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Approach to the Lower Pliocene marine-continental correlation from southern Spain. The micrommamal site of Alhaurín el Grande-1 (Málaga Basin, Betic Cordillera, Spain)

Aproximación a la correlación marino-continental del Plioceno inferior en el Sur de España. El yacimiento de micromamíferos de Alhaurín el Grande-1 (Cuenca de Málaga, Cordillera Bética, España)

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ABSTRACT

A new micromammal site at Alhaurín el Grande (Málaga, southern Spain) located above early Pliocene marine deposits allows an approach to the marine-continental correlation for this age. The early Pliocene marine filling throughout the Málaga Basin is developed in three transgressive-regressive sequences (Pl-1, Pl-2, and Pl-3 units) bounded by discontinuities. At the top of the intermediate sequence Pl-2, peaty sediments have yielded fossils of Rodentia, Lagomorpha, Insectivora, and Crocodylia. The presence of *Cricetus barrieri* Mein & Michaux, 1970 in combination with murids, both of primitive morphology, such as *Apodemus gudrunae* Van de Weerd, 1976, and more advanced forms (i.e. *Occitanomys brailloni* Michaux, 1969 and *Stephanomys donnezani cordii* Ruiz Bustos, 1986), points to an early Ruscinian age (MN 14 biozone). Based on the planktonic foraminifers, the biostratigraphic data indicate that marine sediments just below the micromammal beds belong to the MPl-2 biozone of the early Zanclean. Available paleomagnetic data from the marine sediments show that the micromammal bed must be located between the normal geomagnetic subchron C3n3n (4.89-4.80 Ma) and the subchron C3n2n (4.63-4.49 Ma), limiting the age of this site to the late part of the early Zanclean.

Keywords: Micromammal, Lower Pliocene, marine-continental correlation, magnetostratigraphy, Betic Cordillera, S Spain.

RESUMEN

Un nuevo yacimiento de micromamíferos en Alhaurín el Grande (Málaga, Sur de España) situado sobre depósitos marinos del Plioceno inferior permite una aproximación a la correlación marino-continental para esa época. El relleno sedimentario marino del Plioceno inferior en el conjunto de la cuenca de Málaga comprende tres secuencias transgresivas-regresivas (unidades Pl-1, Pl-2 y Pl-3) limitadas por discordancias. A techo de la secuencia intermedia Pl-2, sedimentos turbosos han liberado restos de Rodentia, Lagomorpha, Insectivora y Crocodylia. La presencia de *Cricetus barrieri* Mein & Michaux, 1970 en asociación con dos múridos, uno con morfología primitiva (*Apodemus gudrunae* Van de Weerd, 1976) y otros más evolucionados próximo a *Occitanomys brailloni* Michaux, 1969 y *Stephanomys donnezani cordii* Ruiz Bustos, 1986, permiten inferir una edad Rusciniense inferior (biozona MN14). En función de los foraminíferos planctónicos, los datos bioestratigráficos indican que los sedimentos marinos justo por debajo del

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nivel de micromamíferos pertenecen a la biozona MPL-2 del Zancliense inferior. Los datos paleomagnéticos disponibles muestran que el nivel de micromamíferos se localiza entre el subcron geomagnético normal C3n3n (4.89-4.80 Ma) y el subcron C3n2n (4.63-4.49 Ma), limitando la edad del yacimiento a la parte superior del Zancliense inferior.

Palabras clave: Micromamíferos, Plioceno inferior, correlación marino-continental, magnetoestratigrafía, Cordillera Bética, Sur de España.

Introduction

Among the abundant micromammal sites throughout the Iberian Peninsula (Sesé, 1988, 2006; Calvo *et al*., 1993 and references therein), those allowing direct stratigraphic correlations with related marine deposits are rare (Mein *et al*., 1973; Montenat *et al*., 1975; Bruijn *et al*., 1975; Montenat & Bruijn, 1976; Torre, 1987; Agustí *et al*., 1983; Alberdi & Bonadonna, 1987; Aguirre *et al*., 1995; López-Martínez & Peláez-Campomanes, 1999; Martín-Suárez *et al*., 2001; Guerra-Merchán *et al*., 2001, among others). Magnetostratigraphy performed on the sediments containing micromammal remains (Krijgsman, *et al*., 1994, 1996; Garcés *et al*., 1996, 1997, 1998, 2001; Opdyke *et al*., 1997; Sen, 1997; Van Dam *et al*., 2001; Agustí *et al*., 2001, among others) constrains the chronostratigraphic framework, which facilitates the correlation between the marine and continental scales.

Málaga Basin is an intramountain depression that developed in the central sector of the Betic Internal Zones (Fig. 1A). In this basin, excavations within the limits of Alhaurín el Grande village exposed peaty beds (labelled as Alhaurín el Grande-1 site; 36º 38’ 22,26’’ N, 4º 41’ 07,24’’ W) containing continental microfossils, which were located stratigraphically between marine sediments. Thus, the micromammal assemblages found at this site provide a biostratigraphic signal of the continental sedimentary record, allowing correlation with related marine sequences that bear planktonic foraminifera. This correlation is strengthened by paleomagnetic data from marine deposits below and above the studied site. In addition, the results derived from the study provide knowledge concerning the sedimentary and paleoenvironmental evolution of the basin.

