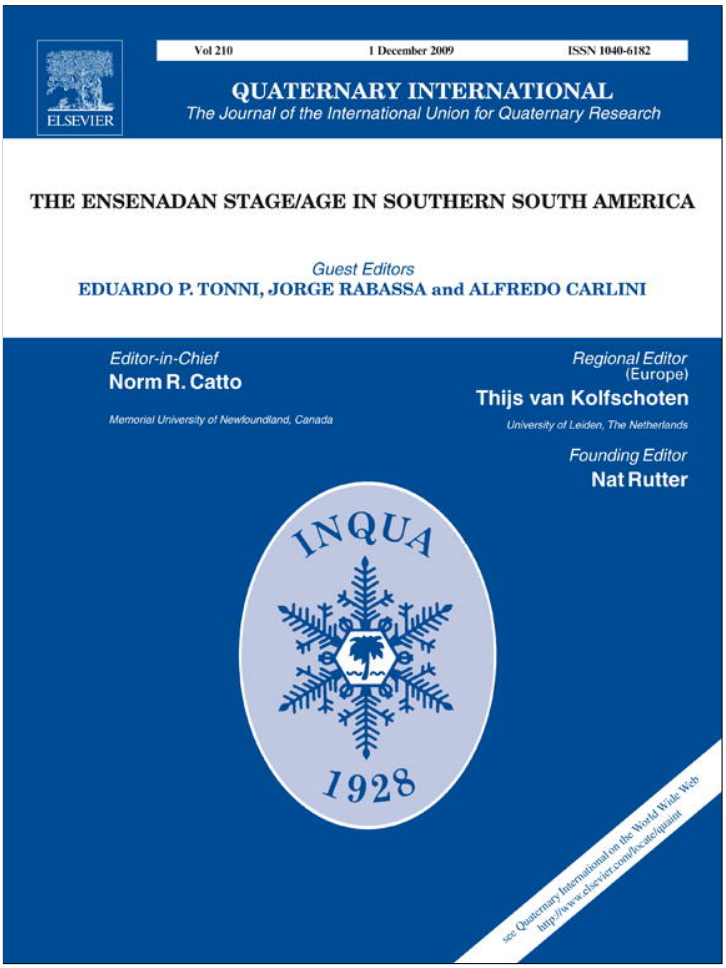

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Correlation of late Cenozoic sequences of southeastern Buenos Aires province: Biostratigraphy and magnetostratigraphy

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ABSTRACT

Correlations among stratigraphic sequences of the continental late Cenozoic of southeastern Buenos Aires province have been historically based on lithostratigraphy and paleontological content. Recent magnetostratigraphic studies supplied new evidence which, together with biostratigraphy, allowed improvement of the chronostratigraphic framework. Recent studies were conducted at four localities of southeastern Buenos Aires province: Playa Santa Elena, Punta Hermengo, Mar del Sur and Centinela del Mar. The studied sequences at Santa Elena and Mar del Sur show normal magnetic polarity, while Punta Hermengo and Centinela del Mar display levels of reverse polarity. Discontinuities in the sequence of Mar del Sur might explain the absence of sediments of reverse polarity. Thus, some units (the lower ones) could correspond to the normal magnetic events C1r1n and/or C2n, as the fossil fauna collected here has no typical Pliocene components that could suggest an age older than the Gauss–Matuyama boundary (i.e., >2.58 Ma). The basal levels of the profile at Punta Hermengo, with reverse polarity, display Ensenadan fauna. This may be the most recent section of C1r (C1r1r, 0.90–0.78 Ma), which took place after the normal Jaramillo event (C1r1n). The lower unit of Playa Santa Elena, of normal polarity (C1n), bears mammal remains suggesting a late Ensenadan age (<0.78 Ma). The base of the Centinela del Mar sequence that shows reverse polarity levels and bears bones of mammals probably is of undifferentiated Pleistocene age.

