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SOIL CHEMISTRY

Arsenic in the Soil–Natural Water–Plant System of the Altai Region

A. V. Puzanov and S. V. Baboshkina

Institute for Water and Environmental Problems, Siberian Branch, Russian Academy of Sciences,
ul. Molodezhnaya 1, Barnaul, 656038 Russia
E-mail: puzanov@iwep.asu.ru, svetlana@iwep.asu.ru

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Abstract—The high natural content of total arsenic in the soil cover of the Altai region has been revealed. Natural waters and plants are distinguished by low arsenic concentrations. The intensity of the biogenic and water migration of arsenic does not depend on its total content in the soil. The accumulative distribution of arsenic in the mountainous forest soils of Altai is mainly due to biogenic processes, while in the steppe soils, it is specified by the evaporative concentration. Favorable conditions for arsenic migration are observed in the southeastern Altai during the periods of seasonal moistening. The arsenic content in the soils and plants of technogenic landscapes in the Altai region considerably exceeds the provisional permissible concentrations and the background concentrations of this element.

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INTRODUCTION

Arsenic is one of the most hazardous pollutants; its elevated concentrations have a toxic effect on living organisms. The processing of polymetallic ores, coal and oil combustion, and the application of As-containing pesticides lead to severe environmental pollution by this element [7, 9]. The further migration of As and its inflow to plants and living organisms depend on the soil properties.

The bulk As content in the unpolluted soils of the world rarely exceeds 10 mg/kg, except for the regions of recent volcanism [11]. The average As content in soils of the former Soviet Union reaches 3.6 mg/kg [6]; the areas with the As content of 10–25 mg/kg are identified as geochemical provinces [6, 7].

The As clarke in river water is 3 μg/l [9]; the concentration of As in seawater may reach 10 μg/l [7]. The concentration of As in the groundwater varies considerably; the highest concentrations (up to 905 mg/l) were determined in carbonic acid, oil, and acid mine waters [9].

The biological role of As is poorly studied, though this element is present in many plants. It is known that As accelerates ethylene biosynthesis in plants [20] and increases the productivity of some mire vegetation [23]. The high content of available As adversely affects the vital functions of plants, impairs their growth, decreases the yield, and leads to leaf fading and to bleaching of root crops [7]. The phytotoxicity of As is most pronounced at the sites with the low content of organic matter [21] and decreases upon the good supply of plants with phosphorus and sulfur [11]. The majority of researchers consider arsenites to be the most toxic As compounds [7, 9, 16, 24, 26, 28, 30]. Being an anionogenic element, As is intensively involved in the biological cycle in the alkaline medium [1]. The average As content in the plants growing on uncontaminated soils is about 0.01–5.0 mg/kg of dry mass [11]. Arsenic hyperaccumulators are Douglas fir (*Pseudotsuga taxifolia*) (8 200 mg/kg in ash) [29] and fern (*Pityrogramma calomelanos*) (400 mg/kg in dry mass) [25].

The previous soil-geochemical studies of Western Siberia [10, 15] report on relatively high background concentrations of As in the soil cover; they exceed the Russian provisional permissible concentrations (PPCs) [17] and do not agree with the European data for nonpolluted territories [11, 27]. Arsenic is present in a paragenetic association of elements typical of polymetallic ore and mercury deposits that are found in Altai. The development of mining industry and the storage of wastes of ore-dressing and processing enterprises in Altai necessitate close attention to the environmental issues. For the Altai region with a stressed ecological situation, the study of the contents and behavior of As in the environmental media are of great theoretical and practical importance.

Our research was aimed at studying the contents and distribution of As in the soil–natural water–plant systems of the Altai region.

OBJECTS AND METHODS

The main types of soils and parent materials, herbaceous plants, and natural waters of Altai were studied. Soil types were specified according to the classification system of 1977.

According to climatic features, the territory under study is definitely divided into three regions, i.e., the northern, central, and southeastern Altai. The northern Altai region is characterized by a relatively warm winter, cool summer, and even distribution of precipitation in the annual cycle. The southeastern Altai is influenced by the Mongolian sharply continental dry climate with cold winters and hot summers. The climate of central Altai can be considered an intergrade between these two climatic types.

The Altai Mountains are composed of chlorite–sericite slates, siltstones, sandstones, and limestones of different ages. The products of their supergene weathering are represented by the physically and chemically heterogeneous deposits that serve as soil parent materials.

