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Characterization of abiotic conditions affecting vegetation distribution in the river Plate coastal plain, Argentina

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ABSTRACT. The river Plate coastal plain is located in northeastern Buenos Aires province, where geological events such as sea transgressions and regressions in the Holocene have produced a stratigraphic column with marine-estuarine, fluviatile and continental sediments, as well as a variety of landforms and soils. The aim of this paper is to describe these different coastal settings and their influence in the distribution of plant communities.

Key words: coastal plain, geomorphology, soils, vegetation, river Plate.

RESUMO. Caracterização das condições abióticas que influem na distribuição da vegetação na planície costeira do rio de la Plata, Argentina. O noroeste da província de Buenos Aires localiza-se na planície costeira do rio de la Plata, área com intensa atividade geológica que levou ao desenvolvimento de uma coluna sedimentar na qual alteram materiais de origem marinho-esturarina, fluvial e continental. A isso atestam também as geoformas geradas durante o ciclo transgressivo-regerssivo do Holoceno. O objetivo do presente trabalho é descobrir os distintos ambientes da planície costeira com respeito à sedimentação, morfologia e solos, analisando a correlação e condicionamento entre tais fatores e a distribuição das comunidades vegetais.

Palavras chave: planície costeira, geomorfologia, solos, vegetação, rio de la Plata.

Introduction

The study area is located on the right bank of the river Plate, in northeastern Buenos Aires province (Figure1). It covers a 160-km long area, parallel to the coastline, ranging in width from 9 to 2.5 km. It includes the following municipal districts: Avellaneda, Quilmes, Berazategui, La Plata, Ensenada, Berisso, Magdalena and Punta de Índio (Figure 1).

The mean annual rainfall is 1040 mm, being March the rainiest month (111 mm) and June the drier month (63 mm). The seasonal distribution of rainfall is quite regular, with a slight decrease in winter. Mean annual temperature is 16.2°C, with means of January (midsummer) and July (midwinter) of 22.8 and 9.9°C. Absolute maximum and minimum annual temperatures recorded were 43 and -5°C. Data (1909-2005) correspond to La Plata Weather Station (Facultad de Ciencias Astronómicas y Geofísicas, Universidad Nacional de La Plata) located at 34°55'S, 57°56W, 15 m above sea level.

An important local meteorological phenomenon is the "sudestada", which consists of strong winds from the SE, accompanied by gentle to moderate persistent rains. These winds cause a rise of the estuary water level and the flooding of the coastal plains in variable degrees, according to the severity of the storm.

According to Thornthwaite's classification (Thornthwaite, 1948), the climate of the region is B1 B'2 r a' (humid, mesothermic with slight or null water deficit and low summer concentration of thermal efficiency). Mean monthly water balance was calculated following the method of Thornthwaite and Mather (1957) using a soil water holding capacity of 200 mm. The balance shows a low soil water deficit in summer and a surplus from late-fall to early-spring. According to these data the soil moisture regime of well drained soils is *udic*. In low-lying areas, which cover most of the study area, the soil moisture regime is *aquic*, or *peraquic* when water saturation is almost permanent.

The soil temperature regime was estimated from the air temperature (Soil Survey Staff, 1999). The mean annual, winter (June, July and August) and summer (December, January and February) soil temperatures at 50 cm depth are 17.2, 11.0 and 21.4°C, respectively. According to these data, the soil temperature regime is *thermic*.

