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Lead concentrations in soils and plants of two altitudinal transects in the Eastern Kyrgyz Tian Shan mountains – a preliminary study

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Abstract. Two altitudinal transects of soil and plant samples from the Kyrgyz Tian-Shan mountains were analysed to determine lead contamination. The first transect (Ak-Sai) is located in the Ala-Archa National Park and the second transect (Arashan) is situated in the Issyk-Kul Province. Both the total and the extractable lead concentrations were determined in the soil samples. The lead content was also measured separately in shoots and roots of grass species and in moss tissues as well. Higher values of total soil lead content were found in Arashan which could be attributed to the geological composition of the bedrock, whereas in Ak-Sai, higher amounts of potencially mobile lead forms in the soil were found. Lead concentrations in the shoots of grasses were generally lower than in the root systems. Relatively high amounts of lead were found in mosses, probably reflecting the atmospheric lead pollution. Principal component analysis revealed correlations between altitude and lead concentrations in soil samples, in grass and moss tissues.

Key words: lead, transects, Tian Shan, grasses, bryophytes

Introduction

A remarkable reduction of atmospheric lead deposition has been recorded during the last decades, mainly due to the decrease in using unleaded petrol (Doucet and Carignan 2001). Soils, waters and vegetation absorb heavy metal deposition with respect to acidity of precipitation, altitude, aspect or wind direction (Salemaa *et al.* 2004).

Plant uptake of heavy metals is affected by a complex of interactions between soil properties, e.g. pH, clay and organic matter contents, cation exchange capacity or presence of other cations. The bioavailability of heavy metals from the soil is influenced by many physical, chemical and biological properties and processes (Ernst 1996). According to Baker (1981), there are three basic types of tolerance strategy to heavy metals in plants: (1) indication – the content of metals in the plants reflects their quantity in external environment, (2) exclusion – the uptake and transport of metals is restricted, the metals are immobilized in root system, (3) accumulation – the plants due to specific physiology active concentrate the metals in aerial parts of the plant.

Essential differences in the uptake of heavy metals appear between vascular plants and cryptogams. Vascular plants take up elements mainly via their root system, although the foliar uptake may also be significant (Marschner 1995). Cryptogams (lichens and mosses), however, have no real roots or epidermis, they absorb water and dissolved elements directly across their surface (Salemaa *et al.* 2004). Therefore, bryophytes have often been used as indicators of heavy metal deposition even at regional scale (Rühling *et al.* 1987, Tyler 1990).

Vascular plants have been used as heavy metals bioindicators primarily for the study of horizontal distribution of pollutants in relation to distance from pollution sources, vertical distribution of heavy metal accumulation by plants has been investigated primarily through moss species (Zechmeister 1995, Šoltés 1998, Gerdol and Bragazza 2006), occasionally through epiphytic lichens (Doucet and Carignan 2001), but never through vascular plants. Janiga (2008) studied the lead content in chamois consumption in the subalpine or alpine level of the Tatra Mts. Unfortunately, without determining the consumed plant species. At higher altitudes vascular plants represent an essential nutrition source for herbivorous animals and contaminated vegetation by airborne metals can present a risk factor for this group of animals. Kalas *et al.* (2000) found that small herbivorous species can accumulate significant levels of lead even though consuming relatively low doses.

The following aims are addressed in this paper: (1) determination of lead concentrations in grass species, bryophytes and soils in two altitudinal transects in the Eastern Kyrgyz Tian Shan and (2) relationship between the altitude and lead concentration in vascular plants, bryophytes and soils.

