# FROM BUENOS AIRES TO SANTA FE: DARWIN'S OBSERVATIONS AND MODERN KNOWLEDGE

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**ABSTRACT**

During his historical voyage around the world, Darwin raided deeply in the South American interior, travelling over 600 kilometers from Buenos Aires to the north along the Río Paraná. During that journey, he crossed a vast plain characterized by aeolian sediments, something unfamiliar to a European naturalist. However, Darwin's acute observation powers and precise descriptions are noteworthy. After more than 170 years since his visit, modern geological knowledge identifies several sectors in the Buenos Aires-Santa Fe region. One of them (the Tertiary at La Bajada) he described admirably and others such as the Paraná flood plain were brilliantly abstracted in only two sentences. In short, Darwin traversed a first sector (Buenos Aires-Rosario) characterized by aeolian and paludal Early Pleistocene sediments. From Rosario to Santa Fe the plain is formed by Late Pleistocene aeolian and fluvial units. At La Bajada (presently Paraná city) lies exposed the marine Miocene and in SW Entre Ríos is a reconstructed loess-paleosol sequence generated at the Early/Middle Pleistocene transition. The Paraná flood plain and the littoral complex at the mouth (practically not observed by Darwin) underwent rather complex Holocene episodes.

Keywords: *Ch. Darwin, Pampa, South America, Quaternary, Tertiary.*

**RESUMEN:** *De Buenos Aires a Santa Fe: observaciones de Darwin y conocimiento actual.* Durante su histórico viaje alrededor del mundo, Charles Darwin incursionó profundamente en el interior de Sudamérica recorriendo más de 600 kilómetros hacia el norte de Buenos Aires a lo largo del río Paraná. Durante ese viaje, él recorrió una gran planicie caracterizada por sedimentos principalmente eólicos, un caso poco familiar para un naturalista europeo. Sin embargo, sobresale su gran capacidad de observación y precisión en sus descripciones. Después de más de 170 años de la visita de Darwin, el conocimiento geológico moderno ha identificado varios sectores en la región Buenos Aires-Santa Fe, uno de los cuales (el Terciario de La Bajada) él describió admirablemente y otros, como la llanura aluvial del Paraná, reseñó magistralmente en solo dos frases breves. En resumen, Darwin recorrió un primer tramo (Buenos Aires-Rosario) caracterizado por sedimentos eólicos y palustres del Pleistoceno Inferior. Desde Rosario hasta Santa Fe la llanura está formada por unidades eólicas y fluviales de edad pleistocena superior. En La Bajada (hoy ciudad de Paraná) aflora el Mioceno marino y en el sudoeste de Entre Ríos se reconstruyó un sistema loess-paleosuelos generado a lo largo de la transición Pleistoceno Inferior-Pleistoceno Medio. La llanura aluvial del Paraná y el complejo litoral de su desembocadura (prácticamente no observados por Darwin) sufrieron cambios dinámicos bastante complejos durante el Holoceno.

Palabras clave: *Ch. Darwin, Pampa, Sudamérica, Cuaternario, Terciario.*

## INTRODUCTION

Charles Darwin made the journey from Buenos Aires to Santa Fe by cart and horse. After several days of work at La Bajada (presently Paraná city) he returned to Buenos Airs by boat along the Río Paraná. Such a trip allowed him (surely by chance) to cross four major geographic and Quaternary geological environments of southeastern South America (Fig.1). The first one stretches from Buenos Aires city (in fact, it begins further south) to Rosario and reaches several tens of kilometers westwards. It is formed by a slightly elevated block characterized by Early Pleistocene formations and marginal Holocene littoral deposits. The second sector covers the Rosario-Santa Fe road and reaches 300 km west to the hills in Córdoba. This system is a relatively sunken region dominated by Late Quaternary loess bounded at the north by the South American region of Chaco. The third area he visited forms the southwestern sector of Entre Ríos province; it is represented by a hilly landscape carved into Miocene marine sediments and Early Quaternary aeolian and swampy formations. The last environment Darwin recorded during his journey is the Paraná river system, composed of a wide flood plain and a littoral complex at the mouth ("Paraná delta"), both of them Holocene in age.

In order to visualize Darwin's experiences, this article is organized in the same sequence of geological terrains that he found during his journey (Darwin 1846, 1945).

When reading his journal or his geological observations of the region, Darwin's


**Figure 1:** Map of the region showing the localities visited by Darwin.

great observation power and exceptional ability for synthesis appear immediately evident, notwithstanding the limitations of geological theory at that time. For instance, the nature and origin of loess (the dominant sediment in the Pampas) was discovered several decades later. It is evident that Darwin did not feel comfortable with such "muds", "clays" and similar. In order to describe and interpret those extensive deposits of the plain, he preferred to hold on to strata and concretions of *tosca* (caliche), intercalated in the sections. His skill as a paleontologist in comparison with his abilities as a sedimentologist is also clear.

Besides, it is interesting to discover in Darwin's writings the existence of qualified observers - i.e., people with some scientific knowledge - among the local population in those early years of Argentina. Some of them were British traders, but others were local inhabitants that were great observers of Nature.

## THE GREAT DROUGHT

An interesting environmental issue was described by Darwin in relation to the trip to Santa Fe. It was the "*Gran Seca*" (the great drought) that particularly affected the north of Buenos Aires and south of Santa Fe from 1827 to 1832. During those five years rain was exceptionally scarce and the plain underwent major changes: vegetation disappeared, minor rivers dried up and the entire country took the aspect of a dusty road, dust clouds continuously dominating the air. The effect on animals was catastrophic; cattle migrated massively to the south and assembled there in a giant flock; droves with thousands of wild horses hurried furiously to the Paraná to drink and later were unable to climb back up the slippery cliff and drowned. Hundreds of thousands of animals floated downstream to the Plata estuary. A few years later Darwin observed ¨*true layers of bones*¨ covering the bottom of some tributaries.

Very probably such great drought was a short late occurrence of the Little Ice Age (LIA) climate, which was characterized by a marked dryness in the Pampas (Parra 1939, Iriondo and Kröhling 1995) and ended around 1800-1810. The Spanish naturalist Azara also described similar events in the late 18th Century. The Little Ice Age provoked advances of glaciers in the Cordillera and related processes in southern South America, but did not produce visible geological effects in the Pampas, probably owing to its relatively short duration and not so severe dryness.

On the other hand, a longer dry period occurred between 3.5 and 1.4 ka BP and formed a thin aeolian mantle which covers the Pampas and surrounding regions, i.e., the San Guillermo Formation (Iriondo 1990, Fig. 2). It is an aeolian gray silt that generally tops the sedimentary sequence in the large interfluves. Most of the sediment is originated locally, by deflation of the A-horizon of soils and the subsequent deposition of dust. In Santa Fe province this mantle is formed by coarse silt with scarce proportions of very fine sand and clay, brownish gray in color (10YR 5/1). It is friable, porous, permeable, and moderately structured. Typical thickness varies from 25 to 55 cm; ceramic shards and Indian *boleadora* balls are included in the upper part of this deposit at some localities.

## BUENOS AIRES/ROSARIO ELEVATED BLOCK

Darwin rode a 250 km long first journey from Buenos Aires to Rosario in a straight northwestern direction. All that time, the road borders the right banks of the Río de la Plata and Río Paraná and runs atop a 10 to 20 m high cliff. This cliff is almost continuous, interrupted in a few places by small Holocene estuaries of minor tributaries (Luján, Areco, Arrecifes and others; Iriondo 2004). The cliff is tectonic in origin and exposes two

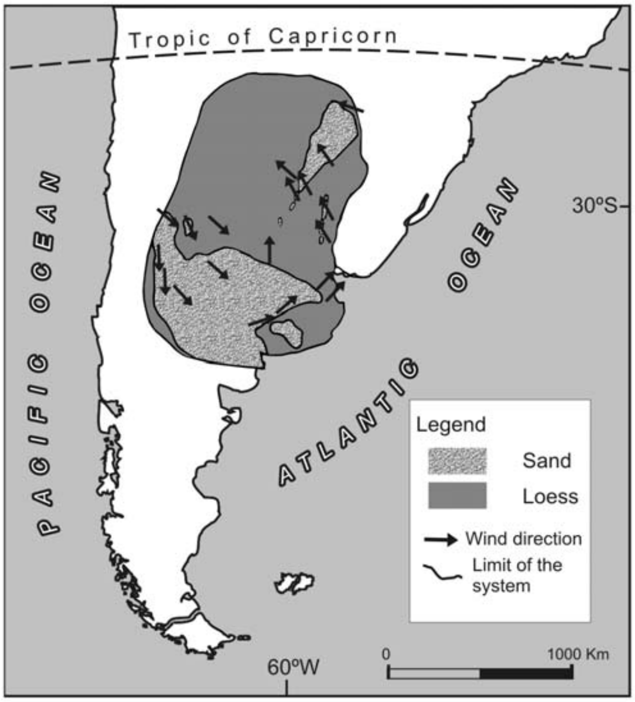


**Figure 2:** Map of the San Guillermo Formation, a late Holocene environmental equivalent of Darwin´s big drought (after Iriondo 1990).

