Heavy metal concentration in selected soils and sediments of Livingston Island, Deception Island, King George Island, James Ross Island (Antarctica)

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Abstract

This paper evaluated the heavy metal concentration in fine earth and skeleton fraction of the Antarctic soil and sediments in the Admiralty Bay (King George Island); Livingston Island; Whaler´s Bay (Deception Island); James Ross Island and the Trinity peninsula (Antarctica). Total concentrations of eight elements (arsenic, chromium, copper, nickel, lead, strontium, vanadium, and zinc) were determined in sixteen sediments/soils samples and skeleton fraction. For the analyses, eight samples were taken from James Ross Island, four samples from Deception Island, two samples from Trinity peninsula, one sample from Livingston Island, and one sample from King George Island. The contents the elements were determined by inductively coupled plasma mass spectrometry (ICP-MS). Most affected by human activity was the sample collected near permanent station General Bernardo O'Higgins Riquelme - Chile on Trinity peninsula. On this site, the highest concentration of copper in fine-earth (201 ppm), zinc in skeleton (163 ppm) and fine-earth (771 ppm) and strontium in skeleton (733 ppm) and fine-earth (1297 ppm) were found. This location was also exceptional by the residues of penguins' eggs shells and excrements. Samples of skeleton had significantly higher maximum values of analyzed elements compare to the available literature data. Results from all sampled localities are summarized in the text.

Key words: heavy metal concentration of soils in Antarctica, James Ross Island, Deception Island, Livingston Island, King George Island, ICP-MS, fine-earth, soil skeleton, arsenic, chromium, copper, nickel, lead, strontium, vanadium, zinc

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Introduction

Even though Antarctica is one of the most isolated continents on the planet, the negative effects of human activity can be seen even here. With exception of coastal oases, the most of Antarctica's surface is considered a polar desert. The deglaciated territories constitute less than 2 % of the continent's surface, but the majority of human activity is focused specifically in these areas (Campbell et Claridge 1987).

On the global scale, the region of Antarctic Peninsula with its adjacent islands represents the third-most rapidly warming site worldwide. Specifically, the surface temperature has increased to 3.7 ± 1.6°C during the last century resulting in considerable glacier losses that occurred in the vicinity of the Antarctic Peninsula (Vaughan et al. 2003). Over the last two decades, the losses of ice mass have increased by ~140% (Rignot et al. 2008).

In this respect, the area of the Antarctic Peninsula thus represents a unique research region typical by newly deglaciated land and the concurrent human influence on them.

Though heavy metals occur naturally in the Earth's crust, human activity often leads to their higher accumulation. However the differentiation between natural and anthropogenic sources of heavy metals is often difficult. They can be transported even over great distances by *e.g.* binding to dust particles. Their persistent character and generally poor mobility within the soil profile are, however, good indicators of anthropogenic load onto the relatively fragile and simple Antarctic ecosystems. The Antarctic terrestrial ecosystems are probably the simplest ecosystems due to the extremely cold climate, very slow rate of chemical weathering, and no or strongly limited liquid precipitation, resulting in scares and patchy vegetation cover. Historically, it has been accepted that climate (*i.e.* precipitation, temperature) exerts the principal control on chemical weathering (Nezat et al. 2001). Although temperature may be an overriding factor in most environments, it may not explain weathering processes in all situations. For example, despite low temperatures and precipitation in Iceland, chemical denudation rates are higher than in Hawaiian catchments of similar geologic character (Bluth et Kump 1994). The results obtained by Matsuoka (1995) at Sør Rondane Mountains (Antarctica) showed an increased level of chemical weathering by increased specific surface area (due to the effects of frost, glacial abrasion and salts). Data from the continental Antarctica published by Nezat et al. (2001) and Lyons et al. (2002) have shown that the Taylor Valley streams had weathering rates comparable to or greater than the world average, as well as some other drainage basins in temperate and tropical climates. This indicates that chemical weathering in polar region is not primarily controlled by temperature and precipitation. In this case, high rates of physical weathering (*e.g.* frost action, salt weathering and glacial grinding) contribute to the chemical weathering rate as a result of newly-deglaciated rock surfaces exposed to weathering (Nezat et. al. 2001).

The aim of this study was to evaluate the content of heavy metals on selected sites on Antarctic Peninsula, James Ross Island and South Shetland Islands. These sites include the King George Island (KGI), the Livingston Island (LI), the James Ross Island (JRI), the Deception Island (DI), and two selected sites of Antarctic Peninsula (AP). We supposed the minimum antropic influence on the old Czech geo-camp in Botany Bay (AP1) and maximum antropic influence at the General Bernardo O'Higgins Riquelme (Chile) station (AP2).

Material and Methods

Regional setting

The South Shetland Islands are a group of Antarctic islands, lying about 120 km north from the Antarctic Peninsula. The South Shetland Islands are separated from the Antarctic Peninsula by Bransfield Strait. The Islands consists mainly of Mesozoic and Tertiary volcanic and sedimentary rocks (Smellie 1984).

King George Island [KGI] is the largest island (1,150 km^2) of the South Shetlands archipelago and has dimensions of about 95 km by 25 km. The island is covered in 90% of its surface by a glacier. The highest peaks reach only 600–700 m a.s.l. Our sampling sites were located near Bellingshausen (Russia) and Presidente Eduardo Frei Montalva (Chile) stations situated on the Fildes Peninsula in the south-western part of the island. Annual mean temperature at Presidente Eduardo Frei station is −2.3°C and annual mean precipitation is 797.2 mm (according to National Oceanic and Atmospheric Administration 2014-[2]).

