Late Cenozoic mammals from the northwest of Argentina

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ABSTRACT

The biostratigraphy and biogeography of late Miocene mammals throughout Northwest (NW) Argentina is reviewed and discussed. FADs (first appearance data) of the earliest immigrants to South America (Carnivora, Procyonidae) were used to get a reliable temporal ordination of the late Miocene faunas from NW Argentina. Results from this analysis are generally consistent with the faunal sequence of stages and zones which was primarily established with faunas from the Atlantic Coast. Exception is a fauna from La Rioja province (Toro Negro Formation) that shows misalignment due to high degrees of endemism and no record of immigrants. Comparison of late Miocene mammalian faunas at the generic level indicate that: i) the differentiation in faunal similarity and composition between Northwest, Northeast and Atlantic Coast areas started near the middle Miocene-late Miocene boundary; ii) this differentiation is reflected by the appearance of the first Holarctic immigrants of the pre GABI (Great American Biotic Interchange); iii) in Northwestern Argentina, faunal endemism increased in the late Miocene, and iv) the boundary between Huayquerian and Montehermosan stages can be established by the FAD of a taxon belonging to a holarctic group (Procyonidae). The classical late Miocene continental faunistic sequence of Chiquimil-Puerta Corral Quemado, Catamarca, NW Argentina containing Huayquerian and Montehermosan faunas in superposition have produced both radioisotopic and lengthy mangnetostratigraphies spanning continuously approximately from Chron C4An to Chron C2Ar, between 9 Ma and 3.2 Ma.
Keywords: biostratigraphy - biogeography - Miocene-Pliocene - mammals - Northwest of Argentina

RESUMEN

La bioestratigrafía y biogeografía de mamíferos del Mioceno tardío del Noroeste (NO) de la Argentina es revisada y discutida. Los FADs (primeras apariciones en el registro) de los primeros inmigrantes a América del Sur (Carnivora, Procyonidae) fueron utilizados para realizar un ordenamiento confiable de las faunas del Mioceno tardío del NO argentino. Los resultados de este análisis son generalmente consistentes con la secuencia faunística de edades y zonas las cuales fueron originalmente establecidas con faunas de la Costa Atlántica. Una excepción es una fauna de la provincia de La Rioja (Formación Toro Negro) que muestra un alto grado de endemismo y ningún registro de inmigrantes. Las comparaciones de las faunas de mamíferos del Mioceno tardío/Plioceno a nivel genérico indican que: i) la diferenciación en similitud faunística y composición entre las áreas del Noroeste, Nordeste y Costa Atlántica comenzaron aproximadamente en el límite Mioceno medio-Mioceno tardío; ii) esta diferenciación está reflejada en la aparición de los primeros inmigrantes holárticos en el pre GABI [Gran Intercambio Bótico Americano]; iii) en el NOA el endemismo de la fauna se incrementó en el Mioceno tardío y iv) el límite entre el Huayqueriense y Montehermosense pude ser establecido por el FAD de un taxón perteneciente a un grupo holártico (Procyonidae). La clásica secuencia faunística de Chiquimil-Puerta Corral Quemado en la provincia de Catamarca que contiene faunas del Huayqueriense y Montehermosense en superposición registra varias dataciones radimétricas y una magnetoestratigrafía completa que cubre aproximadamente desde el Chron C4An al Chron C2Ar, entre los 9 Ma y 3.2 Ma.
Palabras clave: bioestratigrafía - biogeografía - Mioceno-Plioceno - mamíferos - Noroeste de la Argentina

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INTRODUCTION

Northwest Neogene mammal faunas of Argentina have attracted active paleontological inquiry for well over a century. From early on, investigators have pursued mammalian evolutionary studies largely within a stratigraphic framework. Occasional inquiries concerned with the paleoenvironmental and biogeographic contexts of faunal turnovers have been associated with this approach. However, stratigraphic paleontology generally seeks relationships based on faunal similarity while biogeographically based studies seek dissimilarities among isochronous faunas.

The biostratigraphic and biogeographic development of the late Miocene faunas in the Northwest (NW) of Argentina is the central theme of this paper. Elaboration and scrutiny of this problem rests on consideration of the systematic and geochronologic bases of the record of the mammals, rooted in decades of active scientific investigation of the relationships between South American Neogene chronology, continental vertebrate evolution and paleoenvironmental and biogeographic reconstruction.

We first present a general overview of the Neogene Northwest vertebrate-bearing sequences. Then we discuss some of the problems in determining the age of the first appearance of immigrants in the NW of Argentina, and review whether their appearance there is contemporaneous with their first appearance elsewhere throughout South America. We use the well-studied first appearance datum (FAD) as an example of more general problems of correlation and dating, and therefore of the establishment of patterns of faunal change.

The chronology of Neogene mammal-bearing terrestrial deposits from Argentina has traditionally been done by mammalian faunal correlation, because few radiometric dates or paleomagnetic data are available. Age assessments on the Atlantic Coast have been based mainly on mammalian correlations done and faunal similarity found in the area. The stratigraphic units used in this area are stages and zones (Cione and Tonni 1995, 1999, 2005).

The fossiliferous Neogene rocks of NW Argentina are singular in their degree of completeness and represent almost the entire Neogene from about 9 Ma to less than 2 Ma (Marshall et al. 1984; Reguero et al. 2007). This uniquely long faunal sequence records numerous vertebrate taxa and biotic events (pre GABI and GABI), and affords a most unusual opportunity to document the pattern of faunal change in South America biogeographic realm over at least a 7 m.y. interval and to study its dynamics. However, NW-of-Argentina regions have

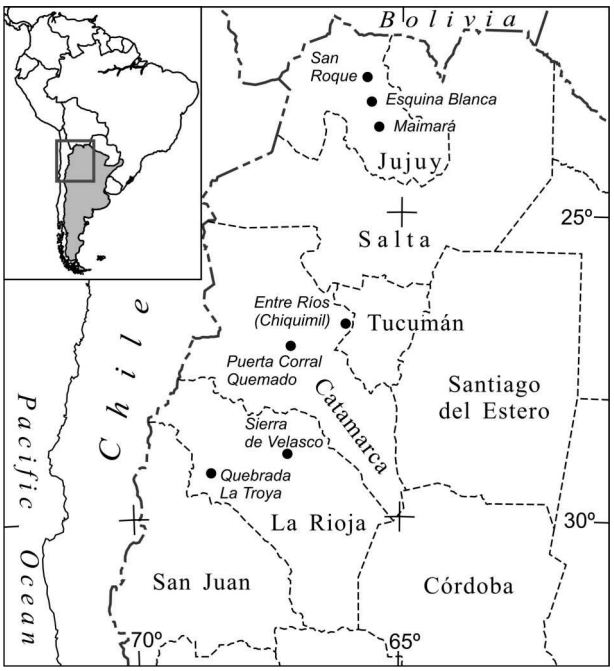


Figure 1. Map of northwestern Argentina and locations of Neogene vertebrate-bearing sites.

a less formalized mammalian biochronology system than other regions of Argentina, *e.g.*, the Atlantic Coast, but recent studies have correlated their late Pliocene/early Pleistocene sequences to the Atlantic Coast biostratigraphic system (Reguero et al. 2007).

The primary reason for the absence of secure chronology can be found in the general nature of the NW fossil sites themselves: most mammal fossils occur in localized settings having very limited stratigraphic expression. It is usually the case that fossil localities in one area cannot be linked to fossil occurrences in other areas by direct stratigraphic correlations. Mammal-bearing rocks of the late Miocene occur extensively in several provinces (Jujuy, La Rioja, and Catamarca) Northwest of Argentina. These provinces have very good outcrops bracketing the late Miocene-Pliocene interval, and have been the subject of geological and paleontological studies mainly focusing the faunistic composition in several localities (Uquía, Esquina Blanca, San Roque, Maimará en Jujuy Province; Quebrada de La Troya, Sierra Velasco in La Rioja province, and Entre Ríos, Hualfin, El Cajón in Catamarca province) (Fig. 1).

