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Chemical Composition of the Oils as an Indicator of Ecosystem Development: a Case Study of Tannu-Ola Ranges

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Study Area: Tannu-Ola mountains
Coordinates: 51°04'12"N; 92°23'25"E

Key words: Accumulation mechanisms, Chemical element Accumulation series, Coefficient of specific relative accumulation, Coefficient of biological accumulation

Introduction:

The time of the beginning of the Tannu-Ola Range rise, estimating by findings of fauna in continental sediments of the Uvs-Nuur Hollow, is identified as the Pliocene (5.3–3.6 million years ago) (Arzhanova & Elpatevskij, 1990). Until that time, in the plain conditions of ancient Central Asian steppes, the accumulative regime seemed to dominate for chemical elements. Further, numerous shallow continental reservoirs also contributed to this fact. The Tannu-Ola Range divided the territory of present-day Tuva into two independent basins — Central Tuvan and Uvs-Nuur ones, with their own modes of accumulation and transformation which caused a change in the ratios of the substance migration mechanisms. Before the appearance of the Tannu-Ola Range, water migration was a dominant mechanism. Atmospheric migration was a subordinate mechanism. Cenozoic aridization and cooling resulted in the enhancement of the biogenic mechanism of substance migration in the study area.

The Tannu-Ola East Range, together with the Western Tannu-Ola that has the adjacent series of deep faults (along the Elegest River), forms a single sub-latitude mountain range that separates the Central Tuvan Basin from the Ubs-Nuur Basin and is a major climate barrier on the path of humid northwestern air currents reaching Central Asia. Geologically and tectonically, the Range has a block structure, representing a horst-anticlinorium uplift with penneplenized watershed surfaces with absolute elevations of up to 2,400–2,900 m, sharply limited by tectonic scarps in

Abstract

Features of distribution of chemical components (micro- and macro-elements) in soils and plant communities of southern and northern slopes of Tannu-Ola range have been studied. Mechanisms of accumulation of some chemical components in dominant plant communities and plant species have been identified. Studied plant species have different selective ability to accumulate chemical components. The results of studies of the chemical composition of soils and plant communities of the Tannu-Ola Range make it possible to consider biogeochemistry of soils and floristic complexes as indicators of an ecosystem.

relief. Tannu-Ola is composed of Middle Paleozoic volcanogenic-sedimentary formations, broken through by Middle-Upper Paleozoic granitoids (Il'in *et al.*, 2003).

Methodology:

The sampling of soil and vegetation was carried out following the standard methods. A total of 102 soil samples were taken from the main root zone horizon (~50 cm) and 117 samples of plants at 1 m² area by cutting off the aerial part.

Qualitative chemical analyzes were carried out in the Physics and Chemistry laboratory of the Center for Collective Use of the TuvSU by X-ray fluorescence method using X-ray machines for spectral analysis SPECTROSCAN MAX.

Selective average and standard deviations were calculated using the Statistica 6.1 software package for each functional zone of the study area. An ecological state of plants was diagnosed by the Fe/Mn, Cu/Zn ratio. The Fe/Mn ratio is one of the most informative indicators of photosynthesis, Cu/Zn – of enzyme synthesis, and Pb/Mn characterizes the ratio of toxic and biophilic elements (Kosheleva *et al.*, 2012).

Coefficients of biological accumulation were calculated as the ratio of the concentration of a chemical element in the grass of a plant to its concentration in the soil: $K_b = C_i \text{ [vegetation cover]} / C_i \text{ [soil]}$, where K_b is a coefficient of biological accumulation relative to the soil; C_i is the concentration of the 'i' chemical element in the plant community (mg/kg); $C_i \text{ [soil]}$ is the concentration of

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the 'i' chemical constitution in soils (mg/kg).

To characterize the specific peculiarities of the concentration function of the studied plants, we calculated the coefficient of specific relative accumulation (CSRA), described in (Manasyrov *et al.*, 2012; Kabata-Pendias, 2010). CSRA is calculated as the ratio of the content of an element in a plant to the average content of this element in all other plants growing on the same territory and under the same conditions (Manasyrov *et al.*, 2012).

Results and Discussion:

The basis of the soil cover of intermontane basins is composed by leached ordinary, southern and mountainous chernozem, and in the driest places –by mountain chestnut soils. The amount of humus is 1.5–2.5% in light chestnut soils and 4–12% in ordinary chernozem, the reaction of the soil varies from neutral to weakly alkaline (Puzanov & El'chinina, 2015). Chestnut soils (light chestnut ones) are represented on the leveled part of the foot of the southern macro-slope.

The northern macro-slopes of the study area are mainly covered by taiga larch, larch and Siberian stone pine or Siberian cedar (*Pinus sibirica*) forests. Under larch wood-meadows on the slopes of the northern exposure and their derivatives with mesoxerophytic grass cover, there are mountain-forest chernozem-like soils. Podzolic, brown-taiga acid neopodzolic soils prevail under larch and cedar-pine-larch forests. The organic matter content in mountain forest soils ranges from 4% in sod-deep podzolic and light gray soils to 18% in mountain-forest chernozem-like ones, the reaction of the soil varies from acidic to slightly alkaline (in lime horizons).

The high-mountain belt is represented by shrub (bushy), shiksha (crowberry) and dryad alpine tundras, subalpine and alpine meadows. Under meadow vegetation, mountain meadow soils were formed, characterized by a thin, crushed stone profile, a discernable sod macro process, leaching profile, lack of signs of podzolization, and an acidic soil solution (Puzanov & El'chinina, 2015).

