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The Ensenada and Buenos Aires formations (Pleistocene) in a quarry near La Plata, Argentina

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Abstract

An interdisciplinary study of a section in a quarry near La Plata sheds new light on the geologic, climatic, and biologic evolution of the northeastern Pampean area of Argentina. The stratigraphic succession is composed of seven mainly eolian levels, each one including a soil and separated by a disconformity. Two geosols defined in northern Buenos Aires Province (Hisisa and El Tala) are identified in the Ensenada Formation. The boundary between the Ensenada and Buenos Aires formations is defined by a conspicuous disconformity which overlies the El Tala Geosol. In the section, the boundary between the *Tolypeutes pampaeus* (Ensenadan) and *Megatherium americanum* (lower Lujanian) biozones coincides with that of Ensenada and Buenos Aires formations. The boundary between the Matuyama and Brunhes zones of polarity occurs in the upper part of the Ensenada Formation above the Hisisa Geosol. According to geologic evidence, most of the succession was deposited under semiarid to arid climate.

Resumen

Un estudio interdisciplinario de una cantera proxima a La Plata, aporta nuevos datos sobre la geologia, el clima y la evolucion biologica de la region oriental de la Pampa Argentina.

La sucesion estratigrafica esta compuesta principalmente por siete niveles principalmente eolicos, a veces lacustres, cada uno de ellos coronados por un suelo y separados por una discontinuidad. Dos geosuelos definidos en el norte de la Provincia de Buenos Aires (Hisisa y El Tala), han sido identificados en la Formacion Ensenada. Entre La Formacion Ensenada y la Formacion Buenos Aires se reconoce una conspicua discontinuidad que sobreyace el Geosuelo El Tala. El limite entre las biozonas de Tolypeutes pampaeus (Ensenadense) y Megatherium americanum (Lujanense inferior) coincide con el de las Formaciones Ensenada y Buenos Aires. El limite entrelas zonas de polaridad de Matuyama y Brunhes se encuentra dentro de la seccion cuspidal de la Formacion Ensenada, por encima del Geosuelo Hisisa. Sobre la base de la evidencia geologica, la mayor parte de la sucesion ha sido depositada bajo un clima semi-arido a arido.

1. Introduction

The stratigraphy and paleontology of the continental Pampean upper Cenozoic are well known in comparison with other areas of South America. However, there are several unsolved problems. Many of the type sections of Pleistocene Pampean chronostratigraphic units (which have been extended to the rest of South America) are not available now because they were studied in excavations (Buenos Aires and La Plata harbors). Besides, few interdisciplinary projects were carried out. This lack of integrated work generated

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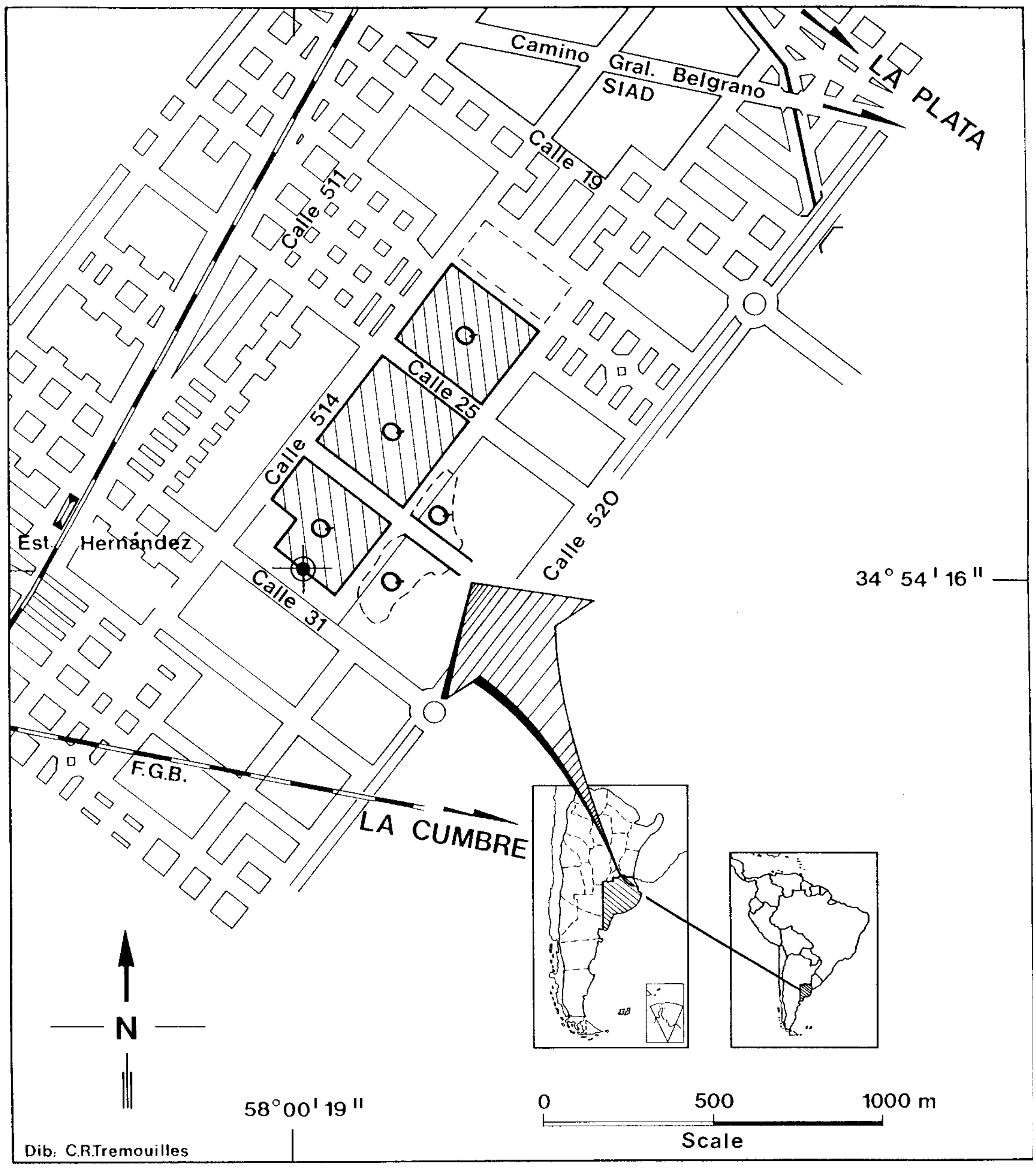

Fig. 1. Location map. Q: quarries.

misunderstandings about the meaning and boundaries of several biostratigraphic and chronostratigraphic units (see Cione and Tonni, 1995a,b).

In the present paper, we describe the stratigraphic succession cropping out in a quarry at José Hernández, central eastern Argentina (Fig. 1). The quarries at José Hernández are relevant for elucidating some problems due to their large size (both in surface and depth) and their proximity to the Ensenadan Stage type section.

We studied the section in order to: (1) define the boundary between the Ensenadan and Lujanian stages (*Tolypeutes pampaeus* and *Megatherium americanum* biozones; Fig. 2); (2) determinate the position of this boundary in relation to that of the Ensenada and Buenos Aires formations and the Matuyama and Brunhes zones of polarity; (3) describe new vertebrates recently collected; and (4) comment on the paleoclimatic aspects.

2. Previous work

D'Orbigny (1842) and Darwin (1846) first studied the geology of the Pampean area. D'Orbigny (1842) gave the name "Argille pampéene" (Pampean clay) to

