Paleontology and stratigraphy of the Aisol Formation (Neogene), San Rafael, Mendoza

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ABSTRACT

A preliminary analysis of the geology and paleontology of the Aisol Formation is presented upon new fieldwork that started in 2007. Three different sections are recognized within the Aisol Formation, with fossil vertebrates in the lower (LS) and middle (MS) sections. The faunal association of the LS includes: Anura indet., two indeterminate species of *Chelonoidis* (Testudininae), Phorusrhacidae indet., Mylodontidae indet., Planopinae indet., Glyptodontidae indet., Propalaeohoplophorinae indet., Nesodontinae indet., *Palyeidodon* cf. *P. obtusum* (Haplodontheriinae), *Hegetotherium* sp. (Hegetotheriidae), *Protypotherium* sp. (Interatheriidae), cf. *Theosodon* (Macraucheniidae), and *Prolagostomus* or *Pliolagostomus* (Chinchillidae), suggesting a middle Miocene age (probably Friasian *s.s.* or Colloncuran SALMAs (South American Land Mammal Age) following the scheme from Patagonia). The vertebrate association of the MS includes: *Hesperocynus dolgopolae* (Sparassocynidae), *Tremacyllus* sp., Dolichotinae indet., Abrocomidae indet., and Ctenomyidae indet., suggesting at least a late Miocene age (Huayquerian SALMA). The new discoveries increase considerably the vertebrate fossil record of the Aisol Formation and argue in favour of at least two different levels of dissimilar age; this view is also supported by geological data.

Keywords: fossil vertebrates - Geology - Miocene - Mendoza

RESUMEN

Se presenta un análisis preliminar de la geología y paleontología de la Formación Aisol sobre la base de nuevos trabajos de campo iniciados en 2007. Se han reconocido tres secciones de la Formación Aisol, con fósiles de vertebrados en la sección inferior (LS) y media (MS). La asociación faunística de la LS incluye: Anura indet., dos especies indeterminadas de *Chelonoidis* (Testudininae), Phorusrhacidae indet., Mylodontidae indet., Planopinae indet., Glyptodontidae indet., Propalaeohoplophorinae indet., Nesodontinae indet., *Palyeidodon* cf. *P. obtusum* (Haplodontheriinae), *Hegetotherium* sp. (Hegetotheriidae), *Protypotherium* sp. (Interatheriidae), cf. *Theosodon* (Macraucheniidae) y *Prolagostomus* o *Pliolagostomus* (Chinchillidae), sugiriendo una edad Mioceno Medio (probablemente Friasense *s.s.* o Colloncurense, siguiendo el esquema patagónico). Por otro lado, la asociación faunística de la MS incluye: *Hesperocynus dolgopolae* (Sparassocynidae), *Tremacyllus* sp. (Hegetotheriidae), Dolichotinae indet., Abrocomidae indet., y Ctenomyidae indet., indicando, al menos, una edad Mioceno Tardío (Huayqueriense). Los nuevos hallazgos incrementan considerablemente el registro de vertebrados fósiles para la Formación Aisol y sugieren la presencia de al menos dos secciones con edades distintas, lo cual es también respaldado por datos geológicos.

Palabras clave: vertebrados fósiles - Geología - Mioceno - Mendoza

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INTRODUCTION

Tertiary outcrops in Mendoza Province are extensive, covering around 80% of the total territory (Yrigoyen 1993). Nevertheless, compared with other regions of South America, paleontological studies focused on Tertiary outcrops are still scarce. Among them, the most prolific Tertiary outcrops are those exposed at: Divisadero Largo, including the Divisadero Largo (early? Eocene) and the Mariño (early Miocene) Formations (Minoprio 1947; Simpson and Minoprio 1950; Simpson et al. 1962; Cerdeño et al. 2006, 2008); Quebrada Fiera, correlated with Agua de la Piedra Formation (late Oligocene) (Gorroño et al. 1979; Bond and Pascual 1983); and Huayquerías de Tunuyán and San Carlos, including the Huayquerías (late Miocene) and Tunuyán (Pliocene) Formations (de Carles 1911; Rovereto 1914; Frenguelli 1930; Rusconi 1939; Marshall et al. 1986). In addition, few other fossil vertebrates were collected from other regions such as Valle Grande, including the Aisol Formation (Miocene) and «Estratos del Diamante» (Pliocene), and several Pleistocene localities distributed throughout the province (Rusconi 1945, 1947; Soria 1983; Pascual and De la Fuente 1993; Cerdeño and Vera 2007; Forasiepi et al. 2009a, 2009b).

The Aisol Formation (Miocene) is exposed on the Department of San Rafael (Mendoza Province, Argentina), outcropping in isolated deposits. Early studies of this unit were carried out by geologists Dessanti (1956) and González Díaz (1972), and paleontologist Soria (1983). New fieldwork was started by the authors in the area of Valle Grande in 2007 (Fig. 1), which resulted in the discovery of several new specimens, most of them belonging to mammals. In this contribution, a preliminary analysis of the geology and the fossil vertebrate context of the Aisol Formation is presented.

Abbreviations: MACN, Museo Argentino de Ciencias Naturales «Bernardino Rivadavia» (A, Ameghino collection; PV, Paleontología de Vertebrados collection), Buenos Aires, Argentina; MHNSR–PV, Museo de Historia Natural de San Rafael (Paleontología de Vertebrados collection), San Rafael, Mendoza, Argentina; MLP, Museo de La Plata, La Plata, Buenos Aires, Argentina.

GEOLOGICAL SETTING

The first reference of the Aisol Formation is found in Groeber (1951, 1952), who informally named it «Estratos Calchaquíes». Later, Dessanti (1954, 1956) recognized the levels in the area of El Diamante hill as «Estratos de Aisol». The Aisol Formation was formally recognized by González Díaz (1972) with the type profile outcropping at the left border of the Arroyo Seco de la Frazada river.

The Aisol Formation is exposed mainly on the Bloque de San Rafael, south of the Atuel river, in a 10-km-long cliff (including the vicinities of the Arroyo Seco de la Frazada river and the Aisol hill) that expands south of the Valle Grande lake to the Nihuil hill. Additional, smaller, isolated outcrops are exposed northwest of the Atuel River (including Mina Zitro/Arroyo Cochicó and Tierras Blancas), south of the Nihuil hill (close to the Nihuil town and the Los Cerritos hill), in the vicinity of 25 de Mayo town, and the Río Seco Salado and the Diamante rivers (Dessanti 1954, 1956; González Díaz 1964, 1972; Núñez 1976; Sepúlveda et al. 2001, 2007). At present, the localities that have provided fossil remains include Tierras Blancas, Mina Zitro/Arroyo Cochicó, Aisol hill, and Arroyo Seco de la Frazada (Soria 1983; Fig. 1). Recent fieldwork has revealed that the latter is hitherto the richest fossiliferous locality.

A new profile was taken in the area of the Arroyo Seco de La Frazada (34º54'S 16.1"; 68º29'19.4"W), about 500 m southwest from the stratotype, which permitted to locate the fossils in the stratigraphic column. The new section includes the same stratigraphic sequence as that of the type profile of the Aisol Formation, nonetheless, rocks are better exposed and the thickness is more clearly evident than in the former. González Díaz (1972) recognized 13 different levels; in the new profile, three main sections are distinguished by the major characteristics of the sedimentites (Fig. 2). It is also worth mentioning that some inconsistencies exist between González Díaz's (1972) profile and the new one, such as different thickness or relative grain sizes of the levels. Detailed comparisons with previously published data will be treated in forthcoming studies.

The lower section (LS) of the profile is composed mainly of medium to fine-grained sandstones predominantly grey, reddish, yellow, and less frequently pale green; the entire bed is roughly sub-horizontal. The sandstones are calcite-cemented and the entire bed has strong cross-stratification (Fig. 2), with higher angles towards the middle and upper parts of the section. Between the sandstones, levels of reddish to brownish, fine siltstones are interbedded. The thickness of the siltstone levels is larger towards the lower part of the section. In contrast, towards the upper part, reddish to greenish siltstones intraclasts are frequently found within the sandstones (Fig. 2). The intraclasts are variable in size and their surfaces are mostly rounded. Fossil wood and vertebrate

