GEOLOGY OF THE AREA OF BAHÍA BLANCA, DARWIN'S VIEW AND THE PRESENT KNOWLEDGE: A STORY OF 10 MILLION YEARS

Mirta E. QUATTROCCHIO[1-2], Cecilia M. DESCHAMPS[3], Carlos A. ZAVALA[1-2], Silvia C. GRILL[1] and Ana M. BORROMEI[1-2]

[1] Departamento de Geología, Universidad Nacional del Sur.
[2] CONICET
[3] Museo de La Plata, CIC
Emails: mquattro@criba.edu.ar; ceci@fcnym.unlp.edu.ar; czavala@criba.edu.ar; sgrill2criba.edu.ar; borromei@criba.edu.ar

ABSTRACT

The aim of this paper is to give an updated outlook of the scenery described by Charles Darwin when he visited Bahía Blanca and surrounding areas, following the itinerary during his voyage on board HMS Beagle. Such an outlook is a state of the art of the current understanding of the Late Miocene-Holocene history in the southwestern Pampas (Argentina). Multidisciplinary results were integrated in a chronosequence chart synthesizing the suggested space-time correlation of the recognized events. Some of the studied localities covering the whole time interval represented in the area were arranged in this chart in a hypothetical E-W line crossing the Río Sauce Grande basin and the surrounding highlands. This line is also approximately the one followed in part by Darwin when riding from Bahía Blanca to Tapalqué (*Tapalguen*) as he crossed the region toward the *Río Sauce*. Paleoenviromental and paleoclimatic inferences for the last 10m.y. are also given. Paleontological studies included vertebrates, ostracods and palynomorphs. Many of the results of these investigations are the answers to Darwin's question when he first visited the area.

Keywords: *Pampas, Tapalqué, Pampean Formation, Punta Alta, Red earth cliffs.*

RESUMEN: *Geología del área de Bahía Blanca, los comentarios de Darwin y el conocimiento actual: una historia de 10 millones de años.*

El objetivo de este trabajo es brindar una actualización del escenario descrito por Charles Darwin cuando visitó Bahía Blanca y sus alrededores, siguiendo el itinerario de su viaje alrededor del mundo a bordo del Beagle. Se trata de una puesta al día del conocimiento de la historia del sudoeste de la región pampeana (Argentina) desde el Mioceno tardío hasta el Holoceno y tiempos históricos. Las investigaciones multidisciplinarias llevadas a cabo por el grupo de investigación del Laboratorio de Palinología, UNS, Bahía Blanca, se integraron en una carta cronoestratigráfica secuencial, en la cual se sintetizaron las correlaciones espacio-temporales de los eventos reconocidos. En esta carta, algunas de las localidades estudiadas que cubren todo el lapso representado en el área, se ordenaron en una línea hipotética E-O que corta la cuenca del río Sauce Grande y sus divisorias. En parte, esta línea también sigue aproximadamente el primer tramo de la cabalgata de Darwin desde Bahía Blanca hacia Tapalqué (*Tapalguén*), cuando cruzó la región hacia el Río Sauce. Asimismo, se brinda información paleoambiental y paleoclimática de los últimos 10 ma para esta región. Los estudios paleontológicos incluyeron vertebrados, ostrácodos y palinomorfos. Muchos de los resultados de estas investigaciones son respuestas a comentarios que Darwin hizo en su visita.

Palabras clave: *Pampas, Tapalqué, Formación Pampeano, Punta Alta, Acantilados de tierras rojas.*

INTRODUCTION

The aim of this paper is to give an updated outlook of the scenery described by Charles Darwin when he visited Bahía Blanca and surrounding areas, following the itinerary during his voyage on board the Beagle (Fig. 1).

Most of the information is taken from Quattrocchio *et al.* (2008) - and references therein - who gave a state of the art account of the understanding of the late Miocene-Holocene history in the southwest Pampas (Argentina) (Fig. 2). This information was assembled by researchers at the Palynology Laboratory of the UNS (Bahía Blanca) over almost 20 years of mapping, stratigraphic studies and analyses of the fossil record. Paleontological studies included vertebrates, ostracods and palynomorphs. Many of the results of these investigations are the answers to Darwin's comments when he first visited the area. Darwin spent 67 days in this area, from September 7 to October 20, 1832, and from August 17 to September 8, 1833. The amount of geological and biological information provided in his notes and further publications, and the acute observations concerning the genesis of the deposits, the past environments and organisms are overwhelming even today, more than one and a half century later. Only those issues that have been revisited by the authors are here discussed.

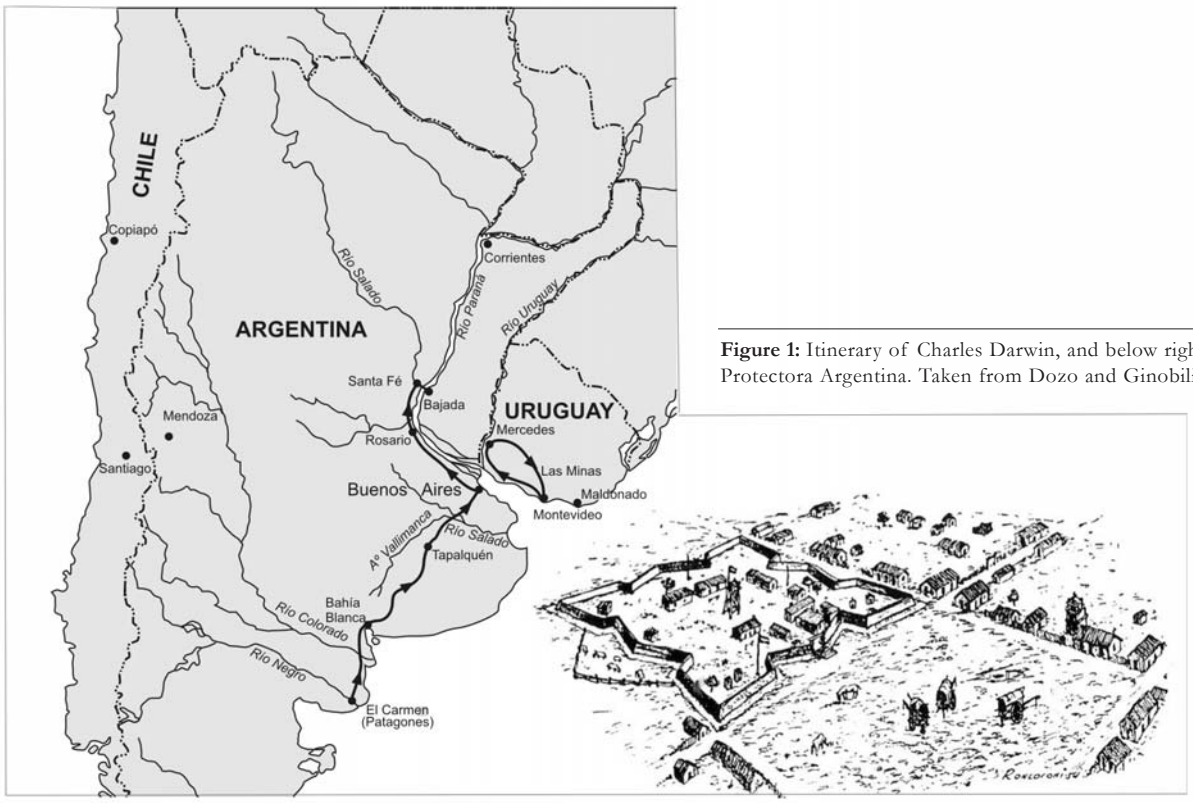

Figure 1: Itinerary of Charles Darwin, and below right, the Fortaleza Protectora Argentina. Taken from Dozo and Ginobili (1999).

