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EVALUATION OF SELECTED BASIC SOIL PROPERTIES AT THE JAMES ROSS ISLAND (ANTARCTICA)

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Abstract

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This study attempts to summarize the basic soil properties of the selected places in the deglaciated areas on the James Ross Island (Antarctica). James Ross Island is a large island near the north-eastern extremity of the Antarctic Peninsula, from which it is separated by the Prince Gustav Channel. The island is approximately 2,600 km^2 large and is covered in 80% of its surface by a glacier. Deglaciated areas cover relatively young soils developing after the parent substrate was deglaciated, but they still have a greatly varying character (fluvial, glacial, volcanic, possibly also aeolian). We determined in a separated fraction of fine earth following proportions of textural fractions: the average *content (±Standard deviation) of clay* was 9.9 ± 1.6%; *silt* 31.9 ± 3.2% and average *content of sand* was 58.6 ± 2.9%. The content of *oxidized carbon* (Cox) was very low, the average Cox content was 0.34 ± 0.06%. The average *active soil reaction* was 6.26 ± 0.45. The average *electrical conductivity* (EC) was 1242 ± 252 µS.cm^{-1}. The average: *calcium content* was 1.48 ± 0.34%; *magnesium content* 1.22 ± 0.19%; *phosphorus content* was 0.06 ± 0.01%; *potassium content* of samples was 0.25 ± 0.05% and *sodium content* was in average 0.46 ± 0.08%.

Keywords: Antarctica, James Ross Island, soil properties, texture, calcium, phosphorus, sodium, potassium

INTRODUCTION

Soil research in Antarctica has been going on for approximately 100 years. Some of the first samples come from Shackleton's expedition in the McMurdo area from 1907–1909, though the samples were analysed first in 1916 by Jensen (Jensen, 1916). Additional studies came virtually only in 1958, which was the International Geophysical Year (IGY) where extensive research in practically all areas of natural sciences was conducted. From the beginning of 1960s also comes one of the first attempts for a detailed classification of Antarctic soils from McCraw (1960). Currently, soil research in Antarctica focuses mainly on the deglaciated areas of west Antarctica, particularly in the Dry Valley, McMurdo Sound or South Shetlands (Bockheim, 2002; Bockheim and Balks, 2008; Campbell and Claridge, 1987; Beyer and Boelter, 2002; Bockheim and McLeod, 2006; López-Martínez *et al.*, 2012). The data on the properties of Antarctic soil can be summarized as follows (Amin, 1993):

1. little chemical weathering or leaching,
2. presence of alkalinity,
3. accumulation of soluble salts,
4. negligible organic matter.

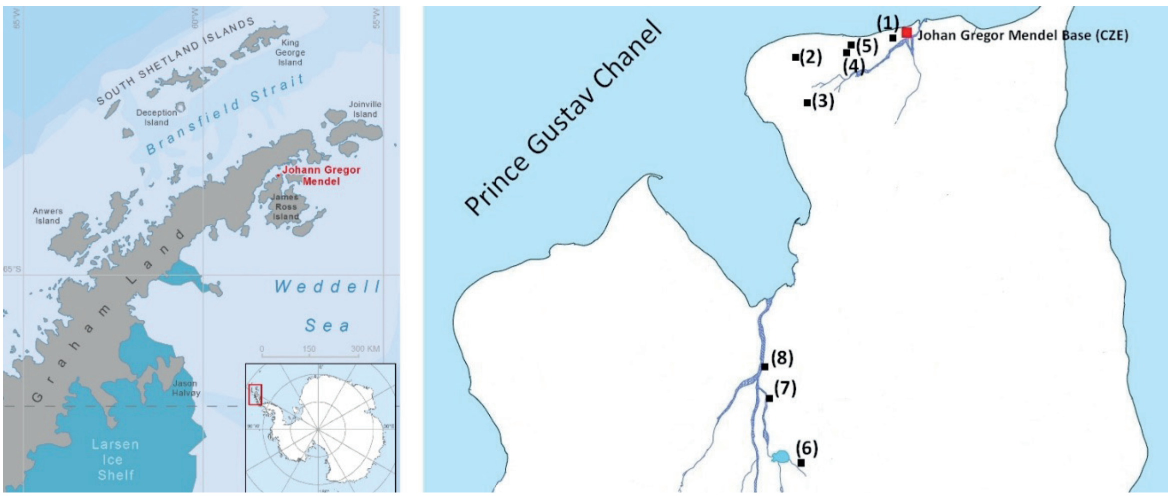
The region of the Antarctic Peninsula represents a unique location for researching newly deglaciated areas, soil creation and the influence of man on these territories. In the last 50 years, significant ongoing warming of these areas has been registered, which can further influence the development of these soils. This study is also important for determining of soil properties and their influence on soil genesis in deglaciated areas. Study attempts to summarize the basic soil properties of the selected sites in the deglaciated areas on the James Ross Island. James Ross Island 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