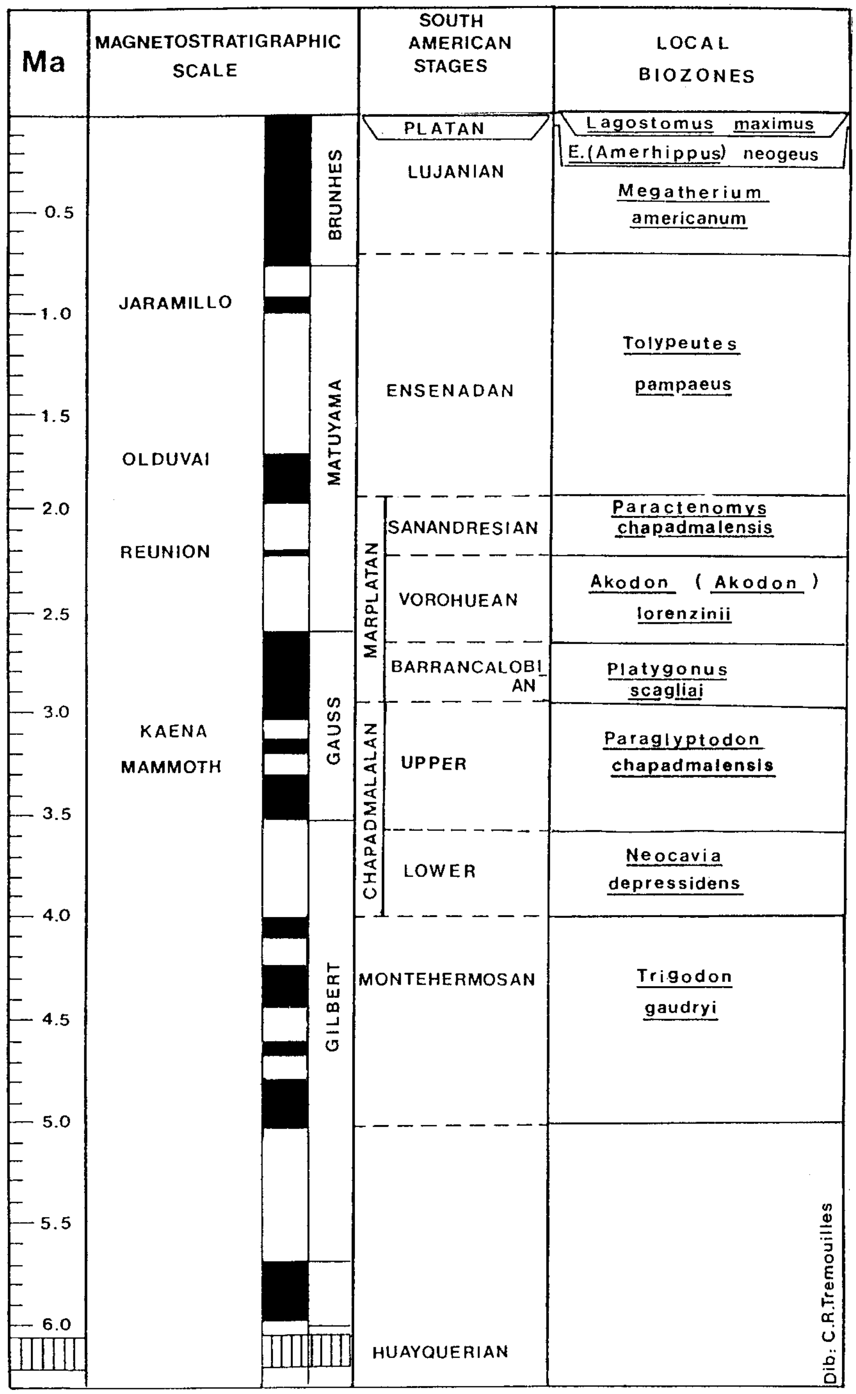

Fig. 2. Magnetostratigraphic, chronostratigraphic, and biostratigraphic scale for Pampean area.

the reddish brown sediments cropping out near the Río de la Plata. The terms "Formación Pampeana", "Formación Pampiano", "sedimentos pampeanos", etc. were derived from this original name (see Fidalgo et al., 1975).

Many authors have studied the geology of northeastern Buenos Aires province. For the sake of brevity, we mention only those dealing with the José Hernández quarries. Since commercial exploitation of the quarries is continuing, the sections studied by various authors have not remained the same.

Cortelezzi (1978) and Cortelezzi and Weibchen (1981) mentioned convolute stratification in sediments attributed to the Ensenada Formation. Teruggi and Imbelloni (1987) recognized seven paleosols in the southwestern quarry. They assigned the upper three

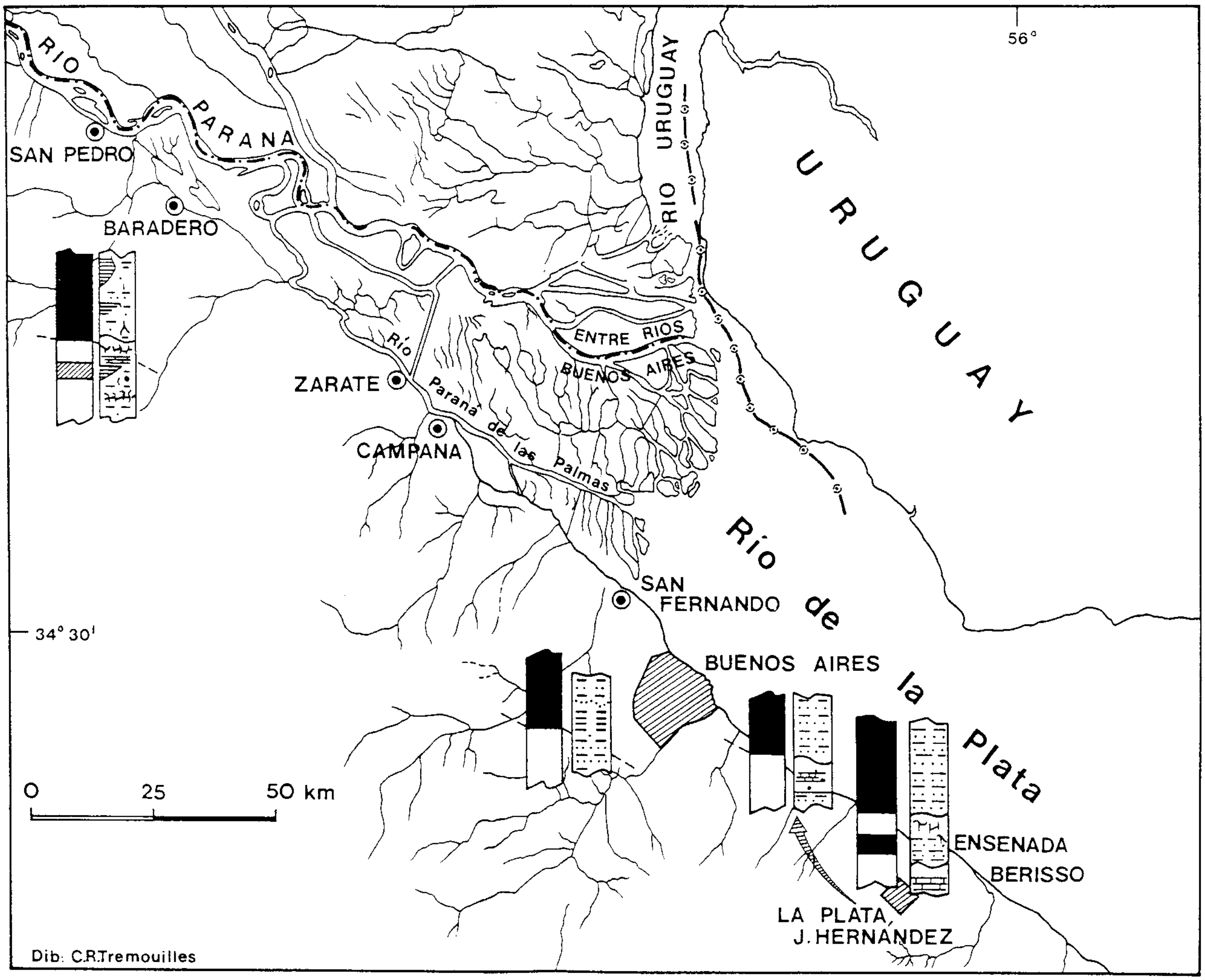

Fig. 3. Magnetostratigraphic and stratigraphic sections at Baradero, the city of Buenos Aires, José Hernández and the Teatro Argentino at the city of La Plata (modified from Nabel, 1993).

paleosols to the La Postrera Formation (late Pleistocene–Holocene) and the lower four paleosols to the "Formación Pampiano" ("Bonarean" *partim*; Fig. 2).

Sediments of the Ensenada and Buenos Aires formations crop out in the western quarry. These units were informally used by many authors (e.g. Pascual et al., 1965). However, the Ensenada and Buenos Aires formations were formally defined and described by Riggi et al. (1986) in the excavation for the Teatro Argentino of La Plata (located about 6 km from the quarry and presently unavailable for examination; Fig. 3). The boundary between the Ensenada and Buenos Aires formations was found at approximately 10 m a.s.l. at the Teatro Argentino excavation (Riggi et al., 1986).

Tonni et al. (1988) studied the western quarry section and described fossil mammals. The taxa recorded are characteristic of the Pleistocene sensu lato and none is a guide fossil of the Ensenadan or Lujanian stages.

Bidegain (1991) provided a magnetostratigraphic analysis of the section at the western quarry. He recognized the Brunhes-Matuyama boundary and the Jaramillo and Olduvai normal polarity events. Later, Bidegain (1994) erroneously assigned some mammal fossils to the reversed part in the base of the section (correlated with the Matuyama Zone of polarity). Actually, all the fossils mentioned by Tonni et al. (1988) were collected in the upper part (correlated with the Brunhes Zone of polarity).

3. Geographic location and methods

The studies were done in the southwestern quarry

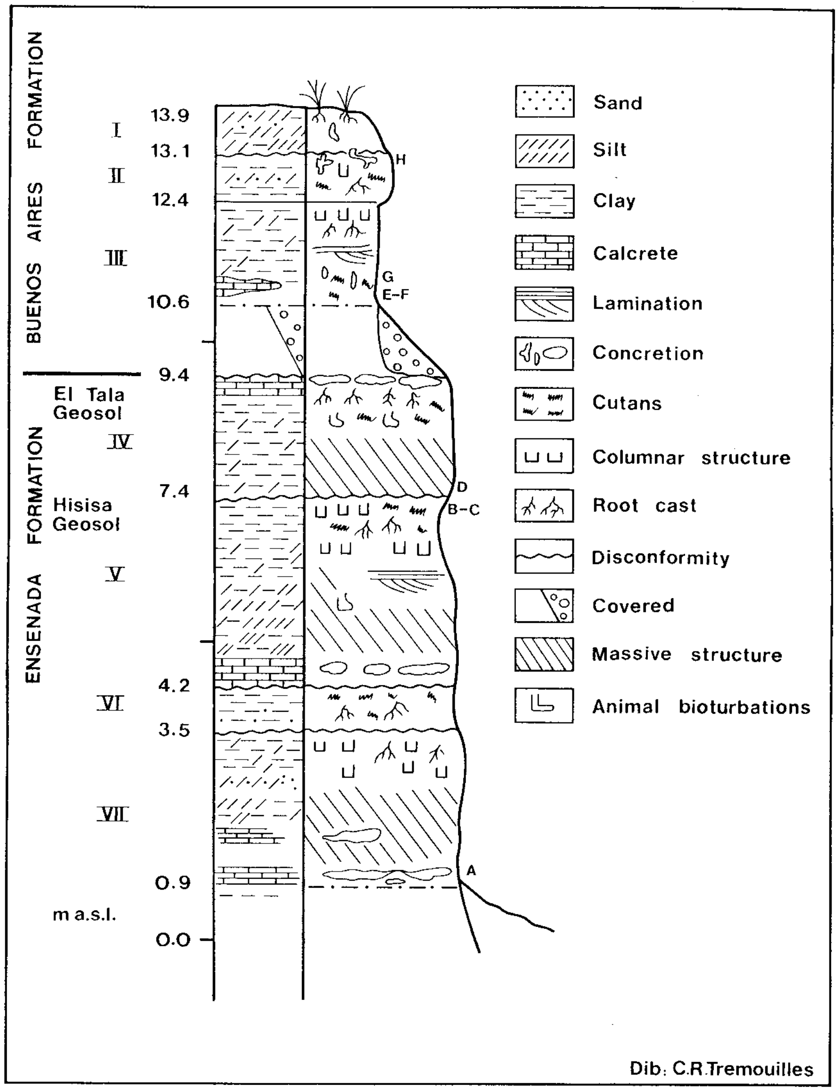

Fig. 4. General stratigraphy of the section. L, loess; P, paleosol; S, soil. Fossils: A, *Mesotherium cristatum*; B, *Panochthus cf. intermedius*; C, *Sclerocalyptus sp.*; D, *Pseudoseisura*; E, *Lomaphorus* cf. *elegans*; F, *Graomys* sp.; G–H, *Glyptodon sp.*

