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Revision of the stratigraphic provenance of *Ethegotherium carettei* (Notoungulata, Hegetotheriidae) by sedimentary petrography

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With 5 figures and 1 table

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Abstract: *Ethegotherium carettei* Minoprio was considered among the species with derived characteristics from Divisadero Largo Formation (Mendoza, Argentina); seven thin rock sections were taken for petrographical analysis to test the hypothesis that it could come from more modern stratigraphic levels. The rock containing the type of *E. carettei* shows scarce matrix, presence of carbonatic cement and accessory minerals (microcline and hornblende), thus being very similar to the sandstone from Mariño Formation and different from the wackes characteristic of Divisadero Largo Formation. This analysis indicates that *E. carettei* proceeds from Mariño Formation and not from Divisadero Largo Formation, as it has been stated since the erection of this species.

Keywords: Argentina, Divisaderan, Paleogene, petrographic microscopy, sedimentology.

1. Introduction

The type locality for Divisadero Largo Formation is located 8 km west of Mendoza city in mid-western Argentina (Simpson et al. 1962), in an area where strong, mainly Triassic, continental sequences are overlaid by Tertiary and Quaternary sinorogenic sediments in erosive discordance (Fig. 1).

Divisadero Largo Formation was defined by Chiotti (1946) to comprise three levels that were at the time recognized with the informal designations "Conglomerado rojo", "Zona con Anhidrita" and "Arcillas abigarradas" by the petroleum geologists of Yacimientos Petrolíferos Fiscales ("YPF", the governmental oil company). Thus, the lower boundary of this unit was represented by the Triassic Víctor Strata, currently recognized as Río Blanco Formation. The upper boundary was delimited by what Chiotti designated as "Serie de las Areniscas Entrecruzadas" or "Inestratificadas" (currently Mariño Formation). According to its current definition, Divisadero Largo Formation only includes the two upper levels defined by this autor, whereas the lower member (i.e., "Conglomerado rojo") is now recognized as Papagallos Formation (Simpson et al. 1962). At the locality studied, Divisadero Largo Formation is exposed as a NNE-SSO-oriented fringe, approximately 2.2 km long and ranging in width between 160 and 250 meters, that extends from Divisadero Largo hill to the locality of Papagallos.

The fauna exhumed from Divisadero Largo Formation, which was the basis for the Divisaderan