Mountain tundra is represented by communities of bushy lichens on mountain tundra light slightly humus soils, grass-lichen communities –on mountain tundra peaty soils, grass-dryad communities –on mountain tundra sod soils. The most characteristic properties of mountain-tundra soils are the strong availability of rank soils in the profile (crushed stone profile), a significant accumulation of low-mineralized, high-ash organic matter of fulvate nature in the organic horizons, the acid reaction of the soil, the uniform distribution of the main components of the bulk chemical composition along with the profile, biogenic accumulation of calcium, manganese, phosphorus, and sulfur in the upper horizons. Floristic complexes of the accumulation zone are represented by meadow-steppe vegetation with the presence of a spiny pea tree (*Caragana spinosa* DC.). The floodplain part is represented by alluvial

soddy steppified carbonate and alluvial-meadow, often with A horizon, soils; soil profile is loamy, rolling in heavy clay loam in the lower part. They also include rarefied *Stipa glareosa* and Pamirian winterfat (*Krascheninnikovia ceratoides*) communities.

Flooded plant communities are represented by the multi-mosaic of steppe floristic complexes –desert (general projective cover (GPC)– 30–40%), true (60–75 to 90% and more) and meadow (GPC– 95–100%) steppes.

Forest phytocenoses are represented by poplar-willow-larch forests with rare undergrowth from *Rosa acicularis*, *Caragana spinosa*, herb layer from *Asparagus pallasi*, *Lathyrus pratensis*, *Equisetum arvense*, *Salsola collina*, *Trommsdorffia maculata*.

The piedmont plain of the foothills of a southern macro-slope is occupied by dry and desert steppes. Desert steppes are represented by the options: nanophyton ones dominated by *Nanophyton grubovii* and *Potentilla acaulis* with the presence of *Cleistogenes squarrosa*, *Artemisia frigida*, *Eremogone meyeri*, *Ephedra monosperma*, *Scorzonera ikonnikovii*, *Iris humilis*, etc.; Forage Kochia (*Bassia prostrata*) desert steppes with highly sparse herbage (GPC— 5–10%); *Caragana* (*Caragana pygmaea*) pasture sagebrush and grass steppe (30% GPC) in whose vegetation cover structure there is *Stipa glareosa*, *S. krylovii*, *Cleistogenes squarrosa*, *Agropyron cristatum* (sp-sol) and subshrubs *Artemisia frigida*, *Bristia-sytara*, rarely *Gypsophila desertorum*, *Dontostemon perennis*, *Stevania canescens* which are usually associated with emissions from the holes of small mammals. In the complex composition confined to the burrows of burrowing mammals (*Ochotona daurica*), such species as *Caragana pygmaea*, *Stipa krylovii* with *Euphorbia tshuiensis*, *Potentilla acaulis*, *Ancathia igniaria* in the structure of the complex (Kurbatskaya *et al.*, 2014) are common.

In accumulative landscapes of both macro-slopes, there are traces of movement of mountain-valley glaciers that are currently represented by areas with a gently undulating relief with small hollows. The transit zone is represented (~1800 m.A.S.L.- 2000 m. A.S.L. on denudation mid-steep and gentle slopes or on steps of slopes with grass-forest cover) by mountain-steppe floristic complexes. The peculiarity of their structure, caused by the meso relief, is the combination of steppified larch forests with respective meadows and bunchgrass steppes with the presence of meadow-steppe shrubs which is typical for the whole belt of the Southern Tuva mountain forest-steppe (Kurbatskaya *et al.*, 2014). The Northern macroslope is represented by dark coniferous, larch and cedar pine (*Pinus sibirica*), larch and mixed forests. There are shrubs in the undergrowth- blackberry cotoneaster (*Cotoneaster melanocarpus*) and *Oriental spiraea*, the grass layer is well developed (GPC- 80–90%, average height of grass stand is 50–60 cm).

The distribution and concentration dynamics of 17

Mean values and standard deviations (M±sd) of chemical elements concentrations in soils of Tannu-Ola Range

In order to understand the consistent patterns and mechanisms of transformation of chemical elements, their concentrations in various types of landscapes and ecosystems of the East Tannu-Ola Range have been studied. The research results are presented in tables 1 & 2.

Table 1: Microelements content (Mean) in soils of various landscapes and ecosystems of the East Tannu-Ola Range (altitude 2295 m)

Microelement (ppm)	V,	Cr,	MnO,	Co,	Ni,	Cu,	Zn,	As,	Sr,	Pb,
Eluvialzone (northernpart)	117.7±29.9	109.6±12.1	1588.2±331.7	22.7±17.3	33.2±11.2	51.1±18.3	90.6±6.8	50.8±28.04	212.4±54.8	H/O
Eluvialzone (southernpart)	128.2±15.5	117.6±9.2	1293.4±263.3	8.9	38.2±10.6	39.8±10.3	83.8±8.3	67±38.1	312±45.7	0
Transit zone on the northern slopes	104±18.04	96.2±5.4	1104.8±267.20	34.6±6.2	41±9.1	84.2±7.04	33±7.7	452±69.4	0	0
Transit zone on the southern slopes (upper lower forest boundary)	124.3±52.4	101.2±22.2	1396.7±127	9.3	24.8±11	45.2±15.1	105.2±18.3	25.6±8.4	245.1±134.5	0
Transit & accumulation zone on the southern slopes (Kara-Khol depres.)	0	77.4±2.12	11013±760	0	7.85±0.63	29.3±6.08	125.5±19.1	26.5±13.4	119.5±53.03	0
Accumulationzonefrom the north	88.5±26.6	74.7±12.4	1361±345.7	0	22.8±7.9	30.6±6.8	79.2±27.8	10.2±7.8	359±255.4	0
Accumulationzonefrom the south	105.2±20.5	98.7±7.3	1909±433.9	0	32.5±6.2	24±4.8	119±29	46.2±5.1	298±27.2	0

