Impact of Heavy Metals on Forest Trees from Mining Areas

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Abstract

The investigation focussed on uptake and distribution of heavy metals by forest trees from heavily contaminated sites. It was carried out on old mining areas from the Southern Black Forest and sites with recent mining activities in the Northern Eifel Mountain, where air pollution even was extremely high. The aim was to trace the pathways of uptake, to find out the rules of internal distribution and to assess the impact of heavy metals on the state of health.

On medieval ore mine spoils from the Black Forest Silver fir and Douglas fir have taken up relatively high amounts of heavy metals. Maximum Pb-contents in the stemwood of a 120-years old tree were 120 µg/g d.m.. However, there was no indication on negative effects regarding to growth and vitality.

The Eifel sites are characterized by a strong soil contamination (Zn 500-70.000 µg /g d.m.; Pb 1.000-7.000 µg/g d.m.; Cd 10-150 µg/g d.m.; Cu 100-2.000µg/g d.m.) and a high input from atmosphere during several decades. The trees had individual heavy metal distribution patterns depending on soil properties, mainly. Even with high deposition rates heavy metals were taken up by the roots, predominantly. No significant uptake via leafs was observed. Roots were mycorrhized on all the sites but the number of species seemed to be reduced. Cenococcum was the most abundant species. The hypothesis that a substantial damage of mycorrhiza could occur, which induces an uncontrolled uptake was not confirmed.

Regarding to the potential toxidity of heavy metals there was no evidence on a specific damage. Norway spruce, Douglas fir, Scots pine, Silver fir, oak, and beech are able to grow normally without any symptoms even with high soil contamination and high atmospheric input.

Introduction

Mining areas are to be found in almost all mountains of Germany. The mining activity in some of these regions has lasted from the early Middle Ages until now (Metz et al., 1957; Goldenberg et al., 1994). One of the most famous places is the Black Forest where mining started in Roman time and was carried on until the end of the Second World War (Goldenberg, 1994). Already in the 7th century silver ore was found in the southern Black Forest close to Freiburg. The mining activity in this region is characterized by a strongly varying intensity depending on the economic situation and the progress of prospection. A widespread collective of small areas with ore veins, ore mine spoils, and wastes is typical for this region. Beside of others silver from the Black Forest was used for financing the Cathedral of Freiburg. Since the 2nd world war the mines are abandoned completely. Despite of a high soil contamination and bad soil conditions the old ore mine spoils are covered with ground vegetation and sometimes even with forest trees like beech, Silver fir, Norway spruce, and Douglas fir.

Another very famous mining centre is located in the Northern Eifel Mountain close to the city of Stolberg. Here mining activity was combined with large metallurgic industries as metal smelters and factories producing heavy metal alloys. In contrast to the Black Forest these sites are characterized both by a strong soil contamination and an extremely high heavy metal input from atmosphere (Anonymous, 1983). Today mining is stopped almost completely, but industrial production is still active. Ore channels at the surface, mining wastes, and the atmospheric emission caused a strong contamination of soils and vegetation. Due to the high lead contamination of the ground vegetation a disease of cattle on the pastures occurred in the vicinity of the emitting factories. However, there were no visible effects on the vegetation.

Aims

Our investigation focussed on uptake and distribution of heavy metals by forest trees. The aims were to quantify total uptake, to trace the pathways of internal distribution, and to check the role of the uptake by leafs. Regarding to the forest decline from the eighties a risk assessment should be done by estimating vitality and state of health of trees from heavily polluted sites.

Material and methods

The investigation was concentrated on old mining areas in the Southern Black Forest near Freiburg and sites with recent industrial activities in the Northern Eifel Mountain near

Table1: Soil heavy metal contents in the root zone [mg/kg]

Site	Cu	Cd	Pb	Zn
Black Forest				
Ore waste	104	9	14980	2150
Silicate soil*	18	0,4	109	216
Eifel Stolberg				
Ore channal	109	201	20700	70000
Carbonate soil	125	48	3480	3190
Silicate soil	65	20	1310	1000

