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INFLUENCE OF THE DUMP SITES ON DEVELOPMENT OF SELECTED PLANTS IN THE ĽUBIETOVÁ AREA (SLOVAKIA)

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Abstract: Natural installation and development of plant species such as *Pinus sylvestris, Betula pendula, Quercus petrea, Salix fragilis, Mentha longifolia, Acetosella vulgaris, Juncus articulatus* can be observed at the old mine waste dumps in the Ľubietová – Podlipa (Zelená Dolina Valley, Slovakia) area, specific to the local chemical conditions such as low content of essential nutrients and high content of heavy metals (Fe, Cu, As, Sb, Cd and others). Content of heavy metals and landscape features of the dump material are not appropriate for the vegetation development. The individual parts of the plant tissues (roots, twigs/stems, leafs/needles, flowers/fruits) are contaminated by heavy metals and tissues are damaged differently, respectively.

Keywords: mine waste dumps, heavy metals, contamination of plant tissues

1. INTRODUCTION

First written evidence about mining activity in the Ľubietová area came from the Anjou monarchy time in 1340 (Koděra et al. 1990). Ľubietová deposit was historically important by mining of copper ores. Gold was obtained in small amount as well. The biggest boom of mining activity was in fifteenth and sixteenth century and lasted almost for 200 years. This period ended by Turkish invasions in 1571 – 1588. In eighteen century, iron became the main component of mining production.

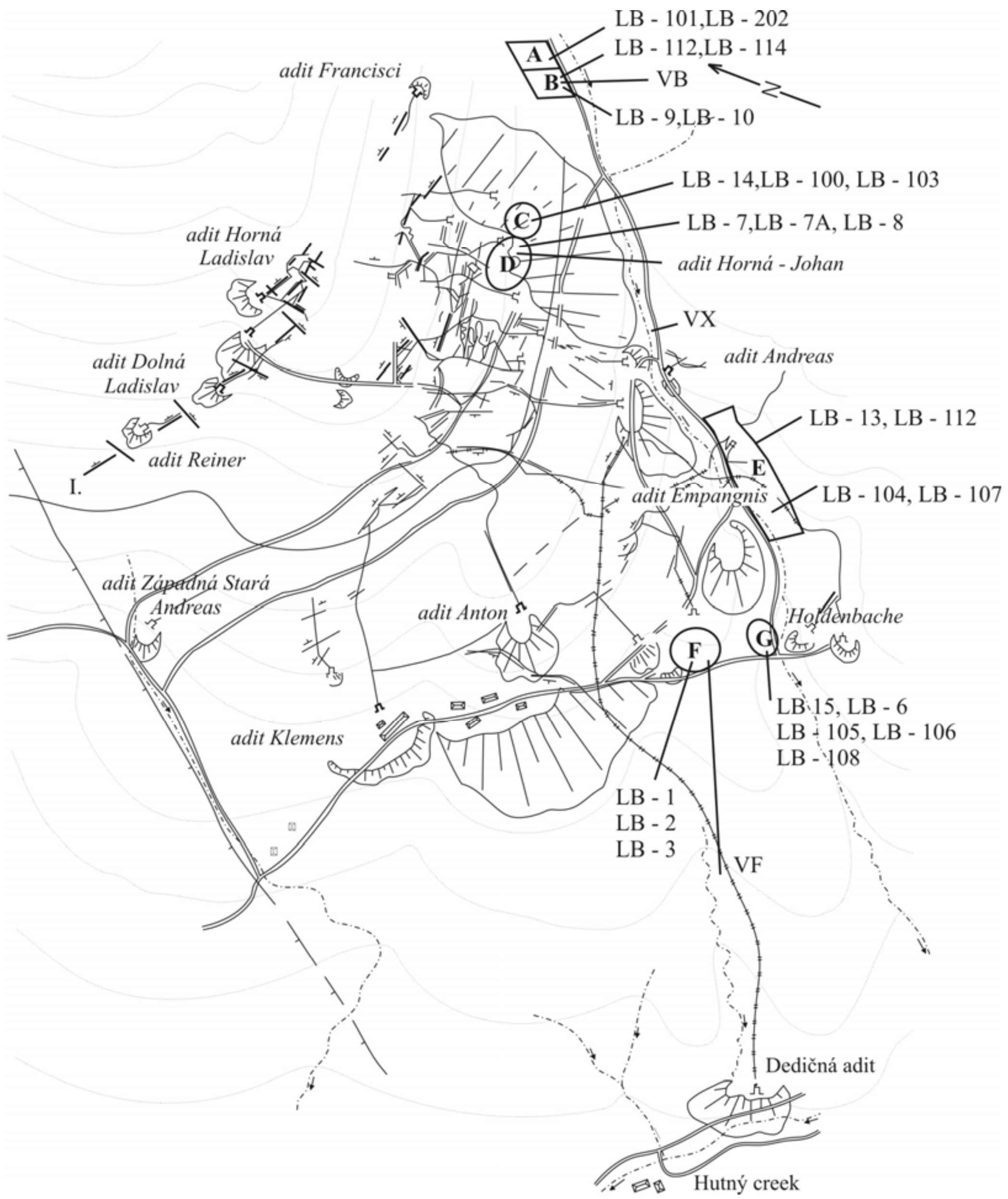

Fig. 1 Localization and sampling points of the studied plant samples from the dump field Podlipa.

The revival of mining activity was in 1810 and the attenuation in 1863. In 1860 – 1870 decline of the European copper mining activity due to competition of oversea ore deposits caused the stopping of mining activity in the Ľubietová area for more than 100 years and mining dumps were interesting only for researchers and mineral collectors (Ilavský et al. 1994).

Hydrothermal ore mineralization is evolved at 3 deposits: Podlipa in the east border of village, Svätodušná and Kolba in closure of the Peklo Valley, 5 km east of village where cobalt, silver and nickel are observed besides iron and copper.