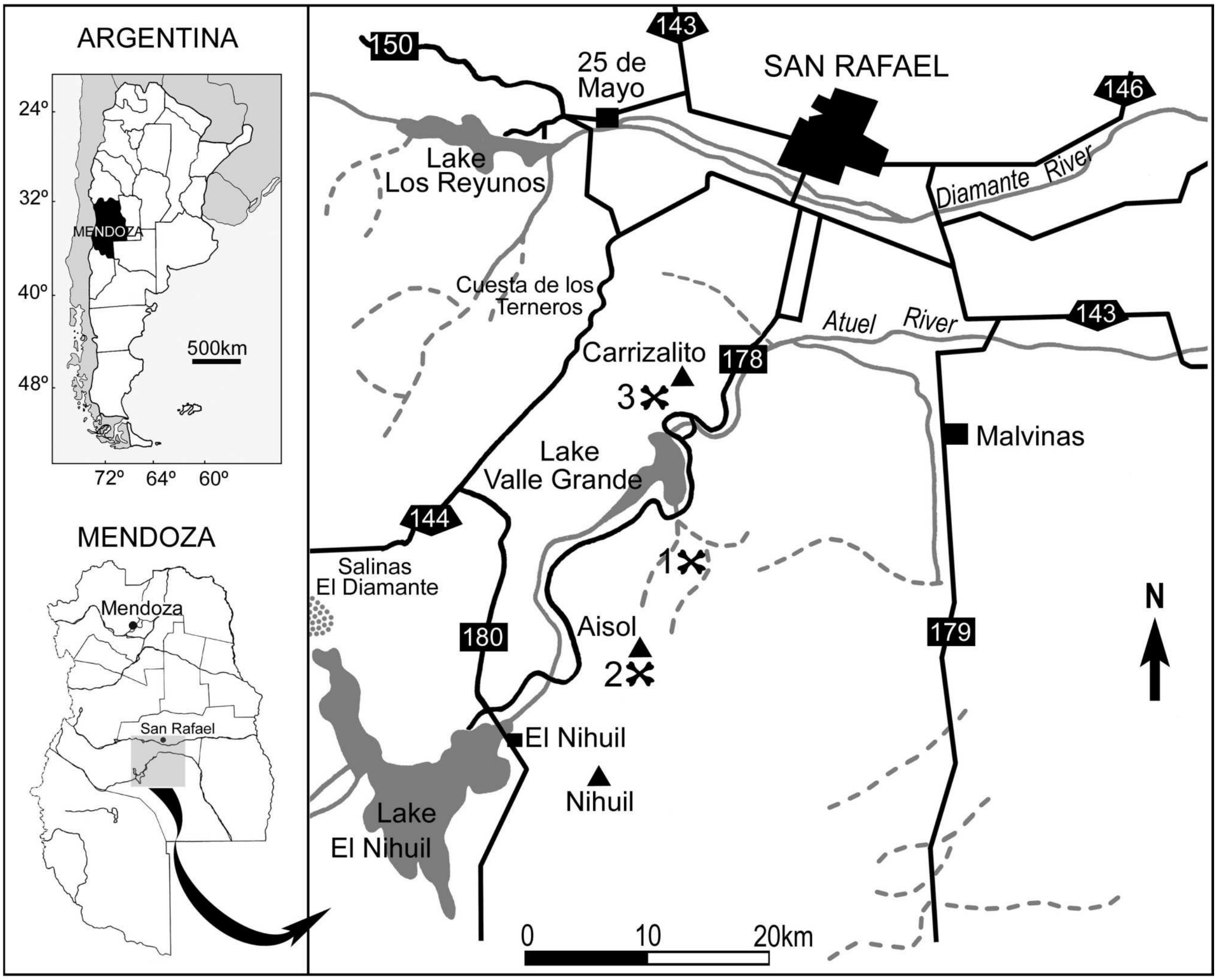

Figure 1. Map of the south central portion of the Mendoza Province, Argentina. Numbers refer to localities with outcrops of the Aisol Formation where fossil remains have been unearthed: 1, Arroyo Seco de la Frazada; 2, Aisol hill; 3, Arroyo Cochicó/Mina Zitro.

remains are common in different parts of the LS. With the exception of the bones found in the siltstone, other material is highly eroded, showing signals of transportation and corrosion of biological organisms. In the area of the profile, the LS is approximately 15 m thick. The base, however, was not observed; it is covered by recent deposits.

The middle section (MS) is composed of fine-grained pebbly lithic sandstones, with good selection. The sandstones are friable and disposed in tabular banks, with low angle inclination (about 4º) to the east (Fig. 2). In the lower and middle parts of the MS, the sandstones include horizontal stratification with intercalation of very fine brownish-reddish mudstone levels, about 1 to 2 cm thick. Mud cracks are found occasionally in the mudstones. In the one-third upper part, the sandstones are massive and the mudstone levels are thicker, about 15 cm (Fig. 2). At first sight, the mudstones provide a brownish-reddish appearance for the entire middle part of the profile. Fossil vertebrates are localized in the two-third lower parts of the section. Unlike the fossils of the LS, fossil material is well preserved, sometimes it is articulated, and lacks signals of transportation. The total thickness of the MS is approximately 8.50 m.

The upper section (US) starts with medium-grained dark sandstones, which at first view stand out from the rest of the US (Fig. 2). Above this level, there is a sand bank of brownish to grayish friable sediments. This bank has horizontal stratification and intercalation of fine levels 15 to 20 cm thick with low angle cross-stratification. The dark sandstones plus the sand bank are about 2.30 m thick. Towards the middle part of the US, there is a

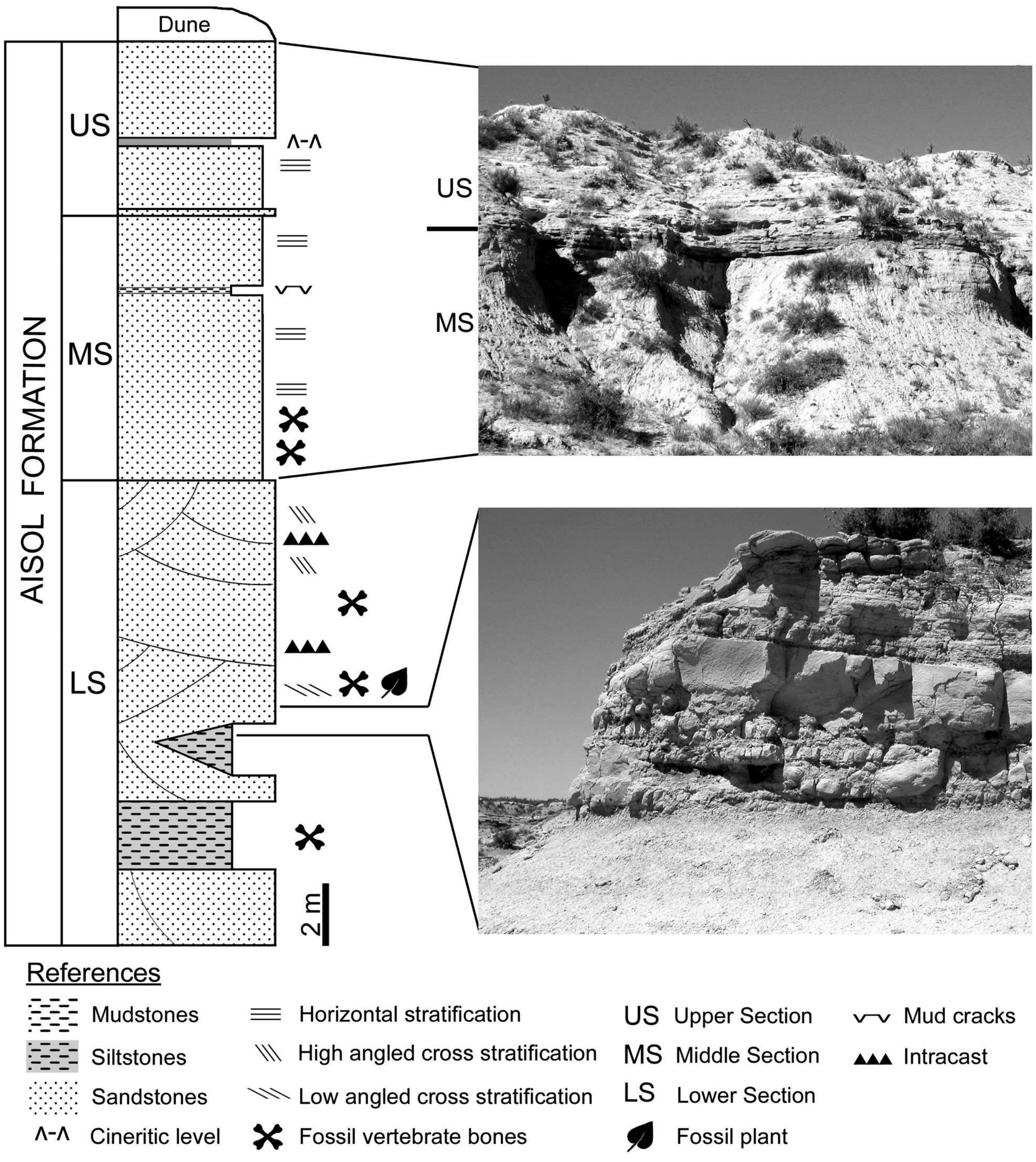

Figure 2. Stratigraphic column of the Aisol Formation in the area of Arroyo Seco de la Frazada, San Rafael, Mendoza.

fine, 10-cm-thick, white cineritic bed, which is continuous along the hill (Fig. 2) and can be used as guide stratum. The upper part of the section ends with 3.20 m of medium-grained, grey sandstones. Until now, no fossil remains have been collected from the US of the profile. The total thickness of the US is approximately 5.6 m and it is unconformably covered by recent dunes.

Preliminary conclusions of the analysis of the profile suggest that the LS would represent an alluvial plain (see also Sepúlveda et al. 2007) with fluvial channels, increasing the energy of the system towards the upper part of the section. Stratigraphically, fossils are abundant, particularly in the fluvial deposits. The sandstones from MS and US, in turn, were deposited in calmer environments. More detailed sedimentary analyses will define the action of lentic waters or even wind as transportation agents. The mineralogical composition of the LS sandstones is much more variable (e.g., quartz, feldspar, fragments of rocks, claystone intraclasts), than that of the MS and US sandstones. The compositional difference plus the already mentioned structural distinction and the different environment in which they were deposited, clearly differentiate the LS from the MS and US. In addition, the sedimentites from the LS are much more consolidated than the rest of the profile, and are now more extensively eroded. These observations together with the fossils (see Discussion) suggest that the LS is much older than the rest of the sequence. Future studies could reveal whether the distinction of members or even the separation of the unit in different formations would be the most appropriate approach to reflect the stratigraphy of the Aisol Formation.

PALEONTOLOGY

The first fossil remains from the Aisol Formation were recovered by field geologists (e.g., Dessanti and Henninger). The material was deposited at MACN and MLP; brief comments were made in geological studies (e.g., Dessanti 1954, 1956; González Díaz 1972). In 1979, Soria organized the first paleontological expedition, the results of which were published in 1983. That paper (Soria 1983) is hitherto the only reference for the fossil vertebrates of the Aisol Formation. According to Soria (1983), the vertebrates occurring in the unit include: probably Crocodilia, probably Psilopteridae (Aves), probably Nesodontinae (Toxodontidae), cf. *Astrapotherium* (Astrapotheriidae), cf. *Theosodon* (Macrauchenidae), indeterminate Propaleohoplophorinae and Hoplophorinae (Glyptodontidae), and indeterminate Megatheriidae and Mylodontidae (Pilosa). Most of the specimens consisted of very fragmentary material (i.e., isolated astragali and vertebrae, partial metapodials, broken teeth, and isolated scutes); thus, the conclusion about the entire vertebrate assemblage was preliminary, based mostly on the mammalian context.

Concomitantly, from the seventies to the eighties, Lagiglia and some colleagues from the MHNSR sporadically collected fossils from the Aisol Formation, which were deposited at that institution. Since 2007, systematic prospecting explorations have been started and new materials have been discovered. In the present contribution, a preliminary analysis of the vertebrates from the Aisol Formation is presented, based upon revision of published data, unpublished specimens of MHNSR, and recently unearthed material.