* reference uncontaminated

Stolberg. For to trace the heavy metal uptake trees were selected from heavily contaminated sites with a strongly varying metal availability in the soil. Thus, tree pairs were investigated from silicate and carbonate soils, respectively. In addition to the strong soil contamination atmospheric input on the Eifel sites was even very high during several decades. In contrast, on the Black Forest sites the recent air pollution was very low.
Almost all of the contaminated areas were covered with vegetation. However, it was difficult to find old trees with normal growth and without mechanical injuries. In order to eliminate effects caused by secondary damages tress were selected on places that were abandoned since at least 100 years.
On the recent mining areas effects on the vegetation are to be expected by a direct impact of atmospheric deposition and/or soil contamination which always occurs in these places. Because of that it was not possible to separate effects caused by deposition or soil contamination, respectively. So in mining areas with a high atmospheric input tree pairs were selected on carbonate and acid silicate substrates where the availability of heavy metals is quite different. The hypothesis was that heavy metal uptake by roots can be neglected on the carbonate substrate. Despite of these hard criteria we found a collective of vital trees, which was feasible for our investigations (table 2).

Table 2: Tree- and site-characteristics

species location	age	site	contamination
Norway spruce Stolberg	42	silicate soil	extremely high Cu
Norway spruce Stolberg	98	ore waste carbonatic	high
Scots pine Stolberg	98	ore waste carbonatic	high
Oak Stolberg	98	ore waste carbonatic	high
Silver fir Black Forest	150	ore waste silicatic	high
Silver fir Black Forest	86	silicate soil control	low
Scots pine	46	Galmei vein	extremely high Zn, Cd

Results

Needles

Depending on the atmospheric input and the soil contamination high contents of heavy metals were found in the needles. The mean contents found in needles from mining areas (table 3) partly were extremely high. Even with these high contents needles had no visible symptoms. Only the number of needles was reduced, partly.

Table 3: Heavy metal contents of 1-years-old needles (mg/kg)

Species	Cu	Cd	Pb	Zn
Norway spruce Stolberg	1356	0,7	7,0	189
Norway spruce Stolberg	39	2,7	22,3	107
Scots pine Stolberg	82	7,6	16	127
Silver fir ore waste	n.d.	1,0	3,2	119
Silver fir control	n.d.	0,4	0,7	30
Scots pine Galmei vein	26	1,4	5,1	173

The distribution in the assimilation organs depended on the age of tissue and the position within the crown (Zöttl, 1985; Fiedler & Heinze, 1987; Trueby, 1994). For Cu, Cd, Pb, and Zn three characteristic distribution patterns were found (figure 1). With high available amounts in the soil or a high deposition rate Pb, Zn, and Cd contents increase with the age of tissue. In contrast, Cu contents decrease. If the availability in the soil is bad, for Cd and Zn a maximum curve was found with highest contents in the 3 to 4 years old needles.

Stemwood

Heavy metals were taken up by trees and were accumulated in the stemwood. In comparison with other compartments wood had relatively low contents. Depending on element, tree species and the availability in the soil, the accumulation is varying in a very broad range. Generally deciduous trees had much lower contents than conifers (figure 2). This holds true for all the heavy metals. Zn contents in the stemwood of oak were very low, close to the determining limit of our methods. An increase of Zn contents in the sapwood is characteristic for all the trees. The contents in the wood tissue of Scots pine and Norway spruce were significantly higher than in the oak from the same site.

Even Pb - known as an element which occurs predominantly at surface of plants - can be accumulated in the stemwood with considerable amounts (Wyttenbach et al., 1989). However, the accumulation rate is very low. Thus, high contents were only found in the stemwood of old coniferous trees from ore wastes (figure 3). The radial distribution mostly has a maximum at the heartwood - sapwood boundary (Trueby, 1988). The contents in the cambial zone generally were very low. Pb was taken up by roots, mainly. There is no indication that Pb could be taken up by assimilation organs, although an uptake of microelements by leafs is well known from plant nutrition (Marschner, 1986). Pb distribution of an oak growing on an arbonate soil aside of the highway A5 in the Upper Rhine Valley (figure 4) was not affected by the deposition from using leaded fuel (Trueby, 1988).

Cu contents in stemwood generally were very low. Even with an extremely high soil contamination up to 12.000 mg Cu/g dm in the organic soil layer, the mean Cu content of the stemwood was 1.1 mg/kg only. Maximum contents were found in the cambial zone. In contrast to lead (Trueby, 1988) there was no axial gradient of the contents.

