New Vertebrates of the Brochero Formation (Córdoba, Argentina): A Review of the Pliocene of Central Argentina

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ORIGINAL PAPER

New Vertebrates of the Brochero Formation (Córdoba, Argentina): A Review of the Pliocene of Central Argentina

Laura Edith Cruz[1] · **Juan C. Fernicola**[1,2] · **Claudio A. Carignano**[3]

Abstract The "Horizonte Brocherense" sensu Castellanos was created on the basis of a mammal assemblage recovered from the San Alberto Valley and Los Reartes Valley (Córdoba, Argentina). This mammal association was placed in the "Uquian Stage" (early Pliocene) according to the stratigraphic scheme proposed by Castellanos in 1944. Later, different authors considered this association to belong either to the Montehermosan Stage/Age (early Pliocene) or Huayquerian Stage/Age (late Miocene), based on more updated stratigraphic schemes. Here, we present new vertebrates recovered from the type locality (San Alberto or Traslasierra Valley) of the Brochero Formation; we provide the first paleoenvironmental interpretation for this unit, and discuss the age of the fauna and its bearing sediments. As the main result, this work contributes to the knowledge of the Pliocene faunas, providing the first records of some anurans, snakes, and mammals for the Brochero Formation, and the biostratigraphic and chronological implications of such findings when comparing the fossil assemblage with its counterparts from South America.

Keywords Montehermosan · Chapadmalalan · Uquian · Brocherense · Stage/Age · South America · Pliocene · Córdoba

✉ Laura Edith Cruz
cruzlaurae@gmail.com

Juan C. Fernicola
jctano@yahoo.com

Claudio A. Carignano
ccarignano@hotmail.com

[1] CONICET. División Paleontología Vertebrados, Museo Argentino de Ciencias Naturales "Bernardino Rivadavia", Av. Ángel Gallardo 470, C1405DRJ Caba, Argentina

[2] Departamento de Ciencias Básicas, Universidad Nacional de Luján, Ruta 5 y Avenida Constitución, 6700, Luján, Buenos Aires, Argentina

[3] CONICET. Facultad de Ciencias Exactas, Físicas y Naturales, Centro de Investigaciones en Ciencias de la Tierra, Universidad Nacional de Córdoba, Av. Vélez Sarsfield 1611, X5016GCA Córdoba, Argentina

Introduction

The Traslasierra Valley (or San Alberto Valley) in Córdoba Province, central Argentina, is well known because of the exposure of a long sequence of Late Cenozoic deposits yielding large and small mammal remains. The first isolated prepampean fossils mammals from this locality were described by Burmeister (1870-1874), Ameghino (1888), and Moreno (1888). During the twentieth century, exploration of the site by Castellanos (1942) led to the collection of abundant different mammals, which were the basis for his "Horizonte Brocherense" (= "Brocherense horizon"). Later, in 1944, he also recognized this horizon at two other localities, Los Reartes Valley (Calamuchita Department) and Pedanía El Cuero (General Roca Department), also in Córdoba Province. "Horizonte Brocherense" was assigned by Castellanos (1944) together with his "Uquian Stage" (=late Pliocene) to the "Formación Uqueana" of Kraglievich (1930). This chronological correlation was based on the mammal assemblages. However, different authors considered this association to be equivalent to the Huayquerian Stage/Age (late Miocene, Marshall et al. 1983), the Montehermosan Stage/Age (early Pliocene; Bond et al. 1995; Bond 1999), the interval Montehermosan-Chapadmalalan Stages/Ages (late Miocene-Pliocene, Bonalumi et al. 1999; Álvarez and Tauber 2003, 2004), or directly rejected this unit because of the presence of mammals with different biostratigraphic ranges (Marshall

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et al. 1984; Cione and Tonni 1995a, b). Despite these discrepancies, the discussion of the age of the sediments assigned to the Brochero Formation, described by Sayago (1975, 1979) and redefined by Bonalumi et al. (1999), was based on the mammal assemblages. More recently, a thorough revision of Castellano's collection (Cruz 2011, 2013) resulted in the reassignment of some of the specimens and led to the biostratigraphic proposal of the *Nonotherium hennigi-Propanochthus bullifer* Assemblage Zone, advocating the Brochero Formation as the stratotype, and referring it to a Montehermosan-Chapadmalalan Stage/Age. Taking those studies as the starting point, and after several seasons of field research conducted by the authors in the Traslasierra Valley and Los Reartes Valley, novel vertebrate assemblages were discovered. Thus, the aim of this work is to report these new vertebrates from the Brochero Formation, recovered at the type locality in the Traslasierra Valley. In addition, we provide the first paleoenvironmental interpretation for the formation, and discuss the age of the fauna and its bearing sediments. As the main result, this work contributes to the knowledge of the Pliocene faunas, providing the first records of some anurans, snakes, and describing new mammal species for the Brochero Formation, and the biostratigraphic and chronological implications of such findings when compared to its counterparts from South America.

Historical Background

Castellanos (1942) described his "Horizonte Brocherense" from its type locality, Traslasierra Valley (San Alberto Department, west-central Córdoba Province, Fig. 1), on the basis of the mammal assemblage integrated by glyptodonts and notoungulates. All materials deposited in Museo Universitario Florentino and Carlos Ameghino (Rosario, Santa Fe Province, Argentina) were recovered by Hennig and Castellanos principally in 1941–1943. The holotypes of *Nopachthus coagmentatus* and *Paraglyptodon cordubensis* (= *Neosclerocalyptus* sp.) were recovered by Moreno and the holotype of *Propanochthus bullifer* by M. Ramallo; they are all currently housed at the Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" (Ciudad Autónoma de Buenos Aires, Argentina). Then, Castellanos (1944, 1956, 1958) annexed to his "Horizonte Brocherense" the fauna from Los Reartes Valley (Calamuchita Department, Córdoba Province) and some materials recovered by M. Dardo Rocha at the "Estancia El Ombú" (General Roca Department, southern Córdoba Province, Fig. 1), and deposited at the Museo Argentino de Ciencias Naturales "Bernardino Rivadavia." As the stratigraphic profiles from where the material collected by Rocha could not be correctly located in the field, we have excluded this material from our study. The list of taxa from Traslasierra Valley and Los Reartes Valley includes mostly notoungulates, cingulates, and rodents (see Table 1).

