

Chemical, physical and mineralogical analysis of soil and marine sediments from King George Island, South Shetland Archipelago, Antarctica

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ABSTRACT

During the summer months 1988/89 and 1991/92, soil and marine sediments samples were collected around the Brazilian Antarctic Station «Comandante Ferraz» (62°S, 58°W) located on King George Island, South Shetland Archipelago. X Ray Diffractions (XRD) of clay fractions and another pedological analysis were carried out. Great differences were observed between soil layer 1 (0-5 cm) and soil layer 2 (5-10 cm) regarding to particle size and chemical characteristics. The XRD patterns did not show differences among layers. The marine sediments present a finer particle size distribution. In these sediments there is a dominance of both regular and irregular interstratified minerals as well as mica-biotite. The physical, chemical and mineralogical soil characteristics suggest a dominant action of geomorphologic process rather than pedogenetic ones, which are on its initial phase. The differences observed on the marine sediments may be related to the sediment sources and solutes of each area of Admiralty Bay.

Key words : Soils, sediments, Admiralty Bay, Antarctica

Análisis químico, físico y mineralógico de suelos y sedimentos marinos de la isla Rey Jorge, archipiélago Shetland del Sur, Antártica

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RESUMEN

Durante los veranos 1988/89 y 1991/92 se colectaron muestras de suelo y de sedimentos marinos en las cercanías de la base antártica brasilera "Comandante Ferraz", situada en los 62°S, 58°W, isla Rey Jorge, archipiélago Shetland del Sur. Se realizaron análisis pedológicos y de difracción con rayos X (DRX) de las partículas de arcilla. Los resultados indican grandes diferencias entre las capas del suelo 1 (0-5 cm) y 2 (5-10 cm) en relación al tamaño de las partículas y a sus características químicas. Los patrones DRX indican que no existen diferencias entre las capas de suelo. Los sedimentos marinos presentaron una distribución de partículas más finas. En estos sedimentos existe una dominancia tanto de los minerales regulares e irregulares inter-estratificados como de la mica-biotita. Las características físicas, químicas y mineralógicas del suelo sugieren una acción dominante del proceso geomorfológico sobre el pedogénico, el cual está en su fase inicial. Las diferencias observadas en los sedimentos marinos podrían estar relacionadas con las fuentes de los mismos y la de los solutos de cada área de la bahía Almirantazgo.

Palabras clave: Suelos, sedimentos, bahía Almirantazgo, Antártica

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INTRODUCTION

During the summer of 1986 and 1987 (Godoy *et al.*, 1989), 1988/1989 and 1991/1992 soil samples, marine sediments, algae and moss were collected near the Brazilian Antarctic Station "Comandante Ferraz" (62°S, 58°W), located on King George Island, South Shetland Archipelago. In the summer of 1988/1989 samples were taken from the Elephant, Nelson and Dee Islands. Cs-137 levels and Ra-226 and Ra-228 were obtained by gama spectography. Chemical, physical and mineralogical parameters were measured in two soil samples and four marine sediments obtained on King George Island, during summer of 1991/1992. The measures were made at the Centro Nacional de Pesquisa em Solos (National Soil Research Center, CNPS), that belongs to Empresa Nacional de Pesquisa Agropecuaria (National Agriculture and Husbandry Research Center, EMBRAPA), located in Rio de Janeiro, Brazil. All the samples were, also, analyzed to determine the concentration of trace elements by neutronic activation at the Radiochemistry Department that belongs to the Instituto de Pesquisas Energeticas e Nucleares (Institute for Energy and Nuclear Research, IPEN), of the Comissão Nacional de Energia Nuclear (National Comission of Nuclear Energy, CNEN) and located in São Paulo, Brazil (Schuch *et. al.*, 1994).

The physical and chemical characteristics of the Antarctic soils differ from soils of other regions as a consequence of the low weathering, observed in that region, resulting in soils with a high percentage of interstratified material, high pH, and low organic carbon due to absence of higher plants. The main objectives of this research was to conduct a pedological analysis and to characterize the clay fraction (by XRD) of environmental samples (soil and marine sediments) collected in Antarctica during 1991/1992 summer.