Roots

In comparison to other plant organes heavy metal contents of the roots were very high. Maximum values The Zn-distribution in the root compartments (figure 5) is typical for all the heavy metals. It is characterized by a strong accumulation in the outer bark of the roots and the fine roots < 1mm diameter. Inner Bark and wood had low contents. However, with low Zn contents in the soil the strong accumulation in the outer bark was missing. The same phenomenon was observed with manganese (Trueby&Lindner, 1990).

Mycorrhiza

The fine roots of all the trees were mycorrhized. Even on the Galmei site (table 1) vital mycorrhizas were found (figure 6). The most abundant species were *Cenococcum geophilum,Tylopilus velereus,* and *Amphinema byssoides*. In comparison to uncontaminated sites the number of species seemed to be reduced (Haug & Oberwinkler, 1992).

Vitality and state of health

In mining areas sites without any vegetation, strongly damaged trees or completely destroyed stands are a common phenomenon. Despite of an extremely high soil contamination combined with a high atmospheric deposition single trees or forest stands were found in all the mining areas. However, vitality and state of health varied strongly. Many of the trees had mechanical injuries of the bark with secondary damages caused by wood destroying fungi. Sometimes trees had severe damages in the crown with loss or yellowing of the leaves. Nevertheless trees occur without any visible symptoms and normal growth. A beech stand in the vicinity of a Pb-smelter from the city of Stolberg is shown in figure 7. These more than 100 years old trees survived with a long-lasting extremely high atmospheric deposition. A Scots pine stand on Galmei site is shown in figure 8. Even with Zn contents up to 7.4% (table 1) growth was normal and there was no evidence on a reduced vitality of the trees. Obviously germination is even not affected by the heavy metal contamination. Vital seedlings are to be found aside of the heavy metal tolerant *viola calaminaria (*figure 9).

The crowns of two old silver firs from the Black Forest are in a good shape, too (figure 10). Regarding to the vitality no differences were observed between trees from uncontaminated silicate soils and ore mine wastes, respectively.

Discussion and conclusions

In mining areas heavy metal contents of the assimilation organes are influenced by soil contamination and direct atmospheric input both. Atmospheric input usually causes an accumulation at the surface of the leaves increasing with the time of exposition. This phenomenon is well known for lead, which forms rather insoluble compounds (Wyttenbach et al. 1989). However, increased Pb-contents in the needles of old trees from ore wastes indicate also a soil uptake and a translocation to the needles. The translocation about these long distances is very ineffective, obviously. So, the phenomenon is to be observed with old trees only. Cu, Zn, and Cd distributions do not form that insoluble compounds. There is no evidence on a substantial accumulation at the surface of assimilation organes. The contents mainly result from soil uptake and the accumulation corresponds with the age of tissue. The cumulative distribution pattern is caused by a leaching of mobile elements from the older needles if uptake rate is lower than leaching rate. Cu distribution is influenced by metabolically controlled translocation processes causing an accumulation in the youngest tissue.

