002@inbox.ru
**** ecolnpk@mail.ru