With respect to the chronological assignment, Castellanos (1944) considered the "Horizonte Brocherense" as prepampean sediments that together with his "Uquian Stage" comprised the "Formación Uqueana" of Kraglievich (1930) (late Pliocene). Later, Marshall et al. (1983) considered the Brocherense older than Marplatan (=Uquian of Castellanos), equivalent to the Huayquerian Stage/Age (late Miocene) based on the mammal assemblages of Castellanos (1942, 1944). However, Marshall et al. (1984) rejected a great part of the assemblage (mammals from Traslasierra Valley plus Los Reartes Valley) because the different mammals were a mixture of Montehermosan and Ensenadan taxa, but retained the earliest record of the family Felidae based on the *Felis pumoides* of Castellanos recovered in the Los Reartes Valley. Cione and Tonni (1995a, b) argued that the "Horizonte Brocherense" was a combination of Huayquerian and Ensenadan taxa. However, Bond et al. (1995) and Bond (1999) suggested that *Nonotherium* was a synonymy of *Xotodon* and, because of this they referred these assemblages to the Montehermosan Stage/Age (early Pliocene). Sayago (1975, 1979) described formally the sediments of the "Brocherense" of Castellanos and named them as the Brochero Formation. This formation was redefined by Bonalumi et al. (1999) in the geological map of Villa Dolores. These authors referred the fauna of Castellanos from the Traslasierra Valley to the Montehermosan-Chapadmalalan because of the presence of *Xotodon* (*Nonotherium* as synonymy of *Xotodon* according to Bond et al. 1995) and mentioned that the mix of Montehermosan and Ensenadan taxa sensu Marshall et al. (1984) and Cione and Tonni (1995a) was given by the fossil mammals from Los Reartes Valley. Bonalumi et al. (1999) mentioned that outcrops where the mammals of the Los Reartes Valley (precisely La Isolina and El Bajo) were found cannot be verified because they are currently under the Los Molinos Dam. Later, Álvarez and Tauber (2003, 2004) based on the new mammal assemblages, still unpublished, assigned the Brochero Formation to the lapse Montehermosan?-Chapadmalalan? Stages/Ages (late Miocene-Pliocene). Gaido et al. (2006) in the geological map of the Calamuchita Valley mentioned the presence of *Nonotherium* and referred the sediments to the early-middle Pliocene. More recently, Cruz (2011, 2013) in a restricted biostratigraphic analysis based only on a re-study of the fauna recovered by Castellanos proposed the *Nonotherium hennigi-Propanochthus bullifer* Assemblage Zone, with type area and profile at Los sauces River, Brochero Formation (sensu Bonalumi et al. 1999), referred to the Montehermosan-Chapadmalalan interval (Pliocene). Initial field trips showed that the sediments where most of the fossils of the Brocherense of Los Reartes Valley have been found could not be re-studied because they are today under the Los

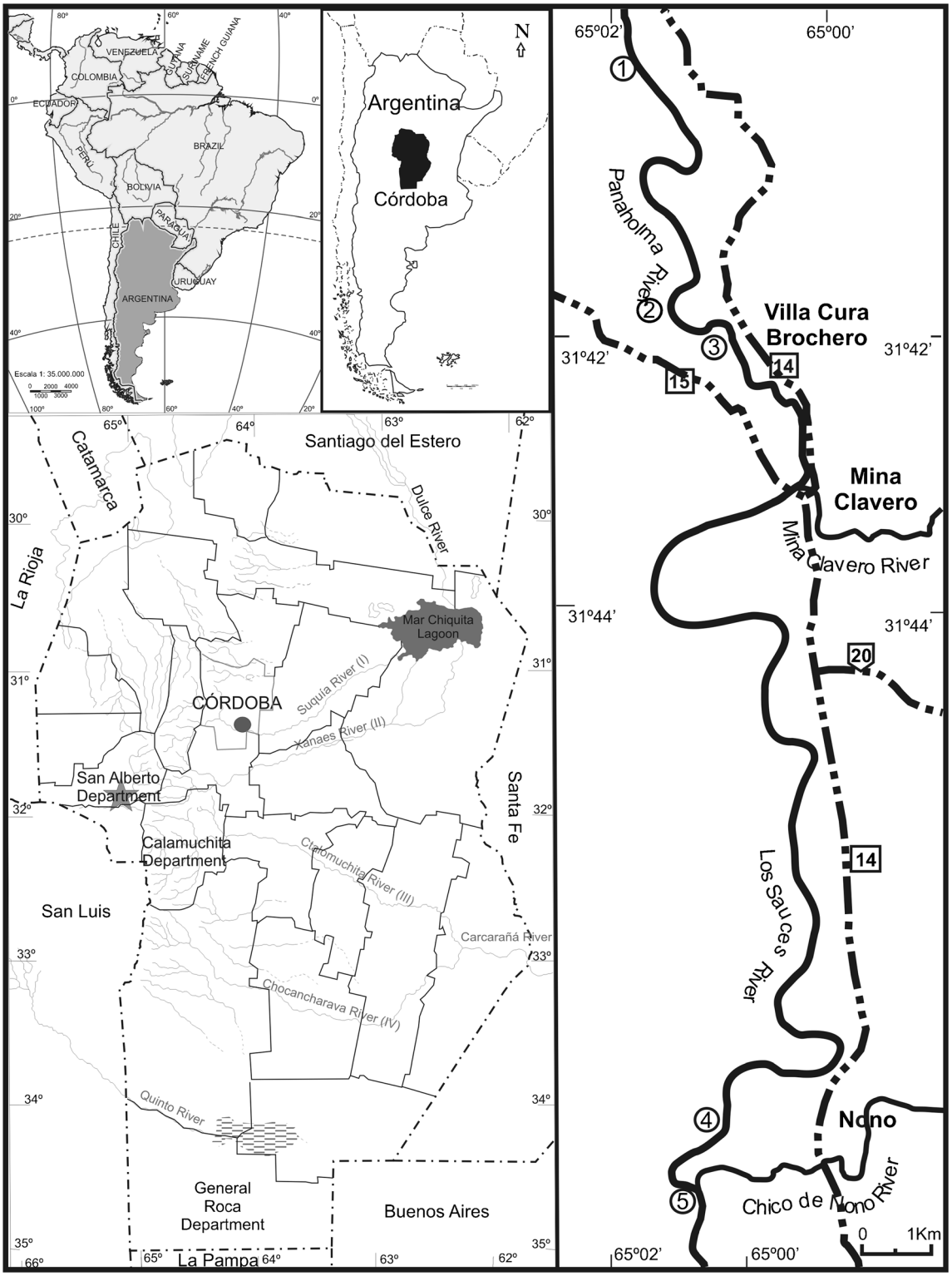

Fig. 1 Location map, Argentina, Córdoba Province, San Alberto Department. 1. Las Maravillas; 2. Los Chiflones stream; 3. Vado de Cura Brochero; 4. Paso del Río arriba cliffs; 5. Heredia cliffs