Stemwood is covered by bark completely and there is no direct contact with the atmosphere. Elements accumulated in the stemwood must be taken up by roots predominantly. Pb distribution in the stem can be explained by an interaction between axial transport and sorption at the cell walls. So, stemwood has the function of a long chromatographic column. Axial gradients (Trueby, 1994) indicate that Pb is fixed in the basal zone of the stem. The radial distribution indicates an accumulation depending on the age of tissue.
Depending on the supply of heavy metals in the soil a strong accumulation of heavy metals in the outer root tissue was observed. This is to be seen as a consequence of a strongly controlled metabolic uptake process. Even in the outer bark or in the mycel of mycorrhiza fungi a strong retention occurs by sorption or precipitation processes. This is to be interpreted as a dicrimination reaction of roots against an excessive uptake. This is well known from literature (Mayer, 1981). Elements with nutrient function like Mg, Zn, Mn, and K do not accumulate in this way if the contents are close to the deficiency range. This is to be concluded by the Zn distribution in the roots silver fir from the Black Forest control site, where available Zn in soil is very low.
Mycorrhization is a very important factor for uptake of nutrients and/or exclusion of bioelements (Denny & Wikins, 1987 a,b; Jones & Hutchinson, 1986; Brown & Wilkins, 1987). Zn uptake can be enhanced or reduced by mycorrhization. The occurrence of vital mycorrhiza even with extremely high soil contamination indicates a considerable tolerance of mycorrhiza fungi of heavy metals. The hypothesis that damages of trees on contaminated soils were caused by a damage of mycorrhiza could not be verified.
Mining areas especially the places aside of smelters or other industries are often free of vegetation. In literature this is mostly interpreted as an effect of heavy metal pollution. Regarding to other very toxic emissions from smelters these conclusions have to be checked critically. The industrial area from Nova Huta (Poland) was completely free from vegetation in a 1 kilometres circle around a strongly emitting Zn smelter. With an experiment carried out by Grezta (1988) just outside of the emission range variable amounts of heavy metals Cd, Pb, and Zn were applies to the soil. The highest dose was about 5 t Cd/ha. Ground vegetation especially mosses were killed with a relatively low dose. However trees (Scots pine) survived up to the maximum dose. It is to be concluded that trees have a high tolerance against heavy metals in the soil and that the complete damage of the vegetation around the Zn smelter is caused mainly by other factors like toxic emissions of SO_2, HF and NO_x.
The occurrence of vital trees in the vicinity of strongly emitting heavy metal industries and on strongly contaminated substrates indicate that forest trees are able to survive even with a long lasting atmospheric deposition and soil contamination. Accordingly, the heavy metal toxicity on higher plants often seems to be overestimated.

Literature

Anonymus (1983): Umweltprobleme durch Schwermetalle im Raum Stolberg. Ministerium für

Arbeit, Gesundheit und Soziales des Landes Nordrhein-Westfalen, Düsseldorf.

Brown, M.T. and D.A. Wilkins (1985): Zinc Tolerance of Mycorrhizal Betula. New Phytol. **99**, 101-106

Denny, H.J. and D.A. Wilkins (1987a): Zinc tolerance in Betula Spp. III. Variation in Response to Zinc Among Ectomycorrhizal Associates. New. Phytol. **106,** 535- 544

Denny, H.J. and D.A. Wilkins (1987b): Zinc tolerance in Betula Spp. IV. The Mechchanism of Ectomycorrhizal Amelioration of Zinc Toxicity. New. Phytol. **106,** 545- 553

Fiedler, H.J. und M. Heinze (1987): Verteilungsmuster nadelanalytischer Grenzwerte in Koniferenkronen. Flora **179**, 281-290

Goldenberg, G., Siebenschock, M. und H. Wagner, (1994): Spätmittelalterliche und früh-neu-zeitliche Verhüttung von Antimonerzen bei Sulzburg. Archäologische Ausgrabungen in Baden-Württemberg 1993, Stuttgart 323-328

Grezta, J. (1988): Detrimental effects of dusts emitted by various industries on trees and forest biotope. Scientific papers of Cracow Agri-cultural Academy **226,** 195 S.

Haug, I. und F. Oberwinkler (1992): Mykorrhizaformen auf den ARINUS-Flächen. Kfk-PEF-Berichte Karlsruhe **94,** 251-261

Jones, M.D. and T.C. Hutchinson (1986): The Effect of Mycorrhizal Infection on the Response of Betula Papyrifera to Nickel and Copper. New Phytol. **102**, 429-442

Marschner, H. (1986) Mineral Nutrition of Higher Plants. Academic Press London 674p

Mayer, R. (1981) Natürliche und anthropogene Konponenten des Schwermetallhaushalts von Waldökosystemen. Gött. Bodenkundl. Ber. **70,** 292 S.

Metz, R., Richter, M. und M. Schürenberg (1957): Die Blei-Zinkerzgänge im Südschwarzwald. Beih. Geol. Jb., Monografien der deutschen Blei-Zink-Erzlagerstätten **14** Hannover

Trueby, P. (1994): Zum Schwermetallhaushalt von Waldbäumen. Freiburger Bodenk. Abh. **33** 286S.