1: *Permafrost distribution in continental Antarctica. Permafrost in ice-free areas (black); Subglacial permafrost (shaded areas). The −8 °C and −1 °C mean annual air temperature isotherms are taken from Weyandt (Bockheim and Hall 2002). James Ross Island is indicated by red arrow*

I: *Basic spatial and parent matterial properties*

Sample	Latitude	Longitude	Altitude	Type of material
JR (1)	63°48′S,	57°53′W	35	Cretaceous deposits undiff. (geodetic point, near JGM Base)
JR (2)	63°48′S,	57°57′W	375	Hyaloclastite tuffs (Bibby Hill)
JR (3)	63°49′S,	57°56′W	328	Hyaloclastite breccias/Polygonal soil patterns (Johnson Mesa)
JR (4)	63°48′S,	57°55′W	55	Cretaceous deposits undiff. (bottom of Bibby Hill)
JR (5)	63°48′S,	57°55′W	53	Cretaceous deposits undiff. (bottom of Bibby Hill)
JR (6)	63°54′S,	57°57′W	70	Glacial/Fluvioglacial deposits (near Monolith lake)
JR (7)	63°53′S,	57°58′W	44	Fluvioglacial deposits (Monolith stream 1)
JR (8)	63°53′S,	57°58′W	38	Fluvioglacial deposits (Monolith stream 2)

Depth of permafrost/ice: JR (1) 60 cm (ice crystal); JR (4) 60 cm; JR (5) 55 cm; JR (6) JR (7) 55 cm (ice crystal/continuous permafrost); JR (8) 50 cm (ice crystal/continuous permafrost).



2: *Left: Antarctic Peninsula and James Ross Island (source: Zdeněk Stachoň, Masaryk University); Right: detail of northern part of James Ross Island (source: Czech Geological Survey, 2009) with sampling places*

Channel. It is one of several islands around the Antarctic Peninsula known as the Graham's Land. The island is approximately 2,600 km² large and is covered in 80% of its surface by a glacier, which also covers the tallest mounting of the island, Mount Haddington (1,630 m).

MATERIALS AND METHODS

Regional Setting of James Ross Island

Our research was focused on the deglaciated territory in the northern part of the island (Ulu Peninsula). The deglaciation of the lower parts began approximately 12.9 ka ago (Nývlt *et al.*, 2014). Mean annual air temperature in deglaciated area (and at sea level) is circa –6.5 °C and the average annual precipitation, is estimated to be around 200 mm water equivalent (Strelin and Sone, 1998). However, the average monthly temperatures strongly depend on the angle of the incident solar radiation. Láska *et al.* (2011) therefore recorded the average monthly maximum temperatures in December 2008 as 15.0 °C (Mendel Base); 12.5 °C (Berry Hill) and 10.9 °C (Johnson Mesa). The local temperature fluctuations and thus thawing and freezing of the permafrost can have a significant influence on the soil development, or the soil's properties.

