GEOLOGIJA. 2008. Vol. 50. No. 4(64). P. 246–253
DOI: 10.2478/v10056-008-0050-1

Effect of natural erosion shear on heavy metal geochemistry in West Siberian natural landscapes

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Roslyakov N. A., Kalinin Yu. A., Roslyakova N. V. Effect of natural erosion shear on heavy metal geochemistry in West Siberian natural landscapes. *Geologija.* Vilnius. 2008. Vol. 50. No. 4(64). P. 246–253. ISSN 1392-110X

The region under consideration is located in the junction zone of two large tectonic structures: the West-Siberian plate and the Altai–Sayan folded area. Their essential tectonic, geological, geomorphologic and climatic peculiarities account for the specifity of the natural landscapes. The up-to-date state of the natural landscapes is manifested in the composition of the latest products of weathering, including soil formation, in different ways. In regard to geomorphology, one can distinctly single out three landscape-structural floors with sets of elementary landscapes typical of them: (1) West-Siberian accumulative plain landscapes; (2) landscapes of the denudation-accumulative zone transitional from the plain to mountains (small peak hills, low hill area); (3) mountainous denudational landscapes (middle and high mountain areas). Two characteristic properties are distinctive of natural landscapes: 1) vertical and lateral geochemical zonality, 2) a wide spread of natural anomalies of heavy metals and radioactive elements, manifested in different manners depending on the level of erosion shear of the contemporary relief. Major standard natural environments in West Siberia are monitored by both latitude-zonal plain and high-altitude-zonal mountain landscapes.

Key words: landscapes, heavy metals, natural anomalies, zonality, geological environment, ecogeochemistry

Received 24 July 2008, Accepted 11 September 2008

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INTRODUCTION

State-of-the-art natural landscapes are essentially affected by natural anomalies of heavy metals and radioactive elements. Their spatial distribution and composition are checked by the surface relief vertical zonality which is in turn a function of a complicated history of the geological and paleogeomorphologic development of West Siberia. The natural anomalies of metals by age and composition that can be observed today are clearly differentiated into Quaternary sedimentary, Chalk-Paleogene eluvial (relict and redeposit) and Mesozoic-Paleozoic endogenous. With regard to geomorphology, they are confined to three landscape-structural floors respectively: 1) West-Siberian accumulative plain landscapes; 2) landscapes of the denudation-accumulative zone transitional from the plain to mountains (small peak hills, low hill area); 3) mountainous denudational landscapes (middle and high mountain areas). Major standard natural environments in West Siberia are monitored by latitude-zonal plain and high-altitude-zonal mountain landscapes.

In West Siberian accumulative plain landscapes, natural anomalies of heavy metals and radioactive elements are formed in processes: oregenous aggradation in the case of Quaternary sediments; accumulative-sorption cumulation in peat bogs; salinization of soils and undergrounds waters; in zones of impact of regional abyssal faults. At present, accumulation of natural toxicants is going on under conditions of neoeluvial elementary landscapes that develop on the Quaternary sediments (Глазовская и др., 1961).

Landscapes of the denudation-accumulative zone transitional from the plain to mountains are mainly formed under conditions of paraeluvial (on Chalk-Paleogene weathering crust) and orthoeluvial (on Prequaternary bedrocks that hold polymetallic, rare-metallic, rare earths and radioactive ore mineralization oxidized to different degrees) elementary landscapes.

Mountain denudational landscapes develop under conditions of orthoeluvial elementary landscapes, mainly on Palaeozoic rocks that contain ore mineralization.

MATERIALS AND METHODS

We have systematized a large geochemical and geological database obtained in 1970–2007 in the course of an overall subject-matter investigation into the system: original preQuaternary bedrocks including ore regions of West Siberia – their weathering crusts – incoherent Quaternary cover sediments – bottom sediments – soils of morphotypic landscapes. The system components were analysed for a broad spectrum of elements that included Li, Be, B, P, Al, Sc, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, Ge, As, Sr, Y, Zr, Nb, Mo, Ag, Cd, Sn, Sb, Te, Ba, W, Au, Hg, Pb, Bi, Th, U, and also Hf, Ta, Rb, Cs, La, Ce, Nd, Sm, Eu, Gd, Tb, Yb, Lu. The main field methods were geologic–geochemical mapping and landscape-geochemical profiling. It is with various degrees of working out. All climatic zones, geomorphologic structures, main types of ore fields and deposits, soil-forming rocks and soils were examined with various levels of detalization.

Eventually, we obtained a substantial factual material which we processed with the help of GIS technologies allowing to obtain a vivid picture of the behaviour of heavy metals and radioactive elements in the following major typical environments of West Siberia: 1) natural virgin land landscapes; 2) landscapes with natural pollution at the expense of oregenous sources; 3) landscapes with various geological, environmental-climatic, physical-geographic and geochemical conditions. In the present paper, an interesting generalization of the outcomes of the investigation within the framework of the task we have set is given: observation of the effect of the natural erosion shear of the surface relief on the behaviour of elements in present-day landscapes of such a large region as West Siberia.

NATURAL ANOMALIES OF HEAVY METALS AND RADIOACTIVE ELEMENTS IN MOUNTAIN LANDSCAPES

One can observe physical and chemical weathering in mountain landscapes under present-day environmental conditions, with *orthoeluvial elementary landscapes* on sedimentary, metamorphic and magmatic rock complexes playing a leading role and covering the age range from Low-Cambrian up to High-Triassic.

In physical weathering, migration of heavy and radioactive metals takes place in detrital rocks and ores that accumulate as slope wash at the slope sole or form alluvial beds, flood plain and channel placers. They serve as a substrate for forming modern neoeluvium and water stray fluxes of ore-forming metals.