Trueby, P. (1998): Bleiverteilungen in Wald-bäumen unterschiedlich belasteter Standorte. Angew. Botanik **64,** 39-45

Trueby, P. und M. Lindner (1990): Mangan-Verteilungsmuster in Fichten (*Picea abies* Karst.) Angew. Botanik **64**, 1-12

Wyttenbach, A. Tobler, L. und S. Bajo (1989): Nadelinhaltsstoffe und Ablagerungen auf Nadeloberflächen von Fichten (*Picea abies* Karst.). Forstw. Cbl. **108,** 233-243

Zöttl, H.W. (1985): Heavy Metal Levels and Cycling in Forest Ecosystems. Experientia (Basel) **41**, 1104-1113

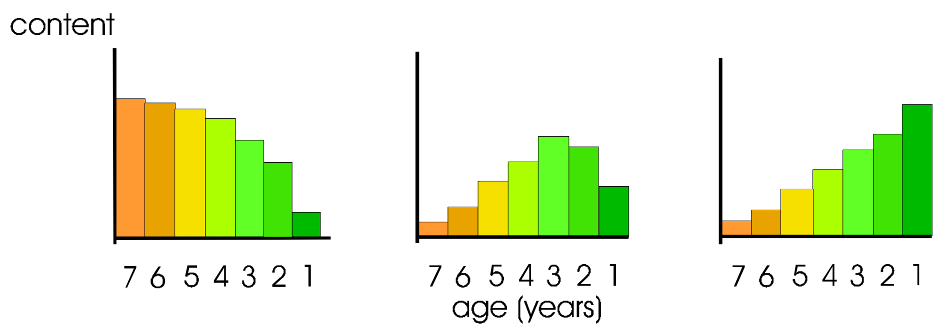

Figure 1: Relationship between heavy metal contents and needle age of coniferous trees

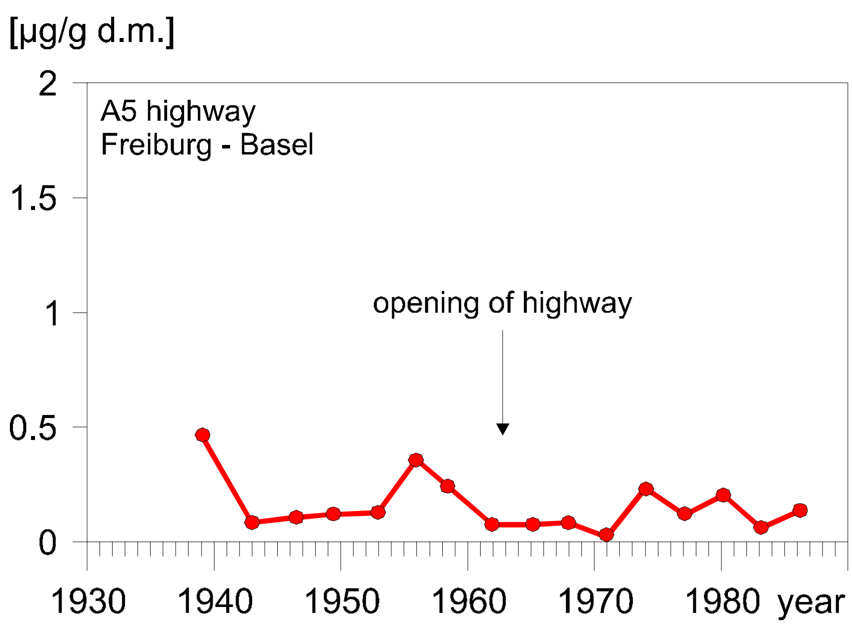

Figure 2: Radial lead distribution in the stemwood of Oak (*Quercus robur* L.) aside of the A5 highway

