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Metallisation and environmental management of mining site soils

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ABSTRACT

The present paper deals with the issue of technogenic metallisation of mining site soils and the biosphere as a whole. The natural biosphere metallisation has probably started long ago. It is connected with destruction of small areas with anomalously high content of metals in rocks and further migration of the released metals in the neighbouring biosphere areas. As a result, their content increases in a much larger area, although only slightly. This concentration increase can capture the pedosphere, hydrosphere, atmosphere, and living matter.

As a result of deposit mining conducted by people, the enrichment of several biosphere parts with metals occurs much more intense and takes far greater areas than the natural metallisation. The metallisation began to have a negative impact on many living organisms, including humans. Therefore, the study and the role of this process from a purely geochemical moved into environmental. The investigation of topsoil pollution was conducted in mining areas of Russia, Kazakhstan, and Ukraine. The emission spectral analyses of thousands of samples showed that the dominant contemporary way of remediation at mining and beneficiation areas does not prevent a metal spread through the decades. The proposed insulation method allows preventing environmental pollution by using polyethylene and polypropylene wastes.

1. Introduction

1.1. Environmental impact of mining

Soils are amongst the most important natural resources, defining sustainable development and independence of states. Preservation of soil fertility should be a major concern and a priority for economic development. In recent decades, the geochemical characteristics of soils have undergone significant changes under the influence of anthropogenic activities worldwide (Gerasimova et al., 2003).

Land areas disturbed by mining activities in Russia are amounted to more than 13,000 km^2 by now. More than 10% of disturbed soils are occupied by storage territories of mining wastes, which are produced during mineral resources extraction and processing (Pashkevich and Petrova, 2014a). Due to the low quality of safety and remediation measures, this leads to a wide range of negative effects (Il'in et al., 2003). The latter are pollution of air, soils, sediments and vegetation, surface and ground water quality deterioration, increase in morbidity and mortality, reduction of the number of plant and animal species, and loss of visual aesthetic landscape characteristics (Alekseenko, 2006; Pavlik et al., 2015).

The most dangerous changes occur in content and distribution of metals (Motuzova et al., 2014). For a long time little attention was paid to metals in soils, and the geochemistry of elements that make up the bulk of the plant organisms was studied (Boyarskikh et al., 2013). These “light” elements gravitate to the upper part of Mendeleev Periodic Table. Their lack as compared with abundance in the Earth's soil is more harmful for plants than a certain excess (Kabata-Pendias and Pendias, 2001; Kasimov and Perel'man, 1992). As for trace elements at the Periodic Table bottom (the main part of them are heavy metals), even a slight excess is much more harmful to living matter than a certain lack (Alekseenko, 2016; Bezel et al., 2015).

1.2. General definition of metallisation

The metallisation of biosphere (Vernadsky, 1965) refers to the number of effects caused by human activities that already engulfed the whole world. In recent decades, the concentration of metals has increased in the atmosphere, hydrosphere and pedosphere. The greatest geochemical changes have occurred in soils, where the high metal concentrations are saved for decades after their direct human use. Therefore metal concentrations in soils and their changes can be considered as a key indicator of anthropogenic pollution (including metallisation) of biosphere.

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Measures to ensure the safe storage of technogenic formations with high metal content are intended to the eradication of contamination pathways (Saet et al., 1990; Puzanov et al., 2012). At the same time, a pollution source must be eliminated in areas subjected to their negative impact (Mandzhieva et al., 2014). The safekeeping arrangements are mostly considered as time-limited solutions. Such measures lead to a certain situation remedial only, because the total liquidation of pollution by appropriate methods is nearly impossible. However, there is a repeatedly need in planning of these solutions as long-acting. This refers to the technogenic deposits, which are potential technogenic mineral resources.

The phenomenon of metallisation undoubtedly depends on internal factors of element migration, which are determined by the geochemical features of the basic elements that make up the ore. However, the external especially technogenic factors (Chalov et al., 2015; Mezhibor et al., 2011) are usually prevalent and man-made metallisation occurs under a general scheme, which can be slightly simplified represented as follows: ore mining, transportation and refining, obtaining ore concentrate, dumping (insulation) of enrichment tails, concentrate transportation, metal smelting and industrial use, corrosion and wear of different machines and mechanisms, and waste burial.

1.3. Research questions

The largest geochemical changes caused by metallisation have occurred in soils (Timofeev et al., 2016). The latter are a medium where the high concentrations of metals are deposited and saved for decades. Thus, the questions for the study of metallisation were formulated as follows:

1. Could we state that mining sites, zones of ore beneficiation, and landfills are the areas of the highest metal concentrations in soils?
2. Does the technogenic source of soil metallisation predominate over the natural one?
3. How effective is the dominant way of remediation of ore beneficiation areas?
4. Which insulation method allows preventing environmental pollution?