(of a group of three main quarries) at José Hernández, La Plata County, Argentina (Fig. 1). The section described is located 5.3 km northwest of the center of the city of La Plata and 0.7 km east of the former Hernández Railway Station (Fig. 1). The coordinates of the section are: 34″ 54′ 35″S and 58° 00′ 15″W (x = 6.137.150, y = 6.407.600 in the Hoja 3557-13-4 "Villa Elisa"; Instituto Geográfico Militar).

The profile was taken at the southwestern wall of the southwestern quarry (Figs. 1 and 4). The section is presently accessible and easy to sample. However, we could not sample a covered portion in level III (see Fig. 4). Lateral variations were observed in more than 4 km of section in the walls of the quarry. Work at the quarries began in the 1940 and were neither synchronic nor systematic.

The level point N° 236 (Dirección de Geodesia of Buenos Aires Province) was used for referring the section to the sea level. Colors were determined according to the Rock Color Chart (Rock Color Chart Committee, 1984) using both dry and wet material. Stratigraphic nomenclature is according to the CAE (1992).

The section was carefully studied, sampled, and described for magnetostratigraphic analyses considering a previous study (Bidegain, 1991). The 98 samples were taken with 2.5 cm wide pipes and were sealed with epoxy. Sediments included in paleocaves and a glyptodont carapace were sampled for studying possible variations in polarity directions. The upper part of the section was irregularly sampled in order to check the characteristic normal magnetic polarity recognized.

Low magnetic field susceptibility was measured with a KT9 field susceptibility-meter with a separation of 1–5 cm. Natural remnant magnetism (NRM) was measured with a fluxgate magnetometer and demagnetized by alternating field treatment (AF).

Grain size was analyzed by standard methods of sieving and gravimetric separation. Clay lumps were disintegrated using the Llambías and López (1995) method, with slight modifications. Light and heavy mineral components were separated using bromophorm. Microscopic analysis and counting of the mineral species was carried out on fine and very fine sand and coarse silt.

4. Description of the section

4.1. Field work

The stratigraphic succession is composed of seven mainly loessic levels (I–VII, from top to bottom) each one capped by a soil and separated by a disconformity (Fig. 4). Sediments are distributed horizontally and the similar granulometry and color make them apparently homogeneous. The apparent monotony is broken by vertebrate fossils, paleocaves, other bioturbation, and green pelitic sediments.

The lower part of the section is more consolidated. The paleosols show lateral variations in thickness, fabric, and edaphic horizons.

4.1.2. Level VII. Thickness: 2.60 m

The section begins with a very compact calcrete of very light yellowish orange color (10 YR 8/6) approximately 1.50 m thick. A well consolidated clayey silt of grayish orange color (5 YR 7/4) overlies the calcretes. This bed includes lime agregates (from 0.3 to 2.5 cm).

The upper part includes a thick paleosol (0.65 m) that is light yellowish brown (10 YR 6/2) when wet and brown (5 YR 4/4) when dry. The sediment is clayey silt. There are very firm columnar structures, abundant root casts, and bluish black cutans (mangans).

4.1.2. Level VI. Thickness: 0.70 m

The basal contact is neat and wavy. The sediment is a sandy clayey silt with tiny lime concretions (0.6–2.0 cm diameter) of very light orange color (10 YR 8/2). Thin remains of a mostly clayish silt paleosol, with irregular root casts and invertebrate bioturbation, of light brown color (5 YR 6/4) occurs at the top.

4.1.3. Level V. Thickness: 3.20 m

The basal contact is diffuse and undulating. The sediment is a sandy clayey silt of moderate yellowish brown color (10 YR 5/4) when dry and slight brown color (5 YR 4/4) when wet. It includes many mammal remains. The basal layers enclose spheric lime concretions (0.2–0.8 cm diameter). There is a gradual increase of voids, channels and cutans to the top.

At the top, a 1.20 m thick clayey silty paleosol is light brown in color (5 YR 7/4) when dry and brown (5 YR 4/4) when wet. The soil includes cutans and irregular root casts. The erosion profile of the paleosol shows a concave molding (media caña in Spanish).

4.1.4. Level IV. Thickness: 2.00 m

The base is neat. The sediment is a well-consolidated sandy clayish silt of grayish orange pink color (5 YR 7/2) when dry and medium brown color (5 YR 5/4) when wet. There are scattered tiny lime concretions and some pores and channels. A 0.80 m paleosol of grayish orange color (10 YR 7/4) when dry and dark yellowish brown color (10 YR 4/2) when wet occurs at the top. The paleosol contains many root casts, iron and manganese cutans and invertebrate bioturbation.

4.1.5. Level III. Thickness: about 3.00 m. Exposed: 1.80 m

The basal contact is a conspicuous disconformity. The basal layers were partially covered and consequently were poorly studied. The clayey silt layer is poorly consolidated and thin and has diffuse lamination. The color is grayish orange (10 YR 7/4) when dry and moderate brown (5 YR 4/4) when wet.

There is a 1.5 m thick silty, friable paleosol at the top. The color is light brown (5 YR 6/4) when dry and moderate yellowish brown (10 YR 54) when wet. The paleosol has thick to medium columnar structure and abundant massive calcretes, usually prolate, cylindric, or tabular, 5 to 20 cm long. There are irregular root casts. Bluish black mangans coating cracks and pedotubules are frequent, and occasionally form dendrites. Clayey plane cutans are scarce.

4.1.6. Level II. Thickness: 0.90 m

The basal contact is neat. The lower part is a clayish silt deposit, moderately consolidated, with few irregular calcretes, isometric (about 5 cm diameter) or prolate (10 cm or more long).

In the top, a 20 cm thick paleosol shows light brown color (5 YR 6/4) when dry and light yellowish brown color (10 YR 5/4) when wet. There are medium subangular blocks and scarce medium columnar peds. Both structures are friable. Small (1–2.5 mm), rounded to subrounded manganese hydroxide concretions of bluish black color are usually associated with mangans coating cracks and channels. Scarce argillans coat planes. Irregular and oblong root casts are frequent.

