

# MAMMALS FROM THE SALICAS FORMATION (LATE MIOCENE), LA RIOJA PROVINCE, NORTHWESTERN ARGENTINA: PALEOBIOGEOGRAPHY, AGE, AND PALEOENVIRONMENT



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**Abstract.** This study analyzes a collection of fossil mammals from the Salicas Formation in the El Degolladito area, La Rioja Province, Argentina. The materials reported herein were recovered from two sites (site 1 and site 2). Reported mammals are *Macrochorobates* Scillato-Yané, *Chasicotatus* Scillato-Yané, and Hoplophorini indet. (Xenarthra, Cingulata); *Paedotherium minor* Cabrera, cf. *Pseudotytherium* Ameghino (Notoungulata, Typotheria); *Neobrachytherium* Soria (Liptopterna, Lopholipterna); *Orthomyctera* Ameghino, cf. *Cardiomys* Ameghino, *Lagostomus* (*Lagostomopsis*) Kraglievich, and Octodontidae indet. (Rodentia, Caviomorpha). This new mammalian assemblage, together with one previously recorded, has several taxa in common with mammalian associations from Central Argentina (*i.e.*, La Pampa Province). Among those coming from Northwestern Argentina, the major affinity is with the El Jarillal Member (Chiquimil Formation) and then the Andalhuala Formation (both in Catamarca Province). The Salicas Formation fauna is considered as latest Miocene in age until new fossil discoveries and radioisotopic dates allow a better calibration. The fossil biota and geological data suggest that the Salicas Formation was deposited in flatlands, under warm and dry conditions. This environment was probably dominated by open grasslands, with forested areas near rivers and lagoons.

**Key words.** Mammals. Paleobiogeography. Paleoenvironment. Salicas Formation. Neogene. Northwestern Argentina.

**Resumen.** MAMÍFEROS DE LA FORMACIÓN SALICAS (MIOCENO TARDÍO), PROVINCIA DE LA RIOJA, NOROESTE DE ARGENTINA: PALEOBIOGEOGRAFÍA, EDAD Y PALEOAMBIENTE. El objetivo de esta contribución es analizar una colección de mamíferos fósiles procedentes de la Formación Salicas en el área de El Degolladito, provincia de La Rioja, Argentina. El material aquí reportado fue recolectado en dos sitios (sitio 1 y sitio 2). Los mamíferos registrados son: *Macrochorobates* Scillato-Yané, *Chasicotatus* Scillato-Yané, y Hoplophorini indet. (Xenarthra, Cingulata); *Paedotherium minor* Cabrera, cf. *Pseudotytherium* Ameghino (Notoungulata, Typotheria); *Neobrachytherium* Soria (Liptopterna, Lopholipterna); *Orthomyctera* Ameghino, cf. *Cardiomys* Ameghino, *Lagostomus* (*Lagostomopsis*) Kraglievich, y Octodontidae indet. (Rodentia, Caviomorpha). La asociación de mamíferos presentada, junto con otra registrada previamente, tiene varios taxones en común con asociaciones de mamíferos del área central de Argentina (*i.e.*, provincia de La Pampa). Entre aquellas del Noroeste de la Argentina, su mayor afinidad se da con las del Miembro El Jarillal (Formación Chiquimil) y la Formación Andalhuala (ambas en la provincia de Catamarca). La Formación Salicas es considerada de edad miocena tardía hasta que nuevos registros fósiles y dataciones radioisotópicas permitan una mejor calibración. La información provista por la biota fósil y la interpretación geológica sugieren que la Formación Salicas se depositó en planicies bajo condiciones climáticas cálidas y secas. Este ambiente estuvo probablemente dominado por pastizales y áreas forestadas cercanas a ríos y lagunas.

**Palabras clave.** Mamíferos. Paleobiogeografía. Paleoambiente. Formación Salicas. Neógeno. Noroeste de Argentina.

CHRONOLOGY of the Neogene mammal-bearing terrestrial deposits from Argentina has been traditionally based on correlation of its faunal content because of the paucity of available radiometric or paleomagnetic data. Neogene units of Northwestern Argentina are uniquely complete and span almost the entire late Miocene–early Pleistocene, from about 9 Ma to less than 2 Ma (Marshall *et al.*, 1984; Reguero *et al.*, 2007; Reguero and Candela, 2011). Although this

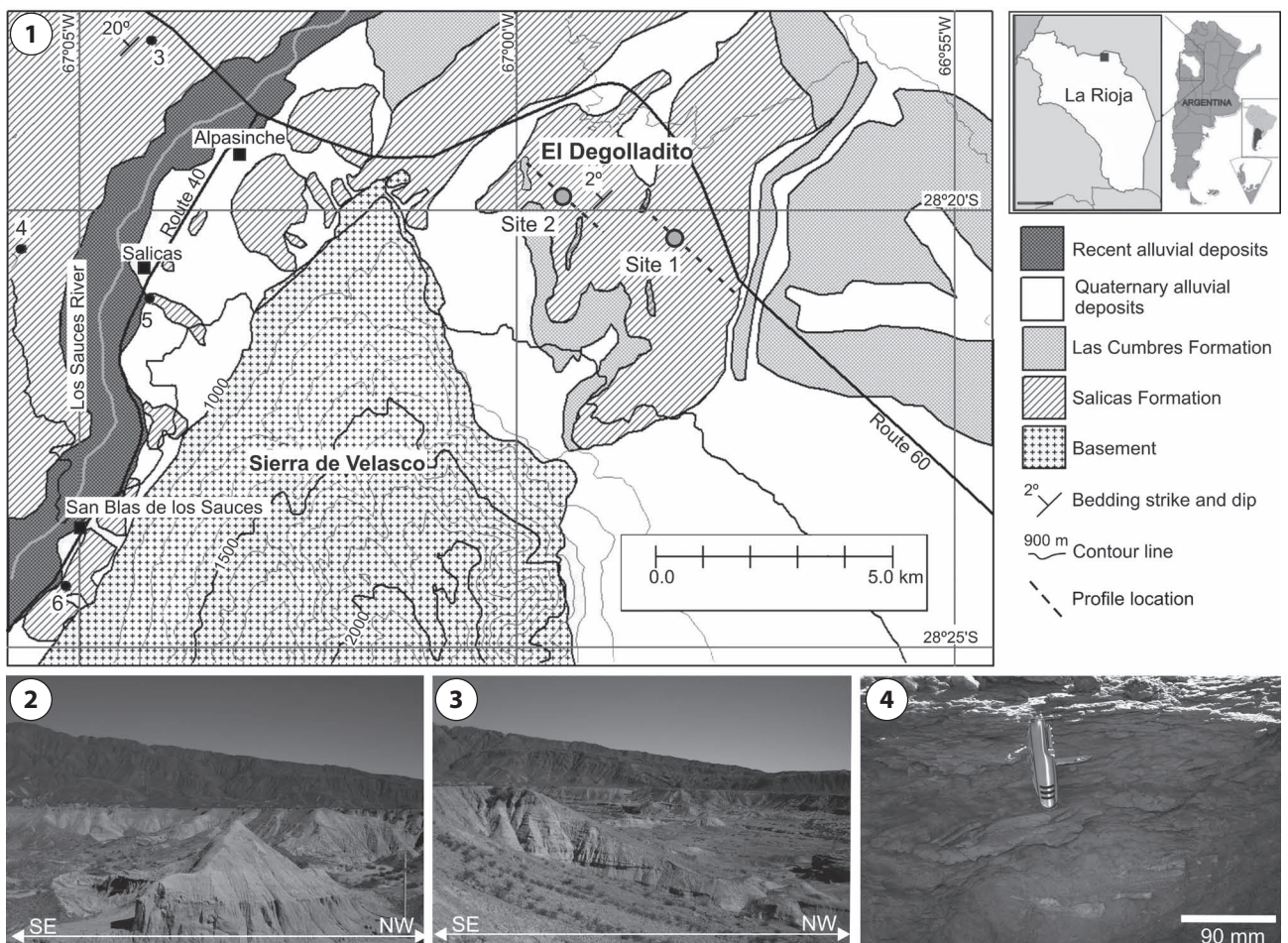
region has a less formalized mammalian biostratigraphic/biochronologic scheme than others (*e.g.*, the Atlantic Coast of Buenos Aires Province and the central Pampean region; see Cione and Tonni, 1999, 2005; Verzi *et al.*, 2008), recent studies have correlated the late Pliocene–early Pleistocene sequences of Northwestern Argentina to those exposed along the Atlantic coast of Buenos Aires (Reguero *et al.*, 2007; Reguero and Candela, 2011). Mammal-bearing