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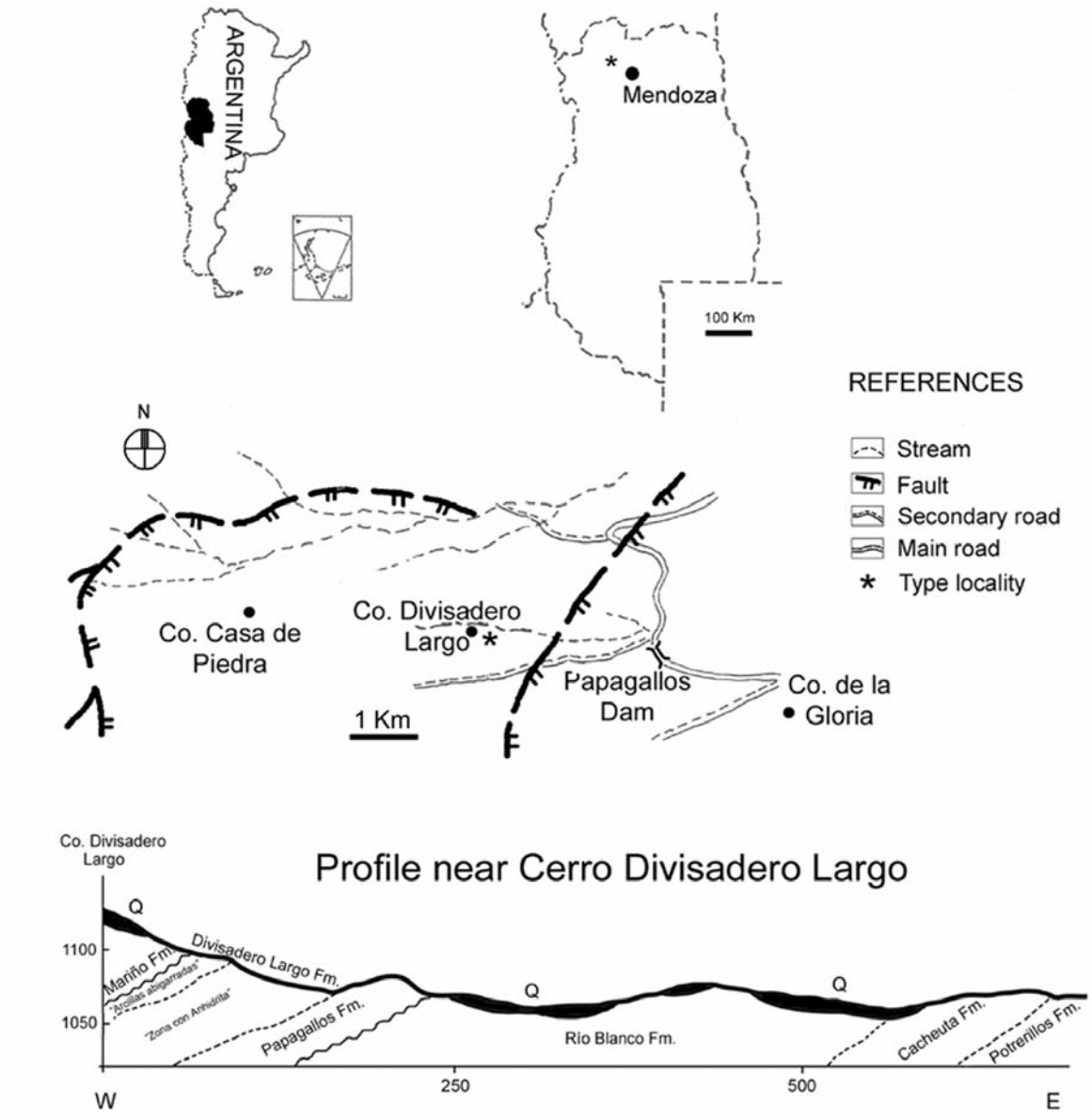

Fig. 1. Location and profile of the Divisadero Largo area (Mendoza, Argentina).

"South American Land Mammal Age" (SALMA), has been defined by Pascual et al. (1965) as an assortment of taxa, some with generalized features (i.e., comparable to "Casamayoran" and Mustersan taxa) and others with much more modern appearance (i.e., comparable to Deseadan and post-Deseadan taxa). It was precisely this peculiar co-occurrence of archaic and advanced types which allowed Pascual et al. (1965) to consider that this fauna corresponded to a different Mammal Age that could partially bridge the gap between the Mustersan and Deseadan Ages. In this context, the Divisaderan SALMA was referred by these authors to the upper Eocene.

Although Simpson et al. (1962: 287) determined that the taxa included in this fauna came from different stratigraphic levels; these authors considered it as a single faunal association on the basis of taxa shared between these levels (e.g., *Brachystephanus postremus* Simpson et al., 1962). Within this fauna *Ethegotherium carettei* Minoprio, 1947 (Notoungu-

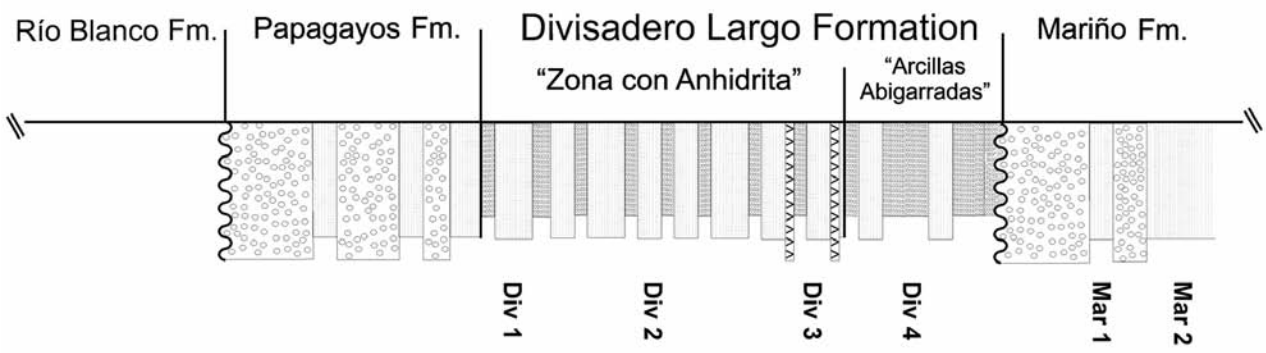

Fig. 2. Generalized stratigraphic section showing relative position of the rock samples. Scale 1:1000.