Geologic setting and stratigraphy

The Neogene Málaga Basin developed on the Internal Zone of the Betic Cordillera during the postorogenic stage. The sedimentary filling comprises mainly Late Miocene and Early Pliocene marine deposits covered by Quaternary continental sediments (Fig. 1B and C). These postorogenic sediments rest unconformably on a substratum comprising rocks of the tectonically stacked Alpujarride, Malaguide, and Campo de Gibraltar Flysch complexes, and locally a post-nappe intraorogenic cover composed of Oligocene-Early Miocene deposits of the Ciudad Granada- and Viñuela-like formations, i.e. Alozaina and Las Millanas Fms, respectively (Bourgois *et al*., 1972a, 1972b; Sanz de Galdeano & López Garrido, 1991; Serrano *et al*., 2006).

The upper Miocene sediments comprise two units. The lower unit is Tortonian in age and consists of conglomerates, sands, and calcarenites deposited in fan deltas, beaches and sea cliffs, as observed from the main outcrops located in Álora, Pizarra, and SE Cártama (Fig. 1B). Outcrops of the upper unit have been noted only in the northeastern part of the basin, near the city of Málaga, and consist of conglomerates, sands and pelites deposited in alluvial and brackish environments. They provide oligohalyne ostracods and mollusks of Paratethys origin, characterizing the Lago-Mare type facies deposited in the Mediterranean during the latest Messinian at the end of the salinity crisis (Guerra-Merchán *et al*., 2008, 2010).

At the beginning of the Pliocene, open marine conditions were reestablished in the Málaga Basin at the same time as in the whole Mediterranean. The lower Pliocene sediments (Fig. 1C) comprises three units bounded by discontinuities (so-called Pl-1, Pl-2, and Pl-3; Guerra-Merchán *et al*., 2000). The Pl-1 unit represents a 30 m thick transgressive sequence consisting of conglomerates with marine mollusk fauna gradually changing upwards to gray and greenish silts and white marls rich in foraminifers.

The Pl-2 unit is represented on the margins of the basin by deltaic and littoral conglomerates, changing distally and vertically to clays and marls rich in benthic and planktonic foraminifers and sometimes bearing abundant pectinids; noteworthy among these is