Soil Sampling

Soil samples were collected from sites in Tab. I to the plastic bags. The samples were air dried at the Johann Gregor Mendel Base (James Ross Island) and they were stored in the room with temperature ≤ 10°C. After transport to the Czech Republic, the samples were ground in a mortar to pass through a 2.00 mm mesh sieve.

Samples Analysis

Soil samples were prepared for chemical and physical analysis according ISO 11464. Soil color were determined by Munsell Soil Color Book on dry samples (Soil Survey Staff, 1993). The particle size analysis were performed by the pipette method (Gee and Bauder, 1986) after the pyrophosphate pre-treatment of the samples. We defined fraction clay-silt-sand texture fraction. The content of Cox was determined by the Walkley-Black method (Schumacher, 2002), with Novak-Pelisek 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); Electrical conductivity was determined by Labquest II (Vernier Ltd.) in the saturated paste (soil:water 1:5) extract methods. Soil reaction was determined by Labquest II (Vernier Ltd.) in the saturated paste and fixed soil:water (1:2.5) extract methods. Content of calcium, magnesium, sodium, phosphorus and potassium in Aqua regia solution were determined by ICP-MS analysis at Bureau Veritas Commodities Canada Ltd.

RESULTS AND DISCUSSIONS

In some cases, these are relatively young soils developing after the parent substrate was deglaciated, but they still have a greatly varying character (fluvial, glacial, volcanic, possibly also aeolian). Though we can agree with the general conclusions that the primary influence here is physical weathering (Jie *et al.*, 2000), the presence of an active layer in the permafrost assumes temperatures above 0 °C in at last a part of the year. For this reason, we can also assume biological activity and chemical weathering of the parent substrate. The surface layer of the studied soils almost always consisted of stone pavement, i.e. a layer of soil skeleton which protects the deeper sections of the soil from erosion. The rest of the profile of the majority of soils consisted of soil skeleton, often in more than 50 (75) %. In a separated fraction of fine earth, a surprisingly large representation of a clay fraction was detected, which amounted to up to 23.3 % in the endopedon of the JRI site (7). Cursory determination even revealed clay materials in some samples. For example, in the clay fraction of sample JRI (5), virtually pure smectite was detected with trace amounts of quartz. Other samples also have similar mineralogy, with smectite predominating over chlorite, illite or zeolite. In Antarctic soils, however, smectite is quite rare (Margesin, 2009). The creation of smectite could partially be contributed to by the terrain geomorphology, since sample no. 5 is the bottom of a dried-up pond not far from sea. Sea salts can increase pH in local cases up to 9, which can cause the change of some micas to illite or even smectite via hydration (Claridge, 1965). The low level of chemical weathering in cold areas need not necessarily be so straightforward. Despite low temperatures and precipitation on the island, Bluth and Kump (1994), among others, lists a higher level of chemical denudation than on the Hawaiian Islands on a similar geological substrate. Matsuoka (1995) also states that the effects of frost, glacial abrasion and salts can increase the level of chemical weathering by increasing the specific surface area, as described at Sør Rondane Mountains (Antarctica). The average content (±SD) of clay is 9.9 ± 1.6% (variation range 1.4–23.3%); silt 31.9 ± 3.2% (variation range 14.0–60.4%) and average content of sand is 58.6 ± 2.9% (variation range 36.3–76.1%). The fraction of sand is evidently the biggest one, it could be caused by dominance of physical weathering. Sand content decreases with depth (JR1 and JR8); it grows (JR5) or it varies with depth (JR7). Content of clay usually decreases with depth. One of the reasons may be the presence or absence of the active layer. The active layer is associated with the presence of liquid water, chemical weathering and formation of clay minerals. The highest correlation is between clay and potassium (r = 0.66).

The content of oxidized carbon (Cox) is very low in general in Antarctic soils: Campbell and Claridge (1987) states values of 0.02–0.04%; Bargagli *et al.* (1998) reported at Edmonson Point (Victoria Land) range 0.1–1.1%; Holgate *et al.* (1967) reported range 0.3–0.7%; Navas *et al.* (2008) lists ranges of 0.09 to 2.65%; and Zvěřina (2012) even provides values on the James Ross Island under lichens of up to 3.3%. Our range of 0.09–0.92% Cox in the fine earth fraction lies on the rather lower limit of these intervals. The average Cox content is 0.34 ± 0.06%.

