

POLISH POLAR RESEARCH	12	2	183—193	1991
-----------------------	----	---	---------	------

Witold PLICHTA<sup>1</sup> and Irena KUCZYŃSKA<sup>2</sup>

<sup>1</sup> Department of Soil Science  
Institute of Biology  
Nicolaus Copernicus University  
Sienkiewicza 30/32  
87-100 Toruń, POLAND

<sup>2</sup> Institute for Land Reclamation  
and Grassland Farming  
Ossolińskich 12,  
85-093 Bydgoszcz, POLAND

## Metal contents in soils of Kaffiöyra, Spitsbergen

**ABSTRACT:** Metal contents in the tundra soils (Gelic Regosols, Gelic Gleysols, Gelic Cambisols) of the maritime lowland of Kaffiöyra, in the western Spitsbergen seashore are presented in this publication. The average heavy metal contents in samples collected from the depth layer 0—130 cm are follows: Fe 2.9%, Mn 392 ppm, Zn 75 ppm, Cu 23.4 ppm, Ni 24.1 ppm, Co 7.4 ppm, Pb 12.5 ppm, Cd 0.24 ppm. The surface soil layer 0 to 25 cm is poorer in Ca and Mg than the underlying layer 25 to 130 cm. The heavy metal contents like Fe, Mn, Ni and Co, are also somewhat lower in the upper layer. The enrichment indices of Pb and Cd are equal in the surface soil layer 1.16 and 1.23 respectively. Correlation coefficients between each studied element and organic carbon, and, on the other hand, soil separates < 20  $\mu$ m and < 2  $\mu$ m are very low.

**Key words:** Arctic, Spitsbergen, soil, metal elements.

## Introduction

Chemical composition of a soil depends on the chemical composition of the parent rock, weathering and pedogenic processes and an external substance inflow. Intensities of the chemical weathering and pedogenic processes differentiating the soil chemical composition are very low in the Arctic zone. An important role is displayed by cryogenic processes.

Due to common large distances from industrial centres and relatively low precipitation, the Arctic soils are believed usually as being of low pollution degree caused by atmospherically transported impurities, especially by heavy metals. Because of the increasing soil pollution in the global scale, the determination of the so-called geochemical background in less polluted areas is

very urgent. This is of a special importance for comparative studies of the the soils pollution degree estimation in various Arctic regions. The determination of the present-day metal contents in the soils of the Kaffiöyra (Spitsbergen) maritime lowland has been the aim of the authors' studies.

## Area of the investigations

The analysed soil samples have been collected in the maritime lowland of Kaffiöyra, Oscar II Land, Spitsbergen (Fig. 1). Kaffiöyra extends over an area

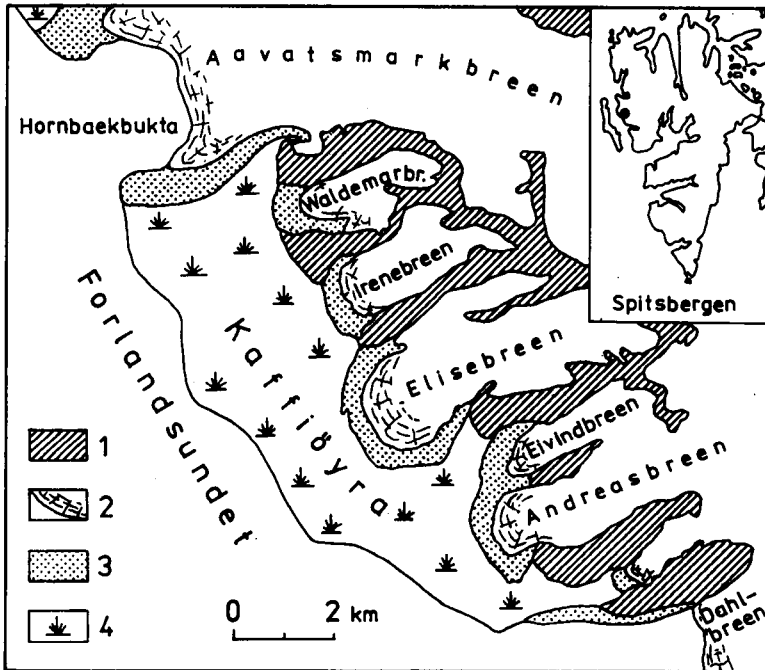


Fig. 1. Sketch map of the investigated area: 1 — mountains, 2 — glaciers, 3 — glacier marginal zones, 4 — tundra plain

