15 Soils of the Argentine Antarctica

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Abstract

Antarctic soils have been studied since the mid-twentieth century. The first studies were focused on the intense influence of seabirds in soil genesis, specially through the microbiological decomposition of guano, while other important pedogenetic processes were less studied. Subsequent studies showed that climate, vegetation and micro-organisms were also key factors in the formation of these soils. Significant differences were found in soil genesis in the different sites studied, which allowed to recognize the current pedogenetic processes and those developed under warmer climates. In the present chapter, we present a review of the edaphic studies carried out in the Argentine Antarctic. They were focused in the ice-free areas of the northern sector of the Antarctic Peninsula and the surrounding islands: Marambio Island (Trinidad Peninsula), Esperanza Bay (Tabarín Peninsula), Potter Peninsula (25 de Mayo Island), Harmony Point (Nelson Island), Cape Spring, Leopard and Penguin Islands (Coast of Danco). A complex landscape, involving soils with different properties, evolved mainly through the participation of the five soil-forming factors. The presence of permafrost, key to soil classification, was observed mainly in the Eastern sector of the northern Antarctic Peninsula. In the Western sector, the melting of the soils in the summer allowed the development of the horizons used for the description. The diagnostic features used were the presence of ochric, mollic, histic, cryoturbation, permafrost and glacic layers and the presence of gelic materials. Soils correspond to the orders Gelisols, Mollisols, Inceptisols, Histosols, Spodosols and Entisols.

Keywords

Antarctic • Soils • Soil Taxonomy • Climate

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15.1 Introduction

Antarctica Continent occupies an area of 14 million km^2. Its climate is by far the coldest and most rigorous on Earth, due mainly to the geographic position that determines a low-incoming solar radiation. Ice-free areas are sparse and scattered, covering approximately 600,000 km^2 (Panzarini 1958). A complete update about Antarctica soils can be found in the Soils of Antarctica (Bockheim 2015a).

Antarctic soils have been studied since the middle of the twentieth century. Some studies, without considering other important pedognetic processes, have described Antarctic soils affected by the fauna and refer to the intense influence of seabirds in the formation of soils through the microbiological decomposition of guano, which by leaching produces phosphate enrichment in nesting areas (Tatur and Keck 1990) or mineralization of penguin excrements and ammonification and hydrolysis of organic phosphate compounds (Blume et al. 1997; Beyer and Bölter 1999; Beyer et al. 2000). These processes are relevant in the formation of some soils, which in the mentioned reports were denominated "ornitogenic soils". On the other hand, some researchers only consider four of the five soil-forming factors (lithology, climate, topography and time) (Tedrow and Ugolini 2013), discarding the action of micro-organisms.

In this chapter, we present the results of edaphic studies conducted in the Antarctic Argentina, an Antarctic sector claimed by the Argentine Republic as part of its national territory consisting of the Antarctic Peninsula and a triangular section that extends to the South Pole, delimited by the meridians of 25° and 74° West, and parallel 60° South (Fig. 15.1). More exactly, soil surveys were located on the ice-free areas of the northern sector of Antarctic Peninsula and surrounding islands: Marambio Island (Trinidad Peninsula), Esperanza Bay (Tabarín Peninsula), Potter Peninsula (25 de Mayo Island), Harmony Point (Nelson Island), Cape Spring, Leopard and Penguin Islands (Danco Coast).