The most important Podlipa deposit is situated 1 km east of village center, at the south slope of the Vysoká spot height (995.5 m), above Zelená Dolina Valley (Fig. 1). It is situated in the Ľubietová crystalline complex of Permian age which consists of greywackes, arcose schists and conglomerates (Koděra et al. 1990). The deposit was exploited by 18 adits from 570 to 700 m (Fig. 1), from the bottom adit Empfängnis to the top adit Francisci (Bergfest 1951). Copper content in manually graded ore was about 4 – 10 wt. %. Copper content in dump waste material was 0.9 – 2.4 wt % (Koděra et al. 1990; Hvožďara 1971).

Heavy metals can reach plants from the soils due to their higher content in the base rocks or from the sources of different anthropogenic activities. Heavy metals from the air pollutants can reach plants through pores/water or soil solution (Ross et al. 1999). Their penetration influences soil-ecological conditions such as soil types, soil pH, concentrations and bonds of heavy metals, humus content in soil, oxidative-reductive conditions around root system connecting with microbial decomposition of inorganic and organic substances, soil moisture, temperature, utilized fertilizes and preparations for the plant protection (Ďurža 2003).

Natural installation of mine waste dumps by plants is inhibited due to fine-grained soil flushing from the slopes and fast draining of rain water from the surface into the basal level of dumps or into the impermeable sub-soil by soil-forming substratum. Therefore only several large mine waste dumps provide the possibility to enroot to resistant plants in depressions or at local plains after centuries.

Many authors have devoted to the study of plant contamination at the mine waste dumps in recent years (Cheng and Zhao 2005; Damian and Damian 2006; Szabados 2006; Petrescu and Bilal 2006, and others). Mine waste dumps with higher content of heavy metals have specific vegetation. The influence of substratum with higher content of heavy metals is demonstrated by strong selective pressure to vegetation. Small group of plants has been selected during many years. This group is able to exist under the specific phytotoxic conditions. Unique plant communities which are not possible to find at different dump have originated (Banásová 1996; Ďurža and Khun 2002).

2. MATERIAL AND METHODS

The samples of sediments from the dumps and soils, surface water (stream water, drainage water, and water from wetland) were collected for the characterization of components of landscape contamination. Following reference sites were selected for comparison of territories loaded by heavy metals and non-contaminated natural environment: planes A and B (Fig. 1) are situated outside of geochemical anomalies of heavy metals and represent graywakes of Permian age) similar to material at the dump field. The samples of plant material were collected from the contaminated planes C, D, E, F (Fig. 1). Planes C and D are situated on the terrace of the highest dump, plane G is below the dump of the Empfängnis adit and plane E is the wetland below the dump-field.

The realization of the plant sampling was difficult at the contaminated planes C and D due to missing vegetation cover. Vegetation creates small isles and is enrooted in few depressions which have enabled limited soil-forming process. The selection of plant species was performed so that it could be possible to compare all identical plant species from the contaminated planes with plants from the reference sites. The samples of hardwood species (*Betula pendula, Quercus petrea*), coniferous species (*Pinus sylvestris, Abies alba*) and herbs (*Juncus articulatus, Menta longifolia*) were studied. The samples of *Acetosella vulgaris* were collected at the contaminated planes.

The samples of sediments from the dumps and soils were dried and after pre-analytical treatment were analyzed by ICP/MS analysis in the ACME Analytical Laboratories (Vancouver, Canada). Plant samples were divided into roots, twigs/stems, leafs/needles and flowers/fruits. The contamination of live and dead parts was compared in several plants. Plants were analyzed in the same laboratory as sediments.

The water samples were analyzed in the National Water Reference Laboratory for Slovakia at the Water Research Institute in Bratislava. Microscopical analyses of plant tissues were realized in the laboratories of the Faculty of Wood Sciences and Technology of the Technical University in Zvolen.

3. RESULTS

3.1. Sediments and drainage water contamination by heavy metals

Table 1 shows the contamination of sediments by heavy metals at the individual planes of sampling.

Tab. 1 Ľubietová, analyses of the dump field sediments

Sample	Fe	Cu	Zn	Pb	Ag	Cd	Ni	Co	As	Sb
	%	ppm								
A	1.38	25	39	16.1	0.1	0.1	8.5	5.1	7	10.4
B	1.12	390	36	13.6	0.3	0.1	7.8	7.1	32	17.5
C	2.58	541	20	24.1	1.6	0.1	31.6	53.6	294	39.2
D	2.14	1977	23	7.9	0.3	0.1	17.1	36.2	34	15.6
E	2.25	6766	19	17.7	0.7	<1	25.8	34.9	153	26.4
F	1.61	1388	29	16.2	0.6	0.3	16.6	15.1	85	17.7

Explanations: Sampling points are localized in the Fig. 1

Table presents concentrations of Fe, Cu, Zn, Pb, Ag, Cd, Ni, Co, As and Sb in the sediments from the reference sites A and B and contaminated planes C – F. Soil from the reference site B contains surprisingly the highest Zn concentrations. It is probably related with the considerable Zn mobility and its flushing from the dump material. Sediments from the dump plant C contain the highest concentrations of Fe, Pb, Ag, Ni, Co, As and Sb. Plant D shows the highest Cu and Co concentrations. Sediment from the wetland (plane E) contains mostly Cu (6766 ppm). Sediment from the plane F is mostly contaminated by Cd and Zn.

Water sample VX from the Zelená Dolina Valley below mine waste dumps has the lowest pH from the collected surface water (tab. 2). This sample has the highest concentrations of Fe, Cd and Co. Sample VF has pH 6.7 and the highest concentrations of Cu (810 µg/ml), Zn (30 µg/ml), Ag (2 µg/ml), Ni (8 µg/ml) and Sb (0.2 µg/ml). The comparison of water from the reference plane with other water samples shows its gradual saturation by heavy metals from the dump material. Concentrations of heavy metals culminate in the wetland where it is assumed partial precipitation of metals.