Material and Methods

Study areas

Investigation was carried out at two vertical sections presented in Fig. 1, (a) Nothern Tian Shan, transect Ak-Sai, Ala-Archa National Park, (b) Central Tian Shan, transect Arashan, Issyk-Kul Province. The bedrock of both transects predominantly consists of granitoids and gneiss. Kyrgyzstan

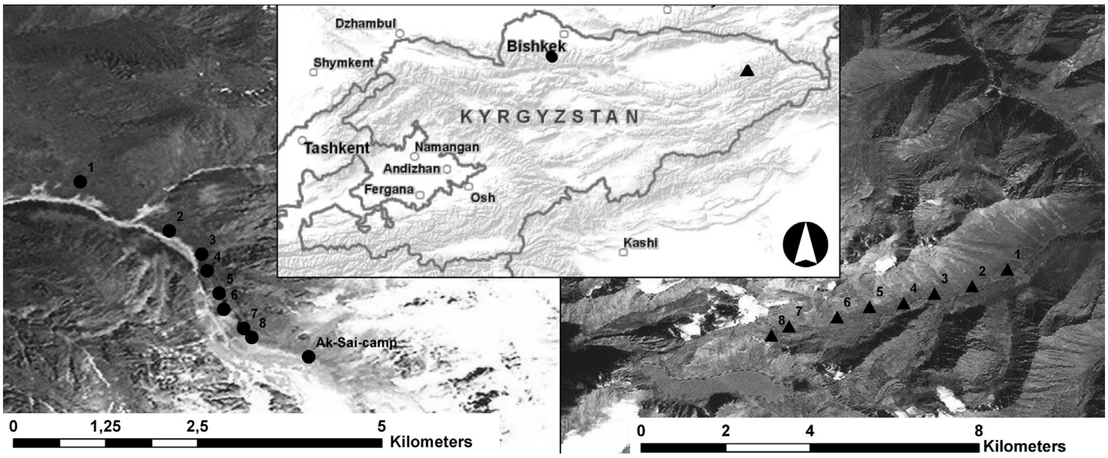

Fig. 1. Kyrgyz Tian Shan mountains: Ak-Sai transect and Arashan transect.

has a continental climate with relatively little rainfall. In the highlands, the temperature varies between -14/-20° C in January to 8-12° C in July. Annual average precipitation varies between 800 to over 1,000 mm per year in mountainous regions. There are heavy snowfalls during winter. The most cloudy weather is in the end of winter and in the beginning of spring. The wind direction frequently changes within a day or night.

Ak-Sai Valley is located about 40 km south of Bishkek. It is a typical glacial, relatively steep valley dominated by grasslands, ascending into Ak-Sai glacier. Arashan valley is situated 10 km east of Karakol. The valley begins with the slightly sloping alluvial land surrounding the Lake Issyk-Kul and then rises steeply through forests and meadows to the timberline at about 3,000 m a.s.l., reaching the altitude 3,400 m a.s.l. at the foot of glaciers descending the north slope of the Terskey Range (Farrington 2005). Ak-Sai Valley is facing west, Arashan Valley is facing north-east. Monitoring of air pollution in Kyrgyzstan is focused on the north part of the country, thus, the data on air pollution for great deal of land is lacking. Moreover, the measurements of heavy metals and other pollutants was disconnected in the early 1990s (United Nations 2009).

According to the data of the Kyrgyz Research Institute of Nature and the Ministry of Ecology, the metal concentrations exceeded the maximum allowed levels for Pb 1.5 - 5.6 times, for Ni 2 - 8 times, for Cu 1.3 - 3 times in the 1990's.

Sampling sites and samples preparation

Soil and plant samples were collected along two altitudinal transects in vertical steps of cca 100 m of altitude between 2,600 – 3,370 m a.s.l., or 3,073 – 3,775 m a.s.l. respectively, in September 2008 (Table 1). Along the transect of Arashan, the grass samples, moss samples, and soil samples were collected at the same altitudes. Along the transect of Ak-Sai, only grass and soil samples were collected, bryophytes were omitted. Selection of plant species was focused on the most wide spread grass and moss species in the study areas. Soil samples were taken from rhizosphere. The samples were placed in the polyethylene bags and dried at room temperature. Debris from root systems and organic matter were removed from soil samples. Soil samples were crushed, sieved (ø 2 mm) and dried at 40° C. Moss samples were gently washed, dried at 40° C and manually homogenized. Each grass sample was divided into two parts, the roots and the shoots. Only root systems with rhizomes were washed with deionized water. Both parts of grasses were dried at 40° C and homogenized separately.