G. Rubio et al. (eds.), *The Soils of Argentina*, World Soils Book Series,
https://doi.org/10.1007/978-3-319-76853-3_15

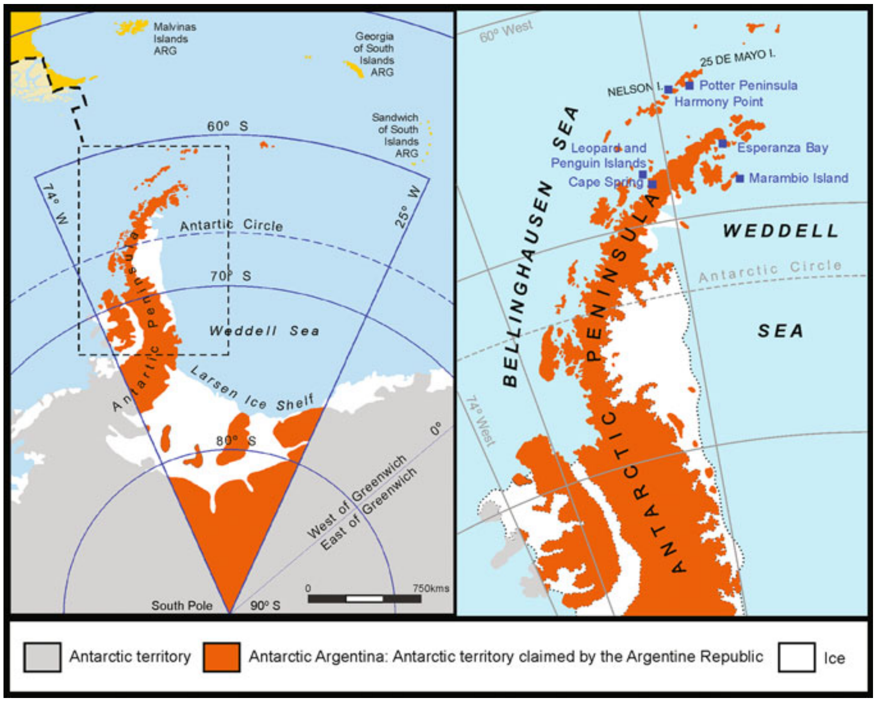

Fig. 15.1 Antarctic Argentina and Antarctic Peninsula (modified by the authors, source IGN (2018))

The area shows a complex landscape, involving soils with different properties, evolved mainly through the participation of the five formative factors and without the relevant influence of the fauna.

The Instituto de Suelos y Agrotecnia (Soils and Agrotechnics Institute) began its studies in Antarctica Argentina in 1952–1953, as a member of the Antarctic Scientific Commission. The institute was represented by Rubén H. Molfino, who described the climate, vegetation and soils of this region (Molfino 1956).

In 1959, Argentina together with eleven other countries signed The Antarctic Treaty, which allowed to continue its research on the local natural resources. In 1994, the Dirección Nacional del Antártico (DNA) and the Instituto Nacional de Tecnología Agropecuaria (INTA) signed an agreement to develop the Antarctic Soils chapter of the Argentine Soils Atlas Project (Godagnone 2001; Godagnone and de la Fuente 2010, 2011). As part of this chapter, soil genesis, classification and mapping of the Antarctic Peninsula (Fig. 15.1) were carried out, increasing existing information and allowing a better understanding of Antarctic soils.

15.2 Parent Material of Soils

Several studies have described the geological materials from which the Antarctic Peninsula soils were formed (Rinaldi 1978; Haus et al. 2015).

The Antarctic Peninsula stands out along a South–North geographic projection, which crosses the Antarctic Circle (64° 33′S) and then turns towards the north-east, constituting the Western limit to the Weddell Sea. Its Eastern Coast is partially blocked by the Larsen Ice Barrier and bordered by Weddell Sea, while its Western Coast is bordered by the Bellingshausen Sea (Fig. 15.1).

The Western and Eastern sectors of the Antarctic Peninsula have quite different characteristics (Goodwin 1993). The Western region is dominated by acid igneous rocks and a subvolcanic epizonal environment, represented by granite-porphyries, rhyolites, riodacites, granodiorites and, in less proportion, porphyritic diorites and andesites. It corresponds to the Cretaceous–Lower Tertiary of the Andean Igneous complex and belongs to the same magmatism composed of different events separated by brief periods preceded by volcanism (Codignoto et al. 1978, Fig. 15.2). The Eastern sector exhibits tertiary outcrops with a thin quaternary cover in some parts. Cretaceous sedimentary rocks can also be distinguished (Paul et al. 1995).

The present geoforms were modelled by glacial and marine action and by the geological structure, characterized mainly by faults and to a lesser extent, diaclases preserved and even increased by geomorphic processes.

Glacial features have a weak development in outcrops, due as much to exaration as to glacial accumulation.