Table 2 Ľubietová, spectrochemical analyses of the surface and drainage water

Sample	Fe	Cu	Zn	Pb	Ag	Cd	Ni	Co	As	Sb
	µg/ml									
VB	260.0	20	0	0	0.4	0.3	4.0	0	0.01	0.0
VX	320.2	35	4.8	0.1	1.1	0.5	5.2	2.8	0.01	0.1
VF	160.3	810	30.0	0	2.0	0.5	8.0	7	0.01	0.2

Explanations: Sampling points are localized in the Fig. 1

3.2. Plant tissues contamination by heavy metals

The knowledge of content of heavy metals in plants is important from the point of foot cycle contamination. The intensity of plant contamination by heavy metals is necessary to critize depending up plant species.

Leafs are the most contaminated part of *Menta longifolia* in case of all observed heavy metals at the dump field and reference site (tabs 3 and 4). As and Sb analysis shows higher contamination of flowers where As content is 1.44 ppm and Sb content is 2.07 ppm. Similarly, the highest concentrations of heavy metals were determined in leafs of *Acetosella vulgaris* from the valley below the dump field besides As and Sb (tab. 3).

Plant roots are the most contaminated part of *Juncus articulatus* from the dump field besides Cu and Sb (tab. 3). The highest concentrations of Fe, Cu, Cd, Ni, As and Sb were determined in the plant tissues from the reference site in root system (tab. 4).

Concentrations of Zn, Pb, Ag and Co are the highest in leafs and stems. *Quercus petrea* shows important contamination by heavy metals in roots at the dump field (tab. 3). The exception is moderate As increase (0.77 and 0.64 vs. 0.50 ppm) in its leafs and twigs.

Contamination of *Salix fragilis* from the wetland below the dump field is significant in leafs (tab. 3). Cu, Co, As and Sb are concentrated in roots. The highest Ag concentrations are in twigs. Leafs of *Betula pendula* from the dump field are the most contaminated part (tab. 3). Exception is the preferential contamination of Pb, As and Sb in roots. *Pinus sylvestris* from the dump field and reference plane tents to preferential contamination of leafs (tabs. 3 and 4). Higher contamination by heavy metals (Fe, Cu, Co, As and Sb) in other plant parts is mostly weak increase of their concentrations compared with concentrations in leafs, e.g. Cu concentrations 8 vs.7, As concentrations 0.16 vs. 0.13, Co concentrations 2 vs. 1.3 ppm in plant from the reference site.

Tab. 3 Analyses of the plant tissues from the dump field Ľubietová – Podlipa

Plant	Sample	Part	Fe	Cu	Zn	Pb	Ag	Cd	Ni	Co	As	Sb
			ppm									
Betula pendula	LB-7	A	92	7	17	24	0	0.08	6	1	2.14	2.90
		b	158	7	17	19	3	0.04	4	1	1.50	0.30
		b_2	309	9	7	76	17	0.15	11	7	0.50	0.10
		c	380	25	35	4	8	0.08	1	3	1.29	0.14
Quercus petrea	LB-100	a	275	9	59	57	40	0.10	12	4	0.50	0.25
		b	204	0	42	5	2	0.10	5	1	0.64	0.09
		c	85	8	10	29	30	0.06	4	1	0.77	0.11
		d	210	7	15	17	0	0.05	3	1	0.37	0.07
Pinus sylvestris	LB-103	a	17	2	15	15	1	0.03	3	2	0.42	0.50
		b	15	3	16	32	3	0.03	3	1	0.56	0.13
		b_2	143	0	17	21	0	0.03	2	1	0.62	0.11
		c	149	60	44	38	8	0.10	5	3	0.15	0.04
		d	95	7	13	15	0	0.03	3	2	0.41	0.10
Picea abies	LB-14	a	222	8	32	39	0	0.07	6	6	3.14	0.53
		b	158	12	16	2	1	0.04	9	1	0.59	0.12
		b_2	-	-	-	-	-	-	-	-	0.19	0.12
		c	134	10	15	2	1	0.03	9	1	0.85	0.19
Abies alba	LB-8	a	125	11	22	15	3	0.06	6	1	0.49	0.96
		b	222	8	28	16	1	0.05	5	2	1.34	0.34
		c	73	9	9	32	21	0.04	5	2	2.24	1.14
Juncus articu-latus	LB-1	a	358	37	85	51	225	0.20	10	9	19.7	1.52
		b	209	70	33	38	5	0.10	5	3	1.40	1.67
		c	208	68	32	36	4	0.10	5	3	1.28	1.60
		d	-	-	-	-	-	-	-	-	3.64	0.44
Menta longifolia	LB-112	a	246	10	23	16	0	0.06	5	1	0.57	0.21
		b	89	14	13	11	0	0.04	2	1	0.05	0.08
		c	594	173	38	41	2	0.10	8	3	0.76	0.26
		d	-	-	-	-	-	-	-	-	1.44	2.07
Salix fragilis	LB-2	a	416	63	84	6	0	0.20	13	10	2.84	0.21
		b	131	0	1	6	5	0.05	4	1	0.26	0.15
		c	566	0	74	99	1	0.20	21	6	0.52	0.11
Aceto-sella vulgaris	LB-13	a	184	133	22	5	0	0.06	9	6	17.31	3.46
		b	177	73	31	23	7	0.08	12	8	13.08	3.30
		c	701	47	186	135	0	0.42	36	26	12.97	3.27

Explanations: a - root; b - live twig and stem; b_2 - dead twig; c – leafs and needles; d - flowers, doughnuts and fruits