Charles Darwin mentioned Bahía Blanca, and described this area several times in his reports. The writer Eduardo Mallea (Bahía Blanca, 1903-Buenos Aires, 1982) already underlined this visit when he wrote in his novel "*Todo verdor perecerá*" (Mallea 1941): "*Cuántas civilizaciones humanas habían evolucionado y perecido cuando este pedazo de desierto emergía de su sopor! En torno al fortín, valla opuesta al indio predatorio, comenzó a crecer, hacia los ochocientos veintiocho, la población militar, y cuatro años más tarde Rosas y Darwin se paraban ante aquellos salitrales que después de los secos calores extendían en la bahía su ardiente sábana blanca.*" ["*All greenness will perish*": "*¡How many civilizations had evolved and perished by the time this piece of desert was emerging from its drowsiness! Surrounding the fortress, boundary for the predatory aborigines, there started to grow, near 1828, the military population, and four years later, Rosas and Darwin stood before those saltpeter beds that, after dry heat waves, spread their fiery white sheet along the bay*"].

THE ARRIVAL

Darwin first saw Bahía Blanca when the Beagle anchored there on September 6, 1832. "*Baia (*sic*) Blanca has only been settled within the last six years: previous to which even the existence of the bay was not known. It is designed as a frontier fort against the Indians & thus to connect Buenos Ayres to Rio Negro*" (Keynes 2001). He stayed in the area until October 19, visiting Punta Alta and Monte Hermoso. Then the Beagle went back to Montevideo. On November 28 they sailed again south to Patagonia, and when returning to Buenos Aires, he left the Beagle at Patagones and rode to Buenos Aires. On August 17, 1833 he wrote:"*Bahia Blanca scarcely deserves the name of a village. A few houses and the barracks for the troops are enclosed by a deep ditch and fortified wall*" (Darwin 1845, p. 76).

Bahía Blanca is located in the southeastern part of the province of Buenos Aires, Argentina, on the Atlantic Ocean. It has a population of 325,000 inhabitants according to the 2005 census. The city was founded as a fort on 11th. April 1828 by Colonel Ramón Estomba (Fig. 3) under the orders of Brigadier-General and subsequent Governor of Buenos Aires, Juan Manuel de Rosas. The original founding was named Fortaleza Protectora Argentina (Argentine Protective Fortress, Fig. 1), intended to protect settlers and their cattle from raids of native aborigines, and also to protect the coast from the Brazilian navy, which had landed in the area the previous year. The fort was attacked by *malones* (incursions of nomad aborigines on horseback) several times, most notably in 1859 by 3,000 Calfucurá warriors.

About the area, he wrote: "*I have several times alluded to the surface of the ground being incrusted with salt. This phenomenon is quite different from that of the salinas, and more extraordinary. In many parts of South America, wherever the climate is moderately dry, these incrustations occur; but I have nowhere seen them so abundant as near Bahia Blanca. The salt here, and in other parts of Patagonia, consists chiefly of sulphate of soda with some common salt. As long as the ground remains moist in the salitrales (as the Spaniards improperly call them, mistaking this substance for saltpeter), nothing is to be seen but an extensive plain composed of a black, muddy soil, supporting scattered tufts of succulent plants. On returning through one of these tracts, after a week's hot*

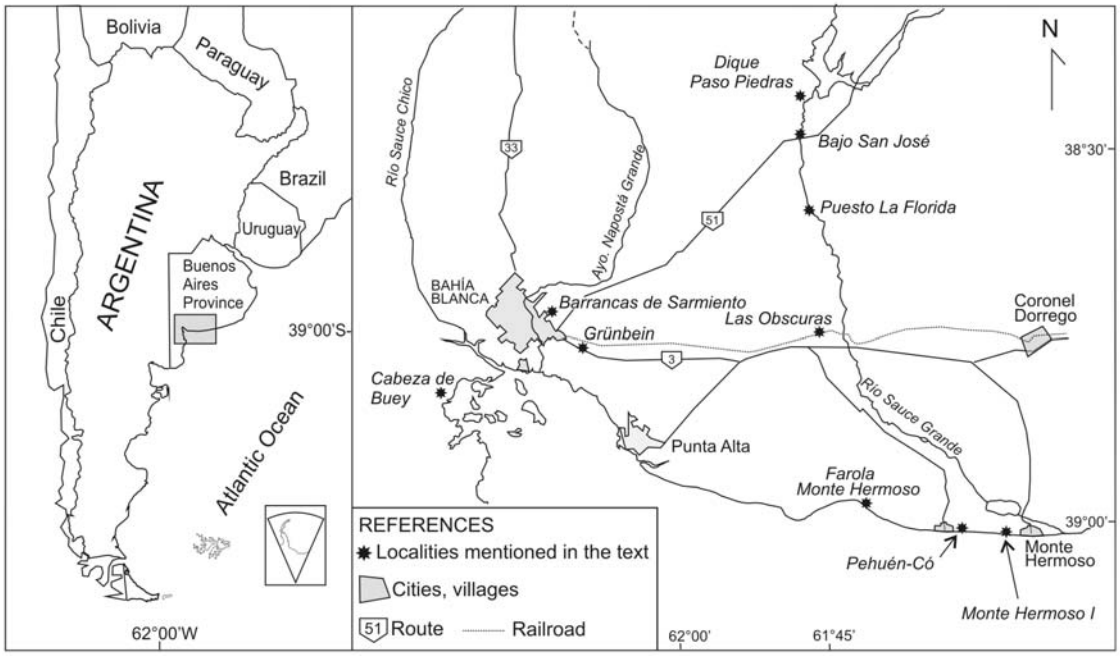

Figure 2: Map of the studied area with the localities mentioned in the text.

weather, one is surprised to see square miles of the plain white, as if from a slight fall of snow..." (Darwin 1845, p. 78).