The sequence of the Uquía Formation at Esquina Blanca and San Roque, Jujuy province, spans from early Matuyama (Chron C2r) to late Gauss (Chron C2A) ages (Fig. 2). The correlation presented by Walther et al. (1996, 1998) is partially consistent with the magnetostratigraphic

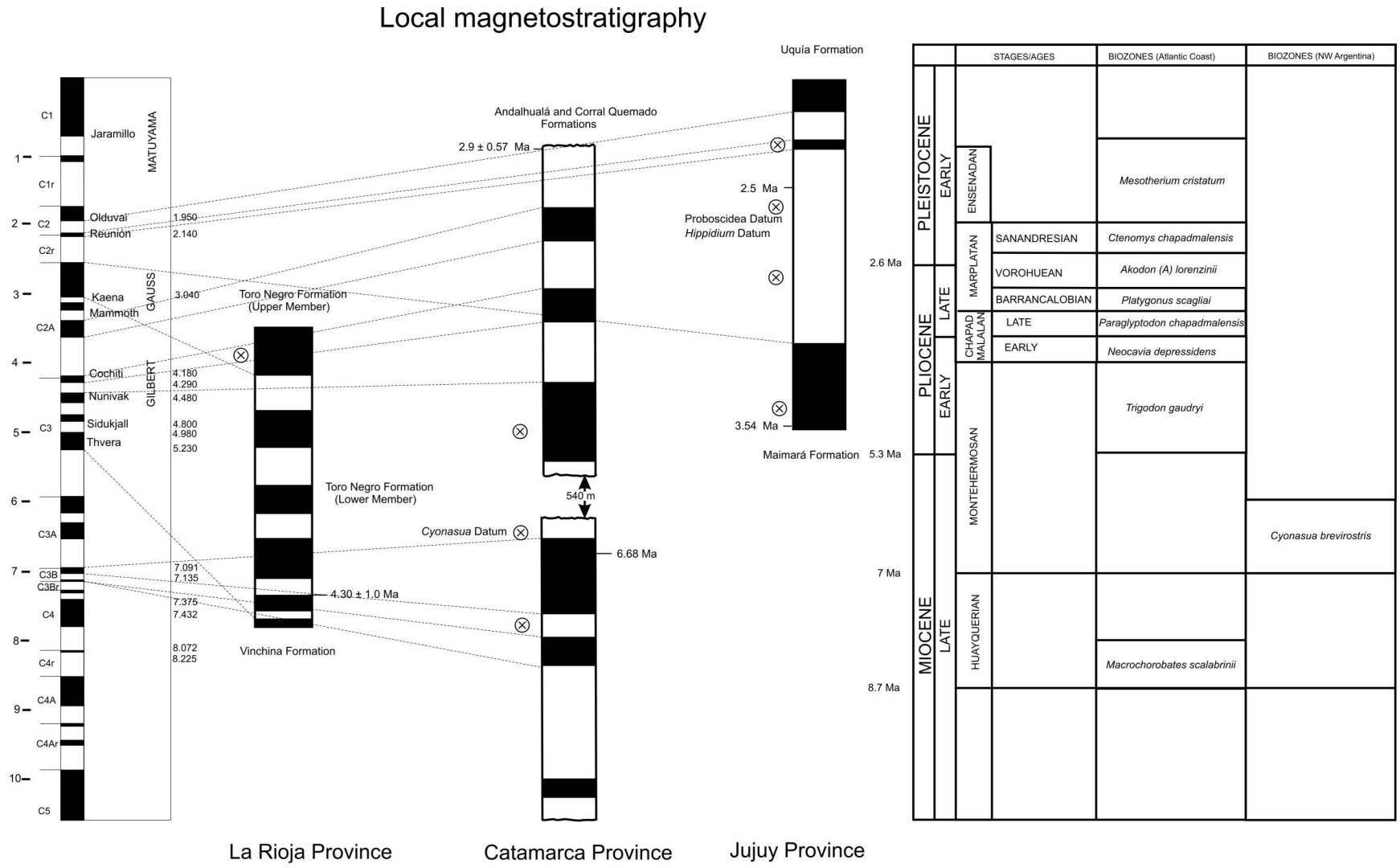


Figure 2. Correlation chart between the magnetic stratigraphy of sections from NW Argentina (Toro Negro, Corral Quemado, Andalhualá and Uquía Formations) and the magnetic polarity time scale (MPTS) after Berggren et al. (1995). Stages/ages and biozones after Cione and Tonni (2005). The base of the Quaternary is assigned as the base of the Gelasian and extends the base of the Pleistocene to 2.6 Ma. The cross included in the circle indicates a fossiliferous horizon.

results of Marshall et al. (1982), who found that the Uquía Formation is dominantly reversed and correlates to the early Matuyama chron between about 2.5 and 1.5 Ma. In Catamarca, the classical sequences at Chiquimil and Corral Quemado, Catamarca province, NW Argentina, containing Huayquerian and Montehermosan faunas in superposition have produced both radioisotopic and lengthy mangnetostratigraphies (Marshall et al. 1979, 1983; Butler et al. 1984) spanning continuously approximately from Chron C4An to Chron C2Ar (after Cande and Kent 1992) between 9 Ma and 3.2 Ma.

The purposes of this paper include a review the available magnetostratigraphy and radioisotopic data obtained from Northwest of Argentina upper Miocene-lower Pliocene continental deposits.

HISTORICAL BACKGROUND

The first record of Neogene vertebrate fossils in NW Argentina was published by Moreno (1882) who named remains of a new species of the glyptodont *Hoplophorus*, *H. ameghinoi*, collected by Inocencio Liberani and Rafael Hernández from Valle Santa María, Catamarca province, in 1887. Moreno (1882) provided additional stratigraphic information: «una formación prepampeana del valle de Santa María en Catamarca» (F. Ameghino 1891; C. Ameghino 1919). In 1889 Adolfo Methfessel collected fossil vertebrates from «el bajo de Andalhualá» near Valle Santa María, Catamarca province (Moreno and Mercerat 1891). He collected specimens referred to *Cyonasua brevirostris*, *Promacrauchenia calceolata*, *Pseudotypotherium studeri*, *Chlamydotherium minutum*, *Eutatus prominens*, and *Praeuphractus scalabrinii*.

In the early twentieth century, the naturalist Enrique de Carles, commissioned by the authorities of the Museo de Historia Natural de Buenos Aires (MACN), explored several outcrops located in the Quebrada de Humahuaca, Jujuy province. De Carles (1912) noted the presence of locally abundant fossil mammals in the outcrops of the Uquía Formation at Esquina Blanca. Description of the fauna of this unit began with the announcement of the discovery of fossil mammals (de Carles 1912) and preliminary descriptions of some new forms (Castellanos 1927; Rusconi 1930; Kraglievich 1934), as well as a review of the fauna as a whole by Castellanos (1950).

MATERIAL AND METHODS

We compiled NW Argentinean mammalian faunal lists from Carles (1912), Rovereto (1914), Castellanos (1927, 1950), Marshall et al. (1983), Peirano (1943), Esteban and Nasif (1995, 1996, 2003), Cione and Tonni (1995, 2005), Powell et al. (1998), and Cione et al. (2000).