To consider the basic processes of soil metallisation, we selected a number of areas where we had been working for several decades exploring mineral deposits and solving environmental problems. The data obtained from these studies were compared with other researches, carried out in different areas.

2. Materials

2.1. Study areas

To study the sequence of metallisation process from ore mining to ore smelting, the most demonstrative and typical individual sites were selected. These include the following: areas of large polymetallic deposits in Kazakhstan (Koksu-Tekeli area) from the Tekeli mine and Tekeli town, and Ust-Kamenogorsk, where metal was smelted from ore concentrates. Soils in the areas of metal smelting plants "Severonikel" and "Severstal" were also examined.

Geochemical features of soils under the influence of land-buried waste and tailings were studied in the areas of Kamensk-Shakhtinsky and Zheleznogorsk, Russia. Regional monitoring of soil metallisation was carried out on the landscape-geochemical basis in the area of the Northwest Caucasus. The impact of non-metallic mineral mining and cement production on soils was considered in the area of Novorossiysk. General information on the geochemistry of soils that are not directly exposed to the mining influence was retrieved in the central and southern regions of the European part of Russia and partially Ukraine, and Jungar Alatau in Kazakhstan.

2.2. Soil types

The samples were taken from the uppermost soil horizon (0–10 cm), which is "the geochemical centre of soils" (Perel'man, 1989) with a critical intensity of geochemical processes in a landscape. We have also found that the main geochemical changes in the studied landscapes took place in this horizon (Alekseenko, 2016). The similar results were obtained by other researchers (Dudka and Adriano, 1997; Il'in et al., 2003; Kleeberg et al., 2008). The investigated mining site soils are recognised in the Classification and Diagnostic System of Russian Soils as *Technogenic Superficial Formations* (Shishov et al., 2004). According to the FAO World Reference Base for Soil Resources, they are *Technosols*. In *Technosols* the technical origin of soils prevails over their properties and pedogenesis (Rossiter, 2007).

2.3. Samples

The number of samples was different depending on various tasks. To establish a direct impact of mined metallic and non-metallic deposits and tailings of enrichment plants on soils, serial samples were collected on the grid and transects beyond the influence of plants and mined deposits. This influence was confirmed by the established geochemical characteristics of soils. Distance between individual samples ranged from 2 to 5 to 10 m on the territory of the main mine yard and at the entrance to auxiliary shafts. The distance between the samples along the reference transects varied from a few metres to 250 m away from mining sites.

Soil sampling was conducted with a distance of 2 to 100 m between the selected sampling points on reclaimed landfills. In the area of liquid waste disposal in lake Atamanskoe (former bayou of the Seversky Donets river) near Kamensk-Shakhtinsky, soil sampling was conducted mainly along reference profiles over 250–500 m with a sampling step of 10–100 m. Profiles ran from the Atamanskoe to the Seversky Donets, where ground water discharges from the storage of liquid waste. In total 58 km of linear profiles were studied and 781 soil samples were taken.

To assess the impact of metal smelting plants and cement production on soils we conducted areal sampling (mainly in settlements) with an average distance between sampling points of about 250 m. Profiles beyond settlements were also studied and over 3000 soil samples were obtained in total.

To evaluate soil metallisation associated with ore and concentrate transportation in the Koksu–Tekeli area, a sampling was performed on individual transects, positioned perpendicular to the roads, in addition to the already mentioned soil sampling related to successful search for ore with the help of geochemical methods.

Data on background metal content in soils that are not subjected to mining enterprise pollution were obtained from analysis results of samples taken in Koksu–Tekeli ore region and Jungar Alatau on 250 × 20 m grid. In general 16,800 samples were taken and 15,600 of them from the upper horizon. In the south of the European part of Russia and Ukraine samples were taken for this purpose from the territory of Voronezh and Luhansk regions to the Black and Azov seas, including the republics of the North Caucasus on a grid of 5 × 5–5 × 10 km.

The wastes stockpiled at the territory of JSC "Mikhailovsky GOK" were studied in the Kursk region (Russia). The amounts of fugitive dust in the atmosphere, as well as the contents of certain metals in the ground water were determined in this area.

3. Methods

3.1. Analyses and control

Because of the total number of soil samples equal to tens of thousands, the control sampling was performed in the amount 3–5% of total samples number, and in Koksu-Tekeliysky area – up to 15%. All samples were treated by a standard technique. The soil samples were

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