Bahía Blanca means White Bay. The name is due to the typical colour of the salt covering the soils surrounding its shores. "*The wide expanse of water is choked up by numerous great mud-banks, which the inhabitants call Cangrejales, or crabberies, from the number of small crabs...*" (Darwin 1845, p. 80).

The bay (which is presently considered an estuary, Perillo *et al.* 2004) was seen by Ferdinand Magellan in 1520 during the first circumnavigation around the world on the orders of Charles I of Spain, as he searched for a pass connecting the Atlantic and Pacific oceans.

Darwin's observations of the area are arranged according to the age of the sediments he described, from the oldest to the youngest.

THE GREAT PAMPEAN FORMATION

"*The Beagle arrived here on the 24th of August, and a week afterwards sailed for the Plata. With Captain Fitz Roy's consent I was left behind, to travel by land to Buenos Ayres. I will here add some observations, which were made during this visit and on a previous occasion, when the Beagle was employed in surveying the harbour. The plain, at the distance of a few miles from the coast, belongs to the great Pampean formation, which consists in part of a reddish clay, and in part of a highly calcareous marly rock*" (Darwin 1845, p. 81).

This sedimentation, including both loess (sediments with a high content of volcanic derived particles) and loessoid sediments (reworked loess) (Zárate 2003), was related to a phase of late Miocene (ca. 10 Ma) orogeny in the Andes, which acted as a barrier to moisture-laden Pacific winds. This initiated "*the desertification of Patagonia caused by the rain shadow while precocious Pampa environment probably came into prominence at about this time*" (Patterson and Pascual 1972).

Traverse (1982) refers to this 10-million-year period as the "Ultimogene". Its inception is based on the presence of practically 100% extant plant genera. By this time, also began the establishment of steppe vegetation, dominated by grasses and by shrubby composites and chenopods in America and Eurasia.

In the southern Pampas (Argentina), at least the last 9-3 Ma record is described as sequences composed of alternating loess and palaeosol units known in general as *Pampean sediments* (Fidalgo *et al.* 1975) and locally as the Saldungaray, La Toma (Furque 1967), and Monte Hermoso (Zavala 1993) formations. These sequences, stretch across South America from 23ºS to 41ºS (Teruggi 1957, Bargo and Deschamps 1996). They indicate climatic fluctuations, alternating between arid and cold (loess deposition) and warm and humid (palaeosol development) intervals. Further interpretation of these sediments and the related *tosca* beds are subject of another article in this volume (Zárate and Folguera 2009).

The stratigraphic correlation among exposures of the *Pampean sediments* is quite difficult because of the lithologic uniformity, but they bear faunas of different ages (from the late Miocene to the Middle Pleistocene) which greatly help in this correlation. The oldest exposures of these Cenozoic sequences in the area are those of Grünbein and Barrancas de Sarmiento near Bahía Blanca city (Fig. 2), including loessoid sediments devoid of pollen, but yielding vertebrate remains. The fauna-especially the octodontoid rodents of the genera *Xenodontomys* and *Phtoramys*-suggests a late Miocene age (Verzi and Deschamps 1996, Deschamps *et al.* 1998, Verzi *et al.* 2008). Other loessoid sediments exposed at Las Obscuras (Fig. 2), in the middle basin of Río Sauce Grande, were also sterile in pollen, but the mammal remains - especially the oc-

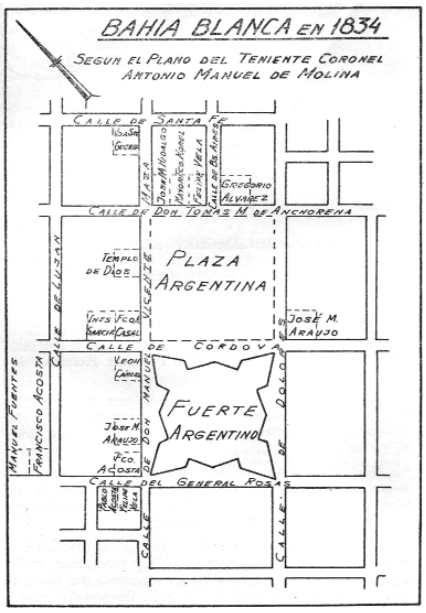

Figure 3: Map of Bahía Blanca city.

todontoid rodent *Actenomys priscus* - suggest an early Pliocene age. On this basis, Las Obscuras Formation may be correlated with the base of the Monte Hermoso Formation - Montehermosan Stage/Age - exposed at Farola Monte Hermoso (Fig. 2) on the Atlantic coast.

MONTE HERMOSO: THE RED EARTH CLIFFS NEAR PUNTA ALTA

On October 19, 1832 he visited Monte Hermoso for the first time: "*The Captain landed for half an hour at Monte Hermoso, (or* Starvation *point as we call it) to take observations*" (Keynes 2001). "*At the distance of about thirty miles from Punta Alta, in a cliff of red earth, I found several fragments of bones, some of large size. Among them were the teeth of a gnawer, equalling in size and closely resembling those of the Capybara* (now *Phugatherium cataclisticum* = *Chapalmatherium perturbidum,* see Vucetich *et al.* 2005*), whose habits have been described; and therefore, probably, an aquatic animal. There was also part of the head of a Ctenomys; the species being different from the Tucutuco, but with a close general resemblance* (now *Actenomys priscus,* Deschamps 2005). *The red earth, like that of the Pampas, in which these remains were embedded,* ...." (Darwin 1845, p. 82). (see also Fernicola *et al.* 2009).

These red earth cliffs, today known as Farola Monte Hermoso (Fig. 4) to distinguish it from Monte Hermoso Beach, were described by Darwin with more detail in 1846:

"*At Monte Hermoso there is a good section, about one hundred feet in height, of four distinct strata, appearing to the eye horizontal, but thickening a little towards the N.W. The uppermost bed, about twenty feet in thickness, consists of obliquely laminated, soft sandstone, including many pebbles of quartz, and falling at the surface into loose sand. The second bed, only six inches thick, is a hard, dark-coloured sandstone. The third bed is pale-coloured Pampean mud; and the fourth is of the same nature, but darker coloured, including in its lower part horizontal layers and lines of concretions of not very compact pinkish tosca-rock*." Zavala (1993) and Zavala and Navarro (1993), based on facies analysis, gave a new interpretation of the stratigraphy and paleoenvironments of this locality, worldwide known by its fossil content since the visit of Ameghino (1887), being the basis for the Montehermosan Age (see Pascual *et al.* 1966). They formally recognized three litostratigraphic units from bottom to top, the Monte Hermoso, Puerto Belgrano and Punta Tejada formations (the first unit including the two lower strata described by Darwin as of Pampean mud). Darwin argued about the origin of these strata at Monte Hermoso: "*...were the strata at Monte Hermoso depositing at the bottom of a great open sea, between 800 and 1000 feet in depth? I much doubt this; for if so, the almost perfect carcasses of the several small rodents, the remains of which are so very numerous in so limited a space, must have been drifted to this spot from the distance of many hundred miles. It appears to me far more probable, that during the Pampean period this whole area had commenced slowly rising ... As the land continued to rise, it appears that this source of sediment was cut off; and in its place sand and pebbles were borne down by stronger currents, and conformably deposited over the Pampean strata*".