Accumulation forms consist of terminal and lateral moraines. They are generally deposits of little thickness, formed

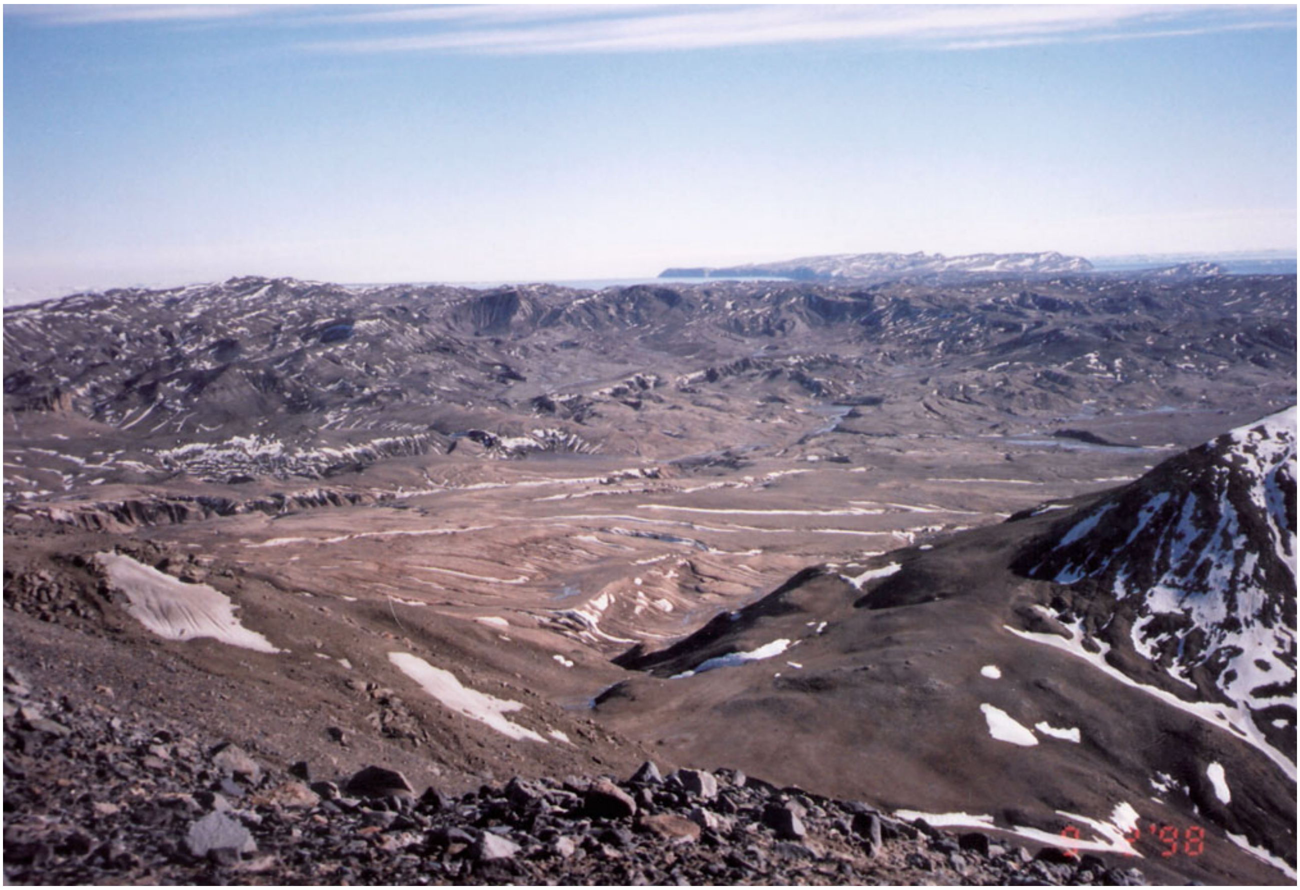

Fig. 15.2 Marambio Island (Photograph by Godagnone)

by non-laminated drifts with little clay and silt and a predominance of gravel. There are also accumulation forms of mass removal, originating from drift deposits and frost-wedging phenomena. These materials allowed the formation of soils (Figs. 15.2 and 15.3).

15.3 Climate

Antarctica continent presents extremely low temperatures and is covered by ice in almost all its extension. Because it is a continent surrounded by sea, climatic differences depend essentially on latitude, altitude above sea level and distance to the coast.

One of the peculiarities of the Antarctic continent is the magnitude of solar energy which, during an austral summer, is greater than in the tropical region during the same period. It is largely attributable to the thinner atmospheric layer resulting from the considerable height of the continental surface, which together the great transparency of the polar air cause less dispersion of the incoming energy.