VERTEBRATES FROM THE LOWER SECTION

Previous fossils collected from the Aisol Formation (Soria 1983) lack precise stratigraphic information. Based on specimen preservation and field observation, we interpret that they come from the LS (Fig. 2). More than 90 new specimens have been collected, including isolated parts of the postcranium, and some fairly complete skulls and dentaries, the most significant of which are mentioned below. Mammals are the most abundant vertebrates, represented by the orders Xenarthra, Notoungulata, Litopterna, and Rodentia. The non-mammalian record is comparatively scarce and includes Anura, Testudines, and Aves.

Anura

The anuran record consists of an isolated vertebra (MHNSR-PV1074) recovered from Arroyo Seco de la Frazada. The vertebral centrum is procoelous and cylindrical, and no nervous foramina nor articular facets of any kind are present. The transverse process is slender and long. This element corresponds to a presacral vertebra, probably a posterior one. The isolated nature of the specimen does not permit allocation in an accurate systematic context; MHNSR-PV1074 is assigned to Anura *incertae sedis*.

Testudines

Remains of two different species of Testudininae were recovered from Mina Zitro and Arroyo Seco de la Frazada. In the first locality, a middle-sized tortoise is represented by a seventh left peripheral bone (MHNSR-PV113) and a right hypo-xiphyplastron (MHNSR-PV121) (De la Fuente 1988). In the second locality, there are two specimens: an almost complete shell (MHNSR-PV1024; Fig. 3A), belonging to the same species of land tortoise from Mina Zitro, and a right femur (MHNSR-PV1064; Fig. 3B) of a giant Testudininae species.

Chelonoidis sp. A. MHNSR-PV1024 includes most of the left side and posterior half of the carapace and almost complete plastron (Fig. 3A). Originally, the carapace would measure about 410 mm in length. The carapace is depressed, oval, without vertebral bosses, and slightly elongated from above. As in almost all testudinines, the proximal end of the second, fourth, and sixth costals

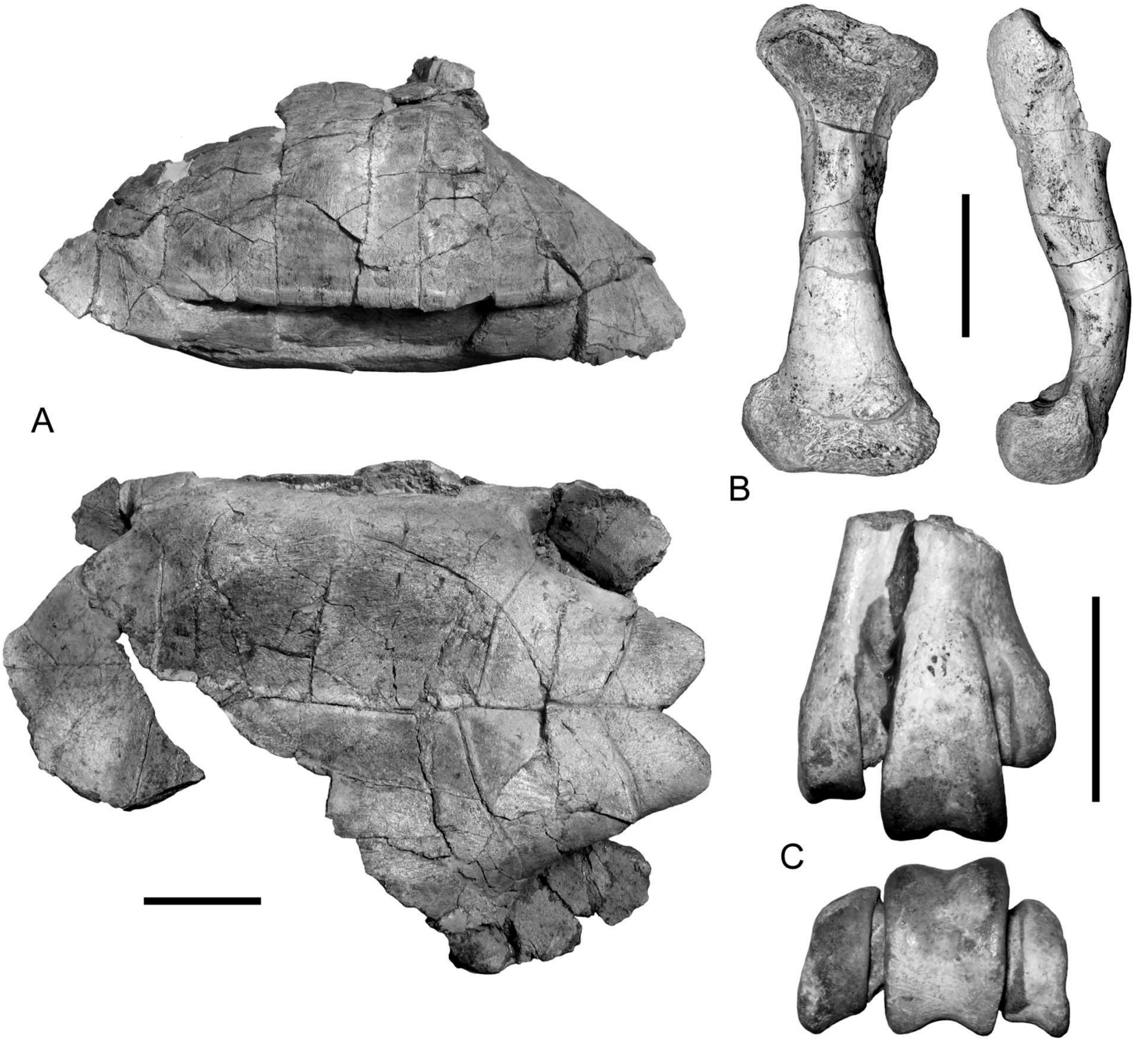

Figure 3. Non-mammalian specimens from LS of the Aisol Formation. A, MHNSR-PV1024, *Chelonoidis* sp. A., carapace and plastron in lateral and ventral views; B, MHNSR-PV1064, *Chelonoidis* sp. B., right femur in dorsal and lateral views (the femoral head is broken); C, MACN-PV18602, distal portion of right tarsometatarsus of Phorusrhacoidea indet. in anterior and distal views. Scale bar = 50 mm.

is much narrower than the proximal end of the adjacent elements. In those proximally narrower costals, the distal portion is expanded. This alternation between wide and narrow costal bones results in a rigid carapace dome. The plastron is 370 mm in length; it is wide with a short anterior lobe. The epiplastral projection is short. The humero-pectoral sulcus is posterior to the entoplastron. The enlargement of the distal portion of the pectoral scutes, seen in the Aisol tortoise, is shared by the extant species of *Chelonoidis* (see Bour 1984). As typical of other tortoises (Auffenberg 1974), the hypoplastron has a process anteriorly and dorsally (axillar process) that articulates with the second peripheral and the first costal bones; while the hypoplastron has a process (inguinal buttress) which usually articulates by sutures with the seventh peripheral and the anterior half of the sixth costal bones. The ratio between the external surface of the base of the xiphyplastron and its basal width (Auffenberg 1971) fits in the variation range that has been measured in the extant *Chelonoidis chilensis* (De la Fuente 1988, 1994). Contrary to *Chelonoidis gringorum*, from the early Miocene of Central Patagonia (see Simpson 1942; De la Fuente 1988, 1994), the inguinal scutes in the Aisol specimens (MHNSR-PV121 and MHNSR-PV1024) are

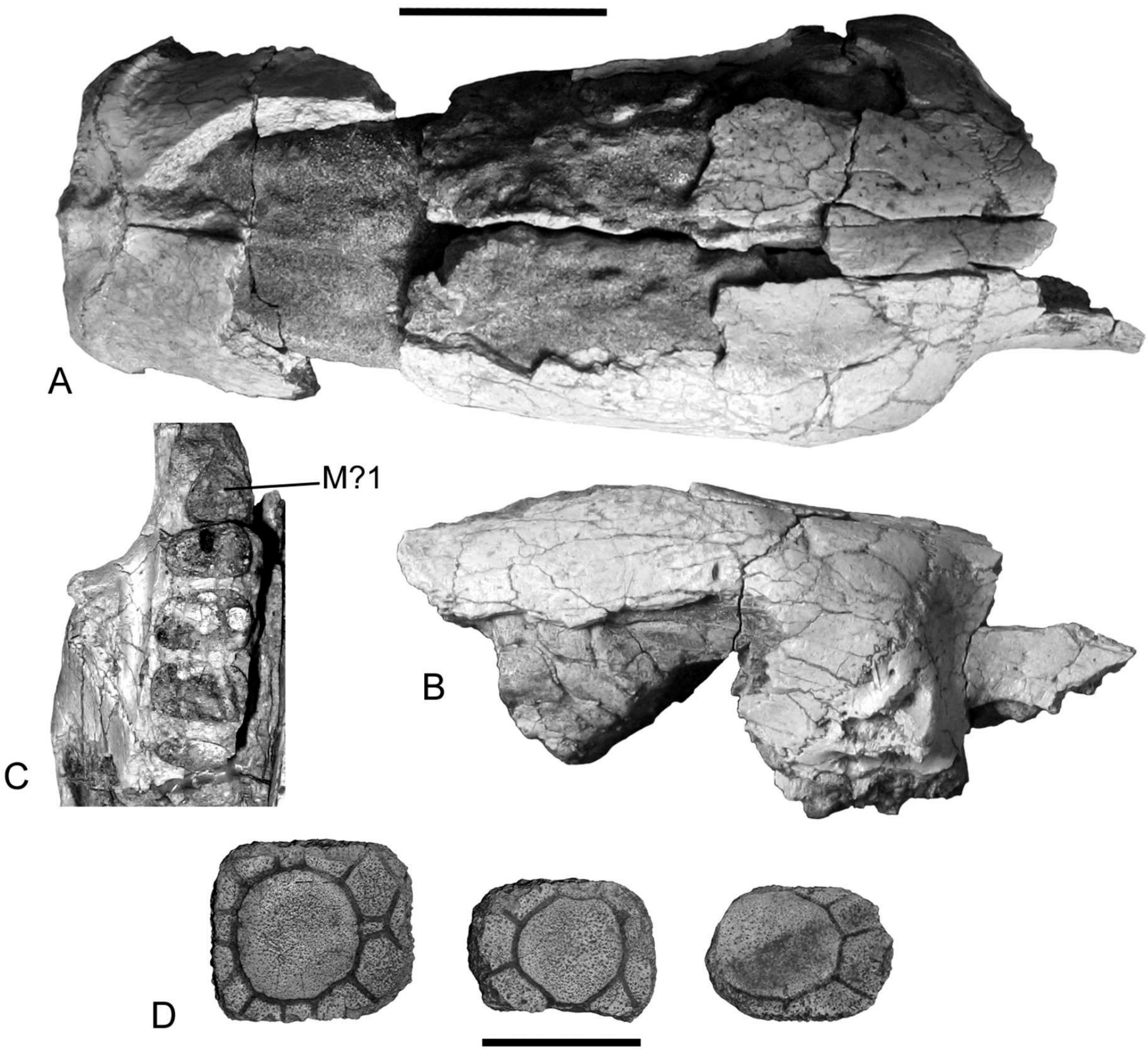

Figure 4. Xenarthrans from LS of Aisol Formation. A-C, MHNSR-PV1028, portion of skull of Planopinae indet. in dorsal (A), lateral (B), and ventral views (C), M?1 refers to a probable alveolus; D, MACN-PV18608, isolated plates of Propaleohoplophorinae indet. in dorsal view. Scale bar = 40 mm, except D that represents 20 mm.