1. Introduction

The mammal-bearing continental sequences of the Argentine Cenozoic have usually been considered as the basis of the South American time scale (Pascual et al., 1965, 1966; Pascual and Ortiz Jaureguizar, 1990) (Fig. 1). Among these, the Pliocene and Pleistocene sites from the coast of southeastern Buenos Aires province are outstanding because of their extraordinary paleontological productivity. The current chronological patterns were based on the paleontological content. On the last decades of the 20th century, numerical dating and magnetostratigraphic studies provided temporal accuracy to the chronostratigraphical models. However, the paucity of datable elements (restricted almost exclusively to glassy "escorias", see Schultz et al., 2004), particularly concerning the lower and middle Pleistocene, make magnetostratigraphy and biostratigraphy unique tools for the interpretation of the chronology of the earliest Quaternary stratigraphic levels.

Magnetostratigraphic studies are partly limited by frequent and numerous discontinuities and wide lateral variations observed in the coastal cliffs of southeastern Buenos Aires province. Consequently, their combination with biostratigraphic studies may give information to improve the chronostratigraphic scheme of the Pampean Region. This methodology has only been used previously in a few papers (e.g. Ruocco, 1989; Tonni et al., 1999; Verzi et al., 2002, 2004; Prevosti et al., 2004; Bidegain et al., 2005a,b; Deschamps, 2005; Verzi and Quintana, 2005; Soibelzon et al., 2006a, 2008a,b,c).

The present chronostratigraphic scheme for the late Cenozoic of the Pampean Region has significant background in the contributions of Ameghino (1908), Frenguelli (1921) and Kraglievich (1952). It has been developed almost exclusively on the eastern area of this region, on the coastal cliffs between Mar del Plata and Miramar (see

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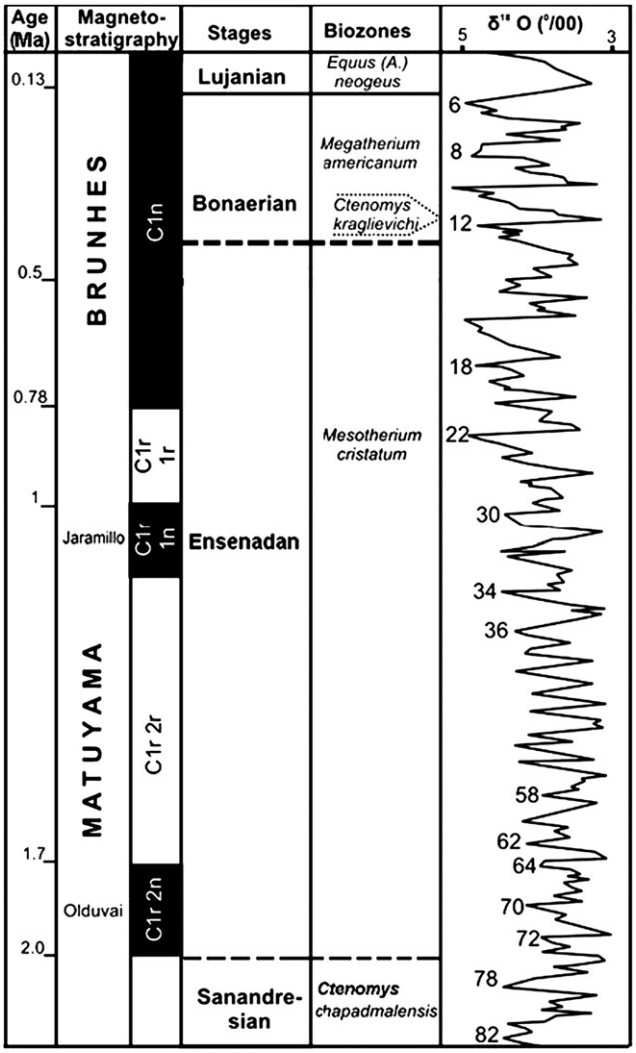

Fig. 1. Chronostratigraphic chart for the Quaternary of the Pampean Region (modified from Soibelzon et al., 2006a). δ^{18}O curve for planktonic foraminifera (modified from Shackleton et al., 1995).

