Electrical resistivity tomography at the “roll along” profile in comparison with geochemical testing of the tailing dump (Salair, Kemerovo region)

Yurkevich Nataliya1,2, Grakhova Sofia1, Fedorova Tatyana1 and Kucher Dmitriy1

1IPGG SB RAS, 3 Koptyug ave., Novosibirsk, 630090, Russian Federation
2Novosibirsk State Technical University, 20 K. Marksa ave., Novosibirsk, 630073, Russian Federation

E-mail: yurkevichnv@ipgg.sbras.ru

Abstract. Mining tailings are the source of a wide range of chemical elements in the environment. One of the main mechanisms of substance migration is the filtration of solutions into groundwater and the river network. In this paper, we consider the results of geophysical studies along the side of the tailings mine production (Salair, Kemerovo region) by the method of Electrical resistivity tomography (ERT). The aim of the research was to identify the leakage of industrial water from a hydraulic structure, as well as to compare the geoelectric parameters of the environment with the geochemical testing of solutions near the tailings. It was found that the direction of the underground fluid flow from the tailings can be traced using geophysical methods, as well as to show the exact anomalous drainage zone on the profile of ERT.

1. Introduction

The rapid growth in the consumption of natural resources is accompanied not only by a change in the quantitative scale of anthropogenic impact, but also by the emergence of new factors whose influence on nature becomes dominant. Every year, a huge amount of mineral raw materials is extracted from the bowels of the Earth, which leads to active chemical pollution of environmental components. Man-made landscapes appear in the form of landfills, dumps, tailings, settling ponds [1].

The relevance of tailing studies is primarily due to environmental risks to the environment. The study of those objects that were abandoned after the shutdown of the enterprises to which they previously belonged, with the collapse of the USSR, is especially relevant. According to the experience of our team, such facilities exist in every mining region of the Russian Federation and Western Siberia, in particular.

There are three main mechanisms of environmental pollution from tailings:
1. filtration of solutions through the body of dumps and pollution of groundwater;
2. Aeolol transport of matter and dusting [2, 8];
3. emanation of gases from the dump body and air pollution.

One of the approaches to the study of tailings, their composition, migration paths of drainage flows and gas emanation is the use of a complex of geophysical methods in combination with geochemical testing. The use of electrical exploration methods allows relatively quickly to conduct non-invasive studies of the structure of tailings, to predict changes in composition to depth, to optimize the monitoring system for tailings, to reduce the number of samples for geochemical studies and to outline areas of drainage flows [3-7].
2. Study area
The tailing dump is located near the city of Salair, in the south of the Salair ore field. Morphologically, the object is two natural logs filled with dumps of enrichment plants. Since 1975, there was stored not only the waste of a lead-zinc processing plant, but a gold recovery factory. Each year until 1992, about 1.1 million tons of waste was delivered to the tailing dump. In subsequent years, the unstable operation of the Salair GOK does not allow reliable estimates of the number of tailings from the factory. There is evidence that it stores more than 30 million tons of waste. The Malaya Talmovaya River flows north of the tailing dump. Using an artificial dam, a technological pond is formed that looks like a lake. The excess water after sedimentation of solid material from the pulp was discharged into the technological pond and partially to the settling pond through a drainage pipe. The bulk of the incoming solid material is composed of quartz, barite, calcite, muscovite, feldspar, pyrite, sphalerite [8].

A continuous profile of ERT (roll along, 600 m) was performed along the western side of the tailing dump (Fig. 1).

![Salair](image)

**Figure 1.** ERT profile layout.

To study the subsurface space, the Skala-48 multi-electrode electrical prospecting equipment was used (developed by the IGIG SB RAS). Using the Schlumberger apparatus with a step between the electrodes of 5 m, measurements were taken along a profile 240 meters long. Using the scheme of the ongoing profile (roll-along) allows you to infinitely lengthen the study area. We captured almost the entire western side of the tailing dump - 600 m - 5 catching profiles along the tailing dump. Depth of research - 40 m. Data inversion was carried out in the Res2DInv program (GeoTomo Corp., Malaysia), the final visualization in Golden Software Surfer.

A test was also conducted of drainage water, water from the drainage well and the Malaya Talmovaya River (in only 12 points). The pH, redox potential, and electrical conductivity were determined on site. Each sample was divided into 2 parts. The first 50 ml aliquot was filtered through a membrane filter, placed in a calibrated tube and acidified with distilled concentrated nitric acid, and transported to the laboratory for subsequent analysis using ICP-MS for 63 chemical elements. Another part of the sample was placed in a 1-liter plastic bottle for transportation to the laboratory and analysis for the content of anions (SO42-, Cl-, HCO3-) by titrimetry, colorimetry, and potentiometry methods.
3. Results

Based on the research results, an ERT profile was obtained along the western side of the tailings pond. (figure 2).