Tab. 4 Analyses of the plant tissues from the reference site Ľubietová – Podlipa

Plant	Sample	Part	Fe	Cu	Zn	Pb	Ag	Cd	Ni	Co	As	Sb
			ppm									
Betula pendula	LB-10	a	192	2	27	19	0	0.06	5	2	0.31	0.2
		b	108	4	17	15	1	0.02	3	8	0.12	0.27
		b_2	109	6	41	76	2	0.12	2	7	0.20	0.05
		c	209	7	26	3	5	0.07	5	2	0.14	0.04
Quercus petrea	LB-9	a	174	4	32	31	0	0.06	8	2	0.35	0.19
		b	67	0	25	2	0	0.04	3	2	0.06	0.04
		b_2	159	3	36	30	0	0.06	4	1	0.63	0.07
		c	123	3	28	22	0	0.03	3	1	0.16	0.09
Pinus sylvestris	LB-101	a	111	8	10	11	0	0.02	2	2	0.16	0.51
		b	84	0	13	11	1	0.02	2	0	0.04	0.03
		c	137	7	23	17	0	0.06	5	1	0.13	0.06
Picea abies	LB-202	a	122	5	22	29	0	0.05	4	4	0.33	0.52
		b	95	8	10	1	1	0.60	7	5	0.07	0.06
		c	91	7	10	1	0	0.52	7	4	0.17	0.08
		d	84	2	9	1	1	0.02	8	1	0.57	0.16
Abies alba	LB-113	a	98	3	20	10	1	0.04	5	1	0.39	1.2
		b	113	5	20	12	1	0.04	4	1	0.07	0.03
		c	42	3	17	22	4	0.03	5	1	0.15	0.11
Juncus articu-latus	LB-114	a	200	34	40	4	0	0.08	5	1	0.59	0.18
		b	103	9	43	15	1	0.05	3	1	0.16	0.07
		c	100	8	38	15	0	0.03	3	1	0.17	0.05
		d	-	-	-	-	-	-	-	-	0.31	0.06
Menta longi-folia	LB-112	a	195	80	21	13	0	0.04	3	1	0.45	0.17
		b	66	11	9	10	0	0.03	2	1	0.04	0.05
		c	492	123	18	28	2	0.09	6	2	0.56	0.16
		d	-	-	-	-	-	-	-	-	1.44	1.98

Explanations: a - root; b - live twig and stem; b_2 - dead twig; c – leafs and needles; d - flowers, doughnuts and fruits.

The comparison of additive concentrations of heavy metals in individual types of plant tissues (roots, twigs/stems and leafs/needles) was realized to obtain more complex contamination model of the plant tissues. The comparison was performed with the following wood species and herbs: *Betula pendula, Quercus petrea, Picea abies, Abies alba, Juncus articulatus, Menta longifolia*. It was possible to collect their samples from the dump field and reference site, respectively. The study showed (Fig. 2) that the highest concentrations of Fe, Pb, As, Sb, Zn and Ag were determined in root system. Cu contaminates leafs and needles in preference. Fe probably enters leafs and needles up to certain concentration level in preference. When this concentration level is exceeded, Fe accumulates in root system after it can not enter leafs and needles.