lata, Hegetotheriidae) and *Trachytherus? mendocensis* Simpson & Minoprio, 1949 (Notoungulata, Mesotheriidae) are the most derived species when compared to the rest of the taxa, because of their hypsodont teeth. The suspicion that one of these species with derived features (i.e. *E. carettei*) could actually come from the overlying Mariño Formation, led us to make petrographic sections of the sediment that bears the type material of this species and from different levels of the Divisadero Largo and Mariño formations. It is noteworthy that the sediment embedding *E. carettei* is well-consolidated red sandstone similar to some levels of the abovementioned formations.

This work presents the results from the petrographic sections and the consequent revision of the stratigraphic provenance of *E. carettei*.

2. Material and methods

The species *Ethegotherium carettei* was established on the basis of a single remain, an almost complete skull preserved within two rock fragments. One of them corresponds to the type (i.e. right side of the skull) published by Minoprio (1947) and Simpson et al. (1962), and was given a collection number from Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" (MACN 16.609), while the left half was designated as "cotype" (Simpson & Minoprio 1949). Both remains, neither of which was ever completely prepared, have preserved bone material or its corresponding natural mold, so that a more or less complete skull outline can be observed in both rock fragments. Currently these two halves of a single individual are deposited in different museums; the

Table 1. Relative abundance of mineral components from a digital point counter (up to 300-point counts).
Abbreviations: MQZ, Monocrystalline quartz. PQZ, Policrystalline quartz. P, Plagioclase. PF, Potassium feldspar. AnVF, Andesitic volcanic rock fragment. C, Chert. AcVF, Acid volcanic rock fragment.

MINERALS SAMPLE	MQZ	PQZ	p	PF	AnVF	C	AcVF	Total points
Sample DIV 1	109	24	98	6	51	12	5	300
Sample DIV 2	92	94	25	49	14	23	3	300
Sample DIV 3	79	53	97	3	29	30	9	300
Sample DIV 4	98	22	107	21	19	2	31	300
Sample MAR 1	93	5	104	17	58	12	11	300
Sample MAR 2	59	12	145	24	31	24	5	300
Sample MACN 16609	61	5	149	19	43	18	5	300

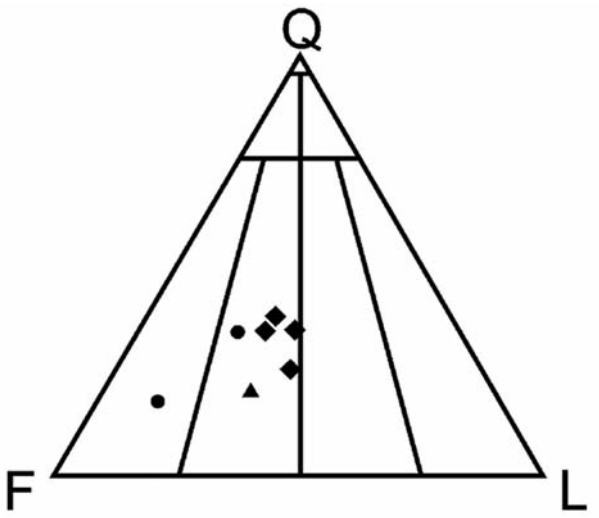

Fig. 3. Quartz-feldspars-lithics diagram showing samples analyzed from the Mariño and Divisadero Largo formations (Folk 1968). *Triangle:* problem sample, MACN 16609; *diamonds:* Divisadero Largo Formation, DIV 1-4; *circles:* Mariño Formation, MAR 1-2.

type is at MACN, whereas the cotype is in the collections of the Museo de Paleontología of Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba (López 2002).