It is the composition of soil waters and water currents of metal scattering as well as the intraprofile distribution of soil elements that are indicative of chemical weathering processes in modern mountainous landscapes (Воротников, 1974; Тригуб и др., 2002).

On the basis of studying the distribution in stratocomplex rocks of Li, Be, B, P, Sc, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, Ge, Sr, Y, Zr, Nb, Mo, Ag, Sn, Te, Ba, W, Au, Pb, Bi, Hg, Th, U, also in magmatic complexes of Hf, Ta, Rb, Cs, La, Ce, Nd, Sm, Eu, Gd, Tb, Yb, Lu, one can draw a conclusion that the background content of the majority of these elements in rocks of the region is at the level of their average content in the Earth's crust (clark). An excess of clark was observed for some limited number of elements (Table 1). Moreover, Pb and Yb accumulate in Low-Cambrian black shale records; Be accumulates in Middle-Ordovician metamorphosed scales; Sc, Ti, Mn accumulate in terrigenous-sedimentary rocks. In the rock complexes that make up the and Tchuisky mountain ranges, there is a region of ore points and localized mineralization.

Table 1. **Elements the content of which in rocks exceeds the clark (1.5 as much) (according to data obtained by Росляков и др., 2001)**
1 lentelė. **Elementai, kurių kiekis uolienoje viršija klarką (daugiau nei 1,5 karto) (Росляков и др., 2001)**

Rock complexes	Average content in the rock is 1.5 as much as the average for earth crust (clark)
Sedimentary and metamorphic rocks	Bi, Ba,Sr, Te, W
Igneous-sedimentary rocks	Sc, Zr, La
Cambrian-magmatic rocks	Hg, Bi, Ba, Sr, Pb,Ga, Sc
Ordovician granitoid rocks	Hg, Bi, Ba, Sr
Devonian granitoid rocks	Hg, Bi, Ba, Sr, Rb, Mn, Cr
Permian–Triassic granitoid complexes	Rare earth, rare and radioactive elements: Li, Rb, Cs, Y, La, Ce, Sm, Gd, Tb, Yb, Lu, Ta, Nb, Hf, U, Th

For magmatic complexes of the Cambrian, Ordovician and Devonian periods, a typical stable geochemical association is presented by Hg, Bi, Ba, Sr. And Pb, Ga, Sc join it in Cambrian magmatic rocks; Rb, Mn, Cr join it in Devonian ones. Granitoid complexes of Permian - Triassic magmatic cycles are rich in rare earths, Li, Rb, Cs, Ta, Nb, Hf, U, Th (see Table 1). The impact of these elements on the biota and man has been studied to various degrees. The ecological–geochemical role of rare earths has been studied most poorly. In this respect, the orthoeluvial mountainous landscapes of West Siberia with young crust-forming magmatic complexes may present original test fields for investigating the impact of rare earth associations on the environment.

Carboniferous rocks and coals of the Kuzbass and the Gorlovsky basin occupy a vast territory and have coal reserves of billions of tons (Fig. 1). In coal, high concentrations of rare earth's elements (Ta, Nb, Zr, Mo, V, Ge, Sn, etc.) have been found (Арбузов и др., 1999). It has been mentioned above (Калинин и др., 2003) that carbon-bearing areas are potential for accumulating benz(a)pyrene in the soils, which increases their ecological tension even more in terms of a natural pollution source.

Rocks that underwent a hydrothermal alteration and superimposed ore mineralization can serve as an important natural storage of heavy and radioactive metals. Their sitting and mineral composition determine the behaviour of oregenous elements in present-day orthoeluvial landscapes to a great extent. These rocks often hold deposits, ore shows and points of REE, rare-metal, polymetallic, mercury–antimony–arsenic, copper–cobalt–nickel and ferromanganese mineralization (Fig. 2). Rare-earth mineralization makes up 4% of the total quantity of mineralized areas in the region. The portion of the rare-metal mineralization makes up 3–18% and it falls mainly on Kuznetsk Alatau, Rudnyi and the Altai Mountains. Polymetallic metallization prevails (37–76%) in mountainous landscapes of all folded structures and especially in the landscapes of Rudnyi and the Altai mountains. The mercury–antimony–arsenic mineralization made up 1–7%. More often it is observed in the West Sayan and the Kuznetsk Alatau. The copper–cobalt–nickel metallization is found in up to 28% of the total area in the West Sayan as well as in the Salair Range. The Rudnyi Altai is characterized by polymetallic deposits. The Gorny Altai is characterized by