Molinos Dam (Calamuchita Department, Fig. 1), as well as those faunas with dubious stratigraphic provenance from "Campo La Isolina" and "El Bajo" cliff, as well was reported by Cione and Tonni (1995a), Bonalumi et al. (1999), and Cruz (2011, 2013). Chimento et al. (2014), in a revision of *Felis pumoides* (MUFyCA 767) of Castellanos, reassigned it to

Table 1 Taxa recorded in the Brocherense with the geographic and stratigraphic provenance sensu Castellanos (1942, 1944, 1956, 1958)

Geographic and stratigraphic provenance	Material and taxonomic assignation
Valle de Traslasierra, Brocherense	*Nonotherium hennigi*, MUFyCA 1 (Holotype)
Valle de Traslasierra, Brocherense	*Paedotherium brocherense*, MUFyCA 372–375 (Serie type)
Valle de Traslasierra, Brocherense	*Nopachtus coagmentus*, MLP 16–122 (Holotype), MUFyCA 1017, 396, 370
Valle de Traslasierra, Brocherense	*Paraglyptodon cordubensis*, MACN A 1210–1215 (Holotype)
Valle de Traslasierra, Brocherense	*Propanochthus bullifer*, MACN PV 1761 (Holotype)
Valle de Los Reartes, Brocherense	*Nonotherium hennigi*¸ MUFyCA 6
Valle de Los Reartes, Brocherense	*Paedotherium isolinense*, MUFyCA 764 (Holotype)
Valle de Los Reartes, Brocherense	*Eutatopsis* sp., MUFyCA 1147
Valle de Los Reartes, Brocherense	*Plaina brocherense*, MUFyCA 769 (Holotype)
Valle de Los Reartes, Brocherense	*Nopachtus coagmentatus*, MUFyCA 1050, 780
Valle de Los Reartes, Brocherense	*Orthomyctera brocherense*, MUFyCA 759 (Holotype)
Valle de Los Reartes, Brocherense	*Ctenomys (Paractenomys) brocherense*, MUFyCA 766 (Holotype)
Valle de Los Reartes, Brocherense	*Paleocavia brocherense*, MUFyCA 765 (Holotype)
Valle de Los Reartes, Brocherense	*Microcavia* (*Xenomicrocavia*) *isolinense*, MUFyCA 763 (Holotype)
Valle de Los Reartes, Brocherense	*Felis pumoides*, MUFyCA 767 (Holotype)

Puma (*Herpailurus*) *pumoides* and they supported it as the earliest record of Felidae in the late Pliocene but the stratigraphic provenance is dubious.

Material and Methods

Institutional Abbreviations CB, Coleccion Botet, Museo de Ciencias Naturales, Ayuntamiento de Valencia, España; **MACN-A,** Museo Argentino de Ciencias Naturales "Bernardino Rivadavia," Colección Nacional de Ameghino, Ciudad Autónoma de Buenos Aires, Argentina; **MACN-Pv**, Museo Argentino de Ciencias Naturales "Bernardino Rivadavia," Colección Nacional de Paleovertebrados, Ciudad Autónoma de Buenos Aires, Argentina; **MCNC-PV**, Museo Provincial de Ciencias Naturales "Dr. Arturo U. Illia," Córdoba Province, Argentina; **MLP**, Museo de La Plata, Buenos Aires Province, Argentina; **MNHN-PAM**, Muséum National d'Histoire Naturelle, Colección Pampéen, París, Francia; **MUFyCA**, Museo Universitario Florentino y Carlos Ameghino, Rosario, Santa Fe Province, Argentina.

The specimens studied were photographed using a Canon EOS Rebel 3 (16.0 M-pixel) digital camera. Observations were performed with a scanning electron microscopy Philips XL30 TMP New Look (MACN, Argentina). Different measurements were taken with a digital caliper. Digital images were improved in contrast using Adobe Photoshop CS5.1 Extended. CorelDRAW X3 software was used to line depict the main features of the remains.

The stratigraphic descriptions and definition of sedimentary facies were carried out following the criteria established by Miall (1985) for fluvial deposits.

Taxonomic identification of the specimens was achieved in accordance with references of the original descriptions, taxonomic revisions (e.g., Cabrera 1944; Cerdeño and Bond 1998; Zamorano et al. 2011; Deschamps et al. 2012, 2013; Teta et al. 2014; Vucetich et al. 2014a, b, 2015); holotypes and referred specimens were deposited in the collections of vertebrate paleontology of the MACN, MLP, CB, MNHN-PAM, and MUFyCA, as well as in the collections of Mammalogy of the MACN and MLP.

The new specimens found in our field trips and presented in the current study are available in the Museo Provincial de Ciencias Naturales "Dr. Arturo U. Illía," Córdoba, Argentina (MCNC-PV).

Results

Geological Setting

Castellanos (1942, 1944) described from Valle de Traslasierra (Fig. 1) at least seven sites where outcropping sediments were assigned to his "Brocherense," but only three with fossils (Los Chiflones stream, Paso del Río Arriba Cliffs, and Heredia Cliffs, see point 2, 4, and 5, respectively in Fig. 1). All these cliffs have been identified in different field trips from 2009 to 2016. The cliff of Paso del Río Arriba and Heredia outcrop along the Los Sauces River near Nono Locality, and Los Chiflones stream is affluent of the Panaholma River near to Villa Cura Borchero Locality (Fig. 1). In our field trips new materials were found in two new sites identified as Las Maravillas and Vado de Cura Brochero (point 1 and 3, respectively in Fig. 1) and in the site established by