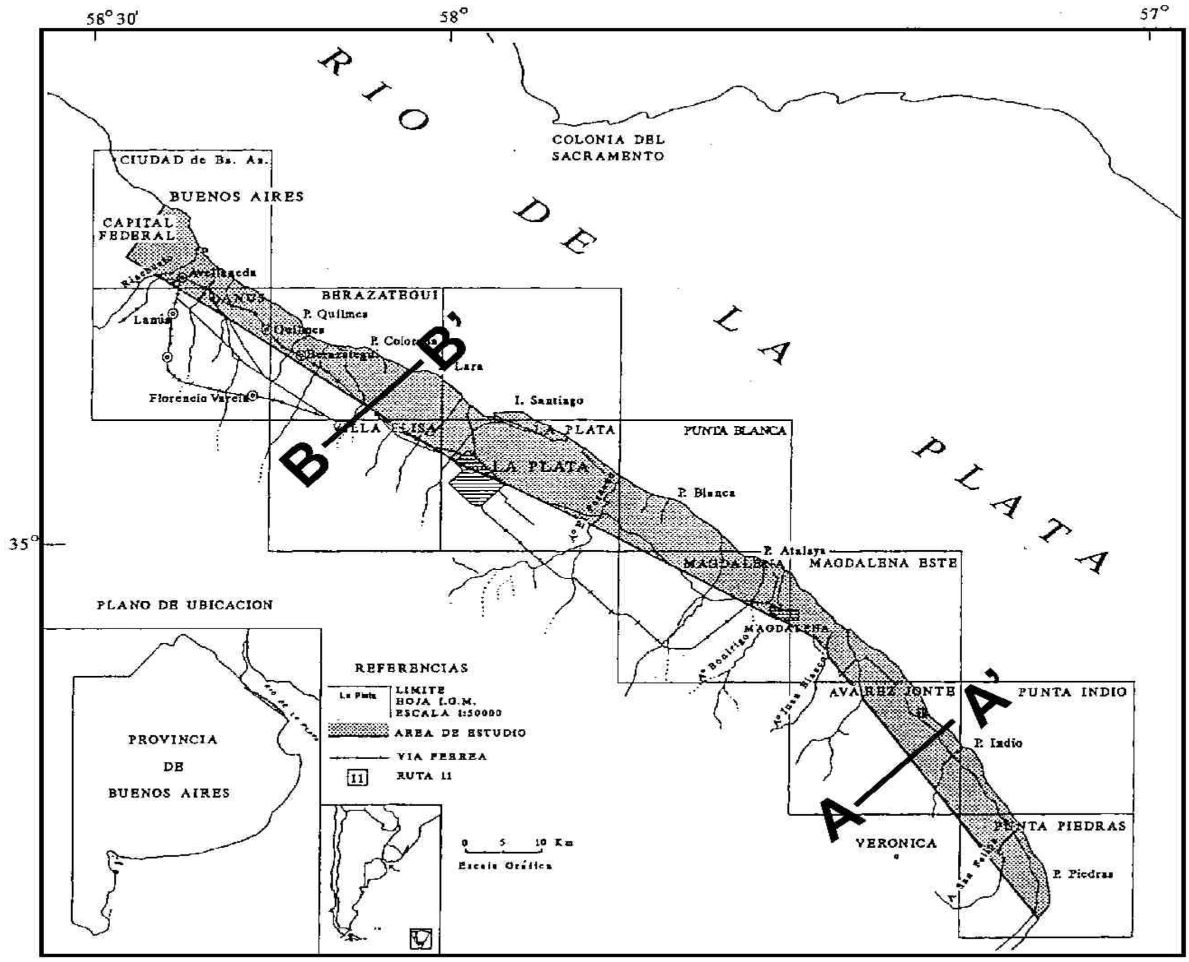

Figure 1. Localizaion map of coastal plain, Province of Buenos Aires.

Material and methods

In this study it was used the conventional method of satellite imagery, aerial photography and topographic charts. Field work was developed during extensive periods involving working groups of different institutions. Laboratorial analyses were processed in their most at the Institute of Geomorphology and Soils of the La Plata National University, La Plata, Argentina.

Results and discussion

The river Plate coastal plain has varied characteristics in lithology, stratigraphy, geomorphology, soil and biota. It is bordered on the southwest by the high plain; the boundary with this upland region (at about 5 m a.s.l.) is marked by a fall line or paleocliff, which is not always well discernible. The high plain is constituted of eolian continental sediments (loess) shaped by fluvial action into a very gently rolling plain.