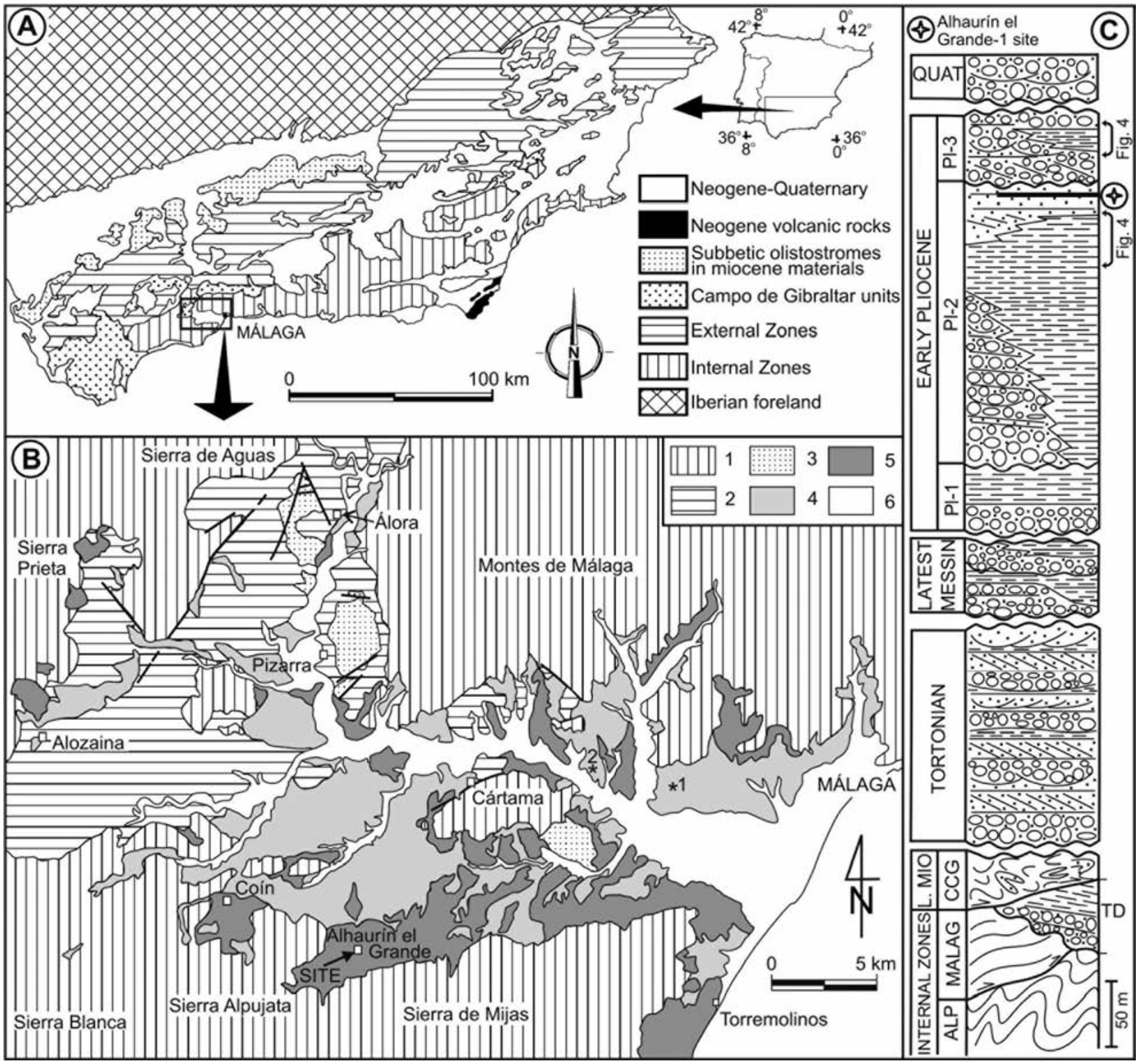

Fig. 1.— (A) Location of the region of Málaga within the Betic Cordillera. (B) Geological scheme of the Málaga Basin. (1) Internal Zones (Alpujarride and Malaguide complexes); (2) Flysch units of the Campo de Gibraltar Complex (C.C.G.) and Oligocene-early Miocene transgressive deposits over Internal Zones (T.D.); (3) Tortonian; (4) Early Pliocene; (5) Pleistocene; (6) Holocene fluvial deposits. (C) Synthetic lithological column of the sedimentary filling in the Málaga Basin. *1: Cercampa quarry outcrop (Pl-2 unit); *2: Cártama highway outcrop (Pl-3 unit). Slightly modified from Guerra-Merchán *et al.*, (2010).

the presence of large, non-fragmented *Amusium cristatum* (Bronn, 1827). The higher part of this unit is composed of sands deposited in a shallow shelf. This unit represents a transgressive-regressive cycle in which sediments over 500 m thick accumulated in the depocentre of the basin, at the same time as the marine deposition reached its maximum extension in the basin. The Alhaurín el Grande-1 site is located at the top of this unit (Fig. 1C). Figure 2 shows the stratigraphic log of the outcrop where the site is located and the fossil assemblage. This site marks the change from shallow marine to continental environment, as a result of the regressive phase during the deposition of the upper part of the PI-2 unit (Insua Arévalo, 2008).

After a phase of slight deformation and of erosion, the Pl-3 unit was deposited throughout a new transgressive-regressive cycle. This unit (40-50 m

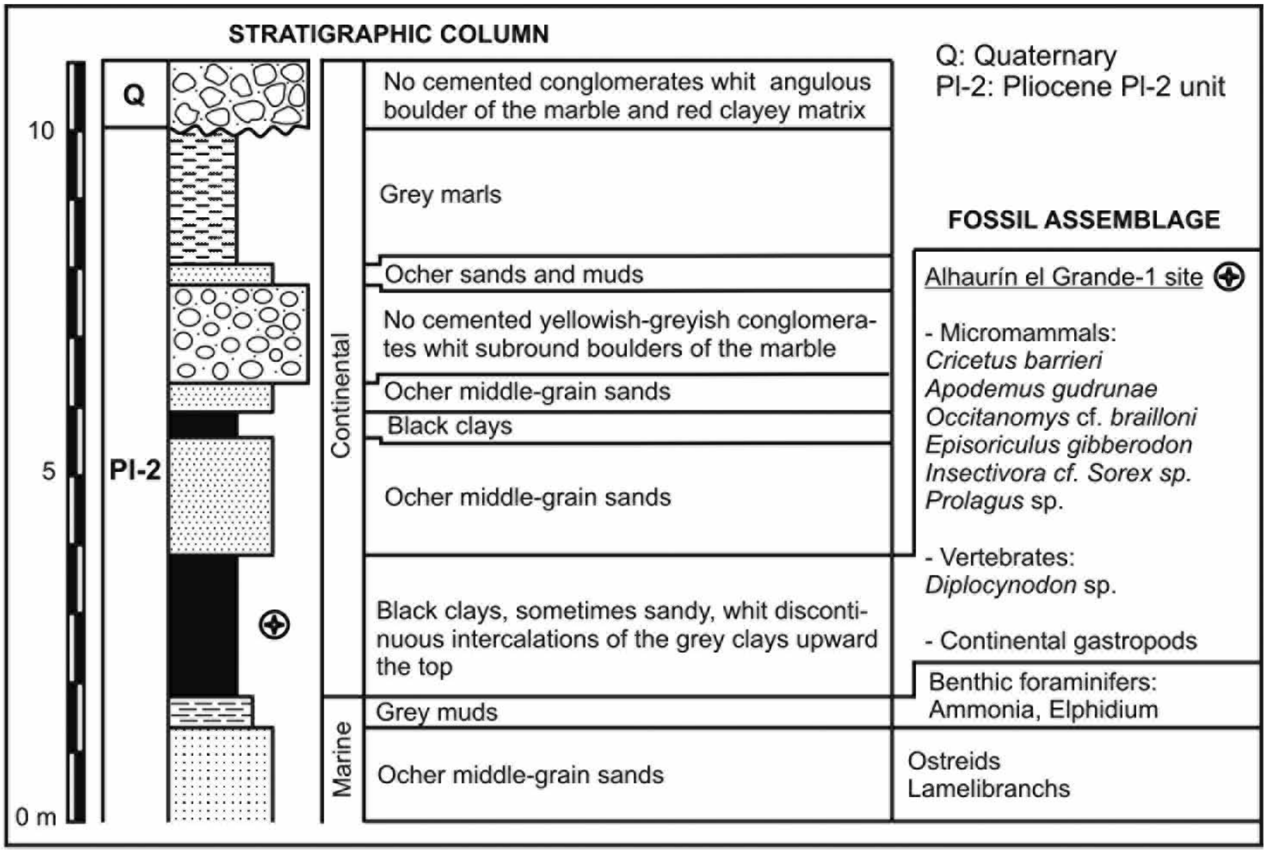

Fig. 2. — Stratigraphic column of the outcrop where the Alhaurín el Grande-1 site is located and fossil assemblages.

thick) is made up at the base by alluvial and deltaic conglomerates, changing distally and vertically to shallow marine sandy pelites which are overlain by coastal and deltaic conglomerates.