of ca. 13 km between the Aavatsmark and Dahl glaciers. Its width reaches 4 km. It consists of a series of the marine accumulation terraces and abrasion terraces, isostatically raised to 65 m a.s.l. Its basement comprises Tertiary clayey shales, mudstones, sandstones and conglomerates and Precambrian/Cambrian Hecla Hoek formation including schists, fyllites, dolomites and marbles. Quaternary pebble deposits, gravels, skeletal sands, tills and silty sediments occur at the surface. The weathered Hecla Hoek formation rocks and Paleogene sandstones and conglomerates occur in small areas of the abrasion terraces. The detailed characteristics of the geographical environment of Kaffiöyra have been published in the papers by Klimaszewski (1960),

Gugnacka-Fiedor and Noryśkiewicz (1982), Niewiarowski (1982) and Sin-kiewicz and Plichta (1987).

## Materials and methods

Samples for analyses have been collected during the Toruń Polar Expedition in 1985. They have been taken from Gelic Regosols (two profile), Gelic Gleysols (six profile) and Gelic Cambisols (eight profiles), according to the FAO-UNESCO classification (1974). The total of 75 samples has been analysed, including 35 samples from the depth layer 0–25 cm and 40 samples from the depth layer 25–130 cm. The upper layer 25 thick has been analysed separately to exclude the surface soil levels enrichment in metals due to biological accumulation.

The analysed samples are mostly the strongly skeletal sands, clays and silty sediments. The majority of the samples bears on more than 5% of clay (Fig. 2).

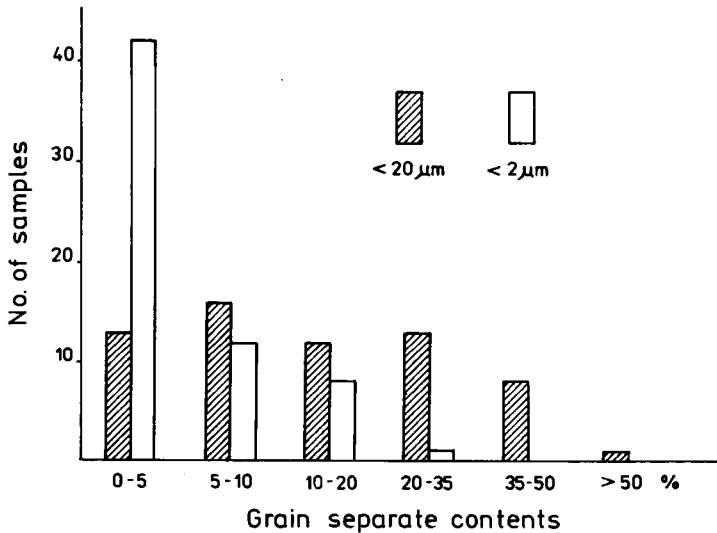


Fig. 2. Frequency histograms of the fine grain separates in studied samples

The chemical analyses have been made using air-dry samples of the grain separate < 1 mm. The samples have been dissolved in concentrated nitric, sulfuric and perchloric acids. The concentrations of the elements: Na, K, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Co, Pb, Cd, have been determined by means of the atomic absorption spectrophotometry.

