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Trace metal (Cd, Cu, Pb, Zn) and sulphur content in soils and selected plant species of Iceland. A pilot study

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SUMMARY

The aim of the project was to determine concentrations of sulphur and selected trace metals (Cd, Cu, Pb and Zn) in the topsoil, bedrock and two moss species (*Racomitrium* sp. and *Drepanocladus* sp.) at selected locations in Iceland. The soil profiles were shallow and the samples were collected from the topsoil layer 0–5 cm, representing AC horizon. The samples were collected from eight sampling sites across Iceland. Three sites were situated in the south-western part of the island near Reykjavík (Mt. Esja, Reykjabyggð, Krísuvík), two in Southern Iceland (Gullfoss Waterfall and Selfoss), two in the northern part of the island (Tjörnes Peninsula, Stórutjarnir) and one in the south-east (Vatnajökull Glacier). Soils at the sites represent three groups: andosols on freely drained sites: Mt. Esja, Tjörnes, Gullfoss, Stórutjarnir and Selfoss; organic soils in wetlands of Reykjabyggð; and soils of barren deserts: leptosols or regosols in Krísuvík and Vatnajökull. The basalt rock material of volcanic nature represented: neovolcanic zone (Reykjabyggð, Krísuvík and Gullfoss), rocks younger than 3.1 million years (Mt. Esja, Tjörnes, Vatnajökull, Selfoss) and rocks older than 3.1 million years (Stórutjarnir).

Concentrations of trace metals varied widely according to the element as well as to the type of sample (soil, rock, plant species). Generally the highest concentrations of metals were found in the topsoil AC horizon and in *Drepanocladus* sp. A comparison of the results with data from two locations in northern and central Europe (Northern Sweden and Poland) reveals that concentrations of Cu and Zn in the topsoils in Iceland are higher than in Swedish Lapland region, and distinctly higher than in the lithogenic topsoils in the Carpathian Mts but presumably are of natural origin. On the contrary, Pb concentrations in Southern Poland are several times higher, and in Northern Sweden slightly higher than in Iceland. The low lead concentrations in surface soil and in the two moss species, when for example, compared with highly or even slightly polluted areas of Poland, indicate no evidence of anthropogenic input in Iceland.

Key words: bed-rock, cadmium, copper, *Drepanocladus* sp., Iceland, lead, moss, *Racomitrium* sp., sulphur, topsoil, trace metals, zinc.

YFIRLIT

Könnun á snefilmálmum (Cd, Cu, Pb og Zn) og brennisteini (S) í íslenskum jarðvegi og mosum

Markmið verkefnisins var að kanna magn snefilmálma (Cd, Cu, Pb, Zn) og brennisteins í jarðvegi, berggrunni og tveimur mosategundum (*Racomitrium* sp. og *Drepanocladus* sp.) á átta svæðum hér á landi. Þrjú sýnatökusvæðanna er að finna í nágreni Reykjavíkur (Krísuvík, Reykjabyggð, Esja), tvö þeirra á

Suðurlandi (Selfoss, Gullfoss), tvö á Norðurlandi (Stórutjarnir, Tjörnes) og eitt á Suðausturlandi (Vatnajökull). Þrjár gerðir jarðvegs er að finna á þessum svæðum: Brúnjörð (Brown Andosol) einkennir þurrari svæðin (Esja, Tjörnes, Gullfoss, Selfoss, Stórutjarnir); við Reykjabyggð var að finna jarðvegsgerðina Mójörð (Histosol), en Frumjörð (Vitrisol) einkennir auðnasvæðin (Krísuvík, Vatnajökull).

Styrkur snefilmálma var mjög breytilegur eftir tegund málms og gerð sýnis (jarðvegur, berg, mosi). Almennt gildir að styrkur málma var mestur í jarðvegi og *Drepanocladus* sp. Samanburður á þessum niðurstöðum og gögnum af tveimur svæðum í norður og mið Evrópu (Norður Svíþjóð og Karpatafjöll í Pólland) sýnir að styrkur kopars og sinks í jarðvegi er hærri hér á landi, en væntanlega stafar það af náttúrulegum örsökum. Aftur á móti er styrkur blýs mun hærri í Karpatafjöllunum og nokkru hærri í Norður Svíþjóð en styrkur þess hér á landi. Lágur styrkur blýs í jarðvegi og mosa hérlendis, t.d. samanborið við mikið og lítið menguð svæði í Póllandi, bendir til þess að mengun af mannavöldum sé verulega lág hér á landi.

