Trace metals in soils of the main geomorphological units in the southwestern part of Western Siberia

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Abstract. Total concentrations of Ti, Cr, Mn, Ni, Cu, Zn, Rb, Sr, and Pb as well as soil granulometric texture were studied for three plot sites representing different geomorphologic units of the southwestern part of Western Siberia: periphery of the upland Tobolsky Mainland, Ishim plain, Turinskaya plain. Interregional difference in the relationship by and among the content of trace elements and particle size distribution of soil horizons is established. Thus, for the soils of Turinskaya plain such interrelations are not observed. For the soils of Ishim Plain moderate negative correlation between Pb concentrations and medium silt, as well as average positive correlations between Zn and fine sand, coarse sand and Pb are found. For the soils of the high terraces of the Irtish and periphery of Tobolsky Mainland interface zone moderate positive correlations between contents of Ti, Zn, Sr and fine sand, weak positive ones between Rb and medium sand, moderate negative ones between Zn and clay, Ti, Ni, Cu, Zn, Rb, Sr, and fine dust, Ti, Cu, Zn, Rb, Sr and medium silt are observed. Consequently, properties and genesis of local parent rocks are significant factors for distribution and accumulation of trace elements in the soils of the southern taiga; at the same time, the processes of bioaccumulation in thick humus horizons of dark gray soils and chernozems apparently play an important part in accumulation and migration of trace elements in forest-steppe soils of Ishim and Turinskaya plains.

1. Introduction

The southwestern part of Western Siberia can be described as a territory with a diverse geomorphological structure, a variety of individual morphological units with different history of formation, combinations of geomorphological processes, and genesis of near-surface deposits.

Soil resistance to different types of industrial impact is largely determined by their elemental composition and granulometry inherited from subsurface unconsolidated sediments [1-4]. The particle size distribution, chemical and mineralogical composition of the soil largely specify migration and accumulation of trace elements in the landscape, the background concentrations of inorganic pollutants in soils.

The main purpose of this research is to determine the differences in total concentrations of Ti, Cr, Mn, Ni, Cu, Zn, Rb, Sr, and Pb in soils of several geomorphological regions of the south-west of Western Siberia associated with the lithological characteristics of the parent rocks.

2. Materials and methods

The main geomorphological units for the territory of the south of Tyumen region and the northern Trans-Urals (figure 1) are Turinskaya base-level dissected clinoplain, Predturgayskaya base-level

occasionaly dissected clinoplain, Ishim denudation clinoplain, base-level constructional low dissected upland Tobolsky Mainland, Sredneirtyshskaya alluvial terraced lowland, Kondinskaya terraced alluvial lowland, Irtysh-Kondinskaya lacustrine-alluvial low dissected plain [5]. Deposits of these geomorphological units differ in chemical composition and properties, which determines the diversity of soil-forming rocks.

Subaeolian quaternary loessy pale or yellow-brown light and medium loams and sandy loams of lacustrine-alluvial genesis with thickness from one to eight meters present near-surface deposits of upland Tobolsky Mainland [5-6]. These deposits are characterized by the high content of coarse silt (up to 35-45%), the absence of carbonates and enrichment in Ti, Mn and Al [7].

Soil-forming rocks of Ishim plain are confined to subaerial sediments – typical for Western Siberia carbonate loess loams with a thickness of 3-8 m or more (in local depressions) [8]. Loess soil-forming rocks of the region are characterized by high content of coarse silt and there are thin layers and lenses of sand in some sections.

Soil-forming rocks of Turinskaya plain are rather similar to the loess-like loams of Ishim plain. Calcareous loams of this geomorphologic structure are characterized by low content of silt fraction and high content of fine sand [7, 9].