The following vertical soil zones are distinguished in the Altai Mountains: (1) the zone of mountainous tundra and mountainous meadow soils of high mountains (1600–3500 m a.s.l.), (2) the zone of mountainous forest soils of middle and low mountains (600–2500 m a.s.l.), (3) the zone of forest-steppe soils of low mountains (<600 m a.s.l.), and (4) the zone (isolated interzonal areas) of steppe soils in the depressions and river valleys [19].

The mountainous tundra and meadow soils are developed under moss–lichen, dwarf-birch–juniper, or forb–sedge–grassy and Kobresia dry-steppe communities from the loamy gravelly eluvial and colluvial deposits. These are acid soils with a high cation exchange capacity, a high humus content with a predominance of fulvic acids, and a monotonous distribution of major chemical elements within the profile.

The mountainous forest soils cover about half of the Altai territory. Large areas near the upper boundary are occupied by the mountainous brown forest soils under broad-herb Siberian pine–larch forests growing on various soil-forming rocks. In central Altai, mountainous chernozem-like forest soils are developed from the eluvium and colluvium of chlorite–sericite slates under larch parklands with rich mesoxerophytic herbs in the ground cover. Within the lower part of the forest zone, soddy deeply podzolic and gray forest soils predominate. The former are developed under fir–spruce taiga on the thick layer of colluvial loamy clays and clays; their fine-earth profile is distinctly differentiated; the soil reaction is slightly acid in podzolized horizons, and the humus content is low. Gray forest soils are often formed on the noncalcareous covering loamy clays and clays under dark coniferous or birch–aspen forests with well-developed tall herbs.

In the intermontane basins, river valleys, and on the slopes of southeastern aspect in central Altai, ordinary and southern chernozems are formed under forb–grassy steppes; these soils have a loamy sandy texture with some content of gravel and rock fragments; the soil reaction varies from neutral to alkaline. In the northern part of Altai, podzolized and leached chernozems are widespread. They are rich in humus and well structured, and their texture is somewhat finer. Most of these soils are cultivated.

In the dry-steppe depressions and river valleys of southeastern Altai, chestnut soils are formed on a thick layer of Quaternary lacustrine and glacial sediments. These are gravelly soils with a predominance of sand and silt particles in the fine earth. The soil humus content is low, and the content of carbonates is high. The water capacity and the infiltration capacity of these soils are low. The vegetation cover of Altai is extremely diverse due to varied natural conditions. The steppe, forest, and alpine zones replace one another with the rise in the absolute height of the territory; these zones have somewhat different vegetation in different parts of Altai. For example, grassy steppes predominate in the central Altai, desert steppes predominate in the southeastern Altai, and meadow steppes predominate in the northern Altai. The forest zone in the northern Altai consists of the fur–spruce forests with bird cherry, snowball, mountain ash, and willow trees in the understory and with tall herbs in the ground cover. In the central Altai, Siberian larch and Siberian pine prevail. The forest zone of southeastern Altai has a fragmentary character and consists of larch groves on the northern slopes. Subalpine meadows are widespread in the northern and central parts and disappear in the dry southeastern part of Altai. In the central and northeastern Altai, short- and tall-herb alpine meadows predominate; in the southeastern Altai, they are replaced by Kobresia meadows. The flora of mountainous tundra is rather poor. Moss–lichen tundra is typical of the northeastern Altai; shrub tundra with dwarf birches occurs in the southeastern Altai; sedge–grass meadow tundra, in the western Altai; and Kobresia meadow tundra, on the plateaus in the southeastern Altai.

The Altai drainage network is well developed; river and lake waters belong to the bicarbonate class; their total salinity varies from 20 mg/l (in the alpine glacial hydrologic region) up to 600 mg/l (in the area of low mountains). The sediment discharge is unstable and generally low because of the coarse gravelly soil textures, channel resistance to erosion, and the dense forest cover with sod mats on slopes [19].

The comparative-geographical method served as the methodological basis of our study. Soil profiles (75) were made in a system of the landscape-geochemical catenas. Soil description and sampling (480 samples) were made with due account for the genetic horizons. Overall, 70 samples of medicinal herbs cut in the areas of soil profiles were analyzed. The main sources of water supply, including salubrious water springs and surface waters were examined (66 samples).