Livingston Island [LI] is the second largest island (798 km^2) of the South Shetlands archipelago and has dimensions of about 73 km by 36 km. Air temperatures is rather constant within a year, rarely exceeding 3°C in summer or -11°C in winter. Average annual temperature is -1°C and average annual precipitation is 377 mm mostly in snowfall (Turner et Pendlebury 2004). Our research, sampling site, respectively was located near Hannah point.

Deception Island [DI] is the caldera of an active volcano, with wildly varying microclimate. Near volcanic areas, the air can be as hot as 40°C and some hot springs water temperatures can reach up to 70°C. Our research was focused in Whaler´s bay. The climate of Deception Island is polar maritime. The mean annual air temperature is -3°C. The mean annual precipitation is 500 mm (INACH 2005-[1]).

Antarctic Peninsula [AP] is the northernmost element of mainland Antarctica, and the only part of the continent that extends outside the Antarctic Circle. It is approx. 2,000 km long. Our research was focused on two sites which are located on the opposite coasts of The Antarctic Peninsula. The General Bernardo O'Higgins Riquelme (Chile) station lies on the north coast and the second site, the old Czech geo-camp in Botany Bay, is situated in front of James Ross Island on the south coast. Chilean station Bernardo O´Higgins has annual mean temperature -3.2°C and annual mean precipitation 770.5 mm (INACH 2005-[1]).

James Ross Island [JRI] is a large island in the vicinity of the north-eastern headland of the Antarctic Peninsula, from which it is separated by the Prince Gustav Channel. The island is approximately 2,600 km^2 large and covered in 80% of its surface by a glacier. Mean annual air temperatures are around -7°C, precipitation estimates ranging from 200 to 500 mm per year (Davies et al. 2013). Our research was focused on the deglaciated territory in the northern part of the island (Ulu peninsula).

Sampling

Surface soil material (top 10 cm) was collected by the Czech Antarctic expedition members during the austral summer 2011/2012. List of sampling localities is given in Table 1.The samples were air-dried at 25°C in the Johann Gregor Mendel station laboratory (Czech Antarctic station at James Ross Island) and sealed into Zip-loc PE bags for transport. After transport to the Czech Republic, the samples were sieved through 2 mm sieve.

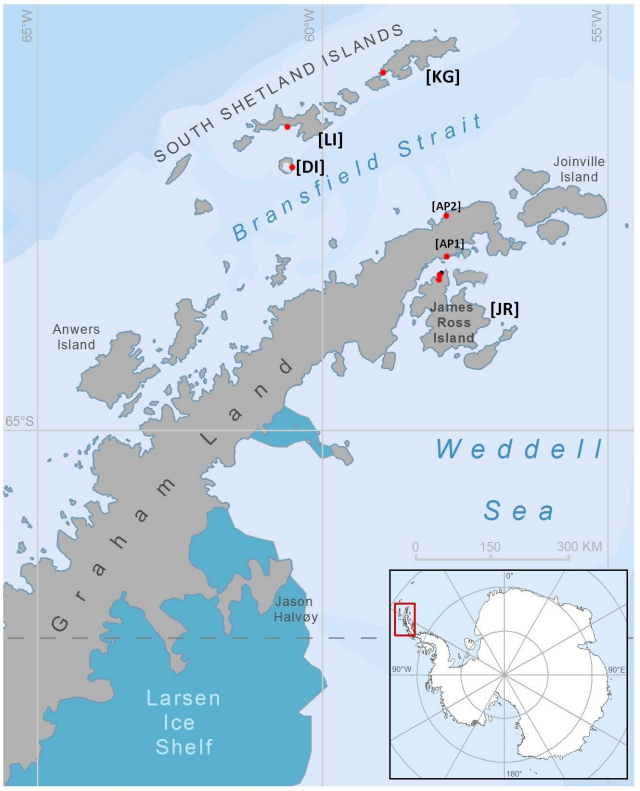

Fig 1: Sampling sites (*Source*: Zdeněk Stachoň, Masaryk University).

Analytical procedures

Soil samples were prepared for chemical and physical analysis according to ISO 11464. The particle size analysis was performed by the pipette method (Gee et Bauder 1986) after the pyrophosphate pre-treatment of the samples. The texture fractions clay-silt-sand (lower than 0.002 mm, 0.002–0.05 mm and 0.05–2.0 mm respectively) were defined. The content of oxidizable carbon (C_{ox}) was determined by the Walkley-Black method (Schumacher 2002), with Novák-Pelíšek modification (C oxidized by 0.167 M $K_2Cr_2O_7$ with addition of H_2SO_4, re-titration with 0.5 M Ammonium iron(II) sulfate). Soil reaction was determined by the saturated paste and fixed soil:water (1:2.5) extract methods (McKenzie 2008).