4.1.7. Level I. Thickness: 0.80 m

The upper part of this level corresponds to the

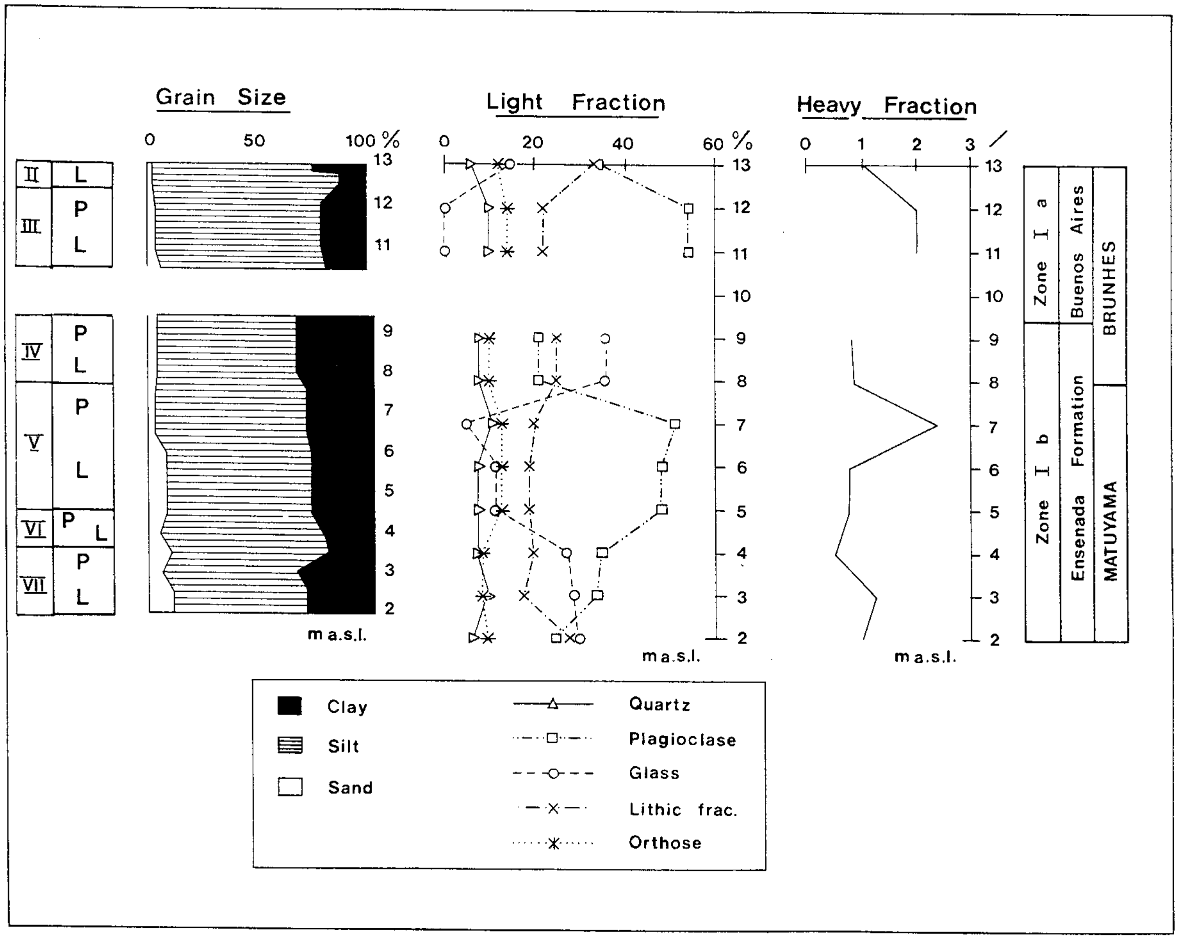

Fig. 5. Mineralogical and grain size analysis in the Ensenada and Buenos Aires formations. L, loess; P, paleosol; II–VII, levels.

recent soil. This soil was formed in a sandy clayish silt bed and includes dendritic and concretional (1.5 cm diameter) calcium carbonate. The soil color is light yellowish brown (10 YR 5/4) when dry and a little darker (10 YR 4/2) when wet.

4.2. Laboratory analysis

4.2.1. Grain size analysis (Fig. 5, Table 1)

In all the samples, the silt predominates (over 59%), followed by clay (11.6–34.3%) and sand (below 12%).

4.2.2. Mineralogy (Tables 2–4)

The light and heavy components show reduced and irregular variations in percentage frequencies. However, heavy component percentages diminish to the base of the section. The peaks are in levels III and V (Fig. 5; Table 2).

Sand and coarse silt are dominated by light components, a mixture of plagioclase, vitroclasts, lithoclasts, orthoclase, and quartz, associated in some levels with biogenic minerals like bone fragments (collophane) and phytoliths (opal), and chemical components (lime concretions). The sharing of each component is unequal, with marked fluctuations in the plagioclase and vitroclast percentages (Table 3).

The higher percentages usually correspond to plagioclases (always over 20%, with maxima between 51 and 54%). The tabular plagioclase fragments are controlled by cleavage, scarcely rounded, with frequent polysynthetic twinning according to the Albita Law, or its combinations with Carlsbad and/or Pericline. The most common plagioclase is andesine, exceeding oligoclase and labradorite. The fragments are clean and fresh, showing aligned square-shaped fluid and glassy inclusions (negative crystals). Rare glassy adherences were observed. Zonality is infrequent.

The vitroclast frequencies are irregular, with few shards (less than 4%) in level III to 35% in level IV (Table 3). Vitroclasts are angular, fresh and mostly colorless, associated with few other of light brown or greyish green color. The refractive index (1.498 and 1.500) shows that they correspond to acid varieties (rhyolites; George, 1924). The vitroclast frequency fluc-

Table 1
Granometric composition of the sediments

Level	Sample	Sand	Silt	Clay
II	Paleosol	3,20	70,60	26,20
II	Loess	2,81	85,59	11,60
III	Paleosol	4,50	74,80	20,70
III	Loess	6,90	73,60	19,50
IV	Paleosol	3,40	62,50	34,10
IV	Loess	3,60	62,50	33,90
V	Paleosol	2,80	67,10	30,10
V	Loess	7,80	64,02	28,18
VI	Paleosol	4,45	72,30	23,25
VI	Loess	9,50	70,00	20,50
VII	Paleosol	6,30	59,40	34,30
VII	Loess	11,45	58,80	29,75

Table 2
Frequency of light and heavy components

Level	Sample	Light fraction	Heavy fraction
II	Paleosol	98,83	1,17
II	Loess	98,96	1,04
III	Paleosol	98,00	2,00
III	Loess	98,90	1,10
IV	Paleosol	99,25	0,75
IV	Loess	99,17	0,83
V	Paleosol	97,60	2,40
V	Loess	99,24	0,76
VI	Paleosol	99,56	0,44
VI	Loess	98,94	1,06
VII	Paleosol	98,74	1,26
VII	Loess	99,00	1,00

tuations are inverse and symmetrical to those of plagioclases. Glass exceeds the feldspar at levels IV and VII. Lithoclasts are composed of very weathered volcanic rocks groundmass (rhyolites, andesites, basalts, etc.). They exceed vitroclasts in some levels.

Quartz and orthoclase show slight fluctuations (Fig. 5, Table 4). Orthoclase rarely surpasses quartz but their highest frequency peaks are coincident. Orthoclase grains are tabular, irregular, and subrounded, generally with clayey weathering. The quartz peak (10%) occurs at level V, and the grains are mainly spheric, subangular, subrounded, and occasionally present ferrigenous coating.

Bony fragments are present in the paleosols of levels III, IV, and V (Table 3). They are very rare, irregular, and subangular collophane clasts of yellow brown color, occasionally isotropous, or with low birefringence and feather extinction.

Due to their size, phytoliths are most common in the silty fraction. They are present in most samples, especially the paleosols. Most of them correspond to long cells of Gramineae (euprismatolithes and nasoprismatolithes) and microsilicophytolithes. In level V, small and very scarce globule pairs and arched conic segments were observed (Bertoldi de Pomar, 1980).

Some scarce, fragmented monoaxonical sponge spicules with broken tips were found.

The mineralogy of the heavy components is similar in all levels and their species show small frequency oscillations (Table 4). The most abundant are amphiboles (common and basaltic hornblende), opaque minerals (magnetite, hematite, illmenite, and manganese oxides) and the epidote group (pistacite and zoinite), followed by pyroxenes (enstatite, hyperstene, and augite), garnets, apatite, and zircon. Tourmalines, micas (biotite and muscovite), rutile, and titanite are of scarce and erratic occurrence.

The most common amphibole variety is green hornblende. The clasts are prismatic, subangular, and subrounded, associated with small amounts of the brownish green, and occasionally with the bluish green variety. The basaltic hornblende fluctuates between 3 and 8% in all levels. The higher concentration of amphiboles in levels IV, V, and VI coincides with paleosols (Table 4).

Opaque minerals are granular, of irregular shape, and well-rounded. Crystalline faces can be observed in magnetite, whereas the hematite has an orange–red color and earthy appearance. Ilmenite is not easily found, and is partially altered to leucoxene.

Manganese oxide and hydroxide occur in violet black grains of 0.125–0.250 mm, as dendrites or coating plates and cavities (cutans). They are common in levels II, III, and IV and rare in VII (Table 4). Opaque minerals show similar frequency variation to amphiboles. Epidote and zoisite have percentages of 18–20%. Epidote occurs as yellowish-green grains, occasionally stained or as dirty aggregates. Zoisite is colorless and presents prismatic subrounded clasts.

Pyroxenes are infrequent, with a predominance of the rhombic varieties. Clasts are prismatic, angular, and serrated. Their color is paler than usual in the Pampean area.

Table 3
Percent composition of light components in thin and very thin sand

Level	II P–L[a]	III P–L	IV P–L	V P–L	VI P–L	VII P–L
Quartz	7–6	9–10	6–8	8–11	8–9	7–10
Orthoclase	13–12	14–14	9–10	13–13	9–10	10–9
Plagioclase	36–34	54–53	20–21	48–51	35–33	25–34
Lithoclast	30–33	19–22	30–25	19–20	20–18	28–18
Vitroclast	13–15	4–+	35–35	12–5	28–30	30–29
Collophane	1	1	+–1	+		
Phytoliths	+–+	+	+–+	+	+	+

[a] References: P, paleosol; L, loess.

Table 4
Percent composition of heavy components in thin and very thin sand

Level	II P–L[a]	III P–L	IV P–L	V P–L	VI P–L	VII P–L
Green hornblende	30–29	35–29	33–35	34–39	30–35	30–29
Brown hornblende	4–5	6–6	2–+	3–2	6–6	8–5
Blue hornblende			+	+–1	+	
Basaltic hornblende	2–5	4–4	6–8	6–6	3–4	3–3
Hypersthene	1–2	3–2	2–3	2–2	5–4	5–5
Enstatite	3–3	2–3	2–1	1–1	2–2	5–1
Augite	3–4	2–1	1–1	3–1	6–3	7–5
Turmaline	1–2	+–1	+	+–+	1–+	+–1
Muscovite	1–+	2–3	1–1	+–+	+	+
Biotite	3–3	+–+	1–+	+–+	+	+
Epidote	17–15	16–18	16–16	16–168	16–18	16–15
Zoicite	3–3	4–4	3–2	4–4	4–3	3–5
Garnet	3–4	4–4	4–5	4–6	3–3	1–4
Apatite	2–2	2–1	+–+	1–2	2–2	3–2
Zircon	1–2	1–1	+–1	1–2	2–1	1–2
Rutile		1	+–+	+–+		
Magnetite	18–17	9–18	14–11	16–9	8–10	8–10
Hematite	6–4	9–3	12–10	8–6	12–8	9–12
Ilmenite	+–+	1	+–3	1–1	+–+	+–1
Titanite	+	+	+–+	+		
Lithoclast		1	2–3	+–+	+–1	+–+
Manganese oxid	2–+	+–+	1–+			

[a] References: P, paleosol; L, loess.