MATERIAL AND METHODS

In January 1992, during the Antarctic Operation X (Schuch 1993a, 1993b, Schuch *et. al.*, 1994), soil samples were collected around the Brazilian Antarctic Station «Comandante Ferraz» and the Polish Antarctic Station «Henryk Arctowski» located on King George Island, South Shetland Archipelago. Figure 1 shows a location map of the Antarctic Peninsula as well as of the archipelago. Figure 2 shows more details of areas where the samples were collected, for both stations.

The samples collected were:

- Two soil samples, one from layer 1, 0-5 cm depth, and another from layer 2, 5-10 cm depth. The collected area dimensions were 10 cm X 20 cm.
- Four marine sediment samples were collected in the Admiralty Bay specified as follows: SedMar1, collected in Martel Inlet at 30.m depth; SedMar2, collected in Mackellar Inlet at 70 m depth; SedMar3 collected in Mackellar Inlet at 60 m depth, and SedMar4, collected in Escurra Inlet, at 60 m depth. Pedological analysis were conducted at the Centro Nacional de Pesquisa em Solos (National Soil Research Center - CNPS) that belongs to EMBRAPA.

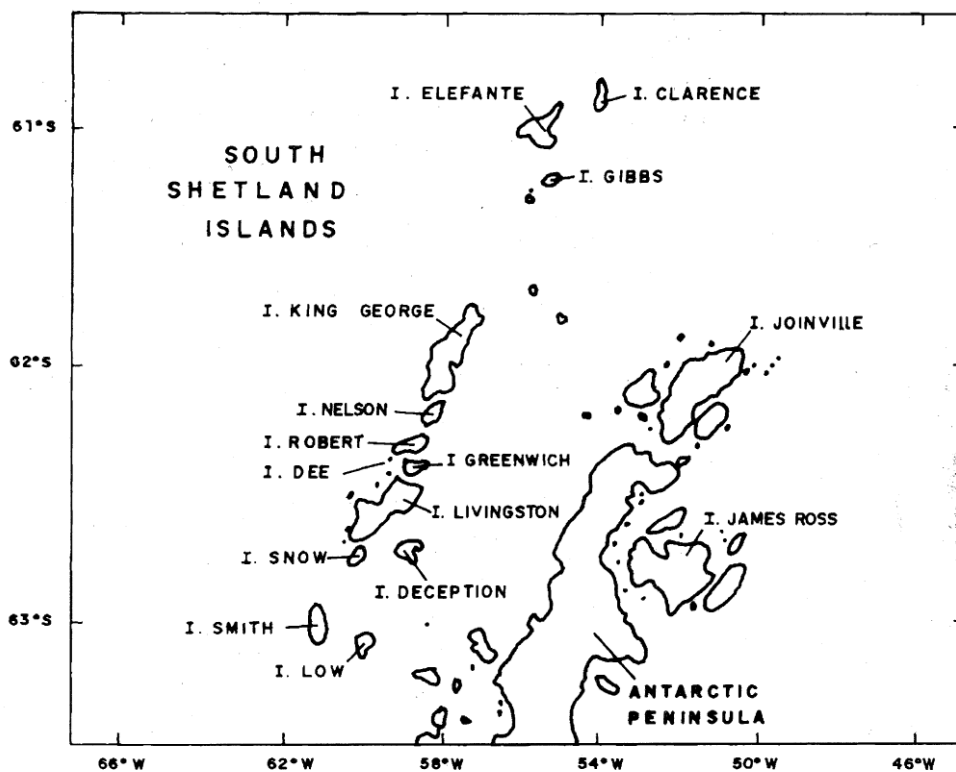


Fig. 1. Location of Antarctic Peninsula and South Shetland Archipelago.