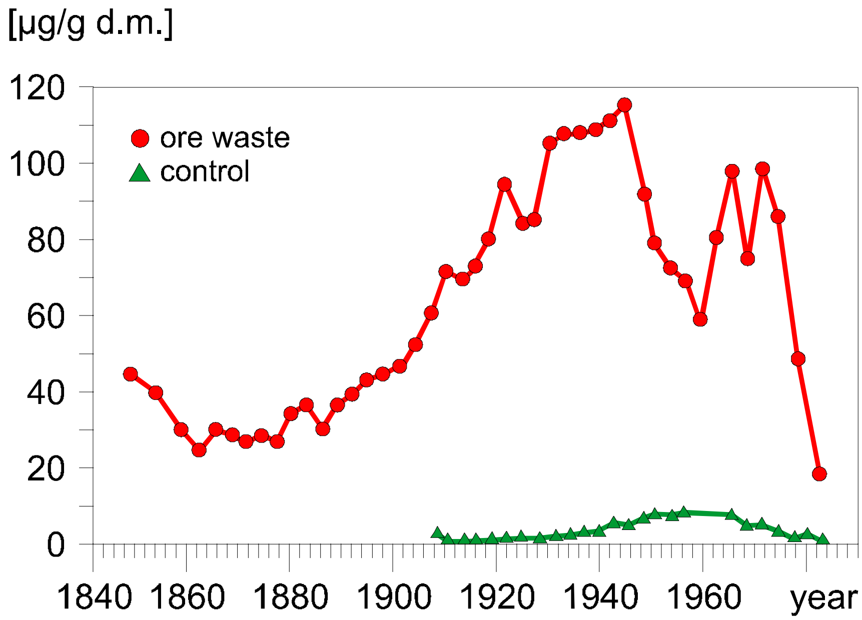

Figure 3: Radial Pb distribution in the stemwood of Silver fir (*abies alba* L.) from an ore waste and an uncontaminated silicate soil

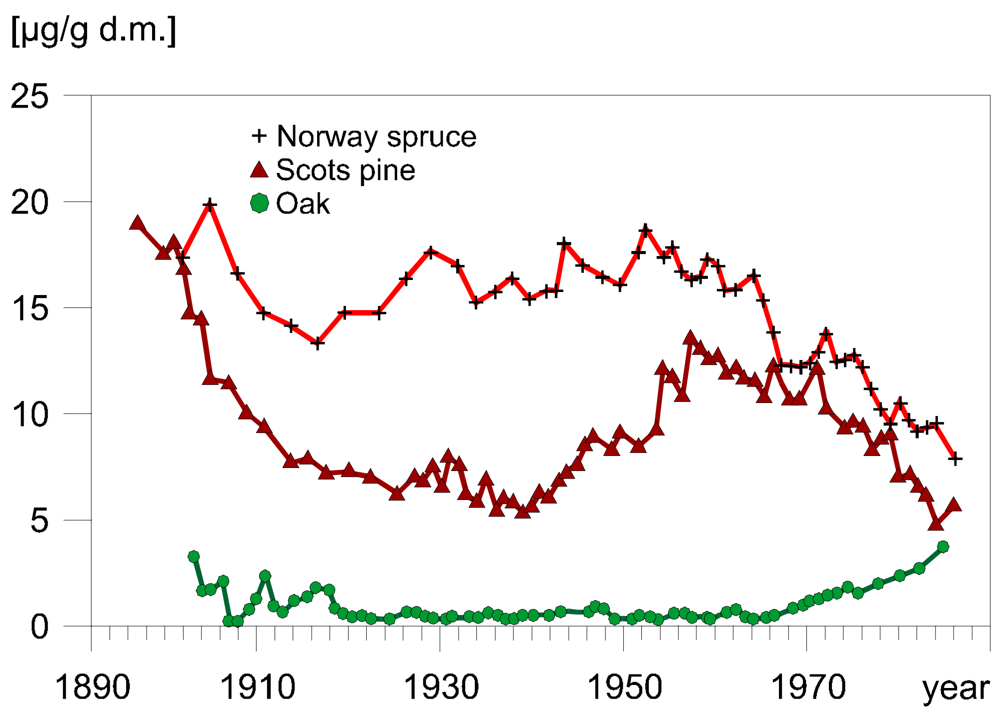

Figure 4: Radial Zn distribution in the stemwood of Oak (*Quercus robur* L.), Norway spruce (*Picea abies),* and Scots pine (*Pinus silvestris)* from a contaminated carbonate soil in the emission range of the Stolberg metallurgic industries.