Castellanos as Paso del Río Arriba. In all profiles the Pliocene sediments recognized were grouped in the Brochero Formation. This formation is composed of two different sedimentary facies associations. Here we described the profiles at the Paso del Río Arriba Cliff (Fig. 2) because in this site both associations are shown, as well as their different sedimentary facies (from bottom to top): 1) Massive gravel (Gm) facies: 20–50 cm of medium to fine gravels with occasional 5 to 10 cm clasts dispersed, with no visible stratification, which are interpreted as lag deposits; 2) Sands with cross bedding (St) facies: they are medium-scale cross strata composed of layers of fine sand with sigmoidal geometry and layers of sand with trough cross-bedding, both forming sets of average thickness varying between 10 and 15 cm (not more than 30 cm), separated by millimetric to centimetric layers of silts and clays arranged parallel to the surface of lateral accretion, interpreted as deposits of lateral accretion bars; 3) Sands with horizontal bedding (Sh) facies: layers of fine to very fine sands with planar bedding, which are interpreted as deposits of chute channels; 4) Sands with small scale trough cross-bedding (St) facies: composed of very fine sandy deposits with trough cross-bedding interpreted as low-energy channel-fill; 5) Laminated sandy-silts and silty-clays (Ll-Fl) facies: layers of sandy silts, clay silts laminated with interbedded lenses and layers of fine to very fine sands, which are interpreted as floodplains deposits; and 6) Laminated sandy-silts and silty-clays with paleosoils (Llp-Flp) facies: layers of sandy silts, clays silts, uniformly laminated, with intercalation of lenses and layers of fine to very fine sands with edaphic processes superimposed, where development of soils and rhizoconcretions, nodulate tosca with carbonates, and iron-manganese nodules are common. Facies 1 to 4 are indicative of lateral-accretion deposits of fluvial point bars, whereas facies 5 and 6 represent the overbank fine sediments of floodplains. The overall sedimentary facies association suggests a fluvial paleoenvironment of meandering type. Overlying unconformably the Brochero Formation is the Mina Clavero Formation, which is interpreted as a fluvial system composed of gravel and sandy facies indicative of braided channels. Thick to very thick deposits of gravels constituted by clast-supported conglomerates are common in the Mina Clavero Formation. However, different exposures of the Brochero Formation in the Traslasierra Valley are covered by younger sediments assigned to the Las Rabonas, Mina Clavero, Toro Muerto, and Charbonier formations. The deposition of these formations occurred in different intervals during the Pleistocene (Bonalumi et al. 1999; Carignano 1999).

Fossiliferous Localities

Las Maravillas (Fig. 1)

Location: 31°40′01.9″S, 65°01′54.4″W, Cura Brochero, Traslasierra Valley (or San Antonio Valley).

Fossiliferous units and facies: Brochero Formation, Llp-Flp facies.

Fossil content: Isolated osteoderms of the posterodorsal region of the dorsal carapace (MCNC-PV 304, Fig. 3A) assigned to *Phlyctaenopyga* sp., isolated osteoderm from the lateral border of the dorsal carapace (MCNC-PV 311), and isolated osteoderms from the lateral region of the dorsal carapace (MCNC-PV 309) assigned to Glyptodontidae indet.

Remarks: The assignment of MCNC-PV 304 to *Phlyctaenopyga* sp. is based on Cabrera (1944), who described as typical of the genus the presence of a very convex (bubble-shaped) main central figure on the superficial surface of the osteoderms, surrounded by two rows of smaller