Quaternary formations described by Darwin as "*pale and red Pampean mud*". Both units were identified and studied later in the Twentieth Century.

González Bonorino (1965) refered the sections outcropping in the Buenos Aires area as the Pampeano Formation. According to its mineralogy, the author differentiated two zones separated by a clear boundary: the upper zone characterized by plagioclase and illite and the lower one dominated by quartz and montmorillonite. Fidalgo *et al.* (1973) later described the Pampiano Formation and Riggi *et al.* (1986) discriminated the Ensenada Formation and the Buenos Aires Formation in the same sections. Both units appear along all the distance to Rosario, but have better outcrops on the left bank of the Paraná, in Entre Ríos province. Here they were defined as Punta Gorda Formation (Iriondo and Kröhling 2008) and Hernandarias Formation (Iriondo 1980).

Pale Pampean Mud/Punta Gorda Formation is an Early and Middle Pleistocene loess-paleosol sequence. It is composed of the Andean plagioclase-illite association and has an origin similar to the classical Last Glacial Maximum Pampean loess (Kröhling 2001). Both minerals were transported by southwesterly winds from the Andes Cordillera. The Punta Gorda Formation was deposited around 1 Ma BP during the most important Quaternary glaciation occurring in South America (Mercer 1976).

The Red Pampean Mud/Hernandarias Formation is a large playa deposit deposited by the Río Uruguay at the Early-Middle Pleistocene transition. It forms the surface of most of Entre Ríos province and below the surface reaches into neighboring regions in Santa Fe and Buenos Aires to the southwest (Iriondo 1980). The typical thickness of this formation varies from 20 to 40 m; it is composed of loam and silty loam with montmorillonite as main clay mineral, and quartz and very fine sand containing gypsum at the base. More than 90 % of the clay minerals, i.e., montmorillonite, beidellite and nontronite, show expansion/contraction properties.

The contact between both formations is concordant - a feature correctly observed by Darwin, who stated: "*I could clearly distinguish in this fine line of cliffs horizontal lines of variation both in tint and compactness*" (Darwin 1846, p. 87). As remarked by Darwin this observation contradicts the insistent assertion of the French naturalist d'Orbigny on the general absence of stratification in the Pampean sediments. The academic point was then whether the Pampean System was diluvial or not: if stratified, not diluvial.

**Baradero Section (NE Buenos Aires province)**

The section on the Río Baradero north of the city of Baradero (100 km from Buenos Aires), is formed by the Punta Gorda Formation (5 m thick), conformably overlain by the Hernandarias Formation (7 m thick, Iriondo 1980). From bottom to top:

0 - 1 m Punta Gorda Formation. Bed of clayish silt, dull brown in colour, moderately consolidated. It contains numerous Fe-oxide segregations, $CaCO_3$ concretions of different sizes and large rhizoconcretions. It is interpreted as a paludal deposit.

1 - 5 m Punta Gorda Formation. Bed of a silty grain-size composition, pale brown in colour, massive in general and in some places with a weak medium to coarse horizontal stratification. Medium to high consolidation (highly calcareous); carbonate (*tosca*) concretions. Fine root moulds covered by black films. The deposit has a general aeolian origin, with local rill reworking and krotovinas in some places. Remains of *Glyptodon* were found in the measured section. At the top, a marked horizontal paleosurface is recognized, locally joined to a residual material of 0.60 - 0.80 m thick, with few local pedogenic features.

5 - 12 m Hernandarias Formation. It is composed of clayish silt to a silty clay, olive gray in general colour and with variations to brown and olive; with abundant large and irregular carbonate concretions. Frequent Fe-Mn sesquioxide segregations appear. It is less consolidated than the underlying unit and is organized in poorly defined coarse strata, and interpreted as a paludal deposit. Numerous dessication cracks appear along all the section. The deposit includes me-

dium to coarse lenticular to tabular strata of pale brown silt, with internal lamination and segregated $CaCO_3$. Such lenses are interpreted as aeolian, locally re-transported material. In some sectors appear lenses of retransported botrioidal $CaCO_3$ concretions.

The forms of erosion of both formations are very different and distinctive along the river cliffs. They were also affected by several gullies with.

12-15 Tezanos Pinto Formation. Yellowish brown, friable, massive and calcareous silty deposits. It is the typical LGM Pampean loess.

Nabel *et al.* (1993) studied the magnetostratigraphy of two sections at Baradero, finding reverse polarity (older than 0.78 Ma) in the lower section of the cliff. Those authors identified two of the lenticular paleosols and named them El Tala (Brunhes paleomagnetic chron) and Hisisa Geosols (Matuyama chron > 780 ka). Nabel *et al.* (1993) discriminated eight litoestratigraphic units at Baradero section: units I to V interpreted as loess and paleosols deposits and units VI to VIII associated with limnic environments. The age of the deposit in the region was attributed to the Ensenadense Mammal Age (Tonni *et al.* 1999). Later, Kemp *et al.* (2006) reconstructed the sequence of pedosedimentary processes in the same locality based on soil science methods and identified paleosols embedded in swamp and aeolian sediments. Their ages as recorded by luminescence methods (OSL dates range from ca. 114 to 14 ka BP) differ considerably from previous paleomagnetic results of Baradero.

**San Pedro Section (NE Buenos Aires province)**

In a quarry excavated into the Río Paraná cliff at San Pedro the following section appears from bottom to top: a paleosol developed on top of the Punta Gorda Formation and truncated by erosion (1.20 m thick) and constituted by brown silt, weakly structured in peds. It contains numerous large root moulds generated by the lixiviation of $CaCO_3$ rhizoconcretions. Pedological features are: fine root moulds covered by black films, argillocutans and ferriargillans. This paleosol corresponds to the unit G attributed by Imbellone and Cumba (2003) -Geosol El Tala-Hisisa-. The Hernandarias Formation forms the rest of the exposed section, with general paludal characteristics and interbedded discontinuous soil horizons in the middle sector of the unit. Numerous large krotovinas appear in this formation.

**Vuelta de Obligado and Ramallo Sections (NE Buenos Aires province)**

The section of the cliff at Vuelta de Obligado is represented by the loessic facies of the Punta Gorda Formation (6.50 - 8 m thick), overlain by a calcrete (2.50 m thick). The unit includes a 1.30 m thick paleosol at the base, composed from top to bottom as follows:

0 - 0.35 m B2t horizon. Brown clayish silt (7.5 YR 5/4), moderately to well structured in very firm, fine to medium prisms, bounded by fine fissures. Common clay cutans and fine root moulds. Very fine to fine Fe-mottles and Fe-Mn oxides segregations frequent.

0.35 - 0.57 m B3 horizon. Brown silt moderately organized in very firm, fine to medium prisms. Scarce argillocutans and fine root moulds.

0.57 - 0.87 m BC horizon. Brown silt, weakly structured in firm and fine blocky peds. Abundant very fine Fe-Mn mottles and fine root moulds.

0.87 - 1.29 m C horizon. Light brown clayish silt with paludal characteristics (very fine resistant blocky peds, frequent Fe-mottles, common $CaCO_3$ irregular and platy concretions).

At that locality, a well developed 1.5 m high notch appears at the base of the cliff; that feature indicates erosional action by waves during the Middle Holocene marine ingression. Such a feature also appears in the same position at Fray Bentos, in the Banda Oriental (Uruguay). The Río Paraná cliff at the locality of Ramallo is formed by the Punta Gorda Formation, represented by the loessic strata with frequent $CaCO_3$ vertical platy concretions, 2.50 to 3 m thick. The unit is covered by the paludal facies of the Hernandarias Formation, with frequent $CaCO_3$ concretions.

**Arroyo Pavón and Arroyo Seco Sections (Southern Santa Fe province)**

Entering the territory of Santa Fe province, Darwin described a cascade about twenty feet high in the Pavón creek, a small tributary of the Paraná. He recorded there two varieties of *tosca*-rock (limestone).