To conduct the analysis, we first reduced the groupings of the provinces to the lowest level possible, and then analyzed a number of assemblages defined *a priori*. The most detailed comparisons were confined to a comparison of three major regions, «Northwest», «Northeast» and «Atlantic Coast». In these analyses, «Northwest» consisted of Salta, Jujuy, Tucumán, Catamarca, and La Rioja provinces. «Northeast» consisted of Entre Ríos and Corrientes provinces. «Atlantic Coast» consisted of Buenos Aires and La Pampa provinces.

The definition of a boundary between two stages or two zones, even locally, requires that the mammal localities used as references have a well-established stratigraphic and biostratigraphic context. Unfortunately, this requirement is only satisfied in a few sedimentary basins.

Abbreviations

AC = Atlantic Coast.
FAD = First Appearance Datum, «changes in the fossil record with extraordinary geographical limits» (Berggren and Van Couvering 1974).
GABI = Great American Biotic Interchange. GABI began about 2.6 Ma (see Woodburne 2010).
LSD = Lowest Stratigraphical Datum, «lowest stratigraphic appearance of a taxon in local section».
MPTS = Magnetic Polarity Time Scale (after Bergreen et al. 1995).
NACSN = North American Commision on Stratigraphic Nomenclature.
NE = Northeast.
NW= Northwest.
Pre GABI = early dispersal events of the GABI.
SALMA = South American Land mammal Age.
Ma = megannum in the isotopic time scale.
m.y. = an abstract consideration of elapsed time not directly tied to the isotopic scales.

GEOLOGY AND STRATIGRAPHY

La Rioja province

Toro Negro Formation

The sequence in La Troya creek (type section) (Fig. 1) is composed by a succession of epiclastic and piroclastic deposits, where thick-bedded sandstones and mudstones with interbedded conglomeradic lenses and tuff levels predominate. The facies analysis suggests a fluvial depositional environment of sand bed braided rivers for the lower Member and high efficiency alluvial fans for the upper Member A tuff from the lower por-

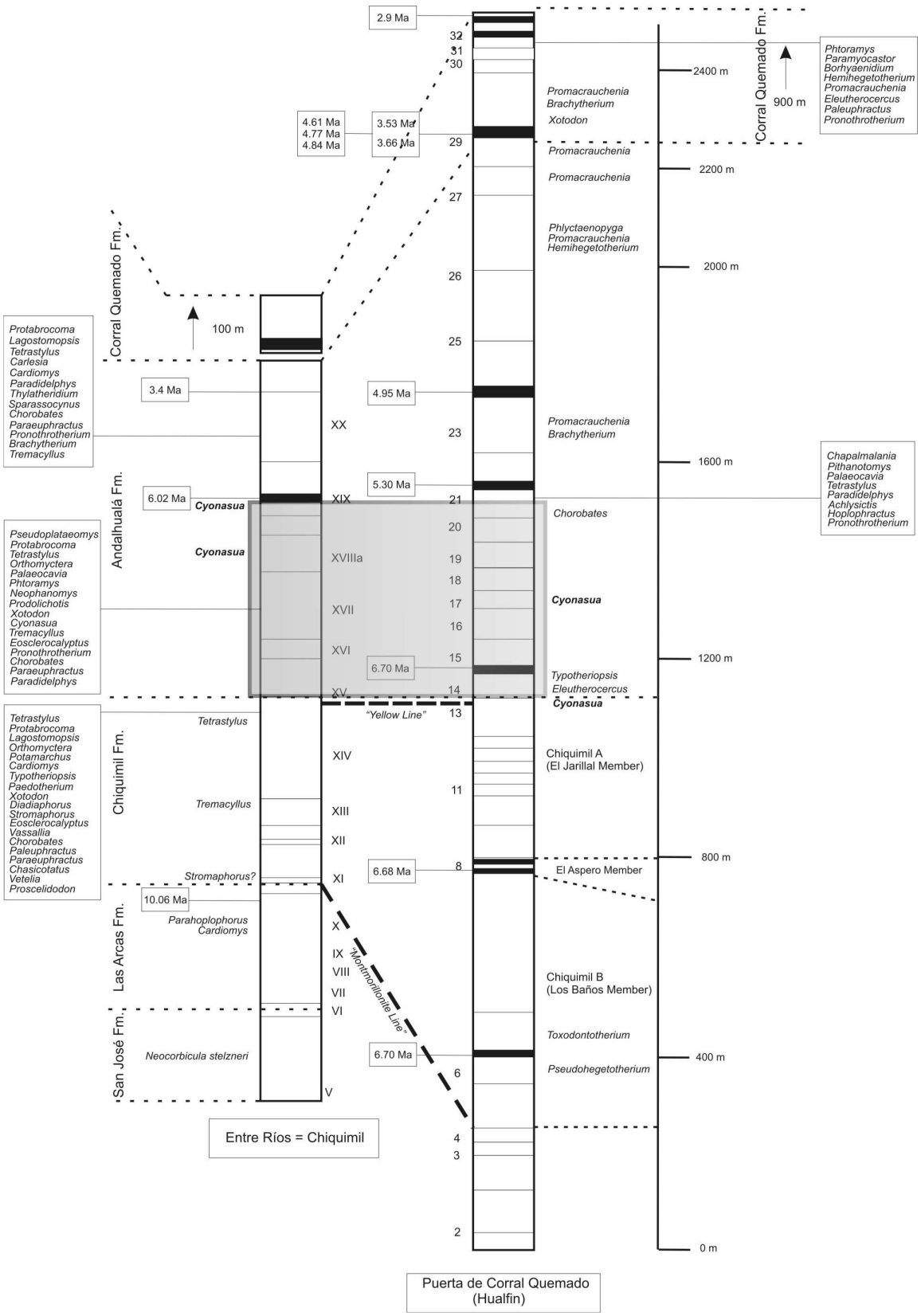


Figure 3. Schematic Stahlecker´s stratigraphic sections of Chiquimil (= Entre Ríos) and Puerta de Corral Quemado (= Hualfin) and correlations of the horizons, faunas and radioisotopic dates. Shaded rectangle represents the range of the *Cyonasua brevirostris* Zone.

tion of the lower member of the Toro Negro Formation was dated with the fission track method as 4.3 ± 1.0 Ma (Tabbutt 1986; Tabbutt et al. 1989). Ré and Barredo (1993) described the local magnetostratigraphy for the exposures at Quebrada de la Troya (Fig. 1). Figure 3 shows the correlation between the local magnetic polarity column (with the position of the sloth skeleton indicated) and the temporal geomagnetic scale (following Berggren et al. 1995). This magnetostratigraphic correlation permits a precise chronology for the deposition of the Toro Negro Formation, and places the age of the sloth *Pyramiodontherium scillatoyanei* between 3.11 and 3.04 Ma (De Iuliis et al. 2004). Rodriguez Brizuela and Tauber (2006) mentioned the following taxa that were recovered from the lower member of the unit: *Abrocoma* sp., *Protabrocoma* sp., *Propediolagus* sp., *Proeuphractus* sp., *Chorobates villosissimus*, *Paleuphractus* sp., *Doellotatus inornatus*, *Lomaphorops corallinus*, *Urotherium* sp., *Neuryurus giganteus*, *Xyophorus* aff. *bondesioi*, *Plesiomegatherium* sp., *Proscelidodon* sp., and *Eoauchenia* sp.

Salicas Formation

Fossil mammals from Salicas Formation come from the northern part of Sierra de Velasco, La Rioja province (Fig. 1). This stratigraphic unit was previously assigned to the Pliocene, upper Pliocene and to the upper Miocene. It is made up of clayey sandstone, friable in general, brownish in the lower layers and reddish brown in the upper levels. There are also intercalated paleosoils layers, and fossiliferous conglomerates of fluvial origins (Tauber 2005).