Zavala and Navarro (1993) interpreted that the Monte Hermoso Formation (including the Hermosense típico, the Limolitas Estratificadas Member and Limolitas Claras Member of Bonaparte 1960) was deposited through a fluvial dynamics of high sinuousity muddy fine-grained rivers, with associated floodplain and meandering channel facies. The discontinuity observed between the lower section (Hermosense típico) and the upper section (Limolitas Estratificadas and Limolitas Claras members) is here interpreted as an internal erosional surface developed during the migration of a highly sinuous fluvial channel over flood plain deposits. The Puerto Belgrano Formation (*arenas estratificadas* of Bonaparte 1960) is interpreted as accumulated in an aeolian environment with facies of low relief dunes, and associated dry interdunes. The cliff is topped by the Punta Tejada Formation, formed by sands and conglomerates with quartzite pebbles accumulated in wadi and fluvial environments.

Several points of this interpretation agree with that of Darwin: "*It appears to me far more probable, that during the Pampean period this whole area had commenced slowly rising ..., and that tracts of land had thus been formed of Pampean sediment round the Ventana and the other primary ranges, on which the several rodents and other quadrupeds lived, and that a stream (in which perhaps the extinct aquatic Hydrochœrus lived)... As the land continued to rise, it appears that this source of sediment was cut off; and in its place sand and pebbles were borne down by stronger currents, and conformably deposited over the Pampean strata*" (Darwin 1846, p. 82). The record of *extinct aquatic capybaras* as evidence for the presence of water-related sediments was analyzed in Deschamps *et al.* (2007).

By this time grasslands were dominant at high latitudes. They developed during a global cooling event and marine transgression (Janis 1993), this latter probably locally responsible for the cliffs of Grünbein and Barrancas de Sarmiento (Zavala and Quattrocchio 2001). For the period between 5 and 3 Ma, Lambeck *et al.* (2002) proposed global warm conditions in view of low values of $\delta^{18}O$ in foraminifera of marine sediments, and

low range sea level oscillations. The environments might have been similar to the modern Chaqueña Phytogeographic Province with open xerophytic woodlands, but more humid, with seasonal differences in rainfall (Pascual and Ortiz Jaureguizar 1990).

THE LATE PLIOCENE-EARLY PLEISTOCENE

"*Even the view was insignificant;-a plain like the sea, but without its beautiful colour and defined outline.*"

Sea level changes produced different geomorphic features in these homogeneous sediments, including erosion, differences in the equilibrium river profiles, regressive and transgressive events, and building of shell terraces during the regressive phases.

During the late Pliocene-Early Pleistocene interval this area was probably affected by erosion processes (and no deposition; see Fig. 9). In the study area, a single late Pliocene event has been identified in the conglomerates of the La Delta Sequence within the valley of Río Sauce Grande at Dique Paso Piedras (Deschamps 2005). The complex terraces in the Río Sauce Grande (see below) were interpreted within an evolutionary model of valleys in arid-semiarid regions (Zavala and Quattrocchio 2001). In this model, valleys were active only sporadically and most of the time behaved as geomorphologically depressed zones, hosting locally sourced gravitational and aeolian deposits. Geologic and sedimentological data suggest that La Delta Sequence could represent the second stage of initial filling within a transport zone, or zone 2 of the evolution of fluvial valleys in arid and semiarid zones. This process is related to the beginning of a transgressive cycle of an interglacial period. Semidesertic environments that began their development during the global climatic deterioration of the late Miocene were dominant during the Pliocene in western Argentina. The final rise of the Sierras Pampeanas acted as a wind shadow, increasing the desertification of the western areas (Pascual 1984). The caviomorph rodent fauna in the southeastern coast of the Buenos Aires Province, suggests a strong arid pulse at the end of the late Pliocene that could be coeval with the global climatic deterioration at the Gauss-Matuyama boundary (Verzi 2001, Verzi and Quintana 2005).

Figure 4: *The red earth cliffs near Punta Alta:* Farola Monte Hermoso.

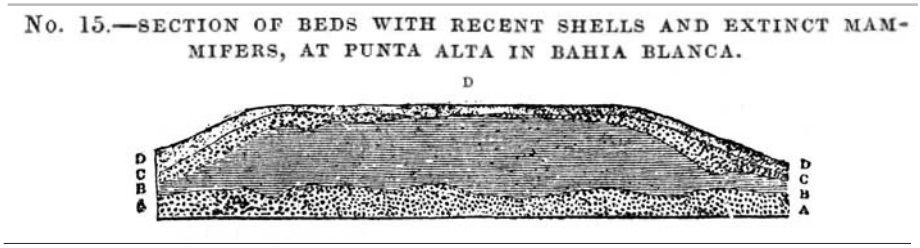

Figure 5: The original drawing of Punta Alta section.

THE LATE PLEISTOCENE: PUNTA ALTA AND THE MONSTERS OF EXTINCT RACES

The Pleistocene-Holocene is recorded in the coastal area as well as in the valleys of the main rivers of the area. One of the most renowned Pleistocene sites visited by Darwin is Punta Alta. He spent here several days looking for fossils in September and October, 1832 and August 1833: "*We passed the night in Punta Alta, and I employed myself in searching for fossil bones; this point being a perfect catacomb for monsters of extinct races.*" (Darwin 1845, p. 80). Vertebrate fossils are referred to in another chapter of this volume (Fernicola *et al. 2009*). This area is today buried beneath the naval base of Puerto Belgrano and could not be revisited; he reported the description and a drawing of the profile (Darwin 1846, p. 82-83): "*Punta Alta is situated about thirty miles higher up on the northern side of this same bay: it consists of a small plain, between twenty and thirty feet in height, cut off on the shore by a line of low cliffs about a mile in length, represented in the diagram with its vertical scale necessarily exaggerated* (Fig. 5). He described four beds (A-D). "*The lower bed (A) ... stratified gravel or conglomerate ... curvilinear, owing to the action of currents, and dip in different directions; they include an extraordinary number of bones of gigantic mammifers and many shells... The second bed (B) is about fifteen feet in thickness*

... of red, tough clayey mud, with minute linear cavities... The bed (C) is of stratified gravel, like the lowest one... These three lower beds are covered by an unconformable mantle (D) of stratified sandy earth, including many pebbles of quartz, pumice and phonolite, land and seashells."