Today the Pavón Cascade is located a few hundred meters from Provincial Highway 11. The cliff downstream the cascade begins at the base with a brown sandy aeolian deposit (1.5 m thick) covered by a loessic unit with segregated $CaCO_3$ (1.5-2 m thick). A paleosol (1 m thick) is recognized on top of it (it very probably correlates with the soil exposed at the bottom of the Vuelta de Obligado section). The section ends with the loessic facies of the Punta Gorda Formation with abundant $CaCO_3$ concretions (2 m thick). Some kilometers to the north, the Punta Gorda Formation forms the banks of the Arroyo Seco (9 m high at the town's camping grounds); locally differentiated is a 3 m thick brown silty strata, paludal in origin.

## ROSARIO/SANTA FE BLOCK

From Rosario to Santa Fe and beyond to the north and west, stretches another sector of the Pampas, dominated by Late Pleistocene geological formations. The landscape is there shaped by two widespread aeolian units: Tezanos Pinto For-mation and San Guillermo Formation. However other units originated in fluvial environments have been described. The stratigraphic sequence is the following:

**Section of the Paraná cliff between Puerto Gaboto and Rosario (Santa Fe province)**

According to Kröhling (1999) the exposed stratigraphic column on the cliffs along the right bank of the Paraná and Coronda rivers, between the cities of Puerto Gaboto and Rosario, begins at the base with the Plio-Quaternary Ituzaingó Formation, deposited by the Río Paraná. The sedimentary record of the unit is represented by mature and well selected sands, typical of channel facies of a fluvial system of high discharge. The conditions that favored the accumulation of the unit changed toward the top of the formation to a fluvial regime of lower energy.

The Ituzaingó Formation is separated by an erosional unconformity from the overlying Late Pleistocene Puerto San Martín Formation, formed by the discontinuous accumulation of fine aeolian sediments. The accumulation environment was of semipermanent swamps, intercalated with periods of subaerial conditions (loess). The existence of Ck-horizons of truncated soils near the top of the unit suggests more benign conditions. In some sites, between the two mentioned formations there are intercalated several paleochannels infilled with alluvial and paludal deposits. These were formed by successive avulsions of the last segment of an important tributary in the region - the Río Carcarañá (Timbúes Formation).

The landscape developed over the Puerto San Martín Formation was later covered and smoothed during the Last Glacial Maximum by the loess of the Tezanos Pinto Formation. The stratigraphic sequence ends with the Late Holocene San Guillermo Formation, which lies over the buried Holocene Optimum Climaticum soil developed on top of the loess.

Darwin described the Paraná cliff in the area of Estancia Grondona, north of Rosario and near the last and more recent segment of the Río Carcarañá. The exposed section was characterized by Darwin as follows, from the base to top: "*it consists of a pale yellowish clay, abounding with concretionary cylinders of a ferruginous sandstone*". It is interpreted as the Ituzaingó Formation. Darwin continues: "*The rest of the cliff at Gorondona, is formed of red Pampean mud, with, in the lower part, many concretions of tosca, some stalactiformed, and with only a few in the upper part… containing mammiferous remains close to its base*" (Darwin 1846, p. 87). It corresponds to the general features of the Puerto San Martín Formation.

The main characteristics of the mentioned formations exposed in the area visited by Darwin were taken from Kröhling (1998) and are presented below:

***Ituzaingó Formation (De Alba 1953, Herbst 1971)***

It is composed of very fine quartz sand, sandy silt to silty clay, grayish yellow in colour (2.5Y 6/2) with variations to olive yellow (5Y 6/3). The sediment has abundant ferric segregations; also the postdepositional rubefication is in general discordant to the stratification. The upper part of the unit has abundant brown Fe-sesquioxides mottles (7.5 YR 5/8), locally concentrated in centimetric levels. The consistence of the sedimentary mass ranges from friable to poorly consolidated non-calcareous. Segregations of $CaCO_3$ form irregular to botrioidal concretions. Locally, in the lower part there are platty $CaCO_3$ concretions forming an orthogonal net or ferruginous concretions of 30 to 50 mm diameter. The unit is arranged into medium to coarse massive lenticular strata with 7-10 m of lateral extension, with variable concentrations of very fine to medium Fe-mottles (up to 40%) and Mn-segregations and mottles. Abundant fine root moulds with black segregations. In some sectors, the top of the unit is marked by a moderately developed B horizon and by calcareous concretions bellow it. Locally, the truncated paleosol is replaced by medium cuneiform strata composed of fine sand, ochre-yellow in colour, that form a set with diagonal stratification. Upwards they are replaced by medium horizontal strata composed of intraclasts in a sandy matrix or by internally laminated strata.

This unit, represented by the fluvial channel sedimentary facies (paludal facies is common too), outcrops at the base of the cliff of the Río Paraná from its junction with the Río Coronda up to the city of Rosario, with variable thickness between 0.5 m and 4.5 m. Locally the formation is covered by the Timbúes Formation separated by an erosional unconformity, but in general the overlying unit is the Puerto San Martín Formation.

Main characteristics of the Ituzaingó Formation in its type area (Corrientes province) are presented in Georgieff *et al.* (2005).

***Timbúes Formation (Kröhling 1998)***

It is composed of silty very fine to fine sand, opaque orange in colour (7.5 YR 7/4), with visible micaceous minerals (frequency of 5-20%). It is organized in coarse to very coarse, internally laminated strata, lenticular to tabular in form, with irregular concordant to erosional contacts among them. Deformational structures are common. There are Mn-segregations, root moulds filled by sand and leaf moulds covered by Mn-films. Platty $CaCO_3$ concretions appear at the contact between some strata, locally forming a calcareous net of phreatic origin. Large elliptic krotovinas are frequent.

At the Paraná cliff near the locality of Puerto San Martín, a B horizon of a paleosol appears at the erosional contact between the Timbúes Formation and the overlying Tezanos Pinto Formation. It is 0.30 to 0.60 m thick, reddish brown in color and weakly to moderately structured in medium angular prisms.

The Timbúes Formation (Late Pleistocene in age) outcrops at the cliff of the Paraná and Coronda rivers, exhibiting a thickness of 5 to 6.5 m and lateral extensions of tens of meters. The sedimentary characteristics indicate a fluvial origin for this unit. It is interpreted according to mineralogical data as a deposit generated by the Río Carcarañá and indicating the position of its previous mouths in the Paraná.

***Puerto San Martín Formation (Iriondo 1987)***

The unit is practically continuous along the Río Paraná cliff from the mouth of the Río Coronda up to the city of San Lorenzo. Its thickness varies from 4 up to 10 m. The unit is overlain by the Tezanos Pinto Formation, separated by an unconformity that indicates an irregular paleosurface.

It is a yellowish brown silty deposit, organized in coarse to very coarse horizontal strata with poorly defined contacts. At Puerto San Martín - the type locality - the section is as follows from bottom to top: 0-0.60 m: bed composed of brownish olive silt, structured in peds, paludal in origin. 0.60-1.60 m: bed of yellowish brown silt, massive, aeolian in origin. 1.60-2.10 m: bed formed by brownish olive silt, organized in peds and accumulated in a swampy environment. 2.10-3.30 m: yellowish brown loess. 3.30-4.80 m: bed composed by yellowish brown silt, moderately structured, paludal in origin. 4.80-5.10 m: brownish olive silt, weakly structured, paludal in origin. 5.10-6.40 m: stratum of yellowish brown silt, weakly structured in angular peds. Locally a level with $CaCO_3$ rhizoconcretions appears immediately below the erosional unconformity at the top of the unit indicating the existence of a Ck horizon of a truncated soils.

At the Río Paraná cliff in front of the city of San Lorenzo, two sectors can be differentiated: the lower one is 4 m thick and formed by olive sandy silt with common ferruginous mottles. The upper part carries calcareous precipitates of phreatic origin. The upper sector is 7 m thick and composed of massive, yellowish brown silt, including a pedogenic horizon marked by $CaCO_3$ concretions.

The Puerto San Martín Formation outcrops at sectors of the Río Carcarañá cliff near the town of Oliveros. On the left bank the unit is also differentiated into two sectors separated by a concordant horizontal contact. The lower silty sector, olive in colour, comprises the Ck horizon of a truncated paleosol. The upper sector is represented by a brownish to reddish brown silt with diffuse crossed stratification. It includes a lenticular fine bed formed by $CaCO_3$ pebbles. A moderately structured B horizon of a truncated soil tops this unit.

The sedimentary unit is interpreted as a continuous sequence of strata representing a temporary swampy environment alternated with typical aeolian facies that suggest an important accumulation of dust in the region. Taking into account the reference of Darwin about the preponderant number of fresh-water species (*Polygastrica* and *Phytolitharia*) scraped from a tooth of one of the mastodons found in the red Pampean mud, we infer that this corresponds to one of the characteristics beds of paludal origin of the Puerto San Martín Formation.