Garnets and zircon are scarce, with uniform distribution (Table 4). Garnets have an irregular shape. Zircon clasts are fragmented and rarely keep a bipyramidal prismatic shape. Apatite clasts are rounded.

The remaining components (rutile, titanite, lithoclasts) are very rare and irregularly distributed (Table 4).

Silt has the same components as sand, with some small quantitative differences. In most levels, quartz diminishes and plagioclase frequencies are similar or slightly smaller. The glass frequency increase is due to fragmentation of the original clasts.

Lithoclasts, amphiboles and pyroxenes decrease as the phytoliths and opaque minerals increase.

In levels II and V, entrapped glass shards form aggregates with clay remains resembling chalazolithes. These aggregates make the central part of clayey clusters of sand size.

The composition of the fraction smaller than 2 μ was analyzed by means of X-ray but only showed qualitative results. The low crystallinity of the clay, the presence of glass and amorphous material in a broad diffraction band of 23°2, increase the background noise. However, a predominance of illite in all of the sections together with interbedded illite–smectite in paleosols was estimated. The clays of the upper part (Buenos Aires Formation) showed better definition than those of the lower part (Ensenada Formation).

5. Magnetostratigraphy

The AF demagnetization process reduced 80% of the NRM intensity with fields ranging from 15 to 40 militesla (mT) in most of the samples (Figs. 6 and 7). Those samples with normal magnetic polarity directions reach the 80% reduction with fields of 15–20 mT. Meanwhile those samples with oblique and reverse magnetic polarity directions require fields of 40 mT or higher to reach the same reduction. Characteristic directions were isolated between 15 and 20 mT (Figs. 6 and 7).

The AF-cleaning procedure was successful in 85% of the samples. In the remaining 15%, this technique was inefficient due probably to the presence of secondary, probably viscous, NRM components (Heller and Liu, 1984; Heller et al., 1987).

The characteristic NRM directions reduced their dispersion in relation with NRM directions and showed a good grouping around the axial dipole inclination of 54° for this area (Fig. 6).

The Brunhes–Matuyama boundary was recognized on top of a geosol located in the upper part of the Ensenada Formation at about 7 m a.s.l. (Fig. 8). All the samples at this level exhibited normal polarity directions and most of those below, reversed polarity. Normal polarity directions were found in one sample in the middle of the geosol (of reversed polarity) and in other two paleocaves samples at the same strati-

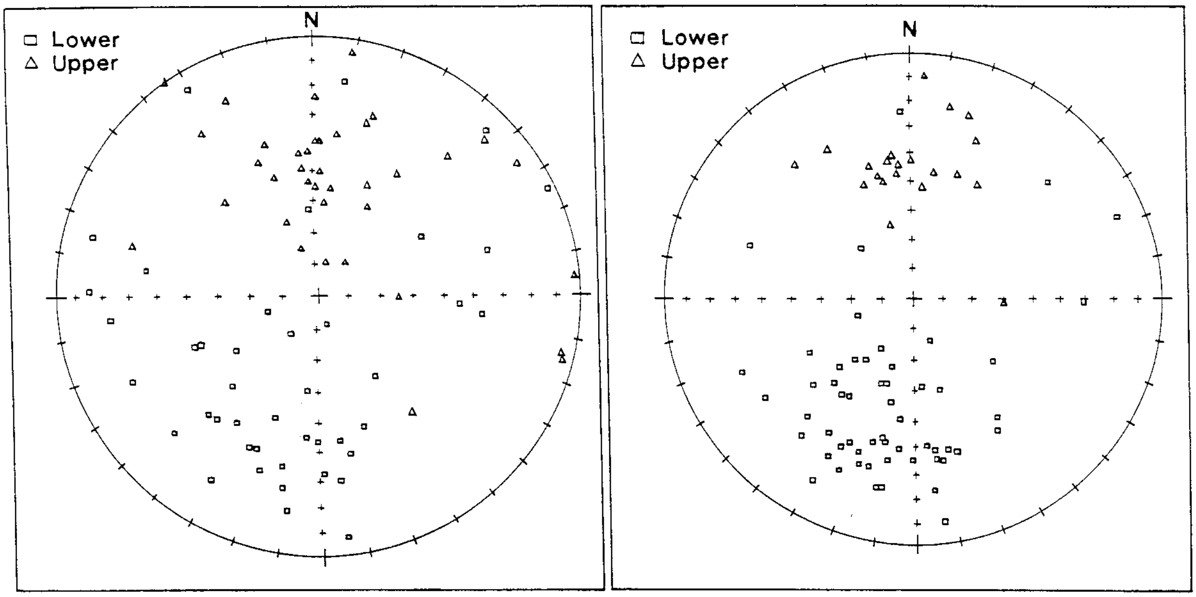

Fig. 6. NRM directions before and after cleaning, showing reduced directional dispersion.

graphic level. Close to these samples, oblique polarity directions were detected. Notwithstanding that the magnetic record from fillings in caves is not highly reliable, this pattern suggests that the Jaramillo subchron (0.915–1.01 Ma) is recorded within this geosol in the Ensenada Formation.

One sample with "abnormal" polarity direction was found in the lower part of one of the profiles. Remarkably, sections at Baradero and San Pedro (northeastern provincia de Buenos Aires), encompassing the same time period, also show oblique polarity directions at the base (Nabel et al., 1993).

The magnetic susceptibility measurements oscillated between 0.3 to 5 SI units, increasing to the base of the section. Paleosols showed lower values in relation to the loessic sediments (Fig. 9). This pattern has been observed in other sections of Buenos Aires Province and has been attributed to the regional pedogenic processes (Nabel et al., 1993; Nabel, 1996).

6. Systematic paleontology

Class AVES
Order PASSERIFORMES
Suborder TYRANNI
Parvorder FURNARIIDA
Superfamily FURNAROIDEA

Family FURNARIIDAE
Subfamily FURNARIINAE
Genus PSEUDOSEISURA (Reichenbach, 1853)
Pseudoseisura sp. *nov.*

Material. Deposited in the Departamento Científico Paleontología de Vertebrados, Museo de La Plata (MLP). MLP 96-III-10-10, distal fragment of humerus, ulna, carpometacarpus; all bones pertain to the same specimen.

Remarks. The material is indistinguishable from the homologue bones of a new species of *Pseudoseisura* (Tonni and Noriega, in preparation). The type material comes from Ensenadan beds at Olivos ("toscas del Río de La Plata", northeastern Buenos Aires Province).

The carpometarpus and ulna show the diagnostic characters of the new species: carpometacarpus with wide intermetacarpal space and circular internal trochlear ring; ulna with marked distal torsion and depression between the tricipital insertion and olecranon not so deep as in recent species of *Pseudoseisura* indicating that the olecranon base is wider.

Class MAMMALIA
Order CINGULATA
Superfamily GLYPTODONTOIDEA

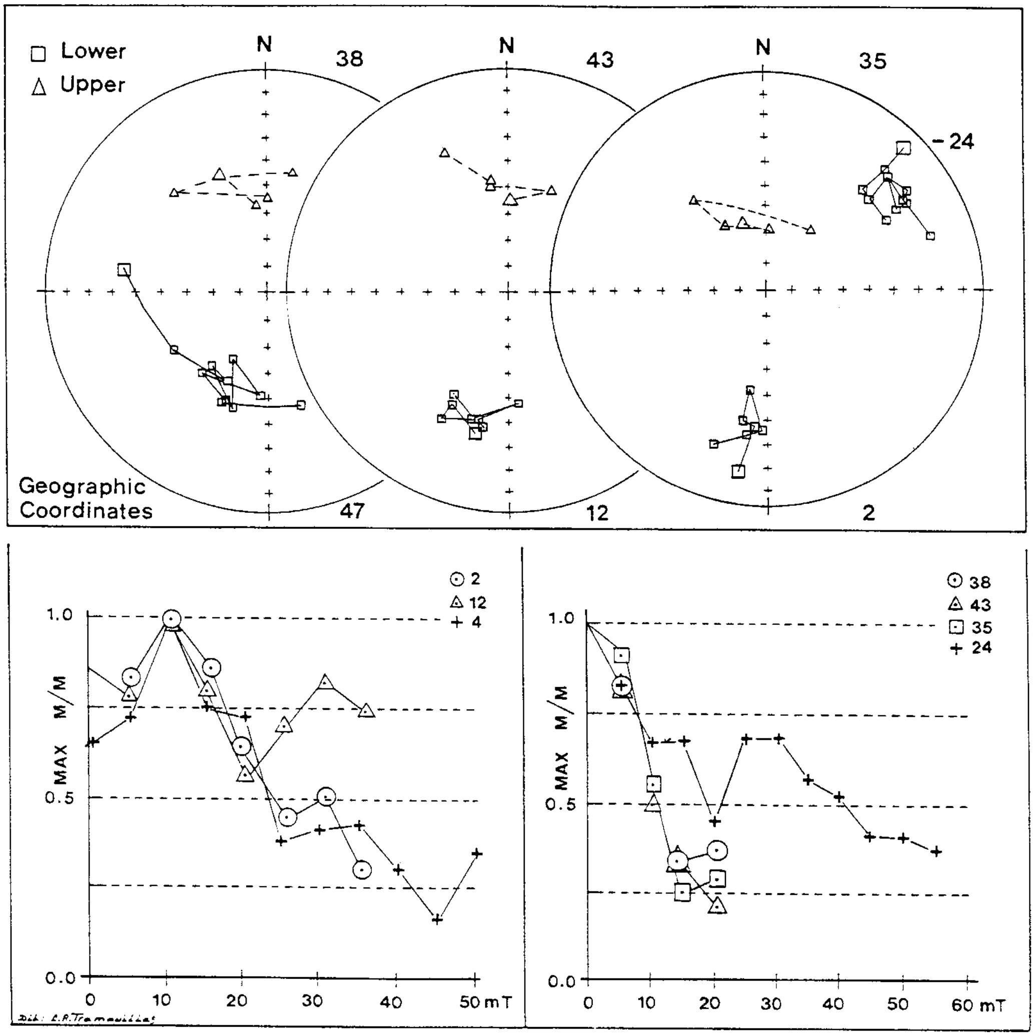

Fig. 7. Alternating field demagnetization of loess and paleosol samples presented as stereographic projection of NRM directions and intensity decay curves.

