The parent material as the dominant factor in Holocene pedogenesis in the Uruguay River Basin

Martín Iriondo and Daniela Kröhling*

Consejo de Investigaciones Científicas y Técnicas – Facultad de Ingeniería y Ciencias Hídricas, Universidad Nacional del Litoral, C.C. 217, 3000 Santa Fe, Argentina.
** dkrohli@fich1.unl.edu.ar*

ABSTRACT

In the Uruguay River basin (South America; 365,000 km²), an episode of pedogenesis occurred during the Climatic Optimum of the Holocene, approximately between 8,500 and 3,500 yr BP. This period of 5,000 years was characterized by a humid and warm climate. In terms of factors of soil formation, an interesting pattern appears. The climate was relatively homogeneous over the whole basin. The age is the same in all cases and the influence of relief and vegetation was modest. Therefore those factors can be considered as basically uniform. On the contrary, the parent materials form a complex mosaic. The granulometric and mineralogical characteristics of the parent materials dominate the nature of the hypsithermal pedogenesis even at the higher level of the soil classification. Several cases of this regional pattern can be cited. Moderately to well developed B-horizons of five buried soils have been registered in the region. Each of them covers a significant area. A conspicuous Vertisol covers the southwestern of the river basin (in Entre Ríos province, Argentina). The parent material of this buried soil is a clayey playa unit (the Hernandarias Formation, lower Pleistocene in age). A buried soil belonging to the Ultisol order was developed on the Oberá Formation (the late Pleistocene tropical loess) in the north of the region (in Misiones province, Argentina and Rio Grande do Sul state, Brazil). On a late Pleistocene–lower Holocene paludal unit (the Tapebicuá Formation, in eastern Corrientes province) a distinct buried soil with a plinthic yellowish brown horizon was developed. A moderately developed Alfisol formed on the lower fluvial terrace of the Uruguay River (the Holocene Concordia Formation). On the late Pleistocene loess, at the southern end of the basin (in southeastern Entre Ríos province and western Uruguay), a well developed Alfisol occurs, which is similar to the typical soil of the Pampa region. Some profiles are pedocomplexes with clear evidence of soil formation interruption by the accumulation of Andean volcanic ashes.

The hypsithermal soil was truncated by eolian erosion in most of the region. Later, it was covered by a thin loess layer (the San Guillermo Formation, deposited during the Upper Holocene). Both, the remaining B and C horizons and the loess layer are affected by the current incipient pedogenesis under a humid subtropical/tropical climate which began 200 years ago. The only exception to this influence is represented by the Ultisol and the Alfisol (in the fluvial terrace), which are covered by 2–4 m of upper Holocene sediments, and consequently isolated from the present dynamic.

Key words: buried soil, tropical loess, Holocene, Uruguay River, South America.

RESUMEN

En la cuenca del río Uruguay (Sudamérica; 365.000 km²) ocurrió una pedogénesis generalizada durante el Optimum Climaticum del Holoceno, aproximadamente entre 8.500 y 3.500 años antes del presente. Este período de 5.000 años de duración, estuvo caracterizado por un clima cálido y húmedo. Un patrón interesante se presenta en términos de los factores formadores de suelos de la región citada. El clima fue relativamente homogéneo en toda cuenca, el tiempo de pedogénesis es el mismo en todos los *casos y la influencia del relieve y la vegetación fue modesta, por lo tanto dichos factores pueden ser considerados como básicamente uniformes. Por el contrario, los materiales parentales forman un mosaico complejo. Su granulometría y mineralogía dominan la naturaleza de la pedogénesis, aun en los niveles más altos de la clasificación de suelos. Varios paleosuelos fueron identificados y mapeados en la región de estudio. Dichos suelos presentan horizontes B moderadamente a bien desarrollados y abarcan áreas extensas. Los límites entre los suelos mapeados están representados por líneas netas, sin catenas u otros tipos de transición. Un suelo Vertisol bien desarrollado se extiende en el sudoeste de la cuenca (provincia de Entre Ríos, Argentina). El material parental de este suelo es la Formación Hernandarias, una unidad representada por un barreal depositado por el Río Uruguay en el Pleistoceno inferior. Dicho suelo está cubierto por un estrato limo arenoso eólico (Formación San Guillermo, de edad Holoceno tardío). Un suelo Ultisol se conserva en la parte media de la Formación Oberá (loess tropical del Pleistoceno tardío), que cubre la mayor parte de la alta cuenca (provincia de Misiones, Argentina y estado de Rio Grande do Sul, Brasil).En el techo de una formación de origen palustre y aluvial del Pleistoceno tardío, depositada por el río Paraná (Formación Tapebicuá, este de provincia de Corrientes, Argentina) se ha desarrollado un suelo con un horizonte plintítico (Plintosol). Este se halla cubierto por una capa loéssica de edad Holoceno tardío (Formación San Guillermo). La sección central del sedimento que compone la terraza baja del Río Uruguay (Formación Concordia, de edad Holoceno) incluye un suelo Alfisol, moderadamente desarrollado. Otro Alfisol enterrado de la misma edad se encuentra en el extremo sur de la cuenca (sudeste de provincia de Entre Ríos, Argentina y oeste de Uruguay), desarrollado en el techo del loess del Pleistoceno tardío (Formación Tezanos Pinto). Este suelo es similar al suelo enterrado del Holoceno medio de la región pampeana. Algunos perfiles de suelo localizados en pequeños valles afluentes del Uruguay son pedocomplejos, con claras evidencias de que la pedogénesis fue interrumpida por la acumulación de cenizas volcánicas andinas (Andosoles).*

El suelo desarrollado en el Holoceno medio ("hypsithermal") está truncado por erosión eólica en la mayor parte de la región y cubierto por sedimentos del Holoceno tardío, principalmente de origen eólico. Los horizontes B y C heredados y el manto sedimentario que cubre el suelo se hallan sujetos a pedogénesis actual en un ambiente subtropical-tropical húmedo, que comenzó hace 200 años. La única excepción está representada por el Ultisol y el Alfisol (en la terraza fluvial), los cuales están cubiertos por 2-4 m de sedimentos depositados en el Holoceno superior y consecuentemente aislados de la dinámica actual.