***Tezanos Pinto Formation (Iriondo 1987)***

This formation is the typical LGM loess of the northern Pampas that overlies the Puerto San Martín Formation, with thickness ranging between 1 and 4 m.

***San Guillermo Formation (Iriondo 1987)***

The brownish gray silty deposit (Late Holocene in age) ends the sedimentary sequence on a truncated soil developed on top of the LGM loess.

## Sections of the lower Río Carcarañá (Santa Fe province)

Darwin was right in making his observations along the banks of the lower Río Carcarañá because its basin constitutes a favorable area for research on geomorphology and Quaternary stratigraphy of the northern Pampas plain (Kröhling 1999).The exposed sedimentary column of the lower Carcarañá basin reveals fluctuating environmental conditions, characterized by dry intervals associated with episodes of accumulation and remobilization of aeolian sand or dust accumulation during the stages of Glacial Maximum. These alternate with humid intervals characterized by pedogenesis and the development of fluvial belts. The sedimentary record of the lower basin was reported by Kröhling (1999) and is explained below (Fig. 3).

***Carcarañá Formation (Kröhling 1999)***

This unit is composed of very fine to fine silty sand, and silt with very fine sand, dull orange in colour (7.5 YR 6/4). It has very thick horizontal strata, not well defined and generally with concordant contacts. The sediment varies in consistency between friable and consolidated and it has a fine to medium blocky structure. In general, it is non-calcareous. It is affected locally by bioturbations, such as krotovinas (up to 0.75 m diameter) and root casts (up to 0.60 m long and 0.10 m diameter). In some places sedimentary structures are visible. These are characterized by an irregular wavy pattern marked by differences in concentrations of colloidal materials, namely dissipation structures. This unit forms the lower sections of cliffs along the Río Carcarañá, forming gentle to subvertical slopes, which reflect its resistance in comparison with the upper units. The maximum outcrop thickness is approximately 5.50 m. It is unconformably overlain by the Tezanos Pinto Formation in the interfluves and by the Lucio Lopez Formation in the main fluvial valleys of the area.

A representative section of the unit is exposed along the cliffs of the Río Cañada de Gómez, near the Río Carcarañá. From bottom to top:

0.00-2.00 m: Bed formed by very fine, slightly silty sand, bright reddish brown in colour when moist, with dissipation structures. The sedimentary mass is non-calcareous and contains medium to coarse and hard Fe-Mn sesquioxide nodules. There are rhizoconcretions of $CaCO_3$ and abundant very fine macropores. Concordant upper contact.

2.00-4.50 m: Bed sedimentologically similar to the underlying one, without sedimentary structures, and with less resistance to erosion. Numerous $CaCO_3$ rhizoconcretions appear at the contact between the units. It includes krotovinas up to 0.50 m in diameter. Near the top

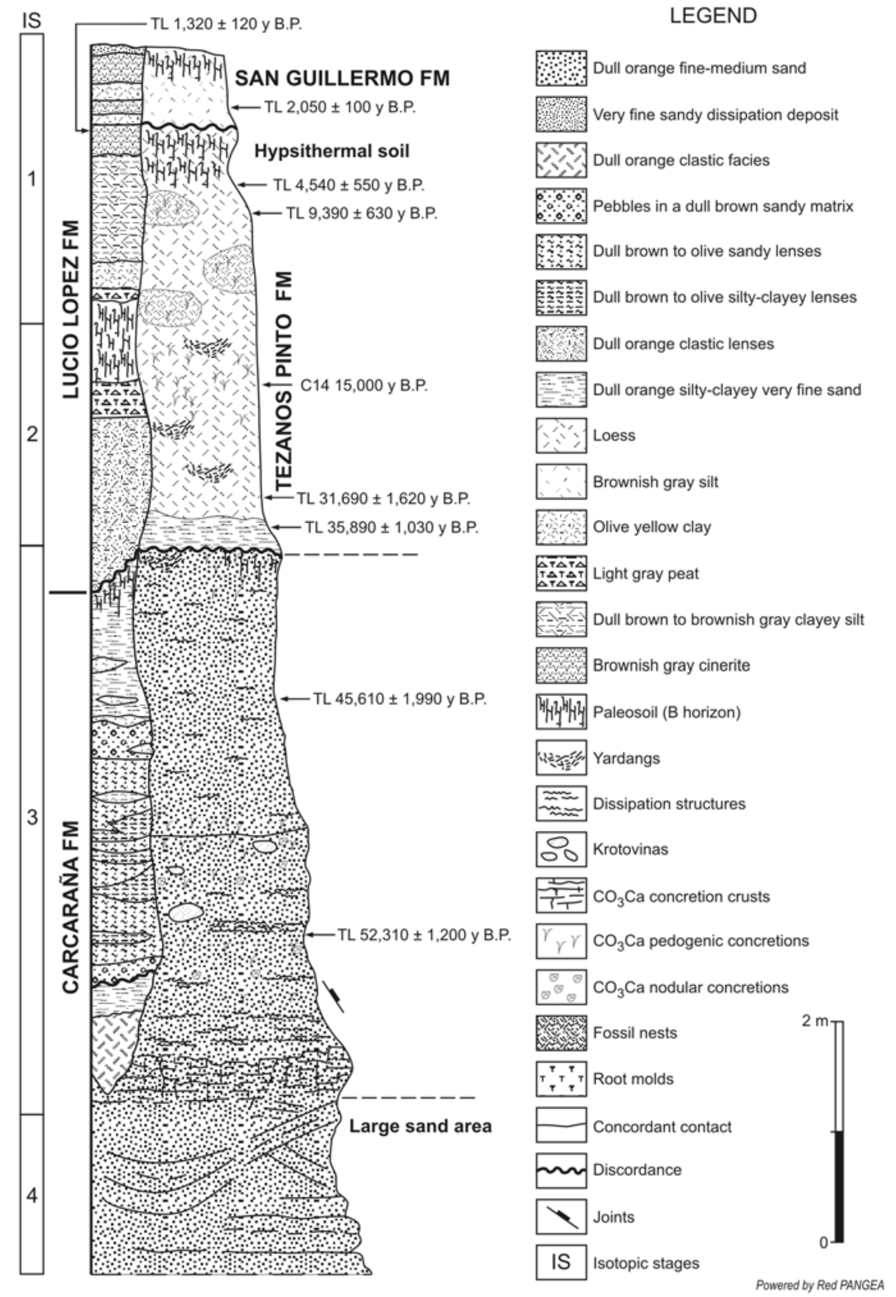


**Figure 3:** General stratigraphic section of the Carcarañá river basin, typical of the Rosario-Santa Fe area (after Kröhling 1999).

there is a level formed by a succession of erosional geoforms, 0.50-0.80 m wide and 0.40-0.50 m high.

Relicts of a palaeosol appear discontinuously at the bottoms of gullies within the fluvial palaeovalleys of the region. Lateral variations are common in that soil: the structure changes from coarse to very coarse blocky (strong) up to angular very coarse prismatic (strong, defined by coarse fissures, partly filled by $CaCO_3$ precipitates). The sediment is weakly calcareous to calcareous. There are numerous epigenetic carbonate concretions produced by partial dissolution. $CaCO_3$ concretions of phreatic origin occupy coarse fissures between peds. Locally, this level is represented by palaeogullies filled with retransported soil fragments. At the top of the Carcarañá Formation another soil was developed. It is represented by a poorly developed B horizon, 0.40 m thick, dark brown in colour, weakly structured and containing $CaCO_3$ rhizoconcretions.

The Carcarañá Formation is Late Pleistocene in age (OIS 3; a TL dating in the middle section indicates an age of 52.31 ± 1.2 ka BP). The mainly aeolian formation is the result of the reworking by erosion of a dune field generated during the OIS 4. Primary structures of the dunes appear in sections located immediately to the south of the area. Locally different paludal and alluvial facies of the Carcarañá Formation are present.

According to Darwin, "*on the banks of the Carcarañá, a few miles distant* (of the Paraná cliff at Grondona; next to the Villa La Ribera -Rosario-Santa Fe road-), *the lowest bed visible was pale Pampean mud, with masses of tosca-rock, in one of which I found a much decayed tooth of the Mastodon: above this bed, there was a thin layer almost composed of small concretions of white tosca, out of which I extracted a well preserved, but slightly broken tooth of Toxodon Platensis: above this there was an unusual bed of very soft impure sandstone*" (Darwin 1846, p. 88). The section of the Río Carcarañá described by Darwin is interpreted as the Carcarañá Formation.