Among the mammals found in Salicas Formation the following taxa are common: *Macrochorobates scalabrinii*, *Proeuphractus limpidus*, *Chaetophractus* sp., *Eosclerocalyptus planus*, *Neophanomys biplicatus*, *Lagostomopsis pretrichodactyla*, *Orthomyctera andina*, *Potamarchus* sp., *Protypotherium* sp., *Pseudotypotherium* sp., *Hemihegetotherium* cf. *torresi* and cf. *Tremacyllus*.

Tauber (2005) proposed a late Miocene latitudinal retraction of the genus *Protypotherium* from the Pampean region (AC) to the Northwest. Biochronologic correlation with El Jarillal Member of the Chiquimil Formation and with the lower part of the Andalhualá Formation («Huayquerian») in Catamarca province is established by the common presence of some taxa (*i.e. Tremacyllus*, *Lagostomopsis*, *Eosclerocalyptus*).

Catamarca province

Bossi et al. (1993) recognized and reinterpreted the stratigraphic sequences at Puerta de Corral Quemado (= Hualfin) and Chiquimil (= Entre Ríos) (Fig. 1). The base of Cenozoic sedimentary succession in the Santa María Valley is a peneplain surface on crystalline basement rocks. The Neogene deposits have been divided into four allostratigraphic units: I, II, III, and IV by Bossi et al. (2001).

Chiquimil Formation

Unit II of Bossi et al. (2001) is 2.300 m thick and overlies a disconformity. Bossi et al. (2001) subdivided this into two subunits (Units II a, and II b) on the basis of volcanic detritus content. Unit II a contains Member «B» of the Chiquimil Formation (Galván and Ruiz Huidobro 1965) formed by lacustrine mudstones (near Tiopunco) changing into continental sabkha deposits in the northern part of the Santa María Valley (Ibañez 2001). Member «A» of the Chiquimil Formation, consisting of sandy braided river deposits (Ibañez 2001) is included in Unit II b.

Chiquimil A unit was recognized by Stahlecker (in Riggs and Patterson, 1939, fig. 6, Appendix II) and is considerably thicker near Puerta de Corral Quemado than in the Valle de Santa Maria. It is composed predominantly of soft, fine-grained sandstones, although some concretionary layers are present at Puerta de Corral Quemado. The third unit, unit C, is characterized by hard layers, sometimes conglomeratic, or gypsum-rich, yellowish-brown sandstone.

The names Chiquimil B and Chiquimil A were applied by Riggs and Patterson (1939) to the second and third units, respectively. Pascual and Odreman Rivas (1973) tentatively assigned Chiquimil A and B to the Chasicoan. Pascual and Odreman Rivas (1973) also tentatively assigned Chiquimil A and B to the Chasicoan. G.G. Simpson (1974, p. 4-5) justly argued that the extremely inadequate fossil evidence did not suffice to permit separation of Chiquimil A from the Araucanense (= Andalhuala) fauna and suggested that Chiquimil B might belong to the Chasicoan.

Powell et al. (1998) recovered a diverse fauna from Chiquimil A but the stratigraphic disposition of the specimens within the unit is not precise. This fauna includes: *Typotheriopsis* sp., *Xotodon* sp., *Eoesclerocalyptus planus*, *Stromaphorus* sp., *Vassalia* sp., *Chorobates* sp., *Paleuphractus* sp., *Paraeuphractus* sp., *Vetelia* sp., *Proscelidodon* sp., *Lagostomopsis* sp., *Potamarchus* sp., *Cardiomys* sp., *Orthomyctera andina*, and *Protabrocoma*. These authors suggested a Huayquerian age for the mammal-bearing horizons within Chiquimil A.

On this basis the Chiquimil Formation is of Huayquerian SALMA age.

Andalhualá Formation

The Andalhualá Fm. crops out in Santa María Valley with a thickness of 1200 m. Numerous volcanic rock samples were collected from several basalt flows and tuffs in the Andalhualá Formation for K-Ar and Ar-Ar age determinations as well as paleomagnetic studies (Butler et al. 1984; Strecker 1987; Latorre et al. 1997).

Riggs and Patterson (1939, Fig. 1) published the Stahlecker's stratigraphic sections of Chiquimil (Entre Ríos, 26°40'60"S, 66°01'60"W), Department of Santa María, and Puerta de Corral Quemado (Hualfin, 27°13"60'S, 66°55"60'W), Department of Belén (Fig. 1). Butler et al. (1984) sampled two late Miocene (associated fauna of uncertain correlation to the SALMA sequence) sections at these localities, which probably include Chron C4r.1n («Chron 7»). Bossi et al. (1987) established that the Corral Quemado Fm. at Puerta de Corral Quemado begins at horizon 32 (Fig. 3). Two important marker horizons, the yellow and montmorillonite lines (Fig. 3), permit direct correlation between Chiquimil and Puerta de Corral Quemado sections (Bossi et al., 1987).

The Andalhualá Formation fauna includes: *Prodolichotis prisca*, *Neophanomys biplicatus, Pithanotomys columnaris*, *Orthomyctera andina*, *Tetrastylus intermedius*, *Cardiomys ameghinorum*, *Palaeocavia* sp., *Chorobates scalabrinii*, *Paraeuphractus prominens, Eosclerocalyptus planus, Sphenotherus zavaletianus*, *«Scelidotherium» pendolai*, *Pyramiodontherium bergi, Phlyctaenopyga ameghinoi*, *Hoplophractus proximus*, *Stromaphorus compressidens*, *Neotamandua* sp., *Paradidelphys pattersonii*, *Achlysictis atrox, Microtragulus catamarcensis*, *Xotodon* sp., *Toxodontherium* sp., *Brachytherium morenoi*, *Brachytherium laternarium*, *Promacrauchenia antiqua*, *Typotheriopsis internum*, *Hemihegetotherium robustum*, *Tremacyllus latifrons*, *Cyonasua brevirostris*, and *Chapalmalania alteafrontis.*

On this basis the Andalhualá Formation is of Montehermosan to Chapadmalalan SALMAs age.

Corral Quemado Formation

The base of the Corral Quemado Formation rests conformably on the horizons of the Andalhualá Formation at Valle de Santa María, to the W of Sierra de Hualfin with nearly 850 m of thickness (Puerta de Corral Quemado). The base consists of fine conglomeradic sediments. Two prominent tuffs are located at the base of the unit. Strecker (1987) dated a tuff at the top of the Corral Quemado Formation at 2.9 ± 0.57 Ma (Fig. 3).

The Corral Quemado Formation fauna includes: *Paramyocastor diligens*, *Phtoramys pulcher*, *Pithanotomys columnaris*, *Pronothrotherium typicum*, *Eleutherocercus solidus*, *Paleuphractus argentinus*, *Borhyaenidium* sp., *Lutreolina* sp., *Hemihegetotherium robustum*, *Xotodon* sp., *Promacrauchenia antiqua*, and *Brachytherium laternarium*.

On this basis the Corral Quemado Formation is of Montehermosan SALMA age.

Jujuy province

Uquía Formation

The thickness of the Uquía Formation. ranges from 260 m in Esquina Blanca to 220 m in San Roque, Jujuy province (Fig. 1). At these localities the sequence is gently folded and faulted, and unconformably overlies by undifferentiated sediments of the Mesón Group of Paleozoic age.