Contents of Copper, Lead, Zinc, Nickel, Strontium, Vanadium and Chromium were determined by inductively coupled plasma mass spectrometry (ICP-MS) analysis at Bureau Veritas Commodities Canada Ltd. (Vancouver, Canada; former Acme Analytical Laboratories) and Czech Geological Survey (*Agilent 7900x*, Agilent Technologies Inc., Santa Clara, USA). Preparation of soil samples prior to the concentration analysis consisted of the sample decomposition using a combined HF–HCl–HNO_3 digestion in a closed vessel using a 3:7 mixture of concentrated HNO_3 (69%) and HF (51%) acids on a hotplate at 180°C for ~24 h. Afterwards, the dissolved samples were evaporated, 3 ml of HNO_3 were added

to the residues and dried 3 times, and re-digested in 6M HCl. Solution aliquot was transferred to another beaker, evaporated to dryness, converted to nitrate by repeat evaporation (3 times) with 250 µl of 14M HNO_3, and finally dissolved in 2% HNO_3. RSD for all measurements was < 6 %.

Sample	Altitude (m)	Parent material	Latitude	Longitude
JRI (1)[a]	35	Cretaceous deposits undiff.	S 63° 48.01'	W 57° 53.66'
JRI (2)[a]	375	Hyaloclastite tuffs	S 63° 48.50'	W 57° 56.92'
JRI (3)[a]	328	Hyaloclastite breccia's	S 63° 49.27'	W 57° 56.00'
JRI (4)[a]	55	Cretaceous deposits undiff.	S 63° 48.34'	W 57° 55.08'
JRI (5)[a]	53	Cretaceous deposits undiff.	S 63° 48.34'	W 57° 55.08'
JRI (6)[a]	70	Glacial/Fluvioglacial deposits	S 63° 53.14'	W 57° 57.69'
JRI (7)[a]	44	Fluvioglacial deposits	S 63° 53.41'	W 57° 57.66'
JRI (8)[a]	38	Fluvioglacial deposits	S 63° 53.45'	W 57° 57.66'
DI (1)	30	post-caldera series, tuffs	S 62° 58.75'	W 60° 33.28'
DI (2)	10	post-caldera series, tuffs	S 62° 58.72'	W 60° 33.44'
DI (3)	10	post-caldera series, tuffs	S 62° 58.75'	W 60° 33.41'
DI (4)	8	post-caldera series, tuffs	S 62° 58.74'	W 60° 33.41'
LI	50	volcanic material on slope near Hannah point	S 62° 39.14'	W 60° 36.22'
KGI	50	tertiary andesitic and basaltic lavas	S 62° 12.19'	W 58° 57.59'
AP (1)	7	andesite/metasediments	S 63° 39.85'	W 57° 53.58'
AP (2)	10	metasediments	S 63° 19.28'	W 57° 53.89'

Table 1. List of localities.
[a] for more information about samples from James Ross Island *see* Vlček (2016).

Results and Discussion

Table 2 summarize the basic soil properties. In a separated fraction of fine-earth, a surprisingly large representation of a ≤ 0.002 mm (clay) fraction was detected. Variation range of clay fraction (particles < 0.002mm) at James Ross Island was from 1.4 to 18.8%; at Deception Island from 2.2 to 3.9%; at Livingston Island 1.9% and at King George Island 14.9% (*see* Table II). The highest content of clay was 18.8 % in the epipedon of the sample JR (5). Soil reaction and organic matter content can differ strongly depending on the specific local conditions. For all the studied samples, the soil reaction was alkaline or slightly acidic in upper layers of the soil. The content of oxidized carbon was generally low with variation range of 0.01–0.92% C_{ox} in the fine earth. Extreme value of 4.94% was from the penguins nesting site (sample AP-2 in Table 2).

Results from the heavy metal analysis of fine earth and skeleton are summarized in Table 3.

Arsenic content in fine earth was low. Variation range was from < 2 ppm to 13 ppm. Variation range of soil skeleton was from 8 ppm to 20 ppm. The lowest values in fine-earth (< 2 ppm) were in hyaloclastite tuffs (sample JRI2); and in post caldera-series (samples DI 1, 3, 4) and the highest values (13 ppm) was in tertiary andesitic and basaltic lavas (sample KGI). The lowest value in skeleton (8 ppm) and the highest value (20 ppm) were in undiff. Cretaceous deposits (samples JRI1 and JRI5). Arsenic had the strongest correlation in fine earth with clay content (r=0.67) and with vanadium (r=0.65).

	depth (cm)	texture class	clay cont. (%)	silt cont. (%)	sand cont. (%)	pH H_2O	Cox (%)
JRI (1)	0–10	SL	7.8	21.0	71.2	7.94	0.70
JRI (2)	0–10	SL	1.4	32.9	65.7	7.90	0.21
JRI (3)	0–10	SL	13.0	28.7	58.3	7.85	0.36
JRI (4)	0–10	SL	6.7	39.2	54.1	6.35	0.92
JRI (5)	5–15*	L	18.8	35.0	46.2	7.94	0.08
JRI (6)	0–10	SL	9.9	14.0	76.1	7.07	0.34
JRI (7)	0–3	SL	15.3	21.5	63.2	7.03	0.25
JRI (8)	0–10	SL	14.1	25.0	60.9	7.01	0.30
DI (1)	0–10	LS	2.4	22.4	75.2	7.18	0.04
DI (2)	0–10	LS	3.9	15.3	80.8	6.88	0.04
DI (3)	0–10	S	2.2	3.6	94.2	7.36	0.02
DI (4)	0–10	LS	3.4	12.4	84.2	5.82	0.35
LI	0–10	S	1.9	1.6	96.4	6.96	0.01
KGI	0–10	SL	14.9	25.1	60.0	7.20	0.54
AP (1)	0–10	-	n/a	n/a	n/a	6.71	0.28
AP (2)	0–10	-	n/a	n/a	n/a	6.09	4.94

Table 2. Basic soil properties in fine earth (particles ≤ 2.00 mm). *Texture class*: SL (sandy loam), L (loam), LS (loamy sand), S (sand). * first horizon under desert pavement.