Palabras clave: suelos enterrados, loess tropical, Holoceno, Río Uruguay, Sudamérica.

INTRODUCTION

The scope of this contribution is to mark the role of the parent material in soil genesis. The relative importance of each soil forming factor is and has always been a matter of discussion. This case involves a large territory of more than 350,000 km^2 located in the lowlands of subtropical South America (lat. 26°15'– 34° S and long. 49° 30'– 58° 30' W) (Figure 1). The border conditions for a non-biased test are reasonably good: the duration of pedogenesis is known; relief is quite homogeneous in the region; climate was also homogeneous, with a slight northeast–southwest trend. The vegetation pattern is generally linked to the parent materials. The Climatic Optimum is the better preserved soil forming period among the several Quaternary humid events described in the region (Kröhling, 1999). In the general context of South America, the studied region belongs to the South Atlantic region (Iriondo, 1999a).

Parent materials, on the other hand, form a mosaic of different and quite contrasting sedimentary bodies deposited in the Quaternary by fluvial, eolian, and paludal processes. A 5,000 years long episode of udic climate, established in the region during the Climatic Optimum of the Holocene (Hypsithermal period), generated soils which are different from each other even at the highest classification levels (Figure 1).

Iriondo and García (1993) used sedimentological, geomorphological and meteorological methods to suggest that the climate during the Climatic Optimum of the Holocene was humid, with 200 to 300 mm/year more moisture than present.

The methodology in this case was based on fieldwork, with accessory laboratory analyses. The climatic scenario at the soil forming period was adopted from other investigations made by us and other colleagues (Iriondo and García, 1993; Iriondo, 1999b, among others). Such results were obtained by applying mainly sedimentological, geomorphological and stratigraphic techniques.

GEOLOGICAL SETTING AND SOURCES OF SOIL MATERIALS

The geological basement of the region is a complex Proterozoic shield, which outcrops in Rio Grande do Sul state (Brazil) and Uruguay. It comprises a series of terranes

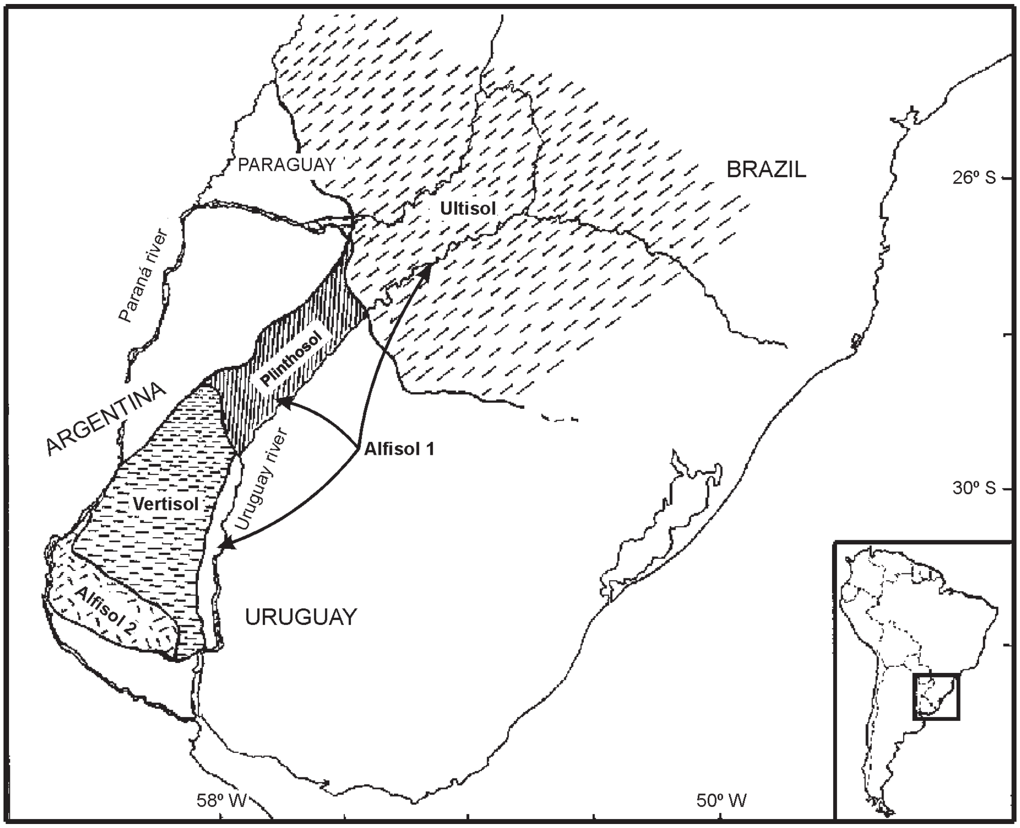

Figure 1. Map of the distribution of Holocene buried soils in the Uruguay river basin.

that have diachronically collided with the Río de la Plata craton in the Neo-Proterozoic. Two glacial stages, at 0.76–0.70 Ga and 0.65–0.55 Ga are registered in that period (Brito-Neves *et al.*, 1999). Those terranes are the ultimate source of the stable minerals found in soils. The Paleozoic Era is represented by a sequence of sedimentary rocks deposited in the Gondwana supercontinent. This system begins with fine-grained rocks of Devonian–Carboniferous age, covered by glacial and glacifluvial deposits sedimented in the upper Carboniferous. The Gondwana cycle ends with a thick sedimentary unit composed of sandstones of eolian origin.

The Mesozoic post-Gondwana rocks are the direct and indirect source of most soil and paleosol parent materials in the region. The Botucatú/Tacuarembó Formation is composed of thick eolian sandstones that provide quartz fine sand. Such materials were, in turn, recycled from the Gondwana desert, and before from Proterozoic rocks in the course of (probably) several erosion cycles. The heavy mineral association is dominated by zircon, staurolite, and tourmaline, and indicates a cratonic origin from the Brazilian shield.

