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Biostratigraphy and biochronology of the Monte Hermoso Formation (early Pliocene) at its type locality, Buenos Aires Province, Argentina

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ABSTRACT

The Monte Hermoso Formation, cropping out at its type locality of Farola Monte Hermoso (Buenos Aires Province), is a classical fossiliferous unit of the South American Neogene, highlighted by the abundance and diversity of its vertebrate remains. However, its biostratigraphy and age have been largely debated, and numerous discrepancies and controversies have been stated. In this regard, the result of the analysis of new materials recovered from the different levels of this formation, following a strict control of stratigraphic provenance, is here reported. As well, the provenance of specimens of previous collections has been evaluated. The studied assemblage consists of Osteichthyes, Amphibia, Reptilia, Aves and Mammalia. These latter are the most numerous and belong to the Didelphimorphia, Polydolopimorphia, Rodentia, Notoungulata, Litopterna and Xenarthra. The recorded taxa suggest no important faunistic variations among the different levels of the Monte Hermoso Formation that would imply significant chronological differences, and hence, justify the recognition of two biostratigraphic units. The analysis of the first and last records as well as the taxa considered as exclusive, does not support the validity of the biozones of *Trigodon gaudryi* and *Neocavia depressidens* previously proposed. On this basis, a new scheme for the Monte Hermoso Formation at its type locality is proposed, including a new single biostratigraphic unit. This unit is the *Eumysops laeviplicatus* Range Zone, which represents the biostratigraphic base for the Montehermosan Stage/Age of the early Pliocene.

1. Introduction

The biostratigraphic units of the late Cenozoic of South America are mainly based on the taxonomic content and distribution of the fossil mammal assemblages (Cione and Tonni, 2005; Cione et al., 2007; Deschamps et al., 2012). In this regard, numerous deposits including levels bearing a rich vertebrate fauna, especially mammals, of the late Miocene–Holocene are exposed at the Pampean Region (Argentina). These deposits, which sometimes include the type sections of the biostratigraphic units of the late Cenozoic, are among the most complete sequences in the continent (Zárate, 2005; Cione et al., 2007).

Farola Monte Hermoso, located at the south-west of the Buenos Aires Province (Pampean Region, Argentina; Fig. 1), is the type locality of the Monte Hermoso Formation, formally defined by Zavala (1993), and one of the most important fossiliferous sites of the South American Neogene. Over time, numerous and varied designations have been used for this locality, including "Monte Hermoso" (Darwin, 1846; Ameghino, 1887; Vignati, 1925; Bonaparte, 1960), "barrancas de Monte Hermoso" (Monte Hermoso cliffs; Leanza, 1948; Fidalgo and Tonni, 1982), "barrancas de la costa atlántica situadas a unos 17 km al sudoeste de Pehuén co" (cliffs of the Atlantic coast some 17 km SW from Pehuén co; Tonni, 1974), "barrancas de la costa atlántica, aproximadamente a 60 km al este de Bahía Blanca" (cliffs of the Atlantic coast near 60 km east from Bahía Blanca; Reig, 1978) or "acantilados marinos cercanos a Bahía Blanca" (marine cliffs near Bahía Blanca; Cione and Báez, 2007).

The deposits currently included in the Monte Hermoso Formation (sensu Zavala, 1993) were mentioned by several authors (e.g. Darwin, 1846; Ameghino, 1887; Kraglievich, 1946; Bonaparte, 1960), who highlighted the abundance and diversity of vertebrate remains. Ameghino (1887: p. 332) noted that these deposits were "… atestados de fósiles. En todas partes se ven asomar puntas de huesos…aquí una mandíbula, allí un cráneo, más allá una pierna,

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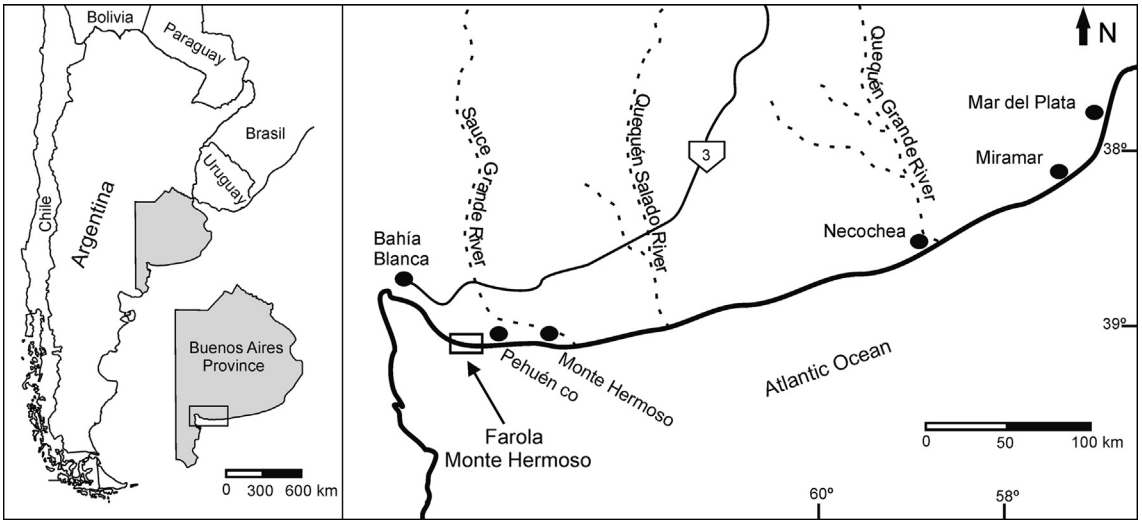

Fig. 1. Location map showing Farola Monte Hermoso, Buenos Aires Province, Argentina.

por otro lado un caparazón monstruo; se camina de sorpresa en sorpresa" (… full of fossils. Tips of bones are exposed everywhere… here a mandible, there a skull, a leg farther, or a monstrous carapace; we walk from surprise to surprise). In turn, this author was first to assign a precise age to these exposures, for which he defined the "Piso Hermósico" (Ameghino, 1889) or "Horizonte Hermosense" (Ameghino, 1908), of the upper Miocene.

Several authors (e.g. Willis, 1912; Wichmann, 1916; Kantor, 1922) recognized two levels in these deposits, different in color and separated by an important erosive discontinuity. Since these studies, the lower level was defined as "Hermosense típico" (Vignati, 1925) and the upper one was assigned to the "Piso Chapadmalense" (Vignati, 1948) or to a transitional horizon between the "Hermosense" and the classical "Chapadmalense" of the area of Mar del Plata-Miramar (Kraglievich, 1946; Parodi and Kraglievich, 1948; Fig. 1). Based on faunistic differences recorded between both levels, a biostratigraphic and biochronologic scheme was proposed for the Monte Hermoso Formation, which included two biozones chronologically successive (Tonni et al., 1992; Cione and Tonni, 1995, 1996, 2001, 2005). The fauna from the lower level, the "Hermosense típico", was assigned to the *Trigodon gaudryi* Biozone, as the biostratigraphic base of the Montehermosan Stage/Age (late Miocene–early Pliocene), whereas that of the upper level, related to the "Piso Chapadmalense" was included in the *Neocavia depressidens* Biozone, as the biostratigraphic base for the lower Chapadmalalan Stage/Age (early Pliocene).

Other authors (e.g., Frenguelli, 1928; Bonaparte, 1960; Deschamps et al., 2012; Olivares et al., 2012; Tomassini, 2012; Tomassini and Montalvo, 2013) noted that the geological and paleontological differences recorded within the Monte Hermoso Formation were minimal, so that it was impossible to define with certainty the existence of two levels of different age.