The Uquía Formation at Esquina Blanca is composed mainly of braided fluvial sediments, sands, conglomeratic sands and conglomerates with cross-bedded sandstone units and channels. These are light colored sediments, grayish-green; yellowish-brown. More than 90% of the pebbles are Cambrian quartzites of the Mesón Group. Some sandy banks are light green with irregular blotches of ochre-colored limonitic and darker manganese oxides. Materials are generally friable, or poorly consolidated. However, the circulation of epigenetic waters partially cemented the sandy and gravely banks forming crusts. This process allowed the preservation of bone remains. Disarticulation and preservation of the bones is compatible with the fluvial environment. There are also some levels of reddish clayey silts, tight, brittle and with spectacular «slickenside» surfaces, and at least a pair of thick horizons of tuffs. The tuffaceous levels are over 2 m thick but are commonly pinched out laterally. The pattern of fluvial sedimentation makes the correlation between banks difficult because of the rapid lateral facies changes.

Three sections can be broadly distinguished. The Lower Section contains thick beds of conglomerate and sandy banks with the conspicuously thick «Dacitic tuff» of Castellanos (1950), Marshall's LGM 202 (Marshall et al. 1982) and the U2 Tuff of Walther et al. (1998). The oldest mammals occur in the basal part of this section, about 30 m below the U2 Tuff. These include the dasypodid *Doellotatus chapadmalensis* and the pampatheriine *Plaina* (Reguero and Candela 2008, Fig. 5).

The Middle Section shows thin, well-defined stratification, more sandy and clayey-silt levels and greater fossil richness than the other units. At Esquina Blanca this section begins above this horizon (40 m) and approximately 10 m above the top of the U2 Tuff on Esquina

Blanca and extends to a stratigraphic level of about 145 m. Most of the genera from the Middle Section of the Esquina Blanca section, *i.e. Paraglyptodon*, *Platygonus*, *Urotherium*, *Pseudomacrauchenia*, and *Microcavia* (Reguero and Candela 2008, Fig. 5), have known records from the Chapadmalalan and Marplatan of the Atlantic Coast, and others like *Hippidion* and *Ctenomys chapadmalensis* (= *Paractenomys chapadmalensis*), are known from the Marplatan.

The Upper Section is composed of coarse conglomerate sheets with less fine-grained sediments. At Esquina Blanca the Upper Section is located in the last 75 m of the sequence and consists of alternating light gray fine grained sandstone, with abundant quartz and muscovite, and green fine grained sandstone that overlies pinkish claystone or dark yellow limestone, and well sortedconglomerate and sandstone (Castellanos 1950, p. 51). Fossil mammals, *i.e.*, *Glyptodon*, and *Scelidotherium* (Reguero and Candela 2008, Fig. 5) are commonly associated with the Ensenadan fauna.

The Uquía Formation is unconformably covered by unnamed reddish conglomeratic deposits, which are probably Upper Pleistocene in age. Marshall et al. (1982, p. 987) designated Esquina Blanca the type section. Although not containing all of the lowest intervals of the formation as exposed farther south (Chucalesna) in the Quebrada de Humahuaca, the stratotype section effectively illustrates the threefold subdivision of the Uquía Formation.

MAMMALIAN FAUNAS AND BIOCHRONOLOGIC CORRELATIONS: PRE GABI AND GABI EVENTS

Tables 1 and 2 provide a composite faunal list for Northwestern faunas (La Rioja, Catamarca, and Jujuy provinces) of Argentina and their known chronologic ranges in the Northwest (NW), Northeast (NE) and Atlantic Coast (AC) of Argentina. For the NW faunas we have listed 99 mammalian taxa belonging to 9 orders: Rodentia (25), Marsupialia (7), Edentata (43), Notoungulata (9), Litopterna (7), Carnivora (2), Perissodactyla (3), Artiodactyla (2), and Proboscidea (1). Eight taxa of Holarctic immigrants are recorded in the Neogene of Northwest Argentina.

In the NW of Argentina typical GABI immigrants have been recorded in the Uquía Formation, Jujuy province. Camelids (*Palaeolama*), cervids (*Morenolaphus?*), peccaries (*Platygonus*), equids (*Hippidium*), and proboscideans (*Stegomastodon?*) occur in the Middle (Marplatan) and Upper (Ensenadan) sections of this unit (see Table 1). From the basal beds of the Uquía Formation the record of a primitive rodent Ctenomyinae brings the minimum age for the differentiation of the genus *Ctenomys* to around 3.5Ma (Verzi 2008).

No records of immigrant mammals appear in the Lower Unit of the Uquía Formation (late Chapadmalalan). However, a new species of the Huayquerian-Chapadmalalan carnivore genus *Cyonasua* (Procyonidae) has been reported from the Maimará Formation (late Miocene) at Maimará, 35 km south of Humahuaca, Jujuy province (Berman 1989) (Fig. 1).

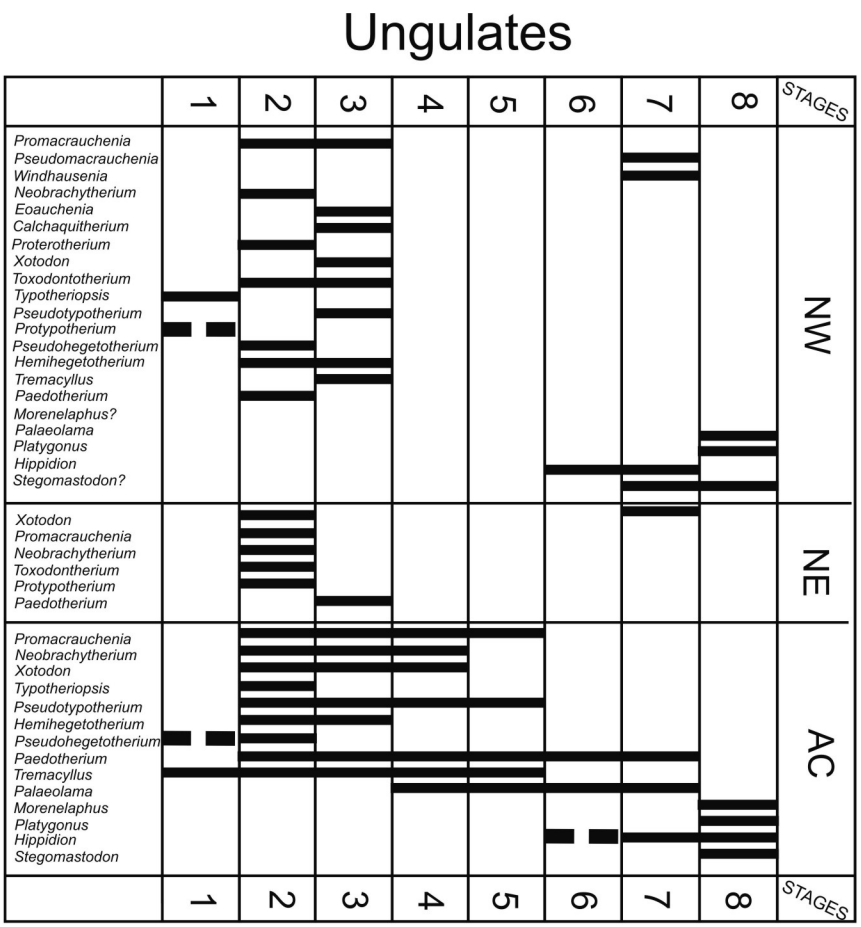
Cyonasua Datum

In this section we summarize salient data that bear on the vitality of selected *Cyonasua* LSDs in order to evaluate the regional validity of a *Cyonasua* FAD in the Northwest of Argentina.