Chromium variation range in fine earth was from 5 ppm to 71 ppm. Variation range of soil skeleton was from 2 ppm to 161 ppm. The lowest values in fine-earth (5 ppm) were in tertiary andesitic and basaltic lavas (sample KGI); and in metasediments (sample AP2) and the highest values (71 ppm) was in hyaloclastite tuffs (sample JRI2). The lowest value in skeleton (2 ppm) was in post caldera-series (sample DI3) and the highest value (161 ppm) was in hyaloclastite tuffs (sample JRI2). Chromium had the strongest correlation in fine earth with silt content (r=0.42) and with nickel content (r=0.65).

Copper variation range in fine earth was from 9 ppm to 201 ppm. Variation range of soil skeleton was from 11 ppm to 160 ppm. The lowest values in fine-earth (9 ppm) were in post caldera-series (sample DI3) and in volcanic material (sample LI); and the highest values (201 ppm) was in metasediments (sample AP2). The lowest value in skeleton (11 ppm) was in fluvioglacial deposits (sample JRI7) and the highest value (160 ppm) was in tertiary andesitic and basaltic lavas (sample KGI). The copper in fine earth indicate the strongest correlation with organic matter (r=0.75) and with zinc (r=0.75) and strontium (r=0.68).

Nickel variation range in fine earth was from 4 ppm to 80 ppm. Variation range of soil skeleton was from 3 ppm to 86 ppm. The lowest values in fine-earth (4 ppm) were in metasediments (sample AP2); and the highest values (80 ppm) was in hyaloclastite breccia (sample JRI3). The lowest value in skeleton (3 ppm) was in post caldera-series (samples DI3) and the highest value (86 ppm) was in hyaloclastite breccia (sample JRI3). Nickel had the strongest correlation with active soil reaction (r=0.50) and with chromium (r=0.85).

Lead variation range in fine earth was from < 3 ppm to 21 ppm. Variation range of soil skeleton was from 4 ppm to 19 ppm. The lowest values in fine-earth (< 3 ppm) were in hyaloclastite tuffs (sample JRI2); and in post caldera-series (samples DI 1, 2, 3) and in tertiary andesitic and basaltic lavas (sample KGI). The highest values (21 ppm) was in metasediments (sample AP2). The lowest value in skeleton (4 ppm) were in post caldera-series (samples DI 1, 2), in tertiary andesitic and basaltic lavas (sample KGI), in undiff. Cretaceous deposits (sample JRI4) and the highest value (20 ppm) was in post caldera-series (sample DI 4). Lead in fine earth had the strongest correlation with clay (r=0.64) and organic matter (r=0.79). With other metals, lead had the strongest correlation with zinc (r=0.80 and strontium (r=0.76).

Strontium variation range in fine earth was from 45 ppm to 1297 ppm. Variation range of soil skeleton was from 186 ppm to 733 ppm. The lowest values in fine-earth (45 ppm) was in post caldera-series (sample DI 3); and the highest values (1297 ppm) was in metasediments (sample AP2). The lowest value in skeleton (186 ppm) was in andesite/metasediments (sample AP1) and the highest value (733 ppm) was in metasediments (sample AP2). Strontium content in fine earth indicate the strongest correlation with organic matter (r=0.94), zinc (r=0.97) and copper (r=0.68).

Vanadium variation range in fine earth was from 30 ppm to 189 ppm. Variation range of soil skeleton was from 76 ppm to 364 ppm. The lowest value of fine-earth (39 ppm) was in metasediments (sample AP2) and the highest value (189 ppm) was in tertiary andesitic and basaltic lavas (sample KGI). The lowest value in skeleton (76 ppm) was in metasediments (sample AP2) and the highest value (364 ppm) was in post caldera-series (sample DI 4). Vanadium contents in fine earth indicate the strongest correlation with organic matter (r=0.44) and arsenic (r=0.65).

Zinc variation range in fine earth was from 19 ppm to 771 ppm. Variation range of soil skeleton was from 53 ppm to 163 ppm. The lowest values in fine-earth (19 ppm) in post caldera-series (sample DI3); and the highest values (771 ppm) was in metasediments (sample AP2). The lowest value in skeleton (53 ppm) was in glacial/fluvioglacial deposits and the highest value (163 ppm) was in metasediments (sample AP2). Zinc contents in fine earth indicate the strongest correlation with organic matter (r=0.99) and with strontium (r=0.97) and lead (r=0.80).

Higher concentrations of trace elements were mostly found in skeleton than in soil samples of fine earth (*see* Table 3). This is in agreement with Malandrino et al. (2009), who found out the systematic presence of higher metal content in the skeleton underlying volcanic material than in soils for the arctic regions. Exception from this trend are sites JRI1 (Cr, Cu, Ni, Zn); JRI4 (Pb); JRI5 (Ni, Pb); JRI7 (Ni); DI 2, 3, 4 (Cr, Ni); KGI (Cu, Zn) and AP2 (Cu, Pb, Sr, Zn).