exposed in plastral view. This condition is similar to the reduction of the inguinal scute seen in plastral view of *Chelonoidis chilensis*.

Chelonoidis sp. B. The specimen (MHNSR-PV1064) is a right femur of a giant species (Fig. 3B). The femur axis is 163 mm in length and is slightly arched, as is usual in tortoises. Its proximal end is less expanded than the distal one. Like in other chelonians, on the proximal end the two subequal processes extend from the ventro-proximal surface of the femur opposite to the head (not preserved). The trochanter minor is connected by a ridge-like union with the trochanter major, a derived condition of Testudininae (Auffenberg 1974). In spite of the fact that the distal end is partially deteriorated, it appears to be dominated by the tibial condyle, as is typical for chelonians. Perhaps, this femur size fits in a large shell, with an average length of 1-1.20 meters.

Aves

Birds are represented by a distal portion of right tarsometatarsus (MACN-PV18602; Fig. 3C; Soria 1983) collected from Mina Zitro. With regard to MACN-PV18602, Soria (1983) assigned it to Psilopteridae, with reservations.

The distal portion of tarsometatarsus (MACN-PV18602) has a maximum width of 51 mm and a width of trochlea III of 22.8 mm; that is, smaller than Phorusrhacinae (e.g., *Phorusrhacos* and *Devincenzia*), larger than Psilopterinae (e.g., *Procariama*), and within the range size of *Tolmodus* (Phorusrhacidae) and *Hermosiornis* (Psilopteridae) (Rovereto 1914; Alvarenga and Höfling 2003). The tarsometatarsus from Aisol (Fig. 3C) differs from phorusrhacines in its overall size and in that it possesses the anterior edges of trochlea III convergent proximally (in *Phorusrhacos,* the edges are parallel); from *Hermosiornis* in that the width of the trochlea III is narrower than the width of the epiphysis base, less anteroposteriorly expanded trochlea III, and larger trochlea II and IV (Agnolin 2009); and from psilopterines, in its larger size and reduced posterior process of trochlea II and IV (Agnolin 2009). In short, MACN-PV18602 resembles tolmodines and non-phorusrhacine phorusrhacids in size and shape, following new systematic revisions (Alvarenga and Höfling 2003; Agnolin 2006).

Mammalia
Xenarthra

Both Pilosa and Cingulata are known from the Aisol Formation. Ground sloths were known basically by two isolated right astragali: MACN-PV18605 assigned to Mylodontidae (probably a Mylodontinae similar to *Glossotheriopsis*; Soria 1983), and MACN-PV18611 assigned to a middle-sized Planopinae (as Planopsinae in Soria 1983) (Megatheriidae), collected from Mina Zitro and Aisol hill, respectively. The new material from the Arroyo Seco de la Frazada consists of a broken skull (MHNSR-PV1028) and several elements of the postcranium of different individuals. The morphology of the skull (Fig. 4A and 4B) suggests it would probably correspond to a Planopinae (Megatheridae), coincident with previous material from the unit (Soria 1983). The postcranium will be treated in forthcoming contributions.

The skull (Fig. 4A and 4B) consists of parts of the snout preserved in two separate pieces and the posterior dorsal portion of the braincase. The specimen is medium size (width at the level of the postorbital process: about 76 mm; length of the upper tooth row: about 50 mm). The general aspect of the skull is tubular, elongated anteroposteriorly (Fig. 4A) with a deep constriction in front of orbits. The tooth rows are parallel. There are undoubtedly four crowned alveoli for molariforms, lacking diastema between them (Fig. 4C). An extra anterior alveolus is suggested by a smaller, rounded depression (indicated by M?1 in Fig. 4C), but with the material at hand we can not verify it. The sockets for M2-M4 are rectangular, twice broader transversely than mesiodistally long, and similar sized, whereas the last alveolus is the smallest of the tooth row, slightly oval in outline.

Cingulata is by now represented by three glyptodontids, already discussed by Soria (1983): MACN-PV15074, a small fragment of caudal tube, MACN-PV18608, fifteen isolated scutes from different individuals (Fig. 4D), and MACN-PV18612, one isolated plate. The first specimen was originally considered as Lomaphorini (Hoplophorinae), but because of the lack of diagnostic features, it is considered here as Glyptodontidae indet. The two remaining specimens are referred to Propaleohoplophorinae (following Soria 1983). The first material belongs to old collections (see Dessanti 1956; Groeber 1952) and its precise provenance is unknown; the remaining comes from the Aisol hill (Soria 1983).

Litopterna

Litopterns are known by fragmentary material belonging to the postcranium. The specimens already mentioned for the Aisol Formation (Soria 1983) are: isolated cervical vertebra (MACN-PV18607), dorsal vertebra and portions of a metapod (MACN-PV18610), and isolated astragalus (MLP77-V-13-2); the first and second specimens were collected from the Aisol hill, whereas the third lacks precise geographical location. Among the new material from Arroyo Seco de la Frazada, there are additional metapods (e.g., MHNSR-PV253; MHNSR-PV1032), astragalus (MHNSR-PV1005), portions of tibia (e.g., MHNSR-PV1016, MHNSR-PV1017), and femora (e.g., MHNSR-PV1025, MHNSR-PV1020).

The new metapods and astragalus are very similar to those previously described (Soria 1983). The metapods are long (MHNSR-PV253 proximo-distal length: 163 mm; Fig. 5A) and slender, with well defined distal trochlea and sharp median keel. Among all specimens, there are only subtle differences in size and robustness. The two best preserved are asymmetric (one lateral surface is straight, while the other is concave), suggesting that they were not axial, but lateral elements of a tridactyle member. Tridactyle litopterns with II, III, and IV metapods subequal in size are characteristic of Macraucheniidae (Scott 1910; Shockey 1999).

The astragalus (MHNSR-PV1005) is nearly rectangular in rough outline (length: 53 mm; width at the level of trochlea: 38 mm; Fig. 5B). The head is slightly eccentric, displaced medially, and with flat navicular facet. The neck is short, such as in Macraucheniidae

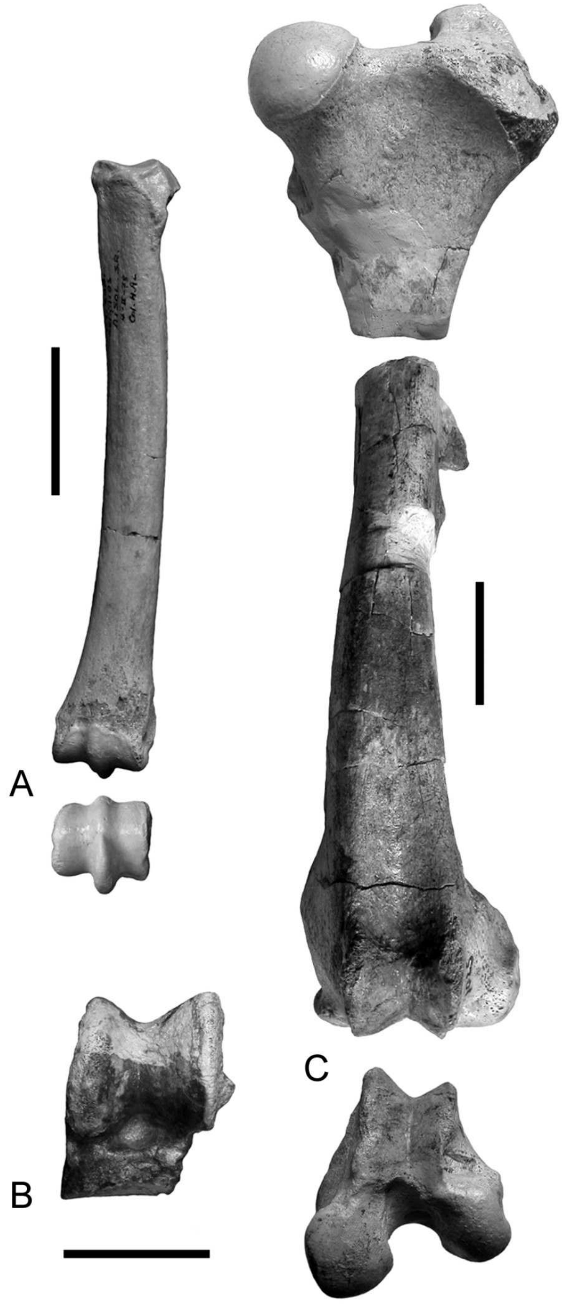

Figure 5. Litopterns from LS of the Aisol Formation. A, MHNSR-PV253, metapod of cf. *Theosodon* in anterior and distal views; B, MHNSR-PV1005, left astragalus of cf. *Theosodon* in dorsal view; C, MHNSR-PV1025, left femur of cf. *Theosodon* in anterior and distal views. Scale bar = 40 mm.