Fig. 2 Stratigraphic profile of Paso del Río Arriba cliff

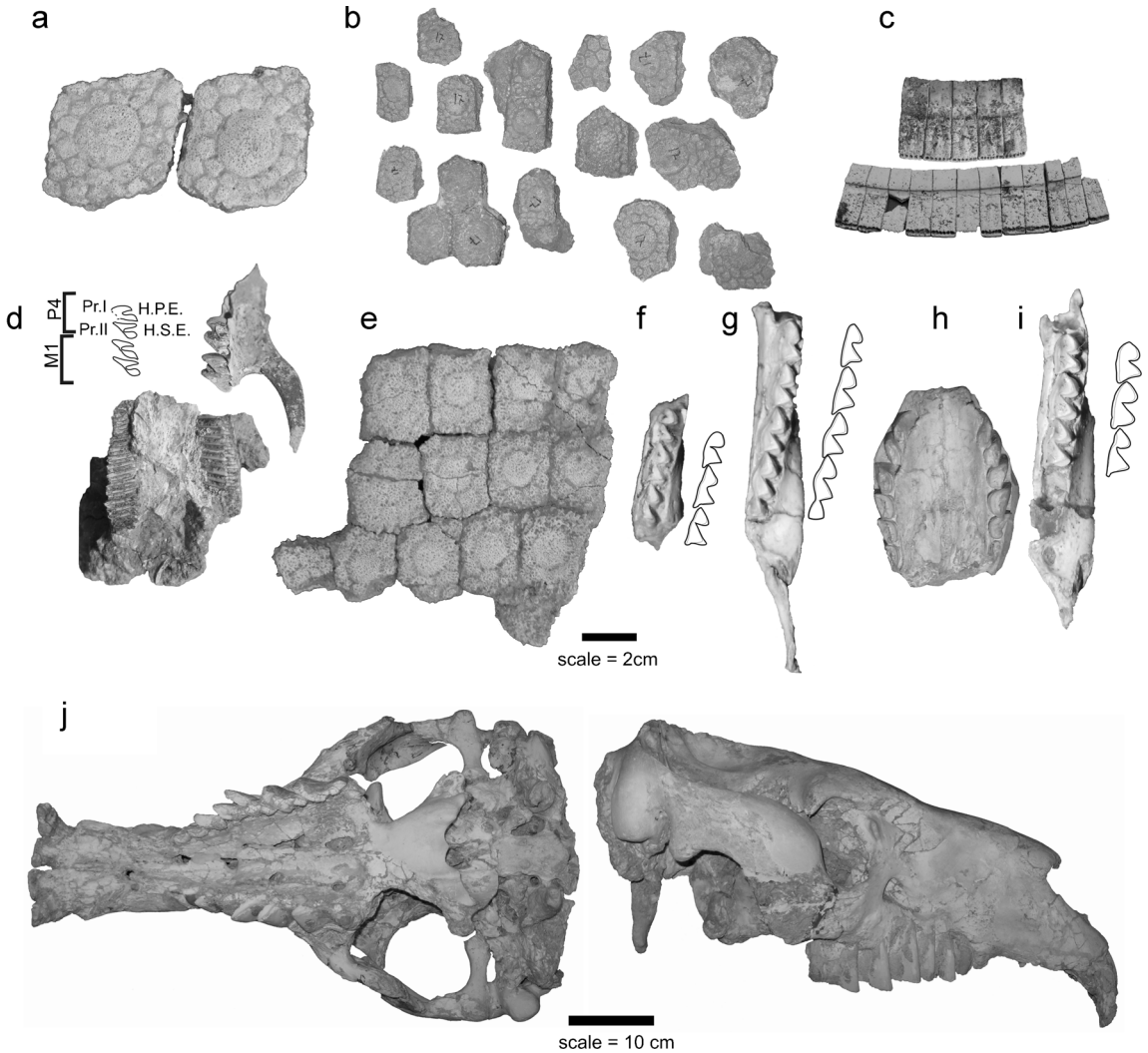

Fig. 3 A-B. *Phlyctaenopyga* sp. (Glyptodontidae, Cingulata) **a.** MCNC-PV 304 osteoderms, **b.** MUFyCA 1017, osteoderms; **c.** *Doellotatus* cf. *D. chapadmalensis* (Dasypodidae, Cingulata), MCNC-PV 305, fragment of the carapace; **d.** *Phugatherium* cf. *P. novum* (Hydrochoeridae, Rodentia) MCNC-PV 302, fragment of the skull; **e.** Hoplophorini indet. MCNC-PV 303, osteoderms articulated; **f-i.** *Paedotherium bonaerense*. **f.** MUFyCA 372, fragment of right mandible with pm4-m2. **g.** MUFyCA 373, fragment of right mandible with pm4-m3. **h.** MUFyCA 374, fragment of skull. **i.** MUFyCA 372, fragment of right mandible with pm4-m2. **j.** *Nonotherium hennigi* (Holotype) MUFyCA 1, skull

peripheral figures being 12 in the first row, all these characteristics are present in this material.

Los Chiflones Stream (Fig. 1)

Location: 31°41′45.0″S, 65°01′44.3″W, Cura Brochero, Traslasierra Valley (or San Antonio Valley).

Fossiliferous units and facies: Brochero Formation, Gm facies.

Fossil content: Several osteoderms (MUFyCA 1017, Fig. 3B) reassigned to *Phlyctaenopyga* sp. (Glyptodontidae, Cingulata).

Remarks: This material was originally assigned to *Nopachtus coagmentatus* by Castellanos (1942, 1944) but the presence of a main bubble-shaped central figure in some osteoderms allows its reassignment to *Phlyctaenopyga* sp. (see remarks about this genus above).

Vado de Cura Brochero (Fig. 1)

Location: 31°41′51.7″S, 65°01′35.0″W, Cura Brochero, Traslasierra Valley (or San Antonio Valley).

Fossiliferous units: Brochero Formation, Ll-Fl facies.

Fossil content: Fragment of carapace (MCNC-PV 305, Fig. 3C) assigned to *Doellotatus* cf. *D. chapadmalensis* (Dasypodidae, Cingulata); fragment of juvenile skull (MCNC-PV 302, Fig. 3D) assigned to *Phugatherium* cf. *P. novum* (Hydrochoeridae, Rodentia); six articulated osteoderms (MCNC-PV 303, Fig. 3E) assigned to Glyptodontidae indet.

Remarks: The mobile osteoderms MCNC-PV 305 are similar in size to *D. chapadmalensis* and larger than *D. inornatus*. In addition, the central figures are wider and flatter that in *D. inornatus* (Cruz et al. 2014). Concerning the hydrochoerid MCNC-PV 302 the lobes of Prisms I and II of the molariforms are asymmetric because the external fissures (H.P.E. and H.S.E.) are oblique, as in *P. novum*. This character is different in the species from Farola Monte Hermosa, *P. perturbidum*, in which the lobes are subequal and the fissures are perpendicular to the anteroposterior axis (Deschamps et al. 2007, 2012, 2013; Cruz et al. 2014; Vucetich et al. 2014a, b, 2015).

Paso del Río Arriba Cliffs (Fig. 1)

Location: 31°47′30″S, 65°00′58″W, Nono, Traslasierra Valley (or San Antonio Valley).

Fossiliferous units: Brochero Formation, St facies.

Fossil content: Concentration of bones in the same sedimentary structure (MCNC-PV 307, Fig. 4A) includes: right nasal, two left maxillae, two left frontoparietals, maxillae, right frontoparietal, right maxilla, left pterygoid, left cleitrum, right scapula, left humerus, four presacral vertebrae, two sacral vertebrae, urostyle, and ischium assigned to *Rhinella* cf. *R. arenarum* (Anura, Bufonidae); sacral vertebra (MCNC-PV 308, Fig. 4B) assigned to *Rhinella* cf. *R. spinulosa* (Anura, Bufonidae); partial left dentary with one complete tooth (MCNC-PV-291, Fig. 4C) assigned to *Teius* sp. (Squamata, Teiidae, Teiinae); partial left dentary with complete teeth (MCNC-PV 292, Fig. 4D), and anterior end of a right dentary with alveoli and six complete teeth (MCNC-PV 293, Fig. 4E) assigned to ? *Liolaemus* (Squamata, Iguanidae, Tropidurine); anterior end of a right dentary with teeth (MCNC-PV-294, Fig. 4F) assigned to Iguanidae indet. (Squamata); one vertebra. (MCNC-PV 295, Fig. 4G) assigned to Colubridae indet (Squamata); two fragments of both hemimandibles (MCNC-PV 297, Fig. 4H) assigned to "*Akodon* (*Abrothrix*)" *magnus*; fragment of right maxilla with the zygomatic plate, M1–3 and the associated portion of the palate (MCNC-PV-298, Fig. 4I), and right m1 (MCNC-PV-299, Fig. 4I), holotype and paratype, respectively of *Chukimys favaloroi*, isolated upper molar (MCNC-PV 300, Fig. 4J) assigned to Echimyidae indet.

Remarks: Most materials here reporter are under study and were presented by Brizuela and Cruz (2013) and Cruz et al. (2014). *Chukimys favaloroi* is a new taxon found in the context of this work, and was described by Barbiere et al. (2016a).