Seven thin rock sections (30 microns thick) were prepared for microscopic examination. One was a sample from the rock bearing the type specimen of *Ethegotherium carettei* (MACN 16609), four were extracted from different stratigraphic levels of Divisadero Largo Formation, representing most of the sequence (*DIV 1, 2, 3 and 4*), and two (*MAR 1 and 2*) were taken from Mariño Formation (Fig. 2). The samples taken from the latter unit correspond to its lower levels only, because the upper section of Mariño Formation is very different from our problematic material in color and appearance.

The sections were studied under petrographic microscope using comparative textural charts to determine their granulometry and roundness. Subsequently, detritic modes were determined by analysis of relative abundance of mineral components using a digital point counter (up to 300-point counts) (Table 1). These data were entered into a compositional QFL (quartz-feldspar-lithics) ternary diagram (Fig. 3).

3. Petrographic description

The sandstones studied under optical microscope present the following general characteristics: fine to medium sand grain size, subrounded to rounded. The composition is feldspathic to lithic-feldspathic with dominant feldspars (oligoclases) and subordinate lithics (andesitic and acid volcanic fragments) and quartz, whereas chert type sedimentary fragments are scarce. The feldspars are fresh and/or altered to sericites.

According to Folk's (1968) classification, these samples fall within the arkose and arkosic litharenite fields, while they correspond to feldspathic-lithic sandstone in Dott's scheme (Dott 1964; see also Limarino et al. 1996; Irigoyen et al. 2002).

3.1. Detailed thin-section descriptions

Sample MACN 16609 (Fig. 4A, B). – Fine to medium sand, 125 to 177 microns, subrounded, very good sorting and scarce matrix, abundant plagioclases in the oligoclase region measured by the Michel-Levy method, and fragments of andesitic volcanic lithics with trachytic texture of oriented and unoriented plagioclases, altered to chlorite. Accessory minerals comprise fresh amphibols denoting volcanic contribution. Prominent presence of calcareous cement. QFL 20-50-30: arkosic-lithic arenite.

Sample MAR 1 (Fig. 4C). – Fine sand, 177 to 250 microns, rounded, good sorting, with dominant feldspars (plagioclases in the oligoclase region) and fragments of andesitic lithics and hornblende indicating volcanic provenance. These appear with oriented and unoriented tabular plagioclases and sedimentary rock fragments with abundant carbonatic cement. QFL 16-73-11: arkosic arenite.

Sample MAR 2 (Fig. 4D). – Fine arenite, 177 to 250 microns, rounded, with good sorting, with dominant zoned microcline feldspars (plagioclases in the oligoclase region), and fragments of lithics and hornblende that appear with plagioclases. Prominent presence of carbonatic cement. QFL 34-44-21: arkosic arenite.

Samples DIV 1-2-3-4 (Fig. 5). – Fine to medium wackes (177 to 250 microns and 250 to 350 microns), rounded, with good to poor sorting, abundant clayish matrix, with dominant feldspars (plagioclases in the