The physicochemical soil properties were determined by standard methods. The Tyurin method was applied to determine the humus content; the particle-size distribution was determined by the Kachinskii method; the adsorption capacity, by the Bobko–Askinazi–Aleshin method; the content of carbonates, by the

Table 1. The bulk content of arsenic in different types and subtypes of Altai soils, mg/kg

Soil type (subtype)	*n*	Variation limits	Mean
Mountainous tundra	13	4.0–40.0	13.6
Mountainous meadow	21	4.2–42.0	22.1
Mountainous brown forest	24	3.0–27.0	13.2
chernozem-like	58	8.0–49.0	20.7
Dark gray	22	9.0–33.0	18.0
Soddy-podzolic	11	19.0–28.0	22.9
Chernozems:			
leached	68	1.4–48.0	18.4
ordinary	141	0.5–33.0	12.1
southern	56	0.4–37.9	12.6
Chestnut	34	3.0–27.0	13.8
Meadow	28	9.0–54.0	20.5

acidimetric method, and the pH values, by the potentiometric method.

To determine the content of available (mobile) As, an acid extraction (0.2 N HCl at 1 : 10 soil/solution ratio) was used according to the Kirsanov method [12]; in calcareous soils, mobile As was determined in 1% NH_4CO_3 extractions using the Machigin method. Overall, the content of mobile As was determined in 113 soil samples.

The total As content in soils was measured by the plasmic spectrophotometry. The As concentration in acid soil extractions, water, and plants was determined by the atomic absorption method with the use of a Perkin-Elmer 3030 Zeeman HGA-60 spectrophotometer with the electrothermal atomization.

Statistical data processing was performed by standard methods [8, 14]. Pearson's chi-square test at the 5% significance level was applied to verify the fit of empiric curves of As distribution to the Gaussian Law. In the case of a positive skew or lognormal distribution, the arithmetic mean insignificantly differed from the geometric mean, which is usually observed upon the small scattering of values. The confidence interval was calculated at $P = 0.95$. Student's *t*-test was used to estimate the significance of differences. In this paper, the following symbols are used: *n*, sample volume; *X*, arithmetic mean; $\bar{x}$, confidence interval; $\bar{x} = \frac{\sigma}{\sqrt{n}} \times 1.96$, where σ is standard deviation; *V*% is the coefficient of variation, and *r* us the coefficient of correlation.

DISCUSSION

The As content in the soil cover of Altai varies within 0.5–346 mg/kg; in 98% of the samples, it ranges from 0.5 to 77 mg/kg. The mean As content (17.4 mg/kg) lies within the range typical of uncontaminated soils of the world (<1 to 95 mg/kg) [11]; at the same time, it significantly exceeds the arithmetic mean established for the European part of the former Soviet Union [6] and the Russian PPC (2–10 mg/kg) [17], which points to the inadequacy of Russian standards rather than to the As pollution of the studied territory.

A generally high content of As in the Altai soil cover is explained by the presence of phosphorite-bearing deposits in the Altai–Sayn mountain province [10, 19]. It is well known that arsenic is often associated with phosphorus [7, 16]. The metallogenic specificity of soil-forming substrates should also be taken into account. The diversity of parent materials is responsible for the nonuniform distribution of As in the Altai soil cover, which is seen from the high variation coefficient (67.4%) and the abnormal double-peaked statistical distribution curve. The first peak (12 mg/kg) character-

Table 2. The content of mobile arsenic in different types and subtypes of Altai soils, mg/kg

Soil type (subtype)	*n*	Variation limits	Mean	% of the bulk content
Mountainous tundra	13	0.15–0.83	0.52	7.3
Mountainous meadow	4	0.33–0.62	0.44	7.2
Mountainous brown forest	11	0.14–0.49	0.32	2.7
chernozem-like	11	0.24–0.58	0.41	1.5
Dark gray	18	0.10–0.73	0.44	2.7
Soddy-podzolic	11	0.15–0.61	0.40	1.7
Chernozems:				
leached	8	0.27–1.03	0.60	2.7
ordinary	19	0.17–0.93	0.41	3.3
southern	7	0.19–0.62	0.40	2.7
Chestnut	11	0.29–1.13	0.59	5.6

Table 3. The content of arsenic in the soil–plant system (mg/kg of air-dry matter)