The mammal bones found in this section "*... were associated with twenty-three species of shells, of which thirteen are recent and four others very closely related to recent forms; whether the remaining ones are extinct or simply unknown, must be doubtful, as few collections of shells have been made on this coast. As, however, the recent species were embedded in nearly the same proportional numbers with those now living in the bay, I think there can be little doubt, that this accumulation belongs to a very late tertiary period*" (Darwin 1845, p. 83). The 23 mentioned species are in fact 20 mollusk species, the other three are barnacles (*Balanus*), anthozoan corals (*Astraea*) and bryozoans (*Flustra*), all of them pertaining to the middle Holocene transgression recorded in the Bahía Blanca estuary (Farinati personal communication). Darwin made extensive observations on one pennatulaceous (Coelenterata, Anthozoa) which he named *Virgularia patagonica*, but known today as *Stylatula darwini* (Farinati 1989): *At low water hundreds of these zoophytes might be seen, projecting like stubble, with the truncate end upwards, a few inches above the surface of the muddy sand*" (Darwin 1845, p. 99).

Especially noteworthy in this area, although not seen by Darwin, is the record of fossil trackways discovered by researchers of the UNS some kilometres east of Punta Alta (Fig. 2), in the paleoichnological site of Pehuén-Có (Fig. 6a). These trackways are quite rare in the fossil record, particularly in such amounts, and have been visited by researches of many foreign countries. They belong to birds, xenarthrans, camelids, macraucheniids, and were dated in 12,000 $\pm$ 100 years ^{14}C BP. They have been extensively studied by Drs. Manera and Aramayo (Aramayo and Manera de Bianco 1996, Quattrocchio and Borromei 1998). (Fig. 6a)

Another outstanding record in this area is that of early aborigines' footprints (Fig. 6b) which were found at the Monte Hermoso1 site and were dated in 7,000 years BP (Bayón and Politis 1996, Zavala *et al.* 1992).

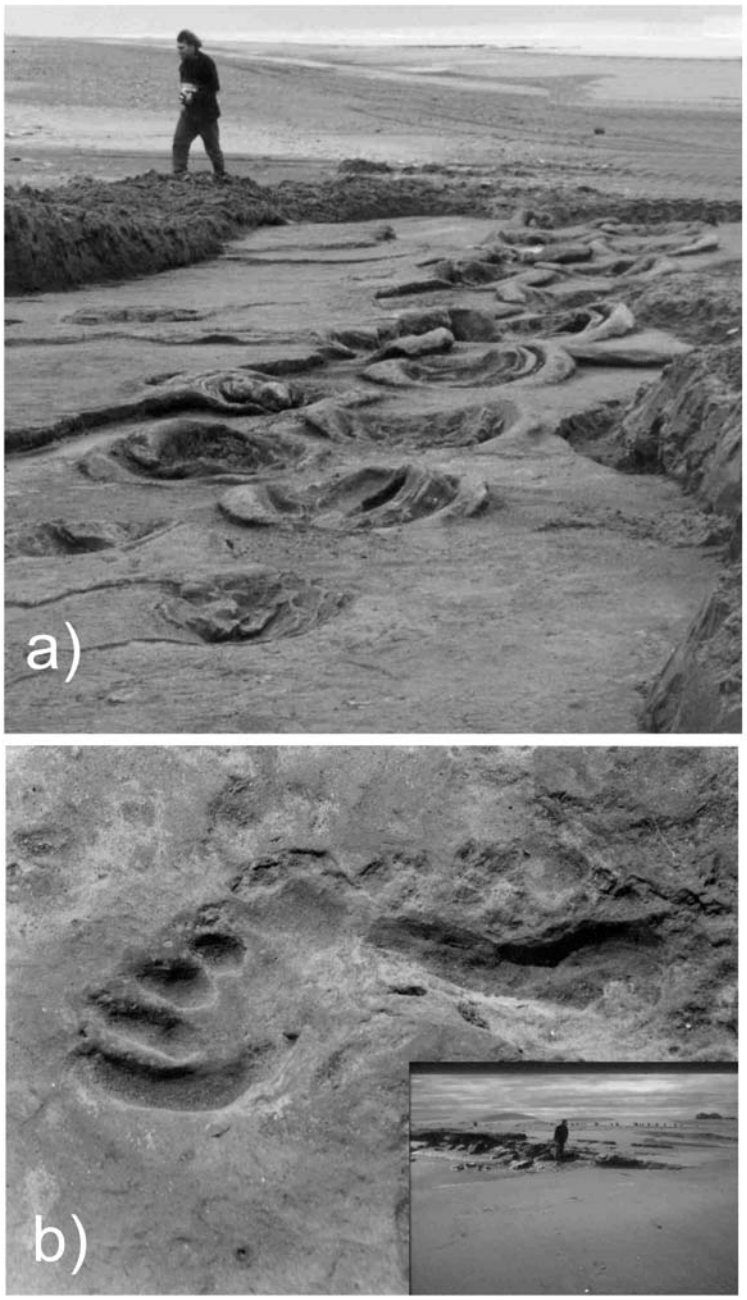

Figure 6: a) Trackway of *Megatherium* on Pleistocene sediments of the Pehuén-Có ichnological site; b) Human footprint on Holocene sediments of the Monte Her-moso I archaeological site.

THE RIO SAUCE

The Late Pleistocene-Holocene is also recorded in the valleys of the main rivers which flow across Tertiary units. The Río Sauce Grande is the main river in the southwestern Pampas, and Darwin crossed it ridding to Buenos Aires on September 8th. 1833: "*I hired a Gaucho to accompany me on my ride to Buenos Ayres... The distance to Buenos Ayres is about four hundred miles, and nearly the whole way through an uninhabited country. We started early in the morning; ascending a few hundred feet from the*

basin of green turf on which Bahia Blanca stands, we entered on a wide desolate plain... After a long gallop, having changed horses twice, we reached the Rio Sauce: it is a deep, rapid, little stream, not above twenty-five feet wide. The second posta on the road to Buenos Ayres stands on its banks; ..." (Darwin 1845, p. 106; Figs. 7 and 8).

Remains of three levels of ancient terraces assigned to La Delta (see above), San José and Agua Blanca sequences (dated as Late Pliocene, Middle Pleistocene and Late Pleistocene-Holocene respectively; Zavala and Quattrocchio 2001, Deschamps 2005), document different episodes of incision and valley infilling.

The Middle Pleistocene was particularly studied at Bajo San José, represented by the Bajo San José Sequence, which was deposited by a braided river, typical of arid to semiarid environments. The characteristic longitudinal bars and channels infilling would have provided varied niches for the rich fauna found in these deposits (Deschamps and Borromei 1992, Deschamps 2003, 2005). No pollen was found, but mammals, especially the octodontoid rodent *Ctenomys kraglievichi* as well as murid rodents and Tayassuidae, suggest the strongest warm pulse so far recognized in the Middle Pleistocene (Bonaerian age) of southern South America (Verzi *et al.* 2004).