Table 2: Microelements content (Mean) in soils of various landscapes and ecosystems of the East Tannu-Ola Range (altitude 2295 m)

Macroelements	TiO ₂ .%	Fe ₂ O ₃ .%	CaO.%	Al ₂ O ₃ .%	SiO ₂ .%	P ₂ O ₃ .%	K ₂ O.%	MgO.%
Eluvialzone (northernpart)	0.37±0.11	6.41±0.96	2.1±.25	11.4±1.6	50.2±8	0.29±0.08	1.5±0.14	1.19±0.4
Eluvialzone (southernpart)	0.38±0.04	6.88±0.88	2.58±0.78	12.2±1.78	54.8±6.8	0.21±0.08	1.5±0.15	2.38±0.53
Transit zone on the northern slopes	0.39±0.04	5.7±0.49	5.56±1.22	10.6±1.05	45±1.7	0.31±0.05	1.38±0.2	2.52±0.21
Transit zone on the southern slopes (upper forest boundary)	0.42±0.12	6.25±1.43	2.62±1.56	9.7±0.45	43±3.74	0.27±0.05	1.37±0.17	1.75±0.74
Transit and accumulation zone on the southern slopes (Kara-Khol depression)	0	7.55±7.28	5±0.14	1.35±0.21	6.7±.28	0.4	0.1	0.6±0.28
Accumulationzone from the north	0.10±0.09	4.39±0.93	3.91±2.48	9.83±2.35	49.25±7.61	0.41±0.47	1.94±0.34	2.23±0.79
Accumulationzone from the south	0.34±0.05	6.42±0.59	4.3±0.77	11.27±2.21	47.4±4.9	0.36±0.16	1.75±0.23	2.57±0.63

The large scatter of values in the content of most of the elements can be explained by a varying degree of atmospheric aerosols influence and a difficultly dissected relief of the study area.

Table 3: Series of the dynamics of chemical elements concentrations in the soils of the East Tannu-Ola Range (chemical element/average concentration, mg/kg)

No.	Eluvial (N)	Transit (N)	Accumul. (N)	Eluvial (S)	Transit (S)	Accumul. (S)	Lake basin (acc. Z-S)	Hole (acc.-trans. Z)
1	Si/5020	Si/4500	Si/4925	Si/5480	Si 4300	Si 4740	Mn 1101	Si 5017
2	Mn/1588	Mn/1104	Mn/1361	Mn/1293.4	Mn 1396	Al 1127	Fe 755	Fe 1504
3	Al/140	Al/1060	Al/983	Al/1220	Al 970	Mn 1101	Si 670	Mn 1123
4	Fe/641	Fe/570	Fe/439	Fe/688	Fe 625	Fe 642	Ca 500	Al 630
5	Sr/212.4	Ca/556	Ca/391	Sr 312	Ca 262	Ca 430	Al 135	Mg 400
6	Ca/210	Sr/452	Sr/359	Ca 258	Sr 245	Sr 298	Zn 125	Sr 362
7	K/150	Mg/252	K/194	Mg 238	Mg 175	Mg 257	Sr 119	Ca 297
8	Mg/119	K/138	Mg/175	K 150	K 137	K 175	Cr 77.4	K 166
9	V/117.7	V/104	V/88.5	V 128	V 124	Zn 119	Mg 60	V 104
10	Cr/109.6	Cr/96.2	Zn/79.2	Cr 117.6	Zn 105	V 105	P 40	Cr 102
11	Zn/90.6	Zn/84.2	Cr/74.7	Zn 83.8	Cr 101	Cr 98	Cu 29.3	Zn 75.5
12	Cu/51.1	Cu/41	P/41	As 67	Cu 45.2	As 46	As 26.5	Ti 41
13	As/50.8	Ti/39	Cu/30.6	Cu 39.8	Ti 42	P 36	K 10	Ni 37.3
14	Ti/37	Ni/34.6	Ni/22.8	Ni 38.2	P 27	Ti 34	Ni 7.85	Cu 31.4
15	Ni/33.2	As/33	As/10.2	Ti 38	As 25.6	Ni 32.5	Vo	As 27.9
16	P/29	P/31	Ti/10	P 21	Ni 24.8	Cu 24	Ti 0	Co 5.1
17	Co/22.7	Co/0	Co/0	Co 8.9	Co 9.3	Co 0	Co 0	P 5

chemical elements studied (Table-3) in the soils of the East Tannu-Ola Range on the slopes of the northern and southern exposures, the Kara-Khol depression are expressed in the following series:

- 1) Si=Mn=Al=Fe=Sr=Ca=K=Mg=V=Cr=Zn=Cu=As=Ti=Ni=P=Co - eluvial zone occupied by mountain shrub and grass tundra;
- 2) Si=Mn=Al=Fe=Ca=Sr=Mg=K=V=Cr=Zn=Cu=Ti=Ni=As=P - transit zone on the slopes of the northern exposure occupied by

- coniferous and mixed forests;
- 3) Si=Mn=Al=Fe=Sr=Ca=K=Mg=V=Zn=Cr=P=Cu=Ni=As=Ti is the accumulation zone of the northern foot of the range represented by different steppes.
- Southern exposure slopes have the following order of reducing the elements concentration:
- 4) Si=Mn=Al=Fe=Sr=Ca=K=Mg=V=Cr=Zn=As=Cu=Ni=Ti=P=Co - eluvial zone;

- 5) transit zone of the southern slopes represented by light coniferous forest with the presence of some hardwoods and mountain steppes: $Si = Mn = Al = Fe = Ca = Sr = Mg = K = V = Zn = Cr = Cu = Ti = P = As = Ni = Co$;
- 6) in the plain part, the relative concentrations of chemical elements are presented as follows: $Si = Al = Mn = Fe = Ca = Sr = Mg = K = Zn = V = Cr = As = P = Ti = Ni = Cu$.