INTRODUCTION

Many papers report atmosphere, soil and plant pollution in the Arctic area as well as in the North Europe (Rühling *et al.*, 1987; Rühling and Tyler, 1984; Nriagu *et al.*, 1991; Tyler, 1992; Pacyna, 1995; Presley, 1997; Reimann *et al.*, 1997). Among the papers relatively few deal with environment pollution in Iceland (e.g. Pálsson *et al.*, 1994; Gústafsson and Steinecke, 1995). Only the most northern part of Iceland is situated close to the polar circle. The problems of environmental pollution in Iceland seem to be similar to those faced in northern Scandinavia, among others, because of similarity of natural climate conditions (precipitation, wind directions) and type of vegetation. In fact, the whole area of Iceland is not affected by pollutants coming from local sources (industrial and urban ones) thanks to implementation of environmentally friendly energies: geothermal and hydropower (Ragnarsson, 2000), but seems to be submitted to the long-range emissions from western and even central Europe countries.

Air pollutants of most concern in the Arctic and in northern Europe are regarded to be: metals, metalloids, and sulphur dioxide (Rühling and Tyler, 1984; Rühling *et al.*, 1987; Nash and Gries, 1995). Mosses and lichens are the best bioindicators of metal pollution (Tyler, 1976; Markert and Veckert, 1993; Grodzinska *et al.*, 1994; Rühling, 1994). The aim of the paper was to determine contents of selected trace metals (Cd, Cu, Pb and Zn) and sulphur in the topsoil, bed-rock and in two moss species in Iceland, in order to detect air pollution.

MATERIAL AND METHODS

The samples representing soil, bed-rock and plants were collected from eight sampling sites across Iceland. Five of the sites were situated in the western part of the island, near Reykjavík (no. 1: Mt. Esja, no. 2: in the vicinity of Reykjabyggð, no. 3: Krísuvík, no. 6: Gullfoss Waterfall and no. 8: in the vicinity of Selfoss) and three other (no. 4: Tjörnes Peninsula, no. 5: Stórutjarnir and no. 7: Vatnajökull Glacier in the vicinity of Skaftafell) in the eastern part (Figure 1). The sampling sites excluded locations close to the roads, urban and industrial centres and single home estates. Data on sampling locations are tabulated (Table 1).

Soils represent three groups: andosols on freely drained sites: Mt. Esja, Tjörnes, Gullfoss, Stórutjarnir and Selfoss, organic soils in wetlands of Reykjabyggð and the soils of barren deserts: leptosols or regosols in Krísuvík and Vatnajökull (Arnalds, 1999). The soil profiles were shallow and the samples were collected from the topsoil layer 0–5 cm, representing AC horizon. The basalt rock material of volcanic nature represents: neovolcanic zone (Reykjabyggð, Krísuvík and Gullfoss), rocks younger than 3.1 million years (Mt. Esja,

Table 1. Sampling site locations.
1. tafla. Sýnatökustaðir.

Site no.	Location	Height a.s.l., m	Landform	Slope orientation
1	Mount Esja	600	Slope	S
2	1 km SE from Reykjabyggð	100	Slope	
3	Krísuvík	50	Flat area	
4	Tjörnes Peninsula	30	Flat area	
5	Stórutjarnir	200	Valley	
6	Gullfoss Waterfall	150	Slope	E
7	Vatnajökull Glacier, near Skaftafell	800	Slope	E
8	3 km N from Selfoss	50	Flat area	

Tjörnes, Vatnajökull, Selfoss) and rocks older than 3.1 million years (Stórutjarnir). Plant samples represent two moss species: *Drepanocladus* sp., and *Racomitrium* sp. Three samples of plant species, soil and bed-rock were collected from each location.