The different interpretations both from the litho and biostratigraphic point of view and the chronological aspects arise mainly in the different denominations of the site, and in the interpretations of the fossil-bearing levels, as well as in the use of controversial taxa. This latter because of dubious taxonomic assignment or dubious or unknown provenances, at least at the time when the schemes were proposed (Tonni et al., 1992; Tomassini, 2012).

Bearing this in mind, the aim of the present paper is to report a new assemblage recovered from the different levels of the Monte Hermoso Formation with precise stratigraphic provenance. The faunistic list is updated, and the validity of the biostratigraphic scheme previously proposed is discussed on the basis of new records and the analysis of specimens from previous collections. Finally, a new biostratigraphic unit is proposed for this formation.

2. Geographic and stratigraphic setting

The fossiliferous site Farola Monte Hermoso (S 38°58′01″, W 61°41′43″) is located on the Atlantic coast, at the south-west of the Buenos Aires Province (Pampean Region, Argentina), approximately 53 km of Bahía Blanca city and 12 km of Pehuén co Beach (Fig. 1). The deposits are represented by NW–SE coastal cliffs exposed along three km, with variable heights that reach 15 m maximum.

This site is the type locality of the Monte Hermoso, Puerto Belgrano and Punta Tejada formations, corresponding to the early Pliocene, late Pleistocene and late Pleistocene-early Holocene respectively (sensu Zavala, 1993). In the first unit, the biozones of *T. gaudryi* and *N. depressidens*, belonging to the Montehermosan and lower Chapadmalalan stages/ages respectively, were defined by Cione and Tonni (2005). These authors assigned the first one to the late Miocene–early Pliocene and the second to the early Pliocene.

According to Zavala (1993), the Monte Hermoso Formation crops out at the lower and middle sector of the cliff along its entire exposure, with 6 m of maximum thickness, and base covered (Fig. 2). Zavala and Navarro (1993) recognized architectural elements of channel, overbank deposits and lateral accretion deposits. In turn, they interpreted that the Monte Hermoso Formation was deposited through a fluvial dynamic of high-sinuosity rivers similar to those proposed by Miall (1985) as "muddy fine-grained rivers".

The overbank deposits display a wide lateral extension in the abrasion platform and the lower part of the cliff; and include the Fl and Fm facies. These levels are equivalent to the "Hermosense típico" of Vignati (1925) and Bonaparte (1960), the "Unidad A" of Fidalgo et al. (1975), and "Unidad Litoestratigráfica I" of Fidalgo and Tonni (1982) (Fig. 3).

The Fl facies is composed mainly of silty mudstones, ranging from reddish brown to yellowish brown; though reddish brown sandy siltstones and silty sandstones are also present. These deposits show a very fine lamination in the lower sector, while in the middle-upper one they are massive (Fig. 2). Besides abundant fossil

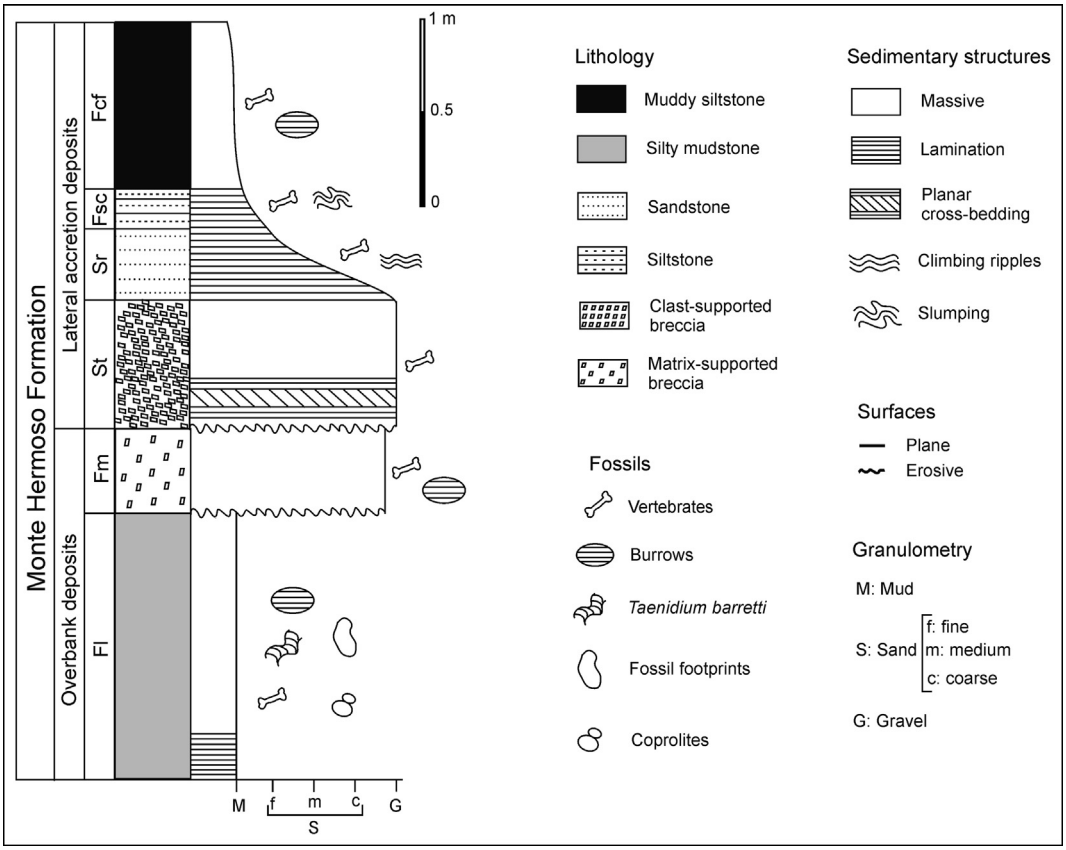

Fig. 2. Stratigraphic section of the Monte Hermoso Formation at Farola Monte Hermoso locality.

remains, burrows produced by different micromammals, fossil footprints produced by xenarthrans, coprolites assigned to carnivores, and traces attributed to *Taenidium barretti* are common (Tomassini, 2012; Tomassini and Montalvo, 2013).

The Fm facies includes matrix-supported breccias, with variable colors between dark brown and reddish brown. They are composed of silty and sandy intraclasts, some of them rounded, without selection and chaotically distributed in a muddy matrix (Fig. 2). These deposits overlie the Fl facies at an erosion surface, generally show a massive structure, although in some cases a fine lamination could be barely distinguished. Several fossil remains, burrows of small mammals similar to those of Fl facies, and traces attributed to *T. barretti* were recorded (Tomassini, 2012).

The lateral accretion deposits are mainly represented at the middle sector of the cliff, and include the St, Sr, Fsc and Fcf facies. These levels are equivalent to the "Piso Chapadmalense" of Vignati (1948), the "Miembro de Limolitas Estratificadas" and "Miembro de Limolitas Claras" of Bonaparte (1960), the "Unidad B" of Fidalgo et al. (1975), and the "Unidad Litoestratigráfica II" of Fidalgo and Tonni (1982) (Fig. 3).

The St facies is composed of dark brown to greenish clast-supported breccias, composed of silty and sandy intraclasts over 15 cm in diameter, some of them rounded, and a silt-sand matrix. In some sections, this facies is massive; while a planar cross-bedding is observed in others (Fig. 2). Generally, the St facies overlie the previously described Fl facies at an erosion surface. Fossil remains are very abundant, mainly Osteichthyes and micromammals (Tomassini, 2012; Tomassini and Montalvo, 2013).

The Sr facies overlies concordantly the St facies and is composed of fine to medium grained sandstones, with colors that range between dark and light brown. They show very fine lamination and climbing ripples. The Fsc facies includes dark brown to light-yellowish brown siltstones, with fine lamination and structures of gravitational deformation (slumping). These deposits rest transitionally over the Sr facies. In both cases, fossil remains are very scarce (Tomassini, 2012).