The coastal plain has a flat to flat-concave relief with a regional slope of approximately 0.03%. Occasionally, knolls not higher than 2 m and not broader than 2000 m are found. When the streams of the high plain reach the coastal plain, they spread the waters over its surface as a consequence of the low slope and lithologic characteristics. Therefore, the drainage network is poorly developed, with a few main collectors and accessory tributaries. Anyway, it is possible to recognize a deranged drainage pattern, with short streams close to the shore and centripetal drainage in lower areas. The water table is high, usually above a depth of 1 m, outcropping for long periods. The coastal plain is the main groundwater discharge area of the high plain.

The sediments of the river Plate coastal plain were deposited by marine-estuarine and fluviatile processes and produced small accumulation landforms from the Holocene transgressive-regressive cycle (Martínez *et al.*, 2001). Due to differences in sediments and landforms, the region was divided into two areas: southern and northern. Location of landforms are indicated in two cross-sections representing the southern and northern study areas (Figure 2) and in the map of geomorphic units (Figure 3).

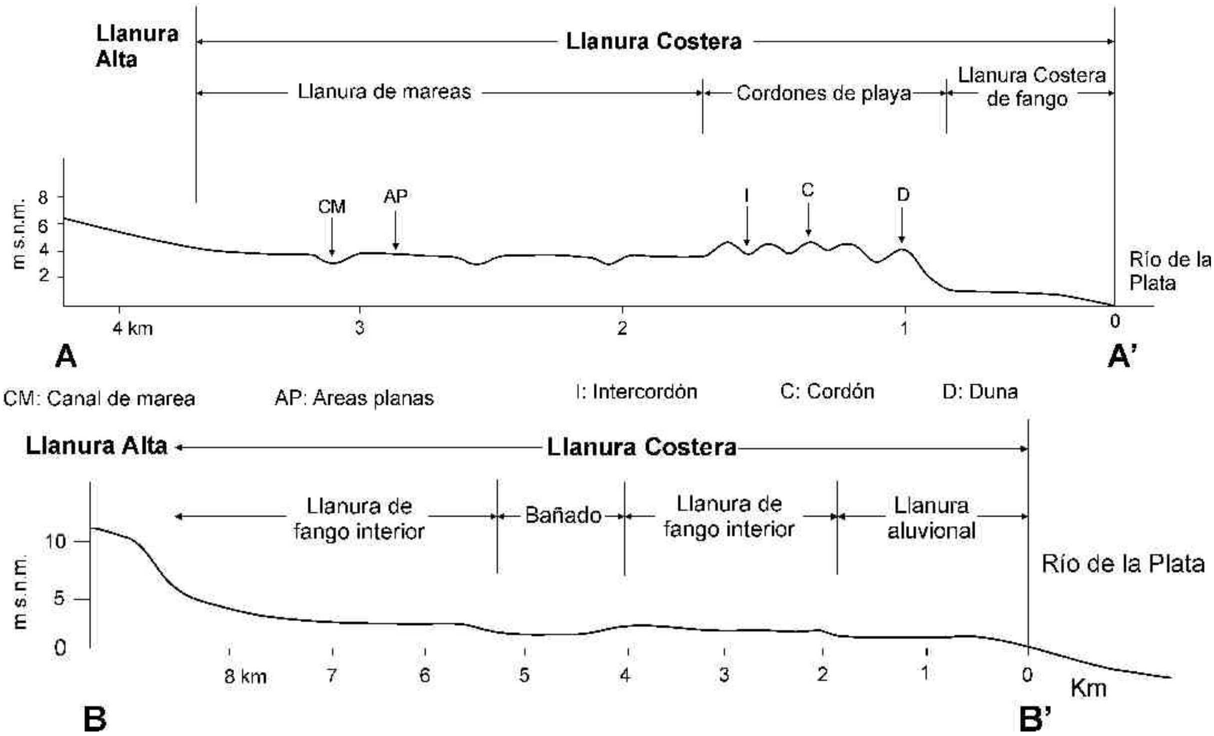

Figure 2. Schematic profiles of the (A) South and (B) North Zones.