Soil samples were dried, grounded and passed through a 1 mm sieve. A fraction finer than 1 mm was grounded further in an agate mortar. Analyses for trace metals were carried out by digesting 1 g of sample in Kjeldahl flask, using, in the case of plant samples 20 ml of a mixture of 65% HNO_3 and 60% $HClO_4$ (4:1), and in the case of soil and rock material 20 ml of a mixture of 60% $HClO_4$ and 65% HNO_3 (4:1). Plant samples were not washed before analyse. The obtained solutions were filtered and diluted to 50 ml with bidestilled H_2O (Ostrowska *et al.*, 1991). Concentrations of Pb, Cd, Zn and Cu were determined by flame atomic absorption spectrophotometry on the spectrophotometer Hitachi Z-8200. Concentrations of sulphur were determined by means of Butters & Chenery nephelometric method on the turbidemeter type Hach 2100AN.

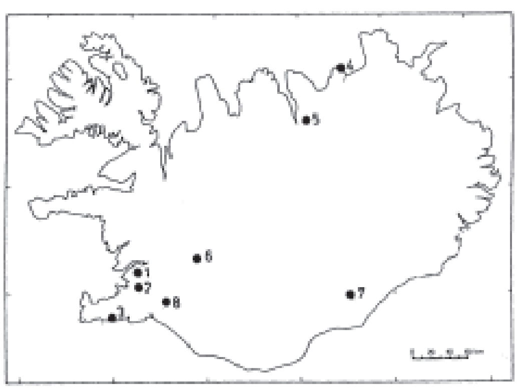

Figure 1. Sampling sites in Iceland; (1) Mt. Esja, (2) Reykjabyggð, (3) Krísuvík, (4) Tjörnes Peninsula, (5) Stórutjarnir, (6) Gullfoss Waterfall, (7) Vatnajökull Glacier og (8) Selfoss.
1. mynd. Sýnatökustaðir; (1) Við Esju, (2) í Reykjabyggð, (3) við Krísuvík, (4) á Tjörnesi, (5) við Stórutjarnir, (6) við Gullfoss, (7) við Vatnajökul í nágrenni Skaftafells og (8) í nágenni Selfoss.

RESULTS AND DISCUSSION

Soil, rock and plant samples were analyzed for concentrations of cadmium, copper, lead, zinc and sulphur and the obtained results were tabulated (Tables 2–6). The highest contents of cadmium were found in the soil, mosses and in the rock material from Krísuvík region (sampling site no. 3), of copper and lead in the area of Reykjabyggð (sampling site no. 2), and of zinc also in Reykjabyggð sampling site (topsoil) and in sampling site no. 1 Mt. Esja (bedrock and two moss species). In case of cadmium relatively high concentrations in plants and soil in Krísuvík may thus be traced to the parent rock material. Cadmium concentrations in other bedrock samples are lower. High Cd concentrations in plants and soil, where its level in bedrock is low, were found in most of the *Drepanocladus*

Table 2. Concentrations of Cd in mg kg^{-1} in topsoil horizon, bed-rock and mosses in selected locations of Iceland.
2. tafla. Styrkur kadmíums (Cd, mg/kg) í jarðvegi, bergi og mosum.

Site no.	Location	Topsoil (AC, 0–5cm)	Bed-rock (R)	*Racomitrium* sp.	*Drepanocladus* sp.
1	Mount Esja	0.35	0.28	0.84	1.34
2	Reykjabyggð	0.41	0.34	0.55	1.30
3	Krísuvík	1.55	1.02	1.13	1.83
4	Tjörnes Peninsula	1.56	0.23	0.92	1.86
5	Stórutjarnir	0.25	0.28	0.21	1.29
6	Gullfoss Waterfall	0.40	0.21	0.25	0.71
7	Vatnajökull Glacier	0.31	0.20	0.65	0.38
8	Selfoss	0.18	0.25	1.50	0.50
	Average	0.63	0.35	0.76	1.15
	SD	0.58	0.27	0.44	0.57

Table 3. Concentrations of Cu in mg kg^{-1} in topsoil horizon, bed-rock and mosses in selected locations of Iceland.
3. tafla. Styrkur kopars (Cu, mg/kg) í jarðvegi, bergi og mosum.