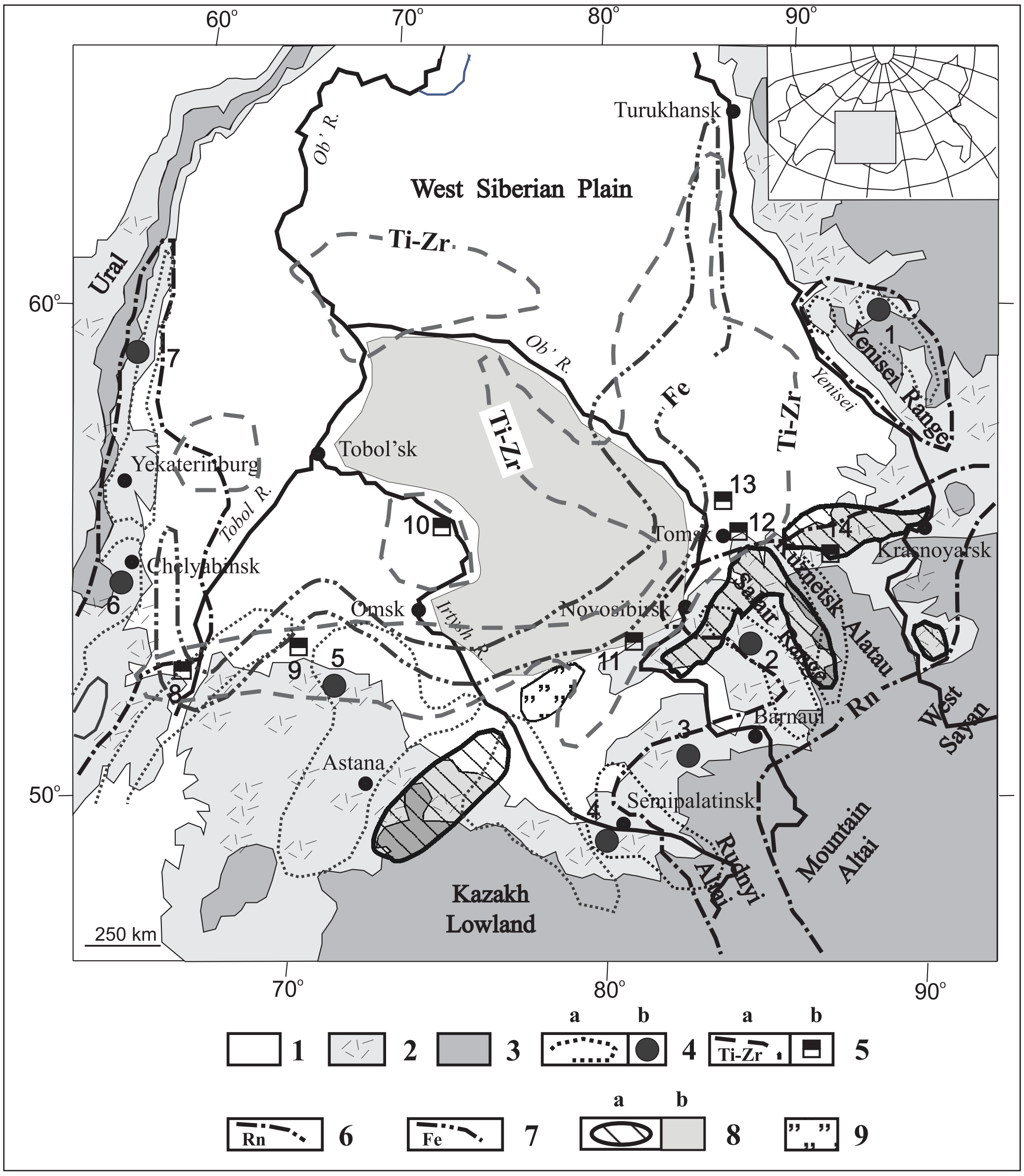

Fig. 1. Localization of sources of natural metals and radioactive elements

1–3. Landscapes: *1* – present accumulative plains of the West-Siberia plate; *2* – present erosive-accumulative weekly rugged high plains of transition zone from mountains to plain; *3* – crown-block mountains of the Altai–Sayan folded region. *4 – 7.* Ore-forming and radioactive elements: *4 a* – geochemical fields of ore-forming elements in the gold-forming provinces; *4 b* – large gold deposits of weathering crust formation: 1. Olimpiada; 2. Egor'evskoe; 3. Murzinskoe; 4. Suzdal'skoe; 5. Vasil'kovskoe; 6. Svetlinskoe; 7. Vorontsovskoe; *5 a* – zircon–ilmenite heavy concentrate areas; *5 b* – deposits of zircon–ilmenite nearshore marine placers with commercial reserves: 8. Shokashskoe; 9. Obukhovskoe; 10. Tarskoe; 11. Ordynskoe; 12. Tuganskoe; 13. Georgievskoe; *6.* Radon-dangerous areas; *7.* Vasyugansky (West-Siberian) iron-ore basin; *8.* Coal basins: *a* – hard coal; *b* – brown coal; *9.* Salt accumulation up to sodium mineral raw materials

1 pav. Gamtinių metalų ir radioaktyviųjų elementų šaltinių lokalizacijos schema

tin-tungsten, rare metallic, mercury and gold-bearing deposits, the Kuznetsk Alatau is characterized by gold ones.

The majority of the elements under consideration form their own ore minerals and become part of the composition of rock-forming mineral-concentrators in the initial ores and rocks. In spite of different forms of their occurrence, these elements generally behave according to one and the same scheme in modern weathering processes: transition into a mobile state – migration – secondary precipitation. The cycles repeat themselves with changes in the level of subsoil waters and climatic conditions.

Precipitates with pH about 5 (the most probable value by the data of international stations of background observations for 1975–1982) (Атмосфера..., 1991) are primordial agents of weathering in mountainous landscapes. An acid geochemical medium under conditions of mountain landscapes with an intensive water exchange is rather aggressive to the initial rock-forming minerals (micas, feldspar, amphiboles, chlorites, carbonates with the pH of water extract equal to 8–11) are resistant in alkaline media. This is assisted by presence of strong oxidizers, and first of all Fe, Mn and O, in the water–rock system, as well as the necessary agents to transfer elements with variable valency into a mobile form including even relatively inert ones, such as Au, Hg, Zr, Sn, W and other placer-forming metals that are conventionally considered as such. In the state-of-the-art orthoeluvial landscapes, a low-acid soil-floral mantle and hydromica (micas, hydrochlorites and mixed-layered argillaceous minerals), nearneutral small-