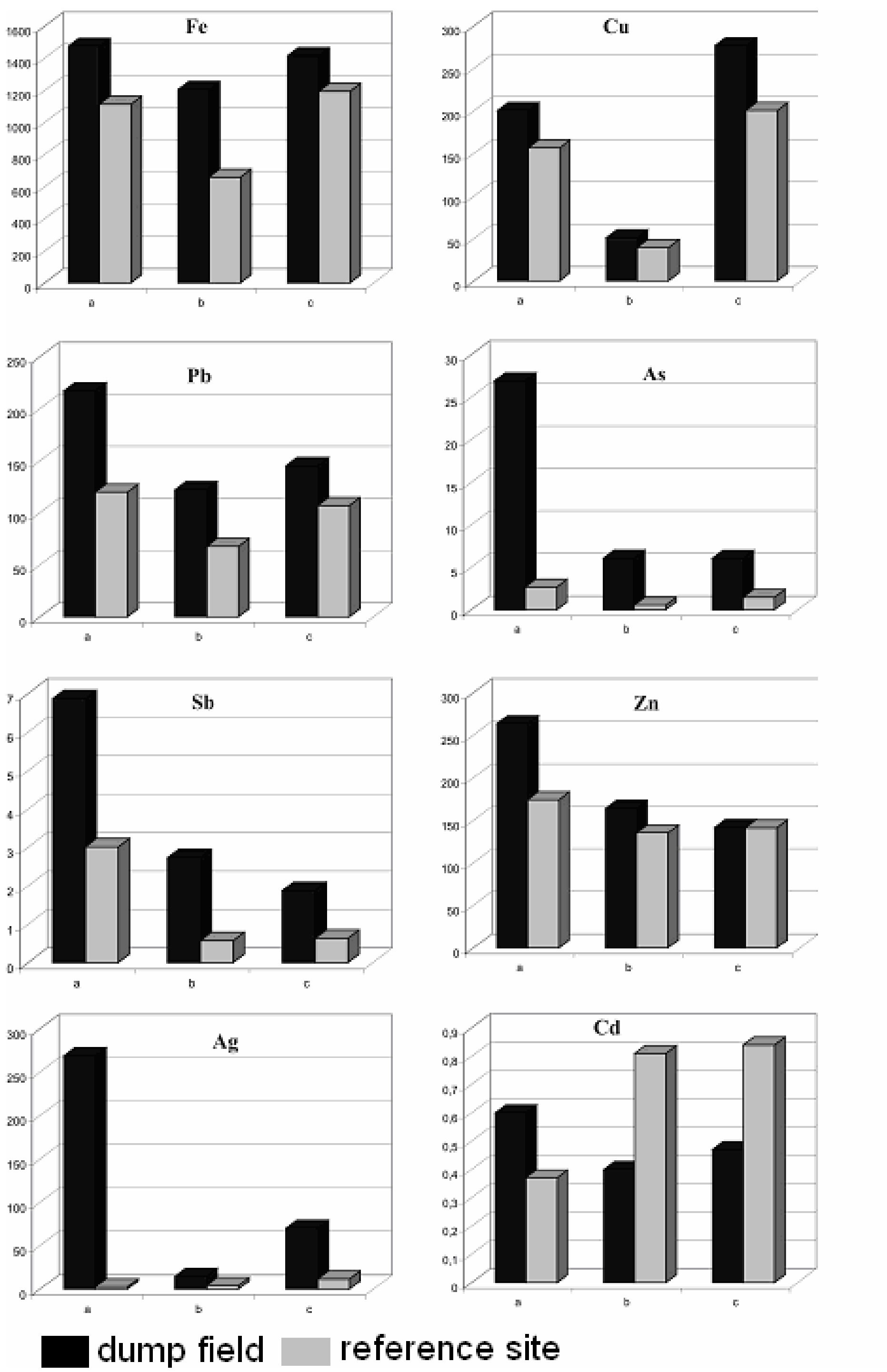

Fig. 2. Histograms of additive concentrations of heavy metals in a - roots, b - twigs/stems, c - leafs/needles of plants from the dump-field and reference site.

The contamination of plant tissues of live and dead twigs was compared in several plants from the dump field (*Betula pendula, Pinus sylvestris, Picea abies*) and reference site (*Betula pendula, Quercus petrea*) (tabs. 3 and 4). *Betula pendula* from the dump field (tab. 3) showed higher As and Sb concentrations in live twig. Higher concentrations of Fe, Cu, Zn, Pb, Ag, Cd, Ni and Co were determined in dead twig. *Pinus sylvestris* (tab. 3) showed higher concentrations of Fe, Cu, Pb, Ag, (Cd), Ni, Co and Sb in live twig and higher concentrations of Zn, (Cd), As in dead twig. As and Sb concentrations were possible to compare in *Picea abies* (tab. 3). Higher As concentrations were in live twig (0.59 vs. 0.19 ppm). Sb concentrations were equal in live and dead twig (0.12 ppm). *Betula pendula* from the reference site (tab. 4) showed higher concentrations of Ni, Co and Sb in live twig. Increased concentrations of Fe, Cu, Zn, Pb, Ag, Cd, Co and As were in dead twig. *Quercus petrea* (tab. 4) showed higher Co concentrations in live twig and higher concentrations of Fe, Cu, Zn, Pb, Ag, Cd, Ni, Co, As and Sb in dead twig.

3.3. Plant tissues

Plants at the mine waste dumps have lack of organic nutrients and moisture besides higher concentrations of heavy metals. They mainly populate depressions or weathered parts of the dumps. Permanent plants prevail at the old mine waste dumps. Annual and biennial plants are rare.

Year shoots in live twig of *Pinus sylvestris* from the dump field are narrow (Fig. 3). Anomalous thin-walled tracheides (weak summer wood) were determined in several year shoots from years 1994 - 1999 (Fig. 4).

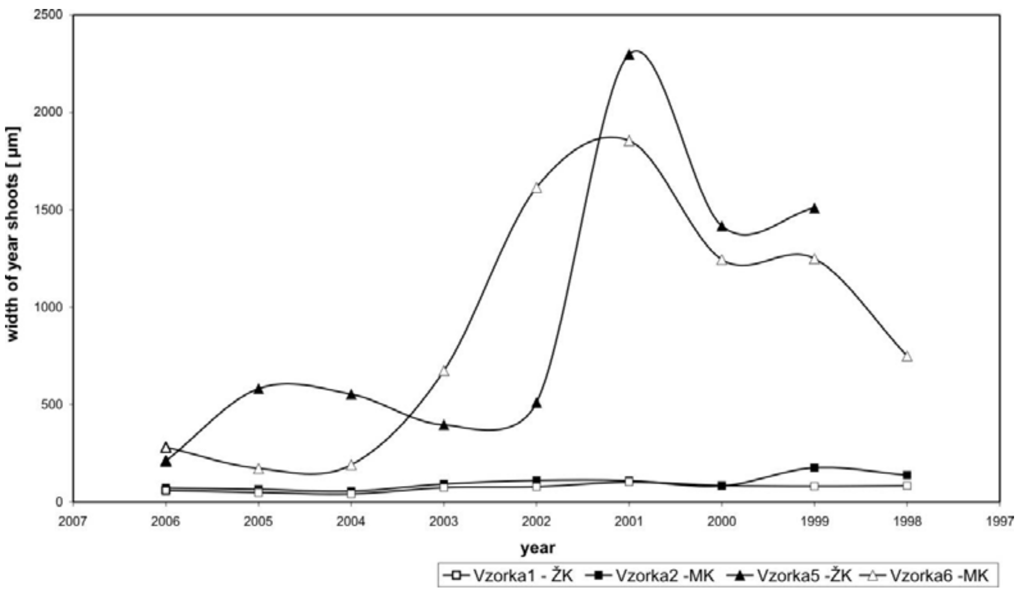

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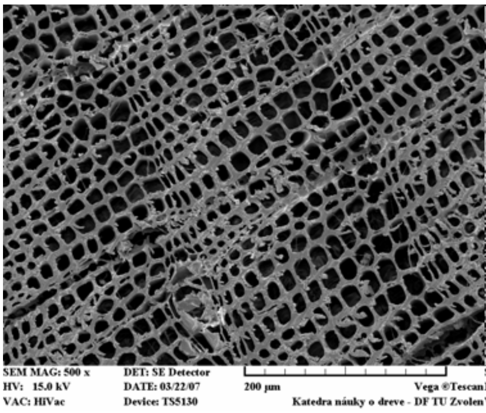
Fig. 3 Comparison of the current year shoots in analyzed samples of *Pinus sylvestris*. Sample LB-103 from the dump field: 1 - live twig, 2 – dead twig; sample LB-101 from the reference site: 3 – live twig, 4 – dead twig.