Family GLYPTODONTIDAE
Subfamily SCLEROCALYPTINAE
Tribe SCLEROCALYPTINI
Genus SCLEROCALYPTUS (Ameghino, 1891)
Sclerocalyptus sp.

Material. MLP 96-III-10-1, incomplete carapace found *in situ* and a carapace fragment from the same specimen previously collected.

Stratigraphic and geographic distribution. Vorohuan (Buenos Aires), Ensenadan (Buenos Aires, Córdoba, and Corrientes), Lujanian (Buenos Aires, Chubut, Córdoba, Corrientes, Formosa, and Santa Fe), upper Pleistocene of Bolivia, Brasil, Chile, Paraguay, and Uruguay.

Remarks. Scute figure is similar to that of species *S. ornatus* (Owen) and *S. pseudornatus* (Ameghino), both Ensenadan in age. There are no recent systematic revisions of the numerous nominal species of *Sclerocalyptus*. Ameghino (1889) cited 15 species of *Sclerocalyptus* (cited as pertaining to the genus *Hoplophorus*).

Tribe PANOCHTHINI
Genus PANOCHTHUS Burmeister
Panochthus cf. *P. intermedius* (Lyddeker, 1894)

Material. MLP 84-IX-2-11, partial skull; MLP 96-III-10-7, right tibia. The fossils pertain to different specimens but come from the same level.

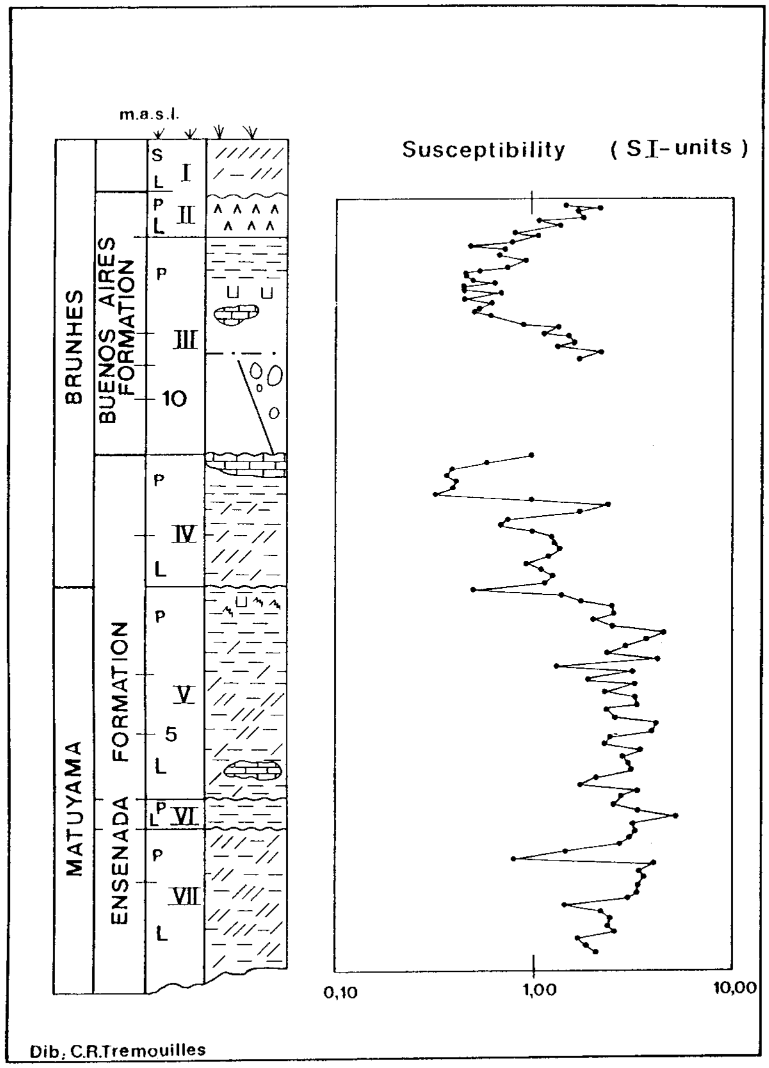

Fig. 8. Low-field susceptibility and lithology. Brunhes–Matuyama boundary is located over paleosol 5. L, loess; P, paleosol; S, soil.

Stratigraphic and geographic distribution. Ensenadan of Buenos Aires.

Remarks. The type material of *P. intermedius* is an almost complete carapace (Lyddeker, 1894; his plate 19, Figs. 1–3) from the Ensenada Formation at Buenos Aires harbour. Ameghino (1895, 1920) erroneously considered this species as a synonym of "*Panochthus*" (=*Propanochthus*) *bullifer* Burmeister. According to Castellanos (1941, p. 489), *P. intermedius* presents "...talla y corpulencia algo menor que las de *Panochthus tuberculatus*...". However, we consider that it is the species of *Panochthus* of larger size. The ornamentation of the carapace shows a more primitive pattern. The central figure is still differentiated in the dorsoscapular and dorsolumbar scutes. The primitive pattern agrees with the older geological age.

Both the skull and tibia from José Hernández are much larger than all the other bones assigned to *Panochthus* (mainly the Lujanian *P. tuberculatus* (Owen) and *P. morenoi* Ameghino). Moreover, they are larger than any other glyptodont homologue bone.

The skull is much more primitive than those of *P. tuberculatus* and *P. morenoi* because: (1) of the lesser pneumaticization of the naso-frontal region, reflected in the profile; (2) the lower position of the facial mass, showed by the location of the orbit; (3) the skull is rounded instead of isodiametric.

Taking into account the extraordinary size of the skull and tibia, we assign the material to the

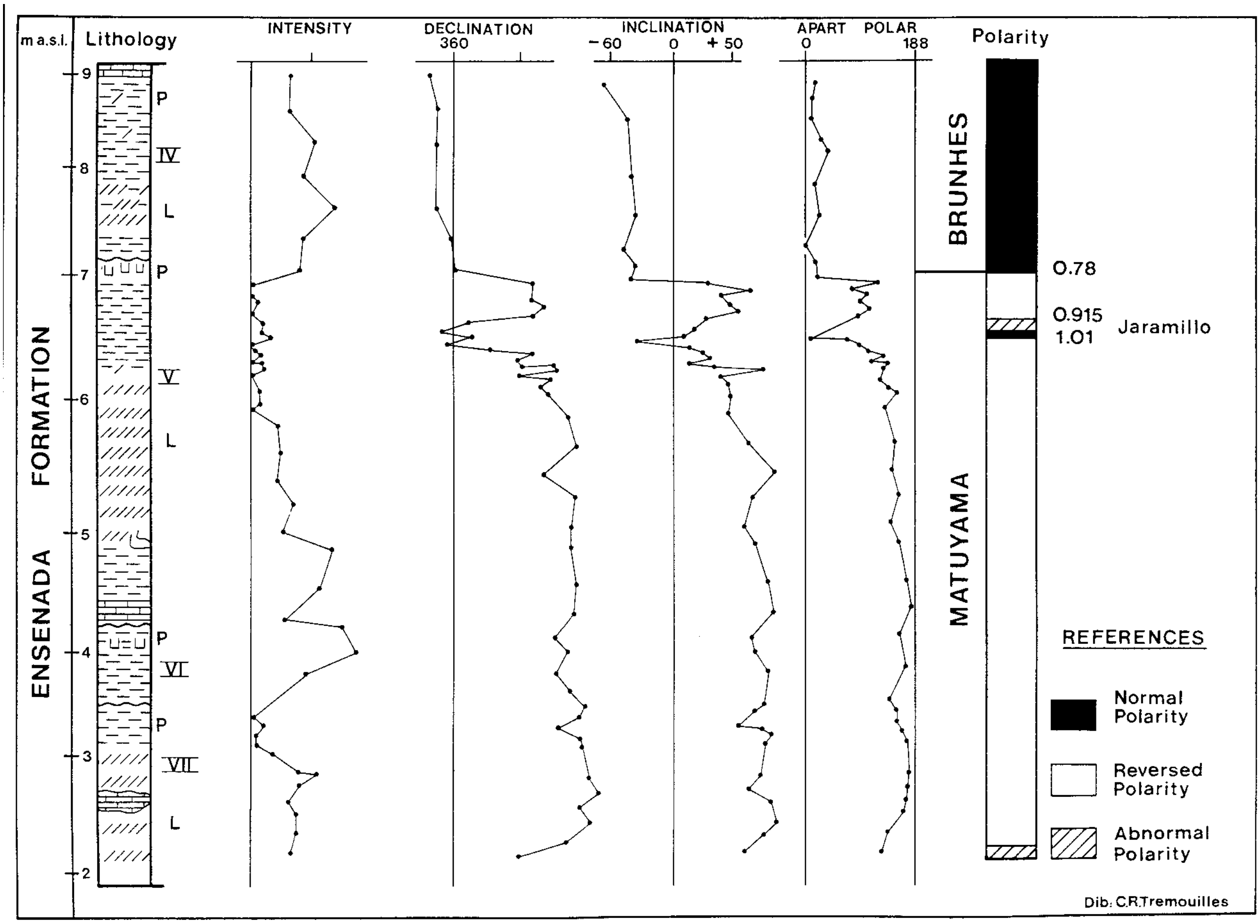

Fig. 9. Stratigraphic characteristic of the Ensenada Formation in the quarry. Absolute ages along polarity column, according to Spell and McDougall (1992) and McDougall et al. (1992). L, loess; P, paleosol.