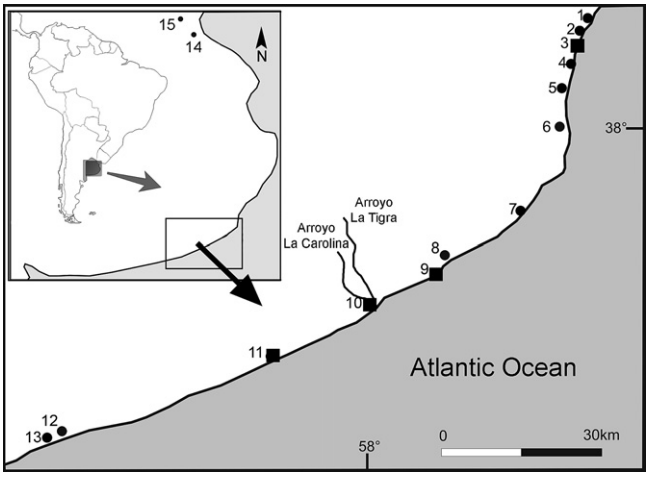

Fig. 2. Localities of the southeastern Buenos Aires Province mentioned in the text. 1, Santa Clara del Mar; 2, Arroyo Santa Elena; 3, Balneario Santa Elena; 4, F.U. Camet; 5, Arroyo La Tapera; 6, Mar del Plata; 7, Chapadmalal; 8, Miramar; 9, Punta Hermengo; 10, Mar del Sur; 11, Centinela del Mar; 12, Necochea; 13, Las Grutas-Punta Negra; 14, San Miguel quarry; 15, San Pedro. Black squares represent the four localities studied here.

Cione and Tonni, 1995, 1999, 2001, 2005), based on a group of biozones defined by Cione and Tonni (1995, 1999, 2005) for the Buenos Aires area of the Pampean Region (Fig. 1). This pattern is currently being tested in other areas of Argentina (see Zurita et al., 2007) and is used in other areas of South America (e.g. Bolivia: Marshall et al., 1984; MacFadden and Shockey, 1997; MacFadden, 2000; Alberdi et al., 2003; Alberdi and Prado, 2004; Tonni et al., 2009; Uruguay: Marshall et al., 1984; Ubilla et al., 2004).

This paper reports the results of recent magnetostratigraphic and biostratigraphic studies accomplished in four localities of the coast of southeastern Buenos Aires province: Playa Santa Elena (Mar del Plata), Punta Hermengo (Miramar), Mar del Sur, and Centinela del Mar (Fig. 2). In addition, the results are compared to those of other localities of Buenos Aires province in which biostratigraphic and magnetostratigraphic studies have been performed (e.g. Bidegain et al., 1998, 2005a,b, 2007; Tonni et al., 1999; Nabel et al., 2000; Soibelzon et al., 2006a) (see Figs. 2 and 3).

2. Materials and methods

Paleomagnetic sampling was carried out with a non-magnetic sampler and a Brunton compass. The sediment thus obtained was placed in plastic boxes of 8 cm^3. In order to avoid the movement of particles a non-magnetic binding material was added (plastic glue).

Sediment samples were taken, from each level recognized, for measurements of specific susceptibility and other magnetic parameters at laboratory, as well as for sedimentological, mineralogical and chemical analyses that are beyond the scope of this contribution. Declination, inclination, and intensity of remnant magnetism were measured at the laboratory of the Instituto de Física Arroyo Seco (IFAS) of the Universidad Nacional del Centro de la Provincia de Buenos Aires using a Molspin rotative magnetometer, and the demagnetization, by alternate magnetic fields (cma). After measuring the natural remnant magnetization of each whole sample, demagnetization by alternating low fields of 2.5 and 5 mT was applied. The behavior of the samples with demagnetization allowed confirmation of what has been established in previous papers, since 90% of the initial magnetization (I^0) is lost around 30 mT of applied peak fields, in some samples at even lower fields (Bidegain, 1998). This "soft" behavior was suggested as generated by magnetites and titanomagnetites with low titanium content (Bidegain, 1998; Bidegain et al., 2005a).