***Tezanos Pinto Formation (Iriondo 1980)***

It is the typical Late Quaternary unit of the Pampas plain, composed of aeolian silts (silt: 71-81%; clay: 13-29%; fine sand: 1-6%). At the base and the top, erosional unconformities connect these deposits with the Carcarañá Formation and with the San Guillermo Formation respectively (Kröhling 1999).

A primary loess facies or aeolian facies of the Tezanos Pinto Formation has the greatest areal representation, with a typical outcropping thickness of 2-4 m, and more developed on the interfluves (6-8 m thick). It is a loose deposit, coarse silt with subordinate clay and fine sand, light brown in colour (7.5 YR 6/4). It is a homogeneous, porous and permeable deposit with a coarse granular to medium-coarse blocky fabric. The sedimentary mass is calcareous; it contains powdery

concentrations and hard concretions of $CaCO_3$ (in a variable frequency; varied forms and centimetric sizes). The loess body is crossed by fine rhizoid ramified canalicula. It is stable in steep walls, in parts altered by subcutaneous subfusion and shaped by columnar disjunction.
TL datings gave ages of 31.69 ± 1.62 ka BP and 32.0 ka BP in samples of the aeolian facies of the formation in the area, at 4 m below the top of the unit (LGM, OIS 2).

***Buried soil (Kröhling 1999)***

The top of Tezanos Pinto Formation is marked by a partially eroded soil, 0.30 - 1.10 m thick, typically represented by a Bt horizon. In a minor geomorphological unit (fluvial valleys of the region) that soil forms an accretionary pedocomplex of argillic horizons separated by the accumulation of Andean volcanic ash, mainly concentrated by alluvial processes. At the interfluves of the region, the Bt-horizon is formed by a dark brown (7.5 YR 3/4) clayish silt, with intense illuviation and formation of cutans. It has a strongly to moderately developed structure in medium angular prisms, strong consistence, with very fine and fine cracks between peds. It lacks nodules or mottles, and the silt fraction is non-calcareous. There are abundant root moulds. The lower boundary is wavy in form and well marked. The Bt horizon is composed of a dull brown (7.5 YR 5/4) slightly clayish coarse silt. This horizon shows a weakly to moderately well-developed structure, formed by medium blocks, very firm, limited by fine and very fine fissures. Nodules or mottles are absent, but fine macropores are present. The silt fraction is non-calcareous. The C horizon shows characteristics transitional to the underlying loess.
The buried soil was generated during the Holocene Optimum Climaticum and it is a distinct pedostratigraphic marker in different areas of the Pampas plain.

***San Guillermo Formation (Iriondo 1987)***

A younger loessic formation overlies the buried soil on top of the Tezanos Pinto Formation, separated from it by an erosional unconformity. It is composed of a brownish grey (10 YR 5/1) coarse silt with scarce proportions of very fine sand and clay. The unit is massive, friable in general, porous, permeable, and moderately structured in very coarse firm prisms bounded by very fine fissures. This deposit lacks nodules or mottles, but contains numerous root moulds, abundant macropores, very fine and fine canalicula and tubes generated by bioturbation. The sediment mass is non-calcareous. The unit is partly the product of deflation of the A horizon of the underlying soil and the subsequent deposition of dust. The typical thickness is 0.30 m, with a maximum of 0.55 m.
The San Guillermo Formation generally forms the top of the sedimentary sequence in the natural sections of the Pampas. It was deposited during a Late Holocene dry period that occurred between 3.5 and 1.4 ka BP (Iriondo 1990).

***Lucio Lopez Formation (Kröhling 1996)***

It constitutes a complex sequence differentiated into three sectors. It includes a clayish silt with scarce very fine sand (silt: 58-77%; clay: 19-37%; sand: 3-6%), organized in fine strata with variations in colour from olive to grey; pedogenic horizons are intercalated in the middle section (pedocomplex). Locally, it exhibits high proportions of biogenic material (mainly gastropods, ostracods, diatoms and abundant plant remains). The Lucio Lopez Formation outcrops along the cliffs of the main rivers of the northern Pampas region, with most typical characteristics and the greatest thickness on the Río Carcarañá cliffs. The thickness varies from 0.50 to 5.00 m. The formation unconformably overlies the Carcarañá Formation in sections located inside the fluvial valleys of the region. The contact indicates a palaeotopography of channels and gullies. In general the formation is covered by contemporary or recent deposits of fluvial origin; locally the unit forms the top of the section. The formation, with a clear paludal origin, constitutes the infilling of erosional landforms located in a recent belt of the main rivers and at the bottom of the major fluvial palaeovalleys of the region. A TL date in the upper section of the formation (a cineritic stratum) indicates an age of 1.32 ± 0.12 ka BP. The soil complex of the middle section was generated during the Holocene Optimum Climaticum. The formation was generated during the Holocene and possibly even the Late Pleistocene too.
This unit correlates with the Luján Formation defined by Fidalgo *et al.* (1973), representing the Late Quaternary continental infilling of the fluvial valleys of NE Buenos Aires province. Toledo (2005) presented a sequence stratigraphic model in the Lujan type section of this unit, based on detailed stratigraphic observations and $C^{14}$ datings on mollusks. The author refered ages from > 40 ka BP to >11 ka for the Guerrero Member (fluvial-paludal deposits or *Lujanense*) and ages from 10.7 to 3.3 ka BP for the Río Salado Member of the Luján Formation (grayish to whitish silty facies or *Platense*). Prieto *et al.* (2004) gave ages ranging from 11 to 3.5 ka BP for the Luján Formation in the Río Luján.

## LA BAJADA SECTION

The town La Bajada is located across the Río Paraná from Santa Fe. At present, that locality (nowadays Paraná) is the capital city of Entre Ríos province. Such area is crossed by an old transcurrent fracture, the Tostado-Gualeguaychú fault, which elevated its southern block some 40 m in the Middle Pleistocene (Iriondo 1989), thus exposing Tertiary marine strata. Darwin payed special attention to those strata, collected an interesting fossil assemblage and made an excellent stratigraphic description of the section.
Darwin quoted that "*In Entre Ríos, the cliffs, estimated at between sixty and seventy feet in height, expose an interesting section: the lower half consists of Tertiary strata with marine shells, and the upper half of the Pampean formation. The lowest bed is obliquely laminated, blackish, indurated mud, with distinct traces of vegetable remains. Above this there is a thick*

*bed of yellowish sandy clay, with much crystallized gypsum and many shells of Ostreae, Pectens, and Arcae: above this generally comes an arenaceous crystalline limestone, but there is sometimes interposed a bed, about twelve feet thick, of dark green, soapy clay, weathering into small angular fragments. The limestone, where purest, is white, highly crystalline, and full of cavities: it includes small pebbles of quartz, broken shells, teeth of sharks, and sometimes, as I was informed, large bones: it often contains so much sand as to pass into a calcareous sandstone, and in such parts the great* Ostrea patagonica *chiefly abounds. In the upper part, the limestone alternates with layers of fine white sand. The shells included in these beds have been named for me by M. d'Orbigny (a list of fossils follows) - M. d'Orbigny has given a detailed description of this section, but as he does not mention this lowest bed, it may have been concealed when he was there by the river. There is a considerable discrepancy between his description and mine, which I can only account for by the beds themselves varying considerably in short distances*" (Darwin 1846, p. 88-89).

In fact, the major discrepancies between both naturalists appeared because Darwin worked in the elevated block of the fault and d'Orbigny researched in the downthrown block, where the marine beds appear only during low waters. Besides, as Darwin correctly stated, the strata vary in short distances. However, Darwin's description fits considerably well with the type section of the Paraná Formation, formally defined there 150 years later by Iriondo (1973).

The marine beds of Bajada were renamed as Paraná Formation in the 20th Century. This formation represents the last widespread marine transgression occurring in the interior of South America (Yrigoyen 1969, Herbst 1971, Iriondo 1973, Marengo 2005) and the Bajada-Paraná area is considered the type locality. Darwin's section, indeed, can clearly be recognized in the type section of the formation (Iriondo 1973, Fig. 4):

- Both sections are composed of five beds and have similar thicknesses; a comparison shows the following:

- The lowest bed - Darwin (profile B of Fig. 4): *Obliquely laminated, blackish, indurated mud, with distinct traces of plant remains.*

Type section: 3 m. Green quartz sand in 30-50 cm thick strata, including a large proportion of clay intraclasts, most of them are platy angular fragments without rounding. Major axes of plates are parallel to stratification planes. Mean grain size around 0.2 mm, finer towards the bottom. Transitional upper contact.