rocks of the late Miocene–Pliocene occur extensively in Northwestern Argentina (*i.e.*, Catamarca, Tucumán, Jujuy, Salta, and La Rioja provinces). Several localities in Catamarca and Jujuy have Miocene–Pliocene outcrops that have been extensively studied from geological and paleontological points of view, focussing mainly on their fossil mammal content. Neogene mammals from La Rioja Province have remained relatively unexplored compared to others which are geographically and coeval nearby units (Chiquimil, Andalhuala, and Corral Quemado formations). Georgieff *et al.* (2004) described mammals collected in the Desencuentro Formation (southeastern La Rioja); Tauber (2005) recorded many taxa from the Salicas Formation; Rodríguez Brizuela and Tauber (2006) analyzed the fossil mammals from the Toro Negro Formation, in the northwest of the province; Krapovickas *et al.* (2009) studied vertebrate tracks and invertebrate traces from the Toro Negro Forma-

tion; and Krapovickas and Nasif (2010) studied dinomyid tracks from the Vinchina Formation.

For the Salicas Formation, Tauber (2005) mentioned the presence of several genera of Cingulata (*e.g.*, *Macrochorobates* Scillato-Yané, 1980; *Proeuphractus* Ameghino, 1886; *Chaetophractus* Fitzinger, 1871; *Eosclerocalyptus* Ameghino, 1919), Rodentia (*e.g.*, *Neophanomys* Rovereto, 1914; *Lagostomus* Brookes, 1828; *Orthomyctera* Ameghino, 1889; *Potamarchus* Burmeister, 1885), and Notoungulata (*e.g.*, *Protypotherium* Ameghino, 1885; *Pseudotypotherium* Ameghino, 1904; *Hemibegetotherium* Rovereto, 1914; *Tremacyllus* Ameghino, 1891).

The aim of this contribution is to analyze a new collection of fossil mammals from the Salicas Formation, and discuss the systematics of the recovered taxa and their biochronological, paleobiogeographical, and paleoenvironmental significance in conjunction with information previously known for the unit.



**Figure 1.** Study area/ *área de estudio*. 1, Geological map including fossiliferous sites (1–2, grey circles) and points of sedimentological and stratigraphic observation (3–6, black circles)/ *mapa geológico que incluye los sitios fosilíferos (1–2, círculos grises) y puntos de observación sedimentológicos y estratigráficos (3–6, círculos negros)*. 2, site/ *sitio* 1. 3, site/ *sitio* 2. 4, Detail of structured sandstones including fossil material in site 2/ *detalle de areniscas estructuradas incluyendo material fósil en sitio 2*.

## MATERIALS AND METHODS

The limits and extent of the Salicas Formation were studied through analysis of satellite images and field surveys. Grain size, sedimentary structures, and stratigraphic relationships were observed in the field. The stratigraphic column was analyzed in two cross-sections: site 1—already studied by Tauber (2005)— and site 2 (Fig. 1.1). Photographs were complementary for interpreting the geometric relations between lithostratigraphic units (Fig. 1.2–3). Bed thickness was calculated by trigonometry, by considering the inclination of beds—c. 2° in the El Degolladito area according to Tauber (2005)— and estimating the difference in elevation between the sites using Digital Elevation Models (SRTM- 90m). Sedimentary facies were recognized in the field and classified following Miall's criterion (Miall, 1990). Collected materials were identified by comparison with specimens housed at the Museo Argentino de Ciencias Naturales “Bernardino Rivadavia” and the Museo de La Plata. The specimens described herein are deposited in the Departamento de Geociencias, Centro Regional de Investigaciones Científicas y Transferencia Tecnológica, Anillaco, La Rioja, Argentina (CRILAR Pv).