Paleontological information is based on materials housed at national collections (MACN, MLP, MMP and MMPH; see below), on those mentioned in the literature (Tonni and Fidalgo, 1978; Tonni et al., 1999; Cione and Tonni, 2005; Soibelzon et al., 2006a,b; 2008a,b,c), and on collections obtained during recent paleontological fieldwork.

Abbreviations. **MACN**, Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" (Buenos Aires); **MLP,** Museo de La Plata, Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata (La Plata); **MMP**, Museo Municipal de Ciencias Naturales "Lorenzo Scaglia" (Mar del Plata); **MMPH**, Museo Municipal "Punta Hermengo" (Miramar).

3. Results

The study area is more than 90 km long (Fig. 2). Five geological profiles were studied in four localities (two from Punta Hermengo, see below), to which biostratigraphic and paleomagnetic information was added. Fig. 4 shows some of the characteristic behaviors of paleomagnetic samples by using AF demagnetization. All of the demagnetized samples from Santa Elena showed normal polarity as

indicated in the stereographic plot, and the same results were obtained from the Mar del Sur samples. Conversely, Punta Hermengo and Centinela del Mar samples are of normal polarity in the upper and middle section analyzed and of reverse polarity at the bottom.

The profile at Playa Santa Elena (37° 51′ 56.8″ S; 57° 30′ 46.2″ W; Fig. 2) of 7.30 m is composed of six stratigraphic units (A–F) and has an extent of ≈ 500 m. Unit A is composed of dark brown silt clayey to sandy–clayey silt sediments and has a calcrete level ("tosca") at the top. Unit B (A of Prevosti et al., 2004), is dark brown clay silt, with horizontal calcrete in its upper section. This unit was observed only in the southern extremity of this locality. Unit C (B of Prevosti et al., 2004) is brown sandy silt, with laminated structures, convoluted laminations, and isolated paleochannels with rounded calcrete clast of 2.5 cm of diameter. Lithological discontinuities separate this unit from unit B. Unit D (C of Prevosti et al., 2004) is composed of brown sandy silts with convoluted lamination, and horizontal calcrete at its base. This unit rests on lithological discontinuities above unit C, and is progressively thinner to the NNE. Unit E (D of Prevosti et al., 2004) is composed of greyish brown sandy silts and silty sands showing paleochannels and abundant horizontal and vertical calcrete veins in its top. This unit lies in lithological discontinuity on unit D. Unit F (E of Prevosti et al., 2004) is composed of light brown structureless silts with a paleosol in its lower section and a horizontal calcrete in the upper one. Units A–E were deposited in fluvial or subaqueous environments, whereas unit F shows evidence of having been accumulated subaerially. Paleomagnetic analyses of samples showed that the whole sequence has normal polarity (Figs. 3 and 4a). In the basal levels of the cliff (units A–B), 10 m south of the pathway to Playa Santa Elena (37° 52′ S; 57° 30′ W), remains of *Theriodictis platensis* (MMP 2700; see Prevosti et al., 2004) and *Mesotherium cristatum* (MMP 2438M) were found.