In Eastern Antarctica, there are temperatures below −80° C, as in the Russian scientific base of Vostok (79° 27′S and 106° 52′E) where a temperature of −89.2 °C was recorded on 21 July 1983. More recently, on 10 August 2010, NASA and the United States Geological Survey using instruments on board a Landsat 8 satellite recorded a new record of −93.2 °C in the high sector between the Argus dome of 4093 msnm (80° 22′S and 77° 21′E) and the Fuji dome at 3.810 m (77° 30′S and 37° 30′E), the highest points of the ice sheet known as the Antarctic Plateau Oriental (NASA-USGS 2013).

In the Antarctic Peninsula (Western Antarctica), January temperature averages vary from 0 °C on the coast to −30 °C on the inner plateau.

Temperature tends to be higher on the Eastern Coast, possibly due to its greater geographical extension of the Peninsula towards the North, which allows greater frequency of thermal inversions in the West than in the East, especially during winter. This is caused by the interaction between inland strong winds and marine storms. Although the average monthly temperature on the coast is below freezing, living conditions are relatively benign because of brief summer periods, when temperature rises causing the superficial melting of snow and ice. Cloudiness is very low especially on the interior high plateau, determining a

Fig. 15.3 Cape Spring (Photograph by Godagnone)

continuous fall of ice crystals. Coastal regions have greater cloudiness accompanied by fog.

Precipitations are rare and generally consist of ice and snow, but in recent years drizzles were observed (SMN 2001). The presence, place and thickness of snow are determined by the influence of winds and topography. Coastal areas are more humid, especially in the eastern part of the peninsula, where in recent years measurable values of summer rains have been recorded.

Soil sampling in the Argentinean sector was carried out mostly in ice-free areas. Due to their importance in pedogenetic processes, temperature and humidity are considered diagnostic properties for the different taxonomic levels of some soil classification systems, such as the Soil Taxonomy (Soil Survey Staff 2010) that was used to classify Antarctic soils. Van Wambeke and Scoppa (1980) placed Antarctica in a Pergelic (temperature)—Udic (humidity) edaphic climate.

15.4 Vegetation

Only 4% of the Antarctic territory has some kind of plant life. With the exception of some algae that can exist in the snow, the botanical forms are scarce and are distributed in different forms of landscape.

In the Western sector of the Antarctic Peninsula, vegetation consists mainly of algae, mosses, lichens and some grasses: Polytrichum alpestre, Chorisodontium aciphyllum, Deschampsia antarctica, Calliergon austro-sarmentosum, Drepanocladus uncinatus, Prasiola crispa, Poa pratensis. Plant growth and development occur from October when ice and snow start to melt to April when temperature starts to decrease reaching freezing point in autumn–winter (spring–summer in the Southern Hemisphere) (Fig. 15.4).

In the Eastern sector, vegetation is very scarce due to its greater climatic rigour. In small areas with fine material accumulation and in depressed areas, dispersed mosses can be found (Fig. 15.5) and some lichens that grow on rocky outcrops.

15.5 Geomorphology and Its Relationship with Soils

The heterogeneous geomorphological features of the Antarctic Peninsula have been described by several authors (MacNamara 1969; Rinaldi 1978; Codignoto et al. 1978).

Fig. 15.4 Deep eroded slope in the Western sector of the Antarctic Peninsula (Photograph by Godagnone)

15.5.1 Eastern Sector of Antarctic Peninsula

The landscape of this sector is characterized by glacial and periglacial forms, which were regulated by the wind action and the summer activity of small streams and lagoons. Glacial processes were the result of ice and snow melting and the regressive dynamics of this area.

Fusion phenomena, such as supraglacier and periglacier water currents, mud flows and cones, have been also found. The coast is relatively low with a small shelf, narrow seashores or sea terraces on a hard substratum. Melting water activity and very intense winds that transport materials to protected areas have modelled this landscape, giving origin to the current soils. The gelifraction is intense on outcrops; morainal arcs have structured soils (polygonal forms).

A variety of soils of weak development can be found in this sector, whose different physical and chemical characteristics can be categorized at different taxonomic levels (Soil Survey Staff 2010). The original materials of these soils are mainly fluvioglacial deposits, redistributed by hydric and/or aeolian processes.

Soils of this sector exhibit a wide range of depths due to the presence of a rock layer (in same areas 15–30 cm deep). In other areas, such as the Marambio Island, deeper soils can be found, developed from sediments exceeding 100 m depth.

Most soils exhibit subsurface layers that remain permanently frozen, with permafrost at 60 cm depth. The exceptions are the above-mentioned shallow soils on a rocky basement at around 30 cm depth, in which the soil matrix thaws completely in summer. Bare rock could be found on the highest sectors of the landscape (Fig. 15.6).

