Macro- and microelements in soil profile of the moss-covered area in James Ross Island, Antarctica

Ondřej Zvěřina[1], Pavel Coufalík[1], Tomáš Vaculovič[1], Jan Kuta[2], Josef Zeman[3], Josef Komárek[1]

[1]*Department of Chemistry, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic*
[2]*Research Centre for Environmental Chemistry and Ecotoxicology (RECETOX), Faculty of Science, Masaryk University, Kamenice 126/3, 625 00 Brno, Czech Republic*
[3]*Department of Geological Sciences, Faculty of Science, Masaryk University, Kotlářská 2, 611 37 Brno, Czech Republic*

Abstract
The study of Antarctic ecosystem provides a valuable insight into the nature development on the Earth. Biocenosis formation and colonization of land by organisms are noticeable especially in newly-deglaciated areas. In this research, soil profile development in the coastal zone of James Ross Island was investigated. The main objective was the characterisation of soil horizons. The contents of As, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Ni, P, Se and Zn were measured using ICP-MS technique. Soil parameters like organic carbon content, pH and content of sub-63 μm fraction were also determined. Based on the results obtained, the mineral-depleted and mineral-enriched layers in the soil profile were distinguished. With increasing depth, the shallow soil profile consisted mainly of weathered regolith. Apparently, the basic processes which are prerequisite for the development of soil ecosystem in the studied area were confirmed.

Key words: Soil profile, macroelement, microelement, James Ross Island

Introduction

With exception of coastal oases, the most of Antarctica's surface is considered as a polar desert. The Antarctic Peninsula presents a unique place for the exploration of newly deglaciated territories. In the last fifty years, ongoing significant warming (Turner et al. 2005) enables an investigation of dramatic changes in the ecosystem. Climatic factors (rainfall, number of non-freezing days), erosion, a presence of soil moisture and a distance from the coast are critical determinants for the soil development. A formation of inland soil takes a very long time mainly due to low temperatures which prevent the growth of soil microorganisms. Just a small amount of soil biota occurs in the surface layer of majority of Antarctic soils. Therefore, the organisms have a little impact to soil formation with an exception of erosive effect of some lichen species (Cambell et Claridge 1987, Øvstedal et Smith 2001).

During the summer season, the temperatures are above freezing point in the James Ross Island. High temperature

---

Received June 28, 2012, *accepted* September 29, 2012.
*Corresponding author: 175365@mail.muni.cz
Acknowledgement: Authors are grateful to Czech Polar project for providing of infrastructure (Johann Gregor Mendel Station).

enables an occurrence of soil water in liquid form which supports the soil development, biological and chemical reactions. In this type of coastal oasis, the colonization of plants such as algae, cyanobacteria, mosses and lichens take place. New soil matter from bedrock is generated in this locality. Besides, an organic material is produced by microflora under propitious conditions. Nevertheless, the soils are formed in shallow layers only.

The main aim of this research was an evaluation of composition of upper soil layer in the maritime area. The subject of interest was the quantification of macro-elements and important nutritious micro-elements (Ca, Co, Fe, K, Mg, Mn, P, Se and Zn) and other elements without nutrition contribution (As, Cd, Cr, Cu and Ni). The second goal is a consideration of development of weathered profile and soil horizons.

Background contents of some elements in Antarctic soils and sediments were published by several authors (*e.g.* Bargagli et al. 1995, 1998 and 1999, Crockett 1998, Giordano et al. 1999, Negoita et al. 2001, Ribeiro et al. 2011). Our aim was to evaluate element content in the soils from the James Ross Island.