## Results and discussion

The average element concentrations within the whole soil profile and in the selected depth layers 0–25 cm and 25–130 cm are given the Table 1. The

Table 1  
Chemical composition of the Kaffiyyra soils

Element	Concentration ranges of all samples	Average value	Standard deviation	Depth cm	Concentration ranges	Average value	Standard deviation	A*
Na %	0.03—0.42	0.16	0.12	0—25 25—130	0.03—0.42 0.05—0.36	0.17 0.16	0.10 0.13	1.06
K %	0.38—2.40	1.08	0.53	0—25 25—130	0.47—2.25 0.38—2.40	1.13 1.03	0.49 0.56	1.10
Ca %	0.07—8.73	2.47	2.48	0—25 25—130	0.07—8.44 0.12—8.73	1.41 3.38	1.85 2.59	0.42
Mg %	0.44—2.51	1.10	0.55	0—25 25—130	0.44—2.34 0.50—2.51	0.92 1.23	0.46 0.60	0.75
Fe %	1.28—6.18	2.90	0.93	0—25 25—130	1.28—5.14 1.78—6.18	2.74 3.04	0.82 0.99	0.90
Mn ppm	97—679	392	120	0—25 25—130	97—644 212—679	366 413	136 99	0.89
Zn ppm	38—152	75	19	0—25 25—130	38—152 41—114	75 74	21 18	1.01
Cu ppm	4.4—102.0	23.4	14.5	0—25 25—130	4.4—54.9 8.9—102.0	20.7 25.7	9.8 17.2	0.81
Co ppm	2.5—24.1	7.4	3.7	0—25 25—130	2.5—13.0 3.1—24.1	6.8 7.9	2.5 4.5	0.86
Ni ppm	12.3—42.5	24.1	7.4	0—25 25—130	12.3—42.5 13.6—41.8	22.7 25.3	5.9 8.3	0.90
Pb ppm	6.1—25.3	12.5	4.2	0—25 25—130	6.5—25.3 6.1—24.2	13.4 11.6	4.3 4.3	1.16
Cd ppm	0.05—0.40	0.14	0.06	0—25 25—130	0.05—0.40 0.07—0.21	0.16 0.13	0.08 0.04	1.23

\*A — The ratio of an element concentration in the depth layer 0—25 cm to its concentration in the layer 25—130 cm.

concentration frequency histograms of the individual elements are presented in the Fig. 3.