Massive basaltic lava flows (Serra Geral Formation) flooded more than 1,200,000 km^2 with a thickness up to 1,700 m (lower Cretaceous). The Serra Geral Formation overlies the aeolian sandstones of Botucatú Formation. Tholeiitic basalts and basaltic andesites form most of the upper Uruguay basin (SE Brazil and NE Argentina) and a large area in northern Uruguay. The basalt underwent several epigenetic processes under different climatic conditions during the Cenozoic Era. The first known widespread event was the segregation of hydrated silica occurred in the lower Tertiary. That segregation produced a significant amount of chalcedony concretions, which were later reworked by erosion and form most of the clasts of the Eemian conglomerates in the lower basin. The second episode was the precipitation of iron hydroxides under a savanna climate in the upper basin. The phenomenon occurred at the denudation surfaces carved in several areas of the basaltic region. The mass of iron hydroxides was transported by runoff and subsurface water to the periphery of the system; there it precipitated as a rim of ferricrete along the southwestern border. Such a major event occurred at the upper Pliocene. Later, the crust was partially destroyed and, consequently, the environment downstream was enriched in iron and manganese concretions developed in some sediments.

Weathering of basalt produced clays of the montmorillonite and kaolinite groups. The genesis of montmorillonite occurred in a dry and presumably warm climate during the lower Pleistocene. At the same time period, or during a shortly younger one, the Uruguay River deposited the montmorillonite a few hundred of kilometers to the south, in the province of Entre Ríos (NE Argentina), building the 20–40 m thick Hernandarias Formation.

In the upper Quaternary, chemical weathering dominated the basaltic terranes. The rock is deeply altered in most outcrops; it was transformed into a dark brown regolith. In some places, the material preserves rock hardness, but the original minerals are not preserved (Riggi and Riggi, 1964). X-ray diffractograms suggest that minerals were transformed to a poorly crystallized mixture, with a poorly defined peak, within dominant amorphous materials. According to grain size data, such materials contain significant proportions of colloids. The dominant clay mineral is kaolinite, an important component of the upper Quaternary sediments in the Uruguay basin.

A minor amount of the sediments and soil materials in the Uruguay River basin originated in the Andean Cordillera and were transported by wind and wind-associated processes to the region. Illite, volcanic glass and plagioclase are the characteristic minerals of that origin.

QUATERNARY OF THE URUGUAY RIVER BASIN

Owing to the regional geological pattern and climatic changes that occurred in South America in the last two million years, the Uruguay basin integrates a mosaic of Quaternary geological formations and paleosols (Iriondo and Kröhling, in press). Studies performed in the neighboring Pampa indicate that the region underwent a sequence of warm/humid and fresh/dry climates in the upper Quaternary. Soils were generated in the humid periods, and five soil forming periods were described for the last 65,000 years (Iriondo and Kröhling, 1995; Kröhling, 1998). The most important and better preserved of them occurred in the region between 8,500 and 3,500 years BP. Such a 5,000 years long period of udic environment produced a pedological development at the top of all exposed geological units.

More detailed recent studies, carried out in the Pampa region, suggest that two intense pedogenic episodes occurred in that period, separated by a less humid interval and deposition, formed a pedocomplex (Kröhling, 1996). In the Uruguay basin, on the other hand, those two pulses affected the same surface, with the exception of fluvial terraces where the accretion of sediments built soil profiles up to 2-m thick (Bombin, 1976; Iriondo and Kröhling, in press).

The nature of the parent material dominated over the rest of the soil forming factors, in spite of the relatively large time involved and the warm climatic conditions. In the late Holocene, the soils were truncated by eolian erosion in most of the region, and were subsequently buried by eolian and alluvial deposits. The thickness of the sediments overlying the erosive contact on the buried B horizon is variable and range from 0.50 to 3 m.

Both, the remaining B horizon of the buried soils and the overlying sedimentary layer, are affected by the current incipient pedogenesis under a humid subtropical/tropical climate, which began 200 years ago. Exceptions to this influence are represented by the Ultisol in a tropical loess and the Alfisol in the Uruguay River terrace, which are covered by 2–4 m of late Holocene sediments, and consequently isolated from the present dynamic.

FIELD DESCRIPTION OF IMPORTANT CASES

Five buried soils developed during the humid phase of the Holocene are described here as representative of such pedological level. All of them cover relatively large areas (Figure 1). It should be noted that they limit each other along neat lines; catenas or other types of transitions do not appear in the field.

Table 1. Main characteristics of buried soils of the upper Uruguay basin.

Buried soil	**Vertisol**	**Ultisol**	**Plinthosol**
Latitude	29°30´ – 33°20´ S	25° – 28° S	27°30´ – 30°40´ S
Parent material	Paludal clay	Tropical loess	Fluvial/Paludal clayey sand (Paraná river)
Estimated mean temperature	21° C	23° C	22° C
Estimated mean precipitation	1,600 mm/yr	> 2,000 mm/yr	1,900 mm/yr
Original vegetation	Wooded savanna	Savanna	Tropical swamp
Overlying sediment	Eolian clayey silt (0.30–0.50 m thick)	Eolian red earth (2 m thick)	Eolian sand (0.30 m thick)
Areal extent	61,000 km^2	> 40,000 km^2	16,000 km^2
Color	Dark gray (5YR 4/1)	Dark red (10R 3/6)	Dark yellowish brown (10YR 4/4)
Segregated mineral	$CaCO_3$	Fe	Fe – Mn
Clay mineral	Smectite	Kaolinite	Montmorillonite / Kaolinite
Thickness (B horizon; m)	0.60	0.35	0.25
Structure	Moderately developed	Moderately developed	Weakly developed
Illuvial features	Few (clay cutans)	Common (clay cutans / Fe-argilans)	Common (ferriargilans)

Table 2. Main characteristics of buried soils of the middle–lower Uruguay basin.