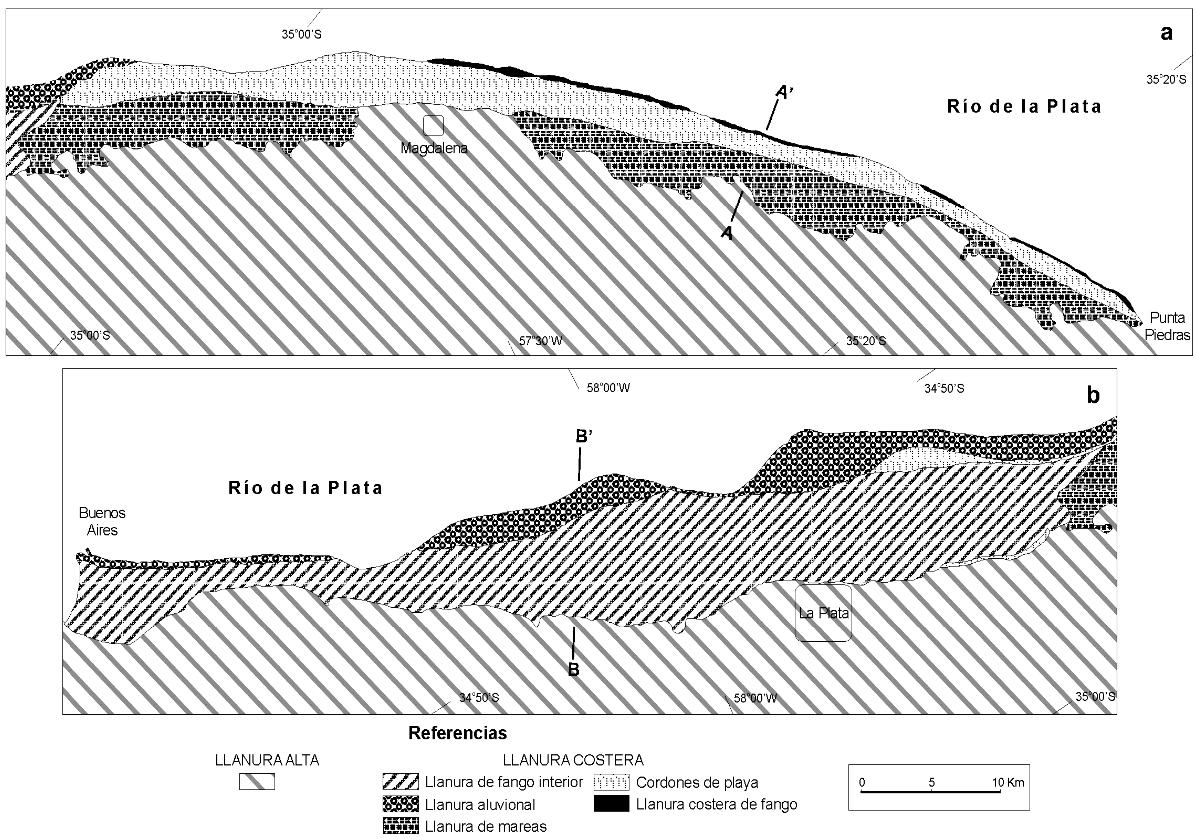

Figure 3. Geomorphological map of the (A) South and (B) North Zones.

The inner units of the Costal Plain are the Tidal Flat and the Inland Mudflat. The Tidal Flat is located in the southern part of the region; it is bordered on the inland by the High Plain and on the coast by the Beach Ridge Plain (Figures 2a and 3a). It is a flat area located between about 3 and 5 m a.s.l. and its maximum width is about 5 km. It includes a system of Tidal Paleocreeks formed during the Holocene transgression and later inactivated by the accumulation of shell bars and alluvial sediments. Extremely flat interfluves or Level Areas are found between the paleocreeks.

The Inland Mudflat extends from the vicinity of El Pescado stream basin to the North (Figures 2b and 3b). The origin of this unit is linked to the deposition of predominantly clayey sediments flocculated as a consequence of a saline water-freshwater interface, under low-energy and shallow water estuarine conditions. The clays are brown to black in color, and have high plasticity, adhesivity and expandibility. The unit includes numerous swamps; the largest one (Maldonado swamp) is 11 km long and 4 km wide (Figure 2b).