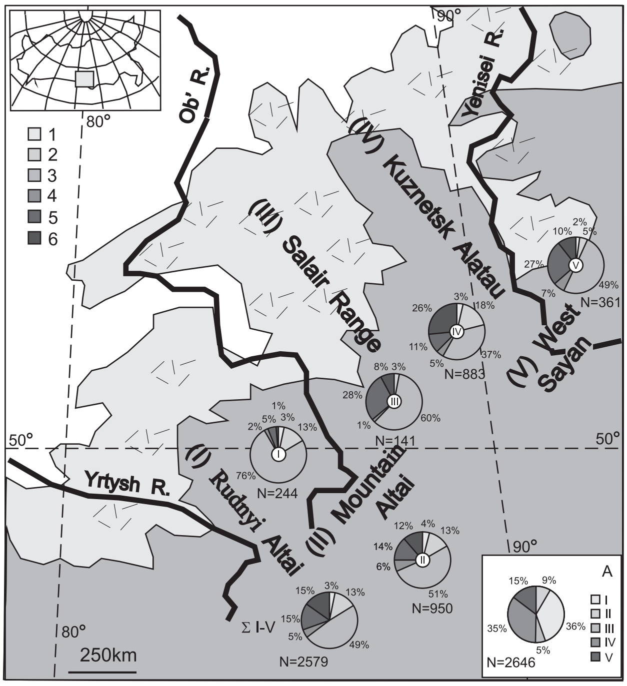

Fig. 2. Distribution of mineral types of endogenic mineralization in Rudnyi (I) and Mountain (II) Altai, Salair Range (III), Kuznetsk Alatau (IV) and West Sayan (V) as well as a whole region (ΣI–V) (% of the total N = 2549)

1 – 6. Types of endogenous mineralization: *1* – REE; *2* – rare-metal; *3* – polymetallic and gold-ore; *4* – mercury–antimony–arsenic; *5* – copper–cobalt–nickel; *6* – ferrum–manganese;
A. Quantity of deposits, manifestations and spots of mineralization in mountainous landscapes of the region (% of the total N = 2646)

2 pav. Endogeninės mineralizacijos mineralų tipų pasiskirstymas Rūdiniame (I) ir Kalnų (II) Altajuje, Salairo kalnagūbryje (III), Kuznecko Alatau (IV) ir Vakarų Sajanuose (V), taip pat regione apskritai (ΣI–V) (% bendro kiekio N = 2646)

thickness saprolite weathering profiles with an active bearing out of oregenous elements are being formed. According to our data, covellite, chalcocite and barite deposit at the ore outcrop, yielding quicks of the same name and aggressive mobile sulphates in their destruction. Atmospheric waters are being neutralized with depth up to almost neutral reaction, and even under conditions of Siberia they are being enriched with organic acids (Table 2) that promote migration of elements from saprolites in the form of metallic-organic and sulphate complexes. The migration distance of mobile ions and metal complexes is determined by their resistance ability in actual physicochemical parameters of solutions that are being changed as they move deep downward the weathering profile as the level of subsoil water changes.

A consecutive oxidation of sulphides as well as the weathering of rock-forming and accessory minerals favour a continuous release of metals, their transition into a mobile and inert state at all stages of formation of a weathering profile. Ore mineralization is a source of water flows of scattered metals that have the most different contrast range and extent (Воротников, 1974).

In mountainous landscapes, the ecogeochemical importance of abyssal faults is manifested most vigorously. Thus, in the Rudnyi Altai all main polymetallic deposits and primary and secondary aureoles that follow them are timed to the Irtysh zone. Large abyssal faults preside over the Sarasinsk and Kurai mercury-ore zones with their well known commercial mercury deposits: Aktash, Tchagan-Uzun and Sarasinsk. The Tchagan-Uzunskoe deposit borders the Kyzyl-Tchinsk polymetallic deposit in the sphalerite of which we have found mercury some time ago. There are other examples to continue. This makes it possible to conclude that allure-fields of Altai are run by large tectonic disturbances, they are permeated by ore mineralization, which favours conditions for environmental pollution with heavy metals (Росляков и др., 1992).

Table 2. **Organic substance content in water of mountainous sod-podzolic soils of North-West Salair, mg/dm^3 (Ковалев и др., 1981)**

2 lentelė. **Organinės medžiagos kiekis Šiaurės Vakarų Salairo kalnų šarminių jaurinių dirvožemių vandenyse (Ковалев и др., 1981)**

Extraction depth, cm	Humic acids	Fulvic acids	Aliphatic acids	C_{org}.
2.0	12.6	12.0	7.3	20.0
6.0	6.0	0.7	13.0	12.0
18.0	2.1	0.4	3.6	9.6
60.0	2.1	0.6	2.4	5.6
165.0	3.3	Not found	4.1	8.0
Average	5.2	3.4	6.1	11.0

NATURAL ANOMALIES OF HEAVY METALS AND RADIOACTIVE ELEMENTS IN LANDSCAPES OF DENUDATION-ACCUMULATIVE ZONE TRANSITIONAL FROM PLAIN TO MOUNTAINS

Landscapes of the transitional zone occupy the Chalk-Palaeogene weathering surface of planation with the absolute marks of 200–500 m. Away from the West-Siberian plain, they give place to mountain landscapes and uplands of the Altai–Sayan folded domain. The behaviour of elements in the landscape changes in the same direction depending upon the level of natural erosion shear.

In the transitional zone from mountains to plain, relict and redeposited Chalk- Paleogene weathering crusts are developed with untraditional types of ore deposits of iron, manganese, aluminium, precious, rare, rare earth's and radioactive metals (Калинин и др., 2006). For this transitional zone, a combination of accumulative, paraeluvial and erosion-denudational orthoeluvial submountain region landscapes is characteristic. There are large quantities of natural sources of metals in this elementary landscapes. For example, 838 natural objects of mineralization have been revealed only in foothills of the Salair Range according to the map at a scale 1 : 200000 (Росляков и др., 2001). The spectrum of anomalous concentrations of toxic metals is wide (Table 3). All of them have a strong influence on the geochemistry of surroundings. Their behaviour in the erosive shear depends on elementary landscapes.