Buried soil	Alfisol 1	Alfisol 2
Latitude	27º –32° S	31° – 33° S
Parent material	Alluvial loam	Pampean loess
Estimated mean temperature	19° C	21° C
Estimated mean precipitation	1,400 mm/yr	1,700 mm/yr
Original vegetation	Tall grasses	Praire
Overlying sediment	Alluvial loam (4-m thick)	Eolian silt (0.20-0.40-m thick)
Geographic extent	1,300 km long	120,000 km²
Color	Reddish brown (7.5 YR 7/6)	Brown (7.5YR 5/4)
Segregated mineral	Fe – Mn	$CaCO_3$
Clay mineral	Smectite	Illite-Smectite
Thickness (B horizon; m)	0.50 – 0.55	0.90
Structure	Moderately developed	Well developed
Illuvial features	Common (clay cutans)	Common (clay cutans)

This contribution does not strictly follow the classification criteria of Soil Taxonomy, rather we use that facet of soil science loosely. Based primarily on descriptive aspects of the studied buried soils, we in general follow the Soil Taxonomy as interpreted by the Government Soil Surveys for surficial soils of the region. In favorable cases, the classification proposed by Mack *et al.* (1993) was adopted. Tables 1 and 2 include a characterization of each buried soil of the region with paleoenvironmental reconstruction.

Buried Vertisol

At the top of the Hernandarias Formation, a Vertisol was developed. This sedimentary unit is a playa deposit sedimented by the Uruguay River in most of the Entre Ríos province. The typical thickness of the formation varies from 20 to 40 m; it is composed of loam and silty loam with montmorillonite as main clay mineral and quartz fine sand, and contains gypsum at the base (Iriondo and Kröhling, in press). Romero (1985) found that more than 90% of the clay minerals are montmorillonite, beidellite, nontronite. Illite is a significant accessory mineral in the upper part of the formation, together with volcanic glass. Both minerals were transported by wind from the Andes, located at a distance of 1,000–1,500 km to the west. This formation was sedimented around one million year BP in the course of an important glaciation occurred in South America (Mercer, 1976).

The profile of the Vertisol at the top of the formation (Figure 2) is as follows, from top to base:

0.00–0.15 m. San Guillermo Formation (upper Holocene in age). Dark gray eolian silt with subordinate quartz sand.

Erosive discordance.

0.15–2.00 m. Vertic buried soil:

0.15–0.45 m. B21 horizon. Plastic silty clay with small proportions of scarcely sorted quartz sand. Moderately structured in very firm coarse prisms, which break into fine to medium angular blocky peds. Dark gray in dry color (10YR 4/1) to black in humid (10YR 2/1). Common slickensides, desiccation cracks and fine fissures. It forms a concave profile in outcrops. Gradual lower boundary.

0.45–0.60 m. B22 horizon. Plastic silty clay, dark gray in humid (10YR 4/1). Contains scarcely sorted quartz grains and fine gravels, and is moderately structured in subangular fine to medium blocky peds. Common slickensides, desiccation cracks and fine fissures. Gradual lower boundary.

0.60–0.75 m. B3 horizon. Plastic silty clay, general color grayish brown in humid (10YR 5/2) with variations in color produced by mass movement (churning). Weakly developed structure in coarse blocks; frequent clay cutans

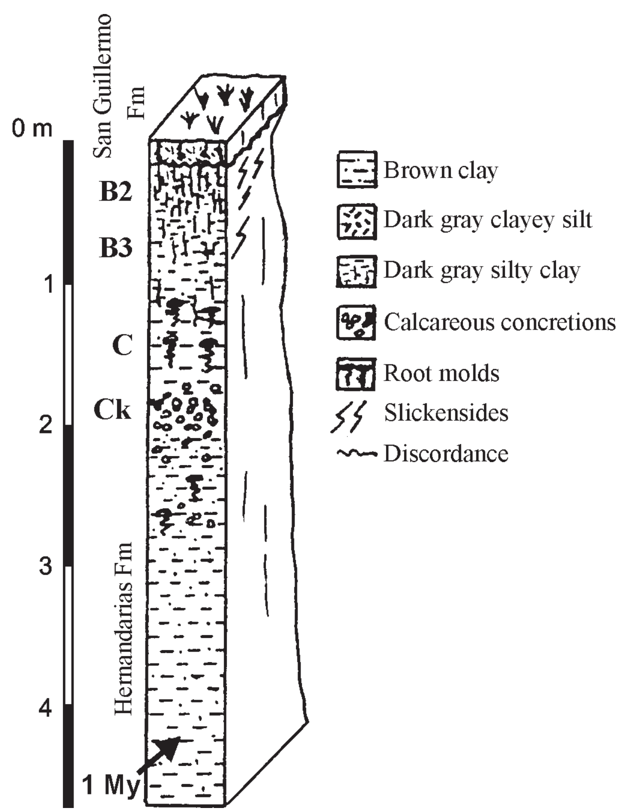

Figure 2. Typical profile of the Hernandarias Formation, with the vertic buried soil on top.

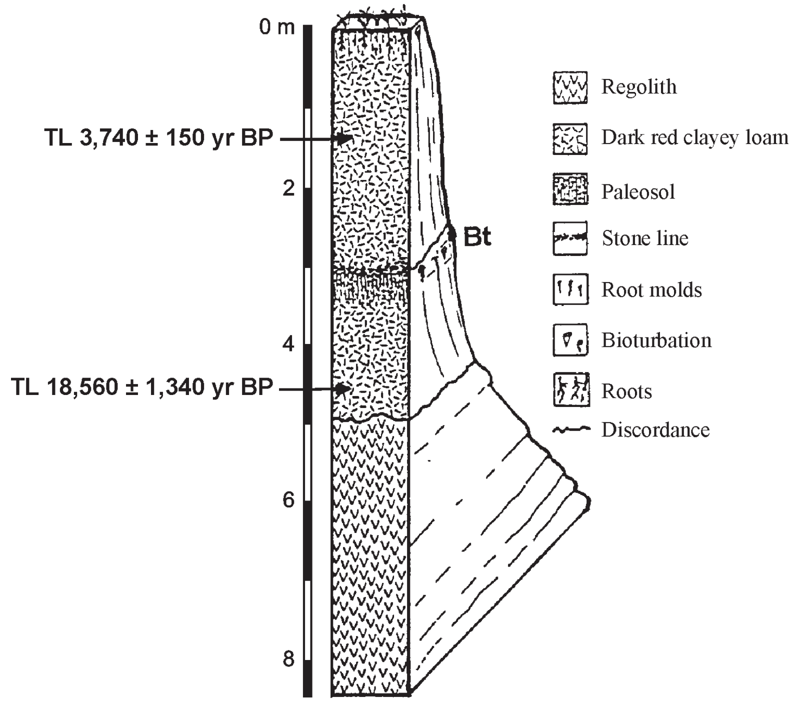

Figure 3. Typical profile of the Oberá Formation, with the buried Ultisol at intermediate depth (taken from Iriondo and Kröhling, 1997).