We suppose that the reason was human activity (transportation, waste burning, use of diesel aggregates) around the sampling sites: AP2 (collected near permanent Chilean station General Bernardo O'Higgins Riquelme) on the Trinity peninsula; sample KGI (near station Prezidento Frei), sample DI (near old camp in Whaler's bay) and some samples JRI (near station JGM). It also has to be mentioned that site AP2 is

	As [ppm]		Cr [ppm]		Cu [ppm]		Ni [ppm]	
	fine earth	skeleton	fine earth	skeleton	fine earth	skeleton	fine earth	skeleton
JRI (1)	5	8	22	10	24	16	22	4
JRI (2)	<2	11	71	161	27	33	67	59
JRI (3)	2	9	43	120	36	40	80	86
JRI (4)	4	9	29	121	21	38	23	61
JRI (5)	6	20	8	17	15	13	15	8
JRI (6)	4	11	38	95	11	13	39	38
JRI (7)	5	11	25	27	13	11	27	9
JRI (8)	5	13	24	80	17	21	29	34
DI (1)	<2	11	12	51	11	52	9	25
DI (2)	3	10	19	9	14	28	11	6
DI (3)	<2	10	10	2	9	45	7	3
DI (4)	<2	11	14	7	18	86	11	8
LI	2	12	7	55	9	23	9	22
KGI	13	13	5	17	183	160	7	8
AP (1)	3	12	36	56	15	19	16	16
AP (2)	2	10	5	16	201	119	4	6

	Pb [ppm]		Sr [ppm]		V [ppm]		Zn [ppm]	
	fine earth	skeleton	fine earth	skeleton	fine earth	skeleton	fine earth	skeleton
JRI (1)	8	7	156	467	99	106	81	72
JRI (2)	3	4	375	567	110	211	71	87
JRI (3)	5	6	258	393	71	115	70	69
JRI (4)	8	4	162	593	83	137	74	74
JRI (5)	13	10	216	329	30	92	67	79
JRI (6)	6	11	90	230	53	111	43	53
JRI (7)	8	15	115	287	56	97	59	58
JRI (8)	8	14	109	300	62	139	65	73
DI (1)	<3	4	56	422	61	334	24	99
DI (2)	<3	4	71	255	66	164	26	74
DI (3)	<3	5	45	340	52	248	19	87
DI (4)	6	19	60	398	64	364	25	94
LI	4	9	192	661	80	212	55	70
KGI	<3	4	87	340	189	293	85	78
AP (1)	9	10	79	186	79	162	73	71
AP (2)	21	15	1297	733	39	76	771	163

Table 3. Heavy metals in fine earth (particles lower than 2.00 mm) and skeleton.

not only in the close proximity of the Chilean station, but it is also the nesting site for colony of Gentoo penguins. Thus, the chemistry of this site can be strongly affected by their presence (excrements, egg-shells, *etc.*). Also, Santos et al. (2005) showed significant heterogeneity in the metal content of Antarctic soil depending on geographical distribution.

Other possible reasons may be the high content of soil organic matter (AP2, JRI 3 and 4) and clay (JR5) in some samples. Due to the limited movement of any released metals only in the active layer at high soil reaction is the assumption that they will be adsorb at clay mineral or soil organic matter.

Maximum values of concentrations (in fine earth) in this study are in most cases higher than other published data (*see* Table 4 and 5). The exceptions are reported by Padeiro et al. (2016), who found higher concentration of the Pb, As, Cr, Ni, Pb, Zn, Cu; Crockett (1998) - Cr, Cu; Amaro et al. (2016) - As, Cu; Choi et al. (2012) - Cu and Kabata–Pendias et Pendias (1984) - Cr. Maximum concentrations in the skeleton fraction of the samples measured in this study for all elements exceeded the maximum values reported by the other authors in the general level of content in basalts (Table 4 and 6, Wedepohl 1987, Mielke 1979, Taylor 1964) as well as some elements in the context of studies aimed at specific locations in the Antarctica (Machado et al. 2001, Santos et al., 2005, Groenewe et Beunk 1992, Santos et al. 2005, Košler et al. 2009) *see* Table 6.