Higher values could be found at sites with living organisms (lichens, algae), and/or with anthracite in epipedon (Campbell, Claridge, 1987). Oxidized carbon decreases with depth (JR1); it grows with depth (JR8) or it fluctuates (JR5 and JR7). The highest correlation is with calcium content (r = 0.30).

While Campbell and Claridge (1987) states that Antarctic soils are typical by their slightly alkaline pH, soil reaction can differ vastly depending on the specific local conditions. The average active soil reaction is 6.26 ± 0.45 with variation range from 3.50 to 7.94. For all the samples studied by us, the soil reaction is alkaline in upper layers of the soil. However, deeper in, the reaction changes all the way to acidic or strongly acidic. This usually happens around the depth of around 30 cm. The only exceptions are samples on fluvial alluvia (JRI 7 and 8), where the change occurs in half the depth. It can be assumed that alkalis are brought to the surface during thawing within the active layer by capillary uplift, where salts condense and pH changes up to alkaline values. This corresponds with the salination, which is generally linked to surface horizons. Our result, decrease in pH with depth, is in opposite to that described by Navas *et al.* (2008). They described increase in pH with depth. The highest correlation is with content of calcium (r = 0.62). But Navas *et al.* conducted research in South Shetlands on soils with parent rock defined as mudstone. According to Dunham (1962), carbonate rocks fall here as well, which would also correspond with increased levels of carbonate content and/or pH with increasing depth. Navas *et al.* result is supported by the results obtained by Zvěřina (2012) on the James Ross Island. In his case, the soil was bounded not by permafrost, but by basalt as the parent rock, i.e. soil, where a limited amount of liquid water within the profile can be expected, which is the opposite of our situation. In our case, the cause could also be the different age of the profiles. The average *electrical conductivity* (EC) is 1242 ± 252 μS.cm^{-1} and variation range is from 116 to 3129 μS.cm^{-1}. %. Electrical conductivity decreases with depth (JR8); increases with depth (JR1 and JR5) or it fluctuates with depth (JR7).

The average *calcium content* in the soil is 1.48 ± 0.34%. Variation range of the total calcium content in soil samples is from 0.60 to 6.19%. Ure (1982) reported in the soils average calcium content 1.96%; Bowen (1979) states average value 1.50% and variation range 0.07–50%. Calcium content is variable with depth: e.g. the content of calcium increases at JR5 to the depth 27 cm and then it decreases; at site JR7: content decreases, then increases and from the depth 16 cm again decreases.

The average *magnesium content* of our samples is 1.22 ± 0.19% and variation range is from 0.36 to 2.92%.The most commonly total magnesium content in the soil varies between 0.4 and 0.6%. The content depends mainly on parent material, Ure (1982) reported in the soils average magnesium content 0.83%; Bowen (1979) states average value 0.89% with variation range 0.04–0.90%. Magnesium content is relatively high, in samples JR 3 and JR 8 are ratio Ca/Mg 0.5 and 0.6. Magnesium content usually decreases with depth (except locality JR1). Contents have higher values in surface horizons.

The most commonly total *phosphorus content* in the soil varies between 0.03 and 0.13%. The average phosphorus content of our samples is 0.06 ± 0.01% and variation range is from 0.03 to 0.12%. Bowen (1979) reported in the soils average value 800 mg.kg^{-1} (i.e. 0.08%) with variation range 35–5300 mg.kg^{-1} (i.e. 0.0035–0.53%). Ugolini (1977) reported from the Antarctic soils values 0.19–0.25% (protoranker and ahumic soil from dolerite); Zvěřina *et al.* (2012) showed from James Ross Island variation range from 0.06 to 0.10%, but only from one place. Content of phosphorus usually decreases with soil depth. Contents are usually higher in surface horizons.