Soil			Vegetation	
Pit no.	As*		Formation, association of the lower story	As
	total	mobile		
13-99, mountainous brown forest loamy	$\frac{27}{22}$	$\frac{0.47}{0.20}$	Siberian pine parkland with forbs and grasses	0.14
22-99, mountainous brown forest loamy sandy	$\frac{11}{7.5}$	$\frac{0.45}{0.14}$	Siberian pine–larch parkland with forbs and grasses	0.37
14-99, mountainous forest chernozem-like	$\frac{17}{20}$	$\frac{0.57}{0.53}$	Larch parkland with grasses, sedges, and forbs	0.23
62-00, mountainous forest chernozem-like above ore deposit	$\frac{34}{49}$	$\frac{0.58}{0.46}$	Larch parkland with forbs and grasses	0.12
49-00, slightly leached ordinary chernozem	$\frac{19}{11}$	$\frac{0.59}{0.40}$	Herbaceous legume–grassy meadow-steppe	0.24
16-99, southern chernozem	$\frac{21}{10}$	$\frac{0.62}{0.27}$	Wormwood–caragana–sedge steppe	<0.08
32-01, peaty mountainous tundra	$\frac{4.0}{5.8}$	$\frac{0.66}{0.44}$	Dwarf birch shrubs with forbs, sedges, and grasses	0.09
33-01, mountainous meadow-steppe	$\frac{4.2}{4.9}$	$\frac{0.62}{0.33}$	Tundra meadow-steppe	0.22
27-99, solonchakous light chestnut sandy	$\frac{17}{5}$	$\frac{1.13}{0.89}$	Steppe with *Achnatherum splendens*	No data

* A1(Ap)/C.

izes the As content in sandy and loamy sandy parent materials and soils; the second peak (21 mg/kg) corresponds to loamy soils and to loamy parent materials of eluvial and colluvial origins.

The soil cover in the western part of Altai is characterized by the lowest arsenic concentrations. Thus, the As content in soils of the Charysh River basin averages 9.9 ± 0.7 mg/kg. The terminal zone of accumulation of weathering products from the Altai–Sayan Mountains in the northeastern Altai represents the area of low mountains. In this area, increased As concentrations are observed in the soil cover.

The As content in the soil-forming rocks of Russia ranges from 1.8–2.1 mg/kg in the moraine and covering loams of the Russian Plain [5] up to 11.0–25.0 mg/kg in the products of weathering of clay slates in the North Caucasus [16]. The mean As content in the parent materials of Altai (except for the areas of element dispersal around ore deposits) is 17.1 mg/kg.

The As content in the humus horizons of Altai soils varies within a wide range. In the plow horizons of chernozems, its average value of 11.5 ± 1.0 mg/kg is informative: the mixing of the upper layer and the soil development under the homogeneous vegetation of agrocenoses result in the leveling of the initial natural variability in As concentrations. The maximum probable background As concentration ($X + 3\sigma$ [12]) in the humus horizons of cultivated soils is 30 mg/kg.

In the European part of Russia, the As concentration in the zonal soils increases as follows: tundra <forest soils <chernozems [5]. In the system of the vertical soil zones in Altai, the inverse regularity is observed: mountainous tundra, forest, and meadow soils developed from the eluvium of bedrock have the maximum As content, whereas sandy and loamy sandy chernozems and chestnut soils developed from the accumulative deposits in the valleys have lower As concentrations (Table 1).

The weighted average background As content in soils of Altai was calculated from data on the average As content in each soil type with due account for the portion of this soil type in the total area. It constitutes 16.2 mg/kg and agrees with the As content in the soils of Western Siberia calculated by Il'in [10].

The closest relationship between the As concentration and the physicochemical soil properties is typical of the illuvial horizons. The element content in soil horizons depends on its content in the parent material.

Water-soluble As was only found in soil samples with the elevated total content of the element, namely,

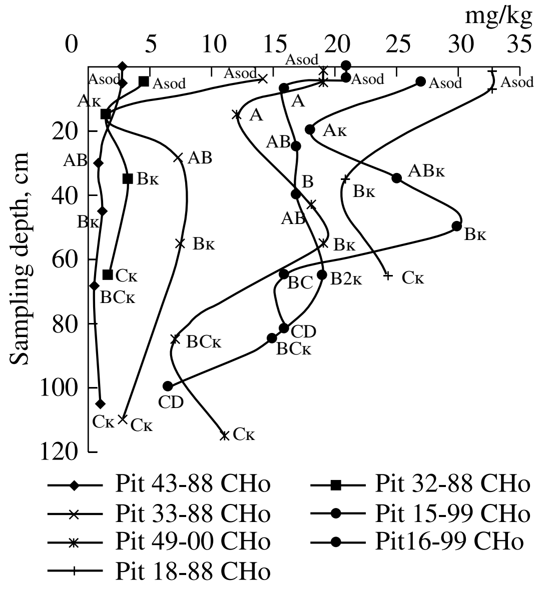

Fig. 1. Distribution of total arsenic in the profiles of ordinary and southern chernozems (CHo and CHs) under natural phytocenoses.

in the area of the former dislocation of an army unit and in the areas of element dispersal around mineral deposits.