Chemical analysis

Approximately 0,5 g of dried plant material was digested with 4 ml of 65% HNO_3, 1 ml of 35 % H_2O_2 and 2 ml of ultrapure water by using the microwave oven CEM Mars Xpress. After mineralization the solution was diluted to 25 ml with ultrapure water and filtered through an acid-resistant cellulose filter (Whatman 42). Lead contents were determined by electrothermal atomic absorption spectroscopy (ETAAS, AAS Perkin Elmer 1100B). The accuracy of analytical results for lead determination in plant samples was checked by the analysis of the certified reference material BCR 60 (Trace elements in an aquatic plant).

Extractable fraction of lead in soil samples was processed, using acetic acid extraction procedure (Žemberyová *et al.* 2007). 1 g of soil was transferred to an extraction bottle and 40 ml of 0.43 mol.l^{-1} acetic acid was added. The mixture was shaken for 16 h by 300 motions min^{-1} at room temperature. The extracts were immediately filtered through a filter paper Whatman 42 previously rinsed with extractants. Lead concentrations in extracts were measured using ETAAS. The certified reference material BCR 483 (Extractable trace elements in sewage sludge amended soil) was used to validate extraction procedure of soil samples and to evaluate the accuracy and precision of measurement.

The soil samples for total lead content (0.5 g) were decomposed with 10 ml of HNO_3. The reaction vessels were allowed to stand for 16 h at room temperature to allow for slow oxidation of organic matter. The mixtures were gently heated and evaporated on the sand bath (150–160° C) to 1–2 ml. After cooling, 3 ml of $HClO_4$ was added and evaporated to 1–2 ml. After addition of 20 ml of HF, the mixtures were slowly evaporated to dryness. The residues were dissolved by 2 ml of HCl, heated, then 10 ml of deionized water was added and the mixture was heated and filtered. The samples were then filled up to 50 ml with deionized water and filtered through a Whatman 42 filter paper. Lead content was measured by ETAAS. The accuracy of analytical results for total lead content in soil samples was assured by comparison with the certified reference material S-SP No. 12-1-09 Soil Rendzina, produced by the Institute of Radioecology and Applied Nuclear Techniques, Košice, Slovakia.

Statistics

Statistical comparison of lead concentrations between Aksai and Arashan areas were performed by Welch Two sample t-test. Differences between lead concentration in roots and shoots of the sampled plants were analyzed by paired t-test. Data on concentrations were log-transformed and percentage data were square root transformed prior to analysis. Statistical tests were performed using R- statistics.

CANOCO 4.5 for Windows package (Ter Braak and Šmilauer 2002) was used for statistical analysis. Since the length of the first gradient in the log report was < 3, we used the indirect linear method – PCA (Ter Braak and Šmilauer 2002). For ecological interpretation of the ordination axes, altitude was plotted onto PCA ordination diagram as a supplementary environmental variable.

Results

Lead concentrations in plant and soil samples (extractable and total lead content) of two altitudinal sections are presented in Table 1.

Soil lead content

The total soil concentrations of lead varied from 14.6 to 54.8 µg.g^{-1} dry weight in Arashan transect, while in Ak-Sai the lead contents in soils were lower and ranged in between 12.2 and 29.7 µg.g^{-1} dry weight. No remarkable differences were found between the total lead levels in the soil samples collected from the rhizosphere of grasses and from soil substrate of mosses at the same elevations of Arashan transect with exception of locality Arashan 4. In this area, the lead concentration in soils under moss was more than two times higher than in soils collected under grass species.

The extractable lead content in the soil samples did not exceed 2.6 µg.g^{-1} dry weight. The differences between both transects as well as between the soil samples collected from mosses or grasses were insignificant. On the other hand, the relative amounts of soil-extractable lead from the total soil lead concentrations were significantly higher in Ak-Sai than Arashan ($t = 2.65$, df = 4.5, p-value $< 0,05$). Lead in the soils of Arashan was predominantly