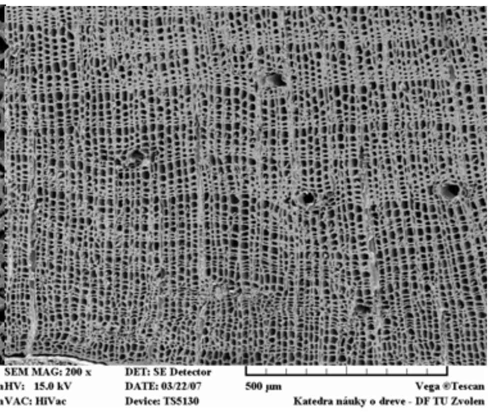
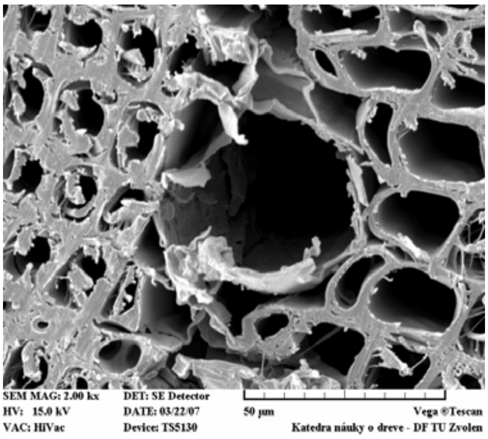


Fig. 4 Formation of tight current year shoots with anomalous thin-walled tracheides in live twig of *Pinus sylvestris* from the dump field.
Fig. 5. Formation of tight current year shoots in dead twig of *Pinus sylvestris* from the dump field.

It shows that secondary coarsening of cell-wall did not pass off and bond between secondary cell-walls of tracheides of reaction wood weakened. Lack of moisture (mostly in summer) is probably the main reason of this state besides contamination of tissues by heavy metals. It is probably the reason of insufficient soil-forming at the dumps or lack of rainfall (?) as well. Formation of pressure reaction wood was determined in tissues from years 1995 – 2007.



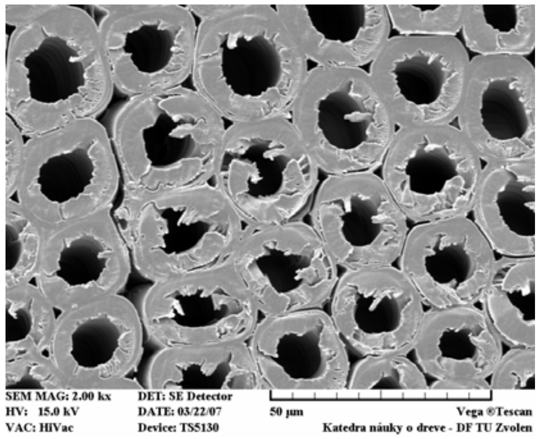


Fig. 6 Dead twig of *Pinus sylvestris* from the dump field: formation of numerous resin canals near by calluses.
Fig. 7 Regular tracheides in live twig of *Pinus sylvestris* from the reference site.

Formation of very narrow year shoots has been observed in dead twig of *Pinus sylvestris* from the dump field over the last 13 years (Fig. 5). Occurrence of numerous calluses with near formation of numerous resin canals was confirmed (Fig. 6). Cell-wall coarsening of the summer tracheides is completely missing in the last year shoots.

Tracheides of reaction wood in live twig from the reference site are relatively regular (Fig. 7). Exfoliation of secondary cell-wall of summer tracheides is possible to observe in the cross-section (Fig. 8). This trend weakened in years 1999 – 2000. Marks of weaken cohesion of secondary cell-wall and its exfoliation (Fig. 9), extreme narrow year shoots are possible to observe in the cross-section of dead twig.

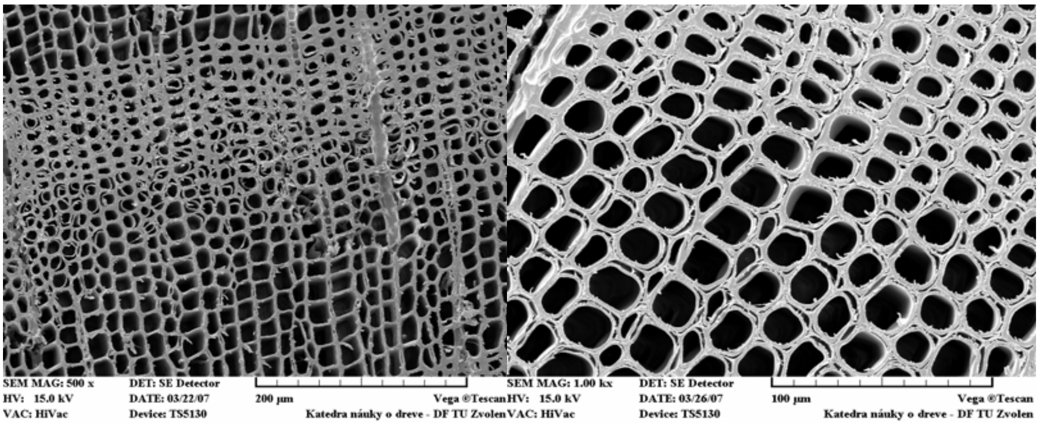


Fig. 8 Exfoliation of secondary cell-wall of summer tracheides in live twig of *Pinus sylvestris* from the reference site.

Fig. 9 Dead twig of *Pinus sylvestris* from the reference site: weakening of cohesion of secondary cell-wall and its exfoliation.