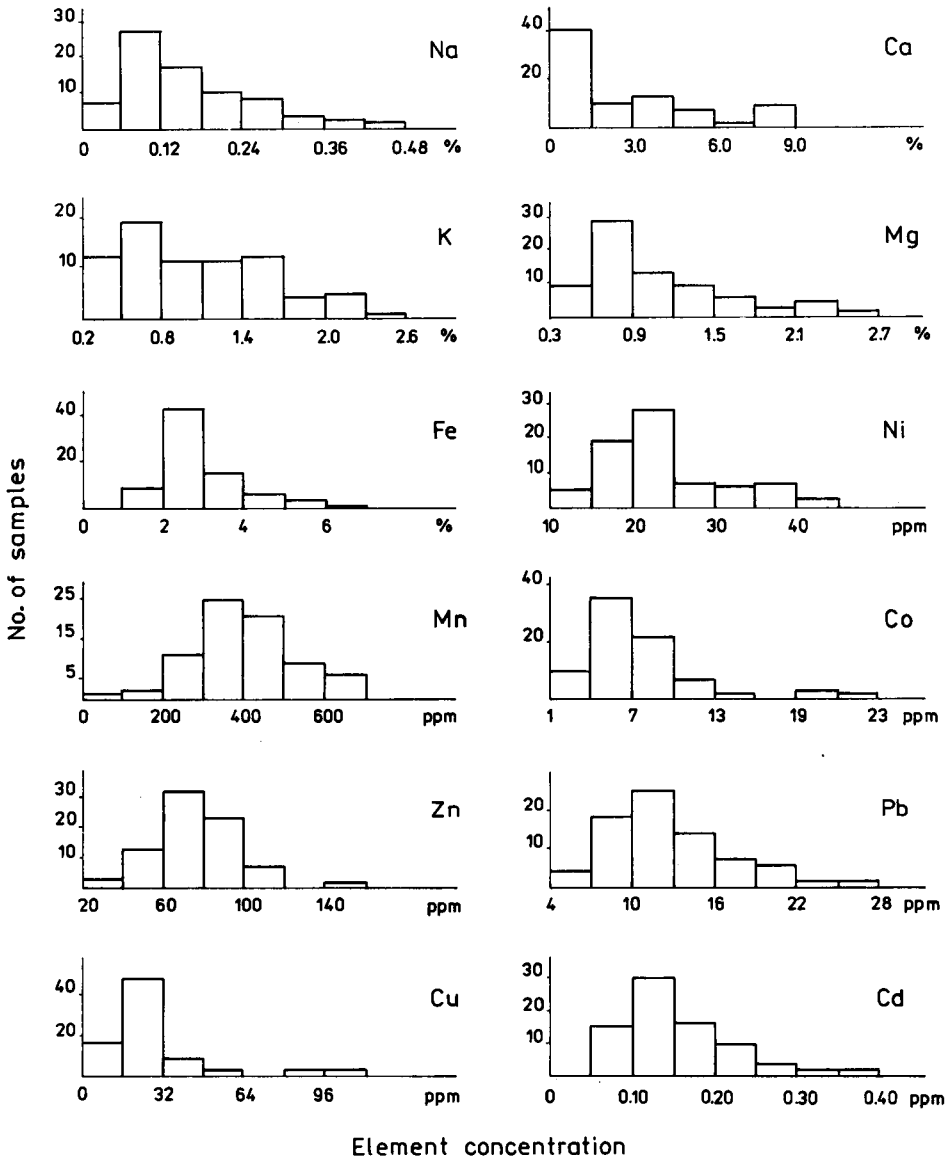


Fig. 3. Frequency histograms of the element concentrations in the Kaffiöyra soil

### Alkali and alkaline earth metal elements

Among the analysed metals, the largest variations of the minimum and maximum contents and the A-coefficient (the ratio of the element content in the depth layer 0—25 cm to its content in the layer 25—130 cm) are shown by

sodium, potassium, calcium and magnesium. These are the elements forming compounds readily soluble in water after their release from weathering primary and secondary minerals and thus having high migration ability (Polański and Smulikowski 1969). These elements occur in relatively high concentrations in sea water and during storms in form of aerosol they enrich the soils neighbouring the seaside (Tedrow 1966; Marks 1978; Bockheim 1980; Campbell and Claridge 1987).

Although sodium and potassium are the elements easily leachable from soils and rocks, they have no a decreased concentration in the surface layer ( $A_{NA} = 1.06$ ,  $A_K = 1.10$ ). However, a distinct enrichment in sodium and potassium have been observed in the organic horizon O and in the humic horizon Ah of the Gelic Cambisols (Plichta, Kuczyńska and Sapek 1991). Hence one may conclude that the contents of sodium and partly potassium in the Kaffiöyra soil depend on the inflow of the marine aerosol. The lack of the noticeable increase of these elements in the depth layer 0–25 cm may be caused by their simultaneous leaching to the deeper soil layer and mainly by cryogenic processes. The latter, especially in Gelic Gleysols, result in blurring the effects of the processes, differentiating the soil profile chemical properties due to vertical and horizontal movements of the soil material and water (Karavaeva 1974).

Sodium concentrations of marine origin have been sporadically found in form of efflorescences of thenardite ( $\text{Na}_2\text{SO}_4$ ) on the frontal-lateral moraines of Avatsmark Glacier. Thenardite (or mirabilite  $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ ) is the mineral precipitating from sea water during freezing, and next blown away from the ice surface (Campbell and Claridge 1987). The thenardite efflorescences presence in Spitsbergen has been stated by Smith (1959).

The surface soil layer is distinctly poorer in calcium and magnesium. The A-coefficient values for these elements equals 0.42 and 0.75, respectively.

The surface horizons of the Kaffiöyra tundra soils, formed from sands and gravels, are generally noncalcareous (Plichta, Kuczyńska and Sapek 1990). The intensive  $\text{CaCO}_3$  removal from the surface layers of the Arctic soils has been indicated by Hill and Tedrow (1964) and Tedrow (1966, 1968). They found few-millimetre thick carbonate precipitates on the lower side of pebbles occurring in the soil profile. Similar pedogenic carbonate precepitates have been formed in soils of Spitsbergen in the regions Hornsund and Kaffiöyra (the present authors' observations).