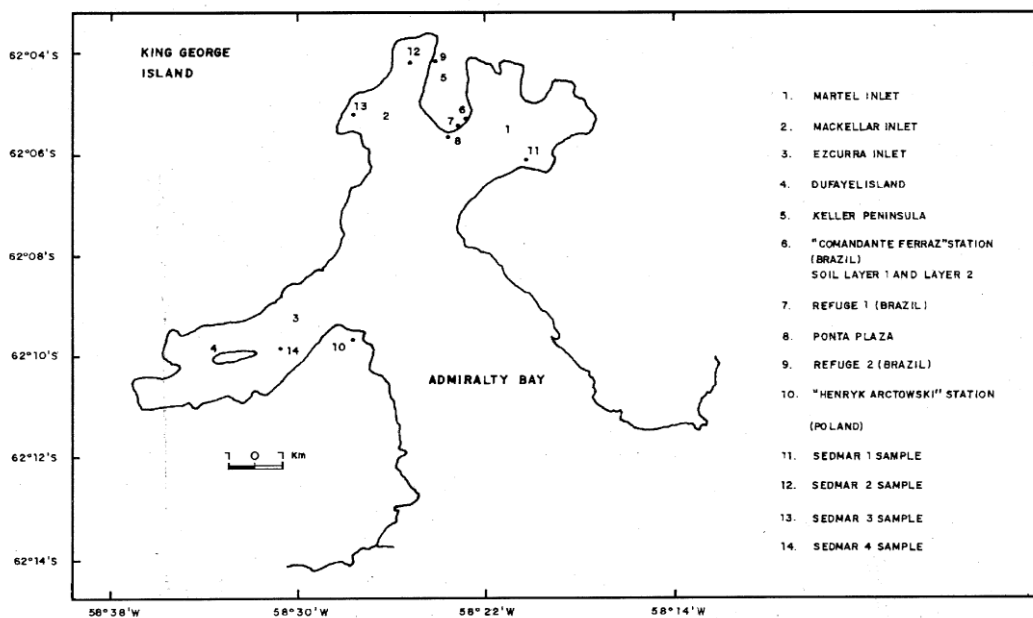


Fig. 2. Reference locals on Admiralty bay, at King George Island, South Shetland Archipelago and sampling points.

The soil particle size distribution was determined by densimeter method (EMBRAPA, 1979). This method is similar to original hydrometer method, however, the sand fractions are determined by wet sieving and clay is determined by densimeter in an upper portion of suspension separated prior densimeter measurement. The iron was extracted by CDB, according Mehra and Jackson (1960) and the clay fraction saturated with $MgCl_2$ 0,5M and KCl 1M. The samples saturated with Mg received two treatments: heated in a oven at 375°C for one hour and ethylene glycol solvation. The samples saturated with K were heated during two hours at 110°C, 350°C and 550°C.

The diffractograms were obtained with a RIGAKU D-Max II A diffractometer using Ka Cu radiation ($\lambda=0,15405$) and 2° /min scan speed (1 sec TC, 1° divergent slit, 1° scattering slit, Ni filter, 4.000 cps).

The clay fraction was studied using the following set conditions (United States of America, 1984):

1. Natural samples with Fe: 25mA, 35 KV scan range 2^{02q} - 45^{02q} ;
2. Fe free, Mg-saturated, glycolated and heated samples 15 mA, 25 KV, scan range 20^{02q} - 35^{02q} ;
3. Fe free, K-saturated, air dried or heated (110°C, 350°C and 550°C) samples: 15 mA, 25 KV, scan range 2^{02q} - 15^{02q} .

The pH was determined in a 1: 2,5 soil water or KCl 1M solution ratio and DpH was calculated ($DpH = pH_{KCl} - pH_{H_2O}$). Aluminium, Calcium and Magnesium were extracted by a KCL 1M solution and Calcium and Magnesium determined by EDTA complexation and Aluminium by Sodium Hydroxide 0,005M. Sodium and Potassium were extracted by a dilute acid solution (HCL 0,05M + H_2SO_4 0,025M) and determined by flame emission spectrophotometry, H+Al was extracted by a calcium acetate solution buffered at pH 7 and determined by NaOH solution. Carbon was determined by humid oxidation and amoniacal FeII sulfate and phosphorus extracted by a weak acid solution (HCL 0,05M + H_2SO_4 0,025M) and determined by colorimetry. All these methods are described in detail in EMBRAPA (1979).