Transect	Altitude m a.s.l.	Taxon	Pb in shoots	Pb in roots	Total soil Pb	Soil-extractable Pb	% extractable from total Pb
Ak-Sai							
Ak-Sai 1	2,599	*Poa alpina*	1.59	4.25			
Ak-Sai 2	2,699	*Avenastrum schellianum*	0.84	3.41			
Ak-Sai 3	2,801	*Avenastrum schellianum*	0.81	2.40	22.90	0.50	2.16
Ak-Sai 4	2,900	*Avenastrum schellianum*	1.07	2.60			
Ak-Sai 5	3,000	*Festuca kryloviana*	1.52	2.57			
Ak-Sai 6	3,100	*Festuca kryloviana*	2.69	8.27	17.90	2.53	14.13
Ak-Sai 7	3,234	*Avenastrum schellianum*	2.13	6.66	12.20	1.50	12.33
Ak-Sai 8	3,296	*Poa litwinoviana*	2.56	8.00	21.70	1.31	6.05
Aksai-camp	3,370	*Festuca kryloviana*	1.73	6.06	29.70	2.45	8.26
Arashan grasses							
Arashan 1	3,073	*Unidentified*	1.55	2.96			
Arashan 2	3,173	*Unidentified*	3.77	2.93	24.30	0.47	1.92
Arashan 3	3,271	*Poa litwinoviana*	1.60	6.00	18.10	0.56	3.07
Arashan 4	3,362	*Unidentified*	1.82	1.19	14.60	0.37	2.53
Arashan 5	3,473	*Unidentified*	1.95	6.06	36.50	0.88	2.42
Arashan 6	3,576	*Unidentified*	2.37	5.38	31.20	0.98	3.14
Arashan 7	3,686	*Unidentified*	3.71	11.65	54.80	2.50	4.56
Arashan 8	3,775	*Avenastrum schellianum*	2.64	21.91			
Arashan mosses							
Arashan 1	3,073	*Tortula muralis*	13.18		23.40	0.21	0.91
Arashan 2	3,173	*Tortella fragilis*	12.24		28.20	0.20	0.71
Arashan 3	3,271	*Tortula ruralis*	13.98		18.30	0.46	2.51
Arashan 4	3,362	*Tortella fragilis*	5.55		33.30	0.55	1.64
Arashan 5	3,473	*Tortula muralis*	13.40		34.10	0.95	2.80
Arashan 6	3,576	*Tortella fragilis*	13.22				
Arashan 7	3,686	*Tortella fragilis*	27.82		49.10	1.36	2.76

Table 1. Sampling sites and lead concentrations (µg.g^{-1} dry weight), Ak-Sai and Arashan transects.

fixed in the chemical structure of minerals and so the extractable content of lead in relation to its total concentration was considerably lower, with a maximum of 4.6%.

Lead content in plants

The lead levels in grass roots ranged from 2.4 to 8.3 μg.g^{-1} in Ak-Sai. The range of lead concentrations in roots was broader in the Arashan transect, from 1.2 to 21.9 μg.g^{-1} dry weight. The lead concentration was significantly higher in the roots than in shoots at all sites of Ak-Sai and Arashan (t = -6.57, df = 16, p-value <0.001). Lead concentration in shoots was significantly higher in Arashan transect than in Ak-Sai (t = -2.11, df = 14.8, p-value = 0,05). Higher lead concentrations were recorded in the moss samples, from 5.6 to 27.8 μg.g^{-1} dry weight.

Correlations between lead concentrations and altitude

In both vertical transects some correlations between altitude and lead concentrations (in soils, in plants) were found (Fig. 2, 4, 6). Lead concentrations at sampling sites of Ak-Sai and Arashan (grasses and mosses) transects are depicted in Fig. 3, 5, 7.

PCA data from Ak-Sai reveals significant correlation between extractable lead content in soils and altitude, also between lead concentration in roots and in shoots. Weaker correlation is shown between altitude and the total soil concentration of lead in the Ak-Sai transect (Fig. 2).

The first axis explains 10.3% of the species-environment relation, positively correlates with the total soil lead and explains 87.2% of the variance of sites. The second axis explains 89.7% of the species-environment relation, this axis correlates with altitude, lead content in shoots, soil-extractable lead and with lead in roots. The indirect linear analysis (PCA) ordination diagram of 5 sites shows major correlations in the direction of the second axis, species-environment correlation of 0.78, while in the direction of the first axis, species-environment correlations is 0.099.