The Fcf facies includes massive muddy siltstones, light-yellowish brown, that overlie the Fsc facies transitionally (Fig. 2). Fossil remains are abundant, as well as small mammal burrows, these latter with similar features as those of Fl facies. Traces attributed to *T. barretti* were also recorded (Tomassini, 2012).

3. Previous biostratigraphic framework

As mentioned above, several biostratigraphic schemes were proposed for the deposits of the Monte Hermoso Formation. Among them, the most recent one is that of Cione and Tonni (1995, 1996, 2001, 2005) who stated that the different levels of this formation showed evidence of important faunistic variations of temporal significance. On this basis, they proposed the existence of two biostratigraphic units, chronologically successive, characterized by the presence of taxa, considered as exclusive. According to their proposal:

1 *T. gaudryi* Biozone: is the biostratigraphic basis for the Montehermosan Stage/Age. It was assigned to the late Miocene–early Pliocene and coincides spatially with the "Hermosense típico" of Vignati (1925), correlated units showed in Fig. 3, and the lowest part of the Monte Hermoso Formation of Zavala (1993). Exclusive taxa: *T. gaudryi*, *Parahyaenodon argentinus*, *Notocynus hermosicus*, *Myrmecophaga caroloameghinoi*, *Palaeodaedicurus antiquus*, *Diplasiotherium robustum*, *Alitoxodon*

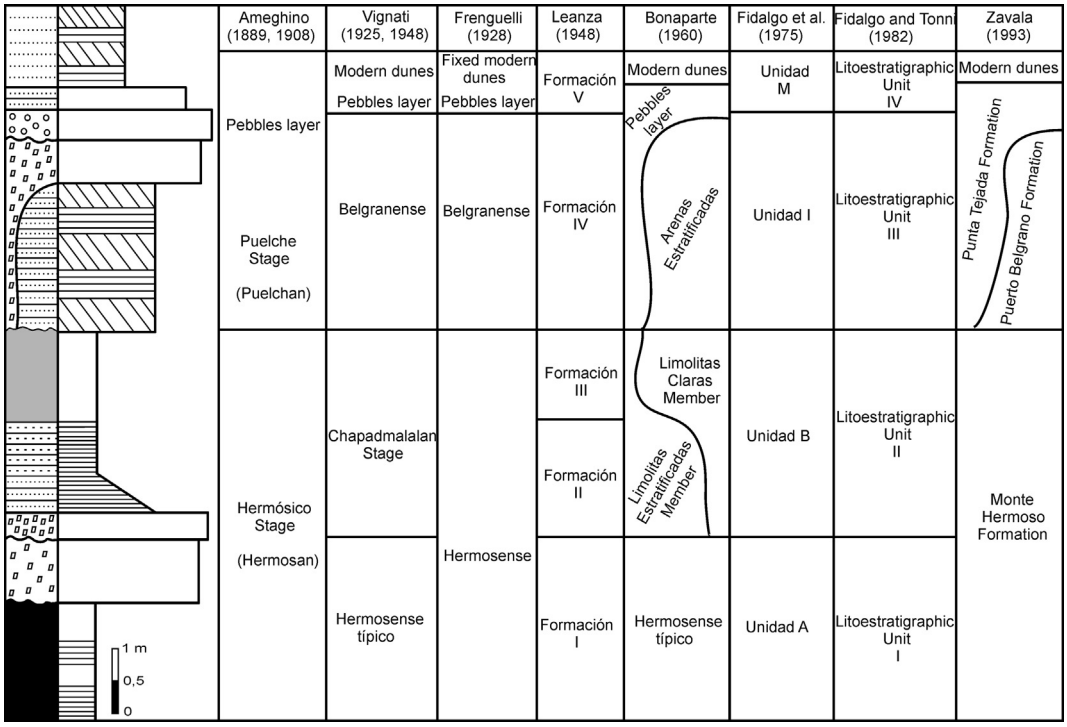

Fig. 3. Stratigraphic interpretations of the Farola Monte Hermoso locality. Modified from Zavala, 1993.

vetustum, *Thylamys contrerasi*, *Nopachtus coagmentatus* and *Auliscomys formosus*. First record of: *Phtoramys homogenidens*, *Paramyocastor diligens*, *Actenomys priscus*, *Eucelophorus chapalmalensis*, *Proscelidodon patrius*, *Chapalmatherium* and *Lestodon*, and the first South American sigmodontines. Probably also *Palaeocavia* is here first recorded.

2 *N. depressidens* Biozone: is the biostratigraphic basis for the lower Chapadmalalan Stage/Age (early Pliocene) and coincides spatially with the "Piso Chapadmalense" of Vignati (1925), correlated units seen in Fig. 3, and the upper part of the Monte Hermoso Formation of Zavala (1993). Exclusive taxa: *N. depressidens*, *Necromys bonapartei* and *Sparassocynus bahiai* (this taxon could be also recorded in the *T. gaudryi* Biozone). First record of: *Plaina*, *Palaeocavia* (this taxon could be also recorded in the *T. gaudryi* Biozone). Last record of *P. homogenidens*. The first record of *Argyrolagus palmeri* and *Thylatheridium pascuali* are those of the Monte Hermoso Formation but they have no stratigraphic data.

4. Materials and methods

The taxonomic analysis of this paper is based on materials recovered from the different facies recognized for the Monte Hermoso Formation, during the past six years of field work. This study included 749 remains of fossil vertebrates, all of them collected with an exhaustive control of their stratigraphic provenance. The NISP or number of identified specimens per taxon (Badgley, 1986) was calculated in each facies, considering the total remains anatomically and taxonomically determinable (bone, tooth or fragments of either). All the materials are housed in the Museo Municipal de Ciencias Naturales "Carlos Darwin" (Punta Alta, Buenos Aires), under the acronym MD-FM.

For the biostratigraphic and biochronologic analysis of the Monte Hermoso Formation, in addition to the new remains, the specimens from previous collections of Argentine institutions that had precise stratigraphic data, were also considered. The schemes and biozones discussed in this paper are those proposed by Cione and Tonni (1995, 1996, 2001, 2005). Formal definitions related to biostratigraphical issues are based on the International Stratigraphic Guide (ISSC, 1999).

Institutional abbreviations: MACN, Museo Argentino de Ciencias Naturales "Bernardino Rivadavia", Buenos Aires, Argentina; MD-FM, Museo Municipal de Ciencias Naturales "Carlos Darwin", Punta Alta, Argentina; MMH-FMH, Museo Municipal de Ciencias Naturales "Vicente Di Martino", Monte Hermoso, Argentina; MLP, Facultad de Ciencias Naturales y Museo de La Plata, Universidad Nacional de La Plata, La Plata, Argentina.

5. Taxonomic analysis

A major issue that hampered the assessment of the faunistic assemblage of the Monte Hermoso Formation is that many specimens had no precise stratigraphic provenance up to date (Appendix 1). In this paper, 749 vertebrate remains from the different facies of this formation were studied (Fig. 4).

The new remains (Table 1) belong to Osteichthyes (Siluriformes indet., Trichomycteridae, Percichthyidae and Characidae), Amphibia (Bufonidae and Ceratophryidae), Reptilia (Testudinidae, Teiidae and Colubridae), Aves (Tinamidae, Dendrocygninae, Cariamidae and Phorusrhacidae), and Mammalia. Mammalia included Didelphimorphia (Didelphidae and Sparassocynidae), Polydolopimorphia (Argyrolagidae), Xenarthra (Mylodontidae, Pampatheriidae, Dasypodidae and Glyptodontidae), Rodentia (Octodontidae, Ctenomyidae, Echimyidae, Chinchillidae, Caviidae, Hydrochoeridae and Cricetidae), Notoungulata (Hegetotheriidae, Mesotheriidae and Toxodontidae), and Litopterna (Proterotheriidae and Macraucheniidae).