At Punta Hermengo, two profiles were studied, one at the "Farola de Punta Hermengo" (the old lighthouse; 38° 17′ 13.8″ S; 57° 50′ 14.9″ W; Fig. 2) and the second some 500 m southwards (38° 17′ 31.4″ S; 57° 50′ 46.8″ W). This is the best fossiliferous locality of the area (more than 100 significant fossil remains collected within the last 50 years). Both profiles are nearly 5 m thick and are composed of fluvial "Pampean sediments". Following Kraglievich (1952), the geologic profile at "Farola de Punta Hermengo" includes sediments of the Vorohué, San Andrés, Miramar and Arroyo Seco Formations. Tonni and Fidalgo (1982) and Soibelzon et al. (2006a) indicated that the base of the profile include Ensenadan mammals (see below). The paleomagnetic data from the basal levels (A–C) show reverse polarity (Figs. 3 and 4b). According to Tonni and Fidalgo (1982), unit A is composed of dark brown clayey silts to sandy–clayey sediments and has horizontal calcrete laminae at the top; Unit B is formed of brown greyish to yellowish brown silts to sandy silts that include larger lithic clasts less than 10 cm in diameter. This unit is a diamicton and it lies in lithological discontinuities over Unit B. Unit C is composed of brown greyish to greenish gray silty sands, whereas unit D is a brown yellowish to greyish brown silty sand to clayey silt, with a silty clay at the top of the unit. Unit E is a brown greyish to greenish gray silty clay to sandy clay. Unit F is composed of light brown yellowish silty sand to clayey silt sediments. This unit rests in lithological discontinuity over unit E. At the top of the profile, unit G is composed of brown to greyish brown silty–clayey sands. The current aeolian deposits lie in lithological discontinuity over unit G. From a biostratigraphic point of view, the record of *M. cristatum* (MLP 81-VIII-20-16 and 08-05-00) in unit B, *Arctotherium angustidens* in unit E (unit D from Tonni and Fidalgo, 1982), and *Ctenomys kraglievichi* (MLP 91-IV-30-35 and 91-IV-30-36) in unit G (unit F from Tonni and Fidalgo, 1982), is noteworthy.

The profile at Mar del Sur (38° 21′ 00.0″ S; 57° 59′ 35.6″ W; Fig. 2), which is 4.1 m thick, is wholly composed of normal polarity

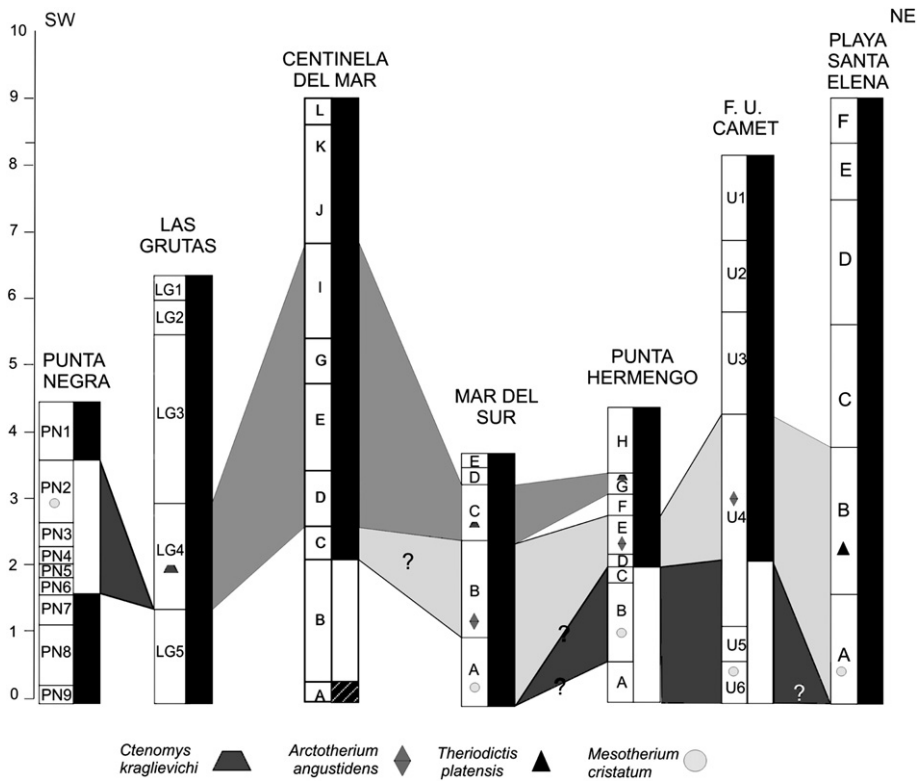

Fig. 3. Magnetostratigraphic profiles mentioned in the text.