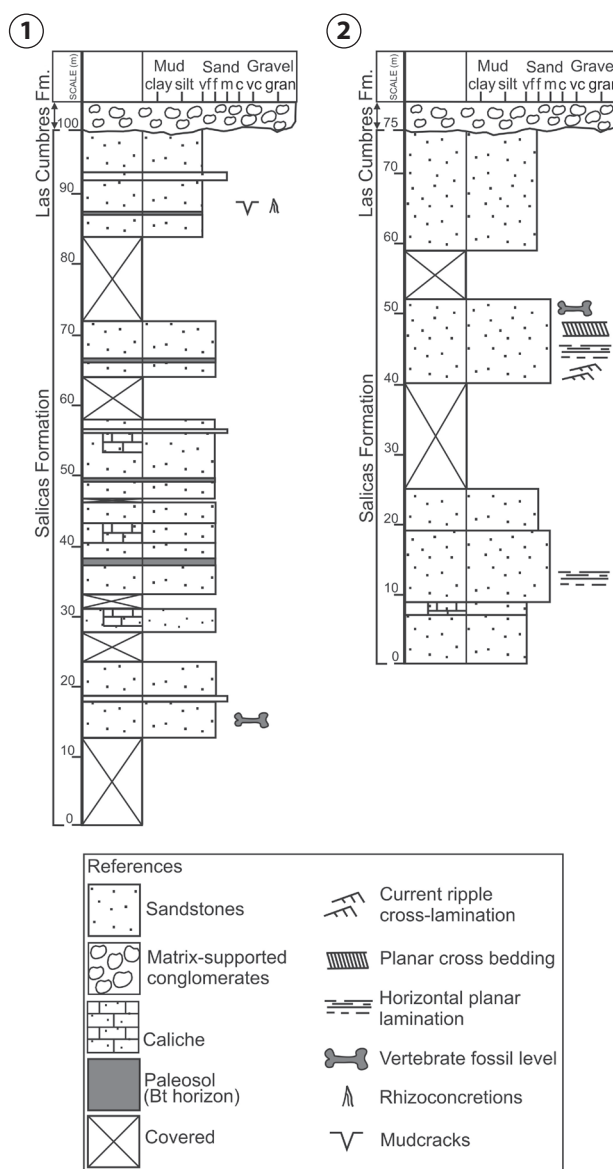
## GEOGRAPHIC AND STRATIGRAPHIC CONTEXT

The north central region of La Rioja Province is characterized by a range and *bolson* system (internal basins enclosed by mountains) that was deformed during the late Cenozoic exposing Paleozoic, Mesozoic, and Neogene units (Fiorelli *et al.*, 2012). The Neogene sediments from the South of Pipanaco Bolsón include two lithologic units: the Salicas (lower) and the Las Cumbres (upper) formations (Socic, 1972; Bossi *et al.*, 2001).

The Salicas Formation (Socic, 1972) is exposed along the eastern and western flanks of the northern portion of the Velasco range (Fig. 1.1). On the western slope of the range, the sedimentary unit overlies the granitic basement on a nonconformity surface (Bossi *et al.*, 2009), being their contact tectonic in origin (Socic, 1972). The eastern side of the range is abrupt, representing the active mountain front. Quaternary alluvial fans cover the contact with the basement (Fig. 1.1). According to surface exposures, Socic (1972) estimated the thickness of the Salicas Formation in 600–800 m at the southern end of Pipanaco Bolsón, whereas Bossi *et al.* (2009) estimated it in 440 m near the village of Alpasinche. The Salicas Formation is overlain by the Las Cumbres Formation (Plio–Pleistocene in age) (Fig. 1.1, 2), which is composed by gravels and coarse sands. The two units are sepa-

rated by an angular unconformity (Bossi *et al.*, 2007, 2009).

Considering the integrated stratigraphic section, the Salicas Formation is dominated by massive fine sands and sandstones (Sm) and clayish silts and siltstones (Fm), which are reddish-ochre in color alternating with clearer yellowish grey interstratified beds. These sediments are amalgamated into tabular banks with horizontal stratification. Thin strata of coarse sand and fine gravel and well-defined levels of white tuffs have also been identified in eastern outcrops at the Villa Mazán–Villa Mervil area (Bossi *et al.*, 2009). The grade of lithification by calcareous cement is variable. Pedogenic features are evidenced by the presence of continuous calcrete levels.



**Figure 2.** Stratigraphic profile of El Degolladito/ perfil estratigráfico de El Degolladito. **1**, site/ sitio 1 (modified from/ modificado de Tauber, 2005). **2**, site/ sitio 2.



Tauber (2005) studied the Salicas Formation and collected fossil vertebrates from La Cortadera and El Degolladito area, near the village of Alpasinche. Our study was also performed in the El Degolladito area, particularly at two sites: site 1 (28°20'35"S–66°58'6"W) and site 2 (28°19'54"S–66°59'21"W) (Fig. 1.1–3). Considering that in the El Degolladito area the beds dip approximately 2° NW (see Tauber, 2005), the thickness of these deposits along 5 km is estimated in 175 m (Fig. 2). The 100 m thick basal column corresponds outcrop at site 1 (Fig. 2.1), and the upper 75 m of deposits are exposed at site 2 (Fig. 2.2). In this area, the basal levels are exposed toward the southeast, whereas the upper levels appear to the northwest (Fig. 1.2–3).

At site 1 (Fig. 2.1), Tauber (2005) identified rhizoconcretions, carbonatic fill of mud-cracks, and darker argillaceous levels, which were interpreted as Bt horizons of paleosols. Most of the fossils studied by Tauber (2005) and those reported herein from this site come from basal strata (*e.g.*, level 2 of Tauber, 2005). At site 2 (Fig. 2.2), the fossil-bearing levels correspond to structured sandstones with ripples, thin parallel bedding (Sh), and cross-bedding structures (Sp) (Fig. 1.4). The fossil materials from this site were recovered from the middle part of the upper stratigraphic section (Fig. 2.2).

**SYSTEMATIC PALEONTOLOGY**

Class MAMMALIA Linnaeus, 1758

Superorder XENARTHRA Cope, 1889

Order CINGULATA Illiger, 1811

Family DASYPODIDAE Gray, 1821

Subfamily EUPHRACTINAE Pocock, 1924

Tribe EUPHRACTINI Pocock, 1924

Genus **Macrochorobates** Scillato-Yané, 1980

*Type species.* *Proeuphractus scalabrinii* Moreno and Mercerat, 1891.

**Macrochorobates** sp.

**Figure 3.1–2**

**Referred material.** CRILAR Pv 420: a fixed and a moveable osteoderm (Fig. 3.1–2).

**Locality.** Site 2 of El Degolladito area, La Rioja Province (Fig. 1.1, 2.2).

**Remarks.** The species of *Macrochorobates* differ by the size of the osteoderms and the convexity of the peripheral figures (Esteban *et al.*, 2001; Urrutia *et al.*, 2008). Tauber (2005) pointed out the record of *Macrochorobates scalabrinii* (Moreno and Mercerat, 1891) from the Salicas Formation.

Tribe EUTATINI Bordas, 1933

Genus **Chasicotatus** Scillato-Yané, 1979

*Type species.* *Chasicotatus ameghinoi* Scillato-Yané, 1979.

**Chasicotatus** sp.

**Figure 3.3**

**Referred material.** CRILAR Pv 428: a fixed osteoderm (Fig. 3.3).

**Procedence.** Site 2 of El Degolladito area, La Rioja Province (Fig. 1.1, 2.2).

**Description.** The osteoderm is smooth (not rugose). The central figure carries a marked keel surrounded by six convex peripheral figures, two on the anterior portion and a pair at both sides of the keel. In addition, four piliferous foramina lie on the posterior margin of the osteoderm, forming a single row.

