Natural and anthropogenic landscapes of the gold-mining regions in Bashkortostan (Russia)

A N Kutliahmetov, A A Kulagin, O V Serova and I M Gatin

Department of ecology, geography and nature management, Akmulla Bashkir state pedagogical university, Ufa, Russia

E-mail: ecobspu@mail.ru, Kulagin-aa@mail.ru

Abstract. This article presents the results of laboratory and field studies of territories in the zone of influence of the gold extracting and mining enterprises of the Southern Urals. Researches were conducted on six sites of gold mining of the past years, in order to identify natural and technogenic mercury in various natural and man-made landscapes of mining Bashkortostan. A brief description of the mineralization of the study area and types of gold deposits is given. The mercury content in bedrock, in various types of ores, man-made soils (fine-grained tailings dump, tailings), soils, bed-silts, in the soil air, in water was determined. The largest technogenic anomalies are Hg dissemination flows in bed silts of watercourses and lakes. Technogenic Hg anomalies in soils are local and are formed in the areas of mining and old ores processing. The practical absence of anomalies in transit environments with intensive Hg accumulation in long-term deposition reflects the regressive residual nature of technogenic mercury anomalies.

1. Introduction
The long-term intensive exploitation of gold placer mine, gold ore deposits and complex gold-copper-zinc containing deposits in the eastern regions of Bashkortostan (Bashkir Trans-Urals) is a large-scale factor in the transformation of the nature and human environment. Gold has been mined in the Bashkir Trans-Urals for over two hundred years [1]. Metallic mercury was used traditionally for the extraction of Au by amalgamation as in many other countries. Mercury accumulated in the tailings and dumps of runner gold-processing plants and was released from them into the environment [2, 3]. Mercury is a typical associate component of the ores of gold and sulphide deposits, which are widespread in the area [4].

2. Methods and materials
Cu-Zn-sulphide and Au are the main types of mineralization of the area. Sulphide deposits (Uchalsinsko, Novo-Uchalsinsko, Ozernoye, Zapadno-Ozernoye) are genetically related to the ore-containing Devonian volcanogenic formations. Gold deposits of the region are divided into gold-quartz, gold-quartz-sulphide, gold-sulphide and gold-polymetallic. Au in the first two types of deposits, mainly in the native form, and in the latter two – as an accompanying element in sulfides. The Uchalsinsky ore region is one of the main gold-bearing regions of the Urals, gold mining in this region started at the beginning of the 19th century: numerous Au placers along the Miass, Ural and their tributaries were exploited. Then bed-rock Au deposits were exploited, the main are deposits of the Buydinsky, Mindyaksky and Ilyinsky ore fields [5]. In addition, Mn, Cr, ornamental and technical
jasper, building materials (granite, limestone, clay, etc.) deposits are known in the area. The largest anthropogenic landscapes are distinguished in the city of Uchaly, Mindyak and Mansurovo villages and their surroundings. Man-made landscapes of abandoned gold placers are located in the form of narrow stripes along the valleys of the rivers Miass, Ui, Ural and their many tributaries.

Mercury is constantly present in increased concentrations in the ores of sulphide deposits and forms extended areolas around their deposits. Hg content in ores varies over a wide range: from 1 to 250 g/t and depends on the mineral composition of the ores. The lowest grades are found in sulphur-sulphide ores – 1–10 g/t, noticeably higher are in copper-sulphide ores – on average about 6–10 g/t and sharply increased in copper-zinc and zinc ores – on average 20–30 g/t. Such differentiation of Hg by type of ores is due to the different levels of the main Hg mineral concentrates in them: sphalerite and fahlores, the Hg concentration in which reaches 0.3–0.5 %, average 0.2 %. Hg own minerals are also known in sulphide ores: cinnabar and coloradoite, but their role in the overall balance of Hg is negligible. High accumulation of Hg (up to 80 g/t) in the oxidation zone of sulphide deposits is typical, where it is in metallic form (Rezenkova, Samoylova, 1975). Almost all of the Hg extracted from the subsoil with sulphide ores goes into concentrates and is removed with them to melting outside the region, and only a small amount of it (up to 5 % of the total mass) remains in the tailings and is stored in the Mining and Processing Plant’s (MPP) tailing dump. Since the temperatures in the ore processing cycle at the processing plant do not exceed 100 °C, and the sublimation temperatures of Hg from its main concentrators – sphalerite and fahlores are 400–600 °C (from pyrite> 600 °C), Hg does not come into the atmosphere. This is confirmed by measurements of concentrations of Hg vapors at the site of the MPP and the territory of the city of Uchaly.