The total *potassium content* in the soil is most commonly higher than content of phosphorus. The average potassium content of samples is 0.25 ± 0.05% and variation range in soil samples is from 0.10 to 0.75%. Bowen (1979) reported in the soils average value 1.4% with variation range 0.01–3.7%; Zvěřina *et al.* (2012) states value 0.19%. Average content of potassium in samples is under average values reported by Bowen (1979), but it is higher than values from Zvěřina *et al.* (2012). Contents of potassium are mainly higher in surface horizon, they decrease to the subsurface horizons.

The total *sodium content* in the soil is most commonly lower than content of potassium because minerals with sodium are unstable and quickly go to water-soluble form. But in permafrost is only limited content of water in the liquid phase. It could be reason why total sodium (or potassium) content in our soil samples has so high value: in our samples is from 0.15 to 1.60%. The average sodium content of our samples is 0.46 ± 0.08%. Bowen (1979) reported approximately same average content 0.50%; with wide variation range 0.015–2.50%. %. Sodium content is very variable in the soil profile. It is usually a sign of accumulation of water-soluble salts in the soil profile and the sign of salinization.

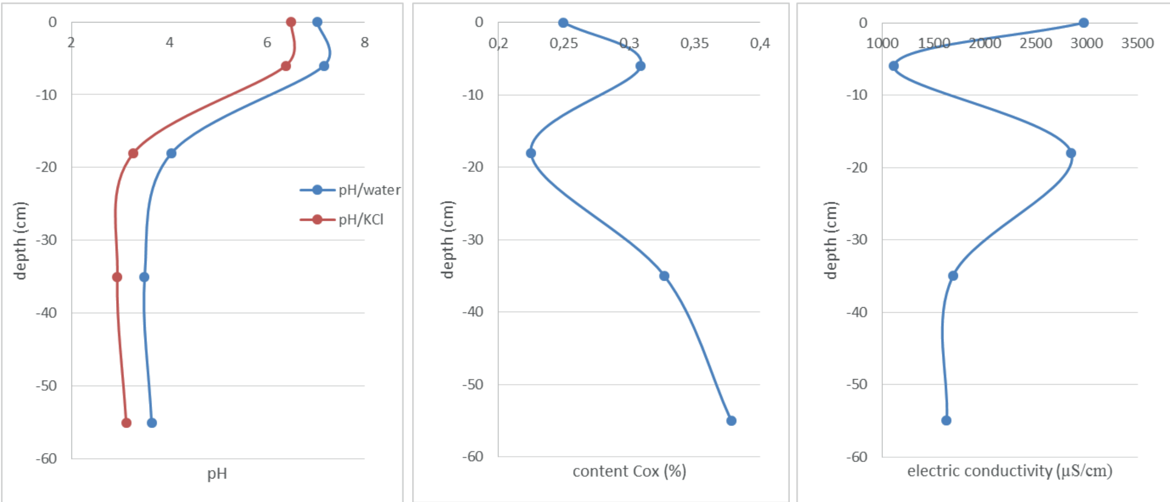
II: *Results analyses of soil color, texture, soil reaction and conductivity in samples from individual sampling points and depth layers in fine earth (particles lower than 2.00 mm)*