A wide taxonomic diversity is recognized, particularly for Fl and St facies which are those with largest amount of identifiable fossil remains, nevertheless mammals are by far the prevailing ones (Table 1). Among mammals, the specimens of Rodentia, Notoungulata and Xenarthra were the most numerous. The remains assigned to Osteichthyes were the most abundant in St and Sr

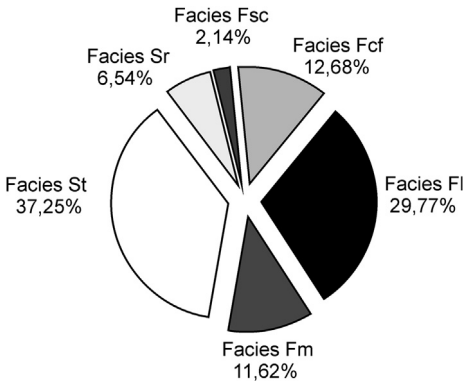

Fig. 4. Pie diagram showing the percentage of vertebrate remains recovered in each facies of the Monte Hermoso Formation.

facies, whereas those of the remaining classes of vertebrates were scarce in all facies (Table 1).

6. Discussion

6.1. General interpretations

Many taxa considered in the definition of the *T. gaudryi* and *N. depressidens* biozones (sensu Cione and Tonni, 2005; see Section 3) are controversial because they have dubious taxonomic assignment, stratigraphic provenance, and representation in the Monte Hermoso Formation. Hence, their utilization in biostratigraphy is debatable. In fact, some of them, especially rodents, have been questioned by Deschamps et al. (2012). Below is an analysis of these taxa.

The materials of *N. hermosicus*, *P. argentinus*, *P. antiquus*, *M. caroloameghinoi*, *A. vetustum* and *D. robustum* have no precise data of stratigraphic provenance. They belong to old collections, when all the recovered remains were referred to the "Hermosense" of Ameghino (1908), previous to the division into two levels of different age proposed by Vignati (1925). In this regard, Cione and Tonni (1995) pointed out that "…todas las colecciones realizadas antes del trabajo sistemático de campo de Parodi y Kraglievich en 1945, incluyen los fósiles registrados en el afloramiento de Farola Monte Hermoso en el Montehermosense en sentido amplio (Kraglievich, 1946)" (…all the collections made before the systematic field work of Parodi and Kraglievich in 1945 include the fossils recorded in the site in the Montehermosan in a broad sense (Kraglievich, 1946)). Especially, and according to Ameghino (1889: p. 332) and Cabrera (1944: p. 69), the holotype of the single record known of *P. antiquus* not even comes from Farola Monte Hermoso, but from another neighboring site (although they give no further details).

Both for *P. homogenidens* and *E. chapalmalensis* (according to Verzi, 2002 the species recorded in the Monte Hermoso Formation is *Eucelophorus cabrerai*) the provenance are uncertain (Deschamps et al., 2012). *P. homogenidens* and *Palaeocavia* sp., are reported by Goin et al. (2000), Verzi and Montalvo (2008) and Verzi et al. (2008) from deposits of the Cerro Azul Formation (La Pampa Province), assigned to the Huayquerian Stage/Age (late Miocene).

The new findings and the analysis of previous collections confirm the record of *Palaeocavia* sp. and *T. pascuali*, *A. palmeri* and *S. bahiai* in different levels of the Monte Hermoso Formation including both in the biozones of *T. gaudryi* and *N. depressidens*.

N. hermosicus, *M. caroloameghinoi*, *P. argentinus*, *P. antiquus*, *D. robustum*, *A. vetustum* and *N. depressidens* are known only through their holotypes. Particularly that of *N. depressidens*, which defines the homonymous biozone, is lost and the original description by Parodi and Kraglievich (1948) shows no details that allow comparison with new specimens, in order to refine its relationships to other caviids (Montalvo and Rocha, 2003). In this regard, Deschamps (2003) suggested not using members of Caviidae in biostratigraphic analyses until they are revised, and their validity is confirmed, as well as their intraspecific variation.

Until recently, both *A. formosus* and *N. bonapartei* have been also represented only by their holotypes. New materials of these taxa were found in the Fl facies (Tomassini and Pardiñas, 2010; Tomassini and Montalvo, 2013). According to Pardiñas et al. (2008), the generic status of these two Sigmodontinae (Cricetidae) is debatable. Montalvo (2004), Verzi and Montalvo (2008) and Montalvo et al. (2009) reported sigmodontines in deposits of the Cerro Azul Formation.

Revisions of Vucetich et al. (2005, 2012, in press) of fossil capybaras (Hydrocheridae), that include specimens from the Monte Hermoso Formation, suggested that *Phugatherium cataclisticum* and *Anchimysops villalobosi* represent juvenile specimens of *Chapalmatherium perturbidum* (=*Protohydrochoerus perturbidus*; see Prado et al., 1998). If this is confirmed, the valid name for the species would be *P. cataclisticum*. In any case, these three taxa are represented in the Monte Hermoso Formation as a whole, and in the "Irene Formation" of the Quequén Salado River, but not in the Chapadmalal Formation (Deschamps et al., 2012).

The materials of the notoungulate *A. vetustum* show dental characters that suggest it is a junior synonym of *Toxodon chapalmalensis* (Oliva, pers. communication), a taxon represented both in the Montehermosan Stage/Age (*T. gaudryi* Biozone) of Farola Monte Hermoso, and the upper Chapadmalalan Stage/Age (*Paraglyptodon chapalmalensis* Biozone) from the area of Mar del Plata-Miramar.

In the revision of the materials of *Nopachtus* from the late Miocene–Pliocene of Argentina, which includes specimens from the Monte Hermoso Formation, Zamorano et al. (2011) stated that the single species represented in the Monte Hermoso Formation is *Nopachtus cabrerai*. The remains assigned to *N. coagmentatus* from this formation belong to *Phlyctaenophyga trouessarti*. In turn, Cruz (2011) said that all the remains assigned to *Nopachtus* found in the Buenos Aires Province should be included in *Phlyctaenophyga*.

T. gaudryi, *P. antiquus*, *D. robustum*, *N. coagmentatus* and *A. vetustum*, considered by Cione and Tonni (2005) as exclusive of the *T. gaudryi* Biozone, are macromammals whose body mass exceeds largely 100 kg (Tomassini, 2012). Taphonomic studies of the faunistic assemblage of the Monte Hermoso Formation (Tomassini, 2012; Tomassini and Montalvo, 2013) suggested that the absence of these taxa in the upper levels of this formation, included by Cione and Tonni (2005) in the *N. depressidens* Biozone, would be actually related to a bias in the preservation of large mammals remains. This bias would result from the particular features of the subenvironment represented in these deposits and the effects of taphonomic processes. The distribution displayed by the macromammals *T. chapalmalensis* and *Eosclerocalyptus lineatus*, also absent in the *N. depressidens* Biozone, but represented both in the previous and the following biostratigraphic units (*T. gaudryi* and *P. chapalmalensis* biozones, respectively) would support this interpretation.

Taxonomic evidence recorded during this work, and the analysis of previous collections (Appendix 1), reflect no important faunistic variations between the levels of the Monte Hermoso Formation that would imply significant chronological differences, and hence, justify a division of two different biostratigraphic units. The new records and the detailed evaluation of the taxa considered as exclusive, as well as the first and last records do not support the validity of the *T. gaudryi* and *N. depressidens* biozones previously proposed. On the other hand, as stated by some authors (e.g.