In orthoeluvial submountain region landscapes enclosing rocks of ore fields and deposits, their endogenous aureoles and zones of sulphide mineralization rather often appear as a state-of-the-art crust and soil-forming substrate. For instance, in landscapes of the Salair Range foot-hills there are about 280 natural geological objects with a wide spectrum of anomalous concentrations of toxic metals (Table 3) indicated in the 1 : 2000 000

Table 3. **Degree and type of natural toxic load on natural landscapes of the Salair forelands (sheets N-44-IV, V, VI, X, XI, XII, XVI, XVII, XVIII, XXII, XXIII, XXIV, N-45-I, VII, XIII)**
3 lentelė. **Salairo prieškalnių natūralių kraštovaizdžių gamtinės toksinės apkrovos mastas ir tipas (N-44-IV, V, VI, X, XI, XII, XVI, XVII, XVIII, XXII, XXIII, XXIV, N-45-I, VII, XIII)**

Mineral product	Geological objects*								
	I	II	III	IV	V	VI	VII	VIII	IX
Fe + Mn	5	10	35			8	5		
Al (bauxite)	15	8	4						
Cr + V			2				1	2	
Ti + Zr	1	1					30		1
Cu + Pb + Zn		12	46	2	11	4	2	1	
Hg	1	2	9		4	2	10	4	
As + Sb	1		6		2	7			
Co + Ni + Cu		5	14		25	2			
Mo + Bi + Cu		2	7		2	2			
Sn + W		6	4	1			9	3	14
Au	3	37	38	25	23		22	5	92
Au + Cu + Pb + Zn		12	8	1	1	18			
Ag + (Cu + Pb + Zn + Hg)		4	9		6	6			
Radioactive elements	1	7	1			26			
Rare earths + Ga + Ge			23	1	1			2	
Total	27	106	206	30	75	74	79	17	107

* Geological objects: I – deposit; II – ore manifestation; III – mineralization point; IV – endogenous aureole; V – lithogeochemical anomalies; VI – hydrogeochemical anomalies; VII – aureoles of heavy concentrates; VIII – flow of heavy concentrates; IX – placer.

map. They are all near the diurnal surface and directly affect the geochemistry of the landscapes. Their behaviour in the natural erosion shear depends on the genetic type of endogenous mineralization in many aspects.

In the state-of-the-art oxidation processes, there take part those ore minerals whose of which are at the top of the Grigoryan–Ovchinnikov (Григорян, Овчинников, 1983) vertical column of the zonality endogenous row. A small-thickness zone of sulphide ore oxidation is being formed, with dissolved metals and sulphur coming into the landscape and with hydroxides of iron, manganese, phosphates and silicates accumulated. We would like to draw attention to the poorly studied parameters of hydrogeochemical and secondary anomalies of arsenic that were observed in the oxidation of arsenopyrites of the Petrovsky deposit located in the orthoeluvial landscape of the Rudnyi Altai forelands.

In the original ores of the Petrovsky deposit, arsenopyrite and pyrrhotite prevail. As other sulphides also sphalerite, pyrite, galenite are found. The sulphides remain well intact from erosion of the Chalk Paleogene stage of weathering crust formation even on the state-of-the-art diurnal surface. They are a natural source of metals for natural landscapes. According to Vorotnikov's observations (Воротников, 1974), the dispersion flows of As together with Cd and Sn in surface and underground waters of the Petrovsky deposit are extremely contrasting and extensive (more than 3 km). Their arsenic concentration reaches 120–160 mg/litre (MPC_V 0.05 mg/litre); as migrates in an anion form that is readily available for a living organism; its dispertion flows, which are as extensive as those mentioned above but less contrasting, are fixed in the bottom sediments.

In paraeluvial foreland landscapes, Chalk-Paleogene weathering crusts of ore fields and deposits, their secondary aureoles and dispersion flows appear as a crust and soil forming substrate rather often.

In paraeluvial landscapes, intensively oxidized ore outcrops and their host rocks that are altered into clays are a source of metals. Residual metals of the primary mineralization are in the state difficult to solve and in a form of placer-forming minerals (native gold, cinnabar, zircon, rutile, scheelite, wolframite, etc.) or secondary ore minerals that are resistant in the aeration zone of state-of-the-art underground water. Elements of the clay eluvium are becoming key migrants. A good example is presented by the West-Petrovsky deposit located in the paraeluvial elementary landscape 1–1.5 km to the north from the Petrovsky deposit and having an analogous composition and geological structure with the latter. They differ in the composition of the ore outcrop.

In the West-Petrovsky deposit, unlike the Petrovsky one, sulphides close to the surface are almost completely oxidized to yield scorodite, goethite, malachite, jarosite, psilomelane, wad, and smithsonite, cerussite, azurite in smaller quantities. The wall-rocks are altered into goethite – hydromicaceous–montmorillonite eluvium. The oxidation zone of this deposit spreads to the depth of 15 m and is a relic of the Chalk–Paleogene crust formation. Its lower borderline coincides with the up-to-date level of underground water. Under state-of-the-art climatic conditions, heavy metals pass into a mobile state releasing themselves mainly from the secondary ore and rock-forming minerals of the oxidation zone. This is confirmed by their finds in water extracts from clayey weathered rocks. Thus, the arsenic concentration in argilliferous eluvium extracts is 0.2 mg/litre and 0.4 mg/litre in the extracts of limonitized eluvium.