- Second bed - Darwin: *Yellowish sandy clay, with much arenaceous crystalline gypsum and Ostreae.*

Type section: 3 m. Massive green sand, without internal bedding, containing up to 10 cm long elliptic clay intraclasts. 20% of the sediment mass is composed of chaotically distributed small platy intraclasts. Grain size around 0.25 mm with variable dispersion, which grows upwards. Lightly cemented with $CaCO_3$. The detachment and fall of intraclasts produces numerous small hollows in outcrops. Neat upward contact.

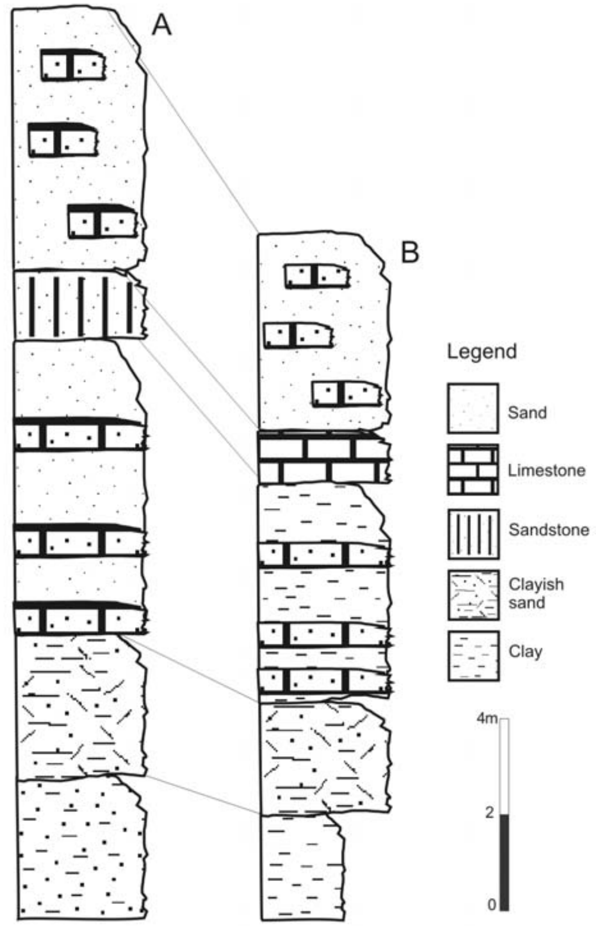


**Figure 4:** The Paraná Formation outcropping in La Bajada. A: Type profile (Iriondo 1973). B: Darwin´s profile.

- Third bed - Darwin: *4 m. Dark green, soapy clay weathering into small angular fragments.*

Type section: 6 m. Sequence of interestratified sand and clayish silt. The sand bodies are short lenses with internal diagonal lamination, up to 1.60 m thick. Loose, quartzose and yellow in colour. Sandy bodies are generally composed of 5-15 cm thick internal units with diagonal stratification. The fine sediments are plastic, gray clayey silts, forming continuous strata 1 to 30 cm thick and at least 50-60 m long; internal laminae of sand are common. In parts with contorted internal lamination. Silt strata conformably cover the underlying sand lenses. Grain size of the fines is 30 microns at the bottom, diminishing upwards to clay-sizes. The upper section of this bed changes to white sandstone with dune structures containing well preserved bivalves. Further on, the bed passes to a fine conglomerate.

- Fourth bed - Darwin: *Sandy crystalline limestone. Where purest, it is white, highly crystalline, and full of cavities: it includes small pebbles of quartz, broken shells, teeth of sharks and sometimes large bones: it often contains so much sand as to pass into a calcareous sandstone, and in such parts the great Ostrea patagonica abounds* (Darwin 1846, p. 89).

Type section: 1.5 m. White calcareous sandstone with dune structures and undulose strata. Lateral and upward enrichment with shells of bivalves and scarce oysters. Bivalve shells underwent an advanced degree of dissolution and re-precipitation, remaining often only as moulds. Oysters are well preserved.

- Fifth (upper) bed - Darwin: *The limestone alternates with layers of fine white sand.*

Type section: 5.5 m. Most of the outcrop is covered by debris. The lower sector is characterized by white sand, incipiently cemented by the carbonate provided by the local dissolution of shells; the upper section is composed of fine quartz sand. Green in colour.

The general scenario suggested by the section in both approaches (Darwin´s and modern) is one of a tidal environment, with subtidal sands and gravels, intertidal muds, changing tidal channels and coastal currents. Two different sedimentary mechanisms can be deduced: a) Transport and accumulation of sand by tractive currents, probably from nearby beaches if one considers the negative skewness of the sediment. b) Flocculation of fines in calm environments. The fossil assemblage also points to a littoral/neritic position in a warm climate.

A general setting of the Paraná Formation is as follows: The Paraná Formation covers an important sector of a major geological event occurring in the Neogene of South America. Around the Middle Miocene occurred a generalized marine transgression in large regions of the continent. The Paraná Formation comprises the portion included in the Chaco-Paranense Basin, which extends from the central lowlands of Argentina at 36° lat. S northwards to the Bolivian and Paraguayan Chaco. The Miocene sea was a shallow, platform branch of the Atlantic Ocean. Mean thickness of the formation is about 100 m; the sediment is dominantly sandy in the type area (Paraná; La Bajada in Darwin times) and characterizes the upper half of the section in all the basin. The lower half appears as composed of green sand.

A research borehole drilled in the center of the basin in the northern Pampas (San Guillermo locality; 30°15'S, 61°50'W) recorded 40.5 m of the Paraná Formation covered by 60.3 m of Quaternary loessic formations (Kröhling and Iriondo 2003).

Following Darwin, "*The upper half of the cliff in La Bajada, to a thickness of about thirty feet, consists of Pampean mud, of which the lower part is pale-coloured, and the upper part of a brighter red… Close above the marine limestone, there is a thin stratum with a concretionary outline of white hard tosca-rock or marl…*" Three Quaternary formations can be recognized in that reference: The upper one is Tezanos Pinto Formation, the main loessic deposit of the Last Glacial Maximum. The "*lower mud*" is the Hernandarias Formation, an Early Pleistocene playa deposit of the Río Uruguay. The *tosca*-rock is a well developed level, which thickens southwards up to 9 m and is known as Puerto Alvear Formation.

## SOUTHWESTERN ENTRE RÍOS

A key area of the region is located in the southwestern part of Entre Ríos province and outcrops along the eastern cliff of the Paraná flood plain. Darwin did not study such outcrops, but navigated along them in his journey back to Buenos Aires. However, he made a few comments on "*the Punta Gorda in Entre Ríos*" (different from the other Punta Gorda in the Banda Oriental), which is an interesting sedimentary cycle that occurred around one million years before present. That locality is placed 60 km south of Santa Fe and has the best stratigraphic section of the area (Fig. 5) in Entre Ríos.

### Punta Gorda Section

The Quaternary geologic column of the region (Kröhling 2001) records two well defined aeolian sedimentation cycles. In both cases, the main source of sediment has been the Andean region, that produced fine materials originated by nival processes and volcanic eruptions.

The older cycle, defined as the Punta Gorda Group, is composed of three units accumulated in paludal and subaereal environments during the Early Pleistocene. The second sedimentary cycle occurred during the Late Pleistocene and Holocene (basically at the Last Glacial Maximum) and is the Pampean Aeolian System traversed by Darwin from Buenos Aires to Santa Fe. It comprises two formations accumulated in subaereal environments. A short period of aeolian remobilization occurred during the Late Holocene.

Several episodes of pedogenesis and local erosional unconformities were recorded in both major sedimentation periods, particularly in the older one. The long sedimentation hiatus, covering all the Middle Pleistocene and a half of the Late Pleistocene constitutes a remarkable regional feature.

Important similarities were found between both sedimentary cycles: i) the same source of sediments; ii) the same long distance transport agent (wind); iii) striking similarity in grain-size distributions; iv) scarce contribution of materials from the Brazilian shield and associated areas in the north.