and numerous slickensides. Gradual lower boundary.

0.75–1.60 m. C horizon. Plastic silty clay with regular proportions of scarcely sorted quartz sand (<20%), brown in general color (moist:10YR 5/3). Weakly structured in coarse to very coarse firm subangular blocky peds. Common slickensides. Contains abundant desiccation cracks and biogenic channels (up to 1.5 cm in diameter) filled with material derived from the upper solum. Scarce calcium carbonate concretions, 5 mm in diameter. Gradual lower boundary.

1.60–2.00 m. Ck horizon. Plastic silty clay containing scarcely sorted sand, brown in color. Molds of small roots, and abundant powdery concretions of calcium carbonate, 2 to 3 cm long.

2.00–6.00 m. Hernandarias Formation.

Buried Ultisol

A buried Ultisol occurs within the Oberá Formation, a tropical loess of late Pleistocene–Holocene age, which covers the province of Misiones (NE Argentina) and neighboring areas of Brazil and Paraguay (Iriondo and Kröhling, 1997; Iriondo *et al.*, 1997).

The Oberá Formation is composed of clayey loam to loamy clay, powdery, porous, in general friable, dark red in color (10R 3/6). The unit lies in erosive unconformity on Cretaceous basalts, sandstones and Tertiary rocks. It covers the landscape as a mantle, with a typical thickness between 3 and 8 m. Light minerals in the fine sand fraction of the Oberá Formation are: 85–97% quartz, 1–11% volcanic glass, 1–4% alterites, and 1–2% amorphous silica. The clay fraction is composed of kaolinite and quartz with hematite and gibbsite as minor components. Ferrimanganiferous concretions and nodules, fine to medium in size, with rounded and subequant shapes are locally abundant (up to 10%).

The Oberá Formation is composed of two members. The lower one (Last Glacial Maximum in age, around 20,000 yr BP) underwent pedogenesis at the top during the Climatic Optimum of the Holocene. The upper member (upper Holocene in age) lays on erosive discordance and has a discontinuous stone line at the bottom.

A representative profile of the Oberá Formation (Figure 3) is as follows, from top to base:

0.00–3.00 m. Upper member of the Oberá Fm. Dark red loam, massive, moderately friable, with scarce siliceous concretions dispersed in the sedimentary mass. Subvertical profile, affected by slope wash.

3.00–3.15 m. Stone line continuous along the whole outcrop (about 100 m). It defines an irregular level, with 40 cm of relief. The composition of clasts is dominated by gravel-sized silica, with few medium pebbles, dominantly platy to tabular angular rough in shape.

3.15–3.50 m. Buried Ultisol:

3.15–3.50 m. Bt horizon. Dark red (10R 3/6) clayey loam, with kaolinite as dominant clay mineral and iron segregations. It is moderately structured in weak to firm medium prisms. Clay cutans and ferriargilans, fine fissures, few macropores, and infilled root molds and molds partially stained by black films. Subvertical profile. Clear lower boundary.

3.50–5.00 m. Lower member of the Oberá Fm (parent material of the buried soil). Dark red clayey loam, massive, moderately friable.

Buried Plinthosol

A Plinthosol was developed at the upper part of the Tapebicuá Formation, a sedimentary unit composed of paludal and alluvial deposits in the province of Corrientes (NE Argentina; Iriondo and Kröhling, in press). The Paraná River conveyed sediments to the area during the late Pleistocene/lower Holocene. The unit is formed by a channel facies that is covered by a 2 to 3 m thick alluvial plain facies. The alluvial plain facies is clayey with poorly sorted fine quartz sand and abundant iron sesquioxides in concretions diffused throughout the profile. It contains up to 10% of quartz granules and gravels. The clay fraction is composed of montmorillonite and kaolinite. Smectitic clays and the activity of iron sesquioxides characterize the sediment as considerably plastic. The sedimentary mass includes concentrations of hard iron concretions (5–10 mm long), welded in larger irregular bodies. Generally, such features have vertical positions suggesting precipitation by infiltration. Besides, the sediment contains abundant hard

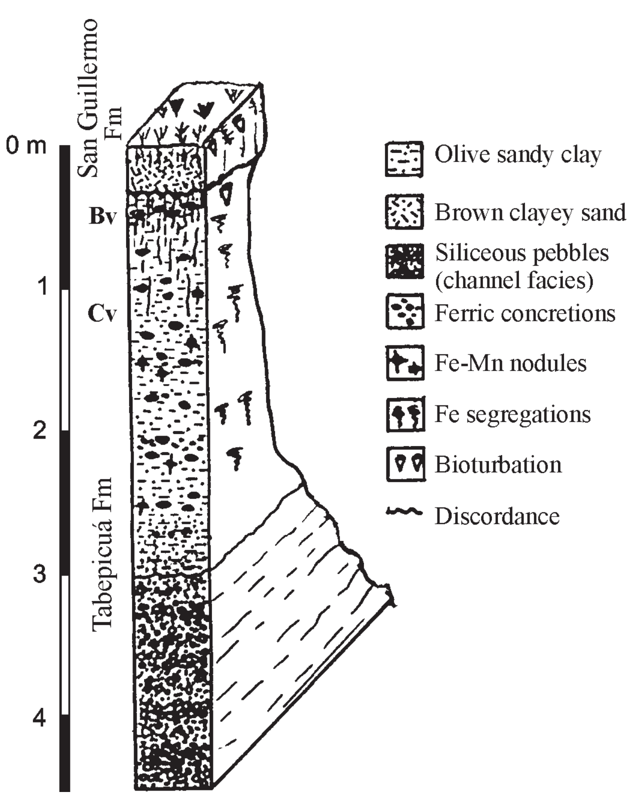

Figure 4. Typical profile of the Tapebicuá Formation, with the plinthic buried soil on top.