Figure 7: The Río Sauce Grande and Sierra de la Ventana, with aborigines as drawn by E. Lassalle in 1827 during the voyage with the French naturalist Alcide d'Orbigny.

Figure 8: The Río Sauce Grande today.

THE VEGETATION AT THAT PERIOD

Darwin wondered about the vegetation coexisting with the large Late Pleistocene mammals of Punta Alta: "*What, it may naturally be asked, was the character of the vegetation at that period; was the country as wretchedly sterile as it now is? As so many of the co-embedded shells are the same with those now living in the bay, I was at first inclined to think that the former vegetation was probably similar to the existing one; but this would have been an erroneous inference, for some of these same shells live on the luxuriant coast of Brazil... Nevertheless, from the following considerations, I do not believe that the simple fact of many gigantic quadrupeds having lived on the plains round Bahia Blanca, is any sure guide that they formerly were clothed with a luxuriant vegetation: I have no doubt that the sterile country a little southward, near the Rio Negro, with its scattered thorny trees, would support many and large quadrupeds*" (Darwin 1845, p. 84-85). This latter issue is developed in another article of this volume (Vizcaíno *et al.* 2009), but pollen and ostracod analyses performed at several localities of the Río Sauce Grande (e.g. Puesto La Florida, Fig. 2), and Arroyo Napostá Grande, including one site at the outlet near Punta Alta (Bertels and Martínez 1990, Borromei 1992, 1995, 1998, Grill 1993, 1995, 1997, Martínez 2002) provided information about the vegetation and climate. These analyses suggest arid conditions associated with more continental environments and related to lower sea level in the Atlantic coast of Buenos Aires province (Quattrocchio *et al.* 1995, 1998), quite different from "the luxuriant vegetation" and close to a "sterile country" of Darwin's comments.

The pollen assemblage is dominated by Chenopodiaceae-Amaranthaceae, Poaceae and Asteraceae. Pollen grains that reflect the shrub and thorn scrub plant communities include among others the families Rhamnaceae (*Condalia microphylla,* or *piquillín*), Papilionaceae (*Geoffroeae decorticans*, or *chañar*) and Mimosaceae (*Prosopis* or *algarrobo*). The pollen assemblage repre-

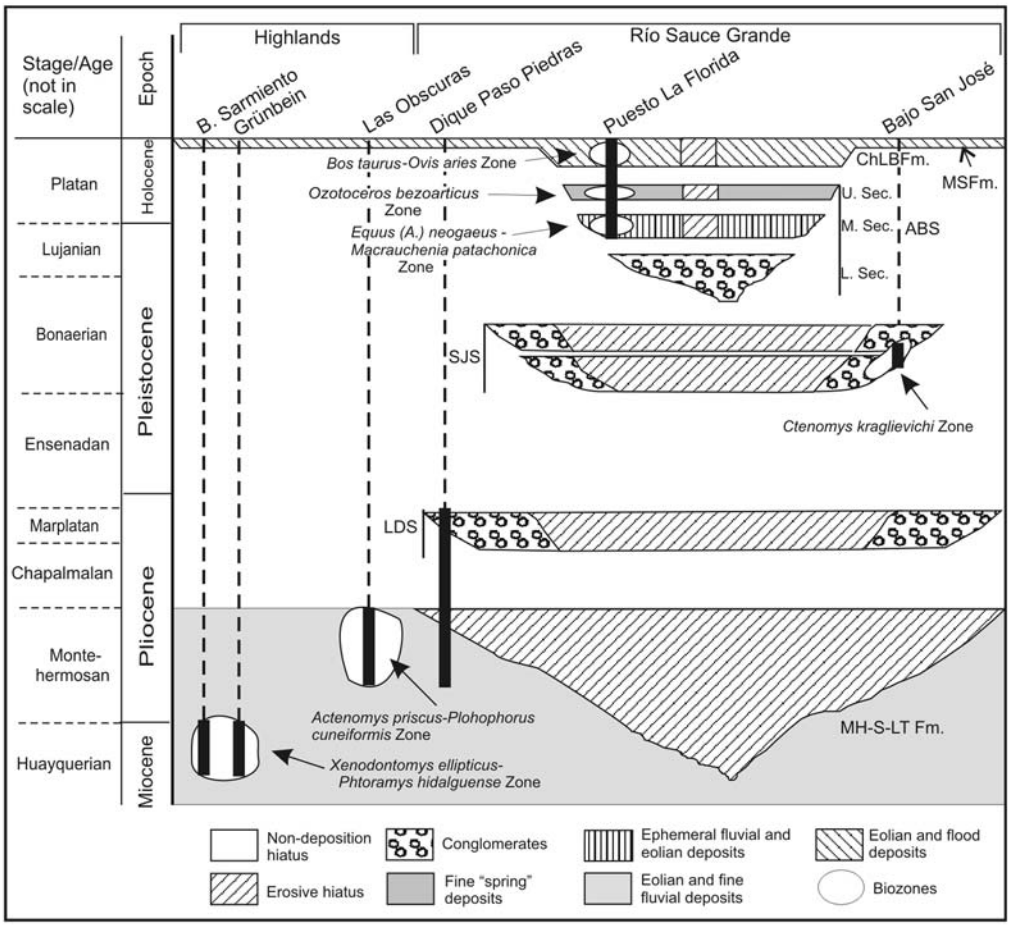

Figure 9: Chronostratigraphic chart showing space-time correlation of the geologic events in the area. ABS. Agua Blanca Sequence; ChLBFm., Chacra La Blanqueada Formation; LDS, La Delta Sequence; MH-S-LT fms., Monte Hermoso-Saldungaray-La Toma formations; MSFm., Matadero Saldungaray Formation; SJS, San José Sequence. Thick black lines indicate the levels exposed at each locality.

sents the modern halophytic steppe and psammophytic herbaceous steppe vegetation, along with shrubby woodland vegetation. Sporadic high abundances of Cruciferae probably reflect habitats subject to natural causes of disturbance such as intense eolian action under an arid climate (from Quattrocchio and Borromei 1998).

THE RECENT PAST

The Late Pleistocene/Holocene transition is characterized by development of palaeosols. During the early Holocene sea level was still lower than today; pollen records reflect the development of a vegetation community characteristic of coastal dunes. Temperature and humidity reached its maximum during the mid-Holocene when the high diversity and abundance of marine dinocysts and acritarchs indicate a transgression. This event is associated with the gramineous steppe in the continent reflecting more temperate or local humid conditions. The relative sea level rise led to the flooding of the riverbeds, producing deposition of grey muddy facies. Approximately at 3000 years BP the marine influence ended in the area. After 2610 years BP, the development of a psammophytic herbaceous steppe suggests arid to semiarid conditions, followed by an interval of higher humidity inferred at approximately 2000 years BP, through the development of gramineous steppe communities. A relative rise of temperature may be inferred by the southward expansion of the Brazilian mammal fauna.