In general, the maximum values found for As, Cu, Ni, Sr, V and Zn insoils in this study can be considered high (according to Salminen et al. 2005). Cr (71 ppm, sample JRI2) and Pb (21 ppm, sample AP2) maximum concentration in our samples are close to maximum values reported by Salminen et al. (2005). The authors suggest the high concentration levels in soil as >24.90 ppm for Pb, >37.40 ppm for Ni and >95.00 ppm for Cr. In our soil samples, Ni concentration reached up to 80.00 ppm (sample JRI3) and Cr concentration up to 71.00 ppm (sample JRI2). The presence of Cr and a higher Ni content in the soil from JRI is maybe caused primarily by their high content in basalt, which forms an essential part of the local bedrock. This is confirmed by a statistically significant correlation between Cr and Ni in studied soils. Such correlation is also shown by Salminen et al. 2005. Similarly, Lu et al. (2012) found significant correlation between Cr and Ni (r=0.85) in Antarctic soils and attributed this relationship to geochemistry of environment. For arsenic, Salminen et al. (2005) suggested the high concentration levels in soil to be >12.10 ppm As. Arsenic concentrations at the studied sites reached up to 13.00 ppm (sample KGI). There was found statistically significant correlation between As and V. This also corresponds with high content of vanadium in soils as the highest vanadium concentration of 189.00 ppm was found in the same sample (KGI). Based on Salminen et al. (2005), the high concentration levels of vanadium in soil can be the values above 96.00 ppm V. Also Santos et al. (2005) reported a high average of V concentration (91.00 ppm) on a site in Admiralty Bay (KGI). Suggested level of high concentrations for Cu by Salminen et al. (2005) is >22.20 ppm. The extremely high values were found on sites AP2 (201.00 ppm) and KGI (183.00 ppm). Cu was significantly correlated with Zn and Sr. Salminen et al. (2005) suggested the high concentration levels in soil as >180.00 ppm for Sr, while the highest concentration obtained during our study (1297 ppm found in sample AP2) was 7 times higher. The highest reported Sr concentration is for Galindez Island: 131.10 ppm (Zhovinsky et al. 2014). Based on Salminen et al. (2005) the high concentration levels for zinc in soil can be values >76.00 ppm Zn. The values obtained during this study are about ten times higher than this value with maximum of 771.00 ppm (sample AP2), as in the case of strontium.

Id	Material	As	Cr	Cu	Ni	Pb	Sr	V	Zn
1	Soil	2.00–13.00	5.00–71.00	9.00–201.00	4.00–80.00	3.00–21.00	47.00–1297.00	30.00-189	19.00-771.00
2	Soil	2.00–3.69	8.29–41.40	4.94–22.10	3.00–21.04	9.75–37.6	_[c]	_[c]	9.43-121.00
3	Soil	_[c]	40.00[a]	44.00[a]	5.10[a]	11.50[a]	118.00[a]	91.00[a]	52.00[a]
4	Soil	_[c]	_[c]	19.00–40.00	8.00–18.00	1.4–23.00	_[c]	_[c]	6.60-64.00
5	Soil[b]	0.008-0.950	0.000005-0.00015	0.005–1.27	0.003–0.3	0.0003–1.4	_[c]	_[c]	0.0025-8.875
6	Soil	_[c]	_[c]	51.10–176.50	7.18–25.03	2.76–60.52	_[c]	_[c]	41.57-80.65
7	Soil	0–5.2	154–480	34–50	80–272	1.6–8.4	_[c]	_[c]	101.00–132.00
8	Soil	0.40–1.80	7.50–25.00	_[c]	19.00–95.00	1.40–3.00	_[c]	_[c]	32.00–62.00
9	Soil	1.10–21.00		22.00–220.00	_[c]	9.00-101.00	_[c]	_[c]	94.00-612.00
10	Soil	13.00–23.00	15.00–263.00	47.00–179.00	12.00–141.00	3.00–418.00	_[c]	_[c]	56.00-949.00
11	Soil	_[c]	0.03–0.44	2.02–11.65	0.03-0.16	0.07–2.20	_[c]	_[c]	0.27-2.05
12	Soil	_[c]	_[c]	_[c]	_[c]	_[c]	131.10	_[c]	_[c]
13	Soil	_[c]	51.70	101.00	30.65	7.10	_[c]	_[c]	59.10
14	Soil	5.90	85.00	41.00	30.00	20.00	_[c]	_[c]	78.50
15	Soil	17.00–19.00	35.00–95.00	62.00–111.00	17.00–35.00	5.30–11.00	_[c]	_[c]	74.00-116.00
1	Rock	8.42–20.22	1.79–161.28	11.06–159.76	3.11–86.04	4.15–19.26	186.43–733.25	75.70-364.26	52.79-162.58
16	Rock	_[c]	_[c]	_[c]	60.70[a]	_[c]	542.00[a]	_[c]	_[c]
17	Rock	_[c]		111.00[a]	12.50[a]	7.70[a]	583[a]	107.00[a]	66.00[a]
18	Rock	_[c]	271.00-579.00	34.00-57.30	53.00-144.00	1.78-4.04	328.00-691.00	142.00-199.00	_[c]
19	Rock	5.40	12.00	17.00	23.00	_[c]	_[c]	_[c]	56.00
20	Rock	_[c]	_[c]	40.00-60.00	_[c]	_[c]	_[c]	_[c]	_[c]
21	Rock	2.00[a]	170.00[a]	_[c]	130.00[a]	6.00[a]	465.00[a]	250.00[a]	105.00[a]
22	Rock	2.00[a]	200.00[a]	100.00[a]	150.00[a]	5.00[a]	_[c]	_[c]	100.00[a]

Table 4a. Compared results with the literature data [ppm] (1/2).
[a] Average concent, [b] 0-15 cm horizon, [c] No information is available