(Cifelli and Guerrero Díaz 1989). The trochlea is pulley-shaped, with a deep median depression (Fig. 5B). The shape of the trochlea fits exactly with the distal articular surface of the tibia considered here as belonging to a litoptern. The distal epiphysis of the tibia has two deep concavities (lateral and medial) separated by a sharp crest which ends anteriorly in a robust median process. There is no protruding medial malleolus. In the lateral face of the tibia, there is a facet for the articulation with the fibula. Separated fibula and tibia is retained in cramaucheniines, among macraucheniids (Soria 1981). The femur (MHNSR-PV1025; Fig. 5C) is robust at the proximal and distal epiphysis but slender and narrow at the diaphysis (proximal width: 93 mm; distal width: 66 mm; length: about 300 mm). The greater trochanter is massive and slightly taller than the head; the lesser trochanter is represented by a small crest. There is a deep intertrochanteric fossa. The third trochanter is crest-like developed below the greater trochanter. Latero-ventrally above the condylar region, there is an elongated, well-developed, supracondylar fossa. The distal epiphysis is broad antero-posteriorly, with massive condyles. In posterior view, the medial condyle is larger than the lateral one. The patellar fossa is narrow and deeply excavated (Fig. 5C). This femoral morphology resembles closely other macraucheniids, in particular because the greater trochanter does not extend far above the level of the head (Scott 1910; Cifelli and Guerrero Díaz 1989).

Because of its size, the presence of tridactyle members, and the morphology of the tarsus, all new material is referred to the family Macraucheniidae (see Cifelli and Guerrero Díaz 1989), and among them, to the subfamily Cramaucheniinae, because of separate zeugopodium (Soria 1981). There is no argument based on the material available to support that there is more than one different taxon. Soria (1983) suggested that previous specimens would probably correspond to the genus *Theosodon*. We follow Soria (1983) in the assignation of the material; nevertheless, it is worth mentioning that with the information at hand, there is no solid argument to support identification accurately. There are other similar sized macraucheniids (e.g., *Phoenixauchenia*; Rovereto 1914), whose postcranium is partially known and which could be represented by the postcranium from the Aisol Formation. Future dental and cranial material will have the potential to settle this taxonomic issue.

Notoungulata

New fieldwork at the Arroyo Seco de la Frazada has revealed that notoungulates are hitherto the most abundant mammalian group. Among them, Toxodontidae, Hegetotheriidae, and Interatheriidae have been collected. Previous Notoungulata remains from the Aisol

Formation were few and fragmentary, the most diagnostic of which were two incomplete upper molars (MACN-PV18603, from Mina Zitro and MACN-PV18609, from Aisol hill) of a Toxodontidae, probably Nesodontinae or primitive Haplodontheriinae (Pascual 1965; Madden 1997) with pre-Chasicoan crown morphology (Soria 1983). It is significant, as Soria (1983) remarked, that the presence of a posterior fosette is more reminiscent of Nesodontinae, and we can add that they are very similar in size and morphology to those of *Nesodon*. Due to the incompleteness of the remains and the presence in these levels of new material that attests to the presence of a probable Nesodontinae different from *Nesodon* (see below), we prefer to maintain the materials described by Soria (1983) as Nesodontinae indet.

The new material assigned to the family Toxodontidae is better represented by two partially preserved skulls (MHNSR-PV1021; MHNSR-PV1004; Figs. 6A and 6D). There are, in addition, some dentaries with partial dentition and several isolated postcranial elements which will be treated in forthcoming contributions. Based on upper dentition, we recognized two different toxodontids: a taxon that we refer to as *Palyeidodon* cf. *P. obtusum* and a Nesodontinae representing very probably a new taxon phylogenetically close to *Nesodon*.

Palyeidodon cf. *P. obtusum.* This taxon is represented by MHNSR-PV1021 (Figs. 6A and 6B); it is smaller and slenderer than *Nesodon* (Scott 1912; Pascual 1954). The snout is tall; the palate is broader at the level of M3, narrowing to P2; at the front, the lateral borders of the palate become parallel. The incisive foramen is large and separated by a robust medial palatine process. The anterior border of the nasal is straight and does not overhang the anterior nasal aperture. The temporal lines are sharper and less divergent than in *Nesodon* (Scott 1912). The orbit is round, with the anterior border at the level of M2-M3 embrasure (Fig. 6A). Only the right P2-M3 and left P3-M2 are preserved (Fig. 6B), being high crowned (as seen in a posterior breakage of the snout), similar to specimen MLP 46-VIII-21-10 of *P. obtusum* (see also Pascual 1954, 1965; Bond and García 2002). The M1-M3 appear to be euhypsodont, without signs of closing the upper end; the P2-P4 are very high crowned but the labial column apparently shows a tapering on the uppermost end, which could indicate a closing of the roots [Madden (1990) states that *Palyeidodon* has rooted premolars]. There is no diastema between consecutive teeth. In the premolars, the enamel is distributed on the labial and anterolingual surfaces; in the molars, it covers the labial and anterior surfaces, and the lingual surface of the metaloph. P2-P4 are roughly trapezoidal, increasing in size posteriorly. P2 has two fossettes: the anterior is oval, whereas the posterior is slightly circular. P3-P4 have, in turn, a single, antero-posteriorly elongated fossette, which is larger in P4. Molars increase gradually in size. In occlusal view, M1-M2 are trapezoidal, whereas M3 is triangular (Fig. 6B). All molars have F1, F2, and primary lingual enamel folds (bifurcated pattern). F2 fold is shorter in M3 than in preceding molars. The primary lingual enamel fold becomes shorter backwardly and is open lingually in all molars; it is also open in the distal part of the root, as seen through the breakage of the skull, differing from nesodontines (Pascual 1954). Protoloph and metaloph form lingual columns, such as in the taxa traditionally referred to Haplodontheriinae (Madden 1997). None of the upper molars have accessory fossettes (Fig. 6B). There is a posterior fold only in M3, which is open postero-lingually.

The skull size and the crown morphology of MHNSR-PV1021 remit immediately to *Palyeidodon obtusum*, the type and only recognized species of the genus *Palyeidodon* (Pascual 1954; Madden 1990). The Aisol specimen compares very well with the morphology of the type of *P. obtusum* (M2-M3 badly preserved; Roth 1899), and more especially with the C1-M3 present in a palate referred to this species by Pascual (1954). Pending a more exhaustive comparison of the Aisol material with all the specimens known of *Palyeidodon*, especially those more recently described (see Madden 1990), we prefer to maintain the Aisol taxon as *Palyeidodon* cf. *P. obtusum*, until its specific assignment is confirmed. *Palyeidodon* was alternatively considered a basal representative of the toxodontinae lineage (Pascual 1954), a Haplodontheriinae (Pascual 1965), or a dubious generalized Haplodontheriinae (Madden 1990, 1997). In the rearrangement of the Toxodontidae family, Nasif et al. (2000) recognized only the Nesodontinae and Toxodontinae subfamilies. Following a cladistic analysis, they treat *Palyeidodon* as the sister group of all other Toxodontinae. Despite these different opinions, all authors concur in considering *Palyeidodon* outside Nesodontinae, especially for possessing the derived feature of euhypsodont molars. The new materials will be instrumental in reviewing the taxonomic status of *Palyeidodon* and its position among Toxodontidae.

Nesodontinae gen. et sp. nov. MHNSR-PV1004 (Figs. 6C and 6D) and probably MACN-PV18603 correspond to a nesodontine, closely similar to *Nesodon* (Scott 1912). The skull (MHNSR-PV1004; Fig. 6C) is large, robust, and massive (anteroposterior length: 446 mm; maximum width of the occipital plate: 205 mm; width at the level of the postorbital processes: 130 mm). The pre-