Table 1
List of vertebrates represented in the facies of the Monte Hermoso Formation and NISP values for each taxon.

Taxa	Monte Hermoso Formation (Zavala, 1993)					
	Facies Fl NISP	Facies Fm NISP	Facies St NISP	Facies Sr NISP	Facies Fsc NISP	Facies Fcf NISP
Class Osteichthyes						
Osteichthyes indet.	5	5	52	30		1
Siluriformes indet.			2			
Trichomycteridae indet.	4		5	3		
Percichthyidae indet.	13		24	3		
Characidae indet.	2					
Class Amphibia						
Anura indet.	2		4			2
Bufonidae indet.			1			
Rhinella cf. *R. pisanoi*		1				
Ceratophrys ameghinorum	3	1	1			1
Lepidobatrachus laevis			1			
Class Reptilia						
Chelonoidis cf. *Ch. australis*	2	2	1			
Tupinambis sp.	3	2	3			1
Colubridae indet.	1		1			1
Class Aves						
Aves indet.	2		1	1		2
Dendrocygninae indet.	1					
Eudromia cf. *E. elegans*	1		1			
Mesembriornis milneedwardsi	1		1			
Chunga incerta	1					
Class Mammalia						
Mammalia indet.	26	18	48	4	5	9
Thylatheridium pascuali	1					
Lutreolina sp.	1					
Hyperdidelphys inexpectata	1		1			1
Sparassocynus sp.	1					
Argyrolagus palmeri	1					1
Macrochorobates chapalmalensis	1					
Holozaedyus laevisculptus	2		2			
Doellotatus inornatus	2	1	4		1	2
Plaina cf. *P. intermedia*	1		1			
Glyptodontidae indet.	7	3	1	1	1	
Plohophorus figuratus	4	2	2			1
Eleutherocercus antiquus	2		1			1
Proscelidodon cf. *P. patrius*	6			1		1
Lestodon sp.	1					
Rodentia indet.	18	5	36		4	13
Pithanotomys columnaris	2		2			2
Neophanomys sp.	1					
Actenomys priscus	14	11	13	2	1	14
Eumysops laeviplicatus	3		3			1
Paramyocastor diligens	2	1	3			1
Lagostomus incises	2		3			2
Caviidae indet.	1		8	2		
Palaeocavia sp.	2	1	2			1
Neocavia sp.	1					
Orthomyctera sp.	2		1			
Prodolichotis sp.			1			
Caviodon australis	1					1
Caviodon sp.			1			
Phugatherium cataclisticum	2	1	2			1
Cricetidae indet.			1	1		1
Sigmodontinae gen. et. sp. nov.			1			
Necromys bonapartei	1					
Auliscomys formosus	2					
Paedotherium sp.	33	26	27	1	1	17
Paedotherium bonaerense	8	2	6		1	7
Paedotherium typicum	5	1	4			2
Tremacyllus impressus	2	1	2		1	1
Pseudotypotherium sp.	11	2	3		1	4
Toxodontidae indet.	6					
Toxodon chapalmalensis	1					
Proterotheriidae indet.			1			1
Aff. *Diplasiotherium robustum*	1					
Eoauchenia cf. *E. primitiva*	1		1			1
Macraucheniidae indet.	2	1				1

Table 1 (*continued*)

Taxa	Monte Hermoso Formation (Zavala, 1993)					
	Facies Fl NISP	Facies Fm NISP	Facies St NISP	Facies Sr NISP	Facies Fsc NISP	Facies Fcf NISP
Promacrauchenia antiqua	1					
Total	**223**	**87**	**279**	**49**	**16**	**95**

Bonaparte, 1960; Deschamps et al., 2012; Olivares et al., 2012), the mammals recovered from the upper deposits of this formation (St, Sr, Fsc and Fcf facies) do not show a greater similarity with those from the Chapadmalal Formation (upper Chapadmalalan Stage/Age). Consequently, the relationship of these levels with the Chapadmalalan Stage/Age is not supported, nor the subdivision of the latter into lower and upper.

This agrees with the view expressed by Zavala and Navarro (1993), who stated that the discontinuity between both units recognized for the Monte Hermoso Formation belongs to a contact surface originated by migration of a high-sinuosity fluvial channel over the surrounding floodplain deposits. Hence, these levels would be genetically related and the temporal difference between them would not be significant.

Thus, based on the above, a new scheme for the Monte Hermoso Formation at its type locality is proposed. It includes the recognition of a single biostratigraphic unit, the *Eumysops laeviplicatus* Range Zone.

6.2. Range zone of *Eumysops laeviplicatus* Ameghino, 1888

Definition: It is a taxon-ranged zone based on the occurrence of *E. laeviplicatus* (Fig. 5A–C).

Type locality: Farola Monte Hermoso (S 38°58′01″, W 61°41′43″), Coronel Rosales, Buenos Aires Province, Argentina.

Type profile – stratotype: Represented in Fig. 2, encompasses the whole thickness of the Monte Hermoso Formation (sensu Zavala, 1993) at its type locality.

Characteristic assemblage: Numerous specimens of *A. priscus*, *Paedotherium bonaerense* and *Paedotherium typicum*, *Tremacyllus impressus*, *Doellotatus inornatus*, *Eoauchenia primitiva*, *Pseudotypotherium* sp. and *Plohophorus figuratus* were recorded in the different levels of the Monte Hermoso Formation. The marsupials *Hyperdidelphys inexpectata*, *S. bahiai* and *A. palmeri* were not recorded in any other Stage/Age, but they are not considered as biostratigraphic indicators because their record is not frequent in this formation, and the specimens with precise stratigraphic provenance are scarce. At this state of knowledge, *Pithanotomys columnaris* is exclusive for this biozone but this taxon is in need of taxonomic revision (Verzi et al., 2002; Verzi and Quintana, 2005). As well, although *P. cataclisticum* and *C. perturbidum* are exclusive of this biozone, they are not included in this category because they are currently under revision, probably being juvenile and adults of the same species (Deschamps et al., 2012; Vucetich et al., 2012).

Boundaries and stratigraphic relationships: The lower boundary was not defined because the base of the unit is not exposed. The upper boundary is represented by the discontinuity between the Monte Hermoso and Puerto Belgrano formations. In this way, the biozone coincides spatially in Farola Monte Hermoso with the "Piso Hermósico" or "Hermosense" of Ameghino (1889, 1908), with the "Hermosense" of Frenguelli (1928) and with the Monte Hermoso Formation of Zavala (1993).

Age: It is the biostratigraphic base for the Montehermosan Stage/Age and is assigned to the early Pliocene.

Remarks: According to the International Stratigraphic Guide (ISSC, 1999), this biozone is recognized in all those sections and localities where *E. laeviplicatus* is recorded. However, in view of the geographic distribution so far known of this taxon (Olivares, 2009; Olivares et al., 2012) and the absence of evidence that allows precise correlations with units and faunistic associations from other regions of Argentina, the definition of the *E. laeviplicatus* Zone has a specific application within the Pampean Region.