The Beach Ridge Plain (Figures 2a and 3a) is mainly represented in the southern part of the area, it is constituted of a succession of subparallel ridges or shell bars, decreasing in altitude towards the coast. The succession of ridges and inter-ridge depressions or swales produces a gently rolling landscape. The ridges are made up of brownish sandy sediments, including whole and fragmented marine mollusk shells and rounded caliche pebbles. Sometimes, they show a coarse stratification and an incipient cementation. The deposits originated from storm waves in a open estuarine environment during the Holocene maximal transgression. Occasionally, there are sand Dunes associated to the beach ridges and contacting the Coastal Mudflat (Figure 2a). They are composed of fine and very fine sand, transported by the wind from nearby beaches.

The Coastal Mudflat (Figures 2a and 3a) is a narrow strip located between the Beach Ridge Plain and the beach. It extends in the southern area, from Magdalena to Punta Piedras. It is a level to concave area, slightly sloping towards the coast. It would correspond to a shorre and a slikke (Tricart, 1973). The schorre identified in this region is made up of highly clayey material and is periodically flooded.

The Alluvial Plain (or Coastal Levee, according to Cavallotto, 1995) (Figures 2b and 3b) extends to the north of El Pescado stream. It is made up of brownish fine to very fine sandy sediments intercalated with layers of gray-blue to greenish finer material. The drainage system is formed by a number of channels which act as tidal creeks, sometimes flanked by small natural levees. In Berisso and Ensenada districts the coastline of the unit advanced about 1-2 km due to accretion in the last 200 years, according to documents and maps of the 18^{th} and 19^{th} centuries.

Soil forming factors and processes

The soil forming factors that played a decisive role in the evolution of the coastal plain soils are the parent material and the landforms. Therefore, these soils should be considered intrazonal. Conversely, in the high plain the predominant soils are zonal, since climate and vegetation have played the main role. Several pedogenetic processes have acted during the development of the soils. A description of the most relevant processes, as well as their environmental implications, is given below.

Hydromorphism

Most soils in the study area are saturated with water for long periods, especially in the Alluvial Plain, the Tidal Paleocreeks and the Swamps, where the soil moisture regime is *aquic* or even peraquic. Water saturation of the upper part of the profile may be due to flooding or perched water originated from the slow permeability of the clayey horizons (episaturation); saturation of the lower part can occur due to water-table rise (endosaturation), although both mechanisms can occur simultaneously. These processes are revealed in many horizons by well expressed hydromorphic features, like Fe mottles, Fe-Mn concretions and gley colors (neutral greenish or bluish colors).

The excess of water in soils saturates the pore space, reducing oxygen content and affecting the respiratory activity of roots and microorganisms. Reducing processes can also give rise to a loss of nutrients, for example nitrogen (denitrification). If these processes are more severe, there is a reduction of sulfates to sulfides and production of methane. Frequent changes in water table increase the risk of corrosion of concrete and metals. Decomposition of hydrocarbon wastes by biological methods (land farming) is difficult due to the low oxygen content that limit the activity of microorganisms (mainly aerobic bacteria and fungi).

Vertisolization

This process involves substantial volume changes of the soil material due to shrinking and swelling when soil moisture conditions change. This movements are caused by the presence of important quantities of expansive clays (smectites). The process is revealed by features such as slickensides, wedge-shaped peds and wide, long cracks. These soils also exhibit a high coefficient of linear extensibility (COLE). High levels of exchangeable sodium contribute to increase expansion.

The process is common in the Inland Mudflat where it involves soils classified as Vertisols. It affects plant growth since swelling and shrinking produce root flattening and constriction and limit root penetration. It can also generate cracks in pipes, walls, floors, pavements, etc. During dry periods, deep cracking facilitates percolation of water or eventual pollutants through bypass flow to bottom horizons and groundwater.

Alkalinization (sodification) and salinization

Accumulation of high quantities of exchangeable sodium (alcalinization) or, to a lesser degree, soluble salts (salinization) affect numerous soils in the Coastal Plain. They are a consequence of the parent material (marine sediments), slow permeability and abundance of low-lying areas.