In the late Miocene members of the Holarctic family Procyonidae (raccoons and their allies) dispersed to South America. The dispersal of this group represents an early event of the pre GABI in South America (Huayquerian and Montehermosan; about 8.5 to 6.8 Ma) (Cione and Tonni 2005). GABI began (GABI 1, see Woodburne 2010) at about 2.6-2.4 Ma with the first major dispersal of both North American and South America taxa. The dispersal of the procyonids to South America was apparently via an interestingly fortuitous sweepstakes prior to the emergence of the Panamanian bridge at about 3.0 Ma (Marshall et al. 1979, 1982; Coates et al. 2004, Woodburne et al. 2006). The earliest record of Procyonidae in South America corresponds to the generalized genus *Cyonasua* from strata assigned to the Huayquerian in the Andalhualá and Chiquimil Formations (= «Araucanense»), Catamarca province. So the first dispersal southward was accomplished by a procyonid carnivoran, reflected by *Cyonasua* (= endemic South American taxon that reflects a dispersal), at about 7.3 Ma.

Therefore, *Cyonasua* is the most likely the result of the earliest Holarctic immigrant to South America.

The oldest records of procyonids in Catamarca are from the section measured by Stahlecker (in Riggs and Patterson 1939) in Puerta de Corral Quemado, Department of Belén (27°13"60'S, 66°55"60'W). This section spans the Chiquimil through Andalhualá Formations and was subjected to paleomagnetic sampling by Marshall et al. (1979) (Fig. 3). Because of a too-sparse sampling density in the uppermost 650 meters (Corral Quemado section 1 after Marshall et al.1979, p. 274), correlation to the geomagnetic time scale is difficult in the youngest segments of the Puerta de Corral Quemado section. A tuff dated at 3.54 Ma occurs within unit 29 at the top of



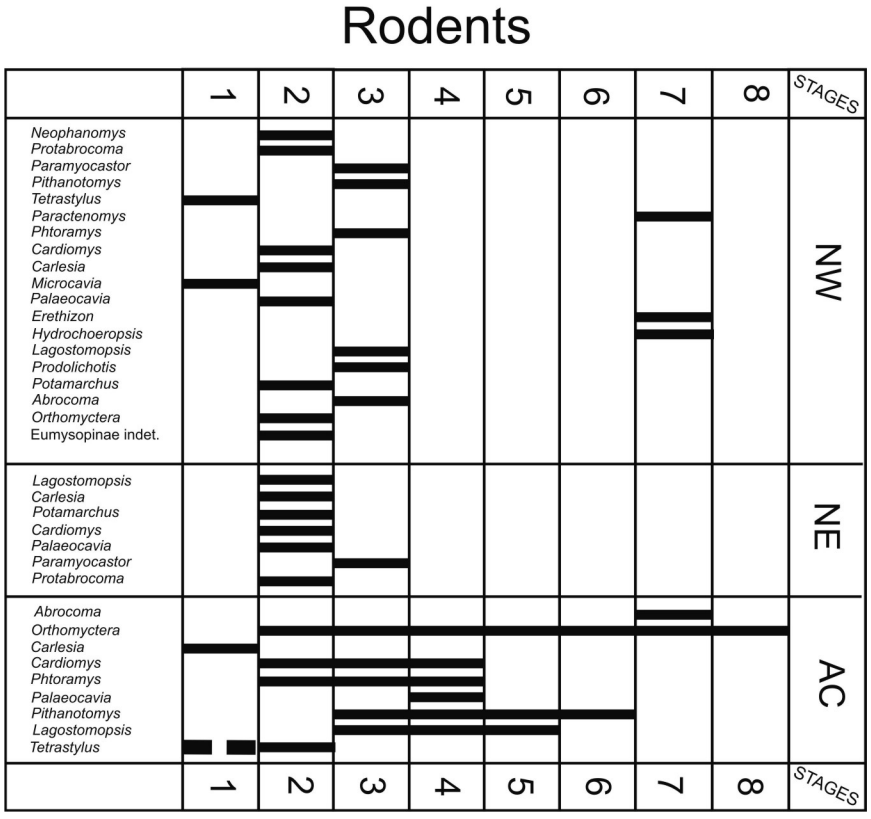


Table 1. Biogeographic range chart for the ungulate and rodent taxa included in this paper. NW= Northwest, NE= Northeast, AC= Atlantic Coast. 1: Chasicoan, 2: Huayquerian, 3: Montehermosan, 4: Chapadmalalan, 5: Barrancalobian, 6: Vorohuean, 8: Sanandresian.

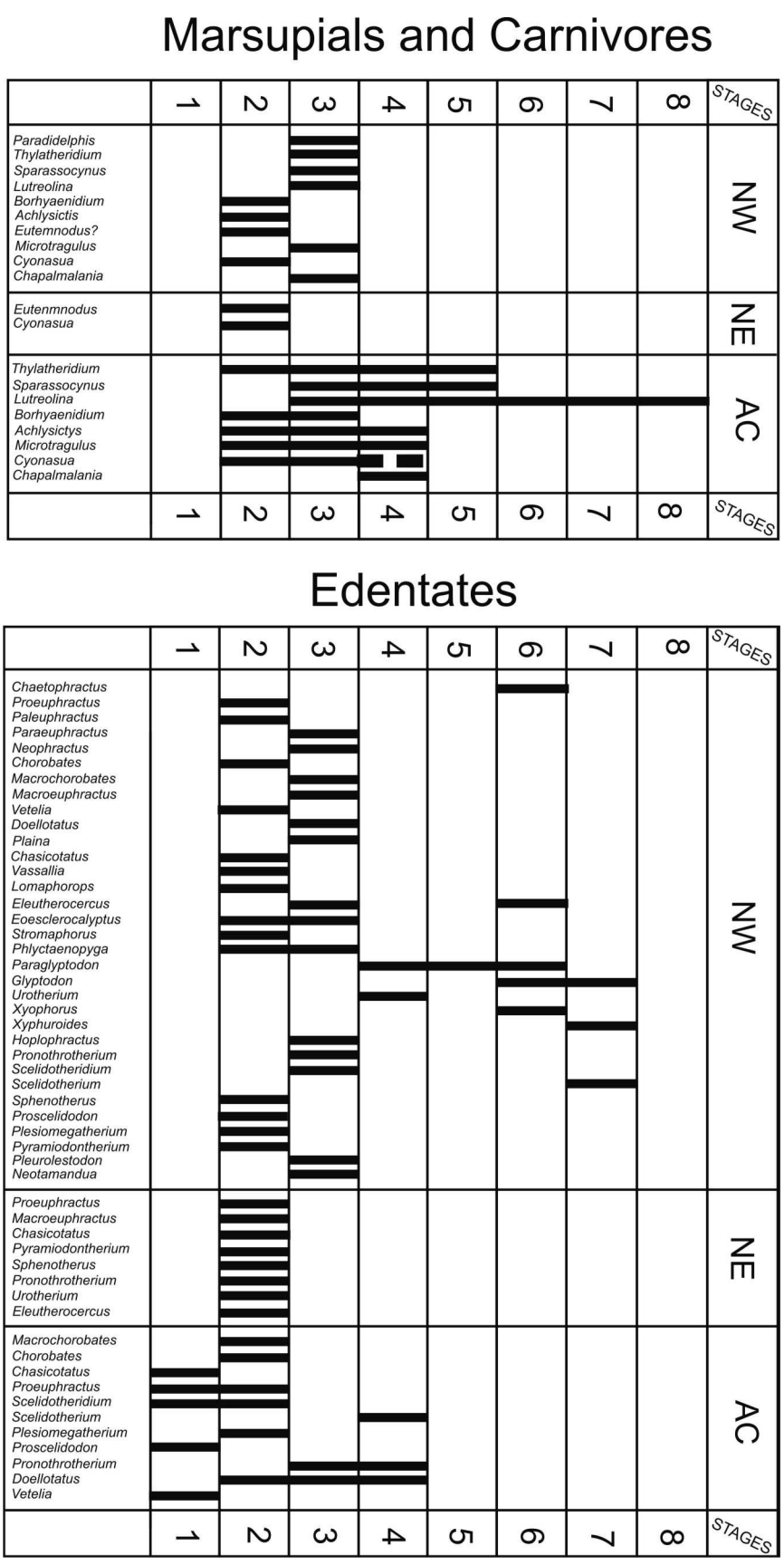


Table 2. Biogeographic range chart for the marsupial, carnivore, and edentate taxa included in this paper. NW= Northwest, NE= Northeast, AC= Atlantic Coast. 1: Chasicoan, 2: Huayquerian, 3: Montehermosan, 4: Chapadmalalan, 5: Barrancalobian, 6: Vorohuean, 8: Sanandresian.

this section. Given this constraint, the correlation of the normal polarity intervals in this section with normal polarity events in the Gilbert epoch is preferred by Marshall et al. (1979).

