Heavy metal mobility at interaction of the sulphide tailings and environmental components

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Geochemical, hydrogeochemical and biogeochemical investigation of the Salair ore field (Kemerovo region, South-West Siberia) has revealed serious environmental contamination by technogenic objects such as quarries, tailings impoundments, recovery plants. Among others, anomalies of the heavy metals (Pb, Zn, and Cd) can be observed as well around the preserved Djukov tailing impoundment. It contains wastes of floto-cyanidation mineral processing of gold-polimetallic oxidized ores. The tailings impoundment is located in a natural valley, its resource is 1.5 mln. tons, size is 100×300 m. There are two shallow ponds at the northern and southern parts of the impoundment and there is a small settler under the tailings dam. Drainage streams from northern and southern ponds flow into the settler. The geomorphologic position of the tailings determines two main mechanisms of solution migration: (i) filtration along a water impermeable layer downward the slope of the valley, (ii) infiltration through penetration into soil capillary pores. The first mechanism controls metal saturation of drainage water; the second one controls their separation in the A-soil horizon, where sorption by soil and vegetation takes place. Based on the processes described above for the Djukov tailings, the studied area was schematically separated into 3 parts: northern pond and area under its influence, southern pond area, and settler.

Results and discussion

Change of relative metal mobility along the migration chain 'solid tailings B sediment of the ponds B water B soil B vegetation' is shown in Tables 1 and 2.

The metal (Pb, Zn, Cd) content of the solid tailings is rather high and shows wide variation, depending on the mechanical differentiation of the tailings and on the secondary redistribution of elements. With respect to the tailings solid, the concentration of Zn and Cd in pond sediment is sufficiently higher in the southern pond and settler, but Pb content is the same (Zn content increased by 1.7, Cd 1.3, Pb 1.1 times only). As a result of water–sediment interaction the metals are leached into solution (presumably by desorption). Increased metal content has been found in bottom water of the ponds (Table 2). Along chain 'northern pond B southern pond B settler' Pb concentration decreases, meanwhile a sharp increase of Zn and Cd content was revealed. Inversely, an increase of Pb proportion was observed as a result of effect of natural system 'pond waters B soil B vegetation'. It is manifested in the occurrence of contrast aureoles of soil pollution in the adjacent territories. Highest level of soil pollution has been found on northern pond area, where Pb content in the water is the highest among the three investigated ponds. Thus, it can be concluded that the living

TABLE 1. Contents of the metals in the different components of the Djukov tailings (Pb, Zn-%, Cd-ppm)

	Tailings, parts		Sediments				Soils%			
	Northern	Southern	Backgr.	Northern	Southern	Settl.	Backgr.	Northern	Southern	Settl.
Pb	0.1–0.45	0.2–0.6	0.003	0.03–0.6	0.4–0.6	0.54	0.0013	0.02–0.08	0.002–0.013	0.002–0.04
Zn	0.3–1.46	0.1–0.27	0.004	0.03–0.3	0.7–0.9	1.94	0.0045	0.03–0.05	0.009–0.03	0.006–0.03
Cd	8.6–44.0	3–12	0.0003	0.2–6.5	26–32	85.0	0.04	1.2–1.9	0.04	0.04–1.3

media of the vegetation is seriously contaminated by heavy metals. Concentration of Zn and Cd with respect to Pb in cattail *Typha latifolia* increases from the northern pond to the settler. Metal content of water and vegetation is shown in Table 2. The accropetal coefficient (ratio of element concentration in underground part of the plant to the aboveground part) is a good indicator of the metal mobility.

In the sequence 'background B northern pond B southern pond B settler' the accropetal coefficient for Pb changes in the order B 0.87-80-2.9-2.1 (reduction of influence); for Zn B 0.6-13-11.2-12.6 it remains stable, for Cd B 6.1-6.9-4-19 it is close to background.

The experiment on metal leaching from different components of the tailings and environment (solid, sediment, soil, vegetation) using 1N HCl showed high extraction of the metals, especially Zn and Cd. Proportion of the easily mobilised metal forms is significant and reaches up to 70% from their total content, averaging between 40 and 50%. These data are adequate to the general distribution of metals in different environmental components, and with data of thermodynamic calculations.

The latter has shown that generally Zn and Cd are present in solutions as cations. The pH stability of these cations is shifted to the weak acidic region, which is usual for the water of technogenic sulphide tailings. At the same time, Pb exists there as carbonate complex [$PbCO_3Caq$], which is characteristic for weak alkaline conditions in solutions of the adjacent soils. The different geochemical behaviour of Zn, Cd, and Pb in this system could be explained by this fact.

Summary

The filtration type is the most common migration type of Zn and Cd in weak acidic solutions of the technogenic system. During drainage infiltration through the solid component of tailings and dam, the metals aren't precipitated on geochemical barriers and penetrate easily to the water reservoir system. Their concentration increases gradually and achieve a maximal level at the discharge point to the settler. For Pb on the contrary, the infiltration type of dispersion to the environment is characterized mainly by precipitation due to formation of solid compounds. The highest Pb concentration in water was found in the northern pond, where water alkalinity can be compared to that of the lower ponds. During filtration of Pb-containing solutions through tailings and dam, Pb is precipitated at geochemical barrier characterized by low pH. Weak alkaline media of adjacent soils favours to deposition of Pb compounds, which are mostly stable under these conditions.

Pb content in water does not exceed of WQS (water quality standard), whereas concentration of Zn and Cd exceeds it significantly (WQS of these metals is 30, 1000, 1 mkg/l respectively). On the contrary, soil and vegetation contamination far exceeds the SQS (soil quality standard). The SQS for Pb is 32 mg/kg and 6.0 mg/kg B for mobile forms. Zn and Cd concentration in soil and vegetation doesn't exceed SQS for these metals (23 and 5 mg/kg respectively).

The mobility of the metals during filtration changes in the following order: Zn>Cd>Pb, whereas during infiltration through soil solution the mobility is inverse: Pb>Cd>Zn.

The geochemical association of the metals in technogenic conditions changes essentially due to: a) formation of new supergenic phases; b) plant uptake of the metals; and c) different mobility of their chemical forms controlled by technogenic and natural physical-chemical conditions. It is presumed, that the most perspective methods for protection of the environment from influence of such technogenic objects are: using of natural or artificial sorption barriers, and biological-accumulators.

TABLE 2. Contents of the metals in pond water and aquatic vegetation

	Water, ponds µg/l							Vegetation (*Typha latifolia*), ppm in dry weight			
	Back.	North		South		Settler		Backgr.	North	South	Settler
		Surf.	Bott.	Surf.	Bott.	Surf.	Bott.				
Pb	6	15	110	9	15	3	5	20/23	600/7.5	2387/816	100/46
Zn	10	31	198	4800	6527	6300	32796	31/51	430/33	448/40	4270/340
Cd	0.14	0.1	0.15	3	12.2	10	105	0.14/0.023	11/1.6	4/1	19/1

Note: 1) 'Backgr.' is the background values of natural river water without influence of technogenic objects; 'Surf' B surface water layer of the pond; 'Bott' B bottom water layer.
2) in column 'vegetation' the contents in underground part of plant are shown in numerator; ones in aboveground part B in denominator.