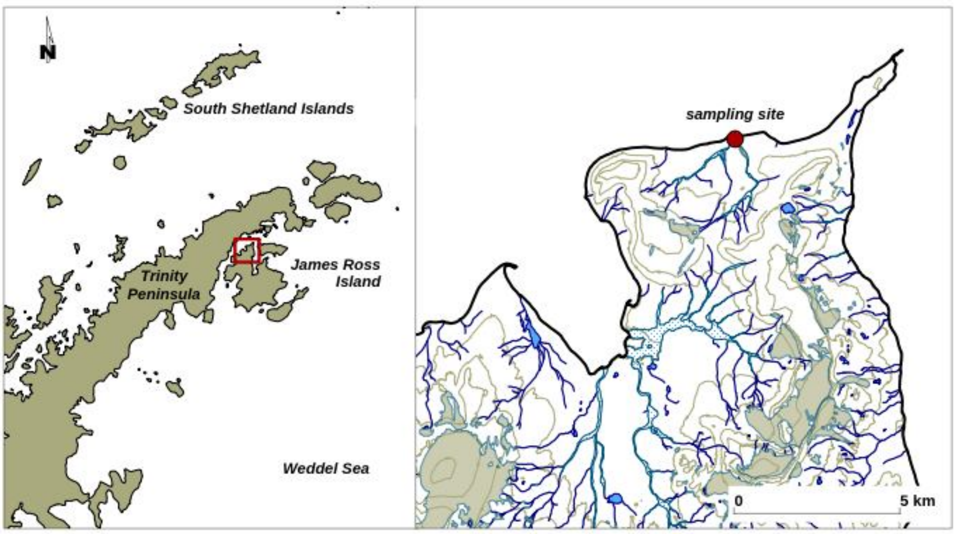

Fig. 1. Location of sampling site on James Ross Island.

Material and Methods

Sampling locality and studied material

The Johann Gregor Mendel Station is located in the northern part of James Ross Island in the coastal zone. Sampling site in the vicinity of Czech polar station in the altitude of 5 m above sea level was chosen (Fig. 1). The selected locality is impacted by sea aerosols which affect the chemistry of soil. Therefore, the studied locality is enriched by minerals transported by sea-spray. Geologically, the island is formed mainly from basalts and andesites of the Antarctic Andes (Cambell et Claridge

1987). Sampling site is localized in permanently deglaciated area which is affected by periodical flooding caused by melting water from snowfields. The soil development in maritime zone is significantly influenced by abundant precipitation and higher temperatures in the comparison with an inland environment. Those factors make this zone more favourable for the plant life and enable the accumulation of organic matter.

The soil profile was taken from the site covered by a moss (*Bryum* sp.). A pit was excavated to the depth of 40 cm and the samples were collected from a side of the pit using a stainless steel trowel (Fig. 2). A special care was taken to avoid any contamination from material falling down by the pit sides. The samples were air-dried at 25°C in the laboratory of J. G. Mendel station, sieved through 2 mm nylon sieve (Linker Industrie-Technik, Germany) and then stored in PE bags at 4°C until the analysis.

Fig. 2. Excavation of sampling pit (Photo: Miloš Barták).

Analytical methods

The soil samples were digested using aqua regia according to ISO 11466, which is the most widely used digestion method. The weight of 3 g of sample was placed into 250 ml Erlenmeyer flask and 30 ml of aqua regia was added. A reflux condenser was mounted due to reduction of the evaporation. The flask was left to stay for 16 hours at laboratory temperature. Then, the mixture was boiled for 2 hours in the open system. After cooling down, digests were carefully decanted and diluted to the volume of 100 ml and analysed immediately.

Quadrupole ICP-MS spectrometer Agilent 7500 CE (Agilent, Japan) was used for the determination of selected elements in soil digestions. The spectrometer is equipped by octopole reaction cell to avoid isobaric interferences, Babington nebuliser and double-pass Scott chamber. The conditions were optimized to obtain the best signal/noise ratio.

The content of organic carbon was determined using Vario TOC cube analyser (Elementar, Germany). The weight of 50 mg of soil was placed onto Ag-foil and the sample was treated by addition of 0.5 ml HCl and dried for 30 min. Afterwards, a capsule was formed from the foil and burned in oxygen flow during the analysis. The performed measurements were based on IR absorption of released CO_2.

Results and Discussion

Soil properties

Geologically young soils formed primarily by physical weathering reflect the characteristics of its parent material. The soils in the studied area are based on basaltic bedrock and soil forming processes are strongly influenced by climatic conditions. It corresponds to relatively shallow soil profile observed. The soil horizons were specified by elemental analysis.

An upper layer of studied profile contained regolith particles greater than 2 mm. Organic residues of moss thallus were also present in the surface layer (0 – 2 cm). The rest of profile showed no significant differentiation of soil horizons, and therefore, the horizons were defined chemically. The color of soil was dark grey, which could indicate a low oxidation state of present iron (oxidation processes are relatively slow in polar conditions). A low amount of soil particles smaller than 63 µm was found (Table 1). In addition, the soil also contained stones of parent material and thus, the profile was not compact and homogeneous. However, the soil permeability allowed possible secondary mineral enrichment.