RESULTS AND DISCUSSION

The results of physical and chemical analysis of the soil and marine sediments collected in the 1991-1992 summer are presented in Tables 1 to 6.

The soil samples showed differences for layer 1 (0-5cm) as compared to layer 2 (5-10 cm) (Table 1). Although the percentage of the total sand in the two layers was almost the same, the difference between coarse sand and fine sand in the two layers is around 10%. The coarse sand for the layer 2 was near the fine sand value for layer 1 (30%) and *vice-versa*. The silt value in the layer 1 (30%) was two times greater than those for layer 2 (15%), which associated with the difference of 10% in the clay value, results in a difference of almost 1,05 for silt/clay ratio.

TABLE 1

PHYSICAL AND CHEMICAL ANALYSIS OF SOIL AND MARINE SEDIMENTS SAMPLES. SUMMER OF 1991-1992.

SAMPLE	PARTICLE SIZE DISTRIBUTION %					%Silt %Clay	pH(1:2,5)		DpH
	SAND			SILT	CLAY		WATER	KCl 1M	
	COARSE 2,0-0,20 mm	FINE 0,20-0,05 mm	TOTAL 2,0-0,05 mm	0,05-0,002 mm	<0,002 mm				
Soil Layer 1	28	22	50	30	20	1,50	5,8	5,1	-0,7
Soil Layer 2	18	34	52	15	33	0,45	7,0	5,8	-1,2
SedMar 1	34	25	59	25	16	1,56	7,9	7,9	0,0
SedMar 2	2	6	8	51	41	1,24	7,1	7,2	0,1
SedMar 3	2	18	20	47	33	1,42	7,5	7,4	-0,1
SedMar 4	6	11	17	46	37	1,24	7,3	7,2	-0,1

Dph=pH KCl 1M - pH water 1:2,5

The marine sediments showed low values of total sand, and higher fine sand/total sand ratio. The exception was observed for SedMar1, with total sand values almost 60% of total sand and higher coarse sand/fine sand ratio. The SedMar2, SedMar3, Sed Mar4 samples showed higher quantities of the finer fractions, once silt plus clay range were at 80-90% of the collected material, while in the SedMar1, it resulted just 41%.

The water and KCl pH also showed big differences in the soil samples. All the samples resulted neutral or alkaline pH, except layer 1, which was acid (Table 4), when compared with the layer 2.

The DpH was more negative in the layer 2 (-1,20) then was for layer 1 (-0,70). Once in both layers the predominant clay minerals are pH-independent charge, the latter may be related to some positive charges from organic matter due to the lower pH, associated with the higher clay mineral contents in the layer 2.

In the marine sediments, all the samples had approximately the same amount of negative and positive charge, except SedMar1, which showed a little excess of negative ones (DpH= -0,1) (Table 1). These values are far from those published by Luzio *et al.*, (1987).

TABLE 2

CHEMICAL ANALYSIS OF SOIL AND MARINE SEDIMENTS SAMPLES. SUMMER OF 1991-1992.

SAMPLE	EXCHANGE COMPLEX cmol/kg							
	Ca ⁺⁺	Mg ⁺⁺	K ⁺	Na ⁺	Sum of Bases	Al ⁺⁺⁺	H ⁺	CEC
Soil Layer 1	10,7	6,1	0,55	0,94	18,3	0	2,3	20,6
Soil Layer 2	14,8	7,4	0,56	1,34	24,1	0	0,8	24,9
SedMar 1	4,6	0,6	2,46	15,12	22,8	0	0	22,8
SedMar 2	8,4	10,4	2,71	18,00	39,5	0	0	39,5
SedMar 3	6,7	6,3	2,41	12,62	28,0	0	0	28,0
SedMar 4	18,3	0,5	3,57	27,02	49,4	0	0	49,4

Ca⁺⁺, Mg⁺⁺, Na⁺ and K⁺ in marine sediments include salts solubles in the extractant solution.
CEC= (Ca⁺⁺ + Mg⁺⁺ + Na⁺ + K⁺ + H⁺ + Al⁺⁺⁺)

The greater acidity in the exchangeable complex is due H contents and has not received Al contribution, due to low weathering of this material (Table 2).