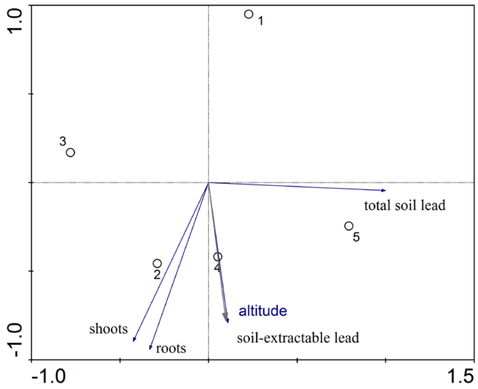

Fig. 2. Ak-Sai transect, principal component analysis PCA, triplot, relationship between lead concentrations and sampling sites, altitude is plotted as supplementary variable. Sites, altitude m a.s.l.: 1 – 2,801, 2 – 3,100, 3 – 3,234, 4 – 3,296, 5 – 3,370. Eigenvalues: 1st axis 0.872, 2nd axis 0.122.

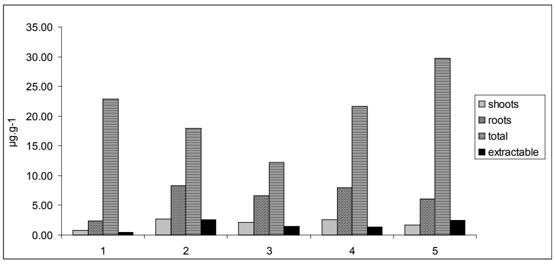

Fig. 3. Lead concentrations of Ak-Sai transect in sampled sites 1 – 5, altitude m a.s.l.: 1 – 2,801, 2 – 3,100, 3 – 3,234, 4 – 3,296, 5 – 3,370.

The principal component analysis of the data of Arashan (soil and grass samples) also showed a significant correlation between extractable lead content in soils and altitude, the correlation between the total soil concentration and altitude is also significant (Fig. 4).

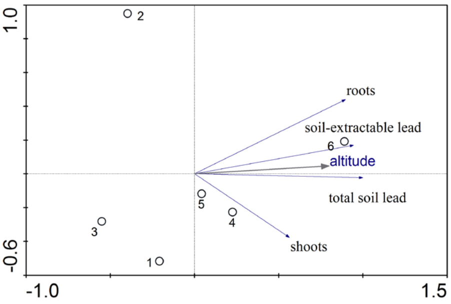

Fig. 4. Arashan transect, grasses, principal component analysis PCA, triplot, relationship between lead concentrations and sampled sites, altitude is plotted as supplementary variable. Sites, altitude m a.s.l.: 1 – 3,173, 2 – 3,271, 3 – 3,362, 4 – 3,473, 5 – 3,576, 6 – 3,686. Eigenvalues: 1st axis 0.985, 2nd axis 0.012.

The first axis shows 99.9% of the species-environment relation, this axis highly positively correlates with altitude, total soil lead, lead in shoots, soil-extractable lead and with lead content in roots. The first axis shows 98.5% of the variance of sites. The second axis explains only 0.01% of the species-environment relationship. The indirect linear analysis (PCA) ordination diagram of 6 sites shows the major correlations in the direction of the first axis, species-environment correlation of 0.797, while in the direction of the second axis, species-environment correlation is 0.046.

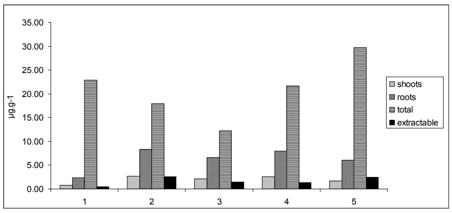

Fig. 5. Lead concentrations of Arashan transect (grasses) in sampled sites 1 – 6, altitude m a.s.l.: 1 – 3,173, 2 – 3,271, 3 – 3,362, 4 – 3,473, 5 – 3,576, 6 – 3,686.

Similarly, the total soil concentration of lead and the extractable lead content in soils under mosses correlate with altitude, but the correlation between the lead content in mosses and altitude is weaker in comparison to the other variables.