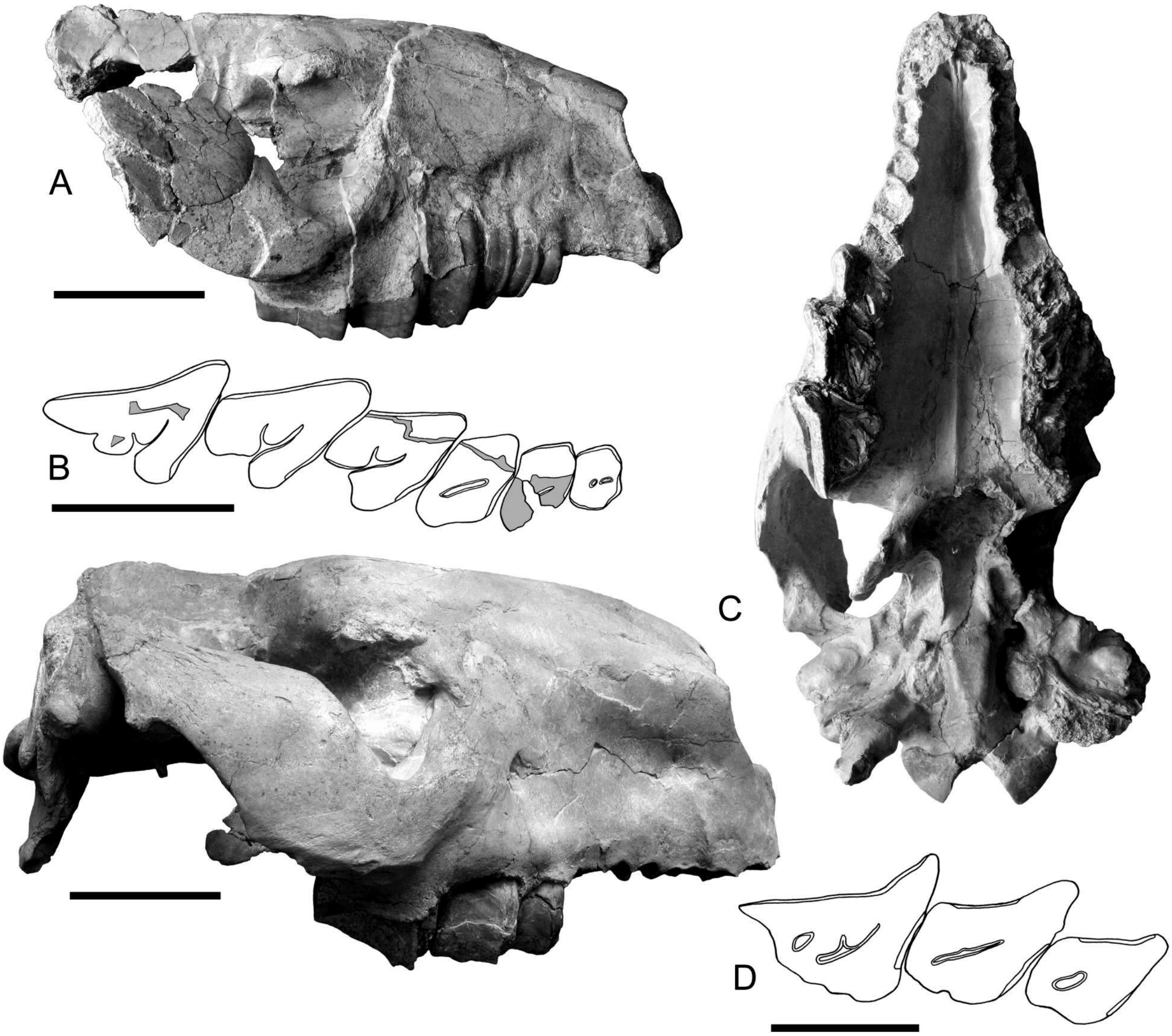

Figure 6. Large-sized notoungulates from LS of the Aisol Formation. A-B, MHNSR-PV1021, *Palyeidodon* cf. *P. obtusum*, partial skull with dentition in lateral view (A) and linear drawing of upper right dentition (P2-M3) in occlusal view (B); C-D, MHNSR-PV1004, Nesodontinae gen. et sp. nov., almost complete skull in lateral and ventral views (C) and linear drawing of upper right molars in occlusal view (D). Gray areas indicate broken surfaces. Scale bar = 100 mm except B and D that represent 50 mm.

orbital portion is nearly half the total length of the skull. The snout is high and wide, with convex dorsal surface. The anterior part of nasals overhangs the anterior nasal aperture. The orbit is oval with the ventral border low on the face; the anterior border of the orbit sets over M3. In ventral view, the palate is nearly triangular with the deepest point at the level of premaxilla-maxilla suture. The incisive foramen is small with slender medial palatine process. The dental formula is I1-3 C1 P1-4 M1-3, similar to other toxodontids (Scott 1912; Madden 1997). Only the crown of right molars is preserved; other teeth are assumed by their alveoli. The occlusal surface of the molars is eroded; even though, their morphology can be distinguished (Fig. 6D). The layer of enamel covers the labial and antero-lingual surfaces of the teeth. The molars increase rapidly in size from M1 to M3. The first two molars have a simpler morphology with non-bifurcated primary lingual enamel fold; it is closed at the lingual border. Accessory lingual enamel folds or fossettes are absent in M1-M2. M3 has bifurcated pattern with F1 and F2 folds. The primary lingual enamel fold is closed, with confluent protoloph and metaloph, such as other Nesodontinae (Madden 1997). There is, in addition, an oval distolingual fold or fossette. In nesodontines (e.g.,

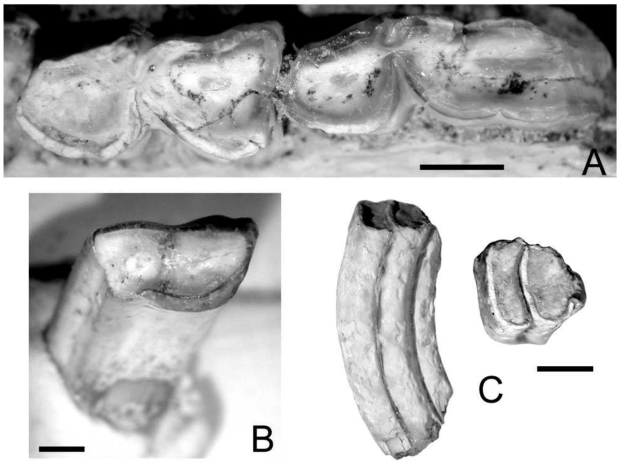

Figure 7. Small-sized notoungulates and rodent from LS of the Aisol Formation. A, MHNSR-PV1050, fragment of left dentary with m2-m3 of *Protypotherium* sp. in occlusal view; B, MHNSR-PV1052, complete right M3 of *Hegetotherium* sp. in occlusal view; C, MHNSR-PV1056, isolated left M3 of chinchillid (*Prolagostomus* or *Pliolagostomus*) in labial and occlusal views. Scale bar = 2 mm.

Adinotherium and *Nesodon*) the primary lingual enamel fold is open lingually in juveniles and closed in adult specimens, such as the specimen from Aisol (Fig. 6D; Scott 1912; Pascual 1954), whereas in other toxodontid groups (e.g., Haplodontheriinae, Toxodontinae; Kraglievich 1930; Cabrera and Kraglievich 1931; Pascual 1954; Madden 1997; Nasif et al. 2000), it stayed open lingually in all ontogenetic stages. Because of tooth morphology, especially that of M3, the specimen from Aisol is considered a nesodontine toxodontid. Nowadays, there are two or three formally known Nesodontinae genera: perhaps *Proadinotherium*, *Adinotherium*, and *Nesodon* (Madden 1997; Nasif et al. 2000); among them, the size and morphology of the new skull immediately remits to *Nesodon*. Noteworthy, in *Nesodon*, accessory fossettes and bifurcated primary lingual enamel fold persist in all molars (Scott 1912), differing thus from the condition observed in M1-M2 from the Aisol specimen. Further studies and new material could reveal the taxonomic position of MHNSR-PV1004; we preliminary considered that it may represent a new taxon.

The family Hegetotheriidae is hitherto represented by a single material: right M3 and broken pieces of the postcranial skeleton (MNHSR-PV 1052; Fig. 7B) collected from Arroyo Seco de la Frazada and assigned to *Hegetotherium* sp. The M3 is euhypsodont, with the crown curved lingually. The tooth has a thick layer of cementum around the crown, with the exception of the posterior face. The occlusal surface is nearly rectangular in outline (the posterior part is slightly narrower), with a shallow lingual and labial groove and a shallow notch in the posterior face of the tooth (Fig. 7B). The parastyle is high. The size of the tooth (antero-posterior length: 7.4 mm; maximum width: 4.2 mm) is similar to that of the Santacrucian species *Hegetotherium mirabile* (e.g., MACN-A632 and MACN-A3336; Sinclair 1909).

Finally, the family Interatheriidae is represented by a fragment of left dentary with dentition (MHNSR-PV1050) assigned to *Protypotherium* sp. (Fig. 7A), collected from Arroyo Seco de la Frazada. This taxon completes the notoungulate listing from the LS of the Aisol Formation. The dentary is high (height below m2: 11 mm), with m2-m3. The teeth are euhypsodont with a layer of enamel and cementum covering the entire surface; the cementum is thicker labially than lingually. In m2, trigonid and talonid are roughly triangular, with talonid wider than trigonid (antero-posterior length: 6.3 mm; width of trigonid: 3 mm; width of talonid: 3.3 mm). In m3, the trigonid is rounded labially; the talonid is long anteroposteriorly, narrower than the trigonid, and with a very shallow vertical groove on its labial surface. The lingual surface of both molars has a shallow groove that separates trigonid from talonid (Fig. 7A). The labial angle of trigonid and talonid is blunter in the Aisol specimen than in the specimens of *P. australe* compared (e.g., MACN-A3914, 3915, 3916, or 3917; Sinclair 1909) and the size is slightly smaller. We prefer to maintain the Aisol specimen as *Protypotherium* sp.

Rodentia

Only one rodent is hitherto available from the LS of the Aisol Formation, consisting of an isolated tooth of Chinchillidae, from Arroyo Seco de la Frazada. MHNSR-PV1056 is an euhypsodont, left M3 (Fig. 7C). The external surface has suffered severe erosion as evidenced by the striations and corrosion surfaces; the layer of cementum is not recognized. The enamel is thicker in the anterior margin of the first and second laminae and thinner in the lingual surface, whereas it is absent in the posterior and labial margins of the tooth. The specimen corresponds to a small chinchillid (maximum width of the molar: 3.2mm). M3 is trilaminar, such as other Lagostominae. In occlusal view, the first lamina is wider than the second, whereas the second is longer than the first; both laminae are tightly packed. The third lamina is noticeably reduced; consequently, it is not possible to distinguish whether the lamina was oblique or transversal to the sagittal axis of the tooth (key feature to distinguish *Prolagostomus* from *Pliolagostomus*; Scott 1905; Vucetich 1984).

VERTEBRATES FROM THE MIDDLE SECTION

The material collected from the MS (Fig. 2) of the Aisol Formation hitherto includes only mammals, represented by Marsupialia, Notoungulata, and Rodentia. Fossil remains were recovered only from the Arroyo Seco de la Frazada locality.

Metatheria
Marsupialia

The marsupial remains consist of a single disarticulated skull with dentaries (MHNSR-PV1046; Fig. 8A and 8B) which was the basis for a taxonomic study (Forasiepi et al. 2009b). The specimen was identified in a new genus, *Hesperocynus*, of the already known species «*Thylatheridium*» *dolgopolae* (Reig 1958; Goin and Montalvo 1988; Goin 1995) of the family Sparassocynidae (see Forasiepi et al. 2009b for taxonomic details). This taxon encompasses small-sized carnivorous feeders, as evidenced by their dental specializations and palate morphology, which is characterized by large alisphenoid and periotic hypotympanic sinuses (though less developed than in *Sparassocynus*), thick and conical ectotympanic bones, horizontal ramus of dentary lower than in *Sparassocynus* and proportionally thicker, especially in labial view, below posterior molars. In the dentition, M1 and M2 have distinct StD and m4 has narrow and long talonid. In the upper molars, the paracone and the protocone are more reduced, the metacone is taller, and the postmetacrista is longer than didelphids, and less than in *Sparassocynus*. In the lower molars, the paraconid is lower, the protoconid is taller, the metaconid is closer to the protoconid, and the talonid is narrower and shorter than didelphids, but less than in *Sparassocynus*. In short, the features of *Hesperocynus dolgopolae* immediately remit to sparassocynid marsupials, but with a more generalized morphology than *Sparassocynus* (Forasiepi et al. 2009b).