On the northern macroslopes, starting from the altitude occupied by mountain tundras to the piedmont plain steppes, a regular decrease in concentrations of the following elements is noted: Al, Fe, V, Cr, Cu, As, Co; Si, Mn, and K are characterized by a decrease in concentrations in the transit zone, and elevated concentrations of the content in the transit zone are observed in Sr, Ca, Mg, Ti, and Ni which decrease in both the eluvial and accumulation zones. The concentration of phosphorus increases from the eluvial zone to the accumulation zone.

For the slopes of the southern exposure, the character of the dynamics varies: down the slope, only V and Cr concentrations decrease, while for Si, Fe, Sr, Mg, K, As and Ni, their concentrations in the transit zone decrease and increase in the accumulation zone. Mn, Al, Ca, Cu, Ti and Co are characterized by a higher content in the transit zone, which decreases to the accumulation zone. Co is completely out of range in the accumulation zone. The concentration of phosphorus and zinc increases from the eluvial zone to the accumulation zone.

The series of changes in the concentration of chemical elements of the transit and accumulation zone (the Kara-Khol lake basin) represented by the alpine meadows - $Mn = Fe = Si = Ca = Al = Zn = Sr = Cr = Mg = P = Cu = As = K = Ni$ should be regarded separately. The concentrations of chemical elements either decrease from altitudes to the bottom of the lake basin (Si, Fe, Al, Sr, Cr, Mg, Cu, As, K, Ni), or increase (Mn, Ca, Zn, P), manganese and iron become the elements determining the structure of a series. On the slopes, the beginning of the rows is represented by the $Si = Mn = Al = Fe$ ratios.

We also investigated a number of ratios of element concentrations in the burrows of small mammals believing that these ancient structures should have a “genotypically determined memory” of biogeochemical homeostasis. The series of decreasing concentrations of the studied chemical elements in the soils of burrows looks as follows: $Si = Mn = Al = Fe = Sr = Ca = Mg = K = V = Cr = Zn = Ti = Ni = Cu = As = Co = P$. By structure, the presented series is close to rows of decreasing concentrations on the northern and southern macroslopes. By the nature of the dynamics of chemical elements concentrations, the presented series differs from the rest. The following number of studied elements exhibits enhanced maximum values: Fe, Mg, Sr, Ca, K, V, Cr, Ti, Ni, Cu, As, Co and Si; concentrations of Mn, Al, Zn, P decrease.

Thus, the recorded dependences of microelement concentrations on landscape and ecological conditions are observed in a vertical structure of the soil of the ridge. The

chemical composition of the soils of the northern and southern macroslopes fit into the general trend of dependencies characteristic of the continental zone, however there are some peculiarities. For example, the concentrations of vanadium, chromium, nickel, and arsenic are significantly lower in the southern macroslopes compared to the northern ones, and cobalt on the southern macroslopes in the transit and accumulation zones of the ridge drops out completely. The dynamics of concentrations and distribution of chemical elements in the soils of the Kara-Khol depression is to a greater degree from other series. Concentration decrease and precipitation of some elements from the series (V, Ti, Co) in the lake basin may be due to the presence of lake water where chemical compounds enter actively during the decomposition of plants, and then they are actively removed from the water column during chemical and microbiological processes without significant atmospheric or lithospheric input. This observation may be true for all bivalent transition metals.

In the accumulation zone, there is a significant enrichment of the soils by Fe, Si, K, Mg, Sr, Mn and insoluble trivalent and tetravalent hydrolysates which are bound to Fe. In the transit zone of the southern macroslopes, Co appears, concentrations of V, Cr in both slopes increase, concentrations of As decrease on southern macroslopes, and on northern macroslopes its concentrations increase. A significant increase of the majority of chemical elements on the eluvial zone may be due to the entry of these elements through atmospheric transport, as well as from decaying plants of high-mountain floristic complexes characterized by high productivity.

The analysis showed that there are four different models of elements concentrations depending on the position on the vertical profile: i) a number of concentration dynamics and chemical elements distribution of the northern macroslope; ii) a series of concentration dynamics and chemical elements distribution of the southern macroslope; iii) a number of concentration dynamics and chemical elements distribution in the high-altitude lake depression; iv) a number of concentration dynamics and distribution in the zone of burrowing complexes of small mammals regardless of the exposure of the slope.

In the mechanisms of chemical elements migration of northern macroslopes of the ridge, in contrast to extremely arid southern macroslopes, atmospheric and water transfers increase, and the biogenic migration becomes significant arid southern macroslopes.

From the above, we can conclude that with the predicted gradual increase in global temperature and the subsequent decrease in the level of water bodies, the concentration of dissolved but little bioavailable organic matter and most microelements that are associated with organic and organomineral colloids will increase. The continuing Alpine stage of tectogenesis may exacerbate differences in the

qualitative structure of the decreasing concentrations series on northern and southern macroslopes that may cause associated qualitative changes in the structure of ecosystems.