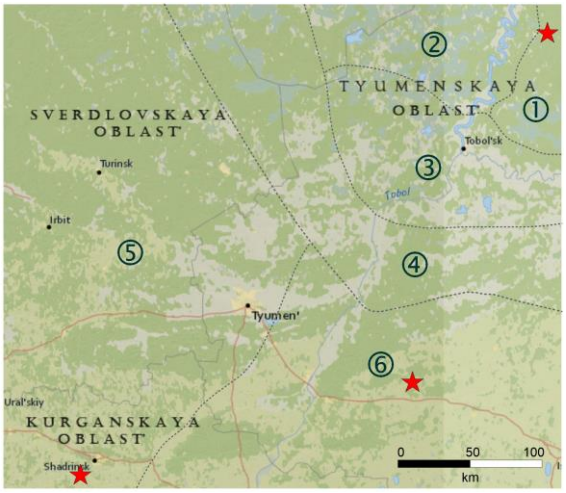

Figure 1. Main geomorphologic units of southwestern part of Western Siberia [5]: 1. upland Tobolsky Mainland; 2. Kondinskaya lowland; 3. Sredneirtyshskaya lowland; 4. Irtysh-Kondinskaya lowland; 5. Turinskaya plain; 6. Ishim plain. Asterisks show the locations of plot sites.

Field studies were carried out on three plot sites (figure 1): high terraces of the Irtysh river, passing into the watershed surfaces of the upland Tobolsky Mainland (outskirts of village Turtas), the central part of Ishim plain (an area near Okunevka village) and river valley part of Turinskaya plain near Shadrinsk. Selected areas are located rather far from the major sources of pollution. Soil profiles (14, 18 and 11, respectively) were placed in basic landscape positions within each site. Samples for further chemical analysis were taken from each genetic horizon of the studied soils; soils were described in accordance with Russian soil classification [10].

Grain size distribution was determined by laser microanalyzer Fritsch «Analysette 22» with the pyrophosphate method [11], total concentrations of trace elements - on the spectrometer Rontec PicoTAX (72, 80 and 51 samples, respectively) (TXRF method) [12]. Classification of particle size distribution in studied soils was carried out in accordance with [13].

Statistical processing of the data and its visualization were performed in STATISTICA software: calculation of the average, minimum and maximum values, standard error of the mean, correlation between the content of trace elements and soil granulometry.

3. Results and discussion

Soils of the upland Tobolsky Mainland are presented by sod-podzolic-gleys with the second humic horizon in elevated landscape positions and gleysols in subordinate positions. In forest-steppe landscapes of Ishim plain predominant soils are dark gray forest soils under aspen-birch groves and arable land on the watersheds and solods in the bottom parts of local depressions. Soils of Turinskaya plain are ploughed clay-illuvial chernozems and solods.

Soils of the studied sites vary in the particle size distribution. Particle size distribution in mineral samples from Tobolsky Mainland ranges from medium to heavy clay loams, higher content of clay was found in organomineral horizons (figure 2). The soils of Ishim and Turinskaya plains are poorly differentiated by particle size distribution, heavy clay dominates (figure 2).