The content of the mobile forms of As in the soils of Altai, as compared with the soils of other regions [12, 16], is rather high and averages 0.45 ± 0.04 mg/kg varying from 0.10 to 1.03 mg/kg (Table 2); the distribution of the values is close to the normal one. The portion of mobile As in 70% of the studied soil samples is less than 3% of the total As content, which agrees with the previously published data [16].

The relative content of mobile As is inversely proportional to the total content of the element ($r = -0.53$). Thus, the migration of As depends on the properties of the soil–plant system rather than on the bulk content of the element in the soil.

The content of As in medicinal plants of Altai varies from less than 0.07 to 0.78 mg/kg with the average of 0.16 mg/kg (or 2.74 mg/kg in conversion to ash). In more than 60% of the samples, it does not exceed 0.07 mg/kg of dry mass. The highest concentration of As is found in the *Panzeria lanata* (0.78 mg/kg), *Potentilla fruticosa* (0.65 mg/kg), *Plantago media* (0.29 mg/kg), and *Rhaponticum cartamoides* (0.26 mg/kg) species.

The coefficient of the biological accumulation (CBA) of As by plants (the ratio of the element concentration in the plants to that in the soils) averages 0.4. According to Perel'man [18], arsenic is the element of the moderate biological uptake with the CBA about 0.n. More intensive uptake of As from soils is typical of *Panzeria lanata* (CBA = 3.45) and *Potentilla fruticosa* (CBA = 1.24).

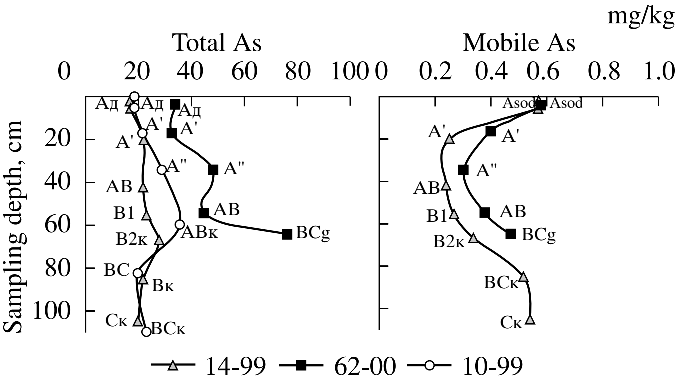

Fig. 2. Distribution of arsenic in the profiles of mountainous chernozem-like forest soils of Altai.

The highest As content has been found in the herbs growing under the cedar–larch canopy on the mountainous brown forest loamy sandy soil (Table 3, pit 22-99). It is probable that the accumulation of As in the humus horizon of this soil is due to its biological uptake by plant roots.

The accumulative distribution of As in the steppe soils of Altai (Fig. 1) is largely due to the evaporative concentration of this element, because, as a rule, the As concentration in steppe plants is very low (<0.08 mg/kg) (Table 3, pit 16-99).

A combination of the soddy process with sufficient moistening (as in the mountainous forest chernozem-like soil (pit 14-99) and in the slightly leached ordinary chernozem (pit 49-00, Table 3) is responsible for the high (0.23 mg/kg) As concentration in the aboveground phytomass of herbs. However, under conditions of the forest zone, this does not lead to the accumulation of As in the upper humus horizon, which may be explained by the downward leaching of the element and its sorption on the carbonate geochemical barrier in the B2k and ABk horizons (Fig. 2).

The elevated content of total As in the soils developed in the areas of mineral deposits can be considered ecologically safe, because the concentration of the mobile forms of As is not high (Fig. 2, pit 62-00), and no excessive uptake of the element by plants is observed (Table 3). The distribution of As in the soil profiles within the areas of mineral deposits is similar to that in the background soils (Fig. 2, Table 3, pit 14-99).

