Ornithogenic Cryosols from Ardley Island, Maritime Antarctica

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Abstract

This study presents the chemical, morphological and physical characterization of a soil transect under the strong influence of abandoned penguin rookery ecosystems at Ardley Island. Soil surveying and sampling were performed during the austral summer, enabling detailed soil and geomorphology mapping. Most profiles expressed advanced pedological evolution despite their shallowness in some cases. Most soils have low pH values at the surface due to oxidation and mineralization of guano. Calcium amounts were high in all profiles even those under weak faunal influence, with high magnesium concentration and moderate potassium concentration for Antarctic standards, with little variation between sites. High exchangeable sodium indicates sea sprays provenance. The soils of Ardley Island are well developed in comparison to other soils from Antarctica, which can be attributed to the chemical weathering promoted by guano deposition and mineralization. Phosphatization of the mineral substrate is one of the most important soil forming processes at this part of Antarctica.

Key Words

Soil thermal regime, Climate change, Maritime Antarctica

Introduction

Ardley Island is one of the oldest ice-free areas of Maritime Antarctica. Home of breeding penguins since the early ice retraction, it supports approximately 10,218 individuals during the summer (Trivelpiece *et al*., 1987). With 2.0 km length and 1.5 km width, it is completely colonized by cushions of moss vegetation and lichens, and is defined as an area of Special Scientific Interest by the Scientific Committee of Antarctic Research (SCAR). Wang *et al*. (2007), found a temporal relationship between penguin population and vegetation abundance as long as 2400 BP, with Penguins playing a dominant role in this delicate ecosystem. Liguang *et al*. (2004) reported relic ornithogenic soils morphologically described as alternating layers of relict plant-rich tundra and sediments enriched with nutrients due to penguin droppings. Ornithogenic Cryosols have been recognized as ecosystems of special interest, because of their narrow C/N ratios, high nutrient levels and diversity of habitats for microorganisms. (Ugolini, 1972; Blume *et al*., 2002; Simas *et al*., 2007; 2008).The aim of this study is to report the chemical and morphological characteristics of a soil transect under the influence of penguins on abandoned rookery ecosystems at Ardley Island, emphasizing the biogeochemical cycling of nutrients.

Materials and Methods

The studied soils are located at Ardley Island (62°13'S, 58°56'W) (Figure 1). The parent material is composed of weathered volcanic rocks, mainly andesitic basalts. Ardley Island has a cold moist maritime climate characterized by mean annual air temperatures of -2°C and mean air temperatures above 0°C up to four months during summer. The temperature stays above freezing point throughout the summer, so that plant communities, mainly mosses, lichens, and algae, can establish and grow vigorously during this period.

Soil surveying and sampling were performed during the austral summer, enabling detailed soil and geomorphology mapping. Sampling pits were dug to the depth of permafrost. Samples of soil horizons were collected down to permafrost level, kept refrigerated and submitted to chemical analysis. Soil pH, exchangeable nutrients and texture were determined for <2 mm air-dried samples according to EMBRAPA (1997). Soil texture was obtained through dispersion of <2 mm samples in distilled water, sieving of coarse and fine sand, sedimentation of silt+clay followed by siphoning of the <2-µm fraction. Exchangeable Ca^{2+}, Mg^{2+} and Al^{3+} were extracted with 1 mol/l KCl and P, Na and K with Mehlich-1 extractant (dilute double 0.05 mol/l HCl in 0.0125 mol/l H_2SO_4). Nutrient levels were determined by atomic absorption (Ca, Mg and Al), flame emission (K and Na) and photocolorimetry (P). H+Al was extracted with 0.5 mol/l calcium acetate buffered at pH 7.0 and determined by titration with 0.0025 mol/l HCl (EMBRAPA,1997). Total organic C (TOC) was determined by wet combustion (Yeomans and Bremner, 1988). Soil samples were also

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subjected to X-ray difractometry, the difractograms were obtained at regular temperatures using a Rigaku Geigerfle, with graphite monochromators and cobalt tube.