### Heavy metals

The concentrations of the majority of the heavy metals in the Kaffiöyra soils are similar to the values typical of the other Earth's regions (Table 2), and they fall in the ranges given for lithosphere by Aubert and Pinta (1977).

Average heavy metal contents in soils

Table 2

Element	Spitsbergen	Poland		Scotland <sup>3*</sup>	Canada <sup>4*</sup>	World <sup>5*</sup>
		1*	2*			
Fe %	2.9	1.83	1.35	—	—	—
Mn ppm	392	465	322	450	520	500—1000
Zn ppm	75	46	36	40	74	50—100
Cu ppm	23.4	12	8.8	12	22	15—40
Ni ppm	24.1	—	12.7	25	20	20—30
Co ppm	7.4	—	4.7	8	21	10—15
Pb ppm	12.5	19	10.3	15	20	15—25
Cd ppm	0.14	0.17	0.27	0.4	—	—

1\* Kabata-Pendias (1981)

2\* soils developed on tills and silty sediments (Czarnowska and Gworek 1987)

3\* Berrow and Reaves (1984)

4\* McKeague and Wolynetz (1980)

5\* Aubert and Pinta (1977)

Higher concentrations of certain heavy metals (e.g. Mn, Pb, Cd, Zn and Cu) have been observed in humic horizons than in their parent rocks in the most of the temperate zone soils (Skłodowski and Sapek 1977; Kabata-Pendias 1981; Czarnowska and Gworek 1987; Dziadowiec and Plichta 1987). This phenomenon is connected with biological accumulation and the airborne industrial pollution of soils. Such an enrichment in heavy metals has not been observed in the depth layer 0—25 cm of the studied soil, except for lead and cadmium. This is caused by absence of a biological accumulation of elements in this layer due to a shallow distribution of plant roots. The main root mass in the Arctic tundra occurs in the surface layer at the depth of 0 to 10 or 15 cm (Aleksandrova 1969; Dennis 1977).

The calculated A-coefficient for the analysed heavy metals shows a small decrease of concentrations of Fe, Mn, Co, Ni and Cu in the surface soil layer resulting from pedogenic processes. The values of the A-coefficient for these elements range from 0.81 to 0.90.

However, the surface layer is enriched in lead and cadmium, with the A-coefficient 1.16 and 1.23, respectively. Because of the small role displayed by the biogenic accumulation in the Arctic tundra soils, the anthropogenic pollution brought by a distant atmospheric transport appears to be the only source of lead and cadmium enrichment.

Generally, soils show a good correlation of the certain heavy metal concentrations and the fine grain separates contents (Woclawek 1963; Kabata-Pendias 1981; Czarnowska and Gworek 1987). However, in the Kaffiöyra tundra soil any distinct correlation between the heavy metal concentrations and the contents of the grain separates <20  $\mu\text{m}$  and <2  $\mu\text{m}$  has not been found (Table 3). Maybe, this feature is typical of the Arctic soils.

Most of the heavy metals in the analysed soil specimens shows a significant correlation one with another. Correlation coefficient higher than 0.7 have been obtained for the iron-nickel, iron-cobalt, copper-cobalt and copper-nickel pairs. The similar behaviour of Fe, Ni and Co results from their similar geochemical properties (Polański and Smulikowski 1969). The linear regression equations for metal pair of the correlation coefficients higher than 0.7 are presented in Fig. 4.