The choice of *E. laeviplicatus* (Echimyidae, Eumysopinae) as the exclusive taxon for the definition of this new biozone is based on the following criteria: 1) the recognition of rodents as significant biochronological and biostratigraphical indicators (Cuenca-Bescós et al., 1997, 2010; Vianey-Liaud et al., 2011); 2) the precise taxonomic classification based on recent, detailed assessments from anatomical and systematical views (Olivares, 2009; Olivares et al., 2012); 3) the existence of several clearly identifiable specimens; 4) the precise stratigraphic provenance, in some cases at the facies level, and accurate representation in the different levels of the

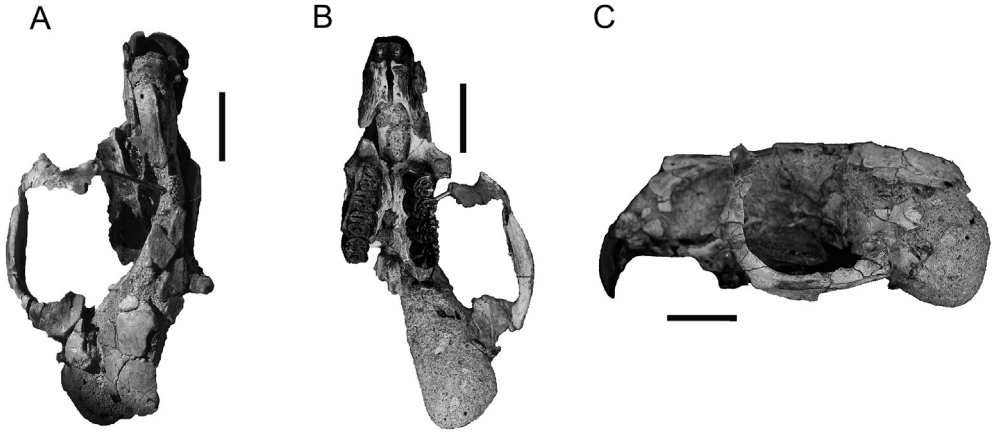

Fig. 5. Holotype of *Eumysops laeviplicatus* (MACN-A 1623), from the Monte Hermoso Formation. A. Dorsal view. B. Ventral view. C. Lateral view. Scale = 1 cm.

Monte Hermoso Formation. In this sense, the new materials were recovered from the Fl, St and Fcf facies of this formation (Table 1); 5) the absence of this taxon in the preceding and succeeding biostratigraphic units within the Pampean Region (Fig. 6). Olivares (2009) and Olivares et al. (2012) stated that although eumysopines are very common and diverse in the Huayquerian Stage/Age, *Eumysops* is not recorded. On the other hand, regarding the abundance of remains of *Eumysops chapalmalensis* and *Eumysops gracilis* in the Chapadmalalan Stage/Age, these authors indicated that the absence of *E. laeviplicatus* in such levels is related to a real pattern and not to a bias in the fossil record; and 6) the presence of this taxon in other fossiliferous localities of the Pampean Region assigned to the same interval, such as Cascada Grande on the Quequén Salado River (Oliva et al., 2010; Olivares et al., 2012) and possibly also Paso Otero on the Quequén Grande River (Prado and Cerdeño, 1998). However, the materials from Paso Otero, not illustrated in the original publication, could not be revised in order to verify the taxonomic determination.

Tomassini (2012) and Tomassini and Montalvo (2013) stated that the remains found in the fluvial sediments of the Monte Hermoso Formation were incorporated into the substrate gradually and later they were affected by different taphonomical processes, according to the peculiar characteristics of the depositional context in which they were preserved. On this basis, these authors recognized the existence of different taphonomical modes for the levels of this unit. Additionally, they suggested that the time involved in the formation of the assemblages of each of these modes, was not significant. This is in agreement with Zavala and Navarro (1993) who proposed little chronological variation between the different levels of the Monte Hermoso Formation. In this regard, according to Behrensmeyer and Chapman (1993), the minimum time necessary for a land-vertebrates taphocoenosis to be formed through the attritional accumulation of remains, would be approximately 10^2 years. In turn, Behrensmeyer and Hook (1992) suggested that the maximal temporal resolution for vertebrate assemblages preserved in fluvial environments would be approximately 10^5 years.

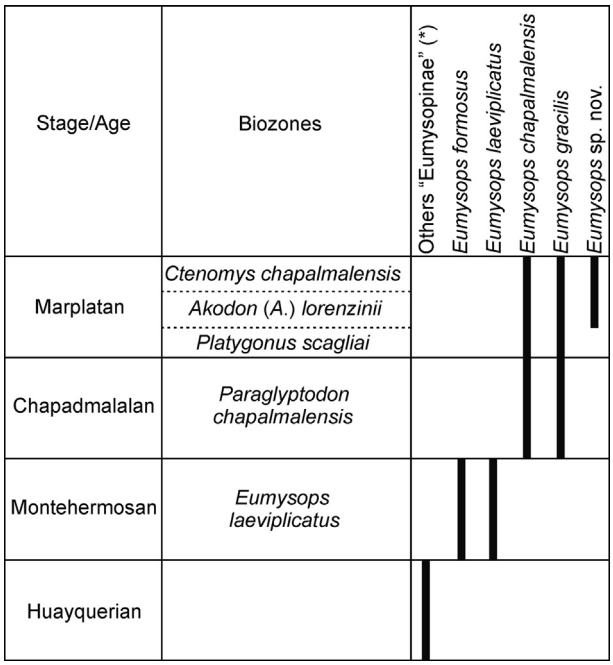

Fig. 6. Biostratigraphic range of the different species of *Eumysops* in the Pampean Region (modified from Deschamps et al., 2012). (*) Includes *Pampamys emmonsae*, *Reigechimys plesiodon*, *Reigechimys octodontiformis*, *Theridomysops parvulus* and aff. *Clyomys*.

Moreover, considering that *A. priscus* (Rodentia, Ctenomyidae) belongs to the *Xenodontomys–Actenomys* lineage, characterized by an anagenetic pattern of evolutionary change, with quick changes in short lapses (Verzi, 2008 and literature therein), the absence of significant morphological change in the specimens of this taxon found in the Monte Hermoso Formation would be in support of the idea of a short interval for this unit. In addition, when these materials are compared to specimens of *A. priscus* found in levels assigned to the Chapadmalalan Stage/Age (from the area of Mar del Plata-Miramar) the latter display a more derived dental morphology (Deschamps, 2003; Tomassini, pers. observation).

Schultz et al. (2006) reported a numerical age from fragments of "escorias" of Cantera Vialidad, near Bahía Blanca (Buenos Aires Province), 45 km northwest from Farola Monte Hermoso, of 5.28 ± 0.04 Ma for the middle level of the profile. A few fossil remains (*Xenodontomys* sp., *Paedotherium* sp. and *Chorobates villosissimus*) were found in these and in the overlying levels, which can be assigned to the Huayquerian Stage/Age (late Miocene) mainly by the record of the ctenomyine rodent *Xenodontomys* sp. (Verzi, pers. communication). According to the evolutionary pattern proposed for this genus (Verzi, 2002, 2008), the especimens of Cantera Vialidad would be morphologically not as derived as *X. elongatus* from the Cerro Azul Formation (Caleufú, La Pampa; Verzi et al., 2003), and consequently, somewhat older than the latter. Differences concerning the composition of the assemblages and the evolutionary stage of some taxa, particularly caviomorph rodents, suggest that the fauna recorded in the Monte Hermoso Formation is more modern than those from Cantera Vialidad, Caleufú and other localities of the region (e.g. Cantera Seminario, Barrancas de Sarmiento, some levels of the "Irene Formation"; Deschamps, 2005; Verzi et al., 2008; Verzi and Montalvo, 2008) which were assigned to the Huayquerian Stage/Age.

Besides, at the cliffs exposed between Mar del Plata and Miramar, on the basis of magnetostratigraphic studies (Orgeira and Valencio, 1984), and a numerical age obtained from "escorias" of the upper sector of the profile that yielded 3.27 ± 0.08 Ma (Schultz et al., 1998), Zárate (2005) proposed that the levels bearing vertebrate remains assigned to the Chapadmalalan Stage/Age (Playa San Carlos and Playa Los Lobos alloformations), would have been deposited between 4.5/5.0 Ma (paleomagnetic correlations) and 3.2 Ma. The faunal evidence shows clearly that these assemblages are younger than those of the Monte Hermoso Formation (e.g. Kraglievich, 1934; Prado and Ortiz Jaureguizar, 1989; Deschamps et al., 2012).