**Remarks.** Species of *Chasicotatus* are primarily diagnosed by the external and internal morphology of the osteoderms (see Scillato-Yané *et al.*, 2010). The described specimen of *Chasicotatus* represents the first record of the genus in La Rioja Province.

Family GLYPTODONTIDAE Gray, 1869

Subfamily HOPLOPHORINAE Huxley, 1864

Tribe HOPLOPHORINI Huxley, 1864

**HOPLOPHORINI INDET.**

**Figure 3.4–6**

**Referred material.** CRILAR Pv 421: two osteoderms from the caudal rings and fragmentary osteoderms of the dorsal carapace (Fig. 3.4–6).

**Locality.** Site 2 of El Degolladito area, La Rioja Province (Fig. 1.1, 2.2).

**Description.** The osteoderms from the caudal rings are rectangular in outline; the central figure is circular in outline and flat. The peripheral figures, located proximally and laterally to the central figure, are pentagonal to hexagonal in outline. Many foramina are developed on the articulation area of each osteoderm.

**Remarks.** Tauber (2005) mentioned the presence of *Eosclerocalyptus planus* (Rovereto, 1914) [= *E. proximus* (Moreno and Mercerat, 1891), according to Zurita (2007)] from the Salicas Formation, based on a scute of the posterior region of carapac. However, Zurita (2007) considered this specimen too fragmentary for specific identification.

Order NOTOUNGULATA Roth, 1903

Suborder TYPOTHERIA Zittel, 1893

Family HEGETOTHERIIDAE Ameghino, 1894

Subfamily PACHYRUKHINAE Kraglievich, 1934

Genus *Paedotherium* Burmeister, 1888

*Type species.* *Paedotherium insigne* Burmeister, 1888.

***Paedotherium minor*** Cabrera, 1937

**Figure 3.7–9**

**Referred material.** CRILAR Pv 425: fragmentary right mandible with p3–m1 (Fig. 3.7); CRILAR Pv 426: fragmentary right mandible with p4–m2 (Fig. 3.8); and CRILAR Pv 427: fragmentary right mandible with p3–m3 (Fig. 3.9).

**Locality.** Site 2 of El Degolladito area, La Rioja Province (Fig. 1.1, 2.2).

**Description.** The three specimens have similar features. The triangular trigonid of the premolars has a straighter and longer lingual face than the talonid. The molars of each specimen have a subtriangular trigonid with more convex sides than those of the talonid. The degree of cheek tooth imbrication is marked.

**Remarks.** The specimens described herein allow identification of *Paedotherium minor* based on anatomical features—*e.g.*, degree of tooth imbrications are slightly greater than in *P. bonaerense* (Ameghino, 1887), and *P. typicum* (Ameghino, 1887)—and size (*i.e.*, smaller than *P. bonaerense* and *P. typicum*).

Family MESOTHERIIDAE Alston, 1876

Subfamily MESOTHERIINAE Alston, 1876

cf. ***Pseudotypotheium*** Ameghino, 1904

**Figure 3.10**

**Referred material.** CRILAR Pv 433: partial palate with both I1, the right tooth row (dP2?–M3), and fragments of the left M2 and M3, and incomplete right zygomatic arch (Fig. 3.10).

**Locality.** Site 1 of El Degolladito area, La Rioja Province (Fig. 1.1, 2.1).

**Description.** The two I1 are slightly anteriorly placed, kidney-shaped, and with a short but marked lingual groove. The outstanding feature of this specimen is the presence of three premolars. The first one (P2) is smaller than P3 and P4 and triangular. The P3 is subtriangular in outline, but with smoothly convex posterior and labial walls, and a hardly marked parastyle. P4 is a more molarized quadrangular tooth, with a Y-shaped lingual groove, and the parastyle projecting over P3. The M1–M2 have a large middle lobe,

reaching the lingual level of the anterior lobe; the posterior lobe is slightly more projected. In M3, the middle lobe is slightly shorter than the others and more triangular in outline. The parastyle projects over M2, and the metastyle directs backward forming a concave posterior face.

**Remarks.** The Subfamily Mesotheriinae is supposed to have an adult dental formula with only two upper premolars, P3–P4 (Francis, 1965; Pascual *et al.* 1966; Cerdeño and Montalvo, 2001). Therefore, the presence of three premolars in this specimen is a striking feature. It is not the only known mesotheriine with three premolars, but other specimens were previously recognized as carrying the deciduous dentition together with permanent molars (see Francis, 1960 and references therein). We consider that all premolars of CRILAR Pv 433 are the permanent ones and at least two interpretations are possible: it may correspond to a new taxon or it is a case of supernumerary tooth. Pending a detailed analysis, which is beyond the aim of this paper (Schmidt and Cerdeño, in prep.), we identify the specimen as cf. *Pseudotypotheium* because of the lingual sulcus in the P4.

Order LITOPTERNA Ameghino, 1889

Suborder LOPHOPTERNA Cifelli, 1983

Family PROTEROTHERIIDAE Ameghino, 1887

Subfamily PROTEROTHERIINAE Ameghino, 1887

Genus ***Neobrachytherium*** Soria, 2001

*Type species.* *Licaphrium intermedium* Moreno and Mercerat, 1891.

***Neobrachytherium*** sp.

**Figure 3.11**

**Referred material.** CRILAR Pv 429: right P3–M1 and left P3 (Fig. 3.11).

**Locality.** Site 1 of El Degolladito area, La Rioja Province (Fig. 1.1, 2.1).

**Description.** Teeth with the anterolingual cingulum restricted to the anterior region, delimiting a fossettid. P3–P4 with protocone, paraconule, and metaconule joined in a continuous wearing surface. M1 squared in outline, showing a pronounced concavity between parastyle and mesostyle, and a groove between protocone and hypocone.

**Remarks.** P3–P4 of *Neobrachytherium intermedium* (Moreno and Mercerat, 1891) are more anteriorly rounded than in CRILAR Pv 429 and the metaconule extends to the metacone, whereas it is joined to the protocone and hypocone in CRILAR Pv 429. P4 differs from that of *N. morenoi* (Rovereto, 1914) in lacking a triangular denticulum at the

base of the hypocone. The anterior cingulum of P3–M1 not projected lingually and the quadrangular outline of M1 resemble *N. ameghinoi* Soria, 2001. A specific determination is not reliable, but these remains represent the first record of *Neobrachytherium* for the Salicas Formation.