rounded equant ferrimanganiferous concretions. These are erratically distributed in the profile (10% of the total sediment). The post-depositional environment of this sedimentary facies was a tropical swamp, with active iron dynamics. Such large and conspicuous amount of active iron is derived from the Apóstoles peneplain upstream, which has been the source of the iron during the Quaternary. The general dry color of this facies is olive yellow (2.5Y 6/6; 5Y 6/6) with light olive spots (5Y 6/4) and variations to brown (7.5YR 5/8) and light olive brown (2.5Y 5/6).

The high energy channel facies of the unit is formed by fine to medium pebles in 0.20 to 0.40 m thick lenticular strata. Clasts have a dominant siliceous composition (quartz, chalcedony, sandstone). Small ferricrusts are erratically distributed.

A representative profile of the truncated soil developed in the Tapebicuá Formation (Figure 4) is as follows:

0.00–0.30 m. San Guillermo Formation. Eolian sandy silt, gray to light brown in color.

Erosive discordance.

0.30–1.25 m. Buried Plinthosol:

0.30–0.55 m. Bv horizon. Very fine clayey sand, with scarce siliceous coarse sand and gravel (quartz and chalcedony), rounded to angular in shape. The clay mineral is dominantly kaolinite. The matrix color is dark yellowish brown (10YR 4/4) dry. The soil horizon has weakly structure. Diagnostic illuvial features are common to many ferriargillans. It contains common plinthite, rounded smooth subequant in shape, and red vertical iron-sesquioxides segregations with sharp limits. The Bv horizon forms a concave profile in outcrops. Diffuse lower boundary.

0.55–1.25 m. Cv horizon. Clayey fine sand with scarce poorly sorted quartz sand, with many iron-sesquioxides segregations. Contains abundant root molds, desiccation cracks and erratic ferricrusts.

1.25–3.50 m. Tapebicuá Formation.

Buried Alfisol 1

A buried Alfisol is included in the body of the lower terrace (Concordia Formation) of the Uruguay River. The terrace occurs along a distance of 1,300 km, from Chapecó (Brazil) to Concepción del Uruguay (Argentina), near the mouth. The width of the terrace is normally less than one km (Iriondo and Kröhling, in press). It is composed of massive to coarsely stratified sandy loam to clayey sand, grayish brown to reddish brown in color. The unit was sedimented as alluvium during two semiarid phases separated by a soil-forming climatic period. The entire sequence corresponds to the whole Holocene. The general aspect and the thickness of the terrace are strikingly homogeneous along the basin. Siliceous clasts (quartz and chalcedony) dominate the sand fraction in the middle and lower river basin reaches. Kaolinite and montmorillonite are the main clay minerals.

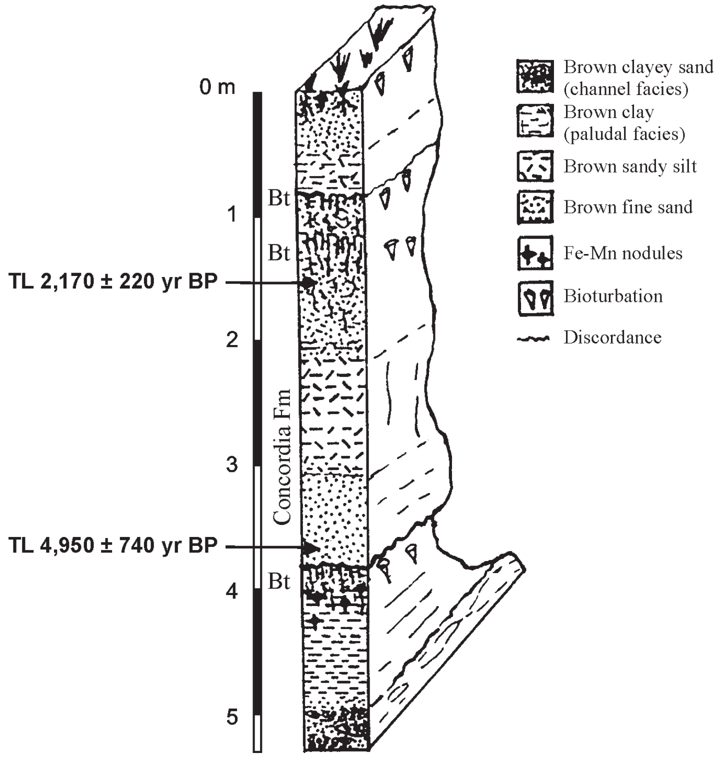

Figure 5. Typical profile of the Concordia Formation, with the buried Alfisol on the lower part.

The Concordia Formation is composed of two members. The lower one has a channel facies at the bottom, with pebbles and gravels, covered by laminated sand and clayey sand at the top. This stratum was transformed by pedogenesis (Alfisol). The upper member of the unit was deposited on an erosive discordance. It is composed of fine clayey sand, silty sand and loam, brown to grayish brown in color (alluvial plain facies). Ceramic shards included in the sediment indicate ages younger than 2,000 yr for this member.

The type profile of the Concordia Formation (Figure 5) is the following, from top to base:

0.00–0.60 m. Present alluvial deposit.

0.60–3.75 m. Upper member of the Concordia Formation:

0.60–0.85 m. Grayish brown clayey silt.

0.85–2.05 m. Buried soil:

0.85–1.75 m. Bt horizon. Very fine silty sand, grayish brown in humid color (matrix), moderately structured in firm coarse prisms that break into smaller firm prisms. Common macropores and fine fissures. Lower clear boundary.