The first axis shows 99.8% of the species-environment relation, this axis highly positively correlates with altitude, total lead in soil, lead content in shoots and with soil-extractable lead. The first axis shows 84% of the variance of sites. The second axis explains 0.2% of the species-environment relation and 6% of the site variance. The indirect linear analysis (PCA) ordination diagram of 6 sites shows major correlations in the direction of the first axis, species-environment correlation of 0.866, while in the direction of the second axis, species-environment correlations is 0.082.

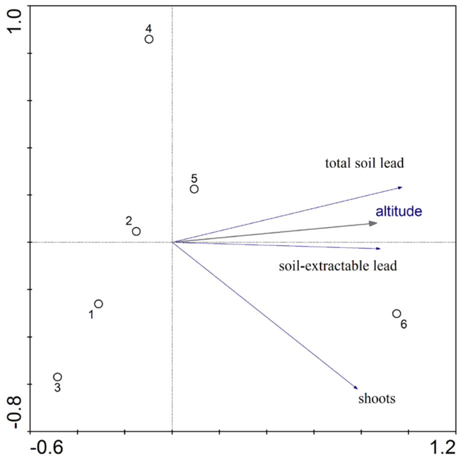

Fig. 6. Arashan moss transect, principal component analysis PCA, triplot, relationship among lead concentrations and sampled sites, altitude is plotted as supplementary variable. Sites, altitude m a.s.l.: 1 – 3,073, 2 – 3,173, 3 – 3,271, 4 – 3,362, 5 – 3,473, 6 – 3,686. Eigenvalues: 1st axis 0.840, 2nd axis 0.160.

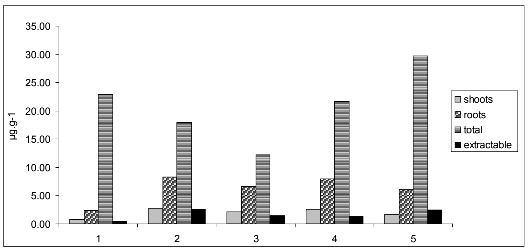

Fig. 7. Lead concentrations of Arashan transect (mosses) in sampled sites 1 – 6, altitude m a.s.l.: 1 – 3,073, 2 – 3,173, 3 – 3,271, 4 – 3,362, 5 – 3,473, 6 – 3,686.

Discussion

Lead levels in soils and plants were investigated in two altitudinal sections of the Kyrgyz Tian Shan mountains. Heavy metals in soils may originate from geological background and may be also of anthropogenic origin. In a mass balance study of lead in soils from southern Germany, Dorr *et al.* (1990) found that virtually all of the anthropogenic lead could be found in the topmost 20 cm of the soil and they concluded that the speed of downward movement of lead was ~ 1 mm/ year. Higher values of total soil lead content in Arashan could be attributed to geological background. In the Earth's crust, lead is found in relatively high concentrations in potassium bearing rock-forming minerals such as K feldspar; in sedimentary rocks, clay minerals arising from weathered K feldspar may also be important (Heinrichs *et al.* 1980). The soil-extractable lead is a potentially mobile form of lead, its relatively low proportion from total soil lead suggests its origin in the geological background of Arashan. On the contrary, in Ak-Sai higher amount of soil-extractable lead were detected, reversibly fixed in the base-exchange complex. Unusual enormous difference between the total lead content in soil under moss and grass samples of locality Arashan 4 could be explained by distinct microhabitat conditions.

Analyses of lead in roots and in shoots of grasses in the majority of the samples correspond with the conclusions of Dahmani-Muller *et al.* (2000) that restriction in the transportation of toxic metals from root to shoot of a plant is often referred to as a strategy for heavy metal tolerance. However distinct differences in transport mechanisms are among plants with distinct affinity to heavy metals. 'Normal' nonhyperaccumulator plants tend to store the absorbed heavy metals in the roots, whereas hyperaccumulator plants transport most of the accumulated heavy metals to the shoots (Lasat *et al.* 1998). It is difficult to explain the high lead content determined in root system of grass sample collected on the highest locality of Arashan transect because question of heavy metal uptake and retention by plants is considerably complex. Although the high lead content may be attributed to long-distance air transfer at high altitudes, this opinion can not be confirmed by soil analyses due to missing samples.