Id	Material	Bedrock	Type of concent / method	Locality
[1]	Soil	Volcanic material	Extraction / ICP-MS	King George Island , Livingston Island, Deception Island, Antarctic Peninsula, James Ross Island
[2]	Soil	Basaltic and rhyolitic rocks	Extraction / ICP-AES	Terra Nova Bay region, northern Victoria Land
[3]	Soil	Basalts, basalt-andesites and andesites	Extraction / ICP-OES	Admiralty Bay, King George Island
[4]	Soil	Granitoid bedrocks	Extraction / ICP-MS	Lake Vanda, McMurdo Dry Valleys region, southern Victoria Land
[5]	Soil[b]	Basalt	Extraction / ICP-MS, ICP-OES	Scott Base, New Zealand
[6]	Soil	_[c]	Extraction / ICP-OES, AAS	Fildes Peninsula, King George Island
[7]	Soil	Basalt	Total / XRF	McMurdo Station, Ross Island
[8]	Soil	Basalt	Extraction / ICP-MS, GFAA, CVAA	McMurdo Station, Ross Island
[9]	Soil	_[c]	Extraction / ICP-MS	Fildes Peninsula, King George Island
[10]	Soil	_[c]	Extraction / ICP-MS	Fildes Peninsula, King George Island
[11]	Soil	_[c]	Extraction / ICP-MS	King Sejong Station, King George Island
[12]	Soil	Rhyolite	Extraction / ICP-MS	Galindez Island, Antarctica
[13]	Soil	_[c]	_[c]	Fildes Peninsula, King George Island
[14]	Soil	Volcanic material	Total	Earth crust
[15]	Soil	_[c]	Extraction / ICP-MS	Fildes Peninsula, King George Island
[1]	Rock	This study	Total / ICP-MS	King George Island , Livingston Island, Deception Island, Antarctic Peninsula, James Ross Island
[16]	Rock	Volcanic Rocks	_[c]	King George Island
[17]	Rock	Volcanic Rocks	_[c]	Admiralty Bay, King George Island
[18]	Rock	Alkaline lavas	Total / ICP-MS	James Ross Island
[19]	Rock	Basaltic	Total / ICP-MS	James Ross Island
[20]	Rock	Basalt and gabro	Total	Earth crust
[21]	Rock	Basaltic	Total	Earth crust
[22]	Rock	Basaltic	_[c]	Earth crust

Table 4b. Compared results with the literature data [ppm] (2/2).

	As				Cr				Cu				Ni			
Id	min	max	aver	med	min	max	aver	med	min	max	aver	med	min	max	aver	med
1	2.00	13.00	4.50	4.00	5.00	71.00	23.00	20.50	9.00	201.00	39.00	16.00	4.00	80.00	23.50	15.50
2	=	+	+	+	-	+	-	-	+	+	+	-	+	+	+	-
3	c –	c –	c –	c –	-	+	-	-	-	+	-	-	-	+	+	+
4	c –	c –	c –	c –	c –	c –	c –	c –	-	+	-	-	-	+	+	-
5	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
6	c –	c –	c –	c –	c –	c –	c –	c –	-	+	-	-	-	+	+	-
7	+	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-
8	+	+	+	+	-	+	-	-	c –	c –	c –	c –	-	-	-	-
9	+	-	-	-	c –	c –	c –	c –	-	-	-	-	c –	c –	c –	c –
10	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
11	c –	c –	c –	c –	+	+	+	+	+	+	+	+	+	-	+	+
12	c –	c –	c –	c –	c –	c –	c –	c –	c –	c –	c –	c –	c –	c –	c –	c –
13	c –	c –	c –	c –	-	+	-	-	-	+	-	-	-	+	-	-
14	-	+	-	-	-	-	-	-	-	+	-	-	-	+	-	-
15	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	+

	Pb				Sr				V				Zn			
Id	min	max	aver	med	min	max	aver	med	min	max	aver	med	min	max	aver	med
1	3.00	21.00	8.25	8.00	47.00	1297.00	210.50	112.00	30.00	189.00	74.63	65.00	19.00	771.00	100.50	66.00
2	-	-	-	-	c –	c –	c –	c –	c –	c –	c –	c –	+	+	-	-
3	-	+	-	-	-	+	+	-	-	+	-	-	-	+	+	+
4	+	-	-	-	c –	c –	c –	c –	c –	c –	c –	c –	+	+	+	+
5	+	+	+	+	c –	c –	c –	c –	c –	c –	c –	c –	+	+	+	+
6	+	-	-	-	c –	c –	c –	c –	c –	c –	c –	c –	-	+	+	-
7	+	+	-	-	c –	c –	c –	c –	c –	c –	c –	c –	-	+	-	-
8	+	+	+	+	c –	c –	c –	c –	c –	c –	c –	c –	-	+	+	+
9	-	-	-	-	c –	c –	c –	c –	c –	c –	c –	c –	-	+	-	-
10	=	-	-	-	c –	c –	c –	c –	c –	c –	c –	c –	-	-	-	-
11	+	+	+	+	c –	c –	c –	c –	c –	c –	c –	c –	+	+	+	+
12	c –	c –	c –	c –	-	+	+	-	c –	c –	c –	c –	c –	c –	c –	c –
13	-	+	+	+	c –	c –	c –	c –	c –	c –	c –	c –	-	+	+	+
14	-	+	+	+	c –	c –	c –	c –	c –	c –	c –	c –	-	+	+	-
15	-	+	-	-	c –	c –	c –	c –	c –	c –	c –	c –	-	+	+	+

Table 5. Heavy metals in fine-earth: compared with the literature data [ppm].

Salminen et al. (2005) refered to the significant correlation between Zn and Pb in the soil. This trend was confirmed by the results of this study. In the case of Pb, suggested high values by Salminen et al. (2005) are values of 24.90 ppm. The maximum value of Pb concentration found in the sample AP2 21 ppm approximates the definition of high-value Pb by Salminen et al. (2005).