The age of the older cycle can be located between the Brunhes - Matuyama magnetic polarity change (the Upper Matuyama Chron > 0.78 Ma.) and the Jaramillo Subchron (1 Ma). This conclusion coincides with recent datings in the "Great Patagonic Glaciation" (Ton-That *et al.* 1999), which rendered ages from 1 Ma to 1.17 Ma. The following sedimentary units outcrop at Punta Gorda:

***Punta Gorda Group (Iriondo 1980): Sedimentary cycle 1***

*Puerto Alvear Formation (Iriondo 1980)*

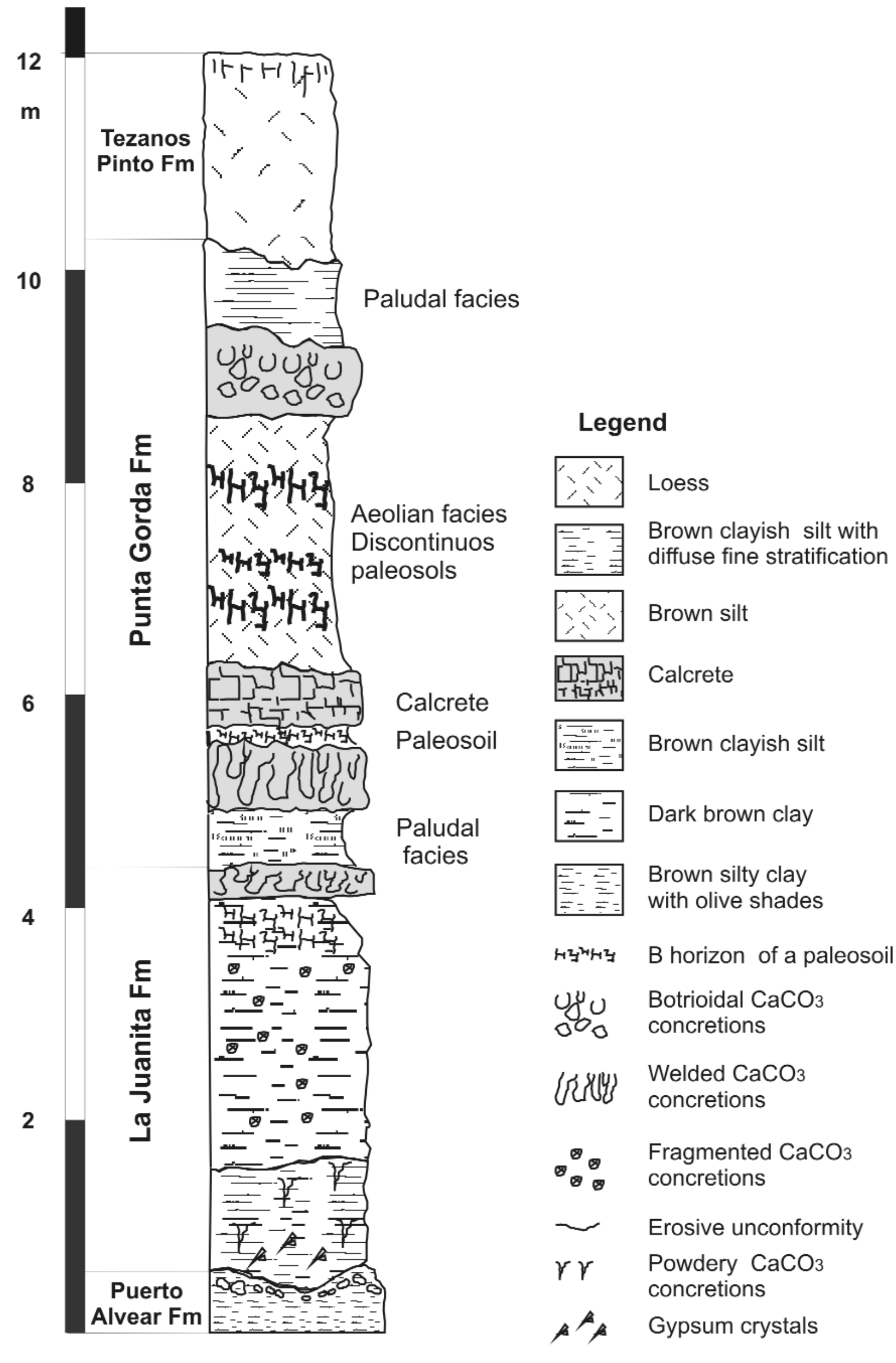


**Figure 5:** Punta Gorda section, representative of SW Entre Ríos province (after Iriondo and Kröhling 2008).

This is a sedimentary body accumulated as infilling of an abandoned belt of the Río Paraná. The unit was a non-permanent swamp at the beginning of the Pleistocene. The formation lies unconformably on the Paraná Formation (marine Miocene), with a maximum thickness of 9 m. The most visible field feature is a closed net formed by $CaCO_3$ plates of phreatic origin, 0.5 to 4 cm thick with a dominant horizontal development. Numerous vertical large and botrioidal concretions indicate a post-depositional remobilization of the carbonate. The clastic component of the unit is a silty clay to sandy silt with diffuse lamination, light reddish brown in colour with olive patches. Abundant Mn- and Fe segregations and nodules are conspicuous. This formation is divided into two members; the lower one is characterized by thick continuous partition walls, with a wavy trace. The upper member includes a similar horizontal carbonate net, although formed by thinner and more irregular platy precipitates. An internal unconformity separates both members; in some places the top of the lower member are the Bw-and C horizons of a weakly developed paleosol. That pedogenic level is non-calcareous.

*La Juanita Formation (Iriondo 1998)*

This unit was formed in a paludal environment during the Early Pleistocene. It lays unconformably on the Puerto Alvear Formation, with a typical thickness of 2 to 3 m. The La Juanita Formation is composed of light brown to olive silt with scarce fine sand with horizontal diffuse bedding. Strata are 15 to 30 cm thick, with internal lamination. Fe- and Mn segregations and root moulds are locally abundant. The sediment is slightly structured in firm blocks. Concretions, which form more than 10% of the sedimentary mass, are rough vertical infillings of roots, 2 to 5 cm thick and up to 20 cm long. The general tendency of the $CaCO_3$ precipitates indicates infiltration in a non-permanent swamp environment with a non-saturated bottom. There are also infillings of horizontal fissures. Frequent Mn films cover the surface of concretions, indicating a younger age for the mobilization of such oxides.

*Punta Gorda Formation (Iriondo and Kröhling 2008)*

This is a brown loess characterized by pedogenesis in several levels and frequent local internal unconformities. According to palaeomagnetic analyses, the age of the unit is Early Pleistocene. Carbonatic cement is widespread in the formation. Local second order variations are the rule in most outcrops. Three sections were described in the unit at the type locality (Punta Gorda, Entre Ríos province). The lower one was unconformably deposited over La Juanita Formation and begins with a paludal deposit composed of clayish silt, light brown in colour, with Fe- and Mn segregations. This is conformably overlain by a petrocalcic horizon formed by vertical cylindrical welded concretions 50 cm high. The central section is formed by 4 m of homogeneuos light brown loess, with a vertical slope. A lattice pattern of $CaCO_3$ precipitates appears in the exposures. Three weak to moderate paleosols (B- and Ck horizons) were recorded at the typical site. These soils are laterally discontinuous as a result of uneven erosional contact with the overlying loess. They are re-calcified from this material too. The upper section begins with a Ckm horizon of another eroded paleosol, covered by a one meter thick paludal deposit.

***Tezanos Pinto Formation (Iriondo 1980): Sedimentary cycle 2***

The unit constitutes the Peripheral Loess Belt of the Pampean Aeolian System, which was deposited during the OIS 2 (36-8 ka BP, Iriondo and Kröhling 1995). The aeolian dust was transported from Andean sources by S and SW winds. In SW Entre Ríos province the unit is yellowish brown loess, 2 to 3 m thick, composed of powderish sandy silt, massive and friable. OSL ages of 32 and 24 ka BP were obtained for the loess in this region. The loess forms typical vertical slopes, with columnar disjunction. It contains small $CaCO_3$ concretions and frequent rhizoconcretions (15.48 ± 0.19 C14 ka BP).The unit received contributions of fine sediments from the Paraná headwaters, located to the northeast.

The clay fraction of the loess is a complex mixture of illite, interstratified illite-smectites and kaolinite. Illite is a pampean mineral whereas smectites and kaolinite are derived from Brazil. A partially eroded soil on top of the loess is represented by well developed Bt-horizon and C horizons. The Bt horizon is 35 to 55 cm thick, clayey silt dark brown in colour, structured in very firm prisms; argillocutans are frequent. The buried soil was developed under humid subtropical conditions during the Holocene Optimum Climaticum.

***San Guillermo Formation (Iriondo 1980): Sedimentary cycle 2***

The sedimentary sequence of Punta Gorda ends with an aeolian unit unconformably accumulated over the eroded soil. It is a brownish gray loess, 20 to 35 cm thick, loamy to silty-loamy. This unit is the result of deflation of the A-horizon of the soil on top of the Tezanos Pinto Loess and the subsequent deposition of dust. Such an event occurred from 3.5 to 1.4 ka BP.

## THE PARANÁ FLOOD PLAIN

Darwin travelled from Santa Fe back to Buenos Aires by boat along the Paraná and made some remarks about the river, its banks and fauna. Particularly, he noted the large number of islands that are permanently eroded and reconstructed by the currents.