1.75–2.05 m. Bt horizon. Composition is similar to that of the overlying Bt horizon, poorly structured.

2.05–3.15 m. Clayey silt with an important proportion of fine to very fine sand, brown in color, friable. It is weakly structured in irregular aggregates. The upper and lower boundaries are diffuse.

3.15–3.75 m. Very fine quartz sand with smaller proportion of silt and clay, friable, brown in color. It is weakly structured in irregular aggregates.

Discordance.

3.75–5.32 m. Lower member of the unit:

3.75–4.27 m. Buried Alfisol (the soil referred at in this paper):

3.75–4.27 m. Bt horizon. Gray clayey silt moderately developed in coarse prisms that break into very firm smaller prisms. Common clay cutans and fine fissures.

4.27–4.82 m. Cohesive clay, gray brown in color, with abundant powdery nodules. Numerous desiccation cracks. Represents the infilling of an abandoned channel (parent material of the soil).

4.82–5.32 m. Channel facies formed by clayey sand containing diffuse lenses of rounded siliceous gravels.

Buried Alfisol 2

An Alfisol, developed in loessic parent material, occurs in the southwestern corner of the Uruguay basin (SW Entre Ríos province) and in large areas of the Pampa plain. That portion of the Uruguay basin belongs to a large sedimentary complex named Pampean Eolian System (Iriondo and Kröhling, 1995; Iriondo, 1999b), which is composed of the Pampean Sand Sea and the Peripheral Loessic Belt. The loess belt surrounds the sand sea in three

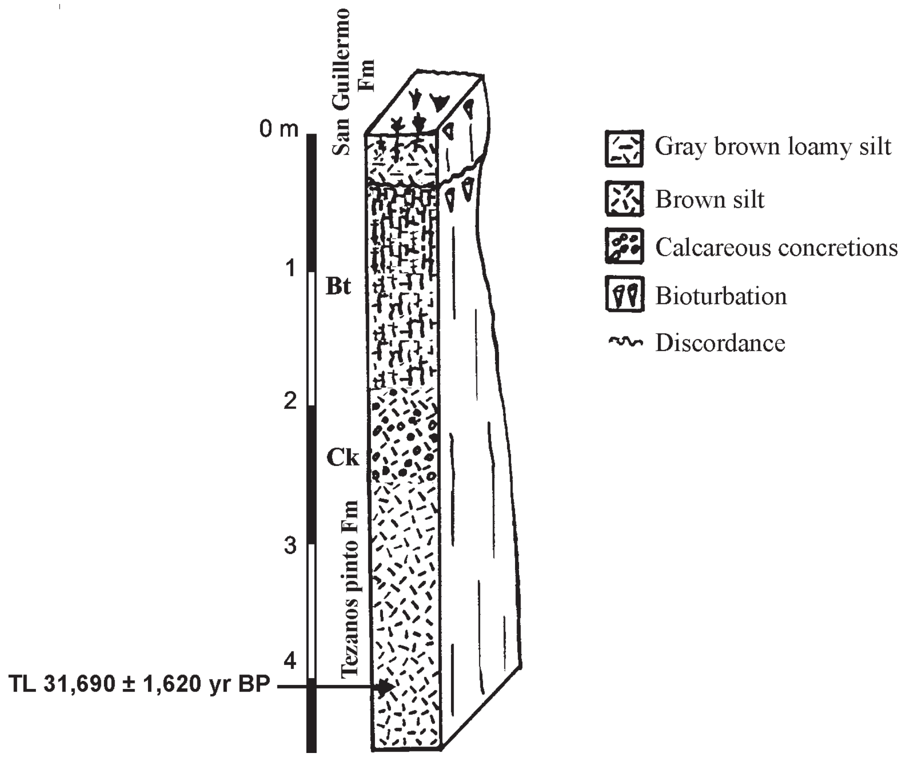

Figure 6. Characteristic profile of the buried Alfisol on top of the Pampean Loess (Tezanos Pinto Formation).

directions, is 250–300 km wide, and about 2,000 km long. The system is Last Glacial Maximum in age.

Typical thickness of the loess is 4–7 m on the interfluves and 2 m in river cliffs. The loess is composed of light brown loose silt with vertical features and frequent calcium carbonate concretions. Inside the sedimentary mass, root casts, fossil nets, krotovinas and erosional surfaces are observed. The sand fraction of the loess is dominated by Andean materials, mainly derived from the physical weathering of Tertiary fine-grained rocks. A significant proportion of those rocks are volcanic. Typical minerals of that origin are plagioclases, amphiboles and volcanic glass. Secondary sources of sediments are the granitic Pampean ranges and direct falls of volcanic ash. The loess is formally named Tezanos Pinto Formation.

The soil developed on top of the pampean loess was eventually truncated by erosion and covered by younger deposits. The typical profile (Figure 6) is as follows, from top to base:

0.0–0.35 m. San Guillermo Formation. Gray brown loamy silt.

Erosive discordance.

0.35–3.20 m. Buried Alfisol:

0.35–0.40 m. B1 horizon. Clayey silty loam, gray brown in color (10YR 5/2), poorly structured in medium angular blocks. Gradual lower boundary.

0.40–0.68 m. B21t horizon. Dark brown (7.5YR 4/2) clayey silt. Well structured in coarse to medium firm prisms. Common clay cutans. Gradual lower boundary.

0.68–0.98 m. B22t horizon. Brown (7.5YR 5/4) clayey silt. Moderately structured in medium angular firm blocky peds. Common clay cutans. Gradual lower boundary.

0.98–1.30 m. B23t horizon. Light brown (7.5YR 6/4) clayey silt moderately structured in subangular medium to fine firm blocks. Scarce clay cutans. Gradual lower boundary.

1.30–1.60 m. B3 horizon. Reddish brown (7.5 YR 7/6) clayey silt weakly structured in subangular fine blocks, moderately weak strength. Gradual lower boundary.