In 78% of cases, higher concentration of metals was found in skeleton than fine earth. This is in agreement with Malandrino et al. (2009), who found out the systematic presence of higher metal content in the skeleton underlying volcanic material than in soils for the arctic regions.

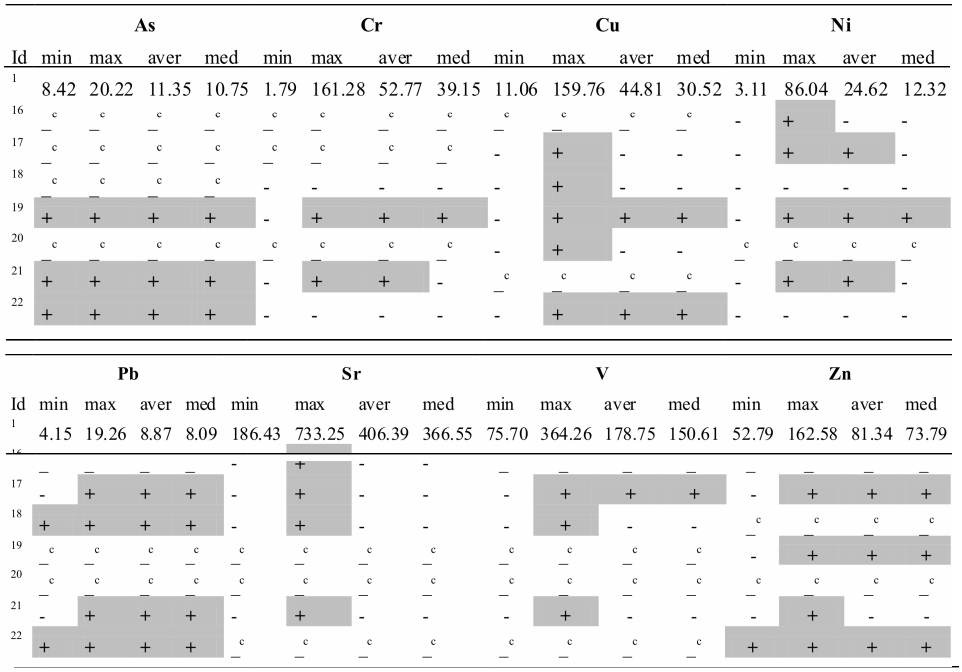

Table 6. Heavy metals in soil skeleton: compared with the literature data [ppm].

+	Higher than literature concent
-	Lower than literature concent
=	Same as literature content
min	in comparison with a minimum published by other authors
max	in comparison with a maximum published by other authors
mean	in comparison with a maximum published by other authors
median	in comparison with a maximum published by other authors

1. This study; 2. Malandrino et al. 2009; 3. Santos et al. 2005; 4. Webster et al. 2003; 5. Sheppard 2000; 6. Lu et al. 2012; 7+8. Crockett 1998; 9. Amaro et al. 2016; 10. Padeiro et al. 2016; 11. Choi et al. 2012; 12. Zhovinsky et al. 2014; 13. Zhao et al. 1998 in Lu et al. 2012; 14. Kabata–Pendias et Pendias, 1984; 15. Pereira et al. 2017; 16. Machado et al. 2001 in Santos et al. 2005; 17. Groenewe et Beunk 1992 in Santos et al. 2005; 18. Košler et al. 2009; 19. Zvěřina et al. 2012; 20. Wedepohl 1987; 21. Mielke 1979; 22. Taylor 1964.

In respect to the Goldschmidt geochemical classification of elements, the correlation between the measured elements are generally following their classification into different groups as litophile (As, Cr, Sr, V) and chalcophile (Cu, Ni, Pb, Zn). Cu, Zn and Pb have high index of correlation between each other thus following their chalcophile nature. The exception from this trend is their strong correlation with Sr, which is provided by the bond to the organic matter as shown by high correlation indexes between organic matter and these elements. Litophile elements As and V show a high correlation. Only the correlation between Cr and Ni cannot be attributed to their geochemical classification.

Conclusions

On selected localities, the content of specified elements: As, Cr, Cu, Ni, Pb, Sr, V and Zn were determined in soil and skeleton samples by ICP-MS. Higher supply of heavy metals in fine-earth (in comparing with soil skeleton) were found for Cu, Pb and Sr in the sampling site AP2; in sample JRI1 for Cr, Cu, Ni and Zn and sample JRI5 for Ni and Pb; samples DI 2, 3, 4 for Cr and Ni; sample KG for Cu and Zn. Anomalous values of some soil samples can be caused by penguin nesting site or by an artificial contamination due to nearby stations (AP2 Chilean Bernardo o´Higgins, KGI – Chilean Prezidento Frei, DI – old camp in Whalers bay *etc*.). At AP2 were found the highest values of Cu, Pb and Zn in fine-earth including the extremely high concentration of Sr (1297 ppm). Most values of the maximum concentrations for the elements As, Cu, Ni, Sr, V and Zn reached higher values of this parameter in comparison with the available literature data.

The maximum concentration of chromium (71 ppm) and lead (21 ppm) closely approach the high values reported by Salminen et al. (2005). The samples of skeleton had a significantly higher maximum values in comparison with available literature.

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