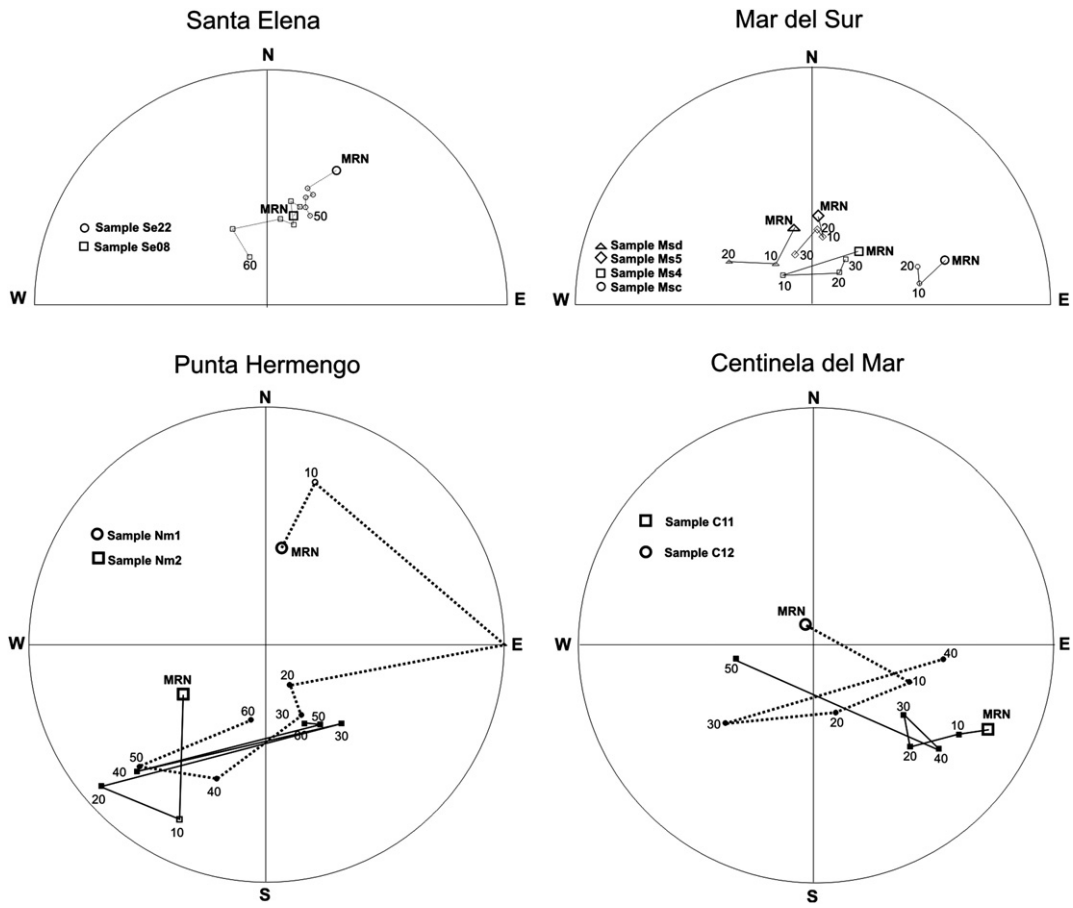

Fig. 4. Stereoplots of normal and reverse polarity samples from the localities studied.

sediments (Figs. 3 and 4c). The profile is composed of 4 units of fluvial origin and has an aeolian sandy unit (a present dune) at the top. Unit A is composed of dark brown, massive clayey silts to sandy–clayey sediments with abundant horizontal and vertical calcrete, and laminar calcrete at the top. Unit B is a reddish brown clayey sand and has horizontal laminar calcrete at the top. This unit rests in lithological discontinuity over unit A. Unit C is a reddish brown to yellowish brown sandy silt and has calcrete stones in its lower section and a palaeosol at its top. This unit lies in lithological discontinuity on unit B. Unit D is a yellowish brown to bright yellow sandy silt and has laminar calcrete at the top. In some parts, a greenish gray silt horizon is developed. *M. cristatum* (MLP 91-IV-20-1) was found in unit A. In the middle levels (unit C), a paleosol with abundant termitaria was observed (Laza and Tonni, 2004), and at the base of this unit, some remains of *C. kraglievichi* (MLP 06-II-2-34) were identified.