Correlation analysis of the chemical composition of soils showed a high degree of dependence of chemical elements content in soils on Mn and Fe concentration and main macro elements on each other, and in high-mountain ecosystems – on humus. The dynamics of iron content in soils of a high-mountainous zone of the ridge, as a whole, coincides with the dynamics of humus content and is characterized by high correlation coefficients. So, it is for the bushy tundra (Fe/humus; $r=0.89$); for moss-lichen tundra (Fe-humus; $r=0.81$); for the crowberry tundra (Fe-humus; $r=0.93$). The manganese content is characterized by a similar dynamics: for bushy tundra (Mn/humus; $r=0.90$); for moss-lichen tundra (Mn/humus; $r=0.85$); for crowberry tundra, the correlation of Mn and humus is 0.71. The content of Fe and Mn in the soils of the transit zone, especially the accumulation zone, is characterized by a gradual decrease in the concentration in the humus horizon which sharply increases at the boundary of the transition horizon (~ 15 cm), i.e. the reverse dynamics of Mn and Fe accumulation relative to the humus horizon is observed.

In tundra soils, all studied concentrations of heavy metals have similar dynamics of change with a depth of 10 cm minimum. This minimum coincides with the boundary between humus and transitional soil horizons. Co, Ni and Cu are associated with humus, as evidenced by high correlation coefficients. The remaining elements show a high dependence on iron concentration. The element Co, Ni, Cu, Zn, As, and Sr show a high dependence on Fe and humus concentrations in the bushy tundra. In moss-lichen tundra, Co, Ni, Zn, As are connected with iron. Strontium is associated with manganese, as evidenced by the high value of the correlation coefficient (0.75). The copper concentration does not show dependence on humus, Fe and Mn decreases to a depth of 10 cm from 46.6 to 65.5 mg/kg, then increases with a depth of up to 74.4 mg/kg. In crowberry and dryad tundra, it has no noticeable dependence on humus, Fe and Mn (correlation – 0.19). Further, Sr is associated with Mn and Fe and has no significant link with humus. The remaining elements (Co, Ni, Cu, Zn) are characterized by high correlation values (> 0.80) and with a maximum at a depth of 10 cm. High correlation rates for chemical elements of tundra soils show that the content of these elements is regulated by humus, Fe and Mn. This is due to the fact that many of the chemical elements studied by us are capable of forming organometallic compounds.

For steppe soils of the accumulative landscape of the study area, pronounced variability of their content in the soil horizons are characterized. For example, there are two peaks of maximum content for Mn- in the transition horizon (AB),

a decrease in (A_0 , A) and again it increases in the transition one from the mineralized horizon (B) to the carbonate horizon that is consistent with the main root-inhabited horizon.

These soil types are characterized by a fairly high content of Zn, Sr that decreases to the upper horizons, which, apparently, connects their origin with a lithological basis. From the upper horizons all over the soil horizons, the content of Si, Al, and Mg is rather high.

The dynamics of the main macroelements content is closely related to each other: Ca-Mg ($r=0.89$); K-P ($r=0.94$); K-Cl ($r=0.85$); S-Si (0.72); S-Cl (0.95); Mg-P (0.69); P-Cl (0.7). At the same time, there is a negative correlation in the content of calcium and silicon.

In the steppe soils, there is a very low phosphorus content that is recorded only in the upper horizons which indicates their biogenic origin and the active involvement of the element in biochemical processes.

The amount of organic mineral compounds on the surface horizons of the soil has a decisive influence on the accumulation of all the elements under consideration, since many organic mineral compounds are weakly mobile, and with increasing of humification, the strength of adsorption on the biogeochemical barrier increases.

Mean values and standard deviations ($M \pm sd$) of the concentrations of the chemical elements in plant communities of the Tannu-Ola Range:

In the content of microelements and macroelements in the plant communities of the study area, the accumulation and transit zones are not directly dependent on their content in the soil (Tables-4 & 5). For example, the content of phosphorus, calcium, sulfur, and magnesium, is more than their values in the soil horizons. This is not surprising since these elements form the structural basis of macromolecules of biological systems of different levels that indicates the presence of a direction of selection aimed at developing adaptation mechanisms to the environment chemise in various floristic complexes.

Some microelements (Fe, Cr) in the aerial organs of the transit zone fall out, and the barium content decreases sharply. In the accumulation zone of the landscape in floodplain floristic complexes, the content of Fe, Cr increases, and zinc is accumulated in floristic complexes of floodplain ecosystems.

By the size of Fe/Mn and Cu/Zn ratios in the aboveground plant organs in the studied zones, there is a significant imbalance in the element ratios from eluvial to accumulative (3.9–3.01–31.7) of a southern macroslope with the exception of the lake basin where the balance is optimal (1,2). Disbalance of ratios is also characteristic of the northern slopes (4.1–23.1–13.6). The Cu/Zn ratio in the study area does not manifest itself since Cu is not fixed in the aboveground plant organs. The same is true for Pb/Mn ratios, where lead is not fixed at most points of the study,

with the exception of the accumulative landscape in the western part of the ridge. There, the ratio value is 0.33 that is higher than the optimal values of indicators of land vegetation – 0.006 (Kovalevskij, 1969; Timofeev & Kosheleva, 2016; Kabata-Pendias, 2010). This characteristic of the ratio of the elements may indicate the atmospheric transfer of many microelements and their weak involvement in biogeochemical processes. We noted ratio values, close to the optimal ones, characterizing the

ecological state of plant communities, during the analysis of the first results of the characteristics of the biogeochemical situation in the area of active work on burrow complexes construction.

Biological accumulation coefficients of chemical elements in plants of East Tannu-Ola Range:

The biological accumulation coefficients of chemical elements in the vegetation cover of tundra ecosystems relative to soil (K_b) are calculated.