In the mountainous peaty tundra soils developed on steep slopes (Table 3, pits 32-01 and 33-01), the distribution of total As in the soil profiles has a regressive pattern (with a minimum in the upper horizons), which is due to the element leaching from these horizons. It is interesting that the high content of mobile As in the topsoil does not favor the active biological uptake of the element (Table 3, pit 32-01). The As concentration in Altai waters varies from <0.5 to 7.3 μg/l and averages 1.5 μg/l. In more than 50% of the samples, the As concentration is < 1 μg/l. The As concentration in the sur-

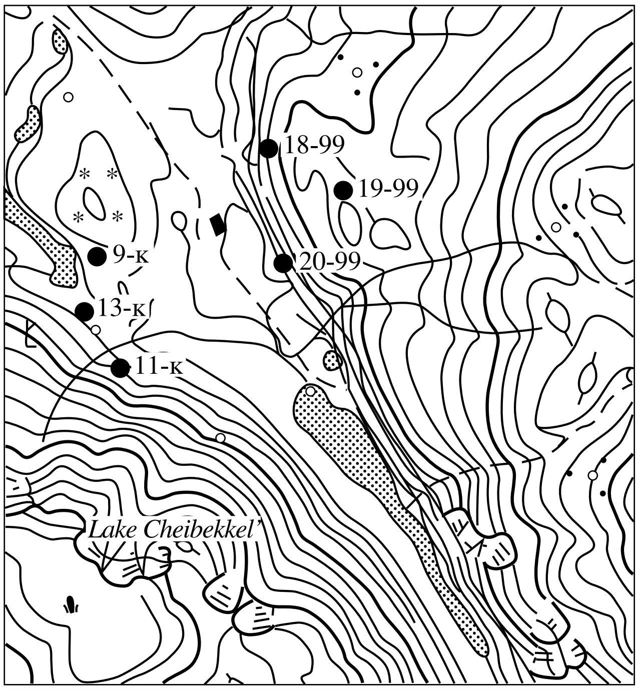

Fig 3. Location of soil profiles studied in the area of the Aktash mercury deposit (southeastern Altai).

face waters varies from <0.5 to 2.6 μ g/l (1.3 μg/l on the average). Increased As concentrations are typical of river waters in the zones of accumulation (in the local depressions and low mountains); these rivers cross the agricultural areas composed of erodible loesslike loams. The average concentration of As in the groundwater is higher and reaches 2.8 μ g/l. A relatively high content of As (up to 7.3 μg/l) is typical of the rivers in the southeastern Altai. The As concentration in drinking water from wells averages 0.9 μg/l varying from 0.5 to 1.5 μg/l. These values are much lower than the maximum permissible concentration (MPC) of As for domestic waters (50 μg/l [4]). The elevated As concentration (6.9 μg/l) in the well in the settlement of Kosh-Agach (southeastern Altai) can be explained by the influence of the adjacent Chagan-Uzun mercury deposit.

Data on the As concentrations in natural waters and rocks can be used to judge the intensity of the water migration of this element. According to Perel'man, the corresponding coefficient is calculated as follows: $Kx = \frac{m_X \times 100}{a n_X}$, where a is the sum of dissolved mineral substances (g/l), m_X is the element concentration in the water (g/l), and n_X is the element concentration in the rock (%) [18]. Thus, though the As content in the loamy and clayey soil-forming materials of northern Altai is relatively high (22.5 ± 3.2 mg/kg (n = 15, V =28%), the average As concentration in the moderately saline (400–500 mg/l) river water in this region is low (1.1 μg/l). Therefore, the intensity of the water migration of As in this case is low ($Kx = \frac{1.1 \times 10^{-6}\ \text{g/l} \times 100\%}{0.4\ \text{g/l} \times 22.5 \times 10^{-4}\%} = 0.1$). Although the As distribution in the profiles of mountainous forest and leached meadow-chernozemic soils of northern Altai is characterized by a pronounced minimum in the upper horizons (the regressive pattern), the As leaching from the topsoil does not lead to the rise in its concentration in the river water. This is explained by the fixation of As by sesquioxides in the illuvial horizons of these soils [13].