Based on the foregoing premises, the age of the *E. laeviplicatus* Zone is estimated as representing a brief lapse. Considering that there are neither numerical ages nor magnetostratigraphical studies for the Monte Hermoso Formation, the precise extension of this lapse and its correlation to the chronological scale cannot be currently defined. However, on the basis of the numerical ages obtained for Cantera Vialidad and Chapadmalal, this lapse would be included within a temporal range whose approximate boundaries are <5.28 Ma and 4.5/5.0 Ma.

The Miocene–Pliocene boundary is proposed as 5.333 Ma (ICC, 2012), hence, the *E. laeviplicatus* Zone, representing the biostratigraphic base for the Montehermosan Stage/Age, would be early Pliocene (Fig. 7). This new biostratigraphic unit is correlated within the Pampean Region, with the *A. priscus–Plohophorus cuneiformis* Biozone, defined by Deschamps (2005) at Las Obscuras (Buenos Aires, Province, Argentina), about 25 km north of Farola Monte Hermoso, and assigned to the lower Montehermosan (early Pliocene). However, the validity of these taxa to define this biozone is currently under revision.

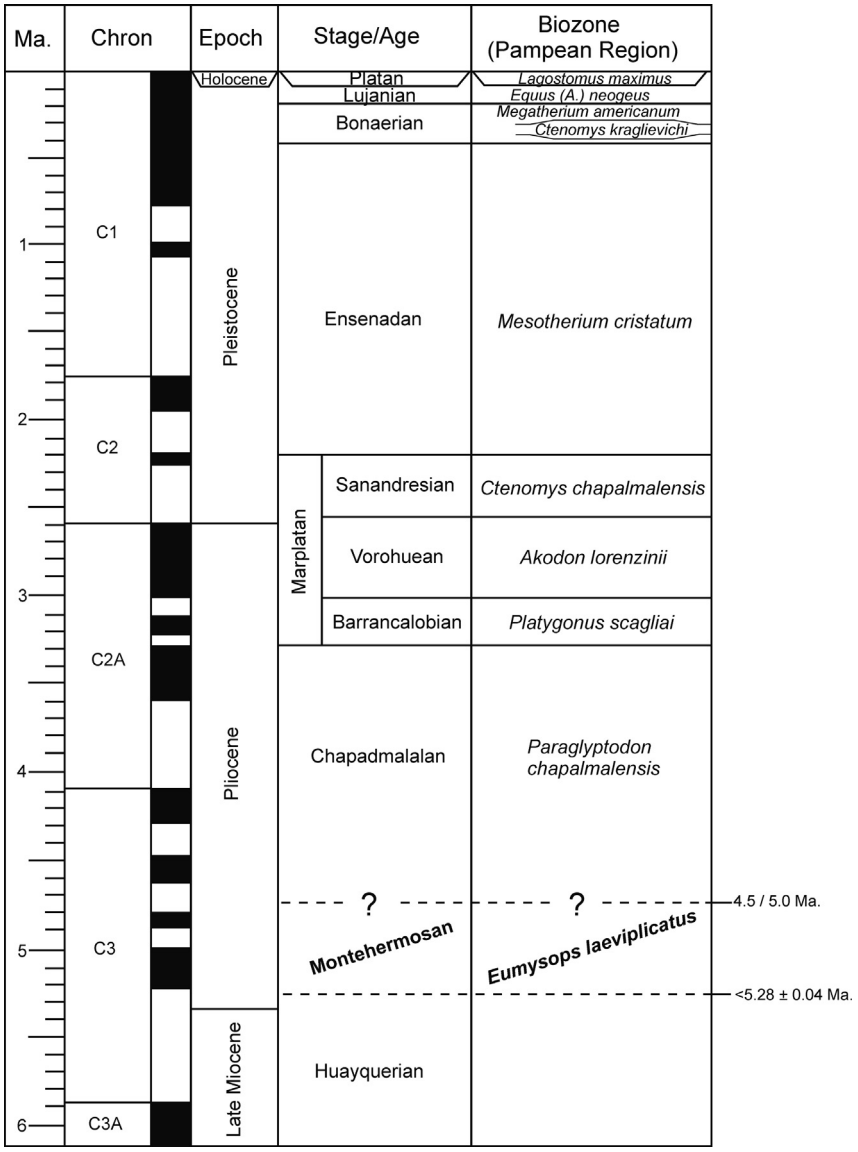

Fig. 7. Biostratigraphic scheme of the late Cenozoic of the Pampean Region, including the *Eumysops laeviplicatus* Zone defined in this paper. Modified from Cione and Tonni, 2005; Cione et al., 2007.

7. Conclusions

The discovery of new specimens, together with the detailed evaluation of specimens of previous collections, all of them with accurate stratigraphic provenance, allowed the proposal of a new biostratigraphic scheme for the Monte Hermoso Formation, at its type locality of Farola Monte Hermoso (Pampean Region, Argentina). This scheme recognizes a single unit, the *E. laeviplicatus* Range Zone, which represents the biostratigraphic basis for the Montehermosan Stage/Age and corresponds to the early Pliocene.

Several authors (e.g. Cione et al., 2007; Zárate et al., 2007) have pointed out the necessity of a strong revision of the biostratigraphic units defined for the late Cenozoic of Argentina. In this sense, this proposal provides a new framework for biostratigraphic comparisons and correlations with other fossiliferous localities of Argentina, mainly in the Pampean Region (e.g. Caleufú, Balneario Saldungaray, Dique Paso Piedras, Las Obscuras, Cascada Grande, Indio Rico, Paso Otero), that contain deposits and faunistic assemblages related to this interval.

The boundaries estimated here for the *E. laeviplicatus* Biozone, and their relationships with the other biostratigraphic units recognized in the Pampean Region, do not support the extension of the Montehermosan Stage/Age up to ca. 6.8/7.0 Ma (late Miocene) previously proposed (e.g. Cione and Tonni, 2005; Cione et al., 2007; Reguero and Candela, 2010). In this regard, it is noteworthy that these ages were proposed on the basis of numerical ages obtained in deposits of other regions of Argentina (e.g. western and northwestern) that yielded faunas clearly different from the one recorded in the Monte Hermoso Formation. In fact, these other faunas show more similarities with the assemblages of the Pampean Region assigned to the Huayquerian Stage/Age than with those of the Montehermosan Stage/Age.

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and help with the taxonomic identifications. I. Olivares provided the photographs of the holotype of *E. laeviplicatus*. Comments of D. Verzi and an anonymous reviewer certainly improved the manuscript. We are especially grateful to the late V. Di Martino for his valuable assistance during field work. This research was supported by CONICET and grants PGI 24/H119 (UNS), 209 (Facultad de Ciencias Exactas y Naturales, UNLPam) and 11/N674 (UNLP).

Appendix 1

Systematic list and provenance of the vertebrate taxa recovered in the Monte Hermoso Formation. Black circles, specimens with precise stratigraphic provenance collected between 2007 and 2012. White circles, specimens with precise stratigraphic provenance of previous collections. White circles with question marks, specimens with dubious stratigraphic provenance of previous collections. Question marks, specimens with uncertain stratigraphic provenance of previous collections.