Table 4: Microelements (mean) content in plant comm. of various landscapes & ecosystems of East Tannu-Ola Range (altitude 2295 m)

Microelements	Zn.	Ni6	Mn.	Cr.	Sr.	Br.	Ba.	Pb.	Ti.	Fe.
Moss-lichen-bushytundra	23.25±9.04	3.89±0.77	292.4±176.3	4.28±1.34	42.3±17.2	5.0±2.3	45.7±15	0	114.5±49.5	1220.5±562.2
Dryad Tundra	56.49±2.29	2.66±0.03	75.06±0.24	3.16±0.24	98.48±1.21	0.43±0.01	73.71±0.7	0	35.27±0.25	295.3±0.35
Larch-cedar pine (<i>Pinus sibirica</i>) forests (northern slopes)	46.8±16.6	3.3±2.9	113.1±78.3	9.4±8.2	53.04±31.4	4.05±2.19	49.9±35.6	0	211±205	2621±1788.9
Larch steppified forests (southern slopes)	46.44±15.4	2.4±0.98	206.1±125.5	3.24±0.62	56.8±36.8	1.41±0.9	83.6±69.5	0	59.97±24.1	621.8±327.4
Alpine meadows on lake basin	20.99±2.35	2.2±0.87	167±12.7	0	49.72±12.8	2.22±0.88	1±0.13	56.1±7.8	29.1±2.8	201.3±17.7
Foothill true steppes (northern foothills)	33±1	1.94±0.27	171±6	17.3±2.8	113±4	20.13±2.02	69±9	0	133.4±18	2341.5±117.7
Nanophyton desert steppes (south)	26.1±10.1	2.4±2.7	106.5±103.2	10.06±9.45	82.5±53.9	5.06±2	86.2±65	0	348.8±273.6	3367.5±4753.9

Table 5: Microelements content (Mean) in plant comm., of various landscapes & ecosystems of East Tannu-Ola Range (altitude 2295 m)

Macroelements	Ca,%	K,%	Al,%	S,%	Mg,%	Si,%	P,%	Cl,%
Eluvial zone (northern part)	0.94±0.28	0.4±0.28	0.13±0.06	0.06±0.02	0.26±0.02	0.29±0.12	0.08±0.03	0.06±0.05
Eluvial zone (southern part)	1.96±0.01	3.54±0.05	0.11±0.01	0.39±0.05	0.38±0.01	1.03±0.1	0.31±0.02	0.13±0.04
Transit zone on the northern slopes	0.96±0.09	2.03±1.93	0.28±0.23	0.2±0.21	0.29±0.09	0.33±0.43	0.27±0.23	0.14±0.12
Transit zone on the southern slopes	0.97±0.05	1.78±0.49	0.08±0.03	0.1±0.06	0.26±0.06	0.42±0.26	0.18±0.12	0.38±0.30
Accumulation zone from the north	1.18±0.06	2.0±0.12	0.09±0.01	0.07±0.01	0.46±0.02	0	0.45±0.08	0.05±0.01
Accumulation zone from the south	1.62±0.2	1±0.32	0.59±0.78	0.10±0.02	0.37±0.27	0.42±0.73	0.14±0.06	0.11±0.09

Table-6: Biological accumulation coefficients of chemical elements of floristic complexes

Floristic complexes	Average concentrations of microelements and coefficients of biological absorption (Kb)							
	Zn, ppm	Ni, ppm	Mn, ppm	Cr, ppm	Sr, ppm	Pb, ppm	Ti, ppm	Fe, ppm
Moss-lichen-bushytundra	0.38	0.11	0.18	0.039	0.19	0	309	203
Dryad tundra	0.44	0.06	0.058	0.026	0.31	0	928	492
Larch-cedarpine(<i>Pinus sibirica</i>)forest softhenorthern slopes	0.55	0.09	0.10	0.03	0.12	0	390	518
Larch steppified forests of southern slopes	0.44	0.09	0.14	0.03	0.23	0	1.42	10.02
Alpine meadows on the lake basin	20.99	0.028	0.015	0	0.41	1.5*	29.1	268
Foothill true steppes of the northern foothills	0.41	0.08	0.12	0.23	11.3	0	13.3	544
Nanophytondesert steppes from south	0.32	0.07	0.055	0.10	0.27	0	34.8	561

Table-6: Biological accumulation coefficients of chemical elements of floristic complexes

Macroelements	Ca.%	K.%	Al.%	S.%	Mg.%	Si.%	P.%	Cl.%
No.-3 Cowberry. southern slope. N50 56.846; E94 16.845; h = 1931 m	0.70±0.01	1.05±0.01	0.15±0.01	0.17±0.02	0.29±0.01	0.57±0.05	0.29±0.02	0.24±0.09
No.-5 Moss - south. N50 57.847; E94 16.861; h = 2011 m	0.38±0.01	0.52±0.01	0.11±0.01	0.03±0.01	0.22±0.01	0.31±0.03	0.10±0.01	0.01±0.00
No.-15 Cowberry. southern slope N50 58.402; E94 17.664; h = 2179 m	0.96±0.01	0.48±0.01	0.04±0.01	0.03±0.01	0.14±0.01	N/A	0.06±0.01	0.02±0.01
No.-16 Rhubarb - southern slope N50 58.402; E94 17.664; h = 2179 m	1.23±0.01	0.76±0.01	0.08±0.01	0.06±0.01	0.32±0.01	N/A	0.09±0.01	0.02±0.01
No.-12 Bergenia. northern slope N50 59.753; E94 18.463; h = 2163 m	0.70±0.01	0.42±0.01	0.06±0.01	0.03±0.01	0.21±0.01	0.48±0.04	0.06±0.01	0.01±0.00
No.-20 moss. northern slope. N50 59.390; E94 18.591; h = 2298 m	0.57±0.01	0.17±0.01	0.16±0.01	0.04±0.01	0.23±0.01	0.57±0.05	0.06±0.01	0.01±0.00
No.-21 Bergenia. northern slope. N50 59.105; E94 18.167; h = 2225 m	1.28±0.01	0.17±0.01	0.12±0.01	0.04±0.01	0.36±0.01	0.24±0.02	0.04±0.01	0.01±0.00
No.-22 lichen. northern slope. N50 55.462; E94 18.348; h = 2280 m	0.34±0.01	0.15±0.01	0.13±0.01	0.04±0.01	0.18±0.01	0.38±0.03	0.04±0.01	0.01±0.00