At the West-Petrovsky deposit which is deeper buried, water flows of As, Cd, Cu, Zn, Pb dispersion are developed only in the underground water. Besides anomalous concentrations of Ti, Fe, Mn and other slow moving elements, oxidized ores and weathered rocks play an important role.

The soils of both deposits are significantly infected with arsenic. Its local background content in the soils corresponds to

40 mg/kg by the data of 345 specimens, which exceeds MPC_p for soils. Arsenic anomalous concentrations reach 1000 mg/kg.

It is necessary to note that the regional radio-geochemical anomaly is confined to the transitional zone (see Fig. 1). The local structure of this anomaly in the Novosibirsk oblast is shown as an example (Fig. 3).

NATURAL ANOMALIES OF HEAVY METALS AND RADIOACTIVE ELEMENTS IN FLAT LANDSCAPES

Flat, mainly accumulative, neoeluvial and boggy elementary landscapes are formed on the mighty cover of Quaternary loose sediments that superpose deeply submerged rocks of the basement (Казаринов и др., 1958). Quaternary, mainly lacustrine–paludal, depositions of sediments are characterized by a persistent composition of heavy metals with contents close to their average value in Earth's crust. Soil sections of natural flat landscapes of Siberia in reference to soils of the world plains are impoverished in Cd, Be, Cr, Ga and enriched in Pb, Zn, Mo, Cu, As, Hg, Sc. In separate landscape zones and specific genetic types of soils, the spectrum of deficient and excessive elements may slightly change. As to separate genetic soil types, Li most often joins regional element concentrators in salt marshes, Rb in meadow soils, Fe, P, U in boggy soils. Concentration clarks of these metals vary from 1.3 to 20 and more. As shown above, they all are typical elements of ore fields and deposits of mountain-folded periphery of the West-Siberian plain.

Mobile components of soils, coating sediments and weathered rocks of neoeluvial landscapes of plains were displayed by means of their extraction together with porous solutions or by means of doubly distilled water expulsion. In water extracts and porous solutions, there were detected Na^+, K^+, Ca^{2+}, Mg^{2+}, $Fe^{3+}Al_2O_3$, SiO_2, O_2, Cl^-, SO_4^{2-}, S^{2-}, SO_3^{2-}, $S_2O_3^{2-}$, H_2S^+, HS^-, CO_3^{2-}, HCO^{3-}, Cu, Cd, Zn, Au, F^-, Br^-. Accumulators of metals in flat country soils are A and C horizons (Ильин, Сысо, 2001).

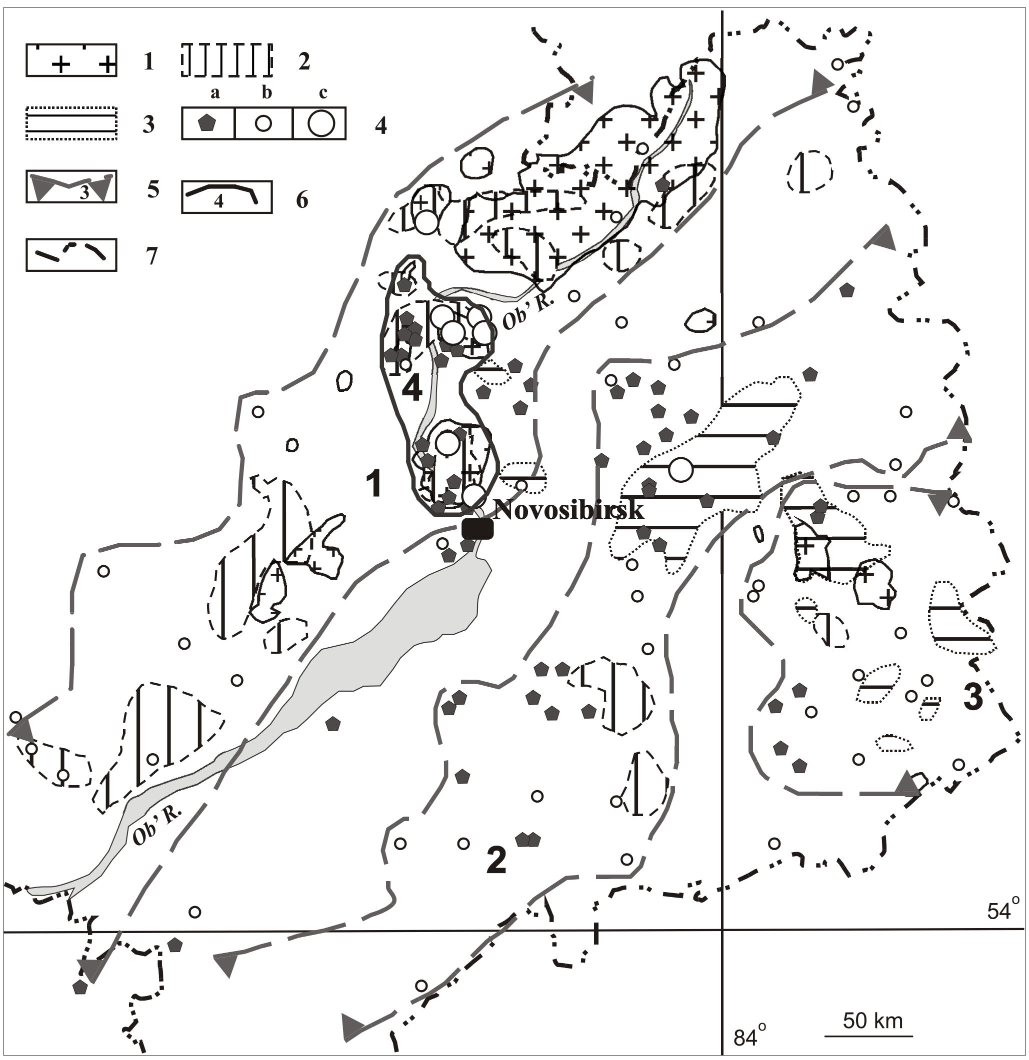

Fig. 3. Detailed structure of radon-bearing area in the west part of the Novosibirsk oblast (see Fig. 1)