Order RODENTIA Bowdich, 1821

Suborder CAVIOMORPHA Wood, 1955

Family CAVIIDAE Fischer de Waldheim, 1817

Genus *Orthomyctera* Ameghino, 1889

*Type species.* *Orthomyctera rigens* Ameghino, 1889.

***Orthomyctera* sp.**

**Figure 3.12**

**Referred material.** CRILAR Pv 423: left mandible with the p4–m3 series (Fig. 3.12)

**Locality.** Site 2 of El Degolladito area, La Rioja Province (Fig. 1.1, 2.2).

**Remarks.** Specimen CRILAR Pv 423 is identified as *Orthomyctera* because of the following features: it is much smaller than living *Dolichotis* Desmarest, 1820, being similar in size to *O. andina* (Rovereto, 1914) and *O. rigens* Ameghino, 1889; the inferred total diastema length is not longer than the p4–m3 series length; and the p4 shows the anterior prism scarcely elongated anteriorly (see Ameghino, 1889; Kraglievich, 1932; Pascual *et al.*, 1966; Ubilla and Rinderknecht, 2003). In reference to the p4, Pascual *et al.* (1966) pointed out that the anterior elongation of the anterior prism of the p4 is variable within *Orthomyctera* (less developed than in *Dolichotis*), being in certain cases barely insinuated. The new material differs from *O. andina*, previously identified in the Salicas Formation (Tauber, 2005), by the following features: the p4 is relatively shorter in relation to the length of the molars (a feature similar to that of *O. rigens* Ameghino, 1889); the anterior prism of the p4 in CRILAR Pv 423 is less differentiated than in *O. andina* (see Rovereto, 1914, p. 59, fig. 25), a similar condition to that of *O. rigens*; and the horizontal crest (sensu Pérez, 2010) is more laterally extended at the level of m1. An important variability is recognized among the Miocene and Pliocene species included in Caviidae, so a taxonomic revision is needed for the group. In this context, we prefer to refer CRILAR Pv 423 to *Orthomyctera* sp.

Subfamily CARDIOMYINAE Kraglievich, 1940

cf. *Cardiomyis* Ameghino, 1885

**Figure 3.13**

**Referred material.** CRILAR Pv 424: portion of right mandibular fragment with the m2 (Fig. 3.13).

**Locality.** Site 2 of El Degolladito area, La Rioja Province (Fig. 1.1, 2.2).

**Description.** The molar has two heart-shaped prisms separated by a deep labial flexid (=hypoflexid). The posterior prism is anteroposteriorly longer than the anterior one. Each prism shows a lingual sulcus (“*surco lobular interno*”; Pascual *et al.*, 1966). The lingual sulcus of the posterior prism is deeper than that of the anterior prism, which is not completely preserved. Enamel is thicker on the labial border of the prisms and reduced on the lingual surfaces.

**Remarks.** Specimen CRILAR Pv 424 is referred to cf. *Cardiomyis* because it presents relatively superficial lingual sulci on both prisms of the tooth; *i.e.*, a diagnostic condition for the genus (Pascual *et al.*, 1966, p. 104–105). The specimen described herein is the first cardiomyine recorded from the Salicas Formation.

Family CHINCHILLIDAE Bennet, 1833

Subfamily LAGOSTOMINAE Pocock, 1922

Genus *Lagostomus* Brookes, 1828

Subgenus *Lagostomus (Lagostomopsis)* Kraglievich, 1926

*Type species.* *Lagostomus trichodactylus* Brookes, 1828.

***Lagostomus (Lagostomopsis)* sp.**

**Figure 3.14**

**Referred material.** CRILAR Pv 430: right maxillary fragment with P4–M3 series (Fig. 3.14).

**Locality.** Site 2 of El Degolladito area, La Rioja Province (Fig. 1.1, 2.2).

**Remarks.** The teeth of CRILAR Pv 430 are very similar in size and general shape to those of *Lagostomus (Lagostomopsis)* spp., having bilaminated P4–M2, and trilaminated M3 (with second and third laminae partially preserved). Note that, previously identified chinchillids from the Salicas Formation are known by lower dentition.

Superfamily OCTODONTOIDEA Waterhouse, 1839

Family OCTODONTIDAE Waterhouse, 1839

OCTODONTIDAE INDET.

**Figure 3.15**

**Referred material.** CRILAR Pv 431: right mandibular fragment with dp4–m1 (Fig. 3.15).

**Locality.** Site 2 of El Degolladito area, La Rioja Province (Fig. 1.1, 2.2).

**Description.** The masseteric crest begins behind the masseteric notch, without continuity between both structures. The masseteric notch is located somewhat above the middle mandibular height and at the level of dp4 and anterior portion of m1. The preserved portion of the incisor shows that this tooth is high and narrow. The deciduous tooth (dp4) is somewhat longer than m1, showing a tetralophodont pattern, with well developed metalophulid I, mesolophid, hypolophid, and posterolophid. In addition, a small crest (metalophulid II? *sensu* Candela, 2002) is connected to metalophulid I, and posterolabially oriented towards the center of the anterofossetid, which is sub-circular in shape. The mesolophid is anterolingually oriented. The metaflexid is shallower than the mesoflexid, indicating that the latter is more persistent, and both flexids are shallower than the hypoflexid. In labial view, this flexid extends to about 2/3 of the emerged crown. Molar m1 is protohypsodont, somewhat longer than wide, and trilophodont, without indication of metalophulid II (*sensu* Candela, 2002). The mesoflexid is projected towards the anterior border of the molar. This flexid is deeper than the metaflexid (a feature clearly seen in lingual view), indicating that the latter closes before the former. Both flexids are less persistent than the hypoflexid.

**Remarks.** Specimen CRILAR Pv 431 is assigned to Octodontidae by the following features: the masseteric crest is posterior to the masseteric notch, so this crest does not include the masseteric notch (Verzi, 1999), and the metaflexid closes before the