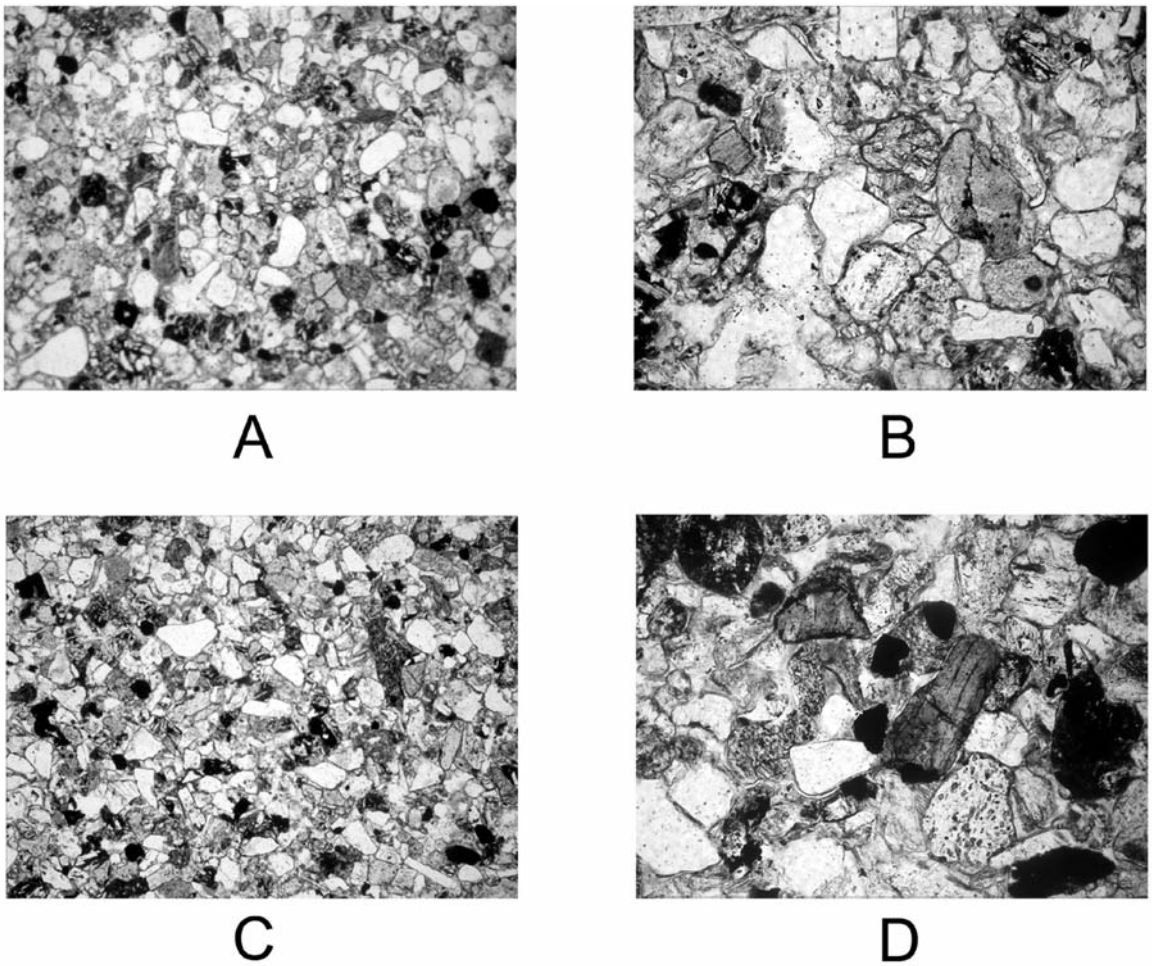

Fig. 4. General view of petrographic sections in plane-light. (A) Close-up detail of quartz and andesitic rock fragments from problem sample, x 40. (B) Close-up detail of altered feldspars and abundant accessory minerals, such as hornblende, from problem sample, x 100. (C) General view of sections from Mariño Formation with abundant hornblende, similar to (B), showing magmatic arc provenance (Dickinson & Suczek 1979), x 40. (D) General view of arenite from Mariño Formation, with green hornblende and feldspars, x 100.

oligoclase region), andesitic lithic fragments and acid volcanic fragments. *DIV 1*: QFL 36-33-50: arkosic-lithic wacke; *DIV 2*: QFL 37-37-26: arkosic-lithic wacke; *DIV 3*: QFL 25-35-40: arkosic-lithic wacke; *DIV 4*: QFL 34-40-26: arkosic-lithic wacke.

4. Discussion

Pascual et al. (1965) considered that the joint occurrence of taxa with generalized characteristics along with clearly more modern forms in a single faunal assemblage allowed distinguishing a different "South American Land Mammal Age", namely the Divisaderan SALMA which could partly fill the gap between the Mustersan and Deseadan SALMAs. These authors referred the new SALMA to the upper Eocene.

The recent discovery of fossil remains of mammals in levels of the Mariño Formation, less than 100 m above the fossil-bearing levels of the Divisaderan fauna (Cerdeño et al. 2006) prompted us to perform this study, which permitted to clarify the stratigraphic provenance of the species *E. carettei*.