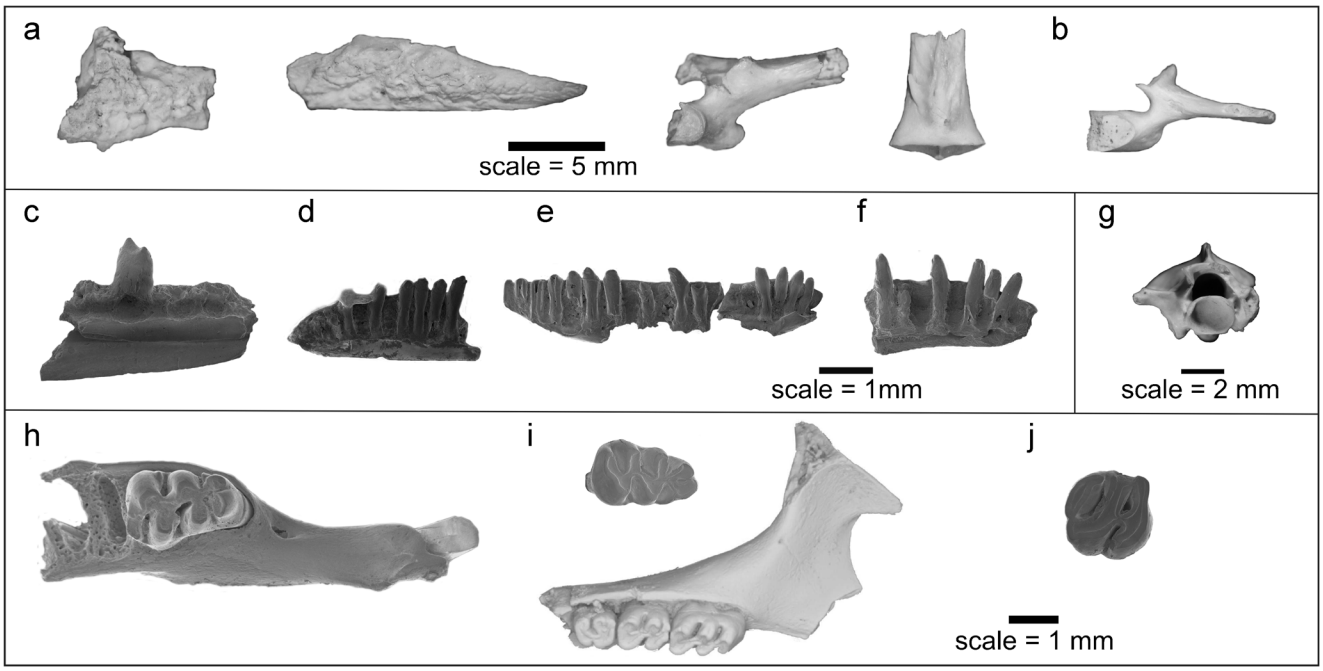

Fig. 4 **a.** *Rhinella* cf. *R. arenarum* (Anura, Bufonidae) MCNC-PV 307, right nasal, left maxilla, sacral vertebrae, and urostyl; **b.** *Rhinella* cf. *R. spinulosa* (Anura, Bufonidae) MCNC-PV 308, sacral vertebra; **c.** *Teius* sp. (Squamata, Teiidae, Teiinae) MCNC-PV-291, partial left dentary with one complete tooth; **d-e.**?*Liolaemus* (Squamata, Iguanidae, Tropidurine); **d.** MCNC-PV 292, partial left dentary with complete teeth; E. MCNC-PV 293, anterior end of a right dentary with 11 tooth positions and six complete teeth; **f.** Iguanidae indet. (Squamata) MCNC-PV-294, anterior end of a right dentary with teeth; **g.** Colubridae indet. (Serpentes) MCNC-PV 295, vertebra; **h.** "*Akodon* (*Abrothrix*)" *magnus* (Rodentia, Cricetidae) MCNC-PV 297, fragment of left hemimandible with m1; **i.** *Chukimys favaloroi* (Rodentia, Cricetidae) MCNC-PV-298 (Holotype), fragment of right maxilla with zygomatic plate, the M1–3 and the associated portion of the bony palate, and MCNC-PV-299 (Paratype), right m1; **j.** Echimyidae indet. (Rodentia) MCNC-PV 300, isolated upper molar

Heredia Cliffs (Fig. 1)

Location: 31°48′25.7″S, 65°01′30.6″W, Nono, Traslasierra Valley (or San Antonio Valley).

Fossiliferous units: Brochero Formation, Gm facies.

Fossil content: Fragment of right mandible with pm4-m2 (MUFyCA 372 Fig. 3F) assigned to *Paedotherium bonaerense*; skull (MUFyCA 1, Fig. 3J) holotype of *Nonotherium hennigi*.

Remarks: Castellanos (1942) described *Nonotherium hennigi* as intermediate in some characters between *Xotodon* and *Toxodon* based on this skull. However, several authors (Cione and Tonni 1995b; Bonalumi et al. 1999) accepted the preliminary synonymy of this taxon with *Xotodon* (Bond et al. 1995). However, Cruz (2011), in a review of the holotype and based on several characters, supported that *Nonotherium hennigi* is a valid taxon. A particular character of this taxon is the very concave ectoloph of the molars, unlike *Calchaquitherium*, *Ocnerotherium*, *Trigodon*, *Paratrigodon*, and *Toxodon*, and similar to *Posnanskytherium* and *Xotodon*, but they are clearly distinguished by the much larger skull and mainly by the length of the diastema. In relation to *Paedotherium brocherense,* it was created by Castellanos (1944) without diagnosis or description, but referring to a description previously made on a single material (MUFyCA 372, Fig. 3F, Castellanos 1942). In 1944, Castellanos assigned this material together with MUFyCA 373 (fragment of right mandible with pm4-m3, Fig. 3G), MUFyCA 374 (fragment of maxillary with right Pm2-M3 and left Pm2-M2, Fig. 3H), MUFyCA 375 (fragment of right mandible with pm4-m2, Fig. 3I) to the type series of *Paedotherium brocherense*. Later, Mones (1986) considered it as *nomen nudum*, because of erroneous publication (Castellanos 1956). Later, Cerdeño and Bond (1998) considered the species as *nomen dubium* and made explicit that a formal synonymy was needed. It is noteworthy that the assignment is based on the original figures given by Castellanos in 1958 (he only figured a copy of the type series - MUFyCA 373), but Cruz (2011) based on the degree of molarization of pm4 and the size of all the materials of the type series reassigned them to *Paedotherium bonaerense* following the revision of the genus made by Cerdeño and Bond (1998).