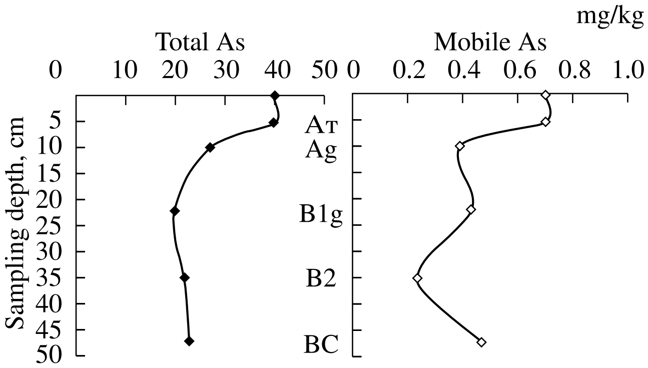

Fig.4. Distribution of arsenic in the profile of semihydromorphic mountainous tundra soil, pit 12-99.

The average As content in the soil-forming rocks of southeastern Altai is relatively low (9.2 mg/kg), whereas the As concentration in the river water in this region is the highest (1.5–2 mg/kg) despite the low total content of dissolved substances in these rivers with glacial alimentation. Hence, the coefficient of the water migration of As in the southeastern Altai is much higher than that in the northern Altai and reaches ($Kx = \frac{2.0 \times 10^{-6}\ \text{г/л} \times 100\%}{0.2\ \text{г/л} \times 9.2 \times 10^{-4}\%} = 2.2$).

The high As content in the groundwater of southeastern Altai favors its evaporative concentration in the soils of dry-steppe depressions and river valleys; particularly, in the upper horizons of solonchakous soils (pit 27-99, Table 3). In this province, the concentration of mobile As in soils is increased, and the element uptake by plants is very active (pits 33-00 and 27-99, Table 3): up to 0.78 mg/kg (air-dry mass) with the CBA of 3.5 in the *Panzeria lanata* species growing in the desert-steppe river valleys. It is likely that the biogeochemical conditions of dry steppe landscapes in the southeastern Altai (during the seasonal moistening) favor the migration of As. Therefore, any anthropogenic activity (for instance, the construction of the motorway to China across the Ukok Plateau) in this region requires special protection measures and control over the concentrations of microelements in the environment. It is known

Table 4. The bulk content of arsenic in soils above the Aktash ore deposit, mg/kg

Horizon	As
Mountainous meadow-steppe soil, pit 18-99	
Asod	17
Asod’	30
A1	36
B	29
D1	26
D2	30
D3	21
D4	31
Mountainous brown forest soil, pit 19-99	
Asod	11
A1	14
A1	18
B	17
CD	25
Mountainous meadow soil, pit 20-99	
Asod	18
AB	21
B	23
BC	18
D1	22
D2	69
Mountainous brown forest soil, pit 11-	
Asod	77
A1	70
B	74
C	72
C	64
Mountainous meadow soil, pit 13-K	
Asod	216
B	208
C	220
Mountainous meadow soil, pit 9-K	
Asod	346
B	298
CD	320

that technogenic loads often result in the environmental pollution with chemical substances of unnatural origin and, also, increase the concentration of mobile element compounds leading to their excessive uptake by living organisms [10].

The biogeochemical situation in Altai is complicated by the presence of areas with elevated and abnormal As concentrations. Soils forming above the sources of natural geochemical anomalies, such as the Tushkanikhinsk polymetallic deposit and the Aktash and Chagan-Uzun mercury deposits are distinguished by the abnormal and elevated As concentrations of 100–2000, 64–346, and 21–70 mg/kg, respectively. In the pits sampled near the deposits and directly above them, the As concentration increases in the deep horizons. The soils of higher hypsometric levels (pits 18, 19, and 20; Fig. 3, Table 4) are characterized by the lower As content in comparison with the soils of lower hypsometric levels (pits 9 and 13). The areas of ore deposits are characterized by the uneven spatial distribution of As due to the vein-type ore concentrations: within a given pit, variations in the As content in the vertical soil profile are insignificant, while the difference in the As contents between separate pits may reach an order of magnitude.

The mountainous semihydromorphic tundra soil studied in place of the former dislocation of an army unit is characterized by an elevated total As content with a sharp maximum in the upper horizons (Fig. 4). This is an example of the anthropogenic soil pollution. However, the content of the mobile forms of As in this soil and the concentration of the element in the phytomass are relatively low. It is probable that the additional input of mobile As compounds to the acid tundra soil with the high organic matter content is neutralized by the firm binding of the element by the organic matter [7, 22, 27, 30], so that the technogenic arsenic is transformed into immobile state without disturbing the ecological balance.