On the basis of a relatively complete skull and mandible, Minoprio (1947) described the species *Prohegetotherium carettei* (Notoungulata, Hegeto-

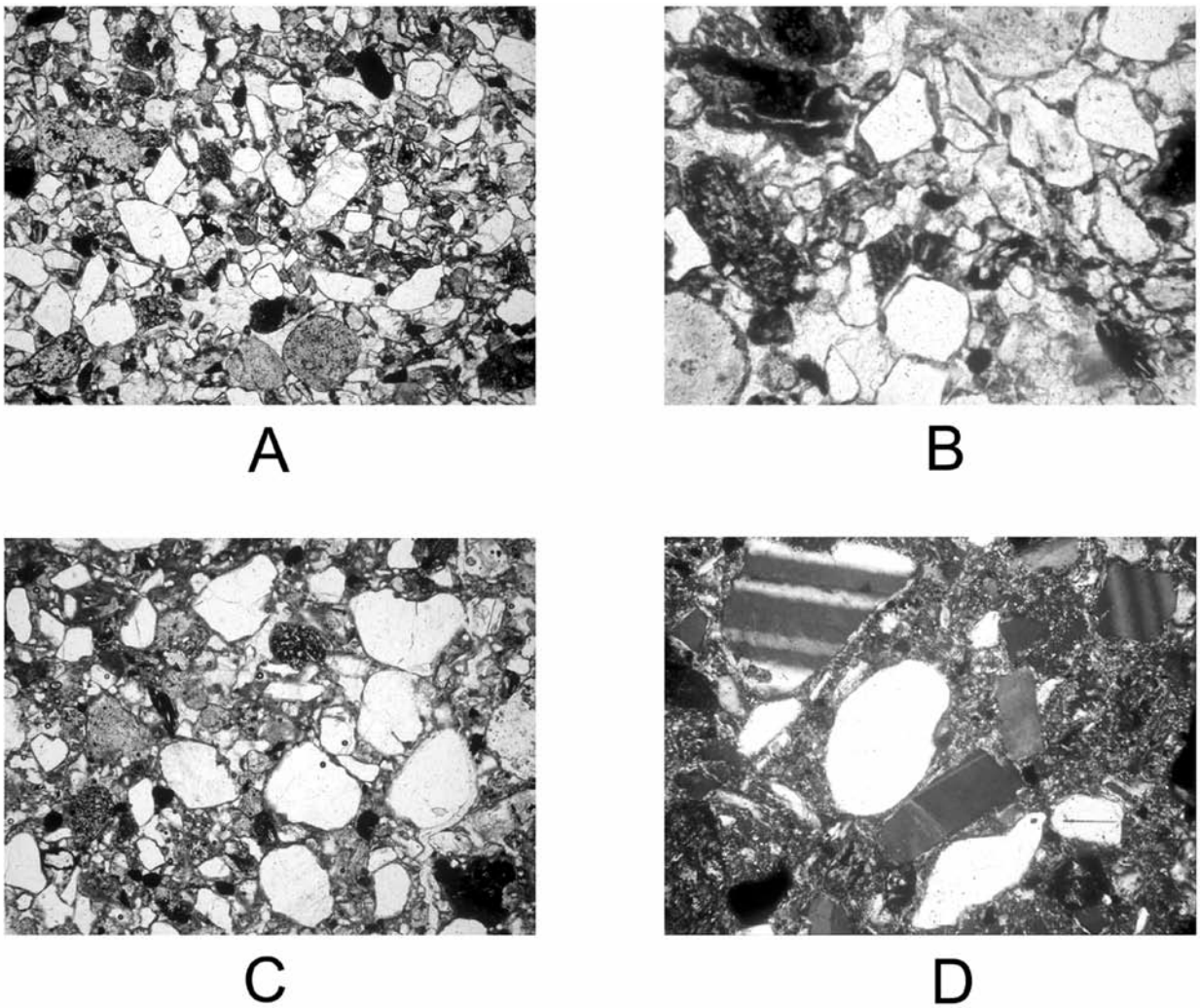

Fig. 5. Close-up view of wackes from Divisadero Largo Formation. (A-B) Quartz, feldspars and rock fragments, (A) x 40 and (B) x 100. (C) Quartz, feldspars and volcanic rock fragments showing volcanic arc provenance, x 100. (D) Quartz and plagioclase with abundant matrix, x 100. (A-C) Under plane light. (D) Under polarized light.

theriidae) along with other fossils from Divisadero Largo Formation. In their comprehensive work about this formation, Simpson et al. (1962: 273) recognized differences at the genus level for this taxon, and established the new combination *Ethegotherium carettei*. López (2002) on the basis of numerous differences (19 as listed), especially the arrangement of cheek teeth enamel, demonstrated that *E. carettei* is a valid taxon and its assignation to a separate genus is justified. Recently, Reguero & Cerdeño (2005) considered *E. carettei* as a junior synonym of *Prohegetotherium schiaffinoi* Kraglievich, 1932, a poorly known species from Fray Bentos Formation in Uruguay and from the Upper Salla Beds in Bolivia.