Ensenadan *P. intermedius*, the largest known glyptodont species.

Order NOTOUNGULATA
Suborder TYPOTHERIA
Family MESOTHERIIDAE
Subfamily MESOTHERIINAE
Genus MESOTHERIUM (Serrés, 1857)
Mesotherium cristatum (Serrés, 1857)

Material. MLP 96-III-10-11, partial skull; MLP 92-VIII-1-5, fragment of left mandible with five molariform teeth. A right mandible fragment with a molariform tooth, five isolated molariform teeth, an incomplete ulna, a pelvis fragment, metapods and elements of the autopodium are also included under the collection number MLP 92-VIII-1-5 (they were in physical association and probably pertain to different specimens).

Stratigraphic and geographic distribution. Sanandresian and Ensenadan (Buenos Aires, Córdoba).

Remarks. The skull is deep and laterally compressed, with a strong sagital crest. The zygomatic arch is prominent and deep. The nasal bones are large, extending over the premaxillae, and the nares are terminal. There is a stronger imbrication in the premolar series than in any other mesotherine.

Mesotherium cristatum is a frequent species in the Ensenadan beds near the city of Buenos Aires. Seventy per cent of the mammal bones in the old collections from the "toscas del Río de la Plata" at Olivos in the Sección Paleozoología of the Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" correspond to *Mesotherium cristatum*. This abundance occassioned interesting anatomical studies (e.g. Cattoi, 1943; Francis, 1965). Consequently, the intraspecific variations are well known. The presence of specimens assignable to the genus *Mesotherium* in pre-Ensenadan (Sanandresian) strata has recently been demonstrated (Tonni et al., 1992; Cione and Tonni, 1995a). Unfortunately, the fragmentary material precluded an identification at species level.

6.1. Previously recorded vertebrates

The previous records were described by Tonni et al. (1988) or mentioned by Bidegain (1994). All the materials come from what has been called "...Miembro superior de la Formación Pampiano" (Tonni et al., 1988, p. 67), that is those beds of the Buenos Aires Formation located under the La Postrera Formation.

Glyptodontidae: *Lomaphorus* cf. *elegans* Burmeister), *Glyptodon clavipes* Owen, *Doedicurus* sp.
Mylodontidae: *Lestodon cf. armatus* Gervais.
Dasypodidae: *Eutatus seguini* Gervais.
Cricetidae: *Graomys* sp.
Felidae: *Smilodon populator* Lund.
Ursidae: *Arctodus* sp.
Toxodontidae: *Toxodon* sp.
Gomphotheriidae: Anancinae gen et sp. indet.

7. Biostratigraphy

Florentino Ameghino established the standard reference scale for the continental Cenozoic of Argentina. Ameghino (1889, 1900–03 and later papers) provided a sequence of stages (pisos, étages) grouped into higher order units (or "formaciones"). Ameghino based his work on the studies by D'Orbigny (1842) and Doering (1882). His scale of stages remains today in the basic scheme for the late Cenozoic (see Cione and Tonni, 1995a,b, 1996; Fig. 2). The standard reference scale of Ameghino was later extended to the rest of the continent (for a synthesis, see Marshall et al., 1984; Cione and Tonni, 1995a, 1996). The type localities for the uppermost Cenozoic are in the Pampean area.

Ameghino's scheme, with modifications, favorably compares with the requirements for the chronostratigraphic units of the Código Argentino de Estratigrafía (CAE, 1992) and other modern guides and codes (e.g. Salvador, 1994).

The "Formación Pampeana" (Pliocene–Pleistocene) included the "Ensenadense", "Belgranense", "Bonaerense", and "Lujanense" stages (Ameghino, 1889). This succession of units has been used by subsequent authors (see Marshall et al., 1984). After Pascual et al. (1965) these units were referred to as "edades (or subedades) mamífero" (in English, "land-mammal ages"). Pascual et al. (1965) recognized the Ensenadan and included the "Belgranense", "Bonaerense" and Lujanense of Ameghino in the Lujanian. In Argentina, during the 1950s and 1960s, many authors included rocks in undefined lithostratigraphic units only transforming the chronostratigraphic units (stages) that previous authors had recognized. For example, the Casamayoran Stage of Frenguelli (1930), the former "Piso Notostylopense" of Ameghino (1901–03), was "transformed" in the Casamayor Formation (Pascual et al., 1965). This practice was extended to the late Cenozoic Pampean units. However, Riggi et al. (1986), formalized the Ensenada and Buenos Aires Formations with their type localities in the excavation for the new Teatro Argentino of La Plata.

Two of us (ALC and EPT) have been working on the biostratigraphy of the Pliocene–Pleistocene of the Pampean area for many years (Tonni and Fidalgo, 1978, 1982; Fidalgo and Tonni, 1981; Tonni et al., 1992; Cione and Tonni, 1995a–c, 1996; Pardiñas et al., 1996). These investigations formalized and confirmed a mammalian biostratigraphy supporting in a great part the original ideas of Ameghino (1889 and other papers). However, Ameghino, as Frenguelli (1950, 1957) did, restricted the representation of the Lujanian to those beds in the river banks. Tonni and Fidalgo (1978), Fidalgo and Tonni (1981) and Tonni (1990) showed that the mammals defining the *Equus* (*Amerhippus*) *curvidens* Biozone (basis for the upper Lujanian Substage) also occur in the eolian sediments in the divides (La Postrera and Buenos Aires formations).

The present upper Cenozoic chronostratigraphic scale is based on a series of biostratigraphic zones defined in the Pampean area: Marplatan Stage, subdivided into three substages, Barrancalobian (*Platygonus scagliai* Biozone), Vorohuan (*Akodon* (*Akodon*) *lorenzini* Biozone), Sanandresian (*Paractenomys chapadmalensis* Biozone), Ensenadan (*Tolypeutes pampaeus* Biozone), lower Lujanian (*Megatherium americanum* Biozone), upper Lujanian (*Equus* (*Amerhippus*) *neogeus* Biozone), and Platan (*Lagostomus maximus* Biozone; Tonni and Cione, 1994; Cione and Tonni, 1995a,b, 1996).

The important faunistic turnover between the Ensenadan and Bonarian was recognized many years ago (Ameghino, 1889). In 1908, Ameghino suggested that an important hiatus existed between both units (including the marine beds of the "Belgranense" at the coast) (Ameghino, 1908).

No exclusive mammal of the *Platygonus scagliai, Akodon* (*Akodon lorenzini*), or *Paractenomys chapadmalensis* biozones (Marplatan) was found at the quarry. From the base of the section to about 6 m a.s.l. there are fossils of *Tolypeutes pampaeus* Biozone (e.g. *Panochthus* cf. *P. intermedius, Mesotherium cristatum*; Fig. 4). Over these 6 m, 2 m of sediments, with normal polarity (attributed to the Brunhes Chron), lack mammals. In this section the bird *Pseudoseisura* sp. *nov*., which also was recorded in the upper Ensenadan in the "toscas del Río de la Plata" at Olivos, occurs. Mammals recovered in the overlying sediments of the Buenos Aires Formation correspond to those of the *Megatherium americanum* Biozone.

8. Discussion and conclusions

8.1. Stratigraphy

The sequence cropping out in the southwestern quarry at José Hernández is divided into two main sections characterized by different consolidation and separated by a conspicuous disconformity located at about 9 m a.s.l (Fig. 4). The lower section corresponds to the Ensenada Formation and the upper to the Buenos Aires Formation. We have no reliable radiometric dates for these formations. However, the marked compaction of the Ensenada Formation sediments and the important faunal turnover suggest a much older age for this unit.

Some field characteristics (paleosurfaces, reduced thickness, concave moulding, edaphic structures) and laboratory characteristics (mineralogical composition, irregular vugs, cutans, and pedotubules) allow the identification of the edaphic horizons in the upper part of the loessic layers. In the exposed sequence, we have recognized 6 paleosols developed on loessic beds and a recent soil. Four paleosols are included in the Ensenada Formation and 2 paleosols in the Buenos Aires Formation (Fig. 4). The southwestern quarry could be a good type locality for the boundary between the Ensenada and Buenos Aires formations due to its proximity to the original stratotype and its permanent exposure. The paleosol located in the top of the Ensenada Formation (paleosol in level IV) is correlated with the El Tala Geosol of Baradero, northern Buenos Aires Province, on the basis of the analogous paleomagnetic age and stratigraphic position (Nabel et al., 1993; Figs. 3 and 4). Here we propose the El Tala Geosol as an upper boundary for the Ensenada Formation. The proposed stratotype is the section at the southwestern quarry at José Hernández.

Our results confirm the volcanic-pyroclastic origin of the sediments. According to the scheme developed for the city of Buenos Aires by González Bonorino (1965), all the section in included in the Zone *1* is characterized by the predominance of plagioclase over quartz and illite over montmorillonite. In the quarry and the Teatro Argentino, the Buenos Aires Formation is mineralogically correlated with the Subzone *a* and the Ensenada Formation with the Subzone *b* (see Riggi et al., 1986). These subzones differ in vitroclast content. There are similarities in percentage variations and distributive tendencies of some light components (plagioclase and vitroclasts) between this section and that of the Teatro Argentino of La Plata (Riggi et al., 1986). The mineralogical zonations of González Bonorino (1965) were found to be useful in Buenos Aires, La Plata and Baradero.