Marshall et al. (1979) found a long interval of normal polarity that can confidently be correlated to C3Bn (6.935-7.091) (Fig. 2). The top of this normal zone lies between unit 9 and unit 7 within approximately 110 meters of section. The 6.68 Ma date from unit 8 near the top of this section (Fig. 3; Puerta de Corral Quemado column) also constrains the polarity to within «Chron 7» ; in old terminology, see Butler et al. (1984), and see also Marshall et al. (1979, 1983) for earlier interpretations of less complete data.

The abrupt appearance of this procyonid in the stratigraphic record of Argentina is considered to be so impressive as to be recognized as a singularly important reference for interregional correlation in the late Miocene of South America. This «event» represents a datum and it is operationally valid as well as geochronologically precise. In this paper we utilize the term *Cyonasua* Datum for this concept. Thus, the *Cyonasua* Datum represents a FAD that is a probabilistic statement that the first appearance of a taxon was regionally synchronous. The concept *Cyonasua* Datum stems from the observation that in a number of Argentinean sites a species of *Cyonasua* appears abruptly and abundantly at a level stratigraphically above deposits in which this kind of procyonid is absent, but in which specimens of the rodent *Tetrastylus*, the glyptodont *Phlyctaenopyga*, and the notoungulates *Typotheriopsis internum*, *Tremacyllus*, and *Hemihegetotherium torresi* may be found. This abrupt appearance of procyonids is followed stratigraphically in several places in Mendoza, Jujuy, Entre Ríos and Buenos Aires provinces (see Table 2).

Thus, the *Cyonasua* Datum represents a FAD, and each FAD is composed of a number of LSDs (Lowest Stratigraphic Datum). If these LSDs are closely time-correlative, then a FAD of a given regional scope can be established. *Cyonasua* LSDs that are directly associated with magnetostratigraphic or radioisotopic data are estimated to be ca. 6-7 Ma, with the sample from Puerta del Corral Quemado believed to be the oldest.

Specimens of *Cyonasua* (FMNH P14451) from unit 14 of the Andalhualá Fm. at Puerta de Corral Quemado are dated between 7.0 and 7.1 Ma and «…may represent the earliest records of *Cyonasua* in South America, and their occurrence in or just below unit XIX, dated at 6.02 Ma at Chiquimil section, provides a minimal age for the arrival of procyonids into the South America continent» (Marshall et al. 1979, p. 276).

Dating the first occurrence of *Cyonasua* in South America is of broad interest because it represents the first immigrant taxon from North America. The local first occurrence of *Cyonasua* (specimen FMNH P14451) at Puerta de Corral Quemado is immediately above unit 14.

Although it is not possible for us to derive an exact age for the lowest stratigraphic datum (LSD) of *Cyonasua* and the apparent Huayquerian-Montehermosan boundary in this section, we are able to provide an estimate. These events (the LSDs of *Cyonasua*) appear to be bracketed between units 14 and 17 of the Andalhualá Formation «...in the hills south of Puerta de Corral Quemado» (Marshall and Patterson 1981). *Cyonasua* has also been recovered few meters above the base of the Andalhualá Formation at Chiquimil. Two specimens, FMNH P14342 from unit XVIIIa and FMNH P14357 from unit XIX, were referred by Tedford (in Marshall et al. 1979) to *Cyonasua brevirostris* (Moreno and Mercerat, 1891) (Fig. 4). Marshall et al. (1979) reported an average age of 6.02 Ma from the prominent tuff of unit XIX, which date is close to the age of the specimens of *Cyonasua brevirostris* at this locality. This part of the sequence is comprised in a magnetically normal interval and probably correlate to chron C3An.1n and based on Berggren et al. (1995) we believe that Chron C3An.1n ranges in age from 5.894-6.137 Ma. Therefore, the Chiquimil *Cyonasua* LSD is about 6.02 Ma or older.

The Maimará *Cyonasua* represents LSD in the stratigraphic sequence in the Quebrada de Humahuaca area, Jujuy province.

BIOSTRATIGRAPHY FOR THE LATE MIOCENE OF THE NW OF ARGENTINA

As a basis for the discussion of the correlation with other areas of Argentina, even South America, *i.e.* Atlantic Coast, we propose the following assemblage zones (*sensu* NACSN 1983) for the late Miocene of the NW of Argentina.

Zone of Cyonasua brevirostris

The stratotype of this biozone crops out in the continental sequence of the Andalhualá Formation at Puerta de Corral Quemado, Entre Ríos, Department of Belén, Catamarca (27°13"60'S, 66°55"60'W). The Zone of *Cyonasua brevirostris* is characterized by the first South American record of the Family Procyonidae of Holarctic origin.

The Zone of *Cyonasua brevirostris* ranges from the base of the Andalhualá Formation –units 14 to 20 after Stahlecker, in Riggs and Patterson (1939) and Marshall