The excess in exchangeable sodium results in a deterioration of physical properties (decrease in permeability, low aggregate stability, increased expansion etc.) which affects plant growth. Sodic soils have very alkaline reaction (pH usually over 8.5). Occasionally, alkalinization is accompanied by salinization; in this case pH is not extremely alkaline and physical soil deterioration is less severe due to the flocculanting effect of the soluble salts.

Clay illuviation

This process consists in the translocation of clay-size particles from eluvial (A, E) to illuvial horizons (mainly Bt, and to a lesser degree, in BA or BC horizons). The soils affected by this process exhibit clay or clay-humus cutans on ped faces of the illuvial horizons. There is generally an abrupt textural change between the eluvial and illuvial horizons.

The process is best expressed in the well drained zonal soils of the high plain, especially in Argiudolls. In the coastal plain it is observed only in sodic soils where the dispersive effect of exchangeable sodium favors clay mobility. In other areas, clay illuviation is less expressed or absent due to various causes which acted singly or jointly: recent water-deposited sediments, soil water excess, clay flocculation in calcareous materials or swell-shrink movements.

The consequences of clay illuviation are a reduction of permeability to air and water in Bt horizons and the difficulty for roots to penetrate in them. On the other hand, the process has a positive effect on soil chemical fertility by increasing the cation exchange capacity.

Melanization

This process consists in the transformation of vegetal and animal remains into humus by microorganisms through the biochemical process of humification. This results in the darkening of the upper part of the soil. Humus present in horizons A contributes to improve permeability, water retention and nutrients availability.

In low-lying areas (especially in the swamps) the occurrence of organic horizons on top of the mineral soil is common. It is a thin accumulation of plant remains in different degrees of decomposition; humification is poor since microbial activity is reduced due to low oxygen content. This process is not considered melanization proper but *littering*.

Anthropogenic activity

Human activities (urban, industrial, military, etc) have modified many of the soils of the region. As some of these activities are developed in depressed areas, natural soils were covered with 1-1.5 m of loessial sediments; these fill materials are found in the high plain or in the coastal plain underlying estuarine and marine sediments. Shells from the Beach Ridges are also mined for different uses. All these extractive activities have created a number of quarries or borrow pits, which are frequently inundated due to outcropping of water table. The excavations in the high plain constitute a loss of fertile soils and a risk of accidents.

Soil and vegetation characteristics

Morphological, physical and chemical characteristics of representative soils of the geomorphic units are described. Soils were classified at subgroup level according to the systems Soil Taxonomy (Soil Survey Staff, 1999) and WRB (IUSS Working Group WRB, 2006). The plant communities for each unit are indicated.

Tidal Flat

In the Level Areas, which cover most of the Tidal Flat, *Typic Natraqualfs* (*Gleyic Solonetz*) are the dominant soils; they are poorly drained soils with sequences: An-Btng-BCng-Cng. Reaction is extremely alkaline (pH 9.0-10.0) due to the high exchangeable sodium content from the surface, with the highest values in the Btng horizons (40-60%) Some horizons have also high levels of soluble salts (reaching 10 dS m^{-1} in some cases). The texture is silt loam to clay silt loam. Redoximorphic features (Fe mottles, Fe-Mn concretions, gley colors) are abundant all over the profile due to frequent waterlogging and shallow water table. Some soils have slickensides in the B horizons (*Vertic Natraqualfs, Vertic Solonetz*). Sealing crusts are frequently observed on the surface; these are 0.5-3 cm-thick crusts, with high silt content and laminar structure, formed through deposition of fine material carried by water.

The high exchangeable sodium content and occasionally soluble salts determine that only a low coverage of plants adapted to these conditions is found. The dominant species is salt grass (*Distichlis spicata* and *Distichlis scoparia*) accompanied by Bermuda grass (*Cynodon dactylon*) and cyanophyceae algae (*Nostoc* sp.).