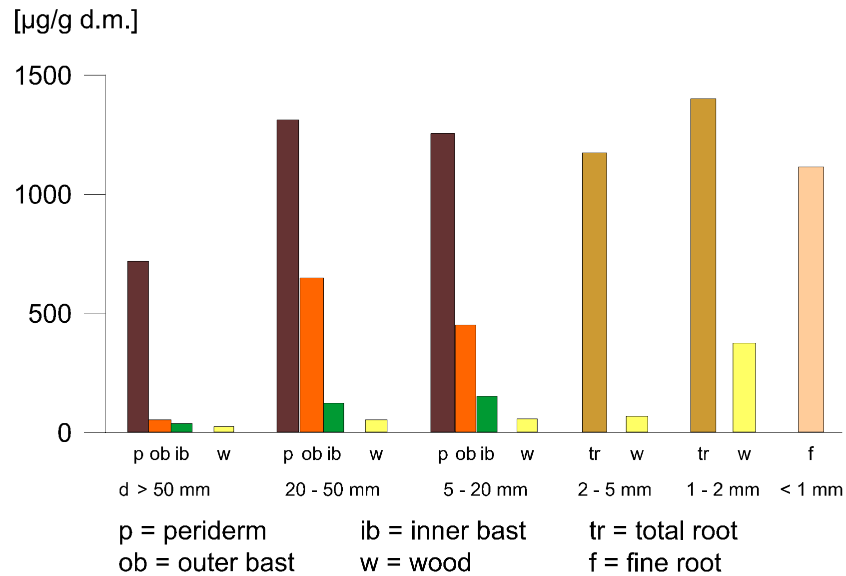

Figure 5: Lead distribution in the roots of Scots pine (*Pinus silvestris)* from a contaminated silicate soil in the emission range of the Stolberg industries.

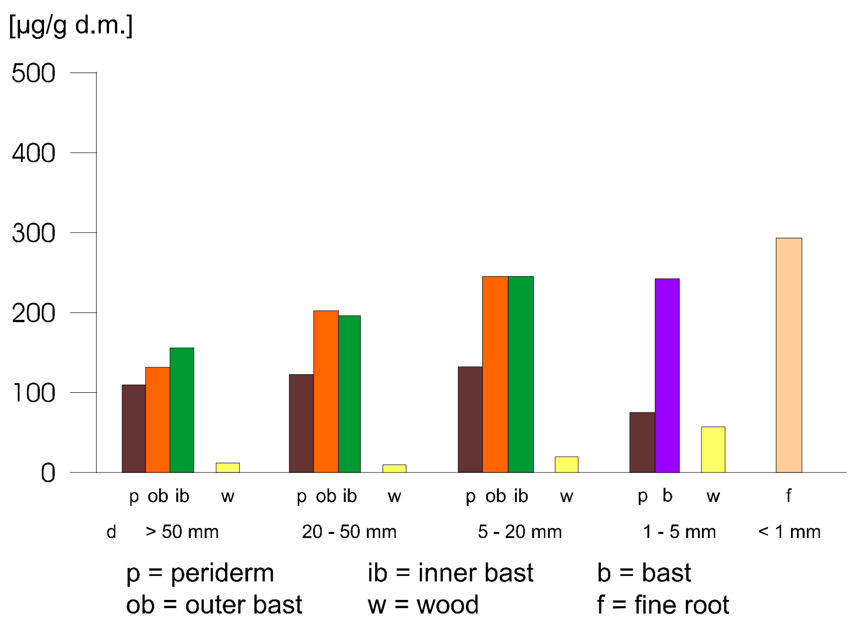

Figure 6: Zinc distribution in the roots of Norway spruce (*Picea abies)* from a carbonate soil in the emission range of the Stolberg industries.

Figure 7: Beech (*Fagus sylvatica)* stand in the emission range of a lead smelter of Stolberg

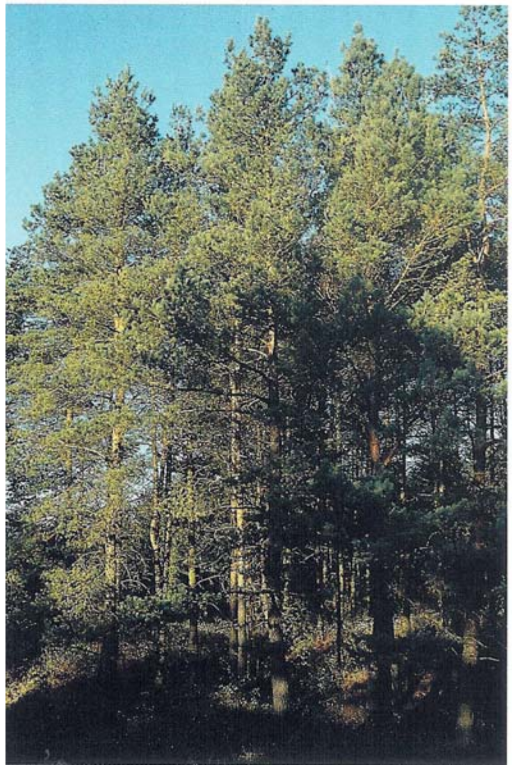

Figure 8: Scots pine stand (*Pinus silvestris*) on an Galmei ore vein in the mining area of Stolberg