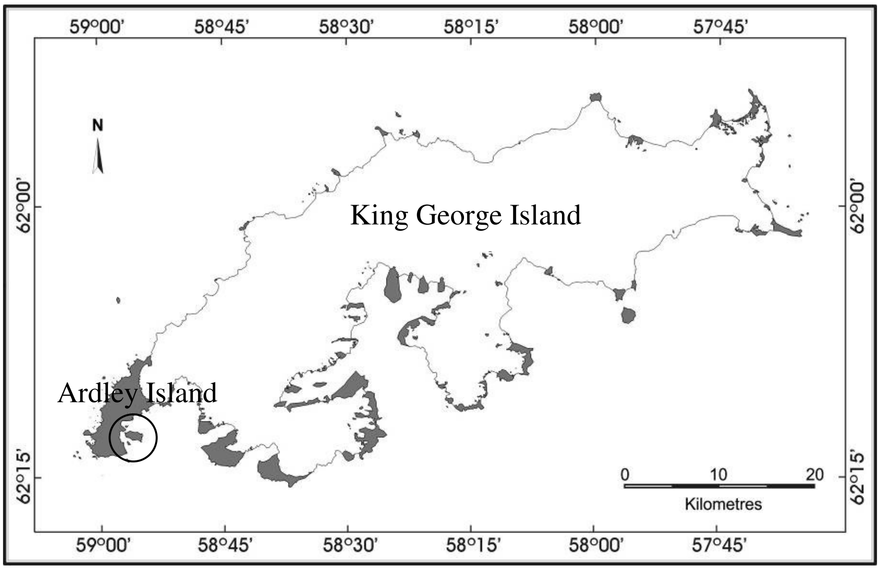

Figure 1. Study site.

Table 1. General characteristics of the studied sites.

Site	Altitude	Soil Class	Vegetation	Depth of the active layer
Ardley 1	77 m	Histic Ornithic Cryosol	Mosses and Lichens (*Usnea sp.* and *Himantormia sp.*)	10 cm
Ardley 2	50 m	Folic Eutric Cryosol	Lichens (*Usnea sp.* and *Himantormia sp.*)	25 cm
Ardley 3	45 m	Cambic Drainic Cryosol	Not vegetated	20 cm
Ardley 4	42 m	Histic Ornithic Cryosol	Mosses	80 cm
Ardley 5	31 m	Leptic Arenic Cryosol	Mosses	40 cm

Results

Most of the studied soils have advanced pedological evolution. Soil A1 (Figure 2) is located at one of the highest portions of the island and is only 10 cm deep. Nevertheless, it has strong structural development, ornithogenic influence and luxuriant vegetation cover. Fine sand (FS) and silt are the main granulometric fractions of the fine earth, while plagioclase, magnetite and quartz are the main minerals. Soil A2 in located near the penguin colony, at an intermediate position, with weaker ornithogenic influence and vegetation cover dominated by lichens. Despite the low primary productivity at this site, it has a 3 cm thick, dark A horizon. High content of coarse sand (CS) and uniform contents of FS, silt and clay were determined. Plagioclase, magnetite, olivine, chlorite, and quartz are the main minerals in the fine earth.

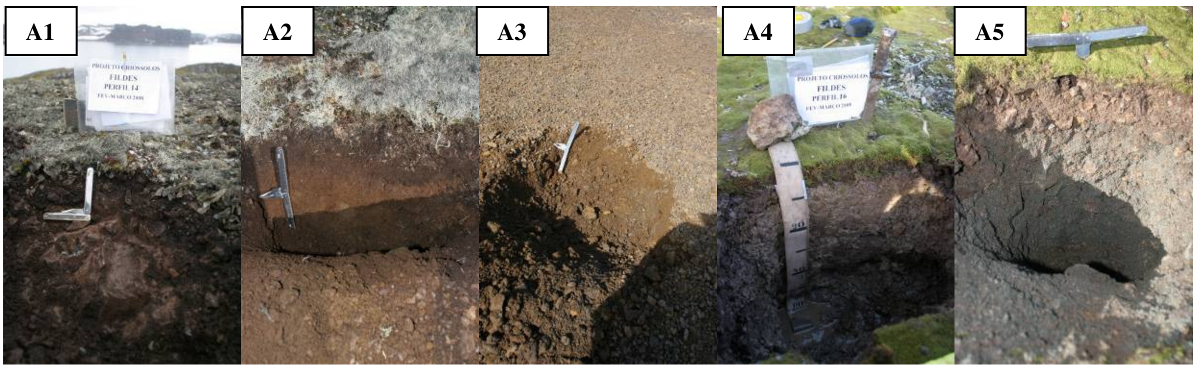

Figure 2. Soil profiles (A1-A5) studied at Ardley Island, Maritime Antarctica.