The family Hegetotheriidae includes small to medium-sized notoungulates whose dentition is characterized by an early gliriform trend, evindeced by the presence of enlarged euhypsodont I1 and i1-2 and evident reduction (absence in advanced forms) of the I2-3, i3, C/c and P1/p1. The upper and lower molariforms are also hypsodont, labially bilobate to trilobate, characteristically imbricated and covered by cement.

Two subfamilies are recognized within this taxon, the Hegetotheriinae with complete dental series and

the Pachyrukhinae with reduced incisors, canines, and even premolars in some genera. The conflictive subfamily Munyiziinae proposed by Simpson (1945) is currently not considered as a valid taxon (Cifelli 1985a, 1993). Mones (1986) listed the species recognized in both subfamilies of Hegetotheriidae.

The species from Divisadero Largo Formation has been considered the oldest record of this family. Records of Hegetotheriidae are relatively frequent in the Deseadan SALMA (Oligocene), and the last representatives occur in sediments of Marplatan (upper Pliocene-lower Pleistocene) age (Cerdeño & Bond 1998).

Because of its very high-crowned teeth, *E. carettei* was one of the elements used to refer the fossil-bearing levels of Divisadero Largo Formation to Deseadan Age (Simpson & Minoprio 1950) or to consider them as "approximately early Deseadan or latest pre?Deseadan" (Simpson et al. 1962: 290). Despite the fact that *E. carettei* could clearly be considered as a more modern species, its stratigraphic provenance was never questioned.

The sandstones studied under optical microscope have the following general characteristics: fine to medium sand grain size, rounded to subrounded, with feldspathic-lithic composition following Folk (1968), with dominant feldspars (oligoclases) and andesitic volcanic fragments; chert type sedimentary fragments are scarce. Other accessory minerals recorded include hornblende (Fig. 4.B), which indicates a nearby volcanic source. The psammites studied in both formational units are texturally and compositionally immature, and their composition is typical of rocks with Andean volcanic contributions, particularly with respect to the acid and andesitic fragments and the fresh accessory minerals. Limarino et al. (1996) have shown that the arenites of Mariño Formation were derived from the Andean magmatic arc, with low compositional and textural maturity.

However, the analysis of the sampled sections clearly shows that the rock that bears the type of *E. carettei* (sample MACN 16609) is very similar to the sandstones from Mariño Formation, with clean texture, scarce matrix, presence of abundant carbonatic cement and accessory minerals that may act as tracers, as in the case of some amphiboles (hornblende). In contrast, the sediments of the entire Divisadero Largo Formation comprise sandstones or wackes, with abundant clayish matrix, greater proportion of acid and andesitic lithics and absence of cement and hornblende.

This analysis strongly supports the assertion that the species *E. carettei* comes from Mariño Formation and not from Divisadero Largo Formation, and therefore does not belong to the Divisaderan fauna.

The Mariño Formation has been traditionally ascribed to the Miocene (e.g., Rusconi 1949; Groeber 1951); Sepúlveda (1999) described some microfloras from Salagasta area and assigned the bearing levels to Late Oligocene-Early Miocene age. Irigoyen et al. (2002) suggested that the deposition of the oldest Mariño Formation spanned 15.7-12.2 Ma. (i.e., middle Miocene) and was associated with a major phase of thrust activity in the Main Andean Cordillera. Nevertheless, in a comprehensive work about Tertiary sinorogenic sediments of Mendoza province, Yrigoyen (1993) suggested that the entire Mariño Formation would correspond to early Oligocene-middle Miocene ages. Recently, Cerdeño et al. (2006) and Cerdeño & Vucetich (2006) have referred these levels to the uppermost lower Miocene based on the findings of mammal remains in basal levels of the middle member ("Areniscas Entrecruzadas") of this formation.