Soils in Tidal Paleocreeks, are very poorly drained. The high water input results in the leaching of exchangeable sodium and soluble salts; therefore these components are found in lesser amounts than in the Natraqualfs. Due to the low oxygen content, mineralization of plant remains is difficult and a thin organic horizon forms on the surface. This is underlain by a dark horizon A rich in organic matter overlying a E horizon. Underneath, a Bt horizon is found, with well defined columnar structure, suggesting that exchangeable sodium content was once higher and produced dispersion of the tops of the Bt horizon. The reaction is slightly acid in the A horizon to moderately alkaline in the B horizons. These soils are classified as *Argiaquic Argialbolls (Mollic Planosols).*

The vegetation found in the tidal creeks include hygrophilous shrubs such as carda (*Eryngium eburneum*) and duraznillo (*Solanum glaucophyllum*), in addition to numerous herbaceous species.

In both soils phreatic water is shallow, exhibiting some differences in its characteristics. In the tidal paleocreeks, with prolonged ponding and rapid infiltration, lenses of freshwater (conductivity about 1 dS m^{-1}) are observed overlying the more saline phreatic water (conductivity about 10 dS m^{-1}). In the Level Area, such freshwater lenses are not observed.

Inland Mudflat

Three layers of different origin are recognized in this unit: the upper material, from which present soils have developed, is probably of mixed origin (fluviatile-marine); it has 0.80-1.50 m in thickness, with very high content (60-80%) of plastic, gray to black clay, showing strong swell-shrink evidences (slickensides and deep cracks). Indications of clay illuviation (clay cutans) are occasionally observed, somewhat masked by vertic features. Underlying the previous layer, materials of marine origin, 1.00 m thick, sandy to sandy loam in texture, are found. Sometimes, layers of coarse and fine texture alternate with shell fragments of varied sizes. Underneath there is a highly compacted, brownish, loam to silt loam material, with coarse caliche concretions (Ensenada Formation). This material appears in the vicinity of the high plain at 1.50-2.50 m depth, becoming deeper towards the coast.

Generally, all soils have poor drainage with aquic moisture regime, due to susceptibility to flooding, waterlogging and shallow water table. This is reflected in the expression of hydromorphic features (mottles, Fe-Mn concretions and gley colors) well represented in the two upper materials. In most cases, the upper two materials have high exchangeable sodium content and soluble salts. Most soils of the unit were classified as *Typic Natraquerts* (*Sodic Vertisols*). The vegetation consist of grasses, mainly Bermuda grass (*Cynodon dactylon*) and salt grass (*Distichlis* sp.).

The soils developed in the lowest areas (swamps) are *Typic Epiaquerts* (*Stagnic Vertisols*). They are similar to Natraquerts, but with lower exchangeable sodium content and sometimes with superficial organic horizons. In these environments, the predominant vegetation are hygrophilous shrubs, like duraznillo (*Solanum glaucophyllum*) and carda (*Eryngium eburneum*).

Beach Ridge Plain

The soils of the ridges are classified as *Typic Haprendolls* (*Rendzic Phaeozems*). The parent material is made up of eolian loess sediments and whole and fragmented mollusk valves (*Mactra isabelleana, Erodona mactroides, Tagelus plebeus, Littoridiana australis, Buccinanops cochlidiu* and *Adelomedon brasiliana*).

As a consequence of the flocculating effect of calcium, these soils are slightly developed with A-AC-C or A-C sequences. The surface horizon is dark with high content of well humified organic matter (5-10%). Humification is favored by the intense biological activity, physical and chemical factors (pH, aeration, calcium and nitrogen richness) and rapid decomposition of vegetal material incorporated into the soil. These conditions favor a good aggregation in the A horizon with a granular and crumb structure and rapid permeability (basic infiltration about 10 cm h^{-1}).

Texture is moderately coarse (loam, sandy loam) in the A horizon and coarser as depth increases. Shell fragments and rounded caliche pebbles are found from the surface horizon and become more abundant with depth in the C horizon. Mineralogy of the modal fraction (50-100 μm) in the A horizon reflects the mixed origin of the materials. 40% of the clastic fraction consists of shell fragments, and 60%

is similar to loess sediments. It is rich in volcanic glass (18-20%), plagioclases and quartz, with scarce heavy metals.