Figure 2. Geoelectrical section at the ERT profile along the western side of the tailings dump.

According to the ERT section, it is seen that layers No. 1 and No. 3 in figure 2 with a high resistivity (> 100 Ohm·m) alternates with a low-resistance layer No. 2 (20 Ohm·m) with a thickness of about 8 m. It can be said that the surface layers are a kind of waterproofing, and the layer with high conductivity (resistivity 1-40 Ohm·m, marked in blue in figure 2) is interpreted as a possible zone of filtration of solutions from the dump body into the groundwater horizon. The depth of the conductive layer is from 15 m. At the beginning of the profile, which is closer to the technogenic lake, the depth of the conductive layer is correspondingly less (from 1 to 15 m), and at the end of the profile of the low-resistivity layer is not observed, since it is located farthest from the lake. It is assumed that this low-resistance saturated layer will go further to a depth (more than 40 m).

The results of geochemical analysis revealed some patterns of migration of chemical elements in the system “man-made lake - drainage - Malaya Talmovaya river”. Man-made waters are characterized by a specific electrical conductivity of 1250-1720 μS/cm (EC), pH values range from 6.56 to 7.66, and sulfate ion concentrations range from 630 to 830 mg/L. The main trend is a decrease in sulfate ion concentrations and electrical conductivity, as well as a slight increase in pH from the place where technogenic waters enter the lake to the drainage well. Along the drainage route, it is cleaned, that is, a decrease in mineralization and sulfate (figure 3, illustrated by five points in different parts of the system).

In the Malaya Talmovaya river, the pH value is 7.59, the EC value is 454 μS/cm, which is almost 4 times lower than at the discharge site, but still higher than the normal level for river waters. The concentration of sulfate ions here is about 100 mg/L, which is 16 times lower than at the initial point.

Kurlov’s formulas were calculated from pH values, total mineralization, and the ratio of the main macrocations and macroanions (table 1). Their analysis allows us to conclude that technogenic waters belong to the sulfate class (with a proportion of sulfates up to 87 mg-equiv.%), Magnesium-calcium type, among the main cations there are Zn (up to 3 mg-equiv.%) and Mn (up to 2 mg-equiv.%). In the river waters of Malaya Talmovaya, both in the anionic and cationic balances, regular rearrangements occur. The predominant anion becomes HCO₃⁻ (65 mg-equiv.%), the proportion of sulfate anion decreases to 33 mg-equiv.%. The type of water is replaced by magnesium-calcium; among the main cations there are “traditional” macrocations Ca, Mg, K, Na (sample B-12, table 1).
Figure 3. Change in pH values, electrical conductivity (EC) and concentration of sulfate ion in the hydrochemical system: “place of technogenic water entering the lake (B-1) - technogenic lake (B-2) – drainage (B-3) – drainage well (B-11) – Malaya Talmovaya river (B-12)”.

Table 1. Kurlov formulas for solutions in the system “place of technogenic water entering the lake (B-1) – technogenic lake (B-2) – drainage (B-3) – drainage well (B-11) – Malaya Talmovaya river (B-12)”.

| Sample                          | Kurlov formula                                                                 |
|---------------------------------|-------------------------------------------------------------------------------|
| B-1 (drain)                     | $\frac{Ca_{51}Mg_{40}Na_{52}Zn_{3}Mn_{1}}{SO_{4}^{2-} - 77HC\text{O}_{3}^{-} - 20Cl^{-} - 4}$, pH$_{6.56}$ |
| B-5 (lake)                      | $\frac{Ca_{52}Mg_{42}Na_{44}Mn_{2}}{SO_{4}^{2-} - 84HC\text{O}_{3}^{-} - 15Cl^{-} - 1}$, pH$_{7.65}$ |
| B-10 (drainage)                 | $\frac{Ca_{57}Mg_{37}Na_{42}Zn_{2}}{SO_{4}^{2-} - 88HC\text{O}_{3}^{-} - 10Cl^{-} - 2}$, pH$_{7.85}$ |
| B-11 (drainage well)            | $\frac{Ca_{56}Mg_{38}Na_{42}Zn_{2}}{SO_{4}^{2-} - 87HC\text{O}_{3}^{-} - 11Cl^{-} - 2}$, pH$_{7.66}$ |
| B-12 (Malaya Talmovaya river)   | $\frac{Ca_{72}Mg_{17}Na_{9}K_{2}}{HC\text{O}_{3}^{-} - 65SO_{4}^{2-} - 33Cl^{-} - 2}$, pH$_{7.89}$ |

An analysis of the distribution of a wide range of chemical elements shows that at point B-1, where technogenic waters enter the lake, the highest concentrations of chloride ion (31 mg / l), Ca (319 mg / l), Mg (150 mg/L), Na (36 mg/L), Zn (28 mg/L), Mn (11 mg/L), as well as elements of the Al ore association (24 μg/L), Ba (33 μg/L), Cd (170 μg/L), Co (52 μg/L), Cu (13 μg/L), Li (16 μg/L), Ni (43 μg/L), in comparison with concentrations at other points. High concentrations of Mn and Zn – at the level of the main macrocations (Ca, Mg, Na) are noteworthy.