mesoflexid (Verzi *et al.*, 1999), whereas in octodontoid Echimyidae, the metaflexid is more persistent than the mesoflexid. Preliminary observations indicate similarities and differences between CRILAR Pv 431 and the octodontids *Neophanomys biplicatus* Rovereto, 1914, previously recognized in the Salicas Formation (Tauber, 2005), *Chasichimys* Pascual, 1967, and certain specimens of *Acarechimys* Patterson, 1965 (in Kraglievich, 1965). CRILAR Pv 431 shares with *Neophanomys* the following diagnostic features of the genus (see Verzi *et al.*, 1999: 84): incisor high and narrow, lingual flexids less persistent than the hypoflexid; tetralophodont dp4, and trilophodont and protohypsodont molars. CRILAR Pv 431 differs from specimens of *N. biplicatus* by its larger size, the relatively less simultaneous closure of the lingual flexid (metaflexid close before mesoflexid), the presence of a small crest within anterofossetid in dp4, and the absence the vestige of metalophulid II in m1, which is present at least in some specimens of *N. biplicatus* (see Verzi *et al.*, 1999). Compared with youngest specimens of *Chasichimys bonaerense* Pascual, 1967 (see Verzi, 1999: fig. 2), the dp4 of CRILAR Pv 431 shows more persistent flexids and lophids. On the other hand, the m1 of CRILAR Pv 431 is comparable in size to that of *Chasichimys bonaerense* (see Verzi, 1999, table 1) and, as in *Chasichimys* spp., the m1 of CRILAR Pv 431 is protohypsodont, trilophodont, with the mesoflexid projected towards the anterior border of the molar, and the hypoflexid more persistent than the lingual flexids. CRILAR Pv 431 shares with some specimens of *Acarechimys* coming from Colloncuran (middle Miocene; Neuquén Province; Vucetich *et al.*, 1993) a small crest crossing the subcircular anterofossetid

TABLE 1. Mammal genera shared among the Salicas Formation and other Miocene-Pliocene units/ géneros de mamíferos compartidos entre la Formación Salicas y otras unidades del Mioceno-Plioceno

	Salicas Fm.	Chiquimil Fm. El Jarillal Mb.	Andalhuala Fm.	Corral Quemado Fm.	Río Quinto Fm.	Cerro Azul Fm.	Arroyo Chasicó Fm.
Macrochorobates	x	x	x		x	x	
Chasicotatus	x	x				x	x
Proeuphractus	x	x				x	
Chaetophractus	x						
Eosclerocalyptus	x	x	x			x	
Paedotherium	x	?			x	x	x
Tremacyllus	?	x	x		x		
Hemihegetotherium	x		x	x		x	
Pseudotypotherium	x					x	
Protypotherium	x						
Neobrachytherium	x		x	x			x
Orthomyctera	x	x	x			x	
Cardiomys	?	x	x			x	
Lagostomus (Lagostomopsis)	x	x	x		x	x	x
Neophanomys	x	x	x			x	
Potamarchus	x	x				x	



in dp4, but differs by having higher tooth crown, and the absence of remnant of second lophid (metalophulid II?), which is frequent in specimens of *Acarechimys* (in *Acarechimys* spp. this lophid is variable in development, being in *A. constans*, at least in the m1 of holotype of this species, more developed). In this context, it is possible to suggest that the CRILAR Pv 431 represents a new Octodontidae. However, differences and similarities between CRILAR Pv 431 and *Neophanomyx biplicatus*, *Chasicimys*, and certain specimens of *Acarechimys* requires further evaluation.

## DISCUSSION

### Diversity

The previously recognized diversity of mammals from the Salicas Formation included twelve genera (Tauber, 2005). This contribution increases the knowledge about the mammalian fossil record by adding the first reports of *Chasicotatus*, *Paedotherium*, *Neobrachytherium*, cf. *Cardiomys* (Tab. 1), and probably two new taxa. The latter are represented by the palate assigned to cf. *Pseudotypotherium* and the mandibular fragment referred to Octodontidae.

Regarding *Chasicotatus*, four species are known from Argentina: (1) *Ch. ameghinoi* Scillato-Yané, 1979, typical of the Arroyo Chasicó Formation (Buenos Aires Province), the Cerro Azul Formation (La Pampa Province), and the Jarillal Member of the Chiquimil Formation (Catamarca Province) (see Esteban and Nasif, 1999; Urrutia *et al.*, 2008; Scillato-Yané *et al.*, 2010); (2) *Ch. peiranoii* Esteban and Nasif, 1996 from the late Miocene of Buenos Aires Province and Andalhuala Formation, Catamarca Province (Scillato-Yané *et al.*, 2010); (3) *Ch. powelli* Scillato-Yané, Krmptotic, and Esteban, 2010, from the late Miocene of the Valle del Cajón, Catamarca Province (Scillato-Yané *et al.*, 2010); and (4) *Ch. spinozai* Scillato-Yané, Krmptotic, and Esteban, 2010 from the “conglomerado osifero” at the base of the Ituzaingó Formation (Entre Ríos Province; Scillato-Yané *et al.*, 2010). These records, and the material here reported from the Salicas Formation, suggest that *Chasicotatus* was broadly distributed in Argentina during the late Miocene (Scillato-Yané *et*

*al.*, 2010). In addition to the scutes of *Chasicotatus*, *Macrochorobates*, and Hoplophorini described herein, several other isolated scutes that belong to different genera of Xenarthra Cingulata were recorded from the Salicas Formation, including *Proeuphractus limpidus* Ameghino, 1886, *Proeuphractus* sp., *Chaetophractus* sp., and *Eosclerocalyptus* sp. (see Tauber, 2005; Zurita, 2007).

In Argentina, *Paedotherium minor* has been recorded from the Arroyo Chasicó and Cerro Azul formations and probably from El Jarillal Member of the Chiquimil Formation (see Cerdeño and Bond, 1998). The genus was also identified in the Río Quinto Formation (San Luis Province; Prado *et al.*, 1998). The record reported herein is the first definite record of Pachyrukhinae other than *Tremacyllus* from the Salicas Formation.