	Depth (cm)	Color (dry)	Texture class	Clay cont. (%)	Silt cont. (%)	Sand cont. (%)	pH H_2O	EC (μS/cm)
JR (1)	0–10	2.5Y 3/2	SL	7.8	21.0	71.2	7.94	116
	10–20	5Y 6/2	L	14.8	36.2	49.0	7.89	133
JR (2)	0–10	10YR 6/6	SL	1.4	32.9	65.7	7.90	523
JR (3)	0–10	10YR 3/4	SL	13.0	28.7	58.3	7.85	433
JR (4)	0–10	10YR 3/3	SL	6.7	39.2	54.1	6.35	815
JR (5)	5–15	2.5Y 4/4	L	18.8	35.0	46.2	7.94	200
	25–30	10YR 5/6	SiL	2.1	52.0	45.9	7.23	1040
	38–45	5Y 6/6	SL	9.8	18.1	72.1	3.79	1480
JR (6)	0–5	2.5Y 5/3	SL	9.9	14.0	76.1	7.07	430
JR (7)	0–3	10YR 2/2	SL	15.3	21.5	63.2	7.03	2970
	3–9	7.5Y 5/2	SCL	23.3	22.0	54.7	7.17	1117
	12–20	10YR 3/4	SiL	3.3	60.4	36.3	4.05	2852
	32–40	2.5Y 4/1, and 5YR 5/8	SL	8.5	29.4	62.1	3.50	1692
	51–57	5Y3/2	LS	4.3	22.4	73.3	3.64	1633
JR (8)	0–10	10YR 2/3	SL	14.1	25.0	60.9	7.01	3129
	30–40	10YR 5/3	SL	4.9	46.7	48.4	3.77	1302
Mean				9.88	31.53	58.59	6.26	1241.6
Standard deviation (SD)				1.57	3.23	2.88	0.45	251.7

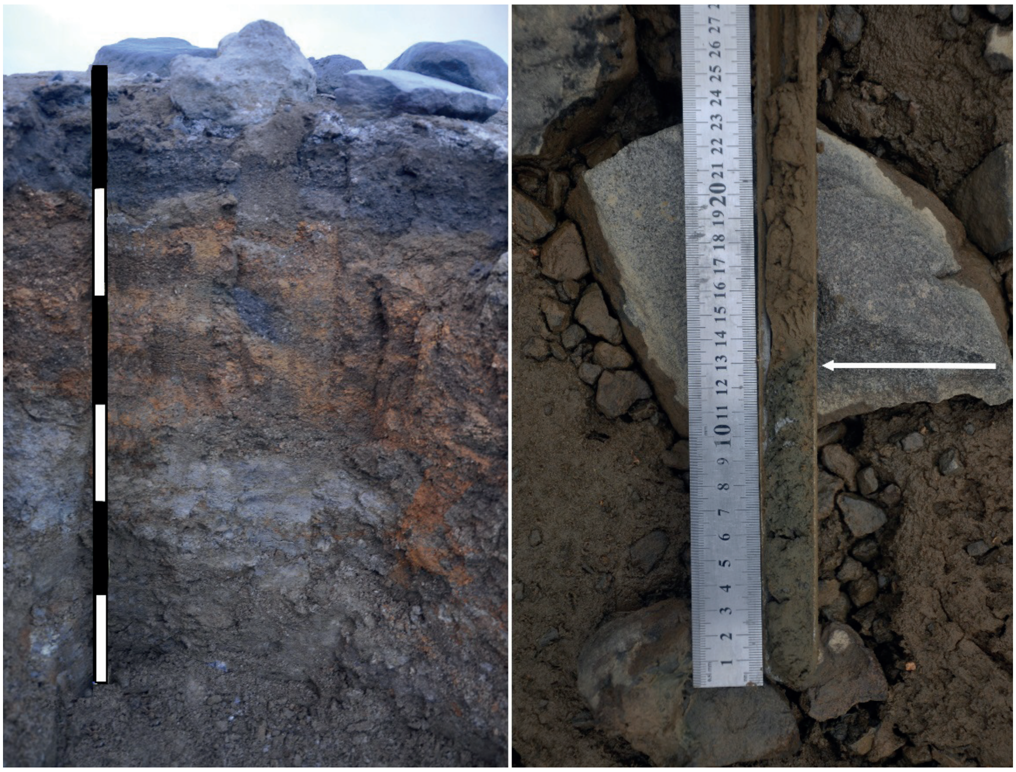
Texture class: SL (sandy loam), L (loam), SiL (silt loam), SCL (sandy clay loam), LS (loamy sand)