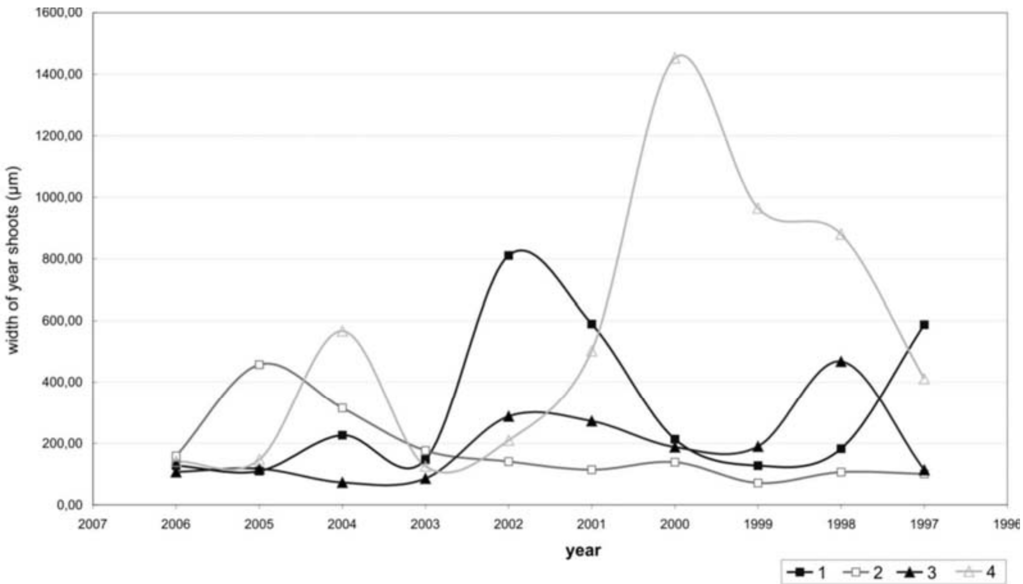
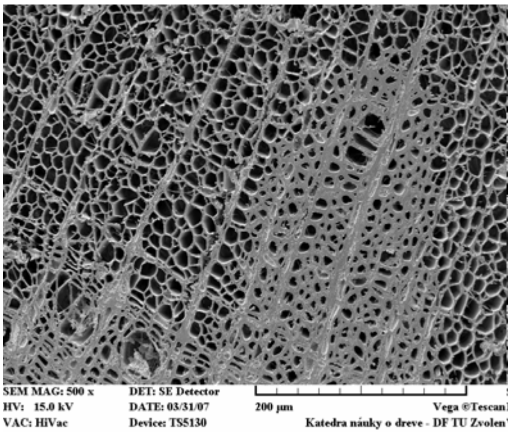


Fig. 10 Comparison of the current year shoots in analyzed samples of *Betula pendula*. Sample LB-7 from the dump-field: 1 - live twig, 2 – dead twig; sample LB-10 from the reference site: 3 – live twig, 4 – dead twig.

Fig. 10 shows comparison of width of year shoots from the analyzed samples of *Betula pendula* from the dump field and reference site. The width of year shoots is narrower in sample from the dump field. It suggests more stressful conditions for vegetation at the dump field.



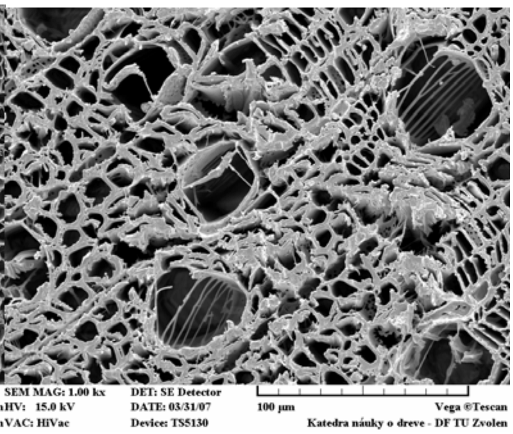
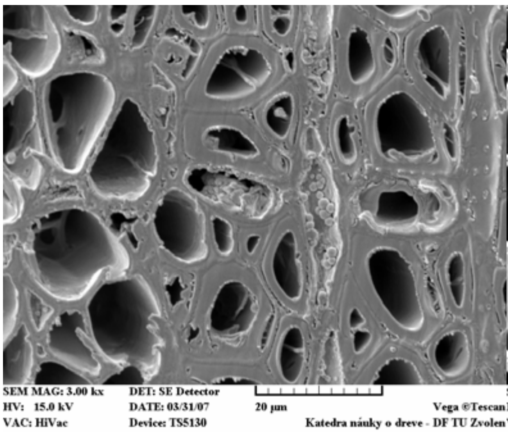


Fig. 11 Live twig of *Betula pendula* from the dump field: zonal occurrence of thick-walled and thin-walled libro-shaped fibres.
Fig. 12 Live twig of *Betula pendula* from the dump field: hyphae and ladder perforation in vessel.

The zonal occurrence of thick-walled and thin-walled libro-shaped fibres and hyphae in vessels is possible to observe in the cross-section of live twig of *Betula pendula* from the dump field by detail enlargement (Fig. 11).



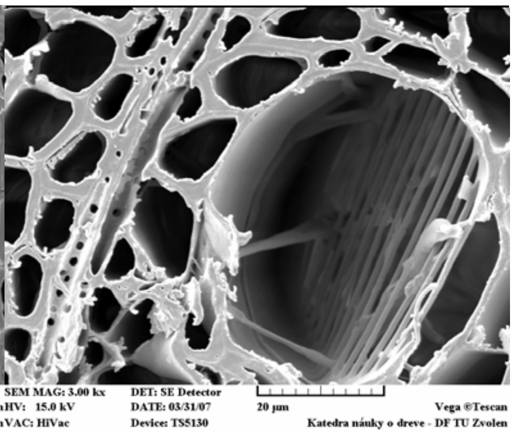


Fig. 13 Live twig of *Betula pendula* from the dump field: irregular width of year shoots.
Fig. 14 Live twig of *Betula pendula* from the reference site: enzymatic decomposabled membranes of thinned parenchyma of medullary ray.