Table-7: Average concentrations of chemical constituents in the above-ground organs of some plant species in the high-mountainous ecosystems of the Tannu-Ola Range

Microelements sampls	Zn. ppm	Ni. ppm	Mn. ppm	Cr. ppm	Sr. ppm	Br. ppm	Ba. ppm	Rb. ppm	Ti. ppm	Fe. ppm
No.-3 Cowberry. southern slope N50 56 846; E94 16 845; h=1931m	27.02±1.09	1.6±0.02	332.09±1.07	3.78±0.29	21.14±0.26	1.31±0.01	37.57±0.36	N/A	109.52±0.78	931.33±1.11
No.-5 Moss - south. bushytundra N50 57 847; E94 16.861; h = 2011 m	27.06±1.10	3.52±0.04	546.26±1.83	5.14±0.39	16.24±0.20	0.49±0.01	24.13±0.23	N/A	107.35±0.77	1266.73±1.51
No.-15 Crowberry. southern slope N50 58.402; E94 17.664; h = 2179 m	22.75±0.92	1.98±0.03	262.61±0.85	1.24±0.09	51.12±0.63	1.53±0.02	15.48±0.15	N/A	21.71±0.15	152.68±0.18
No.-16 Rhubarb - southern slope N50 58.402; E94 17.664; h = 2179 m	17.04±0.69	1.06±0.01	28.31±0.09	1.77±0.14	48.53±0.59	1.51±0.02	34.32±0.33	N/A	33.48±0.24	252.28±0.30
No.-12 Bergenia. head of river Ulug-Shangan N50 59 753; E94 18.463; h = 2163 m	20.59±0.83	4.38±0.06	87.26±0.28	1.43±0.11	26.51±0.32	3.96±0.04	22.40±0.21	N/A	47.56±0.34	397.22±0.47
No.-20 moss. northern slope. N50 59 390; E94 18.591; h = 2298 m	53.30±2.16	4.33±0.06	257.11±0.83	8.36±0.64	31.03±0.38	3.94±0.04	51.24±0.49	N/A	208.54±1.49	2512.28±3.00
No.-21 Bergenia. northern slope. N50 59 105; E94 18.167; h = 2225 m	14.32±0.58	2.39±0.06	82.16±0.27	1.53±0.12	76.34±0.93	1.64±0.02	97.28±0.92	N/A	49.53±0.35	483.53±0.58
No.-22 lichen. northern slope. N50 55 462; E94 18.348; h = 2280 m	22.03±0.89	1.94±0.02	88.55±0.29	2.79±0.21	15.82±0.19	3.04±0.03	9.73±0.09	N/A	89.07±0.64	954.33±1.14

Table-8: Macroelement composition

Macroelements	Ca.%	K.%	Al.%	S.%	Mg.%	Si.%	P.%	Cl.%
No.-3 Cowberry. southern slope N50 56.846; E94 16.845; h = 1931m	0.70±0.01	1.05±0.01	0.15±0.01	0.17±0.02	0.29±0.01	0.57±0.05	0.29±0.02	0.24±0.09
No.-5 Moss - south. N50 57 847; E94 16.861; h = 2011m	0.38±0.01	0.52±0.01	0.11±0.01	0.03±0.01	0.22±0.01	0.31±0.03	0.10±0.01	0.01±0.00
No.-15 Crowberry. southern slope N50 58.402; E94 17.664; h = 2179m	0.96±0.01	0.48±0.01	0.04±0.01	0.03±0.01	0.14±0.01	N/A	0.06±0.01	0.02±0.01
No.-16 Rhubarb - southern slope N50 58.402; E94 17.664; h = 2179m	1.23±0.01	0.76±0.01	0.08±0.01	0.06±0.01	0.32±0.01	N/A	0.09±0.01	0.02±0.01
No.-12 Bergenia. northern slope N50 59.753; E94 18.463; h = 2163 m	0.70±0.01	0.42±0.01	0.06±0.01	0.03±0.01	0.21±0.01	0.48±0.04	0.06±0.01	0.01±0.00
No.-20 moss. northern slope. N50 59 390; E94 18.591; h = 2298 m	0.57±0.01	0.17±0.01	0.16±0.01	0.04±0.01	0.23±0.01	0.57±0.05	0.06±0.01	0.01±0.00
No.-21 Bergenia. northern slope. N50 59 105; E94 18.167; h = 2225 m	1.28±0.01	0.17±0.01	0.12±0.01	0.04±0.01	0.36±0.01	0.24±0.02	0.04±0.01	0.01±0.00
No.-22 lichen. northern slope. N50 55 462; E94 18.348; h = 2280 m	0.34±0.01	0.15±0.01	0.13±0.01	0.04±0.01	0.18±0.01	0.38±0.03	0.04±0.01	0.01±0.00