Site no.	Location	Topsoil (AC, 0–5cm)	Bed-rock (R)	*Racomitrium* sp.	*Drepanocladus* sp.
1	Mount Esja	143.9	81.3	58.5	72.1
2	Reykjabyggð	134.7	128.3	89.7	118.5
3	Krísuvík	82.9	79.1	40.1	53.2
4	Tjörnes Peninsula	84.6	64.5	38.7	43.4
5	Stórutjarnir	103.7	57.1	34.7	47.4
6	Gullfoss Waterfall	118.5	61.0	22.6	94.8
7	Vatnajökull Glacier	54.9	69.5	18.6	31.4
8	Selfoss	52.4	59.1	6.8	28.3
	Average	97.0	75.0	38.7	61.1
	SD	34.3	23.3	25.9	31.8

samples, the highest in Krísuvík where the level in bedrock is relatively high and Tjörnes where the level is relatively low (sampling site no. 4). It is also noteworthy that the plant and soil samples from Tjörnes are high in Cd but the Cd concentration in the bedrock is low. High concentrations of copper in plants and soil in Reykjabyggð correspond with high concentrations in the bedrock. High concentrations of copper were also stated in topsoil from the Esja, Gullfoss (sampling site no. 6) and Stórutjarnir (sampling site no. 5). The highest lead concentrations in topsoil and plant samples from Esja and Reykjabyggð are linked with high concentrations in the bedrock. In the case of sulphur the highest concentrations were found in mosses from Mt. Esja and in the soil and bedrock near Reykjabyggð.

It was difficult to conclude anything about spatial differences in sulphur and trace metal level across Iceland, because of very few sampling sites. Slightly higher concentrations of

Table 4. Concentrations of Pb in mg kg^{-1} in topsoil horizon, bed-rock and mosses in selected locations of Iceland.
4. tafla. Styrkur blýs (Pb, mg/kg) í jarðvegi, bergi og mosum.

Site no.	Location	Topsoil (AC, 0–5cm)	Bed-rock (R)	*Racomitrium* sp.	*Drepanocladus* sp.
1	Mount Esja	10.7	5.6	5.9	7.1
2	Reykjabyggð	11.3	6.4	10.5	6.1
3	Krísuvík	3.2	4.8	6.3	6.5
4	Tjörnes Peninsula	3.2	4.3	5.3	4.9
5	Stórutjarnir	5.5	4.8	6.1	6.3
6	Gullfoss Waterfall	2.8	3.4	4.3	6.3
7	Vatnajökull Glacier	5.3	5.1	3.3	5.0
8	Selfoss	4.2	3.0	2.2	4.7
	Average	5.8	4.7	5.5	5.9
	SD	3.4	1.1	2.5	0.9

Table 5. Concentrations of Zn in mg kg^{-1} in topsoil horizon, bed-rock and mosses in selected locations of Iceland.
5. tafla. Styrkur zinks (Zn, mg/kg) í jarðvegi, bergi og mosum.

Site no.	Location	Topsoil (AC, 0–5cm)	Bed-rock (R)	*Racomitrium* sp.	*Drepanocladus* sp.
1	Mount Esja	87.0	85.4	81.7	80.0
2	Reykjabyggð	123.8	69.8	42.5	58.7
3	Krísuvík	74.9	56.0	61.3	77.6
4	Tjörnes Peninsula	71.0	56.1	48.6	39.8
5	Stórutjarnir	68.0	63.0	39.5	24.5
6	Gullfoss Waterfall	64.5	59.0	27.0	56.0
7	Vatnajökull Glacier	92.0	78.5	44.5	53.7
8	Selfoss	82.8	36.0	23.5	45.0
	Average	83.0	63.0	46.1	54.1
	SD	19.0	15.3	18.7	18.6

studied metals and sulphur in topsoil horizons and in two moss species were stated in the most westerly located sampling sites than in the eastern part of Iceland, but any generalization was not possible.