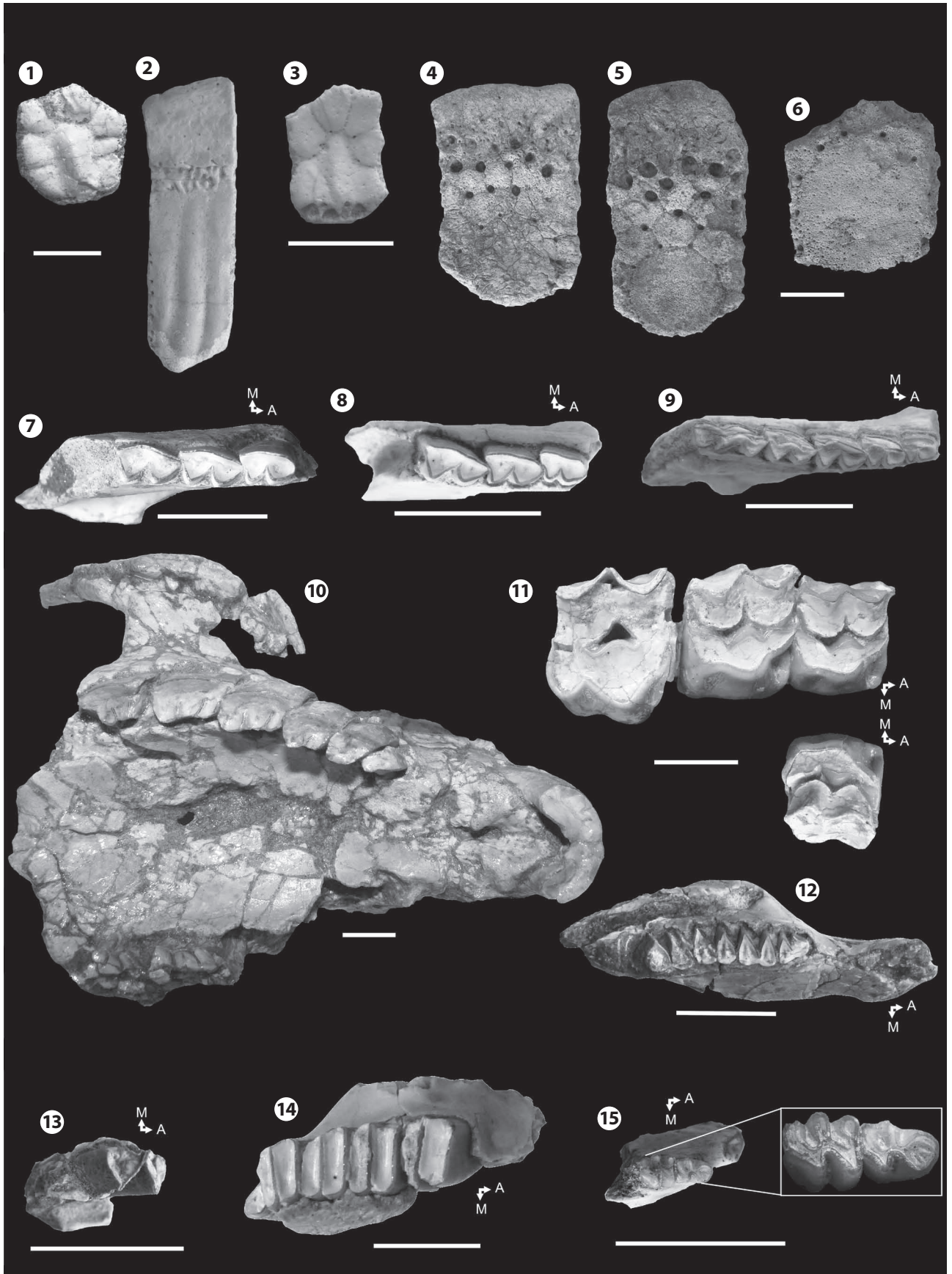
Regarding Mesotheriinae, specimens coming from the Salicas Formation were previously assigned to *Pseudotypotherium* sp. (Tauber, 2005). Although the palatal fragment studied herein is referred preliminarily to cf. *Pseudotypotherium*, it presents some peculiarities in the dentition that might correspond to a new taxon. In addition to these Notoungulata, the hegetotheriid *Hemihegetotherium* cf. *torresi* (Cabrera and Kraglievich, 1931) and the interatherid *Prototypotherium* sp. were also mentioned for the Salicas Formation (Tauber, 2005).

*Neobrachytherium* is known by four species: (1) *N. intermedium* (= *Licaphrium intermedium* Moreno and Mercerat, 1891) from the Corral Quemado Formation, Catamarca Province; (2) *N. morenoi*, from Andalhuala and Corral Quemado formations; (3) *N. ameghinoi*, from the “conglomerado osifero”; and (4) *N. ullumense* Soria, 2001, from the Loma de las Tapias Formation (San Juan Province) and the Arroyo Chasicó Formation (see Soria, 2001; Cerdeño, 2003; Reguero and Candela, 2011). Its recognition in the Salicas Formation is, therefore, not surprising, due to the probable late Miocene age of this locality, and increases the geographical distribution of this species in Western Argentina.

The extinct Cardiomyinae are recognized in Argentina in rocks as early as the late Miocene. In addition to the record reported herein, *Cardiomys* was recorded in the Cerro Azul,

**Figure 3.** Mammals from the Salicas Formation/ mamíferos de la Formación Salicas. **1–2, Macrochorobates** (CRILAR Pv 420), **1**, fixed osteoderm/ osteodermo fijo; **2**, moveable osteoderm/ osteodermo móvil. **3, Chasicotatus** (CRILAR Pv 428), fixed osteoderm/ osteodermo fijo. **4–6**, Hoplophorini indet. (CRILAR Pv 421), osteoderms/ osteodermos. **7, Paedotherium minor** (CRILAR Pv 425), fragmentary right mandible with p3–m1/ fragmento de mandíbula derecha con p3–m1. **8, Paedotherium minor** (CRILAR Pv 426), fragmentary right mandible with p4–m2/ fragmento de mandíbula derecha con p4–m2. **9, Paedotherium minor** (CRILAR Pv 427), fragmentary right mandible with p3–m3/ fragmento de mandíbula derecha con p3–m3. **10**, cf. *Pseudotypotherium* (CRILAR Pv 433), partial palate/ paladar parcial. **11, Neobrachytherium** sp. (CRILAR Pv 429), right P3–M1 and left P3/ P3–M1 derechos y P3 izquierdo. **12, Orthomyctera** sp. (CRILAR Pv 423), left mandible with the p4–m3 series/ mandíbula izquierda con p4–m3. **13**, cf. *Cardiomys* (CRILAR Pv 424), right mandibular fragment with the m2/ fragmento de mandíbula derecha con m2. **14, Lagostomus (Lagostomopsis)** sp. (CRILAR Pv 430), right maxillary fragment with P4–M3 series/ fragmento de maxilar derecho con P4–M3. **15**, Octodontidae indet. (CRILAR Pv 431), right mandibular fragment with dp4–m1/ fragmento mandibular derecho con dp4–m1. A, anterior. M, mesial. Scale bar/ Escala= 10 mm.





Las Arcas (Catamarca Province), Ituzaingó, and Chapadmalal (Buenos Aires Province) formations (Nasif *et al.*, 1997; Goin *et al.*, 2000; Cione *et al.*, 2000; Vizcaíno *et al.*, 2004).

Octodontidae possibly related to CRILAR Pv 431 are well represented in different late Miocene units of Argentina. *Neophanomys biplicatus* Rovereto, 1914, was reported from the Andalhuala and Chiquimil formations (Catamarca Province), Huayquerías and Tunuyán formations (Mendoza Province), Cerro Azul Formation (Verzi *et al.*, 1999; Nasif and Esteban, 2000; Montalvo *et al.*, 2009), and Salicas Formation (Tauber, 2005). In addition to these rodents, *Orthomyctera andina* and probably another species of this genus, *Lagostomus (Lagostomopsis) cf. pretrichodactyla* (Rovereto, 1914), and *Potamarchus* sp. were recorded in the Salicas Formation (Tauber, 2005).