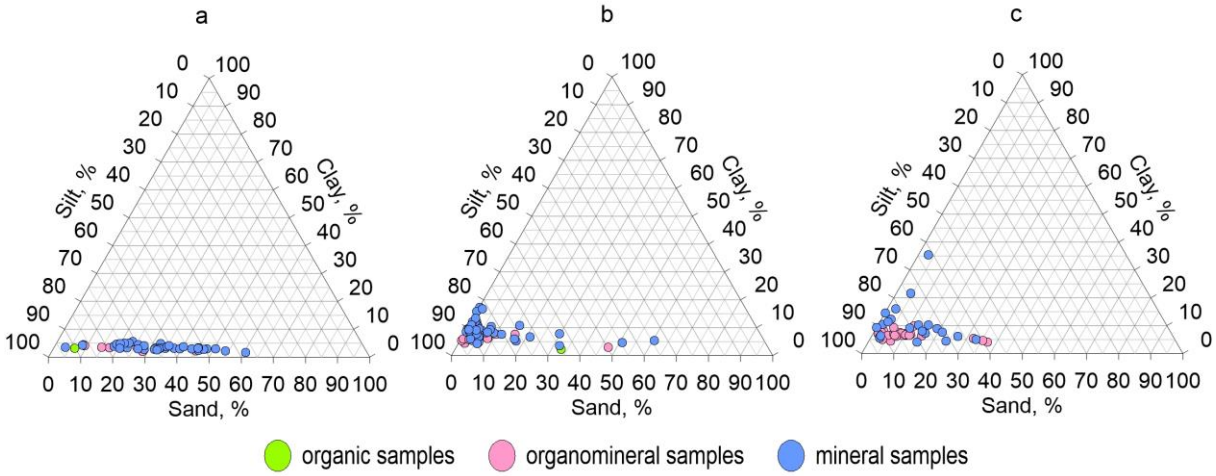

Figure 2. Particle size distribution in soils of three plot sites: *a* – upland Tobolsky Mainland (n=48), *b* – central part of Ishim plain (n=80), *c* – Turinskaya plain (n=51). Particle sizes: clay (<0.001 mm), silt (0.001- 0.05 mm), sand (0.05-1 mm).

The results of the total elements concentrations analysis in the studied soils have led to the following conclusions. Ti is a typical lithophylous element and one of the main components of the silicates, so its maximum average values are characteristic for the soils formed on the most weathered rocks (figure 3b). The behavior of Cr is largely dependent on landscape position and local climatic conditions. In acid environment of the southern taiga Cr intensively precipitates (figure 3a). The maximum Mn concentrations are observed in soils of the southern taiga landscapes due to its accumulation in the form of nodules, intensively formed under hydromorphic conditions (figure 3a). The highest concentration of Ni is typical for loamy soils rich in organic matter (figure 3b). The average Cu values in soils are low in chernozem soils of Turinskaya plain formed on calcareous loams (figure 3c). Highs values of Cu in the soils of Ishim Plain can be probably explained by the intensive processes of its bioaccumulation and relatively low mobility of the metal in steppe landscapes (figure 3b). The average Zn content reduces, while the content of clay particles in the examined soils increases (figure 3c). Low average concentration of Rb is characteristic for sandy soils of terraces (figure 3a); the maximum concentrations are approximately the same, which is associated with the analysis of samples including organic horizons. Sr is concentrated in the most enriched in silt calcareous soils of Turinskaya plain (figure 3c). Intensive removal of Sr is observed in sandy soils of the Irtysh terraces (figure 3a). Pb is less mobile, the content of this element in soils is the same in all plot sites, but it tends to accumulate in soils which are the most enriched in silt (figure 3c).

The relationship between total concentrations of trace elements and soil particle size distribution was studied using the nonparametric Spearman coefficient ($p < 0.5$). Moderate negative correlation between Pb and medium silt (-0.32), average positive relationship between Zn and fine sand (0.3), Pb and coarse sand (0.23) were observed in soils in the high terraces of the interface of Ishim plain. Moderate positive correlation between Ti, Zn, Sr and fine sand (0.34, 0.32 and 0.32, respectively), weak positive ones between Rb and medium sand (0.29), moderate negative ones between Zn and clay (-0.32), Ti, Ni, Cu, Zn, Rb, Sr, and fine silt (-0.34, -0.31, -0.40, -0.32 and -0.36, respectively), Ti, Cu, Zn, Rb, Sr and medium silt (-0.34, -0.31, -0.40, -0.32 and -0.36, respectively) were observed in soils of the upland Tobolsky Mainland. In soils of Turinskaya plain, such correlations were not identified.