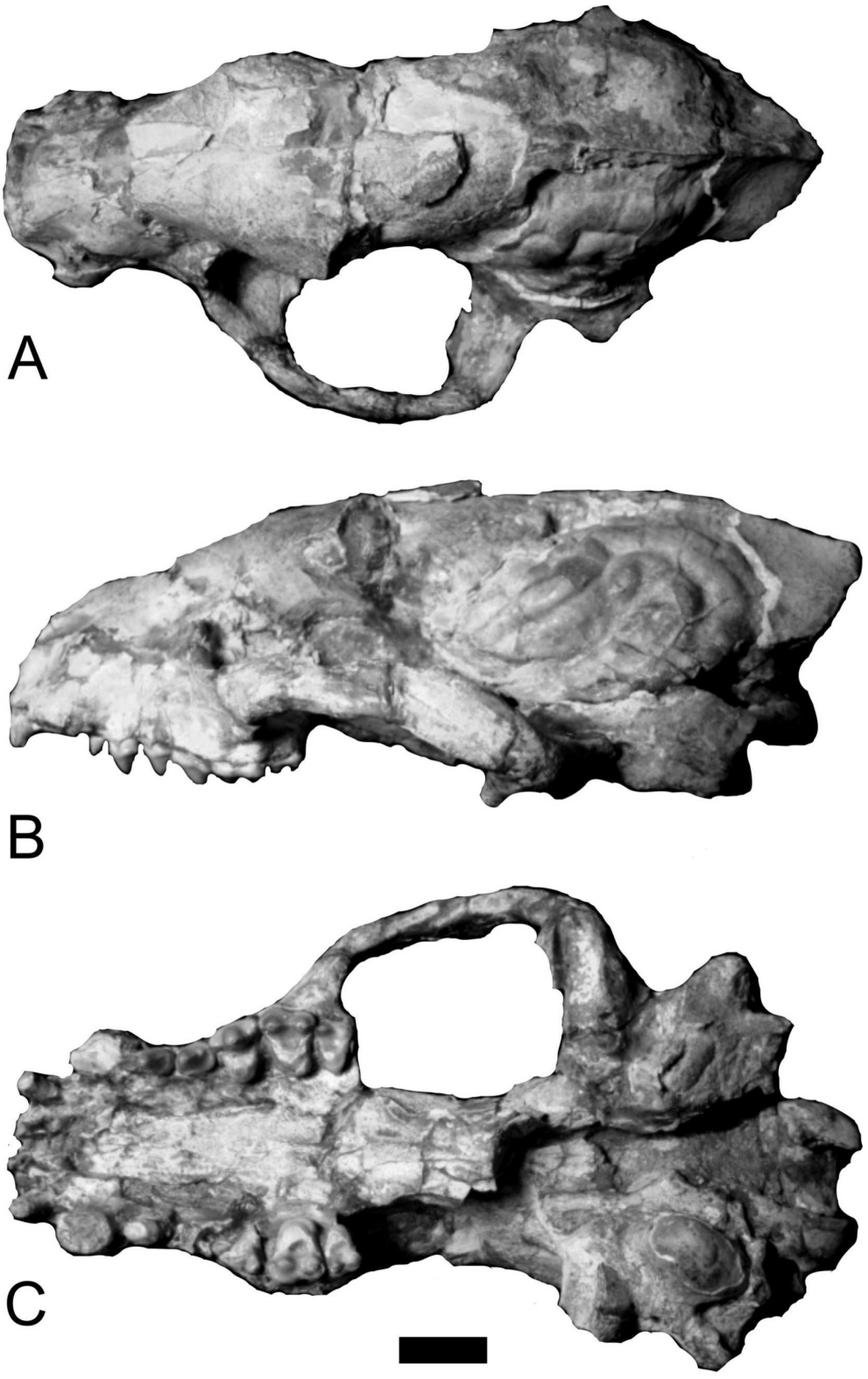


Figure 4. *Cyonasua brevirostris* (Moreno y Mercerat, 1890), holotype, MLP 10-52, incomplete skull. A. dorsal, B. lateral, and C. occlusal views. Scale bar: 2 cm.

and Patterson (1981)– to unit 21 of the same formation, with approximately 400 meters of thickness at Puerta de Corral Quemado, Catamarca. This zone apparently coincides with the *Trigodon gaudry* Biozone in the Atlantic Coast of Argentina (Cione and Tonni 1995). The stratotype of the *Trigodon gaudry* Zone crops out in the marine cliffs at the Farola Monte Hermoso, Buenos Aires province.

The *Cyonasua brevirostris* Zone is defined in a sequence with a clear late Miocene/early Pliocene stratigraphic succession which is lacking in the original type area (see Cione and Tonni 2005). This Zone defines the base of the Montehermosan stage. We define the Montehermosan on the FAD of *Cyonasua brevirostris* and characterize the unit on the basis of the characteristic taxa.

The only exclusive and common taxon of this Zone is *Cyonasua brevirostris.* Characteristic taxa are: *Neophanomys biplicatus, Orthomyctera andina*, *Prodolichotis prisca*, *Tetrastylus intermedius*, *Paradidelphys pattersonii*, *Achlysictis atrox, Microtragulus catamarcensis*, *Chorobates scalabrinii*, *Paraeuphractus prominens, Eosclerocalyptus planus, «Scelidotherium» pendolai*, *Pyramiodontherium bergi, Sphenotherus zavaletianus, Neotamandua* sp., *Brachytherium morenoi*, and *Typotheriopsis internum.*

Huayquerian-Montehermosan boundary

Stratigraphic successions that span the Huayquerian-Montehermosan boundary are rare in South America, *i.e.*, Remedios Formation, Bolivia (Marshall et al. 1992). In general, dates are only available from horizons above Huayquerian faunas or below Montehermosan faunas. The Huayquerian to Montehermosan interval is relatively well-sampled paleomagnetically in Bolivia and NW Argentina but not in the type sequences in Argentina. The base of the Montehermosan does not crop out in its classic type section in the Atlantic Coast (Cione and Tonni 2005). Therefore, the lower boundary of this stage needs to be calibrated in other areas. In addition, no published magnetostratigraphic or radiometric studies have been accomplished in the type section of the Montehermosan.

The classical sequences at Chiquimil and Corral Quemado, Catamarca province, containing Huayquerian and Montehermosan, and perhaps Chapadmalalan faunas in superposition have produced both radioisotopic dates and lengthy magnetostratigraphies (Marshall et al. 1979, 1983; Butler et al. 1984; Strecker 1987; Latorre et al. 1997) spanning continuously approximately from C4An to Chron C2Ar –after Cande and Kent (1992) (see Figure 3); mid-Chron 8 to late Gilbert Chron, in old terminology; Butler et al. (1984), see also Marshall et al. (1979, 1983) for earlier interpretations of less complete data. Marshall et al. (1979) considered the Huayquerian-Montehermosan boundary to be about 5.0 Ma based on preliminary magnetostratigraphy and K-Ar in Argentina and K-Ar dates from below the Bolivian Montehermosan fauna. Butler et al. (1984) tentatively considered the boundary to be about 6.0 Ma based on more extensive magnetostratigraphy data and K-Ar dates. Flynn and Swisher (1995) considered the best estimation for the Huayquerian/Montehermosan boundary the age of 6.8 Ma. If the correlations of Cione and Tonni (2005) are utilized, Montehermosan begins near the base of the Chron C3A or about 6.8 Ma.

The Huayquerian «stage» is presently placed approximately between <7 Ma (ca 6.8 Ma) and 8.5 Ma (see general chronostratigraphic chart by Cione et al.2000, and Cione and Tonni 2005).

Butler et al. (1984) have dated the limit between the Huayquerian and Montehernosan around 6.4 Ma. in Valle Santa María, Catamarca. Magnetostratigraphic and radiometric data on the 2300 m thickness of continental sediments at Puerta de Corral Quemado have permitted the calibration of this boundary. The Andalhualá Formation constrains a mammal fauna of Montehermosan age, and the overlying Corral Quemado Formation constrains a fauna of Montehermosan and probably Chapadmalalan ages. For the purposes of this paper, the Montehermosan is considered to have begun about 7 Ma, based upon the statement that immigrant taxa are useful in boundary definition.

CONCLUSION

The outcrops of the Chiquimil, Andalhualá, and Corral Quemado Formations at Corral Quemado and Chiquimil, Catamarca province, Northwest Argentina contain a remarkably rich, diverse, and well-preserved fossil mammal fauna ranging from late Miocene to Pliocene. These units contain the longest conformable stratigraphic sections known in Argentina, and probably in South America.

Cyonasua LSDs that are directly associated with magnetostratigraphic or radioisotopic data are estimated to be ca. 6-7 Ma, with the sample from Puerta del Corral Quemado believed to be the oldest (and first occurring in a biostratigraphically developed stratigraphic sequence), and another from Chiquimil locality being somewhat younger.

Based upon the principle that immigrant taxa are useful in boundary definition we establish the Huayquerian-Montehermosan boundary using the *Cyonasua* Da-

tum. The base of the Montehermosan stage is best estimated geomagnetically and biostratigraphically calibrated to an age of 7.091 to 7.135 Ma at Puerta de Corral Quemado locality (Valle de Santa María, Catamarca), Northwest Argentina.

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