Table-9: Coefficient of specific relative accumulation (CSRA) of heavy metals in plants of studied alpine ecosystems

Plant type	Zn	Ni	Mn	Cr	Sr	Pb	Ti	Fe
Cowberry	0.31	0.07	0.23	0.04	0.15	N/A	0.03	0.27
Cowberry/Empetrum nigrum	0.26	0.09	0.18	0.01	0.37	N/A	0.006	0.04
Rheumcompactum L.	0.19	0.04	0.02	0.01	0.35	N/A	0.009	0.07
Leatherbergenia	0.23	0.19	0.06	0.01	0.19	N/A	0.01	0.14
Moss	0.31	0.15	0.38	0.05	0.11	N/A	0.06	0.73
Lichen	0.25	0.08	0.06	0.03	0.11	N/A	0.02	0.28

The interaction of plants with the soil, in particular, metabolism of microelements, is twofold. On the one hand, plants regulate the absorption and accumulation of metals while maintaining the genotypically defined “microelement homeostasis”, on the other hand, they cannot completely neutralize “geochemical pressure” of the environment while increasing concentrations of elements in soils above the optimum. Il’in et al., (2003) defines these factors as genotypic and ecological.

Table-6 presents the biological accumulation coefficients of chemical elements in vegetation cover relative to soil (K_b). As we can see from Table-5, for all the studied plant communities, chemical constituents, necessary for plants in the course of their vital activity are characterized by

relatively high values of K_b. It is known that Mn has high biogeochemical activity in tundra and taiga landscapes (Glazovskaya, 1988; Elpat’evskii & Arzhanova, 1990; Kovalevskij, 1969; Kosheleva et al., 2012; Ondar et al., 2015). An additional factor of increased Mn concentration in the tundra vegetation can be a more intensive course of photosynthesis leading to the oxidation of Mn²⁺ to Mn⁴⁺ on the cell surface. The variants of the high-mountainous tundras of the study area (bushy, moss-lichen, crowberry and dryad tundras) studied by us are characterized by similar trends in the accumulation of chemical elements and do not exhibit noticeable features. Moss-lichen tundra is characterized by a more active accumulation of most chemical elements that makes it possible to isolate it in the

form of a content bioindicator of heavy metals.

An active accumulation of iron, having a high bioaccumulation activity in over moistened soils in the crowberry tundra, may indicate its specificity and bioindicator properties with respect to this chemical element. According to the research, we can conclude that in the vegetation cover of the high-mountainous tundras of the East Tannu-Ola Range, macroelements (K, Mg, Fe, Mn), some heavy metals (Ni, Cr, Zn, Sr, Ti), also Br, accumulate actively relative to the soil. The accumulation of the remaining chemical elements in relation to the soil is individual for a particular variant of tundras and may indicate the species specificity of the plant communities.

The content of chemical constituents in the aboveground organs of some economically important plant species of high-mountain floristic complexes. The elemental composition of above-ground organs of some economically significant plant species included in the structure of high-mountain floristic complexes was studied. The research results are summarized in Tables-7, 8.

The general dynamics of the chemical elements contained in all the plants studied by us is the same. However, there are some differences in the content of micro- and macroelements in the above-ground organs of different plant species. So, the cowberry accumulates most of all, in comparison with other studied plant species, such microelements as Mn, Br, Ba & Ti. Among macroelements, the high values of their content in the aboveground organs of cowberry are noted for K, Al, S, Mg, Si, P and Cl. The maximum values of Zn, Ni, Mn, especially Cr, Ti, and Fe, are characteristic of mosses from the bushy lowland tundra of the southern macroslope and from the highland crowberry tundra of the northern macroslope. High content of Ni, Ba and Br was observed in the aboveground organs of *bergenia*. Lichens accumulate Ti, Br and Fe actively. The tendency to accumulate Sr was observed in cowberry, rhubarb, mosses and *bergenia*, and Br accumulation was also characteristic of cowberry, rhubarb and lichen.

Ca as a macro element accumulates in cowberry, rhubarb and *bergenia* in the above-ground organs, K – in rhubarb. Al accumulates actively in mosses and lichens, Mg – in mosses, rhubarb, *bergenia*, Si, except cowberry, accumulates actively in *bergenia* and mosses. The studied plant species have a different selective ability to accumulate chemical elements. Table-9 shows the values of CSRA for 6 plant species studied with respect to the concentrations of iron, manganese, and microelements in them.

As we can see from Table-9, the accumulators for Zn, Ni, Fe are cowberries and mosses. For strontium – *Empetrum nigrum* and *Rheum compactum*, *Leather bergenia* can be a photo indicator for Zn. It is important to note that the indicator function in relation to the concentration of microelements (ME), for the studied plants, is weak. The value of CSRA of the studied plant species for ME varies from

0.25 to 0.73 which on average is 1.5 times higher than the CSRA values for other species of the studied plants.

Conclusions:

1. For the soils of northern and southern macroslopes of the Tannu-Ola Range, a correlated change in the chemical composition with Si-Mn-Fe-Al is characteristic that can be converted by lake systems to Fe-Mn.
2. According to the nature of dynamics and characteristics of chemical constituents distribution in soils, 4 variants of the series can be distinguished: i) the northern macroslope; ii) southern macroslope; iii) lake basin; i) burrow complexes of small mammals.
3. The studied floristic complexes are characterized by different strategies of accumulating the ability of chemical constituents.
4. The burrowing complexes of small mammals of the study area as ancient systems can store the genetically determined structure of biogeochemical characteristics of ecosystems in the conditions of Central Asia.

Acknowledgments:

This work was supported by the Russian Foundation for Basic Research upon project No. 18-44-170003.

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