III: *Results analyses of elements in samples from individual sampling points and depth layers in fine earth (continue)*

	depth (cm)	Ca (%)	Mg (%)	Na (%)	K (%)	P (%)	Cox (%)
JR (1)	0–10	1.20	1.50	0.53	0.21	0.09	0.70
	10–20	1.28	1.74	0.47	0.22	0.08	0.29
JR (2)	0–10	2.54	2.92	1.60	0.75	0.10	0.21
JR (3)	0–10	1.52	2.91	0.62	0.66	0.12	0.36
JR (4)	0–10	0.92	1.27	0.30	0.18	0.08	0.92
JR (5)	5–15	1.32	1.16	0.19	0.13	0.05	0.08
	25–30	6.19	0.80	0.16	0.10	0.03	0.13
	38–45	0.79	0.44	0.40	0.17	0.04	0.09
JR (6)	0–5	0.81	1.31	0.15	0.29	0.05	0.34
JR (7)	0–3	1.12	1.17	0.48	0.21	0.05	0.25
	3–9	0.93	0.91	0.41	0.19	0.05	0.31
	12–20	1.69	0.87	0.55	0.15	0.03	0.23
	32–40	0.69	0.36	0.48	0.17	0.03	0.33
	51–57	0.60	0.41	0.36	0.18	0.03	0.38
JR (8)	0–10	0.83	1.33	0.47	0.22	0.06	0.30
	30–40	1.25	0.49	0.23	0.19	0.05	0.57
Mean		1.48	1.22	0.46	0.25	0.06	0.34
Standard deviation		0.34	0.19	0.08	0.05	0.01	0.06



3: *Examples of changes in a) soil reaction, b) Cox content and c) Electric conductivity within vertical soil profile in site JRI (7)*



4: *Left: soil pits JR(7); right: detail of Soil sampler, example of colour changes (oxidation-reduction conditions) in permafrost (from the arrow down) and in the active layer (from the arrow up)*

CONCLUSION

The deglaciated territories constitute less than 2% of the Antarctic's surface. The area of the Antarctic Peninsula represents a unique research site of these newly deglaciated territories and the human influence on them. The aim of this study is summarize the basic soil properties of the selected places in the deglaciated areas on the James Ross Island (Antarctica). Relatively young soils still have a greatly varying character (fluvial, glacial, volcanic, possibly also aeolian). Primary influence here is physical weathering, the presence of an active layer in the permafrost assumes temperatures above 0 °C mean biological activity and chemical weathering of the parent substrate. One of the reasons may be the presence or absence of the active layer. The active layer is associated with the presence of liquid water, chemical weathering and formation of clay minerals. The highest correlation is between clay and potassium (r = 0.66). The sand has evidently the highest content, it could be create by dominance of physical weathering. Sand content decreases with depth (JR1 and JR8); it grows (JR5) or it varies with depth (JR7). Despite low temperatures and liquid precipitation on the James Ross Island are present clay minerals. Content of clay usually decreases with depth. Oxidized carbon decreases with depth (JR1); it increases with depth (JR8) or it fluctuates (JR5 and JR7). The highest correlation Cox is with calcium content (r = 0.30). The active soil reaction is alkaline in upper layers of the soil, deeper in, the reaction changes to acidic or strongly acidic (in the specific depth, mainly around 30 cm). It can be assumed that alkalis are brought to the surface during freezing/thawing cycles within the active layer by capillary uplift, where salts condense and pH changes up to alkaline values. This corresponds with the salinization in surface horizons. The highest correlation of pH is with content of calcium (r=0.62). Electrical conductivity decreases with depth (JR8); it increases with depth (JR1 and JR5) or it fluctuates with depth (JR7). Calcium content is variable with depth: e.g. the content of calcium increases at JR5 to the depth 27 cm and then it decreases; at site JR7: content decreases, then increases and from the depth 16 cm again decreases. Magnesium content usually decreases with depth (except locality JR1). Contents have higher values in surface horizons. Content of phosphorus usually decreases with soil depth. Contents are usually higher in surface horizons. Contents of potassium are mainly higher in surface horizon, they decrease to the subsurface horizons. Sodium contents are very variable in the soil profiles. It is usually a sign of accumulation of water-soluble salts in the soil profile and the sign of salinization.

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