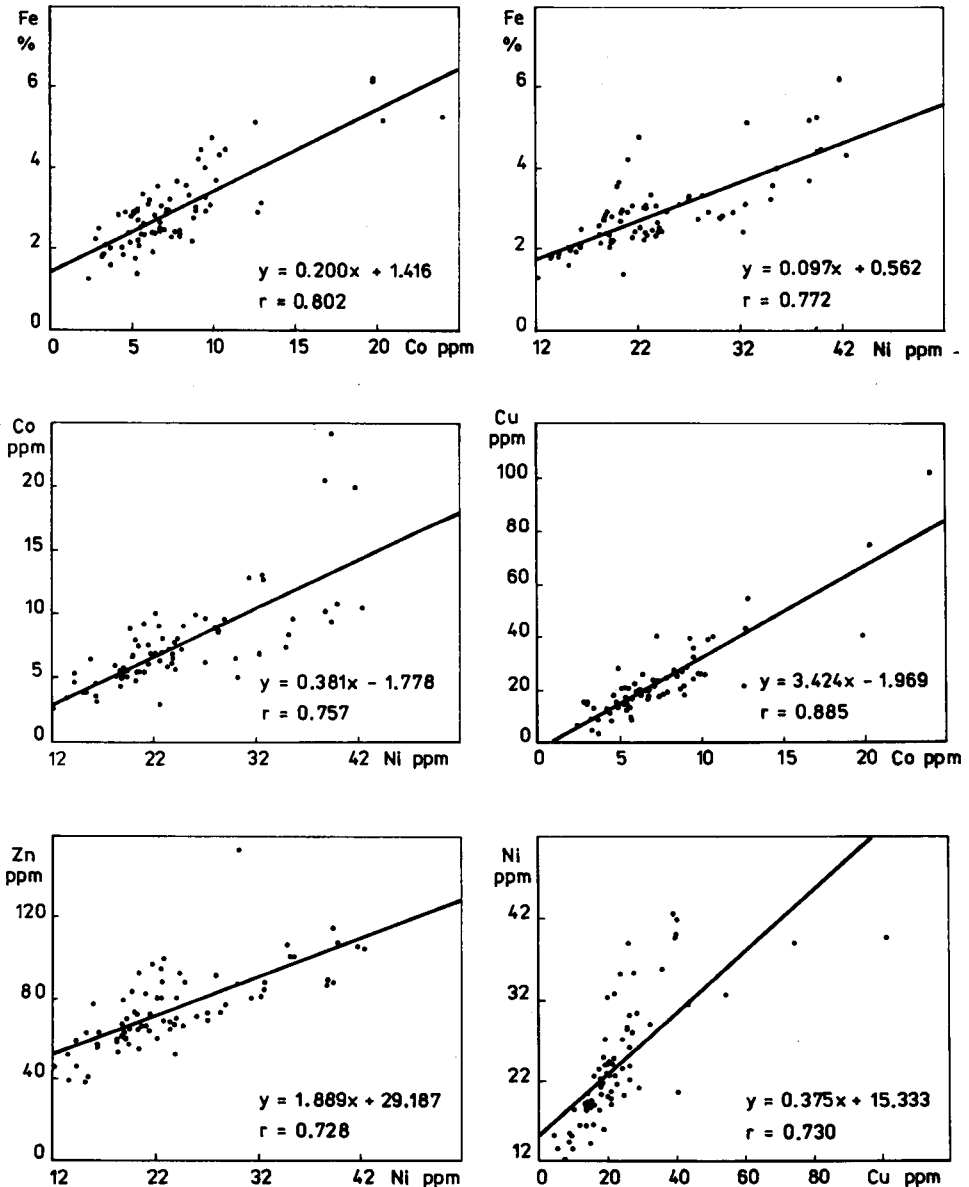


Fig. 4. Linear regressions of the heavy metal pair with the correlation  $r > 0.7$



Correlations between heavy metal concentrations and organic carbon content are shown in the Table 3. Similarly as in the temperate zone soils (Kabata-Pendias 1981; Czarnowska and Gworek 1987), any significant relation between these soil features has not been found in the Arctic tundra soils.

Table 3  
Correlation coefficient of the contents of heavy metals, organic carbon and grain separates < 20  $\mu\text{m}$  and < 2  $\mu\text{m}$

	Fe	Mn	Zn	Cu	Ni	Co	Pb	Cd
C %	0.09	0.25*	0.09	0.06	0.00	0.01	0.10	0.07
< 20 $\mu\text{m}$	0.07	0.12	0.23	0.15	0.42**	0.12	0.06	0.12
< 2 $\mu\text{m}$	0.09	0.09	0.21	0.16	0.43**	0.12	0.13	0.17
Fe		0.52**	0.56**	0.69**	0.77**	0.80**	0.35**	0.39**
Mn			0.28*	0.43**	0.30*	0.47**	0.35**	0.33*
Zn				0.52**	0.74**	0.48**	0.39**	0.65**
Cu					0.72**	0.89**	0.19	0.46**
Ni						0.76**	0.24	0.50**
Co							0.18	0.39**
Pb								0.61**

\* Significant at 5% level.