The Ca/Mg ratio and the proportion of exchangeable cation is closed in both layers, except by Na which is high in layer 2.

The marine sediments had two Ca/Mg ratio behaviors: SedMar1 (7,67) and SedMar4 (36,60) showed a higher ratio, then SedMar2 (0,81) and SedMar3 (1,06) (Table 3).

TABLE 3

Ca/Mg RATIO AND BASIC CATION SATURATION OF SOIL AND MARINE SEDIMENTS SAMPLES. SUMMER 1991-1992.

SAMPLE	Ca ⁺⁺ /Mg ⁺⁺	Ca ⁺⁺ (%)	Mg ⁺⁺ (%)	K ⁺ (%)	Na ⁺ (%)
Soil Layer 1	1,8	51,9	29,6	2,7	4,6
Soil Layer 2	2,0	54,4	29,7	2,2	5,4
SedMar 1	7,7	20,2	2,6	10,8	66,3
SedMar 2	0,8	21,3	26,3	6,9	45,6
SedMar 3	1,1	23,9	22,5	8,6	45,1
SedMar 4	36,6	37,0	1,0	7,2	54,7

$$\% X = (X \cdot 100) / \text{CEC, where } X = \text{Ca}^{++}, \text{Mg}^{++}, \text{K}^{+} \text{ or } \text{Na}^{+}$$

These results may be related to each sediment and solute source, and other environmental factors. SedMar2 and SedMar3 were collected at Mckellar Inlet, SedMar 1 at Martel Inlet and SedMar4 at Escurra Inlet (Fig. 2).

The S value ($S = \text{Ca} + \text{Mg} + \text{K} + \text{Na}$) (Table 2) for SedMar1 and SedMar3 samples was closer to soil, and lower than SedMar2 and SedMar4, but this difference was not reflected in the soil extract concentration of these cations, except for SedMar1. The high concentration of Na in the marine sediments may be seen in Tables 3 and 5, and a relation of extract electric conductivity with Na concentration (Table 5).

The V% value ($V\% = 100S/T$) is 100% for marine sediments samples, while P values are a little less than those found in soil samples, except for SedMar4. For SedMar1 and SedMar4, the C values were in the range of values found in soil samples, although in the SedMar2 and SedMar3 (Mckellar Inlet) were higher (Table 4).

In the soil samples, the %C and %N were three times higher for layer 1 than layer 2, and the C/N ratio is very close in the two layers (Table 4).

The low weathering agrees with clay mineralogy (Moore and Reynolds, 1989; Shawney 1989) and physical and chemical data.

TABLE 4

CHEMICAL ANALYSIS OF SOIL AND MARINE SEDIMENTS SAMPLES. SUMMER OF 1991-1992.

SAMPLE	V (100 S)/T (%)	100AL+++ S+AL+++	P AVAILABLE (mg/kg)	C ORGANIC (%)	N (%)	C/N	Equivalent CaCO ₃ (%)
Soil Layer 1	89	0	167	0,95	0,08	12	-
Soil Layer 2	97	0	167	0,33	0,03	11	-
SedMar 1	100	0	136	0,40	0,03	13	6
SedMar 2	100	0	99	1,53	0,06	25	4
SedMar 3	100	0	112	1,83	0,07	26	2
SedMar 4	100	0	186	0,79	0,06	13	5

The presence of biotite in the clay fraction shows the predominance of physical over chemical weathering, once that mineral is easily chemically decomposed (Rai and Kittrick, 1989). In SedMar1 and SedMar3 samples there was presence of goethite. Also, in SedMar4, in which an estimation of the proportion of the interstratified members was possible, the less weathered one (illite or chlorite) was more than 80% than the most weathered (Smectite) (Table 6).