The change of stratigraphic provenance of *E. carettei*, which allows to consider this species as Lower or Middle Miocene in age, is more in agreement with the derived characters of its dentition (e.g. crown height, reduction of enamel cover, simpler molariforms). Furthermore, a younger age would support the distinction of this taxon from the Deseadan genus *Prohegetotherium,* thus rejecting the synonymy proposed by Reguero & Cerdeño (2005).

The mammal remains recovered from Mariño Fm. (i.e. 100 m above the levels bearing the Divisaderan fauna; Cerdeño et al. 2006) include a fragmentary right maxilla with P3-M3 of a small mesotheriid. The morphology of this small-sized taxon resembles that of *Altitypotherium chucalensis* Croft et al., 2004 from Chucal Formation (Chile) (Cerdeño et al. 2005, Cerdeño, in press). However, the preserved M3 is also indistinguishable from the only currently preserved remain of the species *Trachytherus? mendocensis* Simpson & Minoprio, 1949 (the type specimen MHNM-PV 2494 is lost), which was classically considered as coming from the underlying Divisadero Largo Formation found in the same area (Simpson et al. 1962).

If the provenance of the species *Trachytherus? mendocensis* from Mariño Formation is actually confirmed, the change in the stratigraphic provenance of *E. carettei* presented here is of great significance,

because these evidences would strongly question the validity of the Divisaderan Age (Cerdeño et al. 2005). As these two species have largely been considered as derived taxa of the Divisaderan Fauna, the alleged mixture of primitive and modern taxa proposed to support a different SALMA for the post Mustersan-preDeseadan lapse would be nonexistent.

After the exclusion of these elements with advanced characteristics, the age of the Divisaderan fauna still remains to be established. On the basis of its composition, this faunal association shows more affinity with "Casamayoran" Age faunas than with faunas of Mustersan Age. Based on G. G. Simpson's field notes, Cifelli (1985b) recognized two subages for the "Casamayoran" (i.e. Vacan and Barrancan) and remarkably, although these subages are well supported, they are seldom used in practice and the term Casamayoran is still used in many works. Here, we use the term enclosed in quotation marks to denote this situation.

Referral of the fauna from Divisadero Largo Formation to either of these two Casamayoran subages is debatable because there are no shared taxa between them. Nevertheless, it is possible that the Divisaderan fauna is intermediate between these subages and represents a lapse still unidentified in Patagonia.

5. Conclusions

Petrographic study of seven sandstone samples (one of unknown provenance, four from Divisadero Largo Formation and two from Mariño Formation) presented here supports the following conclusions:

(1) The sandstones analyzed are fine- to medium-sand grain sized, rounded to subrounded. The samples from Divisadero Largo Formation may be considered as arkosic wackes and those from Mariño Formation correspond mainly to arkosic lithoarenites.

(2) Both formations include psammites with Andean volcanic contribution associated with andesitic and/or acid fragments and fresh accessory minerals and feldspars.

(3) Divisadero Largo Formation includes feldspars (oligoclases) and abundant andesitic volcanic fragments, as well as acid volcanic fragments in lesser proportion. Quartz and sedimentary lithics are relatively scarce.

(4) The arenites from Mariño Formation contain accessory minerals such as fresh hornblende that indicate a nearby volcanic source.

(5) The problematic sample MACN 16609, by reason of its clean texture and scarce matrix, presence of abundant carbonatic cement and accessory minerals such as abundant hornblende, is very similar to the samples from Mariño Formation, and differs greatly from those corresponding to Divisadero Largo Formation.

(6) This analysis allows to establish that the type material (and only known specimen) of the species *E. carettei* comes from Mariño Formation and not from Divisadero Largo Formation, as has been assumed since the species was erected.

(7) A younger age of E. carettei is more in agreement with the characteristics of its dentition and reasserts the validity of genus *Ethegotherium.*

(8) This change in the stratigraphic provenance of *E. carettei*, coupled with the new remains exhumed from Mariño Formation, strongly challenges the validity of the Divisaderan SALMA.

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