No sediments dated from late Pliocene are been recorded in the Málaga Basin.

Pleistocene conglomerates and sands from alluvial fans passing distally to broad floodplains cover by means of erosive surfaces the Pl-2 and Pl-3 deposits. Locally, into the southern margin of the basin, travertine patches grew at areas where waters rich in carbonate from the marbles of Sierra de Mijas drained.

Results

Paleontological data

The paleontological study is focused in both, the analysis of the assemblages of micromammals from the Alhaurín el Grande-1 site, and in that of the planktonic foraminifera from the three consecutive units of the early Pliocene (Pl-1, Pl-2 and Pl-3).

The planktonic foraminifer assemblages of the Pl-1 unit are usually dominated by *Globigerinoides* (mainly G. *extremus* Bolli & Bermúdez, 1965). On the contrary, the presence of *Globorotalia margaritae* Bolli & Bermúdez, 1965 is very sporadic and, towards the top of the unit, specimens of *Sphaeroidinellopsis* frequently appear. Also, it is noteworthy that, in some beds, predominantly left-coiled *Neogloboquadrina* specimens appear.

In the lower part of the Pl-2 unit, the planktonic foraminifera are similar to those of the previous unit, although they show more diversified assemblages (Fig. 4). Towards the middle-upper part, G. *margaritae* appears more frequently where the planktonic foraminifera are abundant, while *Neogloboquadrina* shows very predominantly right coiling.

The peaty sediments from the Alhaurín el Grande-1 site (Fig. 3A) at the top of the Pl-2 have yielded remains of continental microfauna (Fig. 3 and Table 1) made up mainly by Rodentia, where