Concentrations of trace metals varied widely according to the element as well as to the type of sample (soil, rock, plant species). Generally, the highest concentrations of metals were found in the topsoil AC horizon and in *Drepanocladus* sp. Bedrock contained low, but variable amounts of metals and sulphur. Of two moss species studied, the higher concentration of metals were found in *Drepanocladus* sp. than in *Racomitrium* sp. Concentrations of copper and zinc were similar and high in all types of samples, whereas Pb contents were about ten times lower, than those of zinc and copper.

Descending sequences of mean S, Cd, Cu, Pb and Zn concentrations in mosses, topsoil and bedrock are as follows:

Table 6. Concentrations of S in % in topsoil horizon, bed-rock and mosses in selected locations of Iceland.
6. tafla. Styrkur brennisteins (S, %) í jarðvegi, bergi og mosum.

Site no.	Location	Topsoil (AC, 0–5cm)	Bed-rock (R)	*Racomitrium* sp.	*Drepanocladus* sp.
1	Mount Esja	0.080	0.019	0.139	0.066
2	Reykjabyggð	0.083	0.027	0.053	0.039
3	Krísuvík	0.066	0.024	0.051	0.046
4	Tjörnes Peninsula	0.067	0.015	0.057	0.047
5	Stórutjarnir	0.023	0.019	0.078	0.048
6	Gullfoss Waterfall	0.013	0.021	0.056	0.048
7	Vatnajökull Glacier	0.060	0.030	0.063	0.057
8	Selfoss	0.074	0.006	0.075	0.034
	Average	0.06	0.02	0.07	0.05
	SD	0.03	0.01	0.03	0.01

S: *Drepanocladus* sp. > *Racomitrium* sp.> soil > bed-rock

Cd: *Drepanocladus* sp. > *Racomitrium* sp. > soil > bed-rock

Cu: Soil > bed-rock > *Drepanocladus* sp. > *Racomitrium* sp.

Pb: *Drepanocladus* sp. > soil > *Racomitrium* sp. > bed-rock

Zn: Soil > *Racomitrium* sp. > bed-rock > *Drepanocladus* sp.

and:

Topsoil:	Cu > Zn > Pb > Cd
Bed-rock:	Cu > Zn > Pb > Cd,
Racomitrium sp.:	Zn > Cu > Pb > Cd
Drepanocladus sp.:	Cu > Zn > Pb > Cd

The environmental conditions in Iceland are in some aspects comparable to those in northern Scandinavia, but differ distinctly from those of the Carpathian Mts, Southern Poland. But especially the bedrock and soils are not comparable. Therefore it is problematic to compare concentration of metals in the AC horizon (0–5 cm) of skeletal lithosols from Iceland with those from the Abisko National Park and Tarfala Valley in Northern Sweden, as well as with those from mountain region of Poland, collected in the alpine floor at the height above 1500 m a.s.l., because, among others, of different lithology of rock material. However, the concentrations of Cu and Zn in the topsoils in Iceland are higher than in Swedish Lapland region, and distinctly higher than in the lithogenic topsoils in the Carpathian Mts., and presumably are of natural origin. On the contrary, Pb concentrations in Southern Poland are several times higher, and in Northern Sweden slightly higher than in Iceland (Chodak and Panek, 1999). The low lead concentrations in surface soil and in two moss species, when for example, compared with highly or even slightly polluted areas of Poland, indicate no evidence of anthropogenic input over Iceland.

The studied moss species scarcely occur in the Carpathian Mts. In the future, to develop the issues presented in this paper, it would be advisable to select such moss species, like *Pleurozium schreberi* and *Polytrichum* sp., for instance, which grow in the most polluted parts of Poland as well in Iceland, in order to compare the level of metal and sulphur contamination from those locations.

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REFERENCES

Arnalds, Ólafur, 1999. Soils and soil erosion in Iceland. In: *Geochemistry of the Earth Surface* (ed. Halldór Ármannsson). Balkema, Rotterdam: 135–138.

Chodak, M. & E. **Panek**, 1999. Content of Pb, Cd, Zn and Cu in soils and selected plant species of forest regions in Northern Sweden – Southern Poland transect. In: *Proceedings of 5th International Symposium and Exhibition on Environmental Contamination in Central and Eastern Europe*, 12–14 Sept. 2000, Prague.