Organic carbon content is generally very low in the Antarctic soils (Campbell et Claridge 1987). A higher content could indicate the presence of organisms which can contribute to the soil-forming processes and biochemical reactions. The values of total organic carbon (TOC) in individual layers are listed in Table 1. TOC in topsoil was 3.3% and was higher than the range of 0.1 – 1.1% reported by Bargagli et al. (1998) for soil beneath the moss cover at Edmonson Point (Victoria Land). However, in the mentioned work, upper 3 cm of surface layer was collected instead of 2 cm in this work. The similar TOC contents ranging from 0.09 to 2.65% with the highest TOC levels in upper layer were reported by Navas et al. (2008) for sediments samples from Byers and Hurd peninsulas (Livingston Island).

A slightly alkaline pH of antarctic soils is reported very often (Campbell et Claridge 1987). Nonetheless, the soil acidity can vary considerably depending on the specific local conditions (Claridge et Campbell 1987). The presence of sea salts and their solubility are important factors influencing soil acidity in the coastal areas. The pH ranged from 6.3 to 8.0 (Table 1) and the alkalinity increased with the depth. It can be presumed that the soil has a weak buffering capacity due to low amount of particles below 63 μm and low carbon content. Thus, the pH balance is affected primarily by the presence of slightly alkaline sea salts. The same trends of increasing pH value with the depth in the sediments were reported by Navas et al. (2008).

subsamples	**<63 μm** [%]	**pH**	**TOC** [%]
0 – 2 cm	1.93	6.5	3.3
2 – 10 cm	2.57	6.3	1.5
10 – 20 cm	4.07	7.7	1.2
20 – 30 cm	3.30	8.0	0.5
30 – 40 cm	0.95	7.9	0.6

Table 1. Soil properties.

Contents of elements

Individual soil horizons were defined according to the elemental analysis of collected subsamples (Table 2). The surface layer (0 – 2 cm) can be defined as soil horizon with mineral depletion. This layer, however, has a high concentration of phosphorus, which could be bound probably in organic matter and in emerging phosphates.

In the following layers (2 – 10 and 10 – 20 cm), the concentration of elements is typical for the enriched soil horizon. The higher content of clay minerals containing Mg, Ca and K, and elements sensitive to redox potential as Fe, Mn and As can be observed in these subsamples. Both clay minerals and iron oxyhydroxides have a high sorption capacity and can accumulate heavy metals. The concentration of mentioned elements decreases with increasing depth of samples (20 – 30 and 30 – 40 cm). Presumably, this horizon corresponds to eroded subsoil with pieces of parent material and the concentration of elements is typical for bedrock.

Measured phosphorus contents in the profile are comparable with the range of 400 – 3710 mg kg^{-1} obtained for similar type of samples by Bargagli et al. (1998). The contents of Fe are slightly lower in comparison with the mentioned report; however, iron originates rather from bedrock and does not evince any substantial nutrition effect. In the another paper, Bargagli et al. (1999) published the contents of selected elements in the surface soil in Victoria Land (continental Antarctica). Observed calcium levels were significantly higher than the levels measured in this work. The same elevated level was found for potassium. On the contrary, Mg, Cu, Mn and Zn contents were consistent. Absolute concentrations of toxic elements (As, Cu, Cd, Cr, Ni) were within the range reported by Ribeiro et al. (2011) in sediment profiles from the

Admirality Bay (King George Island). The total contents of Zn and Cu were comparable with the levels reported by Chaparro et al. (2007) for the nearby Seymour Island, but the content of Cr was significantly lower in our study area and Ni level was also slightly lower. The constant cadmium content among the all subsamples was notable. Bargagli et al. (1998) reported a significant accumulation of Cd in moss, however, in this work, elevated cadmium level was not observed in the upper layer enriched by moss thallus. This fact could be caused by more intensive water elution in the coastal area supported by weak acid environment of surface layer. The chromium content was almost two orders of magnitude lower in the comparison with background concentration reported by Crockett (1998) for the grey soil from McMurdo station. Similarly, lower levels of As, Cu, Fe, Ni and Zn were also found. Most likely, these values are influenced by the composition of source material, since the same elution ability from the soil can not be assumed for these elements.