\*\* Significant at 1% level.

## Conclusions

The performed studies of the chemical composition of the Kaffiöyra tundra soils yield the following conclusions:

1. Average heavy metal concentrations in soil samples collected at the depth 0—130 cm are as follows: Fe 2.90%, Mn 392 ppm, Zn 75 ppm, Cu 23.4 ppm, Ni 24.1 ppm, Co 7.4 ppm, Pb 12.5 ppm and Cd 0.14 ppm.

2. The surface layer 0—25 cm is slightly poorer in Fe, Mn, Co, Cu and Ni.

3. The studied soils have the surface layer slightly enriched in Pb and Cd, probably due to atmospheric pollutions.

4. The surface layer samples are distinctly poorer in Ca and Mg.

5. The correlations between contents of the individual heavy metals and organic carbon, and, on other hand, the grain separates < 20  $\mu\text{m}$  and < 2  $\mu\text{m}$  have not been found.

6. The high correlations ( $r > 0.7$ ) have been found for the measured contents of the heavy metals pairs Fe-N, Fe-Co, Cu-Co and Cu-Ni.

## References

- Aleksandrova V.D. 1969. Nadzemnaja i podzemnaja massa rastenij poljarnoj pustyni ostrova Zemlja Aleksandry (Zemlja Franza-Josifa). — *Prob. Botaniki*, 11: 47—60.
- Aubert H. and Pinta M. 1977. Trace elements in soil. *Developments in Soil Science* 7. — Elsevier—Amsterdam, Oxford, New York, 395 pp.