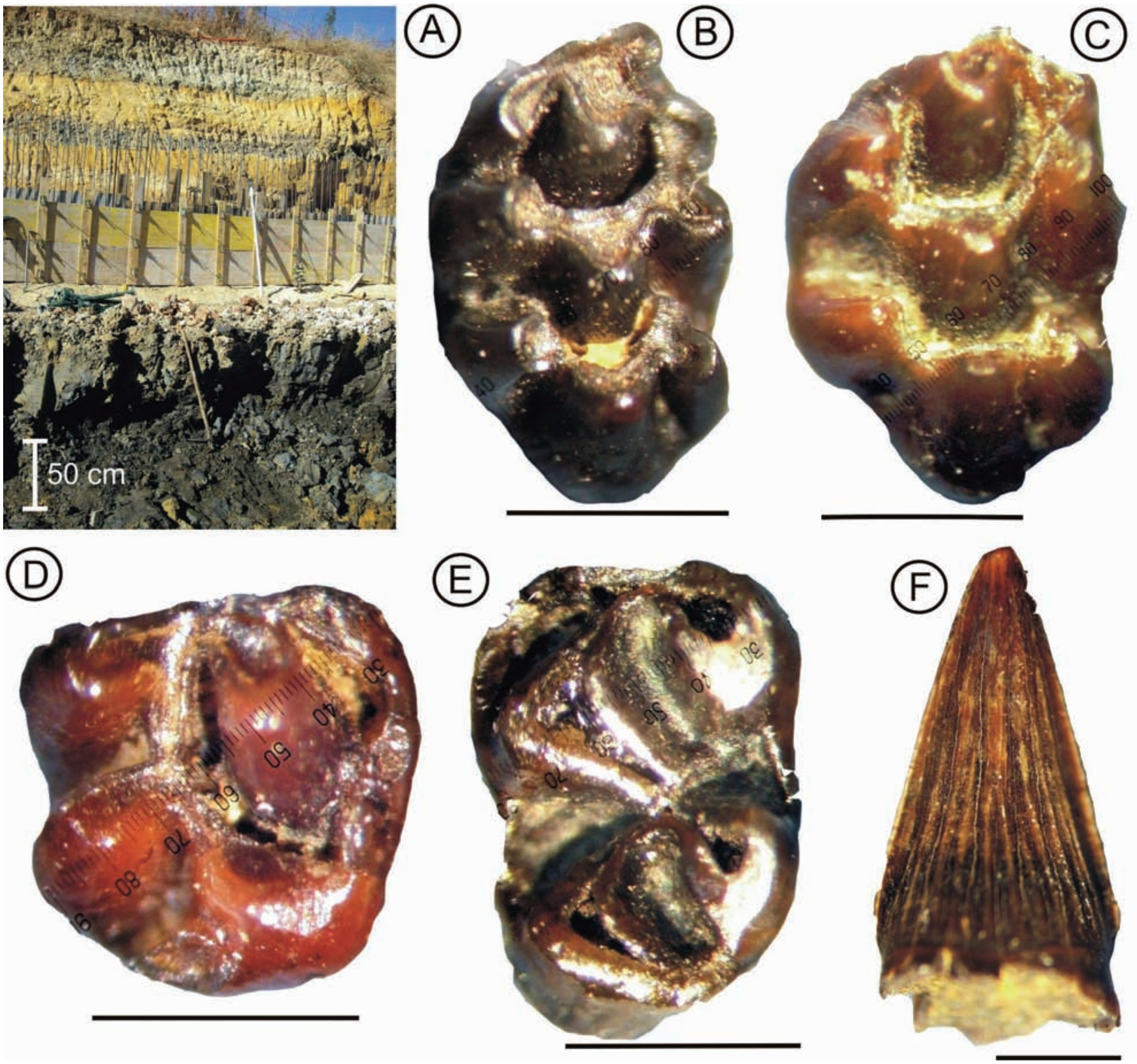

Fig. 3. — Micromammal assemblage of the Alhaurín el Grande-1 site. (A) Photo of the Alhaurín el Grande-1 site; (B) *Apodemus gudrunae* (Right M1); (C) *Occitanomys cf. brailloni* (Right M1); (D) *Stephanomys donnezani cordii* (Right m2); (E) *Cricetus barrieri* (Left *m3); (F) Diplocynodon* sp. The scale bar equals 1 mm.

muriids predominate with *Apodemus gudrunae* Van de Weerd, 1976 (Fig. 3B; specimen AG 97, right), *Occitanomys* cf. *brailloni* Michaux, 1969 (Fig. 3C; specimen AG 94, right), and *Stephanomys donnezani cordii* Ruiz Bustos, 1986 (Fig. 3D; specimen AG 98, right); the cricetiid *Cricetus barrieri* Mein & Michaux, 1970 (Fig. 3E; specimen AG 108, left) is also present. In addition, the Lagomorpha Prolagus sp., the Insectivora *Episoriculus gibberodon* (Petenyi, 1864) and cf. Sorex, and the Crocodilia *Diplocynodon* sp. (Fig. 3F; specimen AG 169) were recognized. The collected fauna is deposited at the Instituto Andaluz de Ciencias de la Tierra, CSIC-Universidad de Granada (Spain).

In the sediments of the Pl-3 unit, benthic foraminifers are strongly predominant, but the rare planktonic ones constitute assemblages similar to those of the previous unit, with *Neogloboquadrina* right-coiling and G. *margaritae* appearing in some beds (Fig. 4).