Taxa	Monte Hermoso Formation facies					
	Fl	Fm	St	Sr	Fsc	Fcf
Class Osteichthyes						
Order Siluriformes						
Siluriformes indet.	○		●			
Trichomycteridae indet.	●		●	●		
Order Perciformes						
Percichthyidae indet.	●		●	●		○
Order Characiformes						
Characidae indet.	●					
Class Amphibia						
Order Anura						
Rhinella cf. *R. pisanoi* Casamiquela, 1967		●				
Rhinella cf. *R. schneideri* Werner, 1894	?					
Ceratophrys ameghinorum Fernicola, 2001	●	●	●			●
Lepidobatrachus laevis Budgett, 1899			●			
Class Reptilia						
Order Chelonii						
Chelonoidis australis (Moreno, 1889)	?					
Chelonoidis cf. *Ch. australis*	●	●	●			
Order Squamata						
Tupinambis sp.	●	●	●			●
Callopistes bicuspidatus Chani, 1976	?					
Colubridae indet.	●		●			●
aff. *Bothrops*	?					
Boa sp.	?					
Class Aves						
Order Anseriformes						
Dendrocygninae indet.	●					
Order Tinamiformes						
Nothura parvula Tambussi, 1989	○					○
Eudromia cf. *E. elegans*	●		●			○
Eudromia olsoni Tambussi and Tonni, 1985	?					
Order Rheiformes						
Heterorhea dabbenei Rovereto, 1914	?					
Hinasuri nehuensis Tambussi, 1995	?					
Order Ralliformes						
Mesembriornis milneedwardsi Moreno and Mercerat, 1891	●		●			
Chunga incerta Tonni, 1974	●					
Order Ciconiiformes						
Vultur gryphus Linnaeus, 1758	?					
Dryornis pampeanus Moreno and Mercerat, 1891	?					
Class Mammalia						
Order Didelphimorphia						
Thylatheridium pascuali Reig, 1958	●		○			
Thylamys contrerasi Mones, 1980	○?					
Thylophorops aff. *T. perplana* Ameghino, 1904	?					
Lutreolina tracheia Rovereto, 1914	?					
Lutreolina biforata Rovereto, 1914	?					
Lutreolina sp.	●					
Hyperdidelphys inexpectata Ameghino, 1889	●		●			●

(*continued*)

Taxa	Monte Hermoso Formation facies					
	Fl	Fm	St	Sr	Fsc	Fcf
Hyperdidelphys parvula Rovereto, 1914	○?		○			
Sparassocynus bahiai Mercerat, 1899	○					○
Sparassocynus sp.	●					
Order Sparassodonta						
Notocynus hermosicus Mercerat, 1891	?					
Achlysictis lelongi Ameghino, 1891	?					
Order Polydolopimorphia						
Argyrolagus palmeri Ameghino, 1904	●					●
Microtragulus argentinus Ameghino, 1904	?					
Order Cingulata						
Euphractini sp. "a" nov. Scillato-Yané, 1982	?					
Holozaedyus laevisculptus Rovereto, 1914	●		●			○
Macrochorobates chapalmalensis Scillato-Yané, 1980	●					○
Chorobates villosissimus (Rovereto, 1914) Reig, 1958	?					
Chorobates rescens (Ameghino, 1887) Reig, 1958	○		○			○?
Macroeuphractus retusus Ameghino, 1887	○					○
"*Eutatus*" *praepampaeus* Ameghino, 1904	?					
Doellotatus inornatus (Rovereto, 1914) Bordas, 1932	●	●	●		●	●
Doellotatus chapadmalensis Bordas, 1933	○					○
Ringueletia simpsoni (Bordas, 1933) Reig, 1958	○		○			○
Plaina cf. *P. intermedia* Castellanos, 1937	●		●			
Pampatherium sp.	?					
Eosclerocalyptus lineatus Ameghino, 1888	○					
Trachycalyptus nov. sp. Scillato-Yané et al., 1995	?					
Nopachtus cabrerai Zamorano et al., 2011	○					
Plohophorus figuratus Ameghino, 1887	●	●	●			●
Plohophorus cuneiformis Ameghino, 1904	?					
Plohophorus sygmaturus Ameghino, 1895	?					
Plohophorus coronatus Rovereto, 1914	?					
Plohophoroides sp.	?					
Phlyctaenopyga trouessarti (Moreno, 1888)	?					
Eleutherocercus antiquus (Ameghino, 1887)	●		●			●
Palaeodaedicurus antiquus Ameghino, 1889	?					
Order Tardigrada						
Proscelidodon patrius Ameghino, 1889	○?					○?
Proscelidodon cf. *P. patrius*	●			●		●
Lestodon sp.	●					
Diheterocnus sp.	?					
"*Plesiomegatherium*" *gaudryi* Moreno, 1888	?					
Myrmecophaga caroloameghinoi Kraglievich, 1934	?					
Order Rodentia						
Phtoramys homogenidens Ameghino, 1887	?					
aff. *Neophanomys biplicatus* Rovereto, 1914	?					
Neophanomys sp.	●					
Pithanotomys columnaris Ameghino, 1887	●		●			●
Pithanotomys macer Ameghino, 1888	?					
Pseudoplataeomys formosus Kraglievich, 1934	?					
Eucelophorus cabrerai Kraglievich, 1927	?					
Actenomys priscus (Owen, 1840)	●	●	●	●	●	●
Eumysops laeviplicatus Ameghino, 1888	●		●			●
Eumysops formosus Ameghino, 1906	○?					
Paramyocastor diligens (Ameghino, 1888)	●	●	●			●
"*Tribodon clemens*" Ameghino, 1887	?					
Lagostomus (*Lagostomopsis*) *incisus* (Ameghino, 1888)	●		●			●
Palaeocavia sp.	●	●	●			●
Neocavia depressidens Parodi and Kraglievich, 1948						○?
Neocavia sp.	●					
Microcavia sp.	?					
Orthomyctera sp.	●		●			○
Prodolichotis sp.			●			
Caviodon australis (Ameghino, 1888)	●					●
Caviodon sp.			●			
Cardiomys sp.	○?					○?
Phugatherium cataclisticum Ameghino, 1889	●	●	●			●
Telicomys giganteus Ameghino, 1904	?					
Sigmodontinae gen. et. sp. nov. Tomassini, 2012			●			
Phyllotini gen. et. sp. nov. Bond et al., 1998						○?
Necromys bonapartei Reig, 1978	●					○?
Auliscomys formosus Reig, 1978	●					
Reithrodon auritus (Fischer, 1814)						○?
Order Notoungulata						
Paedotherium bonaerense Ameghino, 1887	●	●	●		●	●
Paedotherium typicum Ameghino, 1887	●	●	●			●

(*continued*)

Taxa	Monte Hermoso Formation facies					
	Fl	Fm	St	Sr	Fsc	Fcf
Tremacyllus impressus Ameghino, 1888	●	●	●		●	●
Pseudotypotherium sp.	●	●	●		●	●
Toxodon chapalmalensis Ameghino, 1908	●					
Alitoxodon vetustum Rovereto, 1914	?					
Trigodon gaudryi Ameghino, 1882	○?					
Trigodon minor Rovereto, 1914	○?					
Xotodon prominens Ameghino, 1889	○?					
Xotodon ambrosetti Rovereto, 1914	○?					
Xotodon sp.	○					○?
Order Litopterna						
Eoauchenia primitiva Ameghino, 1887	○					○
Eoauchenia cf. *E. primitiva*	●		●			●
Epitherium laternarium Ameghino, 1888	○?					
Diplasiotherium robustum Rovereto, 1914	?					
Aff. *Diplasiotherium robustum*	●					
Promacrauchenia antiqua Ameghino, 1889	●		○			○
Promacrauchenia kraglievichi Parodi, 1931						○?
Order Carnivora						
Parahyaenodon argentinus Ameghino, 1904	?					
Tetraprothomo argentinus Ameghino, 1908	?					
Cyonasua clausa Ameghino, 1904	?					
cf. *Cyonasua*						○?

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