Soil A3 is located at the centre of the island with no ornithogenic influence and no vegetation cover. CS and silt are the main granulometric fractions in the fine earth, which has 20 % of clay (Table 2). Plagioclase, pyroxene, chlorite, magnetite, olivine and quartz are the main minerals. Profile A4 is located on the top of a

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gentle slope near the coast, under strong past and present ornithogenic influence, showing a grayish color and exuberant moss cover. It has up to 20 % of CS, 45% of silt and up to 30% of clay. Plagioclase, pyroxene, chlorite, magnetite, olivine, quartz and phosphate minerals are present. Profile A5 is located at the marine terrace expressing not only present ornithogenic influence but also occasional inputs of marine mammals droppings. CS content reaches up to 55 % in surface and 77 % in sub-surface. Plagioclase, pyroxene, chlorite, magnetite and quartz are the main minerals. Most soils have acidic reaction at the surface due to oxidation and mineralization of guano. Only A3 has pH values higher than 7.0, reflecting the nature of the mineral substrate with no ornithogenic influence. Calcium and magnesium levels values are high in all profiles. Potassium did not vary much between sites. High exchangeable sodium indicates sea sprays, with higher values at the topmost position indicating a dryer soil condition upland, as verified for the western coast of Admiralty Bay by Simas et al. (2007). Aluminum values were low, if not null, for the majority of the samples, except for sites A2 and A4, which have lower pH values.

Table 2. Chemical characteristics of the studied profiles.

Hor.	depth (cm)	CS	FS	Silt	Clay
		A1 Histic Ornithic Cryosol			
O	0-5	25	34	32	9
A	5-10	16	38	33	13
		A2 Folic Eutric Cryosol			
A	0-10	43	21	20	16
Bi	15-25	54	19	16	11
		A3 Cambic Drainic Cryosol			
Bi	0-20	32	12	36	20
		A4 Histic Ornithic Cryosol			
A	0-10	19	7	45	29
B1	10-30	20	8	44	28
B2	30-60	24	15	37	24
BC	60-70	23	12	43	22
		A5 Leptic Arenic Cryosol			
A	0-10	55	12	15	18
C	10-30	77	8	8	7

Total organic carbon (TOC) is closely related to ornithogenic influence (Table 3), with soil A3 presenting the lowest values (0.3 % of TOC). Soil A1 has the highest TOC values, reaching 21.2 % in surface. Soil A5 has high values only at the surface. On the other hand, at soil A4 the TOC values increase with depth, suggesting podzolization. The values of available P were extremely high for samples under penguin guano influence. Soils A1, A4 and A5 present values close to 2500 mg dm^{-3}. Soil A5 showed greater values in surface which is consistent with the present day colonization at this site. Soil A2 presents moderate values and A3 very low P, illustrating a low background for P in the parent material at Ardley.

Table 3. Chemical characteristics of the studied profiles.

Horizon	Depth (cm)	pH H_2O	pH KCl	Ca^{2+}	Mg^{2+}	K^+	Na^+	Al^{3+}	H+Al	T	V %	TOC %	P mg dm^{-3}
				----------	----------	----------	cmol$_c$ dm^{-3}	----------	----------	----------			
					A1 Histic Ornithic Cryosol (77 m)								
O	0-5	5.09	3.77	3.36	2.22	174	498.0	1.45	24.3	32.50	25.2	21.2	2218.9
A	5-10	5.41	3.97	4.97	2.36	239	628.1	0.96	26.6	37.27	28.6	18.5	2748.9
					A2 Folic Eutric Cryosol (50 m)								
A	0-10	6.19	4.33	3.92	7.68	139	235.7	0.58	13.8	26.78	48.5	5.42	195.4
Bi	15-25	5.64	3.42	6.15	12.23	182	239.7	5.69	19.2	39.09	50.9	0.6	253.8
					A3 Cambic Drainic Cryosol (45 m)								
Bi	0-20	7.69	6.66	6.55	3.42	25	44.8	0.00	0.3	10.52	97.1	0.3	0.2
					A4 Histic Ornithic Cryosol (42 m)								
A	0-10	5.68	4.10	5.53	4.51	149	285.7	0.77	12.2	23.86	48.9	5.7	2469.1
B1	10-30	6.32	4.70	7.26	4.51	147	319.8	0.10	8.6	22.14	61.2	2.6	3181.9
B2	30-60	5.84	4.19	4.51	2.58	148	265.7	0.67	14.9	23.53	36.7	9.4	1125.7
BC	60-70	4.01	3.64	0.18	0.16	65	69.8	3.37	26.4	27.21	3.0	10.5	564.5
					A5 Leptic Arenic Cryosol (31 m)								
A	0-10	5.49	4.33	7.92	3.76	134	217.9	0.00	7.6	20.57	93.1	3.9	2284.5
C	10-30	6.32	3.42	5.85	2.90	145	197.9	0.00	2.1	12.08	82.6	0.4	448.5

Conclusion

The soils of Ardley Island are well developed for Antarctic standards due to chemical weathering favoured by guano deposition and mineralization, similarly to soils from the western coast of Admiralty Bay. The phosphatization of the mineral substrate is one of the major soil forming processes, influencing soils chemical, mineralogical and morphological characteristics.

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