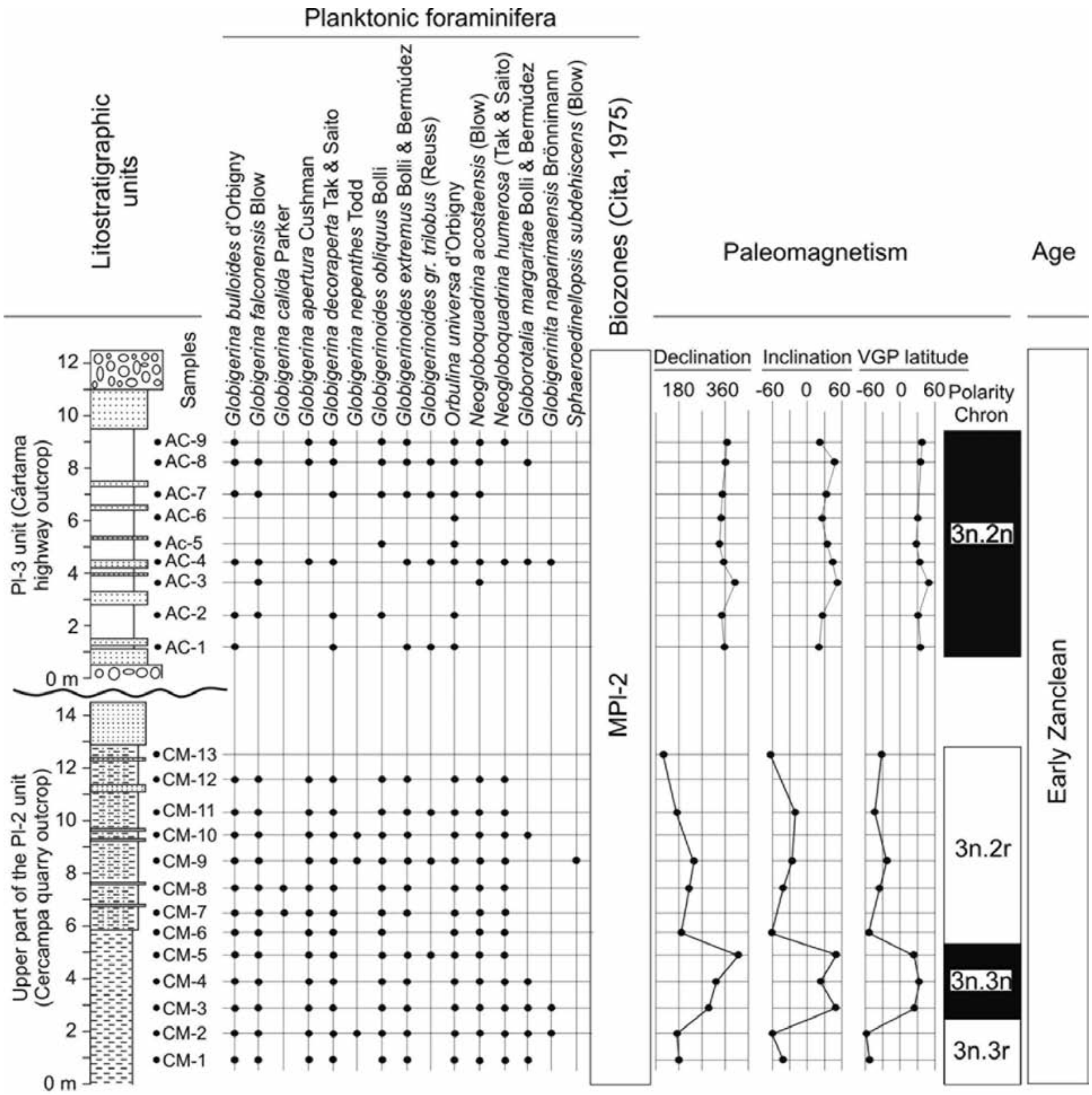

Fig. 4. — Planktonic foraminifer assemblages and results of magnetic polarity and declination/inclination for the lower Pliocene Pl-2 and Pl-3 units (see stratigraphic location of the studied sections in Fig. 1C). In the polarity column, the white interval denotes reversed polarity while the black interval denotes normal polarity.

Paleomagnetic data

Magnetostratigraphic data from Pl-1 are available from an earlier work (Guerra-Merchán *et al*., 2010) showing that the unit is composed of a single reversed magnetozone. On the contrary, new data from the upper part of the Pl-2 and Pl-3 units are provided in the present study.

The Pl-2 unit was sampled throughout an interval of about 12 m below the upper regressive sandy facies in the Cercampa quarry outcrop (36º 42' 39,43'' N, 4º 31' 18,75'' W; Figs. 1 and 4). Thirteen cylindrical samples were taken using an electrical drill and oriented *in situ* with a sun compass. Sampled lithologies, consisting of gray marls and sandy marls, were subjected to stepwise ther-

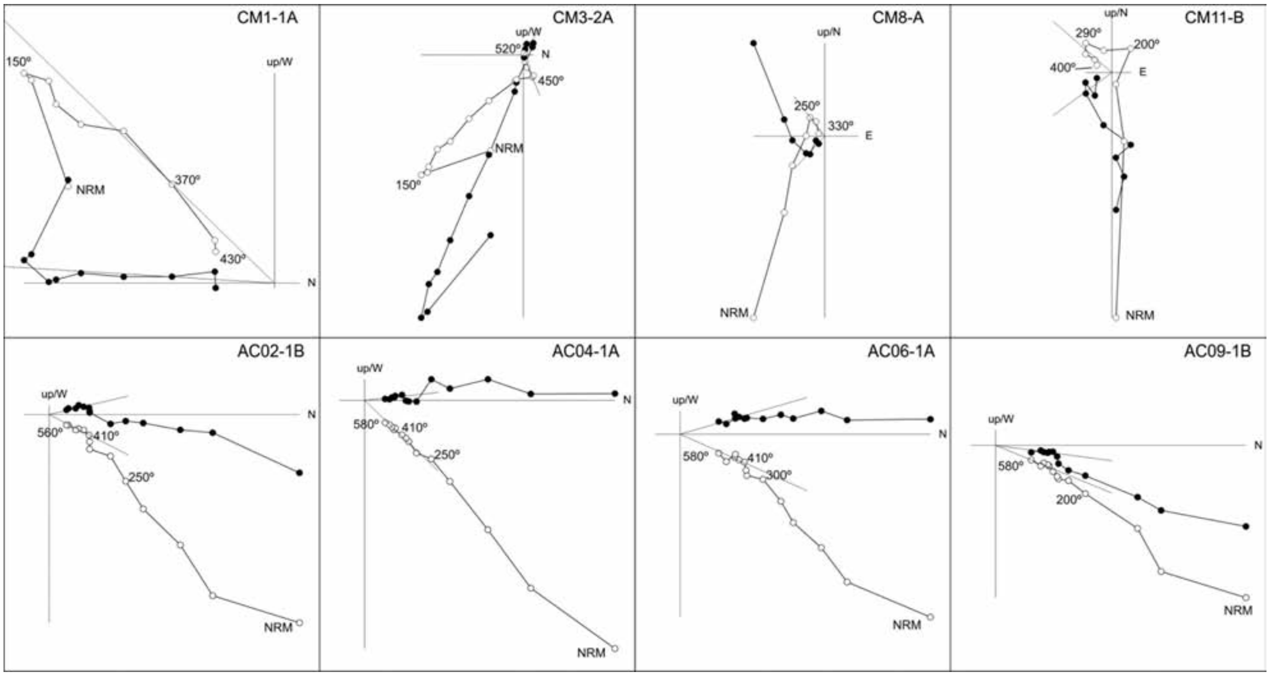

Fig. 5. — Stepwise thermal demagnetization results of representative paleomagnetic samples (see stratigraphic location of samples in Fig. 4). Data presented in vector endpoint diagrams in stratigraphic coordinates (no bedding correction required).

mal demagnetization in order to isolate the contributing components to the natural remanent magnetization (NRM). A characteristic remanent magnetization (ChRM) was isolated at variable temperatures ranging from 150-450 ºC to 330-520 ºC (Fig. 5). The intensity of the ChRM component averaged 0.217 mA/m and a mean direction of 005/52 (k: 6, α_{95}: 21).