15.5.2 Western Sector of the Antarctic Peninsula

The landscape of this sector has been modelled by glacial and marine action and influenced by its geological structure. This structure is composed by faults and to a lesser degree diaclasas which, due to geomorphic processes, may have increased over time. Resulting geoforms have been classified as glaciers, erosion, accumulation and coastal (Rinaldi 1978).

Glacial geoforms show weak development on outcrops and were produced by ice sheet exaration or by the mere

Fig. 15.5 Severely eroded plateau in the Eastern Sector of the Antarctic Peninsula (Photograph by Godagnone)

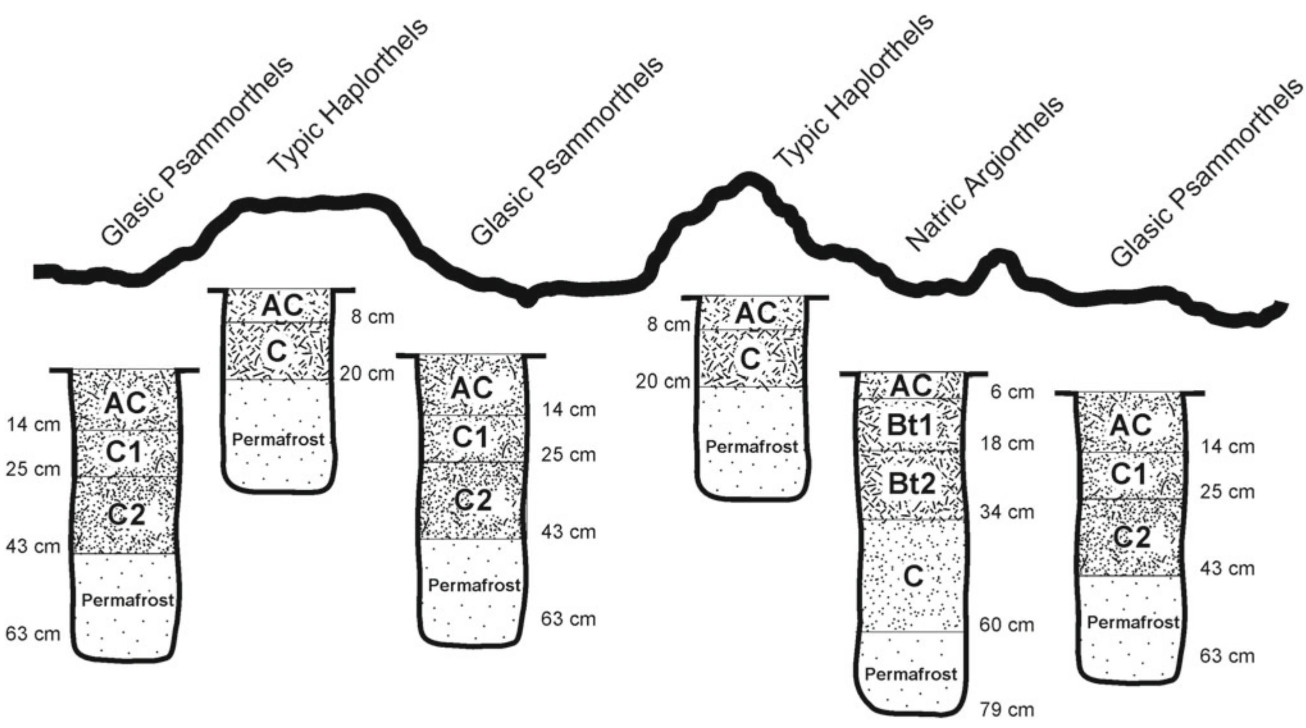

Fig. 15.6 Scheme of soil distribution along the landscape (Eastern sector, Antarctic Peninsula) (created by the authors)