At Centinela del Mar (38° 26′ 33″ S; 58° 13′ 22″ W; Fig. 2), the cliffs, more than 2.5 km long, have a maximum height of 15 m and are composed of 10 units (Cenizo and Agnolin, 2007; Cenizo and de los Reyes, 2008) or 14 units (Bogan et al., 2009). Here, the profile and lithological terminology of Bogan et al. (2009) are used. A detailed stratigraphic description of this locality was performed by Cenizo (submitted for publication), but in general, the profile is composed of fluvial facies in the basal and middle section (A to J lithofacies), whereas the upper section corresponds to marine sediments (K, L and M lithofacies). The top of the sequence (N lithofacies) corresponds to aeolian lithofacies. Paleomagnetic study indicates that there are levels of reverse polarity at the base of the sequence in Centinela del Mar (Figs. 3 and 4d). Fossils of units J and K belong to the *Equus* (*Amerhippus*) *neogaeus* biozone (Lujanian, see Tonni et al., 1987; de los Reyes et al., 2006). The fauna of the lower levels (units A and B) suggests an undetermined Pleistocene age (de los Reyes et al., 2006).

4. Discussion and conclusions

4.1. Interpretation of the studied profiles

The presence of *T. platensis* and *M. cristatum* (MMP 2700 and MMP 2438M, respectively) in sediments with normal polarity of units A and B of Playa Santa Elena suggests a late Ensenadan age (0.78 – ≈0.5 Ma) for the base of the profile, in agreement with the previous suggestion of Prevosti et al. (2004).

The basal levels of Punta Hermengo (units A, B, and C), with reverse polarity, might represent the most recent part of the Matuyama Chron (subchron C1r1r; 0.90–0.78 Ma), since they bear mammals characteristics of the Ensenadan Stage/Age (*M. cristatum*, MACN 5861, MLP 81-VIII-20-16 and 06-II-2-33). Likewise, from unit E (unit D from Tonni and Fidalgo, 1982) of normal polarity (base of chron C1n) remains of the Ursidae *A. angustidens* (MLP 87-V-5-1 and MLP 01-IV-1-1; Soibelzon, 2004) were unearthed. In unit G, the fossil *C. kraglievichi*, indicating the base of the Bonaerian Stage/Age, was found.

The entire sequence of Mar del Sur has normal polarity. The lower levels of the outcropping sequence south of the "Arroyo La Tigra" outlet (unit A) contain *M. cristatum* (MLP 91-IV-20-1), which suggest an Ensenadan age. This unit might represent the uppermost Ensenadan Stage/Age. The lack of discontinuities would

account for the absence of sediments with reverse polarity. Hence, this unit might also correspond to some of the normal events of the Matuyama Chron (i.e. the Jaramillo and Olduvai events). Farther north of "Arroyo La Carolina", the middle levels of this sequence (unit C) have paleosols with frequent termitaria that were referred to an interglacial period, probably the one corresponding to Marine Isotopic Stage (MIS) 11 (Laza and Tonni, 2004). Termitaria assignable to the same group (*Termes*) are found at the base of the Buenos Aires Formation, exposed at the excavations of the "Teatro Argentino" of the city of La Plata, Buenos Aires province (Laza and Tonni, 2004; Laza, 2006; Laza, pers. comm., 2007). Unit C includes *C. kraglievichi* as well, which represents the base of the Bonaerian Stage/Age. This, and other faunistic indicators of warm conditions led Verzi et al. (2004) to suggest that the Bonaerian Stage/Age began during the MIS 11 interglacial, around 0.4 Ma (see also Laza, 2006; Merino et al., 2007). This was the warmest and longest interglacial period recorded in the last 0.5 Ma, which generated a strong sea level rise (Hearty, 2007) to which beach sediments of the southeastern coast of Buenos Aires province have been referred (Cione et al., 2002).