Figure 9: Scots pine (*Pinus silvestris*) seedling aside of heavy metal tolerant violets (*viola calaminaria*) on an Galmei ore vein in the mining area of Stolberg

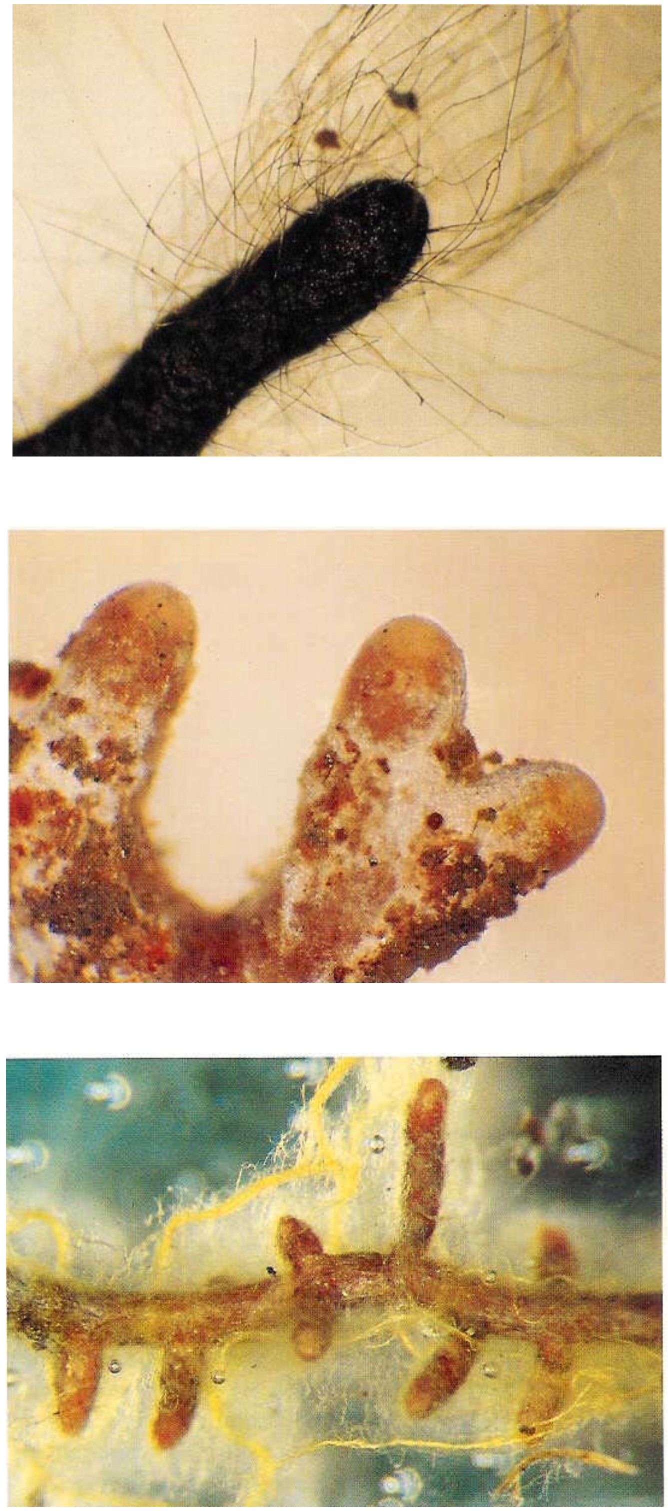

Figure 10: Mycorrhization of Sctos pine roots (*Pinus silvestris)* on ore veins in the mining area of Stolberg (top: *Cenococcum geophilum;* middle: *Tylopilus velereus;* bottom: *Amphinema byssoides)*

Figure 11: Crowns of Silver fir (*Abies alba* M.) on an ore waste (top) and an uncontaminated silicate soil (bottom) from the Southern Black Forest