subsample	Ca	Co	Fe	K	Mg	Mn	P
0 – 2 cm	3.3×10^3	8.7	26×10^3	1.9×10^3	5.8×10^3	410	1000
2 – 10 cm	3.6×10^3	13	35×10^3	2.2×10^3	8.2×10^3	590	720
10 – 20 cm	3.8×10^3	13	37×10^3	2.2×10^3	8.3×10^3	600	850
20 – 30 cm	3.3×10^3	12	33×10^3	1.9×10^3	7.6×10^3	600	640
30 – 40 cm	3.2×10^3	12	32×10^3	2.0×10^3	7.5×10^3	540	600

subsample	Se	Zn	As	Cd	Cr	Cu	Ni
0 – 2 cm	0.3	43	4.6	0.07	2.7	14	19
2 – 10 cm	0.1	56	5.4	0.07	12	17	23
10 – 20 cm	<0.02	57	4.9	0.07	16	20	26
20 – 30 cm	<0.02	52	4.6	0.07	8.0	17	24
30 – 40 cm	<0.02	49	4.5	0.07	4.9	18	24

Table 2. Contents of elements in soil profile in mg kg^{-1} (RSD for all measurements was < 8 %).

Conclusion

The Antarctic soils represent a unique component of the fragile Antarctic ecosystem. Just as in desert areas, a comprehensive development of soil is significantly limited by natural conditions. In this research, the samples from a soil depth profile were collected at the James Ross Island and characterised with respect to the evaluation the soil development. Absolute content of the elements and their distribution in relation to the depth was studied. In essence, the studied profile showed a typical features of soil development. Although the profile is shallow and the possibility of chemical weathering is limited, it can be expected that chemical weathering takes place and affects the formation of soil profile.

References

BARGAGLI, R., BROWN, D.H. and NELLI, L. (1995): Metal biomonitoring with mosses: procedures for correcting for soil contamination. *Environmental Pollution*, 89: 169-175.

BARGAGLI, R., SANCHEZ-HERNANDEZ, J.C., MARTELLA, L. and MONACI, F. (1998): Mercury, cadmium and lead accumulation in Antarctic mosses growing along nutrient and moisture gradients. *Polar Biology*, 19: 316-332.

BARGAGLI, R., SANCHEZ-HERNANDEZ, J.C. and MONACI, F. (1999): Baseline concentrations of elements in the antarctic macrolichen *Umbilicaria decussata*. *Chemosphere*, 38: 475-487.

CAMPBELL, I. B., CLARIDGE, G. G. C. (1987): *Antarctica: Soils, Weathering Processes, and Environment: Development in soil science 16*. Elsevier Science Publishers. Amsterdam.

CROCKETT, A. B. (1998): Background levels of metals in soils, McMurdo Station, Antarctica. *Environmental Monitoring and Assesment*, 50: 289-296.

CHAPARRO, M.A.E., NUÑEZ, H., LIRIO, J.M., GOGORZA C.S.G. and SINITO, A.M. (2007): Magnetic screening and heavy metal pollution studies in soils from Marambio Station, Antarctica. *Antarctic Science*, 19: 379-393.

GIORDANO, R., LOMBARDI, G., CIARALLI, L., BECCALONI, E., SEPE, A., CIPROTTI, M. and COSTANTINI, S. (1999): Major and trace elements in sediments from Terra Nova Bay, Antarctica. *The Science of the Total Environment*, 227: 29-40.

NAVAS, A., LÓPEZ-MARTÍNEZ, J., CASAS, J., MACHÍN, J., DURÁN, J.J., SERRANO, E., CUCHI. J.A. and MINK, S. (2008): Soil characteristics on varying lithological substrates in the South Shetland Islands, maritime Antarctica. *Geoderma*, 144: 123-139.

NEGOITA, T.G., STEFANIC, G., IRIMESCU-ORZAN, M.E., OPREA, G. and PALANCIUC, V. (2001): Chemical and biological characterization of soils from the Antarctic east coast. *Polar Biology*, 24: 565-571.

ØVSTEDAL, D.O., SMITH, R.I.L. (2001): *Lichens of Antarctica and South Georgia. A guide to their Identification and Ecology.* Cambridge University Press, Cambridge, p. 411.

RIBEIRO, A.P., FIGUEIRA, R.C.L., MARTINS, C.C., SILVA, C.R.A., FRANÇA, E.J., BÍCEGO, M.C., MAHIQUES, M.M. and MONTONE, R.C. (2011): Arsenic and trace metal contents in sediment profiles from the Admiralty Bay, King George Island, Antarctica. *Marine Pollution Bulletin*, 62: 192-196.

TURNER, J., COLWELL, S.R., MARSHALL, G.J., LACHLAN-COPE, T.A., CARLETON, A.M., JONES, P.D., LAGUN, V., REID, P.A. and IAGOVKINA S. (2005): Antarctic climate change during the last 50 years. *International Journal of Climatology*, 25: 279-294.