Discussion

Paleoenvironmental Interpretations

Historically, the finning upward lithofacies of the Brochero Formation were interpreted as depositional processes of alluvial cones, with the apex to the west (Kraemer et al. 1993; Astini et al. 2014 and references there in). This interpretation was supported by the presence of gravel facies at the edges of the valley that represent proximal and basal fan deposits, covered by fine facies that represent the medial and distal fan deposits. These gravel facies have been described in lower topographic sections as well as intercalated in more fine sections at topographically higher sites. The alluvial model can explain the sedimentary facies association present in the topographically lower sites such as "Rincon La Mora," but gravel facies appear associated with fine facies in the profiles farther from the this sites as "Paso del Río Arriba" and "Las Maravillas." Therefore, the facies associations here described suggest a fluvial paleoenvironment of meandering type where two major sub-environments are recognized: channels or channel belts (facies 1 to 4, Fig. 2) and vegetated floodplains (facies 5 and 6, Fig. 2). The meandering river systems consist of a single high sinuosity channel (with point bars or bars spurs) and floodplain deposits with fine sedimentation and overflow lobes and channels. At the same time, meandering systems may have sandy or gravelly channels (higher energy), and the degree of channels confinement in the floodplain, which is controlled by the development of levees, will be more or less important considering floods types predominating in the basin and sediment load. This scenario almost always indicates extensive flat, low areas densely vegetated, associated with stable water bodies with free water circulation. This is supported by the presence of at least three taxa recorded in this study that need water as a vital resourcecr. The modern capybaras need water not only for ingestion, but also to control their body temperature, as an escape from predators, usually mate in the water, and most of their food is found near or within water bodies (Barreto and Quintana 2012). So, capybaras establish territories in which water is the key resource (Herrera and Macdonald 1989). In regard to anurans, *Rhinella spinulosa* need the temporary and permanents ponds to reproduce and actually this species inhabits mountain valley in the Andes (Márquez-García et al. 2009; Sanabria et al. 2015). Although they depend on wetlands and water bodies for their reproduction, they are quite resistant to arid conditions. Actual distributions of these two species are complementary, being generally *R. arenarum* of flat areas and *R. spinulosa* of high areas; however, they are sympatric in many mountain environments (Urra 2013). According to the paleogeographic location during Pliocene times of the Valle de San Alberto, it is considered that these fluvial systems were developed under temperate climate, with wetter conditions than today, as inferred from the high amount of clays and manganese nodules in the sediments of the Brochero Formation. This is also supported by the presence of *Teius* which would indicate wetter conditions that today in the area (Donadio 1984; Albino 1994).

Biostratigraphic Interpretations

The first chronological scheme of the continental Cenozoic of southern South America was established on the basis of mammal assemblages from Argentina by the Ameghino brothers (e.g., Ameghino 1889, 1898, 1908). Afterwards, Kraglievich (1952) re-defined Ameghino's stratigraphic scheme adding the lithological information obtained from the fossil bearing sediments. Frenguelli (1957), on the other hand, kept using the Ameghino's scheme but only with a chronostratigraphic connotation. Later, Pascual et al. (1965) established the first South American Land-Mammal Ages (SALMAs) scheme, following the proposal of Ameghino. Hence, the chronological adjustment of the continental late Miocene-Holocene in South America is based mostly on mammal faunas from the pampean region of Argentina (Marshall et al. 1983, 1984; Cione and Tonni 1995a, 1995b, 1999, 2005; Tonni 2009, and references therein). In most of these works the fossil mammals of the Brocherense collected from Traslasierra and Los Reartes valleys were considered as from the unit. Furthermore, the synonymy proposed between *Nonotherium* and *Xotodon* was maintained by the different researchers and used as the correlation with the Montehermosan Stage/Age of the Atlantic Coast, thus, raising more doubts than solutions to the correct biostratigraphy of the Brochero Formation, especially when considering the presence of Pleistocene fauna (e.g., *Neosclerocalyptus*) mixed with taxa characteristic of the Pliocene (e.g., *Plohophorus*, *Xotodon*, *Nopachthus*). Cruz (2011, 2013) recognized the *Nonotherium hennigi-Propanochthus bullifer* assemblage zone assigned to the Brochero Formation. This biozone was defined by the co-occurrence of *Nonotherium hennigi*, *Propanochthus bullifer*, *Phlyctaenopyga* sp., *Plohophorus* sp., and *Paedotherium bonaerense* (Cruz, 2011, 2013) and referred to the Montehermosan-Chapadmalal interval (Pliocene). However, and according to the new vertebrates presented here and careful study about the exact stratigraphic and geographic provenances, it is very difficult to determine the age of deposition of the Brochero Formation of Traslasierra Valley.

According to this study the vertebrate assemblages from the Brochero Formation are formed by *Nonotherium hennigi*, *Paedotherium bonaerense*, *Phlyctaenopyga* sp., *Doellotatus* cf. *D. chapadmalensis*, *Phugatherium* cf. *P. novum*, "*Akodon* [*Abrothrix*]" *magnus*, *Chukimys favaloroi*, *Rhinella* cf. *R. arenarum*, *Rhinella* cf. *R. spinulosa*, *Teius* sp., ?*Liolaemus*, and Iguanidae, Colubridae, and three indeterminate glyptodonts (see Table 2). This vertebrate assemblage disagrees with the biochronology (based mainly on mammals) from South America represented principally in records of the Atlantic Coast. The last taxonomic and biostratigraphic studies of the giant capybaras (Deschamps et al. 2007, 2012, 2013, Vucetich et al. 2014a, 2014b, 2015, and references therein) based on the dental evolution of the family Hydrochoeridae concluded that this group of rodents is a very good biochronologic indicator. In these works *Phugatherium novum* is recognized only for the Chapadmalal Formation (4 to 3.3 Ma); this is Chapadmalalan Stages/Ages (late Zanclean). The stratigraphic distribution of *Doellotatus chapadmalensis* is Monte Hermoso, Chapadmalal, and "Irene" formations, Montehermosan and Chapadmalalan Stage/Age from Buenos Aires Province, and in the Cerro Azul Formation, Huayquerian Stage/Age from La Pampa Province (Scillato-Yané et al. 1995; Esteban et al. 2001, 2003; Urrutia et al. 2008). Zamorano et al. (2011) in the last revision of *Phlyctaenopyga* assigned it to the Montehermosan Stage/Age. With regard to "*Akodon* (*Abrothrix*)" *magnus* it is recorded in sediments of the Vorohue Formation, assigned to the Vorohuean Substage/Subage (Reig 1987; Teta et al. 2014), whereas *Paedotherium bonaerense* has been undoubtedly recorded in sediments of the Monte Hermoso, Chapadmalal, Barranca de Los Lobos, and Vorohué formations as well as the Necochea beds, so the records of *P. bonaerense* cover from the Montehermosan to Marplatan Stages/Ages. The squamates are interesting, principally because it is the first record of *Teius*, and the Iguanidae indet. is a basal tropidurinae, which together with? *Liolaemus* increase the Pliocene records of the few squamates known (Albino and Brizuela 2015 and references therein), whereas the first occurrence of Colubridae is from the early Miocene (Albino and Brizuela 2015). Regarding the anurans, the oldest certainly fossil record of *Rhinella arenarum* came from the "Irene" and Chapadmalal formations (Maciel et al. 2010; Pérez Ben et al. 2014). Finally, *Nonotherium hennigi* and *Chukimys favaloroi* are so far exclusive taxa from the Brochero Formation.