At Centinela del Mar, the recorded fauna in the lower and middle levels is also referable to a Pleistocene age s.l., whereas that found in the upper level (units J and K) is referred to the late Pleistocene (Lujanian Stage/Age) (see also Tonni et al., 1987; de los Reyes et al., 2006). The magnetostratigraphic profile surveyed at this locality shows that the entire sequence has normal polarity, except for basal units A and B. However, Heil et al. (2002) referred this sequence as deposited between the middle Pliocene and the middle Pleistocene; the lower level would have been deposited during the Kaena event (3.04–3.11 Ma). In the present study, the magnetic changes reported by these authors have not been verified. Moreover, as mentioned above, the fauna is typically of Pleistocene age, with none of the obvious elements characteristic of the upper Chapadmalalan and the Marplatan (Pliocene), such as *Paedotherium* and *Actenomys*, having been recorded here.

Schultz et al. (2004) reported ^{40}Ar–^{39}Ar dating ages on glassy "escorias" (which had been thus interpreted as impact glasses) present in the sequence. The samples come from units E and I (see Fig. 3). The sample from unit E is dated at 0.23 ± 0.04 Ma, whereas unit I (upper) has been so at 0.445 ± 0.021 Ma. According to the authors, the sample from unit I would have been deposited on a lower stratigraphic level.

4.2. Correlations with other profiles of the Pampean Region

The information obtained from the new profiles allows the correlation of these sequences with others previously studied. In this sense, unit B of Playa Santa Elena corresponds to the lower levels of Arroyo Santa Elena (U4 of Bidegain et al., 1998, 2005a) and to unit B of Vialidad Nacional quarry of San Pedro (Buenos Aires; see Prevosti et al., 2009). These sediments have normal polarity and Ensenadan mammals, and would have been deposited in the uppermost Ensenadan Stage/Age.

Units A–C of Punta Hermengo, with reverse polarity and Ensenadan fauna, correlate with the middle levels of Punta Negra (Necochea; units PN6–PN2 of Bidegain et al., 2005b) and with the sediments of reverse polarity of the lower levels of Félix U. Camet (U7–U5 of Bidegain et al., 1998, 2007), middle levels of La Plata (units J–Q of Bidegain, 1998; upper part of the unit V of Tonni et al., 1999), some profiles of Buenos Aires city (see Nabel et al., 2000; Soibelzon et al., 2008a) and northern Buenos Aires province (units II and III of Nabel, 1993; see also Soibelzon et al., 2006b), units E of San Pedro quarry and units E and D of San Miguel quarry (see Soibelzon, 2008; Soibelzon et al., 2008c; Fig. 2), as well as with the depositional (VII) and postdepositional (VI) cycles determined and correlated in three localities of La Plata (El Cristo, Juárez and Gorina; Bidegain et al., 2007). These levels are referred to the uppermost section of the Matuyama Chron, and several of these localities (e.g. La Plata, San Pedro, Punta Hermengo, Punta Negra) bear Ensenadan mammals (Bidegain, 1998; Tonni et al., 1999; Bidegain et al., 2005b; Soibelzon et al., 2006a, 2008c), indicating their age would be between 0.90 and 0.78 Ma.

Units G of Punta Hermengo (level F of Tonni and Fidalgo, 1982), C of Mar del Sur, LG4 of Las Grutas (in Necochea, Bidegain et al., 2005b) and other correlating levels of the Pampean Region (see Verzi et al., 2004) contain typically Bonaerian mammal remains (*C. kraglievichi* Biozone).

At Centinela del Mar the upper units (J–K) bear Lujanian fauna, such as that present in different correlated horizons elsewhere in Buenos Aires province (see Tonni et al., 1999, 2003). These correlation hypotheses should be contrasted and refined in the future through more interdisciplinary work, combined with numerical dating.

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