The flora developed in Haprendolls is typical of the extrazonal community of the Monte Phytogeographic province, which extends in subhumid or semiarid regions of central Argentina. The presence of this community in more humid climates is due to the higher topographic position of the shell bars and low water retention of the soils with abundance of sand and coarse fragments. In the woody and shrub stratum the dominant species are adapted to well drainage conditions, such as: tala (*Celtis tala*), coronillo (*Scutia buxifolia*), sombra de toro (*Jodina rhombifolia*) and brusquilla (*Discaria longispina*).

The swales found between the ridges are frequently flooded and with high water level. The soils have finer texture and lower shell content than those in the ridges. They have A-Cg sequences and have been classified as *Typic Endoaquolls* (*Mollic Gleysols*). The species of the adjacent ridges are not found due to the poor drainage conditions, instead, hygrophilous species like *Puccinellia glaucescens*, *Scirpus californicus, Cynodon dactylon* and others are frequent in these areas.

Dunes

The soils of the dunes are poorly developed (sequence A-AC-C). In the A horizon and subsoil no structure is visible (single grain). The horizon C, includes, at approximately 1.00 m depth, a series of subparallel textural lamellae originated by clay and silt illuviation. The whole profile has sand texture, with dominance of very fine and fine sand. The cation exchangeable capacity is low (7 to 5 $cmol_c\ kg^{-1}$) and reaction is acid (pH 5.5-6.5) throughout the profile, except in the lowest part (at 1.50-2.00 m depth) where shell fragments are found. These soils were classified as *Lamellic Udipsamentes* (*Lamellic Arenosols*).

The woody, shrubby and herbaceous vegetation is similar to that of the beach ridges but sparser. The low vegetation cover can favor wind erosion in areas under livestock production. The digging activity of the rodent tucu-tucu (*Ctenomys talarum*) revealed by the frequent presence of krotovinas (infilled burrows), may also contribute to soil deflation (Sánchez *et al.*, 1976).

Alluvial Plain/ Coastal Mudflat

The soils in these environments were formed in sediments deposited by the river Plate. Texture is mainly sand in the Alluvial Plain and clay in the Coastal Mudflat. This marked grain-size difference is ascribable to the presence of the freshwater-saline water interface near the Coastal Mudflat, which caused clay flocculation (Cavallotto, 1995). Soils are acid, without significant contents of soluble salts, showing variable content of organic matter in the profile (buried river debris). The oxygen deficit favors the accumulation of organic horizons (Oi) on the surface, formed from plant remains with very weak decomposition. A characteristic sequence of horizons is: (Oi)-A-Cgl-2Cg2-3Cg3. The dominant soils are *Typic Fluvaquents* (*Gleyic Fluvisols*); in the Coastal Mudflat *Typic Epiacuerts* (*Gleyic Vertisols*) are also found.

The soils evolved under important hydromorphic conditions as a consequence of shallow water level and frequent waterlogging and flooding. They exhibit hydromorphic features such as greenish to bluish-neutral colors, Fe mottles and Fe-Mn concretions.. They frequently show perched waters on clay deposits. Some soils, in small natural levees, have slightly better drainage conditions.

A complex mosaic of plant communities is found in these units: cord grass (*Spartina* sp.); marshes of rush (*Schoenoplectus californicus*), cattail (*Typha* sp.), bulrush (*Scirpus giganteus*) and espadaña (*Zizaniopsis bonariensis*) and wet prairies of *Scirpus chilensis* (Cabrera, 1968; Vervoost, 1967). In the natural levees of the Alluvial Plain relicts of the world's southermost gallery forest are found; they are formed by a 12-15 m high woody stratum, accompanied by shrubby, herbaceous, and muscinal strata with abundant creepers, lianas and epiphyts. The most common woody species are: mataojo (*Pouteria salicifolia*), laurel (*Ocotea acutifolia*) and blanquillo (*Sebastiana brasiliensis*). Other vegetal communities include seibales (Consocies of *Erythrina crista-galli*), saucedales (Consocies of *Salix humboldtiana*) and riparian shrubs of *Sesbania punicea*.

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