The lead concentrations in grass shoots from Ak-Sai and Arashan are more comparable and depend on various factors. According to Kålås *et al.* (2000), the majority of the lead content comes from atmospheric deposition and the differences in lead content among plant species may be attributed to the surface structure of the plants (e.g. leaf surface), and the variation between the parts of the plants (e.g. leaves vs. twigs) may be put down to the different exposure periods. There is striking seasonal variation in lead concentrations in plant tissues. The frequently recorded concentration decrease during spring is generally referred to as a 'dilution effect' (intensive growth), rather than the loss of the element, because corresponding recordings of absolute amounts of the elements in leaves do not seem to decrease similarly (Jastrow and Koeppe 1980). Towards the autumn changes in plant biomass are normally less pronounced, and differences in metal uptake or translocation, availability or surface contamination may probably contribute more to the observed concentration changes (Brekken and Steinnes 2004).

Heavy metal bioaccumulation in mosses is well-known and depends on cation exchange capacity that is related to the concentration of peptic substances in moss tissue. In the case of terrestrial mosses, the increased heavy metal content is attributed to changes during the process of aging (Siebert *et al.* 1996), but for lead the difference in accumulation between the older and younger parts is not so pronounced than e.g. for cadmium (Brown 1984). In Arashan, due to bioaccumulation capacity the confirmed lead levels in mosses were several times higher than the concentrations in shoots of grass samples collected at the same elevations. Some differences among the results in mosses could be influenced by the specificity of microhabitats, but they primarily reflect atmospheric deposition of lead because mosses receive water and nutrients only by atmospheric deposition. Zechmeister (1995) reported heavy metal concentrations in mosses on five mountain ranges of the Alps and he mostly found comparable or higher levels of lead in moss tissues at altitudes from 1,000 to 2,260 m a.s.l. as we reported from Tian Shan. In the Tatra Mountains, the amount of lead in moss tissues from altitudes 1,050 – 2,050 m a.s.l. (Šoltés 1998) were several times higher than the lead levels in mosses of Tian Shan. Considerably high concentrations of lead in the Tatra Mountains could be connected with air pollution sources in Poland (Markert *et al.* 1996).

The results can be compared to the disposable lead contents of various grass species from alpine and subnival level of The Tatra Mountains (Table 2) collected in October 2006. Amounts of lead were analysed separately in root systems and in shoots, and also total lead contents in soils from rhizosphere of grasses were determined. The average lead concentration in grasses from Tatra Mts was approximately twice higher (for roots it was 13.4 μg.g^{-1} and for shoots 5.4 μg.g^{-1} dry weight) than the average content reported in both transects of Tian Shan (in roots 6.0 μg.g^{-1}, in shoots 2.0 μg.g^{-1} dry weight). Distinct differences were seen especially in the amounts of total lead in soils. The average total soil lead in Tatra Mts reached 115.8 μg.g^{-1}, while in Tian Shan only 25.8 μg.g^{-1} dry weight of soils bearing grasse.

Locality	**Altitude m a.s.l.**	**Pb in shoots**	**Pb in roots**	**Total soil Pb**
Solisko	2,093	3.88	-	164
Solisko	2,093	2.35	4.85	180
Solisko	2,093	2.60	7.95	149
Slavkovský nos	2,239	4.62	-	132
Slavkovský štít	2,395	4.01	10.72	81
Slavkovský štít	2,395	3.06	9.64	132
Slavkovský štít	2,395	3.86	6.03	82
Kriváň	2,428	10.82	22.70	129
Kriváň	2,428	7.92	14.40	80
Kriváň	2,428	7.05	11.80	66
Kriváň	2,428	4.58	10.45	130
Kriváň	2,428	9.39	30.08	82
Kriváň	2,428	5.98	19.13	99

Table 2. Lead concentrations (μg.g^{-1} dry weight) in grass and soil samples of Tatra Mts (Janiga, unpublished).