1. Granite, granodiorite. *2 – 3.* Radiogeocemical anomalies: *2* – at the surface; *3* – in boreholes. *4.* Local areas of elevated radioactivity: *a* – water points with activity more than 120 Bk/litre; *b* – in soil air more than 30 mkR/hour; *c* – manifestations with uranium mineralization. *5* – zones with strained conditions and their numbers: *1* – Obskaya; *2* – Iskitim-Toguchinskaya; *3* – Sissalairskaya. *6.* Novosibirsk-Kolivanskaya zone (4) of a critical ecologic situation. *7.* Administrative borders of the Novosibirsk oblast

3 pav. Detali radono paplitimo ploto Novosibirsko srities vakarinėje dalyje struktūra

Table 4. **Parameters of uranium showings in peatlands of the Novosibirsk oblast**
4 lentelė. **Urano rodikliai Novosibirsko srities durpynuose**

Showings	Parameters of ore bodies, m			Uranium content, g/t	Position of ore body
	Length	Width	Thickness		
Penzensk	1100	250	1.5	10–600 (in ashes)	In peat
Tyul'kinsk	300	50–150	2	100–3800	In silt on bottom of peatland
Angoshsk Sogra	1300	400	2	10–100 (in ashes)	In peat
Mokrushinsk	1200	700	3	10–900 (in ashes)	In peat

The geochemistry of natural landscapes is substantially influenced by natural anomalies of heavy and radioactive metals. At least four groups of their potential sources can be readily pointed out: 1) accumulative areas (palaeobasins of sedimentation accumulation); 2) areas of sorption-infiltrational accumulation (peat bogs); 3) zonal salinization of soils and natural waters; 4) zones of regional abyssal faults.

In accumulative areas of the West Siberian plain, vast natural anomalies and large-scale deposits of iron, titanium, zirconium and sulphidized brown coal occupy substantial areas. In West Siberia there is the largest in the world Vasyugan ferriferous ore basin of the Oligocene epoch, in which more than 700 billion tons of brown iron ore are connected with products of weathering crust redeposition and iron carried out by surface and underground water into the basin of sedimentation (Михайлов и др., 1984). In the Ob-Irtysh coal basin, 600 billion tons of brown coal of the Palaeogene epoch are deposited at a depth of 15–200 m only in the Novosibirsk oblast (Геология..., 1969). Ashes of lignit contain Y = 100–300 g/t, Yb = 10–30 g/t, Ce = 300 g/t, La = 83 g/t (Росляков и др., 2001). The titanium–zirconium placers that are famous for their resources are unique. They are also enriched with the REE. Huge masses of ore-profiling metals and their associated elements accumulated in the sediment formation are state-of-the-art sources localized in geochemical fields of a directed-concentrated impact upon natural landscapes. The analysis of the distribution of element contents shows that in the waters of the region boggy lowlands, the average iron content exceeds the permissible sanitary norms. The hydrogeochemical background is heightened for Mn and Fe in the underground water of the plain (boreal coniferous) forest and mountainous steppe zones. A regional background for barium is high in waters of mountainous steppes. Coals are a possible source of rather dangerous benzo(a)pyrene and many metals. Microadmixture content of fossil coals shows that the content of such elements as Ge, Ga, Y, Yb, Mo, Co, Ni, P, Ba, Ce, La, Sc etc. often significantly exceeds the index corresponding to a norm and sometimes reaches commercial levels (Росляков и др., 2001).

Sorption–infiltration accumulation of metals takes place in the marshy landscapes that occupy areas many times larger than agricultural lands in West Siberia. Processes of swamping and paludification started in the region beginning with the Holocene and conditioned formation of a rather mighty (1–1.5 m) peat bog horizon. The share of the West Siberian plain in the world turf supply is about 39%. The content of the ash chemogenetic part of turf is in direct dependence on the lithologic composition of rocks in the area of feeding peat-beds. Waters close to rocks with an increased phosphorus content come into the peat-beds and introduce phosphorus (more than 1 mg/litre of P_2O_5) contributing to accumulation of boggy phosphates that are represented by vivianites – $Fe_3(PO_4)_2 \cdot 8H_2O$ (P_2O_5 more than 15%) and peatvivianites (P_2O_5 = 2.5–15%). Fe, Si, Ca, and Al concentrate together with P_2O_5. It is known that in exogenous processes radioactive elements are satellites of phosphorus, but boggy phosphates of the region have not been actually studied in terms of radioactive components. The mass survey made it possible to reveal vast anomalies of uranium, thorium, radon and radium. Elevated uranium content (more than 0.01%) was found in 70 from 167 peatlands examined in the Novosibirsk oblast with four showings (Table 4). Ore concentrations of uranium are timed to a lower part of peat beds. The thickness of productive peatlands ranges from 1.5 to 3.0 m, but sometimes it reaches 4.5 m (Росляков и др., 2004). Radionuclides accumulate at the expense of biogenous accumulation and sorption in the muddy fraction of bottom sediments. The source of radionuclides is zones of tectonic disturbances of the foundation which is testified by radiohydrogeochemical anomalies in pressure fracture waters.