The fossil fauna of vertebrates recorded from the Brochero Formation allows us to propose the following hypothesis regarding the age on the basis of the biochrons discussed above: (1) this assemblage may be Chapadmalalan in age; this hypothesis is based on the presence of *Phugatherium novum*, taxa recovered in the Chapadmalalan Stage/Age from Atlantic Coast, and is intermediate between Monterhemosan, suggested by *Phlyctaenopyga*, and Vorohuean, suggested by "*Akodon* (*Abrothrix*)" *magnus*. In this case both latter taxa would have the youngest record and the oldest record, respectively; (2) alternatively, a Montehermosan age as suggested by *Phlyctaenopyga*. In this case it would be the single record of *P. novum* out of its type area, and the biochron of "*Akodon* (*Abrothrix*)" *magnus* would be much longer than so far known. In both cases, the other records, such as *D. chapadmalensis* and *P. bonaerense*, have longer biochrons and do not contradict the proposed age; (3) and the last hypothesis endorses the Marplatan Stage/age, more precisely the Vorohuense Substage/Subage. This idea is based in the presence of "*Akodon* (*Abrothrix*)" *magnus* recorded in the sediments assigned to the Vorohuense Substage/Subage. In this

Table 2 Taxa recorded in the Brochero Formation from Valle de Traslasierra according to this paper with their geographic and stratigraphic provenance

Geographic and stratigraphic provenance	Material and taxonomic assignation
Heredia Cliff, Brochero Formation	*Nonotherium hennigi*, MUFyCA 1 (Holotype)
Heredia Cliff, Brochero Formation	*Paedotherium bonaerense*, MUFyCA 372
Villa Cura Brochero (Valle de Traslasierra), Brochero Formation?	*Paedotherium bonaerense*, MUFyCA 373
Villa Cura Brochero (Valle de Traslasierra), Brochero Formation?	*Paedotherium bonaerense*, MUFyCA 374
Nono (Valle de Traslasierra), Brochero Formation?	*Paedotherium bonaerense*, MUFyCA 375
Valle de Traslasierra,?	*Nopachtus coagmentus*, MLP 16–122 (Holotype)
Los Chiflones stream, Brochero Formation	*Phlyctaenopyga* sp., MUFyCA 1017
Pizarro Cliff, Brochero Formation?	? *Plohophorus,* MUFyCA 396
Nono (Valle de Traslasierra), Brochero Formation?	*Propanochthus bullifer*, MUFyCA 370
Villa Cura Brochero (Valle de Traslasierra), Brochero Formation?	*Neosclerocalyptus* sp., MACN A 1210–1215 (Holotype)
Villa Cura Brochero (Valle de Traslasierra), Brochero Formation?	*Propanochthus bullifer*, MACN PV 1761 (Holotype)
Las Maravillas, Brochero Formation	*Phlyctaenopyga* sp., MCNC-PV 304
Las Maravillas, Brochero Formation	Glyptodontidae indet., MCNC-PV 309, 311
Vado de Cura Brochero, Brochero Formation	*Doellotatus* cf. *D. chapadmalensis*, MCNC-PV 305
Vado de Cura Brochero, Brochero Formation	*Phugatherium* cf. *P. novum*, MCNC-PV 302
Vado de Cura Brochero, Brochero Formation	Glyptodontidae indet., MCNC-PV 303
Paso del Río Arriba, Brochero Formation	*Rhinella* cf. *R. arenarum*, MCNC-PV 307
Paso del Río Arriba, Brochero Formation	*Rhinella* cf. *R. spinulosa*, MCNC-PV 308
Paso del Río Arriba, Brochero Formation	*Teius* sp., MCNC-PV-291
Paso del Río Arriba, Brochero Formation	?*Liolaemus*, MCNC-PV-292, 293
Paso del Río Arriba, Brochero Formation	Iguanidae indet., MCNC-PV-294
Paso del Río Arriba, Brochero Formation	Colubridae indet., MCNC-PV 295
Paso del Río Arriba, Brochero Formation	"*Akodon* (*Abrothrix*)" *magnus*, MCNC-PV 297
Paso del Río Arriba, Brochero Formation	*Chukimys favaloroi*, MCNC-PV-298 (holotype) MCNC-PV-299 (paratype)
Paso del Río Arriba, Brochero Formation	Echimyidae indet., MCNC-PV 300

situation, the biochron of *Phlyctaenopyga*, *D. chapadmalensis*, and *P. novum* would be much longer than so far known. So, perhaps the first option is the better, but it is essential to study new materials with precise stratigraphic and geographic provenances from other sites where the Brochero Formation is exposed, such as Los Reartes Valley, to support this hypothesis. This work emphasizes the importance of considering the stratigraphic provenance whenever possible, as well as the need to present all data of provenance, to avoid errors of records present in the literature, and generate diverse paleobiogeographic hypotheses with taxa whose stratigraphic provenance are uncertain (e.g., the earliest Felidae presented by Chimento et al. [2014]). In summary, the assemblage presented here is unique until now in Argentina, and considering that it was not possible to find materials to carry out some absolute dating, the only chronological approach that is possible to follow is the biochrons of the faunal assemblage, it's necessary to continue with these studies that allow us to know part of the faunal evolution during the Pliocene times.

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