- Berrow M.L. and Reaves G.A. 1984. Background levels of trace elements in soils. — Proc. Int. Conf. Environmental Contamination, London, July 1984, CEP Consultants Ltd, Edinburgh: 333—340.
- Bockheim J.G. 1980. Properties and classification of some desert soils in coarse-textured glacial drift in the Arctic and Antarctic. — *Geoderma*, 24: 45—49.
- Campbell I.B. and Claridge G.G.C. 1987. Antarctica: soils, weathering processes and environment. — *Developments in Soil Science* 16. Elsevier—Amsterdam, Oxford, New York, 359 pp.
- Czarnowska K. and Gworek B. 1987. Metale ciężkie w niektórych glebach środkowej i północnej Polski. — *Rocz. Glebozn.*, 38 (3): 41—57.
- Dennis J.G. 1977. Distribution patterns of belowground standing crop in Arctic tundra at Barrow, Alaska. — *Arctic and Alpine Res.*, 9 (2): 113—127.
- Dziadowiec H. and Plichta W. 1987. Materiały do przyrodniczej charakterystyki gleb Rolniczego Zakładu Doświadczalnego UMK w Konieczynie i pól doświadczalnych we wsi Grębocin. — *Acta Univ. N. Copernici, Biologia* 35, 72: 41—62.
- FAO-UNESCO 1974. Soil map of the world, 1, Legend, Paris., 59 pp.
- Gugnacka-Fiedor W. and Noryśkiewicz B. 1982. The vegetation of Kaffiöyra, Oscar II Land, NW Spitsbergen. — *Acta Univ. N. Copernici, Geografia* 16 (51): 203—238.
- Hill D.E. and Tedrow J.C.F. 1961. Weathering and soil formation in the Arctic environment. — *Am. J. Science*, 239: 84—101.
- Kabata-Pendias A. 1981. Zawartość metali ciężkich w glebach uprawnych Polski. — *Pam. Puławski*, 74: 101—111.
- Karavayeva N.A. 1974. Major kinds of gley soils of the tundra and northern taiga regions in the Soviet Union. — *Geoderma*, 12: 91—99.
- Klimaszewski M. 1960. Geomorphological studies of the western part of Spitsbergen between Kongsfjord and Eidembukta. — *Zesz. Nauk. U.J., Przegl. Geogr.*, 1: 91—179.
- Marks R. 1978. O emisji i przenoszeniu aerozolu morskiego w rejonie fiordu Hornsund na Spitsbergenie. — 5 Symp. Polarne, Gdańsk-Gdynia, Mat., 2: 60—69.
- McKeague J.A. and Wolynetz M.S. 1980. Background levels of minor elements in some Canadian soils. — *Geoderma*, 24: 299—307.
- Niewiarowski W. 1982. Morphology of the forefield of the Aavatsmark Glacier (Oscar II Land, NW Spitsbergen) and phases of its formation. — *Acta Univ. N. Copernici, Geografia*, 16 (51): 203—238.
- Plichta W., Kuczyńska I. and Sapek A. 1991. Profile distribution of metals in Gelic Cambisols of Kaffiöyra, Spitsbergen. — *Pol. Polar Res.*, 12 (2): 00—00.
- Polański A. and Smulikowski K. 1969. *Geochemia*. — Wyd. Geol., Warszawa, 663 pp.
- Sinkiewicz M. and Plichta W. 1987. Możliwość wykorzystania panchromatycznych zdjęć lotniczych w kartowaniu gleb arktycznych na przykładzie Kaffiöyry, NW Spitsbergen. — *Fotointerpretacja w Bad. Polarn., Ogólnopolskie Seminarium, Toruń 1987. Mat.*: 46—52.
- Skłodowski P. and Sapek A. 1977. Rozmieszczenie Fe, Zn, Mn, Cu, Co, Ni, Pb i Cd w profilach czarnoziemów leśno-stepowych. — *Rocz. Glebozn.*, 18: 71—84.
- Smith J. 1956. Some mowing soils in Spitsbergen. *J. Soil Sci.* 7, 1: 10—21.
- Tedrow J.C.F. 1966. Polar desert soils. — *Soil Sci. Soc. Am. Proc.*, 30: 381—387.
- Tedrow J.C.F. 1968. Pedogenic gradients of the polar regions. — *J. Soil Sci.*, 19 (1): 197—204.
- Tedrow J.C.F. 1973. Polar soil classification and the periglacial problem. — *Biul. Perygl.*, 22: 285—294.
- Wocławek T. 1963. Studia nad zawartością mikroelementów w niektórych glebach erodowanych i deluwialnych środkowej części Pojezierza Mazurskiego. — *Zesz. nauk A.R.T., Olsztyn, Rol.* 1: 5—56.

Received July 5, 1988

Revised and accepted March 15, 1989

## Streszczenie

W pracy przedstawiono zawartość metali w glebach tundry niziny nadmorskiej Kaffiöyra, Spitsbergen (fig. 1). Średnie zawartości metali ciężkich wynoszą: Fe — 2,9%, Mn — 392 ppm, Zn — 75 ppm, Cu — 23,4 ppm, Ni — 24,1 ppm, Co — 7,4 ppm, Pb — 12,5 ppm i Cd — 0,24 ppm (tabela 1). Warstwa powierzchniowa gleb 0—25 cm jest zubożona w Ca i Mg w stosunku do warstwy 25—130 cm. Również zawartości metali ciężkich jak Fe, Mn, Co, Ni i Co są w tej warstwie nieco niższe. Współczynniki wzbogacenia powierzchni w Pb i Cd wynoszą odpowiednio 1,16 i 1,23. Wskazują one na dopływ tych pierwiatków do gleby prawdopodobnie z zanieczyszczeń atmosferycznych. Współczynniki korelacji pomiędzy poszczególnymi pierwiastkami a węglem organicznym i frakcjami uziarnienia  $< 20 \mu\text{m}$  i  $< 2 \mu\text{m}$  są bardzo niskie (tabela 3). Wysoka korelacja ( $r > 0,7$ ) występuje pomiędzy zawartościami Fe, Ni i Co oraz Cu, Co i Ni. Na fig. 4 przedstawiono równania regresji prostoliniowej dla metali wykazujących korelację  $r > 0,7$ .