The anomalies are 750–800 m long, 50–200 m wide and contain U = (5–7) · 10^{-6} g/litre, Ra = (1.6–3.84) · 10^{-12} g/litre, Rn = 12–42 eman, and U = (2.2–20) · 10^{-6} g/litre in the epicentres, Ra = 5 · 10^{-12} g/litre, Rn = 126 eman. Uranium and thorium are often accompanied by Co, Ni, Cu, As and REE.

It should be noted that radioactive anomalies in plain landscapes of the region against the background of U = 1.58 · 10^{-6}g/litre, Ra = 0.32 · 10^{-12} g/litre, Rn = 3–5 eman are often present in the soil and underground water as well as in various parts of the section of capping loose sediments. There is even a uranium deposit known to have been formed in the palaeovalley on the reduction barrier at the expense of radionuclides from the weathering crust of granitoids.

A zonal salting of soil and natural water is connected with a lateral climatic zonality and is a particular feature of natural flatland landscapes of the south of West Siberia. On the Kulunda plain in the south and west of Baraba, salinized soils and subsoils of the aeration zone occupy almost 2/3 of the land. Accumulation of soda reaches the commercial concentrations. One can see an exceptional changeability of chemical composition and salinizatiom degree depending on the profile of the aeration zone. Chlorides, sulphates and carbonates accumulate in salinization processes. All the facts are of great importance for us while estimating the ecological state of human and biota habitats.

The active transporting role of abyssal fractures is well known. Both the lightest volatile elements and compounds (helium, hydrocarbons, radionuclides, etc.) and mobile heterofils (Hg, As, Sb) enter the highest structural floors along such extensive and highly permeable structures during a long geological time. For example, the Mediumlatitudinal-Sisob regional linear anomaly of mercury is distinct (Лукин, Гарипов, 1992).

CONCLUSIONS

These are acidic, acidic gley, carbonate, carbonate-sulphate, carbonate-natrium, sodium classes of water migration elements that are able to form state-of-the-art eluvium (neoeluvium), to make-up "false" geochemical anomalies and to deplete true ones.

In natural landscapes, we can see a vertical zonality of the genetic sources of heavy and radioactive metals. In flat landscapes, ore anomalies related to the processes of sediment accumulation prevail; in landscapes transitional from mountains to plain, formation of state-of-the-art anomalies proceeds at the expense of weathering of residual crusts and endogenous mineralization; in mountainous landscapes they occur at the expense of endogenous mineralization and rocks with element contents higher than clark. The great variety of natural sources of metals, along with the diversity of elementary landscapes, requires a unified approach to estimating the load on the ecosystems, with their division into natural and technogenous.

ACKNOWLEDGEMENTS

This study was supported by the RFBR (project 06-05-64697).

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EROZINĖS DENUDACIJOS POVEIKIS SUNKIŲJŲ METALŲ GEOCHEMIJAI VAKARŲ SIBIRO GAMTINIUOSE KRAŠTOVAIZDŽIUOSE

Santrauka

Šio straipsnio tikslas – atskleisti sunkiųjų ir radioaktyviųjų metalų gamtinių anomalijų neigiamą poveikį dabartiniams kraštovaizdžiams, atsižvelgiant į stiprų vertikalų zoniškumą ir rūdinės mineralizacijos įvairiarūšiškumą. Vertinant metalus iš ekologijos pozicijų, buvo pateikti palyginamieji elementų pasiskirstymo duomenys priklausomai nuo vertikalaus zoniškumo ir Vakarų Sibiro elementarių kraštovaizdžių genetinės priklausomybės.

Gamtinės geocheminės anomalijos pasižymi ilga raida. Išanalizuota Li, Be, B, P, Sc, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, Ge, Sr, Y, Zr, Nb, Mo, Ag, Sn, Te, Ba, W, Au, Pb, Bi, Hg, Th, U ir taip pat Hf, Ta, Rb, Cs, La Ce, Nd, Sm, Eu, Gd, Tb, Yb, Lu bendra pasiskirstymo tendencija pagrindinėse regiono uolienose ir jų anomalinių koncentracijų lygiai. Regioniniame fone išryškėjo ženklus sunkiųjų ir radioaktyviųjų metalų poveikis dabartiniams ekogeocheminiams kraštovaizdžiams, kurių kilmė ir sudėtis išreikšta reljefo paviršiaus vertikaliame zoniškume.

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ВЛИЯНИЕ ЭРОЗИОННОГО СРЕЗА НА ГЕОХИМИЮ ТЯЖЕЛЫХ МЕТАЛЛОВ В ПРИРОДНЫХ ЛАНДШАФТАХ ЗАПАДНОЙ СИБИРИ

Резюме

Цель работы – показать негативное влияние природных аномальных концентраций тяжелых и радиоактивных металлов на ландшафты с учетом их вертикальной зональности и многообразия состава рудной минерализации.

Приведены сравнительные данные по распределению элементов в зависимости от вертикальной зональности и генетической принадлежности элементарных ландшафтов Западной Сибири. Показано, что природные геохимические аномалии имеют длительную историю формирования. Проанализирована общая тенденция распределения Li, Be, B, P, Sc, Ti, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, Ge, Sr, Y, Zr, Nb, Mo, Ag, Sn, Te, Ba, W, Au, Pb, Bi, Hg, Th, U, а также Hf, Ta, Rb, Cs, La Ce, Nd, Sm, Eu, Gd, Tb, Yb, Lu в главных типах пород региона и уровни их аномальных концентраций. На региональном фоне показано большое влияние на экогеохимию современных ландшафтов природных аномалий тяжелых и радиоактивных металлов, генезис и состав которых находит отражение в вертикальной зональности рельефа поверхности.