These multidisciplinary research results are presented in a chronosequence chart synthesizing the suggested space-time correlation of the events recognized (Fig. 9). In this chart, some of the studied localities-covering the whole time interval represented in the area- were arranged in a hypothetical E-W line crossing the Río Sauce Grande basin and the highlands. In part, this line is also approximately the one followed by Darwin when riding from Bahía Blanca to Tapalqué (*Tapalguen*) as he crossed the region toward the Río Sauce and stopped at the *second posta*.

ACKNOWLEDGEMENTS

The authors thank Dr. Beatriz Aguirre-Urreta and the Asociación Geológica Argentina for the invitation to participate in this volume, and the reviewers Drs. M.G. Vucetich and M. Toledo for their fruitful comments which certainly improved the manuscript. Dr. E. Farinati kindly provided information about Pleistocene shells.

WORKS CITED IN THE TEXT

Ameghino, F. 1887. Monte Hermoso. Diario "La Nación", March 10: 1-10, Buenos Aires.

Aramayo, S.A. and Manera de Bianco, T. 1996. Edad y nuevos hallazgos de icnitas de mamíferos y aves en el yacimiento paleoicnológico de Pehuén-Có (Pleistoceno tardío), provincia de Buenos Aires, Argentina. 1º Reunión Argentina de Icnología, Asociación Paleontológica Argentina, Publicación Especial 4: 47-57.

Bargo, M.S. and Deschamps, C.M. 1996. El registro de *Mylodon* Owen, 1840 (Mammalia, Tardigrada) en el Pleistoceno del sur de la provincia de Buenos Aires. Comentarios sobre la distribución de los "sedimentos Pampeanos". Ameghiniana 33: 343-348.

Bayón, C. and Politis, G. 1996. Estado actual de las investigaciones en el sitio Monte Hermoso 1 (Prov. de Buenos Aires). Instituto de Ciencias Antropológicas, Facultad de Filosofia y Letras, Universidad de Buenos Aires, Arqueología 6: 83-116.

Bertels, A. and Martínez, D. 1990. Fresh water and transitional environments ostracodes of the Buenos Aires Province, Argentina. European Ostracodologists Meeting (EOM 1989) 123: 141-159.

Bonaparte, J. 1960. La sucesión estratigráfica de Monte Hermoso (Provincia de Buenos Aires). Acta Geológica Lilloana 3: 272-290.

Borromei, A.M. 1992. Geología y palinología de los depósitos cuaternarios en el valle del río Sauce Grande, provincia de Buenos Aires, Argentina. Unpublished PhD Dissertation, Universidad Nacional del Sur, Bahía Blanca. 200 p.

Borromei, A.M. 1995. Palinología, estratigrafía y paleoambientes del Pleistoceno tardío-Holoceno en el valle del río Sauce Grande, provincia de Buenos Aires, Argentina. Polen 7: 19-31.

Borromei, A.M. 1998. Vegetación y clima del Cuaternario tardío en el valle superior del Río Sauce Grande, Provincia de Buenos Aires, Argentina. Polen 9: 5-15.

Darwin, C. 1845. Journal of researches into the natural history and geology of countries visited during the voyage of HMS Beagle round the world, under the command of Capt. Fitz Roy, R.N. Second Edition, corrected, with additions. John Murray, 519 p., London.

Darwin, C. 1846. Geological observations on South America. Being the third part of the geology of the voyage of the Beagle, under the command of Capt. Fitzroy, R.N. during the years 1832 to 1836. Smith Elder and Co. 280 p., London.

Deschamps, C.M. 2003. Estratigrafía y paleoambientes del Cenozoico en el sur de la Provincia de Buenos Aires. El aporte de los vertebrados. Unpublished PhD Dissertation, Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata. 317 p.

Deschamps, C.M. 2005. Late Cenozoic mammal bio-chronostratigraphy in southwestern Buenos Aires Province, Argentina. Ameghiniana 42: 733-750.

Deschamps, C.M. and Borromei, A.M. 1992. La fauna de vertebrados pleistocénicos del Bajo San José (provincia de Buenos Aires, Argentina). Aspectos paleoambientales. Ameghiniana 29: 177-183.

Deschamps, C.M., Tonni, E.P., Verzi, D.H., Scillato Yané, G.J., Zavala, C.A., Carlini, A.A., and Di Martino, V. 1998. Bioestratigrafía del Cenozoico superior continental en el área de Bahía Blanca, provincia de Buenos Aires. 5° Jornadas Geológicas y Geofísicas Bonaerenses, Actas 1: 49-57.

Deschamps, C.M., Olivares, A.I., Vieytes, E.C. and Vucetich, M.G. 2007. Ontogeny and diversity of the oldest capybaras (Rodentia: Hydrochoeridae; late Miocene of Argentina). Journal of Vertebrate Paleontology 27: 683-692.

Dozo, A.L. and Ginóbili, M.E. 1999. Bahía Blanca en imágenes 1828-1929. Edi UNs (Editorial de la Universidad Nacional del Sur, 326 p., Bahía Blanca.

Farinati E. 1989. Pennatuláceos (Coelenterata, Anthozoa) en sedimentos marinos holocenos de Bahía Blanca, Argentina. Ameghiniana 26: 229-231.

Fernicola, J.C., Vizcaíno, S.F. and De Iuliis, G., 2009. Historical review of the fossil mammals collected by Charles Darwin in South America during his travels on board the HMS Beagle. Revista de la Asociación Geológica Argentina 64(1): 147-159.

Fidalgo, F., De Francesco, F. and Pascual, R. 1975. Geología superficial de la llanura bonaerense (Argentina). In Geología de la Provincia de Buenos Aires. 6° Congreso Geológico Argentino, Relatorio: 103-138, Buenos Aires.

Furque, G. 1967. Estratigrafía de la Región de Pillahuincó. Acta Geológica Lilloana 9: 79-114.

Grill, S.C. 1993. Estratigrafía y paleoambientes del Cuaternario en base a palinomorfos en la cuenca del arroyo Napostá Grande, provincia de Buenos Aires. PhD Dissertation, Universidad Nacional del Sur, (unpublished), 145 p., Bahía Blanca.

Grill, S.C. 1995. Análisis palinológico de un perfil cuaternario en la cuenca del arroyo Napostá Grande, Localidad García del Río, provincia de Buenos Aires. 4° Jornadas Geológicas Bonaerenses (Junín), Actas 1: 99-107.

Grill, S.C. 1997. Análisis palinológico de un perfil cuaternario en la cuenca media del arroyo Napostá Grande, Localidad García del Río, provincia de Buenos Aires, Argentina. Implicancias paleoambientales. Polen 8: 23-40.

Janis, C.M. 1993. Tertiary mammal evolution in the context of changing climates, vegetation, and tectonic events. Annual Review of Ecology and Systematics 24: 467-500.