Inside the Pl-3 unit, nine samples were taken along a succession (12 m thick) of red pelites and sandy pelites in the Cártama highway outcrop (36º 43' 10,23'' N, 4º 34' 06,27'' W; Figs. 1 and 4). The NRM was markedly intense, with average values of 6 mA/m. After thermal demagnetization, the ChRM components were determined (Fig. 5), with a temperature range between 410 ºC and 580 ºC, and an average intensity of 1.3 mA/m. All samples provided normal polarity directions, with a mean direction of 355.9 / 35.0 (dec/inc), k: 21.4 and α_{95}: 11.4.

The magnetic polarity of the study sites was determined after the calculation of the corresponding virtual geomagnetic pole (VGP) latitude, revealing three magnetic polarity zones in section PL-2 and a single normal polarity zone in section PL-3 (Fig. 4).

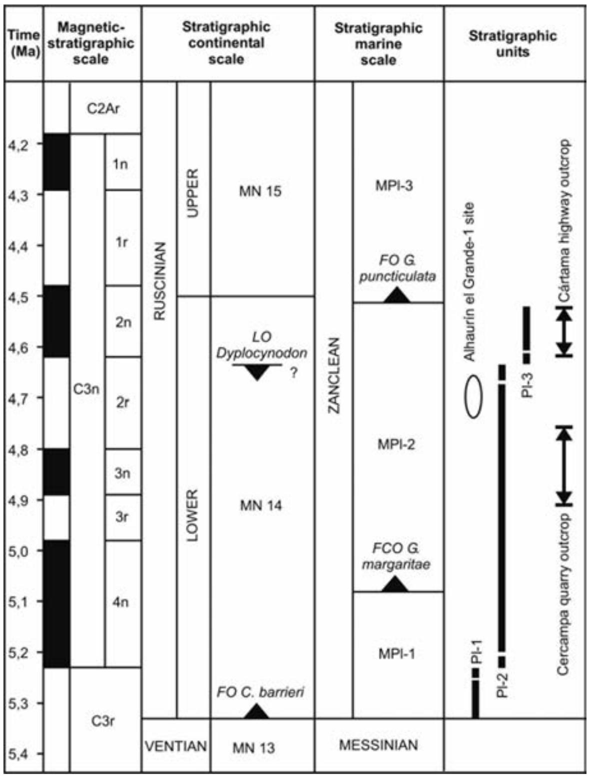

Fig. 6. — Chronology and correlation of the Alhaurín el Grande-1 site.

Table 1.—**Taxonomy and dental material (measures in mm) of the micropaleontological remains provided by the Alhaurín el Grande-1 site.**

RODENTIA Bodwich, 1821		
MURIDAE Illiger, 1811		
Apodemus gudrunae Van de Weerd, 1976	M1	2.10x1.40 (Fig. 3B)
		2.21x1.42
	M2	1.39x1.35
	M1	2.04x1.19
Occitanomys cf. *brailloni* Michaux, 1969	M1	2.30x1.61 (Fig. 3C)
		2.38x1.59
		2.21x1.61
	M2	1.51x1.47
		1.56x1.50
		1.49x1.45
	m1	1.77x1.23
		2.07x1.38
		2.02x1.35
		1.80x1.20
	m2	1.36x1.32
		1.42x1.27
		1.49x1.30
Stephanomys donnezani cordii Ruiz Bustos, 1986	m2	1.53x1.47 (Fig. 3D)
CRICETIDAE Rochebrune, 1883		
Cricetus barrieri Mein y Michaux, 1970	m3	2.55x1.44 (Fig. 3E)
LAGOMORPHA Brandt, 1855		
OCHOTONIDAE Thomas, 1975		
Prolagus sp.	P2	1.27x2.20
INSECTIVORA Bowdich, 1821		
SORICIDAE Gray, 1821		
Episoriculus gibberodon (Petenyi, 1864)	m2	1.36x0.78
	m3	1.10x0.52
Insectivora cf. *Sorex sp.*	M2	0.78x1.76
CROCODILIA Owen, 1842		
ALLIGATORIDAE Gray, 1844		
Diplocynodon sp.		3.26x1.27 (Fig. 3F)

Discussion and conclusions

Ruiz Bustos (2011) established for the Betic Cordillera, the "Biostratigraphic Scale Ruiz Bustos-90/2010" based on an integral system formed by data of the Bioecozonation Matrix. Bio-stratigraphic data obtained in the Betic basins were incorporated to the standard European biostratigraphy. The following steps were considered for the establishing the integral system:

(1) A model of the Betic Lacustrine Stages, based on the observation of the sequence of strata in the Betic intramountain basins, where fluvial detrital sediments alternate with lacustrine ones (chemical precipitation), in which fossil mammal bearing sites are located.

(2) Biozonemarks (SI) corresponding to morphochrons within the biozones, based on the morphologic evolution and size of the mammal molars from the sediments of the Betic intramountain basins.

(3) Palaeoecological data provided by the biocenograms, developed with the mammalian record from each biozonemark.