Multiplicity of excess of concentration over maximum permissible concentration (for reservoirs of domestic water use, [10]) the highest for elements of ore association: 100-230 Cd, 10-150 - Mn, 5-30 - Zn, 2-3 - Ni. Further, in the course of the drainage in the system under consideration, the concentrations of all elements decrease. There is a dilution of natural groundwater and atmospheric waters, and the formation of natural geochemical barriers. For example, colloids of hydroxides Al (III) and Mn (IV) with associated sorption and coprecipitation of other chemical elements from solutions. The Malaya Talmovaya River has the lowest concentration of most elements. However, it is worth noting that even in river waters, the endpoint of the migration route, the concentration of cadmium, an element of the 2nd hazard class, is 1 μg/L, which is equal to the MPC (for reservoirs of domestic water use), and indicates a possible leak man-made waters and their release into the river.
Comparison of concentrations of chemical elements with average values in river waters [11], revealed a number of hydrochemical anomalies in Pb, Ba, Cd, Co, Cu, Zn, Li, along the entire drainage route. Although concentrations from the initial to the final points decrease by 2–3 orders of magnitude, nevertheless, a whole spectrum of anomalies is recorded in river waters. So, in the waters of the Malaya Talmaya river, the concentration of Cd is 5 times higher than the clarkova one, Pb and Zn - 4 times, Ba and Co - 2 times.

![Figure 4](image.png)

**Figure 4.** The excess of concentrations of chemical elements (C) over their average values in river waters [Clark, 11] in the system "place of technogenic water entering the lake (B-1) – technogenic lake (B-2) – drainage (B-3) – drainage well (B-11) – Malaya Talmovaya river (B-12)."

4. **Conclusions**

The use of the electrotomography method according to the roll-along profile made it possible to determine the vertical zonality of the substance composing the tailing dam. Layers with high resistance (water repellent) alternate with a conductive horizon with a thickness of about 8 m, which is interpreted as a possible zone for filtering solutions from the body of the dump into the groundwater horizon.

The results of the analysis of the chemical composition of water in the system “the place where technogenic waters enter the lake - technogenic lake - drainage - drainage well - p. Malaya Talmovaya (B-12)” made it possible to draw a conclusion about the possible migration of a number of elements of the ore association beyond the tailings and water streams. In particular, abnormal concentrations of Cd, Zn, Pb, Ba, Co were found in the Malaya Talmovaya river below the object under study.

In 2020, a detailed study is planned of the composition of water in wells with drinking water in the vicinity of the facility, and the soils from gardens for the detection of heavy metals. It is worth noting that the problem requires further research both at this facility and at other similar hydraulic structures of mining and processing enterprises of Siberia. Our experience allows us to recommend a comprehensive geophysical and geochemical approach for the study of "problem" storages of production waste.

**Acknowledgements**

This work was financially supported by the RFBR project No. 20-05-00336 and basic research project No. 0266-2019-0008.

**References**

[1] Hudson-Edwards K A, Jamieson H E et al 2011 *Mine wastes: past, present, future, elements* 7(6) pp 375–380
[2] Nordstrom D K, Blowes D W et al 2015 *Applied Geochemistry* **57** 3–16
[3] Acosta J A et al 2014 *J. of Geochem. Expl.* **147** 80–90
[4] Yurkevich N V et al 2017 *Toxicological & Env. Chemistry* **99(9-10)** 1328–45
[5] Olenchenko V V et al 2016 *Russian Geology and Geophysics* **57(4)** 617–628
[6] Nikonow W et al 2019 *Applied Geochemistry* **104** 51–59
[7] Epoz M I et al 2017 *Russian Geology and Geophysics* **58(12)** 1543–52
[8] Bortnikova S B et al 2003 *Man-made lakes: formation, development and environmental impact* (Novosibirsk: SO RAN, GEO) 120 p
[9] Loke M H (2003). Res2dinv-2D resistivity and IP inversion. Geotomo Software Malasya.
[10] Maximum permissible concentration (MPC) of chemicals in water of water bodies for economic drinking and cultural and domestic use: Hygienic standards. GN 2.1.5.1315-03. Moscow: Russian Register of Potentially Hazardous Chemical and Biological Substances of the Ministry of Health of the Russian Federation 2003 154 p
[11] Taylor S R and McLennan S M 1985 *The continental crust: Its composition and evolution*