TABLE 5

PHYSICAL AND CHEMICAL ANALYSIS OF SOIL AND MARINE SEDIMENTS SAMPLES. SUMMER OF 1991-1992.

SAMPLE	SATURATED PASTE		SOLUBLE SALT (EXTRACT 1:5) cmol/Kg			
	E.C.OF EXTRACT (ds/m) 25°C	WATER (%)	Ca ⁺⁺	Mg ⁺⁺	K ⁺	Na ⁺
Soil Layer 1	0,89	43	0,10	0,10	0,01	0,19
Soil Layer 2	0,32	64	0,10	0,02	0,01	0,14
SedMar 1	42,00	38	2,50	3,70	0,60	21,60
SedMar 2	41,50	84	1,60	0,50	0,92	48,03
SedMar 3	38,00	67	1,00	0,40	0,71	32,16
SedMar 4	40,80	75	1,00	0,40	0,82	42,52

The great variation of particle size distribution between the two layers of soil was not related to the mineralogical differences and suggest that this difference is due to a fluvio-glacial deposition, in which the ice movements grind rocks that are carried by the melted ice. In summer there is a superficial water flow and the selection capacity is higher, and these deposits are generated. The coarse materials are less carried while sand is transported to the plains and silt and clay to the bays and lakes bottoms, what is coherent with the higher contents of fine materials in the

inlet bottoms. Nevertheless, the existence of interstratification of clay minerals with the members of typic soils with low weathering degree (Clorite ® smectite; Illite ® smectite) and the presence of organic carbon, lead us to the idea that the soil samples were collected in an incipient soil developing over a fluvioglacial deposit (Table 6).

TABLE 6

MINERALOGICAL COMPOSITION OF SOIL AND MARINE SEDIMENTS ANALYZED.

SAMPLE	INTERSTRATIFIED MINERALS		OTHERS
	IRREGULAR	REGULAR	
Soil Layer 1 and Soil Layer 2	ILITE (60%) SMECTITE	CLORITE/SMECTITE	BIOTITE
SedMar1 and SedMar3	ILITE/SMECTITE	CLORITE/SMECTITE	BIOTITE GOETHITE
SedMar 2	ILITE/SMECTITE	CLORITE/SMECTITE	BIOTITE
SedMar 4	CLORITE (80%) /SMECTITE ILITE (80%) /SMECTITE		

The difference between the two layers may be associated to changes in the physical weathering of the materials source, and/or in the transport agent, once the close C/N ratio values in the two layers suggest an alike organic activity in both ones, but quantitatively higher in the layer 1 (Table 4). So, it is hoped that particle size distribution be related to a pre-depositional event (geologic/geomorphic), while the chemical differences may be related to an «in situ» (pedogenetic) process. Then, the chemical weathering is higher in the layer 1, due the H, C and pH values. (Table 2). On the other hand, the marine sediments (except SedMar1) showed a higher proportion of clay and silt fractions (Table 1), in accord with the hypothesis of fluvioglacial transport and deposition.

The chemical differences may be related to environmental effects as well as source of materials of each measured place.

The water pH observed is lower than those reported by Luzio *et al.* (1987) while the KCl pH were similar, implying higher amplitude of pH (DpH). The Ca, Na, K and Mg at lower extreme range were similar to those reported by Luzio *et al.* (1987), however, it did not affect the sum of exchangeable bases (S).

The K values found by Luzio *et al.* (1987) are higher considering soils samples and lower for marine sediments. The observation made suggests that samples collected by Luzio *et al.* (1987) are from more recent sediments or less weathered locals. The found higher values of pH and more negative DpH also support the latter.

CONCLUSIONS

Interstratified regular and notregular minerals as well as mica-biotite were the most abundant in the mineralogy. The physical, chemical and mineralogical characteristics suggest higher action of geomorphic process than pedogenetic one, although, there is evidence of initial pedogenetic process. The differences among marine sediments seem to be associated with their source.

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