Eutheria
Notoungulata

The scarce notoungulata remains from the MS at present consist of two specimens assigned to *Tremacyllus* sp., left dentary with p2-m2 and trigonid of m3 (MHNSR–PV1087; Fig. 8C) and fragment of left dentary with broken m2 (MHNSR-PV1061). MHNSR-PV1087 (Fig. 8C) has a dental formula of p2-p4/m1-m3, lacking p1 as typical of Neogene, «rodent-like», hegetotheriid Pachyrukhinae (Cerdeño and Bond 1998; Croft and Anaya 2006). The teeth row is concave lingually with imbricate premolars and molars. Premolars are less molariform than in *Pachyrukhos* and *Paedotherium*; they are shorter than molars, with p2 the smallest. The m1 and m2 are well-preserved (m1 length: 3.3 mm; m2 length: 3.5 mm). In m1 and m2, the trigonid is narrower than the talonid; this width difference is more conspicuous in m1. The labial angle of trigonid is rounded, whereas it is sharp angled in the talonid. All teeth have a thick layer of cementum on the lingual side of the crown. The size and morphology of the teeth are the evidence to refer the specimen to the genus *Tremacyllus.* Nonetheless, a revision of all the recognized species is needed (see Cerdeño and Bond 1998), in order to clarify the taxonomic status of some of the taxa described, especially from the «Araucanian» of Catamarca and Mendoza provinces (Rovereto 1914). The material from MS is similar in morphology and size to *T. impressus*, from the Montehermosan to Marplatan SALMAs, but until the taxonomic status, morphological and size variation of the «Araucanian» species (e.g., *T. incipiens* and *T. subdiminutus*) is not clarified, we prefer to maintain the taxon from Aisol as *Tremacyllus* sp.

Rodentia

Three different caviomorph taxa, each one hitherto represented by a single specimen, have been recovered (Fig. 8D and 8 F). The specimens preliminary identified as Dolichotinae (MHNSR-PV1047; Fig. 8D), Abrocomidae (MHNSR-PV1059; Fig. 8E), and Ctenomyidae (MHNSR-PV1048; Fig. 8F) are currently under revision. We mention here the occurrence of Ctemonyidae, among them. This family encompasses six different genera: *Xenodontomys*, *Actenomys*, *Eucoelophorus*, *Praectenomys*, *Paractenomys*, and *Ctenomys*, with *Chasichimys* as sister group, ranging from the late Miocene (Huayquerian SALMA) to Recent (Verzi 2008). MHNSR–PV1048 consists of a fragment of left dentary with m2-m3 (Fig. 8F) and isolated upper and lower teeth of the same specimen. The teeth are euhypsodont, similar to other crown ctenomyids (Verzi 2008). In occlusal view, the teeth are roughly oval, less elongated than *Ctenomys*, and with the lingual concavity shallower than in the living genus. In the dentary, m2 sets obliquely, its main axis is anterolabial-posterolingual, imbricating with m3. The m3 is more circular in outline than previous molars, reduced but not atrophied, thus differing from *Ctenomys*. In both lower teeth, the anterior lobe is larger than the posterior one. Dentine tracks are distributed in the posterolingual part of m2 and anterolabial corner of m3. Among ctenomyids, MHNSR-PV1048 closely resembles *Eucoelophorus* (see Verzi 1999, 2008; Verzi et al. 2004). Future material and detailed analysis of the specimens recovered will have the potential to clarify rodent diversity and the inferred age for the MS of the Aisol Formation.

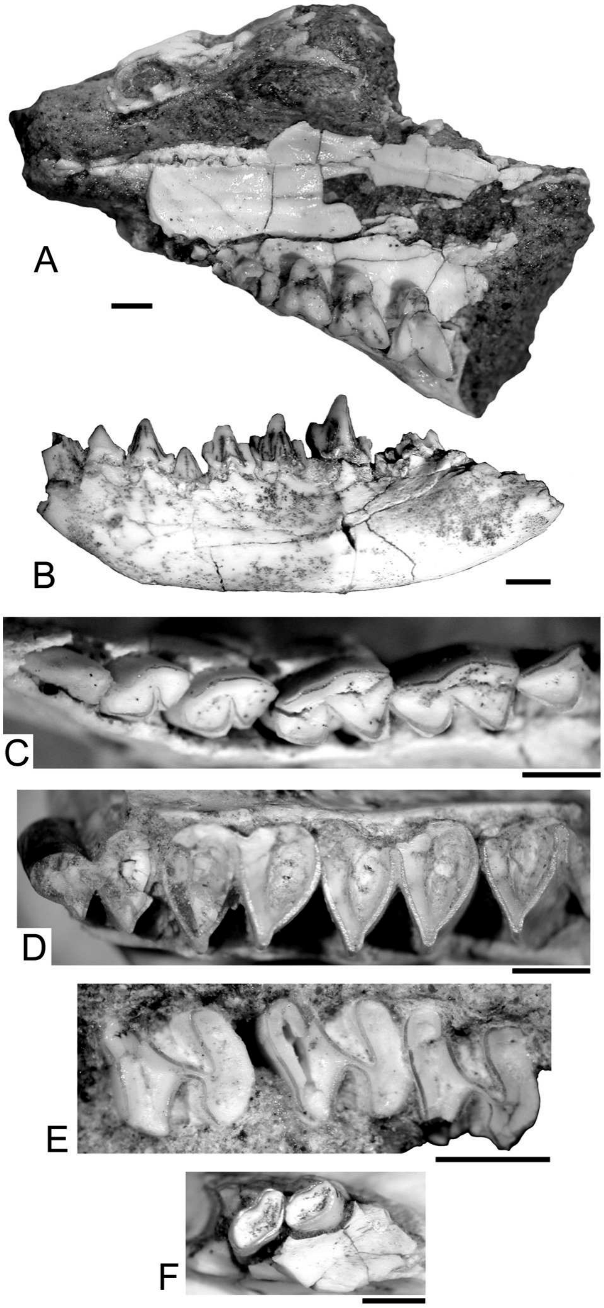

Figure 8. Marsupial, notoungulate, and rodents from MS of the Aisol Formation. A-B, MHNSR-PV1046, *Hesperocynus dolgopolae*, snout in ventral view (A) and left dentary in lateral view (B); C, MHNSR-PV1087, portion of left dentary with p2-m2 and the trigonid of m3 of *Tremacyllus* sp. in occlusal view; D, MHNSR-PV1047, left dentary of Caviidae Dolichotinae indet. with p4-m3 in occlusal view; E, MHNSR-PV1059, right portion of maxilla of Abrocomidae indet. with p4-m2 in occlusal view; F, MHNSR-PV1048, fragment of left dentary with m2-m3 of Ctenomyidae indet. in occlusal view. Scale bar = 2 mm.

DISCUSSION

TAXONOMIC DIVERSITY

With the recently unearthed fossil material, the vertebrate taxonomic diversity of the Aisol Formation increases up to 19 different taxa (Table 1). The LS of the sedimentary sequence is hitherto richer than the MS. No fossil remains have been collected from the US. In the LS, 14 different taxa have been recognized. Among them, one frog, two tortoises, at least one giant bird, and 10 mammals: two pilosa and two cingulata xenarthans, two toxodontid, one hegetotheriid, and one interatheriid notoungulates, one macraucheniid litoptern, and one chinchillid rodent. In the MS, five different mammals are known: one sparassocynid marsupial, one pachyrukhine notoungulate, and one caviid, one abrocomid, and one ctenomyid rodent.

It is also worth mentioning that Soria (1983) referred three dental fragments (MACN-PV18604) to an indeterminate Crocodilia and, should that be the case, to Sebecosuchia. This record was significant then because it was used for paleoenvironmental reconstructions. A reexamination of the material led us to conclude that MACN-PV18604 specimens are fragments of roots and a basal portion of the crown lacking the enamel of large mammals (perhaps litopterns or more probably toxodontid notoungulates). Considering this identification, there are no Crocodyliformes in the Aisol Formation. In addition, Soria (1983) identified specimen MLP77-V-13-5, a broken tooth with an oblique wear facet, as a fragment of canine of cf. *Astrapotherium* sp. due to the fact that «…para el Mioceno los únicos mamíferos portadores de grandes caninos fueron los Astrapotheria.» (Soria 1983, p. 303). The piece preserved is straight with an ellipsoidal section. All the dentine preserves a small lateral thin layer that could be a remainder of enamel or another kind of dentine. The nearly rectilinear form of the shaft is reminiscent of the upper canines of the astrapotheres (the lower ones are more curved). From its wear facet, it would belong to an adult specimen if it was an astrapothere. MLP77-V-13-5 is devoid of the furrows observed in the sections of astrapothere canines, which strengthen the implantation. It is more ellipsoidal in section and bigger than the corresponding canine of *Astrapotherium*, the last representative of this group in Patagonia, recorded in the Santacrucian, Friasian, and probably Colloncuran SALMAs. It could represent a canine of an unknown Astrapotheria, or even a different taxonomic group (i.e., the caniniform of a large Pilosa). Because of its fragmentary nature, the taxonomic assignment of MLP77-V-13-5 is very problematic, even if it belonged to an astrapothere. Until new elements are discovered, we exclude this specimen from Astrapotheria and consider it Mammalia *incertae sedis*.

Finally, Polanski recovered material, which was assigned to *Nesodon imbricatus* (Dessanti 1954, 1956; González Díaz 1972), but unfortunately, it was not figured and apparently is now missing from the collections (see also Soria 1983, p. 300). At the time, Patterson (see Groeber 1952) doubted the original identification, making determination uncertain. There is no sure record of *Nesodon* among the Toxodontidae unearthed recently; therefore, we do not include this taxon among the listing of mammals from the Aisol Formation.