The purpose is given results of laboratory and field studies of territories in the zone of influence of the gold extracting and mining enterprises of the Southern Urals.

Samples were taken from: bedrocks, man-made soils (fine-grained part of beneficiation tailings, tailings), soils, bed silts, soil air (mercury survey), water (processed 2,742 samples). Analyses of rocks, subsoils, soils and bed silts samples for gross Hg content were performed on an AGP-01 gas-port analyser with a UV-1 thermosublimation unit. The resulting material was processed by statistical methods using Microsoft Excel.

3. Results

Thus, anthropogenic “sulphide” Hg cannot be considered as a source of mercury contamination of the environment. However, high Hg content in tailings indicates the potential environmental hazard of the tailings as a source of local secondary mercury contamination. The dumps of quarries and underground mines, which exploit sulphide deposits, in which ore-containing low-mineralized rocks with anomalous (areolas) Hg content accumulate, may be of greater importance in the input of Hg into the environment. Mercury can flow from them into landscapes as a result of air and water migration. However, so far no noticeable increase in Hg concentrations in landscape components in connection with the tailing dump, Uchaly MPP concentrator and dumps of sulphide deposits has not been established.

Mercury, in anomalous (one to two orders of magnitude lower than in sulphide deposits) contents, has been established at all types of gold ore deposits and in their areolas. The degree of Hg concentration there varies: relatively low contents (up to 0.1 n g/t) are characteristic of gold-quartz and gold-sulphide-quartz deposits, and higher (from n up to n100 g/t) – for gold-sulphide and, especially, gold-polymetallic [5, 8].

The fact that at the industrial site of the Bashkir Gold Mining Company, where mercury-containing Au ores are currently being processed by heap leaching, using sodium cyanide solution, the environmental mercury contamination is practically not manifested is confirmation of the decisive importance of amalgamation at the gold mining of the past years as the primary source of pollution of the environment [6]. It should be noted that the absolute majority of modern gold mining factories work with cyanation [7–10].
From the results of research by the following authors: N.Yu. Antoninova, N.V. Gonchar, A.V. Kivatskaya, V.V. Lodeyschikov, M.A. Meretukov, V.I. Sotnikov, G.V. Sedelnikova, M.I. Fazlullin, V.A. Chanturia and others – it follows that the most common technological processes for gold-bearing ores processing are based on the use of a highly active toxic substance – sodium cyanide. The use of sodium cyanide predetermines the danger of emergencies at gold ore processing enterprises, the number of which has recently been growing [11, 12].

The use of Au amalgamation in gold mining in the Uchaly district in the period of 1823–1995 led to a significant income of Hg in the environment. Considering that Hg consumption during amalgamation is about 1.5 kg per 1 kg of extracted Au, and the total volume of extracted Au exceeds 40 tons (including 29 tons before 1917 year), the environment received about 70 tons of anthropogenic Hg, which is firmly held by subsoils, soil cover and bed silts of water bodies and watercourses.

The regional Hg geochemical background (BG) in the rocks is 30 µg/kg, in soils – 40 µg/kg, and in bed silts of waterscourses – 12 µg/kg. For atmospheric air the background concentrations are 2 pg/L. The content of Hg in the studied waters below the threshold of its detection is 0.01 µg/L with the used method of analysis [4].

The bottom sediments of the rivers Buydy, Zirikly and Yamjelga and the soils were studied on the dumps and in the vicinity in the village of Buyda (Figure).