The "Biostratigraphic Scale Ruiz Bustos-90/2010" shows the following sequence for the lower Ruscinian sites:

- Biozonemark SI14-1. Sites: Cuzo-1, Cuzo-2 and Cuzo 3 (Guerra-Merchán and Ruiz Bustos, 1991), Bacochas (Alonso Diago, 1989; Sesé, 1989) and Caravaca-1 (Bruijn 1974, Bruijn *et al*., 1975).
- Biozonemark SI14-2. Sites: Fayona (Alfaro *et al*., 1995), Gorafe-A (Ruiz Bustos *et al*., 1984), Gorafe-1 (Bruijn, 1974) and Colorado-2 (Guerra-Merchán *et al*., 1991).
- Biozonemark SI14-3. Sites: Aljibe-2 (Guerra-Merchán *et al*., 1991), Aljibe-3 (Guerra-Merchán *et al*., 1991) and Yeguas (Soria Mingorance and Ruiz Bustos, 1991).
- Biozonemark SI14-4. Sites: Rambla del Conejo (Alonso Diago, 1989; Sesé, 1989), Gorafe-3 and Gorafe-4 (Agustí and Martín Suárez, 1984; Agustí, 1986; Martín Suárez, 1988; Gibert *et al*. 1994).
- Biozonemarks SI14-15. Site: Gorafe-2 (Bruijn, 1974).

Regarding the micromammal material yielded by the study site, the presence of *Cricetus barrieri* (Fig. 3E) has been used to characterize a Pliocene age in the Betic Cordillera (Ruiz Bustos, 1990, 1992; Sesé *et al*., 2001). In addition, the presence of primitive muriids such as *Apodemus gudrunae* (Fig. 3B) and evolved ones such as the small-sized *Occitanomys* cf. *brailloni* (Fig. 3C) points to a Ruscinian age (biozonemark SI14-4) for the Alhaurín el Grande-1 site.

From a paleoecological standpoint, the presence of the crocodile *Diplocynodon* (Fig. 3F) suggests a warm and eutrophic lacustrine environment. It is noteworthy that this site would be the youngest site of those described in the Betic Cordillera where this crocodile appears.

The planktonic foraminifer data from the Pl-1 unit and the recognition of the first common occurrence (FCO) of G. *margaritae* in the overlying Pl-2 unit, suggest that the former unit should belong to the earliest Zanclean MPL-1 biozone (Cita, 1975; Iaccarino *et al*., 2007). The zonal marker *Sphaeroidinellopsis*, as pointed out from Iaccarino (1985), is not always frequent, often being absent at the base of the zone. Given that the magnetostratigraphy of Pl-1 unit is made of a single reversed magnetozone (Guerra-Merchán *et al*., 2010), the combination of both data suggest that the age of this unit could be restricted to the lower part of the MPL-1 biozone, before the start of normal geomagnetic subchron C3n4n (5.23 Ma, Cande and Kent, 1995). This would mean that the Pl-1 unit was deposited within the first 100,000 years of the Pliocene (Fig. 6).

The assemblages of planktonic foraminifera from Pl-2 unit characterize the final part of the MPL-1 and the MPL-2 biozones. It should be emphasized that in this unit, we did not detect the presence of *Globorotalia puncticulata* (Deshayes, 1832), a marker species that usually appears in abundance from the level of first occurrence (FO). This leads us to assign the entire Pl-2 unit to the early Zanclean. The paleomagnetic data reveal three magnetic polarity zones in this unit correlating most likely with chrons C3n.3r, C3n.3n, and C3n.2r, in accordance with its correspondence with the MP1-2 biozone of G. *margaritae* (Fig. 4 y 6).

Likewise, we did not detect, either, the appearance of G. *puncticulata* in the Pl-3 unit, indicating that it still belongs to the MPL-2 biozone of the early Zanclean. Integration of these results with the paleomagnetic data indicates that the PL-3 unit was deposited during the subchron C3n2n, with an age between 4.63 and 4.49 Ma. Since the FO of G. *punticulata* (4.51 Ma, Hilgen, 1991; Sprovieri, 1993, Scott *et al*., 2007) is not recorded within this unit, deposition of the Pl-3 is inferred to range between 4.63 and 4.51 Ma (Fig. 6).

In order to establish the marine-continental correlation based on the study of the Alhaurín el Grande-1 site, the following features should be taken into account: (a) the study site is located at the top of the Pl-2 unit, (b) the biostratigraphic data place the boundary between Pl-2 and Pl-3 units towards the upper part of the MPL-2 biozone at the lower Pliocene, before the appearance of G. *punticulata*, (4.51 Ma, Hilgen, 1991; Sprovieri, 1993; Scott *et al*., 2007), and (c) the paleomagnetic data from the marine sediments of the Pl-2 and Pl-3 units show that the micromammal site must be located between the normal geomagnetic subchron C3n3n (4.89-4.80 Ma) and the subchron C3n2n (4.63-4.49 Ma).

Based on the above, the Alhaurín el Grande-1 site, correlating with the upper part of the MPL-2 biozone of planktonic foraminifera, dates approximately around 4.65-4.75 Ma (Fig. 6). The age proposed for this site is consistent with marine-continental correlation of European mammal units made by Steininger *et al*. (1996), who located the limit between zone MN14/MN15 at 4.2 Ma. Thus, the study site could be slightly younger than the Fuente del Viso site (Teruel basin), in which *C. barrieri* and *E. gibberodon* appear jointly also (Opdyke *et al*., 1997), and it is located within the Chron C3n.3r, at 4.9 Ma (Agustí *et al*., 2001).

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