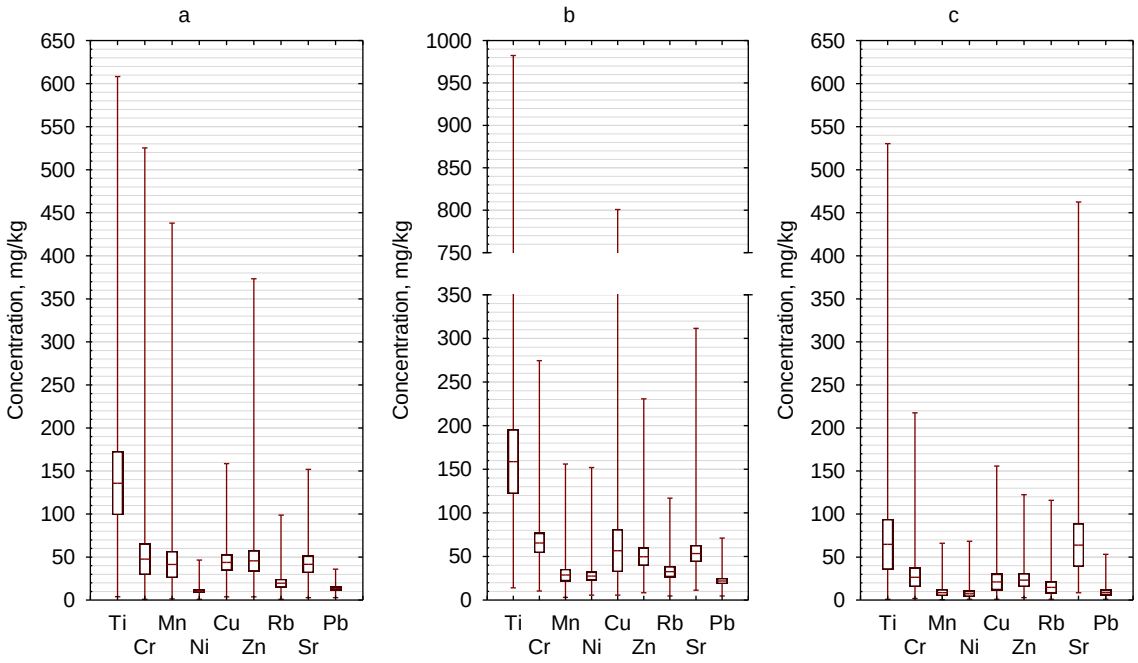

Figure 3. Average concentrations and variance of trace element concentrations in soils of studied plot sites: *a* – upland Tobolsky Mainland (n=72), *b* – Ishim plain (n=80), *c* – Turinskaya plain (n=51). Concentration of Mn and Ti are given in mg/100 g of soil.

Noteworthy is the fact that the content of elements such as Ti, Cr, Ni, Rb, and Sr in the studied soils is lower than their average content in the soils of the world, and the most common soil-forming rocks in Western Siberia (table 1). Primarily, some features of the sampling procedure can explain these results. We analyzed samples collected not only from the upper horizon, but also throughout the whole profile depth, which lead to the sample heterogeneity. In total, the average total concentrations of trace elements in soils of the studied geomorphological regions were significantly different (table 1), which, perhaps, may result from differences in particle size distribution of soils.

Table 1. Mean total concentrations of trace elements in soils of different geomorphologic units of Western Siberia, mg/kg

	Tobolsky Mainland (n=72)	Ishim plain (n=80)	Turinskaya plain (n=51)	Southwestern part of Western Siberia	Loess loams of Western Siberia [2]	Average concentrations in world soils [14]
Ti	1360	1590	650	1270	4100	4600
Cr	48	66	27	50	61	200
Mn	410	290	90	280	835	850
Ni	10	28	7	16	40	40
Cu	44	57	21	43	43	20
Zn	46	50	23	42	92	50
Rb	20	33	15	24	-	100
Sr	42	53	64	52	595	300
Pb	13	22	9	16	18	10

4. Conclusion

The content of trace elements in soils of the main geomorphological units of the south-west of Western Siberia is not always determined by the characteristics of particle size distribution and genesis of local parent rocks. The intensity of the biological cycle and the water regime are the main factors

determining their content in soils and landscapes of a particular territory. Properties and genesis of local parent rocks are significant factors for distribution and accumulation of trace elements in the soils of the southern taiga; at the same time, the processes of bioaccumulation in thick humus horizons of dark gray soils and chernozems apparently play an important part in accumulation and migration of trace elements in forest-steppe soils of Ishim and Turinskaya plains.

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