The Hg content in river Yamjelga bottom sediment is near-background and typical, and only at 2 points they are anomalous (3.7 and 5 GB). This is consistent with the absence of ore occurrences and Au placers in the river basin. An almost continuous flow of Hg dissemination, approximately more than 12 km (its eastern continuation in the deposits of the Kiddysh river is not contoured), is established in the bed silts of the Buydy river. Its anthropogenic source is the heaps of the runner factory in the Buyda village. Hg concentrations are sharply increased to 0.69 mg/kg (16.5 GB) in the soils on them, and Hg concentrations in the atmospheric air at the site of the former runner factory are 61 pg/L (30 GB). The maximum values reach the concentration of Hg in the bed silts of the river directly near the dumps – 1.34 mg/kg (112 GB).

Downstream, the Hg content in bed silts generally decreases, but unevenly, depending on the slope of the river bed, increasing in areas of its flattening and, accordingly, the accumulation of silty sediments. Highly abnormal Hg content (up to 10 GB) is also noted in the bottom sediment of the Kiddysh river, in its most studied eastern part.

A sharp decrease in the Hg content in the sediments upstream from the dumps is the proof of the spatial connection of the Buydin Hg dissemination flow with the erosion of the spoil dumps. The average Hg content here is 2.7 GB, and the maximum – 6 GB, although up-stream Buydy river the burial waters of the Uchalinsky mine come in along the drain channel. The latter indicates a low level of Hg content in these waters.

3 intervals with abnormal levels of Hg are established in the bed silts of the Zirikly river. Relatively long (2.5 km) and intense (up to 54 GB) flow was detected in the western part of the site outside the Buydinsky ore field. It is spatially conjugated with complex (with Hg) geochemical anomalies in rocks and soils. The second local (0.6 km) intensive (up to 12.4 GB) flow also records the continuation of the ore zone of the Uragan-Idrisovsk Au deposit. At 6 km downstream from this stream, third rather long (1.7 km) and less intensive (up to 9.4 GB) Hg flow is detected. There are no manifestations of ore mineralization and geochemical anomalies in bedrock in this site. Therefore, its formation should be attributed to the accumulation of thin Hg-rich sediments carried from the area of the Buydinsky ore field, due to the abrupt flattening of the Zirikly riverbed at its exit to the foothill plain. There are no signs of the connection of the Hg dissemination flows, detected at Zirikly river, with anthropogenic sources and its apparent conjugation with ore-bearing zones and ore-genic geochemical anomalies in rocks and soils indicates the ore-generating nature of these flows. They drastic differ from the Buydin anthropogenic flows in smaller length (up to 2.5 km), intermittent propagation and, in general, lower intensity.
4. Conclusion
As a result of the conducted research, it was established that anthropogenic Hg, associated with the gold deposits exploitation, is one of the sources of its income into the landscapes of the region and the main source of local mercury pollution of the surrounding environment. The most intensive anthropogenic source of Hg are the dumps of gold-processing plants that processed gold ores using amalgamation.

The largest anthropogenic anomalies are Hg dissemination flows in bed silts of watercourses and lakes. Hg anthropogenic anomalies in soils are local and are formed in the areas of mining and processing of gold ores using the amalgamation method.

Hg anomalies in waters are not established, and in the atmospheric air have low intensity and are fixed in the places of processing of gold ores. The practical absence of anomalies in transit environments with intensive Hg accumulation in long-term deposition environments reflects the regressive residual nature of anthropogenic mercury anomalies.

Due to the substantially absence of natural and local manifestations of environmentally hazardous anthropogenic mercury contamination (identified in Buyda, Ilyinka villages), the overall environmental situation in the region with regard to mercury contamination is rated as relatively satisfactory.

Figure 1. Buydinsky plot. Mercury dissemination flows in the bed silts of the Buydy, Zirikly, Yamyelga rivers. Legend: deposits and ore occurrences: 1 – Kalkan, 2 – Novo-Timofeevskoe, 3 – Vorontsovskoe, 4 – Oktyabrskoye, 5 – Staro-Timofeevskoe, 6 – Asfandyarovskoe, 7 – Ganeevskoe, 8 – Arslanovskoe, 9 – Uragan-Idris, 10 – Pik-Tau, 11 – Puchkovskoe, 12 – Vorontsovskoe, 13 – Staro-Zharakovskoe, 14 – Leninskoye

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