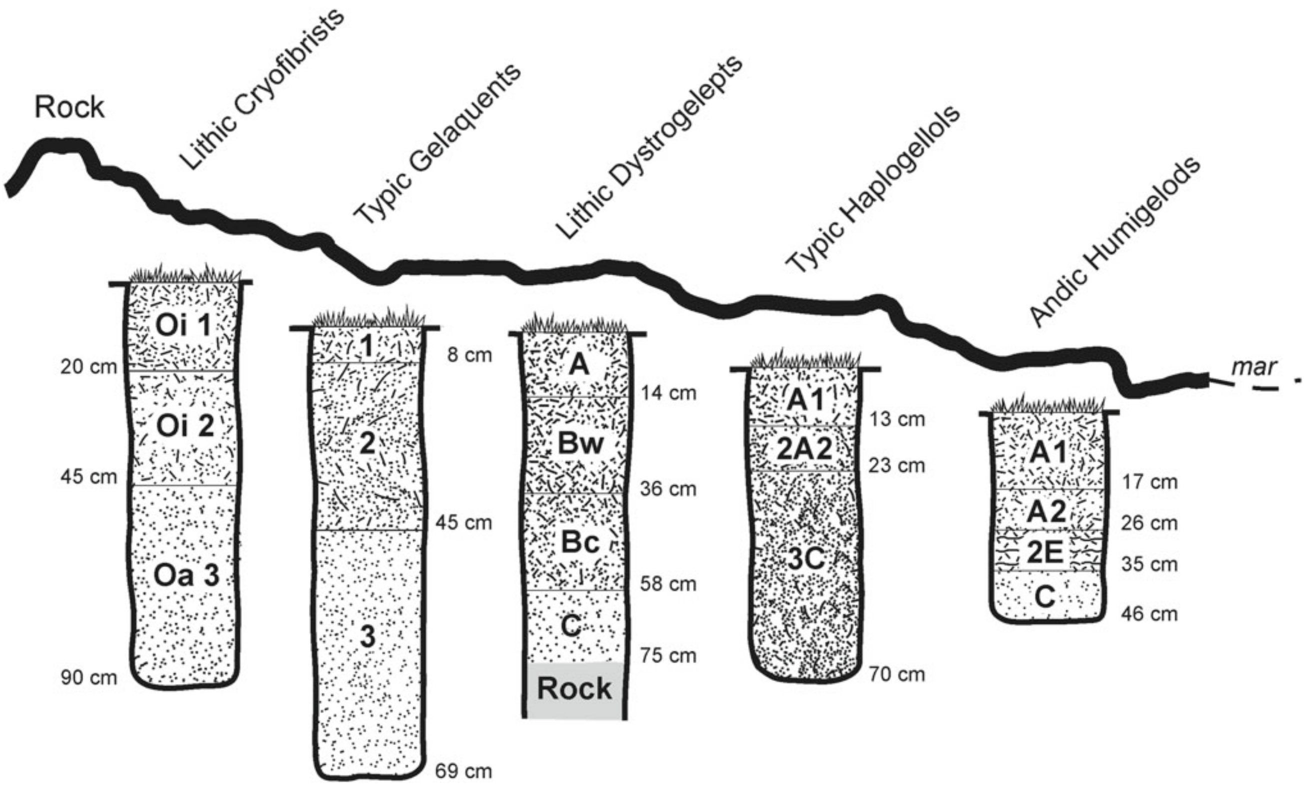

Fig. 15.7 Scheme of soil distribution in the landscape (Western sector, Antarctic Peninsula) (created by the authors)

presence of the ice layer. Erosion geoforms are typical of this region and can be found as plucked rocks and marks and/or grooves (glacial streaks) produced by the slow motion of glaciers. The accumulation geoforms show rests resulting from the destruction of rocks by erosive agents, from which these soils were formed. There were also small waterfalls and lagoons that in the thawing season increase their water level and modelled the structures.

Coastal geoforms are generally associated with glaciation and with the structural and lithological characteristics of each particular site. Geoforms derived from sea activity are well developed and were also affected by glaciation. Relicts of past higher sea levels could be detected on some sea terraces.

Climate and organism activity were the soil-forming factors that exerted the highest influence on soils of this sector. These soils were generally developed in the absence of permafrost. The presence of soil diagnostic horizons allowed the taxonomic classification of the representative units (Fig. 15.7). Podzolization processes can be found as in other sectors of Antarctica (Beyer et al. 1997; Tatur 1989). Bare rock appeared in the highest positions of the landscape (Fig. 15.7).

15.6 Soils: Classification and Properties

The severe climatic conditions of Antarctica has conditioned the formation of soils (Bockheim 2015b). Climate, vegetation and micro-organisms were key factors in soil development of this region, as have been shown by several studies of the Antarctic Peninsula (Bockheim 2015b). Important differences in soil genesis have been found at the different sites studied, where both current pedogenetic processes and those developed under warmer climates could be recognized.