### ***Paleobiogeography and age of the Salicas Formation***

Most of the specimens analyzed herein could not be identified at the specific level mainly because of their fragmentary preservation. However, generic identifications may possibly help to establish chronological and biogeographical relationships among the Salicas Formation mammal association and those coming from other late Miocene–Pliocene units of Argentina (see Marshall and Patterson, 1981; Prado *et al.*, 1998; Cerdeño and Bond, 1998; Goin *et al.*, 2000; Esteban *et al.*, 2001; Cione and Tonni, 2005; Rodríguez Brizuela and Tauber, 2006; Zurita, 2007; Reguero *et al.*, 2007; Urrutia *et al.*, 2008; Verzi *et al.*, 2008; Montalvo *et al.*, 2009; Scillato-Yané *et al.*, 2010, among others).

Considering the presence of mammal genera (including dubious records), the Salicas Formation shares twelve genera with the Cerro Azul Formation, eleven with the El Jarillal Member of Chiquimil Formation, nine with the Andalhuala Formation, four with the Río Quinto Formation, four with the Arroyo Chasicó Formation, and two with the Corral Quemado Formation (Tab. 1). Among those associations, the Salicas Formation fauna shares more taxa with from Central Argentina (*i.e.*, La Pampa Province). Among those coming from Northwestern Argentina, its major affinity lies with the El Jarillal Member (Chiquimil Formation) and secondly the Andalhuala Formation (both in Catamarca Province) (see Marshall and Patterson, 1981; Tauber, 2005; Reguero and Candela, 2011).

The calibration of the stages/ages scheme for the late Neogene of South America is controversial. The boundaries between the Chasicóan and the Huayquerian, and the Huayquerian and the Montehermosan remain unresolved

as there is no agreement among researchers. Traditionally, the base of the Huayquerian (*i.e.*, the Chasicóan/Huayquerian boundary) was placed at about 9 Ma and its top at 6.8 Ma (Flynn and Swisher, 1995; Cione *et al.*, 2000; Reguero and Candela, 2011). Recently, the Huayquerian/Montehermosan boundary was placed at about 5.3 Ma (Verzi and Montalvo, 2008; Verzi *et al.*, 2008).

An accurate age for the Salicas Formation is not easily deduced given the absence of radiometric datings for the unit. Tauber (2005, p. 456) suggested a Huayquerian age for the Salicas assemblage, considering a Montehermosan age less probable. As mentioned, the Salicas Formation shares many genera with the geographically nearby Chiquimil and Andalhuala formations, for which radiometric ages are available. A dating of the base of the El Jarillal Member (Chiquimil Formation, at level 8, in the Puerta de Corral Quemado area, according to Marshall and Patterson, 1981) rendered an age of 6.68 Ma; whereas the Andalhuala Formation (at level XIX, in Chiquimil area, according to Marshall and Patterson, 1981) rendered an age of 6.02 Ma (see Marshall and Patterson, 1981; Reguero and Candela, 2011). As detailed above, this range corresponds either to the Huayquerian or the Montehermosan depending on which authors are followed.

For the base of the Montehermosan, Reguero and Candela (2011) defined the Biozone of *Cyonasua brevirostris* (Moreno and Mercerat, 1891) for Northwestern Argentina on the basis of the Andalhuala Formation mammal assemblage (see Reguero and Candela, 2011). Until now, *Cyonasua brevirostris* has not been recorded in the Salicas Formation, but other taxa with a broader chronological distribution (*e.g.*, *Tremacyllus*, *Orthomyctera*) are also present in this biozone. On the other hand, *Macrochorobates scalabrinii* is used to define a local biozone in Buenos Aires Province, referred to the Huayquerian (Cione and Tonni, 2005) and present in the Salicas Formation.

In summary, we consider the Salicas Formation fauna as latest Miocene in age until new fossil discoveries and radiometric dates allow a better calibration.

### ***Paleoenvironment***

The current understanding of the biota in the Salicas Formation does not allow a complete paleoenvironmental interpretation. Recent contributions dealt with a scattered record of fossil mammals (Tauber, 2005) and with paleobotanical evidence of the presence of Leguminosae Mimosoideae (Pujana, 2010). The xenarthran cingulate com-

munity suggests the predominance of open environments under warm conditions (see Zurita, 2007; Scillato-Yané *et al.*, 2010). In addition, dry environmental conditions were proposed for the habitat of *Paedotherium* (Kraglievich, 1926; Zetti, 1972; Bondesio *et al.*, 1980). Mesotheriids were formerly compared ecomorphologically to the extant giant semi-aquatic capybara rodents (Bond *et al.*, 1995). However, Shockey *et al.* (2007) recently indicated some fossorial or semi-fossorial adaptations for them. Morphological variation within proterotheriids —mainly reflected in different hypsodonty degree and size— suggests different habitats, from closed and forested areas to open environments (Villafañe *et al.*, 2006). With few exceptions (Candela, 2004; Candela and Picasso, 2008), late Miocene caviomorphs have not been analyzed from a morphofunctional adaptive perspective, making it difficult to infer their palaeoenvironmental significances. However, if the metabolic and ecological requirements of chinchillids from the Salicas Formation were comparable to those of the related living forms; then, they would probably had preferred relatively open areas, such as most current species of those groups do. In addition to the mammal community, Tauber (2005) recorded turtles, birds (probably Ciconiidae), anurans, gastropods, and aquatic plants. He also interpreted the facies association as channel deposits and alluvial plains suffering oscillating flooding and drought periods. The caliche soils indicate periods of semiarid climate, whereas alternative Bt levels (argillaceous) would represent a more humid climate with more stable hydrological conditions, for example inside inter-channel areas. The differences in average grain-size between the Salicas and Las Cumbres formations would evidence the passage from a lower energy environment to a more dynamic regimen. This would be related to a tectonic inversion episode during the Plio–Pleistocene (Bossi *et al.*, 2009). These authors inferred that the Salicas Formation was associated to an environment of plains with source areas characterized by a lower and smooth relief, representing a stage previous to uplift of the Velasco range.

The information provided by the fossil biota and the geological interpretation suggest that the Salicas Formation may have been deposited in flatlands under average warm and dry conditions. This environment was probably dominated by open grassland with forested areas near rivers and lagoons, being exposed to episodic flooding typical of semi-desertic environments. Levels of argillaceous palaeosols, evidenced mainly in the lower portion of the stratigraphic sequence, would be indicative of alternative periods of climatic improvement.

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