Figure 12 shows the occurrence of stock substances in parenchyma of medullary wood, hyphae and ladder perforation in the vessel without coating. Sample of dead twig shows more abundant occurrence of vessels without coating with typical ladder perforation. Membranes of axial parenchyma and parenchyma of medullary ray are enzymatic decomposabled and parenchyma of medullary ray is without stock substances.

Irregular width of year shoots (Fig. 13) and preferential setting of vessels into radial groups is possible to observe in the cross-section of live twig from the reference site. Membranes of thinned parenchyma of medullary ray were enzymatic decomposabled (Fig. 14).

4. DISCUSSION

Changes of pH and oxidative-reductive potential affect the release and precipitation of heavy metals. It causes the heavy metals transfer into the bottom sediments, solution or soil/rock environment. Bowen (1979) states that Ag, As, Cd, Cu, Pb, Sb and Zn metals have the tendency to accumulate in the upper soil horizon due to vegetation recycling, atmospheric deposition and adsorption by organic mass. Fe, Co and Ni metals usually accumulate in higher concentrations in dislocated clay minerals and autigene sesqui-oxides in lower horizon of the soil profile enriched in clay and oxyhydroxide components.

Plant contamination by Fe causes the atrophy of plant tops and the root coarsening (Cannon 1960). It has been observed by *Picea abies* where the deformation of tree tops and the formation of „stork nests" has been occurred.

Plant contamination by Cu causes the formation of dead stains on lower leafs at steam, purple and violet stem colouring (*Acetosella vulgaris*), atrophy of the root system and leaf chlorosis with green veining.

Cannon (1960) states that the flora loading by Zn causes the abundant occurrence of plants with leaf chlorosis with green veining (*Picea abies, Betula pendula*), dead stains on leaf-tips (*Acetosella vulgaris*) and rudimentary root system (*Picea abies*). Plant loading by Ni and Co causes the formation of white stains (Cannon 1960). White stains were described by *Salix fragilis*.

Plants receive Cd mostly by roots (Haghiri 1973; Hovmand 1983) in Cd^{2+} form (Greger and Lindberg 1986) by diffusion due to metal chelatation by organic acids secreted by plant root system (Mullis and Sommers 1986). Hagrini (1973) states that the highest Cd contents are in roots, lower in leafs and then in stems and fruits. The lowest Cd contents are in seeds. Our research of plant tissues from the dump field and reference site confirmed these statements.

Higher Cd contents cause several diseases such as leaf chlorosis (Page et al. 1972), root darkening (Imai and Siegel 1973) and formation of violet-brown stains on leafs (Weigel and Jáger 1980) which is probably caused by metabolism change of phenols (Barceló et al. 1986). Diseases have been observed at the studied locality by *Picea abies* (needle chlorosis), *Quercus petrea* (root darkening), *Acetosella vulgaris* (formation of violet-brown stains on leafs). Shedding of leafs and needles is present frequently as well. Lack of Cd causes increase of biomass formation. High Cd content causes unproportional growth of leafs and roots, cell extension and stagnation of cell division (Fuhrer 1983). For instance, needle length is ultra small by *Pinus sylvestris* (only 2 cm) at the mine waste dumps in Podlipa.

Pitter states (1990) that in neutral and alkaline area which is typical in Ľubietová, the following complexes can form in higher concentrations: $[Pb(CO_3)_2]^{2-}$, $[Pb(OH)_2(aq)]^0$ and $[PbOH]^+$. Pb shows the affinity to form complexes with insoluble humic substances. It causes Pb fixation in upper humus layer (Beneš and Pabianová 1987). Extracellular uptake based on ion exchange and complex formation with ligands of cell-wall predominates in Pb uptake by organisms (Lane and Martin 1977). Pb accumulates mostly in roots if Pb uptake by roots predominates (Beneš and Pabianová 1987). This statement was confirmed in our study (Table 3). It is possible to observe in contaminated plants the atrophic plant growth (*Picea abies, Quercus petrea, Betula pendula*), leaf chlorosis and drying, root damage and decrease of wood reproducing ability.

Lagerwerff (1971) states that the content of Cd, Pb, Mn, Zn and Co decreases in plant tissues with increasing pH in case of their identical concentrations in soil. This explains the relatively low contamination level observed in plants at the Ľubietová locality.

Generally, As toxicity increases in the following order: organic compounds of As^{5+}, arsenates – inorganic compounds containing As^{5+}, organic compounds of As^{3+}, arsenites - inorganic compounds of As^{3+}, arsanes (Virčíková and Pálfy 1997). Arsenates and arsenites can form methylane compounds whereby merge into the lower toxic forms (Matschullat 2000). Specific anomalous of flora caused by As and Sb contamination were not determined.

Concerning the plant distribution it was not possible to obtain the identical plant species from the each plane A – F (Fig. 1). It was impossible to compare the contamination level of plant tissues with contamination level of soils and sediments from the planes, neither with contamination level of surface water.

5. CONCLUSIONS

It was determined that at the Podlipa locality the concentrations of heavy metals decrease in plant tissues in the following order: Fe, Zn, Pb and Cu. The comparison of contamination of individual plant tissues showed that the highest concentrations of heavy metals have roots then leaves and stems. Flowers, seeds and fruits have the lowest concentrations of heavy metals. Plant tissues are considerably damaged at the dump field and increments of year shoots are extremely narrow. Anomalous cell-wall coarsening, occurrence of calluses, resin canals and numerous hyphae in vessels suggest defense mechanism of plants which are exposed to the stress factors at the dump field such as contamination by heavy metals, soil and moisture deficiency, movement of incohesive material down to slope.

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