The presence of permafrost, a key diagnostic tool for soil classification, was observed mainly in the Eastern sector of the northern Antarctic Peninsula. In the Western sector, the soils remain frozen during the winter and thawed in summer, which allowed horizon development that can be used for soil description purposes (Tedrow and Ugolini 1966; Godagnone 2001).

The diagnostic features used in the present study were the presence of ochric, mollic, histic, cryoturbation, permafrost and glacic layers and the presence of gelic materials. The soils found in the area belong to the following orders: Gelisols, Mollisols, Inceptisols, Histosols, Spodosols and Entisols (Table 15.1, Soil Survey Staff 1999, 2010).

Table 15.1 Analytical data of soils sampled in the present study

Order	Histosols			Entisols			Mollisols			Inceptisols			Spodosols				Gelisols			
Horizon	Oi1	Oi2	Oa3	1 N	2nk	3nk	An1	2An2	3Cn	An1	2An2	3Cn	A1	2A2	2E	2C	ACn	2Btkn1	Btkn2	3Cnk
Depth (cm)	0–14	35	42	0–8	45	100	0–13	23	70	0–3	19	55	0–17	26	35	46	0–6	18	34	60
Organic carbon	43.3	43.8	35.9	0.7	0.5	0.70	2.38	2.85	3.22	18.4	18.6	12.2	1	2	12	13	1.03	–	–	–
Organic matter	74.6	75.5	61.9	1.2	0.86	1.2	4.1	4.9	5.5	31.7	32.2	24.1	2	2	20	22	1.77	–		
Organic nitrogen	2.21	1.86	1.97	0.06	0.04	0.05	0.29	0.26	0.32	1.03	1.3	0.85	0.1	0.2	2	2	–	–	–	–
C/N	19.6	23.5	18.2	–	–	–	8.2	10.9	10	17.8	14.3	14.4	9	9	8	7	–	–	–	–
Extractable P	345	731	634	–	–	–	310	330	320	1118	38.1	6.3	49	94	223	264	–	–	–	–
Clay	–	–	–	8.7	18.4	9.01	8.0	11.8	9.1	13.6	14.4	14.2	7	8	11	9	28	34	32	25
Silt	–	–	–	26.6	33.6	12.2	19.4	20.7	11.5	18.3	16.2	25.5	35	43	30	20	43	42	35	41
Sand	–	–	–	64.1	48	78.8	70.6	68.4	79.4	47.6	50.9	47.6	58	49	59	71	29	24	33	34
Cakcium cabonate (CaCO3)	–	–	–	–	0.7	0.8	–	–	–	–	–	–	–	–	–	–	–	1	0.8	0.7
Electrical conductivity E.C. (mS/cm)	0.75	0.65	1,25	0,12	0,14	0.11	0.61	0.51	0.36	0.27	0.3	0.1	1	0	3	3	3.6	3.2	2.9	4.6
Water pH	5.3	4.9	4.6	6.7	7.6	8	4.8	5.4	5.3	4.1	4.4	5.3	5.5	6.5	5.6	5.1	7.8	8.2	8	8.2
1 N KCl pH (1:2.5)	4.5	4.4	4.2	5.6	6.5	6.6	4.2	4.6	4.4	3.6	3.8	4.3	4.5	4.7	4.8	4.9	7.3	7.5	7.5	7.7
1 N NKCl pH	8	8.8	9.5	8	8	8	9	9	9	9	9	10	9	9	10	10	–	–	–	–
Exchangable cations m.e./100 g																				
Ca++	–	–	–	3.6	–	–	2.1	6.1	3.6	4.2	5.7	7.4	4.7	4.3	11.7	15	11.6	–	–	–
Mg++	–	–	–	1.2	–	–	1	2.2	2	3.1	3	2.8	4	3	4.4	5.7	4.5	–	–	–
Na+	–	–	–	2	3.1	2.2	0.5	1	0.9	0.8	1	1.1	1.2	1.2	2.1	2.2	4.2	4.3	5.2	3.7
K+	–	–	–	0.8	0.8	0.4	0.3	0.3	0.3	0.5	0.5	0.7	1.5	1.5	1.7	1.4	0.6	1.1	8.0	0.8
Sum of extractable bases m.e./100 g (S)	–	–	–	7.6	–	–	3.9	9.6	6.8	8.6	10.2	12	11.4	10	20	24	20.9	5.4	13.2	4.5
Cation-exchange capacity (CEC)	–	–	–	–	–	–	10.5	13.1	10.5	37.3	42.7	33.8	16	15	33	34	20	21	19.8	20.3
ESP exchangeable sodium. (%)	–	–	–	25.6	21.6	27.5	4.8	7.6	8.6	2.1	2.3	3.3	7.5	7.7	6.4	6.5	21	20	26	18
Suborder	Spahgnic Cryofibrists			Typic Gelaquents			Typic Haplogelolls			Lythic Dystrogelepts			Andic Humigelods				Natric Argiorthels			