AGE OF THE AISOL FORMATION

In preliminary studies, the Aisol Formation was considered early Miocene (probably Santacrucian SALMA; e.g., Groeber 1951; Dessanti 1954, 1956; González Díaz 1972; Núñez 1976) based upon few fossil findings and stratigraphic correlations. Nonetheless, it is also worth mentioning that in one of those preliminary studies, Groeber (1952) suggested that the unit (informally called «Estratos Calchaquíes» by then) was late Miocene, and was included among the «Arauco-Entrerriano» levels. Later studies did not further the debate. Pascual and Odreman-Rivas (1973; see also Pascual and De la Fuente 1993) placed the Aisol Formation in the Miocene, in the temporal interval between the Santacrucian and Friasian SALMAs. It was after the analysis of new fossil findings that Soria (1983) specifically allocated the Aisol Formation to the Friasian *s.l.* (including Colloncuran, Friasian *s.s.*, and Mayoan, following Bondesio et al. 1980), because of the occurrence of post-Santacrucian and pre-Chasicoan mammals. This hypothesis was also followed by later authors (Sepúlveda et al. 2001, 2007).

The analysis of the new fossil material and the stratigraphic control of the findings led to recognize two different fosiliferous sections in the profile, with faunal assemblages of different ages. The LS is probably middle Miocene, as Soria suggested (1983), perhaps Friasian *s.s.* (older than 15 Ma; Marshall and Salinas 1990) or Colloncuran (15.5-14 Ma; Marshall et al. 1977; Marshall and Salinas 1990), following the Patagonian scheme. Unfortunately, there is no consensus about the time span covered by some of the SALMAs, including the Friasian one. Specific studies on age and taxonomic composition are needed before making any comparisons with more distantly located stratigraphic units. We present here a preliminary analysis mainly aimed at discussing and comparing the sections of the profile of the Aisol Formation. *Palyeidodon* is hitherto known only from middle Miocene outcrops, from the Friasian *s.s.* and Colloncuran SALMAs of Patagonia (Roth 1899; Pascual 1954; Bondesio et al. 1980; Madden 1990; Croft et al. 2003); thus its occurrence restricts the LS to this time span. With regard to the nesodontine, its occurrence is also significant. The Aisol material resembles *Nesodon* species, though anatomical differences would be indicative of a new taxon. *Nesodon* was thought «*to be one of most useful indicator taxa for Santacrucian age*» (Croft et al. 2003, p. 295); this taxon is abundant in Patagonia (Argentina) and well documented in Chile (Scott 1912; Croft et al. 2003, 2004). Other records of *Nesodon* based upon scarce material, recovered outside the southern regions and from beds younger than Santacrucian age, have been questioned (e.g., Flynn et al. 2002; Croft et al. 2003). At present, the indeterminate nesodontine from Aisol does not contribute to elucidate the age of this unit, but at least it does not contradict the idea that it comes from a horizon different from the Santacrucian levels. Other taxa, such as *Protypotherium*, *Hegetotherium*, and *Prolagostomus* or *Pliolagostomus*, known presently in the LS, have a larger biochron. The genus *Protypotherium* is known from Colhuehuapian to Huayquerian SALMAs in different South American localities (e.g., Roth 1899; Sinclair 1909; Cione et al. 2000). Records of the genus *Hegetotherium* come from Colhuehuapian SALMA of Patagonia, Santacrucian of Argentina and Chile, Colloncuran of Argentina, and possible Laventan of Bolivia (Sinclair 1909; Bondesio et al. 1980; Oiso 1991; Flynn et al. 2002; Croft et al. 2004). With regard to the rodent, the biochron of *Prolagostomus* and *Pliolagostomus* ranges from the Santacrucian to the Colloncuran SALMAs (Vucetich 1984, 1986) in Patagonia, with *Prolagostomus* exceptionally recognized in the Laventan SALMA from Bolivia, and the Colloncuran record being the most abundant (Bondesio et al. 1980). Finally, Planopinae xenarthrans have a biochron that ranges from the Santacrucian to the Colloncuran SALMAs (e.g., Scott 1903-1904; Scillato-Yané and Carlini 1998); though imprecise, it is also

Table 1. List of taxa recovered from the Aisol Formation.

Lower Section:

Anura Rafinesque, 1815
gen. et sp. indet.

Testudines Linnaeus, 1758
Cryptodira Cope, 1868
Testudininae Batsch, 1788
Chelonoidis sp. A
Chelonoidis sp. B

Aves Linnaeus, 1758
Phorusrhacidae Ameghino, 1889
gen. et sp. indet.

Mammalia Linnaeus, 1758
Eutheria Huxley, 1880
Xenarthra Cope, 1889
Pilosa Flower, 1883
Mylodontidae Gill, 1872
gen. et sp. indet.

Megatheriidae Gray, 1821
Planopinae Simpson, 1945
gen. et sp. indet.

Cingulata Illiger, 1811
Glyptodontidae Gray, 1869
gen. et sp. indet.
Propalaeohoplophorinae Ameghino, 1891
gen. et sp. indet.

Notoungulata Roth, 1903
Toxodontidae Owen, 1845
Nesodontinae Murray, 1866
gen. et sp. indet. A
gen. et sp. indet. B
Haplodontheriinae Ameghino, 1907
Palyeidodon cf. *P. obtusum* Roth, 1899
Hegetotheriidae Ameghino, 1894
Hegetotherium Ameghino, 1887
Interatheriidae Ameghino, 1887
Protypotherium Ameghino, 1882

Litopterna Ameghino, 1889
Macraucheniidae Gervais, 1855
Cramaucheniinae Ameghino, 1902
cf. *Theosodon* Ameghino, 1887

Rodentia Bowdich, 1821
Chinchillidae Bennet, 1833
Lagostominae Pocock, 1922
Prolagostomus Ameghino, 1887 or *Pliolagostomus* Ameghino, 1887

Middle Section:

Mammalia Linnaeus, 1758
Metatheria Huxley, 1880
Marsupialia Illiger, 1811
Sparassocynidae Reig, 1958
Hesperocynus dolgopolae Reig, 1958
Eutheria Huxley, 1880
Notoungulata Roth, 1903
Hegetotheriidae Ameghino, 1894
Pachyrukhinae Lydekker, 1894
Tremacyllus Ameghino, 1891

Rodentia Bowdich, 1821
Caviidae Fischer and Waldheim, 1817
Dolichotinae Pocock, 1922
gen. et sp. indet.
Abrochomidae Miller and Gidley, 1918
gen. et sp. indet.
Ctenomyidae Gervais, 1949
gen. et sp. indet.

coincident with the chronological distribution of the other taxa of the Aisol Formation. With regard to the land tortoises, they do not provide major chronological information. The middle-sized *Chelonoidis* sp.A represents a taxon clearly different from the smaller Colhuelhuapian *Chelonoidis gringorum*. The second taxon, *Chelonoidis* sp.B., is a giant testudinine. Large-sized tortoises are known from the Colloncuran to Montehermosan SALMAs in Argentina (De la Fuente 1988). Other material from the LS lacks precise taxonomic identification. Based on the material hitherto recovered and identified, we consider that the LS of the Aisol Formation could be referred to the middle Miocene (probably Friasian *s.s.* or Colloncuran SALMAs according to the Patagonian scheme), in agreement with Soria (1983).

With regard to the MS of the Aisol Formation, the collected specimens indicate a younger age, probably late Miocene (?Huayquerian SALMA) or even younger. The taxa that led us to support this hypothesis are especially *Hesperocynus dolgopolae*, and the crown Ctenomyidae indet. The sparassocynid marsupial, *Hesperocynus dolgopolae,* was previously recovered from late Miocene deposits (Huayquerian SALMA), from the Andalhualá (Catamarca Province) and Cerro Azul (La Pampa Province) Formations (Reig 1958; Marshall and Patterson 1981; Goin and Montalvo 1988; Goin et al. 2000). In turn, in younger levels of Buenos Aires Province (i.e., Montehermosan to Marplatan SALMAs), the family is represented by *Sparassocynus* (Simpson 1972), which exhibits more derived cranial and dental morphology. Despite the fact that there are no biological arguments or enough recoverings to restrict the biochron of *Hesperocynus dolgopolae* to the Huayquerian, until now it is known only in these levels. Regarding the recorded notoungulate, *Tremacyllus* sp., it pertains to the «rodent-like» Pachyrukhinae (Hegetotheriidae), with the genus occurring from the Chasicoan (late Miocene) to Marplatan (late Pliocene) SALMAs (Cerdeño and Bond 1998). Although specific identification of the material has not been achieved yet because of the uncertainties about the taxonomic status of many of the already described species (see Cerdeño and Bond 1998), its record agrees with the hypothesis of a late Miocene age for the MS, or even younger. With regard to geographical distribution, *Tremacyllus* is known from Buenos Aires, La Pampa, Catamarca, and Mendoza provinces. In addition, it is also worth mentioning that in the Huayquerian beds of Mendoza, *Tremacyllus* is more frequent than *Paedotherium,* whereas the opposite is true in the Pampean region (Cerdeño and Bond 1998). Dolichotinae and Abrocomidae rodents appear in the fossil record in the latest middle Miocene (Laventan SALMA) and late Miocene (Huayquerian SALMA) respectively (e.g., Vucetich 1986; Montalvo et al. 1995; Walton 1997), whereas the biochron of the Ctenomyidae crown group ranges from the late Miocene (Huayquerian SALMA) to Recent (e.g., Verzi 1999, 2008; Verzi et al. 2008). Furthermore, the morphology of the ctenomyid from Aisol (MHNSR-PV1048) resembles closely that of *Eucoelophorus*, which is hitherto known from Pliocene to Pleistocene deposits (i.e., Montehermosan to Ensenadan SALMAs; Rovereto 1914; Kaglievich 1927; Verzi et al. 2004; Verzi 2008). Noteworthy, according to recent phylogenetic studies, *Eucoelophorus* occupies the basalmost position within Ctenomyidae, predicting that this lineage could be also present in older times (i.e., Huayquerian SALMA; Verzi 2008). These data together suggest that the MS of the Aisol Formation should be no older than late Miocene (Huayquerian SALMA). In short, the mammalian association of the MS is clearly different from that of the LS, which includes typical component of middle Miocene times. This view differs from Soria's (1983) from and later geological studies (e.g., Sepúlveda et al. 2001, 2007) that considered the entire Aisol Formation as middle Miocene (Friasian *s.l.*). Further material and fieldwork studies are decisive for a better understanding of the sequence, regarding both paleontological and geological aspects. Moreover, the Neogene fauna of the Aisol Formation will be useful for a broad understanding of the evolution of the sedimentary Tertiary units in the region of San Rafael and neighbouring areas, providing new data for comparing and calibrating units from extra-patagonian regions.

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