Keynes, R.D. ed. 2001. Charles Darwin's Beagle Diary. Cambridge University Press. 464 p., Cambridge.

Lambeck, K., Esat, T.M.and Potter, E.-K. 2002. Links between climate and sea levels for the past three million years. Nature 419: 199-206.

Mallea, E. 1941. Todo verdor perecerá. Espasa Calpe Argentina, 222p., Buenos Aires.

Martínez, D. 2002. Microfauna (Ostracoda, Crustacea) del Cuaternario de las cercanías de Bahía Blanca, República Argentina. PhD Dissertation, Universidad Nacional del Sur, (unpublished), 378 p., Bahía Blanca.

Pascual, R. 1984. Late Tertiary mammals of southern South America as indicators of climatic deterioration. Quaternary of South America and Antarctic Peninsula 2: 1-30.

Pascual, R. and Ortiz Jaureguizar, E. 1990. Evolving climates and mammal faunas in Cenozoic South America. Journal of Human Evolution 19: 23-60.

Pascual, R., Ortega Hinojosa, E.J., Gondar, D. and Tonni, E.P. 1966. Paleontografía Bonaerense. Fascículo IV. Vertebrata. Comisión de Investigaciones Científicas de la Provincia de Buenos Aires, 202 p., La Plata.

Patterson, B. and Pascual, R. 1972. The Fossil Mammal Fauna of South America. In Keast, A., Erk, F.C. and Glass, B. (eds.) Evolution, Mammals, and Southern Continents, State University of New York Press, 247-309, New York.

Perillo, G.M.E., Piccolo, M.C., Palma, E., Pierini, J.O. and Pérez, D.E. 2004. Oceanografía Física del estuario de Bahía Blanca. In Piccolo, M.C. and Hoffmeyer, M. (eds.) El Ecosistema del Estuario de Bahía Blanca. Instituto Argentino de Oceanografía, 61-67, Bahía Blanca.

Quattrocchio, M.E. and Borromei, A.M. 1998. Paleovegetational and paleoclimatic changes during the Late Quaternary in southwestern Buenos Aires province and southern Tierra del Fuego (Argentina). Palynology 22: 67-82.

Quattrocchio, M.E., Borromei, A.M. and Grill, S.C. 1995. Cambios vegetacionales y fluctuaciones paleoclimáticas durante el Pleistoceno Tardío-Holoceno en el sudoeste de la provincia de Buenos Aires (Argentina). 6° Congreso Argentino de Paleontología y Bioestratigrafía (Trelew), Actas: 221-229.

Quattrocchio, M.E., Grill, S.C. and Zavala, C.A. 1998. Chronostratigraphic and palynozone chronosequences charts of Napostá Grande Creek, southwestern Buenos Aires Province, Argentina. Quaternary of South America and Antarctic Peninsula 11: 111-133.

Quattrocchio, M.E., Borromei, A.M, Deschanps, C.M., Grill, S.C., and Zavala, C.A. 2008. Landscape evolution and climate changes in the Late Pleistocene - Holocene, southern Pampa (Argentina): Evidence from palynology, mammals and sedimentology. Quaternary International 181: 123-138.

Teruggi, M. 1957. The nature and origin of Argentine loess. Journal of Sedimentary Petrology 27: 322-332.

Traverse, A. 1982. Response of world vegetation to Neogene tectonic and climatic events. Alcheringa 6: 197-209.

Traverse, A. 2007. Paleopalynology. In Landman, N.H. and Jones, D.S. (eds.) Topics in Geobiology, Springer (Second Edition), 28 , 813 p., Dordrecht.

Verzi, D.H. 2001. Phylogenetic position of Abalosia and the evolution of the extant Octodontinae (Rodentia, Caviomorpha, Octodontidae). Acta Theriologica 46: 243-268.

Verzi, D.H. and Deschamps, C.M. 1996. Presencia de roedores ctenominos del género *Xenodontomys* en Loma Sarmiento, Provincia de Buenos Aires. 3º Jornadas Geológicas y Geofísicas Bonaerenses (1995), Actas 1: 47-54.

Verzi, D.H. and Quintana, C.A. 2005. The Caviomorph rodents from the San Andrés Formation, east-central Argentina, and global Late Pliocene climatic change. Palaeogeography, Palaeoclimatology, Palaeoecology 219: 303-320.

Verzi, D.H., Deschamps, C.M. and Tonni, E.P. 2004. Biostratigraphic and paleoclimatic meaning of the Middle Pleistocene South American rodent *Ctenomys kraglievichi* (Caviomorpha, Octodontidae). Palaeogeography, Palaeoclimatology, Palaeoecology, 212: 315-329.

Verzi, D.H., Montalvo, C.I. and Deschamps, C.M. 2008. Biostratigraphy and biochronology of the Late Miocene of central Argentina: evidence from rodents and taphonomy. Geobios 44: 145-155.

Vizcaíno, S.F., Fernicola, J.C. and Fariña, R.A., 2009. Young Darwin and the ecology of South American fossil mammals. Revista de la Asociación Geológica Argentina 64(1): 160-169.

Vucetich, M.G., Deschamps, C.M., Olivares, A.I. and Dozo, M.T. 2005. Capybaras, shape, size and time: a model kit. Acta Paleontologica Polonica 50: 259-272.

Zárate, M.A. 2003. Loess of southern South America. Quaternary Science Reviews 22: 1987-2006.

Zárate, M.A. and Folguera, A. 2009. On the formations of the Pampas in the footsteps of Darwin: south of the Salado. Revista de la Asociación Geológica Argentina 64: 124-136.

Zavala, C.A. 1993. Estratigrafía de la localidad de Farola Monte Hermoso (Plioceno-Reciente). Provincia de Buenos Aires. 12° Congreso Geológico Argentino y 2° Congreso de Exploración de Hidrocarburos (Mendoza), Actas 2: 228-235.

Zavala, C.A. and Navarro, E. 1993. Depósitos fluviales en la Formación Monte Hermoso (Plioceno inferior-medio), provincia de Buenos Aires. 12° Congreso Geológico Argentino y 2° Congreso de Exploración de Hidrocarburos (Mendoza), Actas 2: 236-244.

Zavala, C.A. and Quattrocchio, M.E. 2001. Estratigrafía y evolución geológica del río Sauce Grande (Cuaternario), provincia de Buenos Aires. Revista de la Asociación Geológica Argentina 56: 25-37.

Zavala, C.A., Grill, S.C., Martínez, D., Ortíz, H.O. and González, R. 1992. Análisis paleoambiental de depósitos cuaternarios, Sitio paleoicnológico Monte Hermoso I, provincia de Buenos Aires. 3° Jornadas Geológicas Bonaerenses (La Plata), Actas: 31-37.

Recibido: 19 de agosto de 2008
Aceptado: 30 de septiembre de 2008