In fact, according to modern geomorphology the river flows there within a large flood plain, approximately 600 km long, stretching from the Paraguay-Paraná junction (27°25'S) to south of Rosario (33°S). Downstream it passes transitionally to a well-developed Holocene littoral complex. The general direction of the flood plain is north-south, crossing several tectonic blocks in a perpendicular or diagonal manner. This relationship has generated local segments within the plain, with slightly different directions and slopes. The width of the floodplain varies from 13 to 45 km, with typical values between 25 and 35 km. It is composed of several internal geomorphological units, the most modern of them is the "bar plain", that is developing at present (Iriondo 2007).

The bar plain is a belt of large elliptic bars composed of very fine sand, that encloses the main channel along the whole flood plain. This belt is permanently modified by erosion and sedimentation and has a width of 2-7 km; it is formed by islands inside the main (navigation) channel and sand bars juxtaposed to the margins. The large bars are crossed by minor active channels, most of them with intense lateral migration, resulting in minor meander belts. The powerful braided mainstream - with a mean discharge between 16,000 and 20,000 $m^3$/sec - continuously reshapes islands and banks. This is the environment described by Darwin.

Other important geomorphological units of the flood plain are the hindered drainage plain and the deltas of tributaries. The hindered drainage plain was described by Darwin as a labyrinth of small branches separated by low islands covered by forest, he observed this landscape when crossing the flood plain from Santa Fe to La Bajada. This unit is characterized by a morphology of flat areas with numerous shallow ponds, swamps and small adventitious channels. Such channels are tortuous, active only at the beginning and end of floods, conveying water into ponds during rising and back to the main channel at low levels. The number of ponds and shallow lakes is huge - about 5,000 according to Paira and Drago (2007). This system was generated under a hydric regime different than the present one. The deltas of tributaries are areas of sedimentation formed inside the flood plain during a recent dry climate period (from 3.5 to 1.4 ka BP, according to the latest datings). Water discharges were lower than today in all the system and tributaries did not reach the collector, depositing the sediment loads in lateral positions inside the flood plain; the Paraná River itself was also smaller then than it is today. That resulted in relatively short and wide delta-like sedimentary bodies. Most of such deltas (Los Amores, del Rey, Corrientes) are located north of Santa Fe, a region not visited by Darwin owing to health problems. Terraces also appear in the north, in Chaco and Corrientes provinces.

The sediments of the flood plain are very homogeneous. Practically all the sedimentary mass is composed of only three sedimentary facies: a) Channel facies, which are composed of fine and very fine quartz sand, generally in 10-40 cm thick horizontal strata with diagonal internal structures. Such sand was originated in Mesozoic sandstones of the upper basin and comprises the major part of the buried sediments. b) Levee facies, which are characterized by silty-clayish very fine sand with intermediate plasticity; ochre to greenish-gray in color, mottled, with numerous pores, tubes and root moulds. Gley processes are frequent. c) Lake-and-swamp facies, composed of dark gray silt with abundant organic matter in different degrees of decomposition. It is compact, with low porosity; sand and clay are scarce. A really modest proportion of the sediment volume is represented by a fourth facies, i.e., aeolian dunes composed of very fine sand, which appear in isolated spots in the northern half of the flood plain.

## THE LITTORAL COMPLEX AT THE RÍO PARANÁ MOUTH

Darwin noted that "*Some leagues downstream Rosario begins, at the western margin of the Paraná, a line of perpendicular cliffs that extends beneath San Nicolás…The banks of the river are formed by very soft earths; in consequence the waters are muddy…*". The author has entered the Paraná Delta, which in fact is a large littoral complex of Holocene age formed by several geomorphological and sedimentary units sequentially generated. Four main phases have been identified there by Iriondo (2004, Fig. 6):

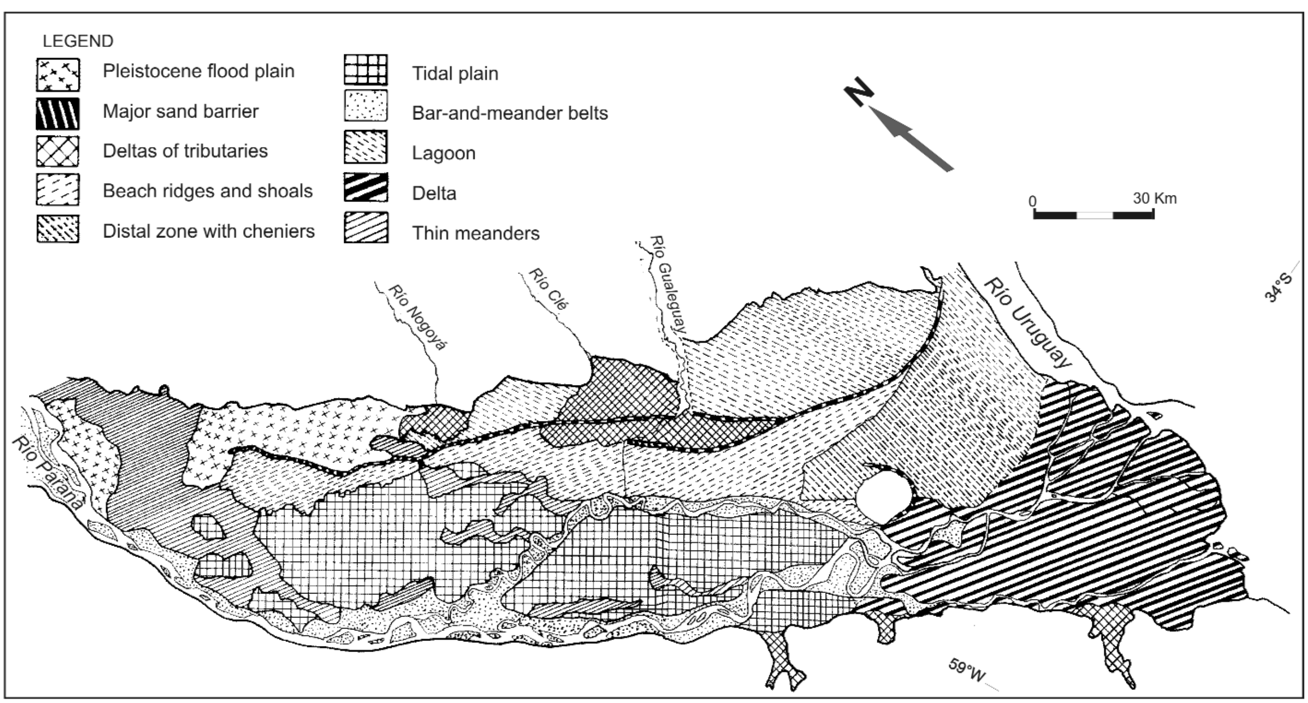


**Figure 6:** Map of the Holocene littoral complex at the Paraná mouth (after Iriondo 2004).

1) A fluvial period represented by river flood deposits; 2) A marine ingression with development of a sand barrier, a lagoon, minor tributary deltas and estuaries and well-developed regression deposits; 3) An estuarine phase characterized by extensive tidal deposits in the central area; and 4) The present fluvial period, with channel deposits and a deltaic unit advancing into the Río de la Plata. The present dynamics of the deltaic complex is dominated by the Paraná floods, the floods of the Uruguay and Gualeguay rivers, Atlantic tides, and floods produced by the southeasterly winds.

The southeasterly wind (*Sudestada*), indeed, is a major factor in the water dynamics and navigation in that area and downstream in the Río de la Plata. The wind can be strong and blow sometimes during several days, provoking a rise of the water level. Records of up to 2.5 m above the terrain have been reported at several places. During such periods, navigation in boats and small vessels stops; surely, Darwin underwent such a meteorological phenomenon: "*At night, the wind is scantly favorable and we stop; the next day blows a strong wind…*"

## COMMENTS AND CONCLUSIONS

Undoubtedly, the short incursion of the great naturalist to the interior of the Argentine plains was a very modest portion of his famous trip around the world, with plenty of discoveries, experiences and amazing landscapes such as Tahiti or Tierra del Fuego. The attention paid by Darwin to these flat plains in his subsequent studies was necessarily far more modest than those devoted to the Galapagos Islands or the Andes Cordillera. However, the few pages dedicated to the Buenos Aires-Santa Fe journey reveal the extraordinary abilities of Darwin for keen observation and logical thinking, in spite of the limitations of geological theory at that time. No real errors can be noted in his geological observations recorded during this journey, rather good science and acute synthetic descriptions. In order to make a comparison between the geological contributions of Darwin and the present knowledge on the region, the authors of this contribution necessarily follow the general structure of Darwin's books, a traveler's diary enriched by digressions on Science, Politics and History.

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