Similarly, higher average values were found in plants from ridges of The Tatra Mts, The Low Tatras Mts and The Great Fatra Mts, picked up predominantly in autumn months of 1989 and 2005. Plant samples were divided into vegetative and generative parts and separately analysed, the results are presented in Table 3. The average lead concentration of vegetative parts was 5.9 μg.g^{-1}, the lower average content of lead (3.1 μg.g^{-1} dry weight) was reported in generative parts.

The relationship between altitude and heavy metal deposition in mountainous regions is complex and comprises several factors. Generally it is known that there is a strong correlation between orography, the amount of wet deposition and rainfall composition (Fowler *et al.* 1993). Although precipitation generally increases with altitude along transects in small mountainous areas (Zechmeister 1995), the precipitation pattern is usually affected by a complex of factors, especially geographic location and slope aspect (Fliri 1975). Zechmeister (1995) and Šoltés (1998) reported increasing concentrations of trace metals, especially Pb, Cd and Zn with altitude in some forest floor mosses and *Sphagnum* mosses. The precipitation intensity strongly correlates with heavy metal deposition, and seem to be the main source of heavy metal fallout at higher altitudes. This trend was confirmed by Janiga (2008), who found increasing levels of lead and aluminium with altitude in the diet of chamois. However, according to Gerdol and Bragazza (2006), concentrations of lead and cadmium in mature *Hylocomium splendens* tissues peaked at altitudes 1,400 – 1,800 m a.s.l. where the most frequent occurence of cloudy weather was recorded, and so occult deposition by mist-water may account for a significant fraction of the total deposition of anthropogenic trace metals, in close relation to cloudy weather frequency.

Principal component analysis revealed correlations between altitude and lead concentrations in soil samples, in grass and moss tissues. Significant correlations were found between altitude and soil-extractable content of lead. Correlations between altitude and total soil lead were found to be weaker, because in this case geological background is relevant. Extractable lead content in soil is more influenced by anthropogenic sources of heavy metal deposition. Also lead concentrations in roots and in shoots of grasses correlates less strongly with altitude. In the case of moss analyses, more distinct correlation between altitude and lead concentrations were expected, but several other factors might have affected this relationship. Better comprehension of the discovered relationships would require larger data set on precipitation and cloud cover.

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Locality	Altitude m a.s.l.	Taxon	Pb in vegetative part	Pb in generative part
Malino Brdo	1,209	*Rumex crispus*	1.76	1.51
Chopok, Konský Grúň	1,844	Unidentified	17.40	
Chopok, Konský Grúň	1,844	Unidentified	16.55	
Chopok	1,981	*Avenella flexuosa*	29.50	
Chopok	1,981	*Avenella flexuosa*	10.20	
Téryho chata	1,997	*Carex lachenalii*	7.32	4.15
Téryho chata	1,997	*Poa annua*	2.21	2.15
Téryho chata	1,997	*Cerastium fontanum*	2.60	1.69
Téryho chata	1,997	*Poa annua*	0.88	0.17
Téryho chata	1,997	*Festuca supina*	2.36	2.47
Téryho chata	1,997	*Festuca supina*	4.87	3.46
Téryho chata	1,997	*Bistorta vivipara*	5.71	0.85
Téryho chata	1,997	*Campanula alpina*	2.40	3.08
Téryho chata	1,997	*Alchemilla sp.*	3.02	5.58
Sedlo Hlúpy-Jatky	2,000	*Bistorta vivipara*	1.21	<LOD=0.95
Sedlo Hlúpy-Jatky	2,000	*Carex firma*		2.97
Poľský hrebeň	2,156	*Oreochloa disticha*		1.59
Poľský hrebeň	2,156	*Festuca supina*	2.07	<LOD=0.90
Jahňací šyít	2,166	*Agrostis rupestris*	4.27	4.29
Javorový štít	2,362	*Festuca supina*	1.37	1.22
Javorový štít	2,362	*Carex sempervirens*	2.54	3.73
Kriváň	2,428	*Agrostis rupestris*	4.86	7.83
Kriváň	2,428	*Agrostis rupestris*	4.84	11.30
Rysy	2,450	*Poa alpina*	2.75	2.68

Table 3. Lead concentrations (μg.g^{-1} dry weight) in vegetative and generative parts of plants from ridges of Slovak mountains, LOD – limit of detection (Janiga, unpublished).

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