Grodzinska, K., G. **Szarek**, B. **Godzik**, S. **Braniewski** & E. **Chrzanowska**, 1994. Mapping air pollution in Poland by measuring heavy metal concentration in mosses. In: *Climate and Atmospheric Deposition Studies in Forests* (eds J. Solonen, E. Roo-Zielinska & A. Bytnerowicz). Conference Papers 19. IGSO PAS, Warszawa, Poland: 197–209.

Gústafsson, Lúðvík E. & K. **Steinecke**, 1995. Airborne contaminants and their impact on the city of Reykjavík, Iceland. EPA International Symposium on the Ecological Effects of Airborne Contaminants, October 4–8, 1993, Reykjavík, Iceland. *Science of the Total Environment* **160–161**: 363–373.

Markert, B. & V. **Veckert**, 1993. Time and site integrated long-term biomonitoring of chemical elements by means of mosses. *Toxicological and Environmental Chemistry* **40(1–4)**: 43–57.

Nash, T.H. & C. **Gries**, 1995. The response of lichens to atmospheric deposition with an emphasis on the Arctic. EPA International Symposium on the Ecological Effects of Airborne Contaminants, October 4–8, 1993, Reykjavík, Iceland. *Science of the Total Environment* **160–161**: 737–748.

Nriagu, J.O., R.D. **Coker** & L.A. **Barrie**, 1991. Origin of sulphur in Canadian arctic haze from isotope measurements. *Nature* **349(6305)**: 42–46.

Ostrowska, A., S. **Gawlinski** & Z. **Szczubialka**, 1991. *Metody analizy i oceny wlasciwosci gleb i roslin. Katalog*. IOS (Institute of Environmental Protection), Warsawa, Poland.

Pacyna, J.M., 1995. The origin of Arctic air pollutants: lessons learned and future research. EPA International Symposium on the Ecological Effects of Airborne Contaminants, October 4–8, 1993, Reykjavík, Iceland. *Science of the Total Environment* **160–161**: 39–54.

Pálsson, Sigurður E., Kristbjörn **Egilsson**, Skarphéðinn **Þórisson**, Sigurður M. **Magnússon**, Elísabet D. **Ólafsdóttir** & Kári **Indriðason**, 1994. Transfer of radiocaesium from soil and plants to reindeer in Iceland. *Journal Environmental Radioactivity* **24(2)**: 107–126.

Presley, B.J., 1997. A review of Arctic trace metal data with implications for biological effects. *Marine Pollution Bulletin* **35(7–12)**: 226–234.

Ragnarsson, Árni, 2000. Geothermal development in Iceland 1995–1999. In: *Proceedings of the World Geothermal Congress, Japan, 2000*: 363–375.

Reimann, C., R. **Boyd**, P. **de Caritat**, J.H. **Halleraker**, G. **Kashulina**, H. **Niskavaara** & I. **Bogatyrev**, 1997. Topsoil (0–5 cm) composition in eight Arctic catchments in Northern Europe (Finland, Norway and Russia); *Environmental Pollution* **95**: 45–56.

Rühling, A. (ed.), 1994. Atmospheric heavy metal deposition in Europe – estimations based on moss analyses. *Nord* **9**: 54 pp.

Rühling, A. & G. **Tyler**, 1984. Recent changes in the deposition of heavy metals in northern Europe. *Water, Air and Soil Pollution* **22**: 173–180.

Rühling, A., L. **Rassmusen**, K. **Pilegaard**, A. **Mäkinen** & E. **Steinnes**, 1987. Survey of atmospheric heavy metal deposition in the Nordic countries in 1985. *Nord* **21**: 2–44.

Tyler, G., 1976. Metal concentrations in moss, leaves and other indicators of metal exposure in the environment. *Institute of Electrical and Electronics Engineers, Annals no.* **75CH1004 1–3**: 1–4.

Tyler, G., 1992. Critical concentrations of heavy metals in the mor horizon of Swedish forests. *SNV-Report* **4078**. Solna, Sweden.

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