The absence of pebbles in the upper horizons of some high-mountain soils of Altai suggests the aerogenic origin of their fine earth. Hence, it is probable that the extra pool of As in the upper horizons of mountainous tundra and meadow soils is formed owing to the aerial input of fine material from the polluted areas of eastern Kazakhstan containing elevated concentrations of As [6] and other elements.

Arsenic is known to be an indicator of gold-bearing ores [3]. In this context, we analyzed the As content in the technogenic soils around the Zmeinogorsk gold-mining plant. The As content in the soil samples was relatively low: 19–20 mg/kg. However, the As concentration in plant samples taken from the slopes of reclaimed tailings was high: 5.6 mg/kg in *Echium vulgare* and 9.8 mg/kg in *Gypsophila patrinii*. These values considerably exceed the background As concentrations in plants of Altai (<0.7 mg/kg) and the average world data on the As concentration in plants of unpolluted territories.

Abandoned tailings of the Altai ore-dressing and processing enterprise are the powerful source of environmental pollution in the piedmont zone of northwestern Altai [2]. The soils developed on them are distinguished by the abnormal As concentration (Table 5).

Table 5. The content of As in soils of the Alei River basin

Plot	n	As, mg/kg	
		variation limits	mean
Tailings	22	15.0–440.0	171.0
Gornyak town	40	9.6–24.0	15.1
Left bank of the Alei River	73	1.6–28.9	14.4
Right bank of the Alei River	55	1.0–23.9	11.7

The most important factor of the migration of As and heavy metals in arid climate is the aerial transport of solid particles from the tailings; it is of great intensity in the northeastern direction due to the prevailing southwestern winds.

In relation to this, the As concentration in chernozems on the left bank of the Alei River is significantly higher ($t_{st}1.98 < t_d2.9$) than in the soils on the right bank of this river, though it does not exceed the regional background (Table 5). A local peak in the As concentration (44.3 mg/kg) has been found in the upper humus horizon of the stratified loamy sandy alluvial soil.

The closer to the source of pollution, the higher the coefficients of the vertical (radial) differentiation of arsenic in the profiles of chernozems; these coefficients increase more noticeably than the weighted average content of the element in the studied soils (Table 5).

CONCLUSIONS

(1) The As content in the soils of Altai exceeds the clarke value and the provisional permissible concentration accepted in Russia and averages 17 mg/kg.

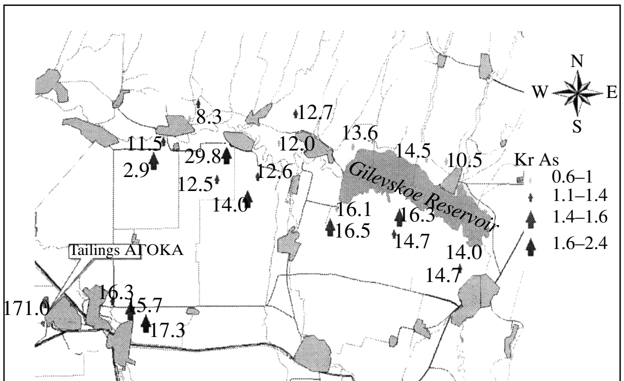

Fig. 5. Scheme of the spatial distribution of arsenic (weighted average content, mg/kg) and coefficients of the radial differentiation of As (Kr) in the profiles of chernozems in the Aleir River basin and near the town of Gornyak (Altai region).

(2) The content of mobile forms of As in the soils of Altai is rather high; however, the ratio of mobile As to total As does not exceed the values typical of other territories.

(3) The As content in medicinal herbs and natural waters of Altai is low and corresponds to the world's background values.

(4) The As content in soils depends on its initial content in the parent material; the mobility and redistribution of the element in the soil profiles depend on the intensity of soil-forming processes and the involvement of the element in the biological cycle.

(5) Mountain-steppe landscapes of southeastern Altai during the periods of seasonal moistening have the most favorable conditions for As migration; these landscapes are biogeochemically vulnerable to anthropogenic loads.

(6) Soils with the high bulk content of As do not manifest an increased intensity of the involvement of this element in the biological cycle; the distribution pattern of As in the vertical profiles of such soils does not change much.

(7) The As content in technogenic soils and in plants of the northwestern piedmont landscapes of Altai exposed to technogenic impacts considerably exceeds the sanitary norms and background values.

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