15.6.1 Gelisols

Originated from several parent materials, local Gelisols are mainly found on slopes, terraces, plateaus and depressions. The following suborders have been identified: Glacic Psammorthels; Typic, Glacic and Fluventic Haplorthels; Psammentic and Glacic Aquorthels; Glacic Mollorthels. Soils belonging to the Natric Argiorthels (Fig. 15.8) subgroup had its development interrupted by the presence of permafrost at a depth between 20 and 60 cm.

15.6.2 Mollisols

Mollisols from very cold regions, although already described in the 1990s (e.g. Godagnone 1997), were incorporated into the Key to Soil Taxonomy only in 2006. These soils had a certain genetic evolution, presented a block structure, high percentage of organic matter (3–10%). They were found on flat surfaces that remained stable over time. Lithic, Cumulic and Typic Haplogelolls (Fig. 15.9) suborders were recognized. The soil profiles of the two last mentioned suborders presented the following sequence of horizons: Oi-2ACk-3Cn_1-3Cn_2.

15.6.3 Inceptisols

Local Inceptisols show slight development of diagnostic horizons and usually high exchangeable sodium percentage. They are mainly located in depressed areas, on slopes of small elevations and in penguin nesting areas where the vegetation had been totally displaced. The main subgroups of this order recognized in the North of the Peninsula are the Histic, Lithic, Fluvaquentic, Aeric and Humic Gelaquepts (Fig. 15.10) and Lythic Distrogelepts.

15.6.4 Histosols

Histosols are soils that evolved from organic materials. They are present on slopes of different gradients. Their horizons show a different evolutionary state, in some of which still can be traces of vegetal fibres. Cryphibrists Sphagnic and Lithic, and Fluvaquentic Haplohemists were found. The subgroups Sphagnic and Lithic Cryofibrists, and Fluvaquentic Haplohemists (Fig. 15.11) have been identified in this sector of Antarctica.

15.6.5 Spodosols

Spodosols are not a widespread order in the northern sector of the Antarctic Peninsula. They can be found in depressed coastal areas (old marine terraces). The predominant textural class is sandy loam, although finer textures can also be found. Some of the local Spodosols would have formed during interglacial periods with more favourable climates (Paul et al. 1995; Goodwin 1993). Local surveys identified the presence of the suborder Andic Humigelods (Fig. 15.12).

Penguin skeletons dated 6000 years old were discovered (Godagnone and de la Fuente 2010) at 35 cm deep in the undisturbed E horizon of a local Spodosol, which testify the

Fig. 15.8 Landform and profile of a Natric Argiorthels (Marambio Island) (Photograph by Godagnone)

Fig. 15.9 Landform and profile of a Typic Haplogerolls (Cape Spring) (Photograph by Godagnone)

Fig. 15.10 Landform and profile of a Humic Gelaquepts (Cape Spring) (Photograph by Godagnone)

Fig. 15.11 Landform and profile of Fluvaquentic Haplohemists (Cape Spring) (Photograph by Godagnone)

Fig. 15.12 Landform and profile of Andic Humigelods (Harmony Point) (Photograph by Godagnone)

amount of material accumulated and the evolution of the soil during that period.

15.6.6 Entisols

This order comprises soils with scarce genetic evolution. Local Entisols usually show several superimposed layers of deposition and are usually found on plateaus, moraines, slopes, terraces, sea coasts, depressions and alluvial planes of water channels. Soil organic matter content and texture were the morphological and analytical elements that allowed the differentiation of the soil horizons. The evaluations allowed recognizing the following subgroups: Aquic and Typic Xerorthents, and Typic Gelaquents (Fig. 15.13).

Fig. 15.13 Landform and profile of Typic Gelaquents (Cabo Spring) (Photograph by Godagnone)

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