1.60–2.25 m. C horizon. Light brown silt, massive and friable. Abrupt lower boundary.

2.25–3.20 Ck horizon. Light brown massive friable silt. Scarce hard calcium carbonates concretions.

3.20–5 m. Pampean loess (Tezanos Pinto Formation).

Some profiles in small valleys of minor tributaries of the Uruguay River lower basin are pedocomplexes with clear evidence of interruption of the soil formation by the accumulation of Andean volcanic ashes; they show a tendency to Andisols. A characteristic section was described in southeastern Entre Ríos province:

0.00–0.25 m. San Guillermo Formation. Eolian sandy silt, grayish brown in color.

Erosive discordance.

0.25–1.62 m. Buried pedocomplex:

0.25–0.35 m. Bt horizon. Clayey silt with subordinated medium sand, gray in color. It is moderately structured in medium to coarse prisms that break in very firm to strong fine blocks. Discordant lower boundary.

0.35–0.57 m. Cineritic stratum. Light gray to white in color, with low density. It is weakly structured in very coarse prismatic aggregates. Abrupt lower boundary.

0.57–1.02 m. Bt horizon. Clayey silt, gray in color. It has a strongly developed structure in very coarse prisms that break into fine very firm to strong peds, limited by fine fissures. Vertical to concave profile in outcrops. Gradual lower limit.

1.02–1.62 m. Ck horizon. Brown silt with scarce clay content. It is weakly structured in fine to medium prisms, very firm in strength. Root molds and segregations of manganese-oxides. Powdery calcium carbonate concretions.

>1.62 m. Pampean loess (Tezanos Pinto Formation).

CONCLUSIONS

In accordance with the descriptions and arguments developed in the above paragraphs, the main conclusion of this work is that the parent material was the dominant factor in the Holocene soil genesis in the studied region during a 5,000 years long episode under humid tropical/subtropical climate.

An accessory result was the observation that all soils were partially eroded (losing the A horizon) and eventually covered by younger, mainly eolian sediments. Note that environmental conditions then were not really severe; subtropical semiarid climate and no human pressure were involved.

REFERENCES

Bombin, M., 1976, Modelo paleoecológico evolutivo para o Neoquaternário da região da Campanha oeste do Rio Grande do Sul. A Formação Touro Passo, seu conteúdo fossilífero e a pedogénesis pós-deposicional: Porto Alegre, Pontifícia Universidade Católica Do Rio Grande Do Sul, Comunicações Museum de Ciências, 15, 1–90.

Brito-Neves, M., Campos-Neto, C., Fuck, R., 1999, From Rodinia to West Gondwana; an approach to the to the Brasiliano-Pan African orogenic collage: Beijing, Episodes, 22 (3): 155–166.

Iriondo, M, 1999a, Paleosols and Climates in the Quaternary of South America, *in* Xiao-Min, F., Nettleton, D. (eds.), International Symposium and Field Workshop on Paleosols and Climatic Change: Beijing, Chinese Science Bulletin, 44(1), 8–14.

Iriondo, M., 1999b, Climatic Changes in the South American plains; records of a continent-scale oscillation, *in* Partridge, T., Kershaw, P., Iriondo, M. (eds.), Quaternary Palaeoclimates of the Southern Hemisphere: Quaternary International, 57-58, 93–112.

Iriondo, M., García, N., 1993, Climatic variations in the Argentine plains during the last 18,000 years: Palaeogeography, Paleoclimatology, Palaeoecology, 101, 209–220.

Iriondo, M., Kröhling, D., 1995, El Sistema Eólico Pampeano: Comunicaciones del Museo Provincial de Ciencias Naturales "Florentino Ameghino", 5(1), 1–68.

Iriondo, M., Kröhling, D., 1997, The tropical loess, *in* Zhisheng, A. Weijian, Z. (eds.), Proceedings of the 30th International Geological Congress: Quaternary Geology, 21, 61–78.

Iriondo, M., Kröhling, D. (in press), Cambios ambientales en la cuenca del Uruguay (desde el Presente hasta dos millones de años atrás): Santa Fe, Universidad Nacional del Litoral, Colección Ciencia y Técnica, 350 p.

Iriondo, M., Kröhling, D., Orfeo, O., 1997, La Fm. Oberá, un sedimento eólico tropical, *in* I Congreso Latinoamericano de Sedimentología, Memorias, Tomo I: Porlamar, Venezuela, Sociedad Venezolana de Geología, 343–348.

Kröhling, D., 1996, La Formación Lucio Lopez (Holoceno), noreste de la llanura pampeana, *in* XIII Congreso Geológico Argentino, Actas IV: Buenos Aires, p. 69.

Kröhling, D., 1998, Geomorfología y Geología del Cuaternario de la cuenca del río Carcarañá, desde la confluencia de los ríos Tercero y Cuarto, provincias de Córdoba y Santa Fe: Córdoba, Argentina, Universidad Nacional de Córdoba, Facultad de Ciencias Exactas, Físicas y Naturales, Doctoral Thesis, 224 p.

Kröhling, D., 1999, Upper Quaternary of the lower Carcarañá basin, North Pampa, Argentina, *in* Partridge, T., Kershaw, P., Iriondo, M. (eds.), Paleoclimates of the Southern Hemisphere: Quaternary International, 57/58, 135–148.

Mack, G., James, W., Monger, H., 1993, Classification of Paleosols: Geological Society of America Bulletin, 105, 129–136.

Mercer, J., 1976, Glacial history of southernmost South America: Quaternary Research, 6, 125–166.

Riggi, J., Riggi, N., 1964, Meteorización de los basaltos en Misiones: Revista de la Asociación Geológica Argentina, 19 (1), 57–70.

Romero, S., 1985, Estudio geológico-económico del área yesífera de Piedras Blancas, Provincia de Entre Ríos: Buenos Aires, Universidad de Buenos Aires, Departamento de Geología, tesis de licenciatura, 60 p.

Manuscript received: February 28, 2002
Corrected manuscript received: June 4, 2002
Manuscript accepted: June 19, 2002