8.2. Magnetostratigraphy

The boundary between the Brunhes and Matuyama zones of polarity (0.78 Ma) has been detected inside the upper part of the Ensenada Formation, over the thick paleosol in the top of level V (about 7 m a.s.l.) and, separated by a disconformity, under a loessic bed (Fig. 4). The same relationship was observed at Baradero, where the magnetic turnover is in the top of the Hisisa Geosol (Nabel et al., 1993; Fig. 3). The Hisisa Geosol also seems to be regional in extent. We propose it as an indicator of the upper boundary of the Matuyama Zone of polarity in the Pampean area. The Subzone of polarity Jaramillo (0.915–1.01 Ma) was detected within the Hisisa Geosol (Fig. 4). The boundary between the Matuyama and Brunhes zones of polarity is also recognized by Bidegain (1991).

The peak of cineritic sedimentation in the lower part of the Brunhes zone of polarity (also recognized at Baradero; Nabel, 1993; Nabel et al., 1993) indicates that the change of polarity coincided with intense volcanic activity in the Cordillera. A similar event was described for the South Pacific Ocean (Kenneth and Watkins, 1970).

The Matuyama–Brunhes boundary was also detected inside the Ensenada Formation in the excavation for the Teatro Argentino of La Plata (Fig. 3). In this section, the boundary is correlated with an disconformity at 4 m a.s.l. over a K horizon (Bobbio et al., 1986, pp. 10–12). Probably, this horizon is correlated with the Hisisa Geosol (Fig. 3).

In the city of Buenos Aires, the Matuyama–Brunhes boundary was tentatively identified within the Bonarian (Buenos Aires Formation; Valencio and Orgeira, 1983; Fig. 3). Apparently, Valencio and Orgeira (1983) marked the boundary between the Ensenadan and Bonarian following Frenguelli (1957). Valencio and Orgeira (1983, pp. 25–26) commented that "...en la secuencia expuesta en la excavación objeto del presente estudio la definición de dicha transición (Ensenadense–Bonaerense) resulta también difícil dada la homogeneidad litológica de los sedimentos expuestos. Sin embargo, se ha notado que en la parte inferior de la secuencia los sedimentos pierden

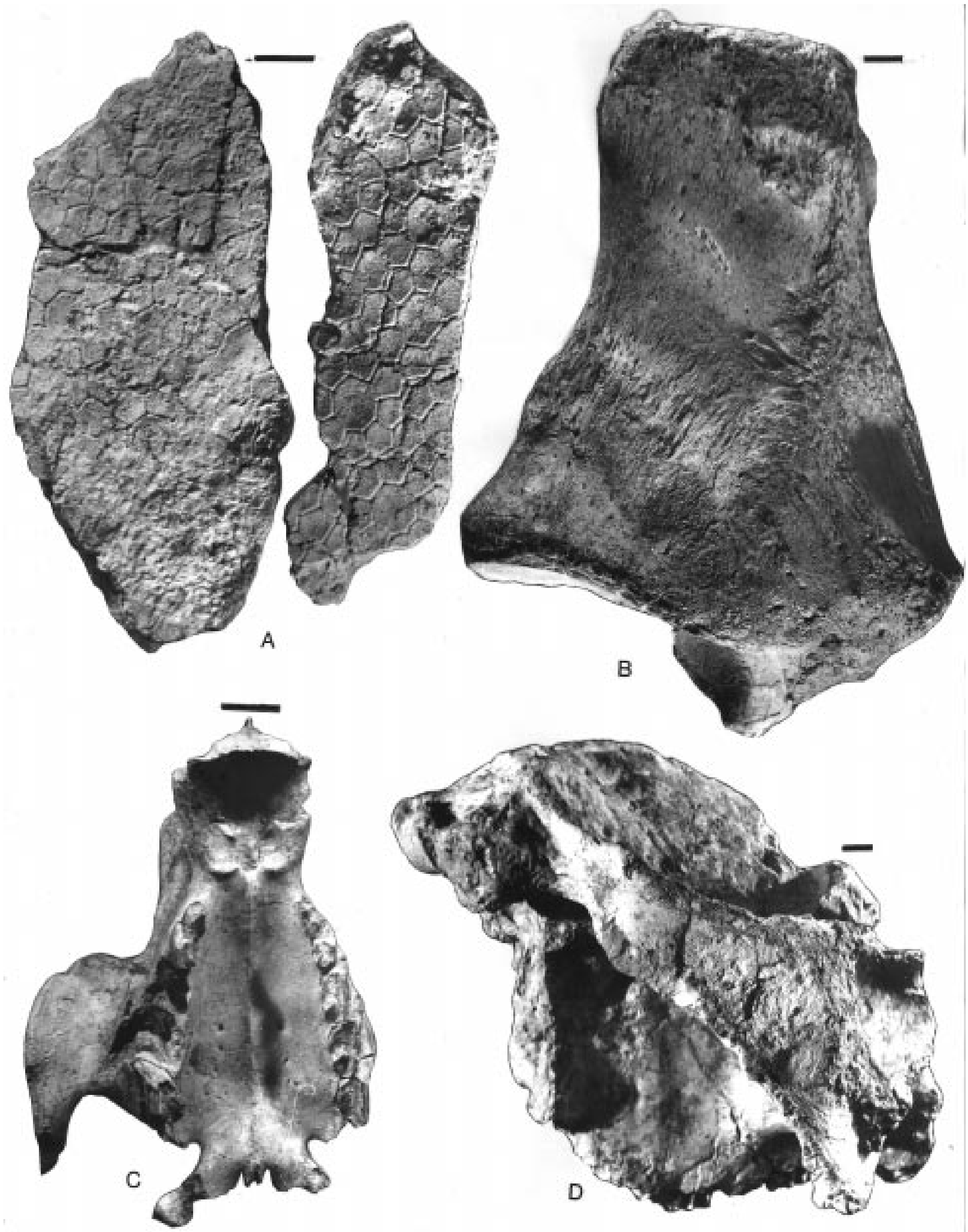

Fig. 10. A: *Sclerocalyptus* sp., two carapace fragments. B: *Panochthus cf. intermedius*, MLP 96-III-10-7, right tibia. C: *Mesotherium cristatum*, MLP 96-III-10-11, partial skull. D: *Panochthus* cf. *intermedius*, MLP 84-IX-2-11, partial skull with complete region posterior to interobital narrowing and anterior right. Bar = 20 mm.

algunos de los caracteres típicos que individualizan al Bonaerense, por lo que cabe considerar la posibilidad que los mismos correspondan al Ensenadense..." Consequently, it has not been demonstrated that the upper boundary of the Matuyama Zone of polarity is inside the Buenos Aires Formation at Buenos Aires.

In the "El Muelle" section (Chapadmalal, near Mar del Plata, southeastern Pampean region), the base of the Arroyo Seco Formation (supposedly Lujanian in age; Kraglievich, 1952) presents reversed polarity and was attributed to the Matuyama Zone of polarity (Orgeira, 1987, 1990). However, the Arroyo Seco Formation was not formally defined and Kraglievich did not mention the occurrence of fossils.

In summary, in the Pampean area the Matuyama–Brunhes boundary occurs at different topographic levels: José Hernández (7 m.a.s.l.), city of La Plata (4 m.a.s.l.), Buenos Aires (6 m.a.s.l.), Baradero (7 m.a.s.l.), and San Pedro (7.5 m.a.s.l.; Nabel, MS).

8.3. Biostratigraphy

Apparently, the boundary between the *Tolypeutes pampaeus* (Ensenadan) and *Megatherium americanum* (lower Lujanian) biozones coincides with that of the Ensenada and Buenos Aires formations. The upper part of the Ensenada Formation (between 7 and 9 m a.s.l) has normal polarity but scarce fossils. However, the occurrence of a new species of genus *Pseudoseisura* suggest that the *Tolypeutes pampaeus* Biozone (and the Ensenadan Stage) extend to the upper boundary of the Ensenada Formation. The *Tolypeutes pampaeus* Biozone (and the Ensenadan and the Ensenada Formation) reaches the Brunhes Zone of polarity. The *Megatherium americanum* Biozone (and the lower Lujanian) is restricted to the Biozone of polarity Brunhes and the Buenos Aires Formation.

4.4. Climate

The marked immaturity of minerals, the abundant fresh plagioclase and volcanic glass, the presence of abundant carbonatic glebules and calcretes, indicate arid to semiarid, seasonally marked climate.

The alternation of loessic levels with paleosols indicate periodic climatic changes. The loess was deposited under semiarid to arid climate. The soils probably developed during wetter periods, with grass cover, as shown by the abundant phytoliths. The edaphic processes did not destroy or alter the more unstable components, although the partial dissolution and low frequency of pyroxenes could be attributed to those processes. Manganese nodules and dendrites in certain paleosols indicate wetness and bad drainage.

The variation of magnetic susceptibility, larger in the loessic levels than in the paleosols, could be related with the observed mineral immaturity. In this case, the parental mineral contribution to magnetic susceptibility is significant and analogous to that found in other sections in the Pampean area (Nabel et al., 1993).

The faunistic evidence also suggests that the end of Ensenadan deposition corresponds to glacial times. In the upper part of the *Tolypeutes pampaeus* Biozone of the Pampean area, many mammals adapted to arid and cold climate occur for the first time: *Eligmodontia* (Tonni et al., 1993), *Microcavia* , *Reithrodon, Zaedyus*, and *Tolypeutes* (Tonni and Cione, 1994, 1995). Consequently, the beginning of the Brunhes Chron was characterized in the area by a change to a drier, more arid climate.Fig. 10

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