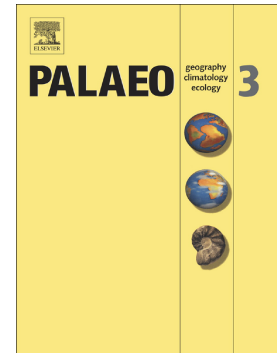


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EARLY PLIOCENE CONTINENTAL VERTEBRATE FAUNA AT PUERTO DE LA CADENA (SE SPAIN) AND ITS BEARING ON THE MARINE-CONTINENTAL CORRELATION OF THE LATE NEOGENE OF EASTERN BETICS

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ABSTRACT

In this paper, we synthesize sedimentological, magnetostratigraphic and paleontological data from the continental vertebrate site of Puerto de la Cadena (Murcia, SE Spain), in order to clarify its age. The study site is located on the northern edge of the Carrascoy

mountain range, in the upper part of the Cigarrón Unit. The end-Messinian discontinuity has been detected at the base of this unit, which indicates it has an early Pliocene age. Abundant remains of small and large vertebrates, including rodents, lagomorphs, primates, carnivorans, perissodactyls, artiodactyls, proboscideans, testudines, squamats, and crocodiles, have been found in this area. Some of these elements are of African origin, such as *Debruijnimys* sp., *Macaca* sp., and *Sivatherium* cf. *hendeyi*, and their presence is related to the Messinian Salinity Crisis. In addition, remains found at this site verify the persistence of Crocodylia in the European record beyond the late Miocene. The association includes typical elements of the early Ruscinian terrestrial record (MN14), like *Apocricetus* cf. *barrierei*, *Sivatherium*, *Gazella* aff. *baturra*, and *Hipparion fissurae*. The Puerto de la Cadena site is located in a reversed geomagnetic chron that has been correlated with C3n.3r (from 4.997 to 4.896 Ma). According to this correlation, the MN13/MN14 boundary has a minimum age of 4.9 Ma.

Keywords: Messinian Salinity Crisis, biostratigraphy, mammals, reptiles, magnetostratigraphy, Iberian Peninsula.

1. Introduction

The importance of the newly discovered site of Puerto de la Cadena lies in its great abundance and diversity of fossil vertebrate remains, as the large mammal association is novel for the Spanish fossil record of the Miocene/Pliocene boundary. In fact, contemporary large-vertebrate sites are scarce in the Iberian Peninsula, which makes Puerto de la Cadena a reference locality.

The area of Puerto de la Cadena has a rich paleontological record, known since the early 1970s (Montenat and Crusafont, 1970; Montenat, 1973; Mein et al., 1973). The sites of La Alberca and La Paloma stand out among the sites with continental vertebrate remains as they were identified during the first geological study in the area (Montenat and Crusafont, 1970). Aguirre et al. (1974) and Bruijn et al. (1975) established a late Miocene age for these localities by correlating them to the site of El Arquillo (Teruel, Spain). La Alberca yielded an important fossil assemblage, being Montenat (1973) the first to report its faunal list, which has been subsequently revised and updated (Morales, 1984; López Martínez, 1989; Freudenthal et al., 1998; Pérez-García et al., 2011): *Cricetus kormosi* (= *Apocricetus alberti*), *Stephanomys medius* (= *Stephanomys dubari*, *Stephanomys cordii*), *Ruscinomys lasallei*, *Paraethomys miocaenicus* (= *Paraethomys meini*), *Castillomys* sp., *Eliomys* sp., *Hispanolagus crusafonti* (= *Trischizolagus crusafonti*), *Prolagus michauxi*, *Percrocuta minor*, *Plioviverrops guerini*, *Hipparion concudense*, *Dicerorhinus schleiermachersi*, *Birgerbohlinia* sp., Cervidae indet., Bovidae indet., *Titanochelon* cf. *bolivari*, and Trionychinae indet. The La Paloma site has only yielded two taxa (Montenat and Crusafont, 1970): Cervidae indet., and *Decennatherium pachecoi*. Based on the faunal assemblage, these localities were correlated with the MN13 unit (Aguirre et al., 1976; Morales, 1984), and more recently with the Ventian land mammal age (latest Miocene/earliest Pliocene; Morales et al., 2013).

Besides the giant tortoise shell from the locality of La Alberca (here reassigned to *Titanochelon* sp.), additional specimens have been recovered from the vicinity of Puerto de la Cadena. This is the case of the unpublished, more-incomplete shell remains found at the Autovía site (Murelaga et al., 2007), which could belong to the same taxon. Another example is the carapace of an adult specimen from Barranco del Cigarrón

(located to the west of the Puerto de la Cadena site), which Mancheño et al. (2001) reported and preliminary assigned to '*Testudo*' *bolivari*. This taxonomic ascription is not supported here, thus we consider the presence of a second synchronous testudinid from Barranco del Cigarrón (see Supplementary Information).

From the stratigraphical and sedimentological points of view, the fossil remains recovered from the Puerto de la Cadena area come from roughly equivalent levels to those of Autovía and Barranco del Cigarrón, and were deposited under similar depositional environments (Murelaga et al., 2007; Romero and Fierro, 2010). Even though the area of Puerto de la Cadena is very rich in continental vertebrate remains, none of these outcrops has been hitherto accurately dated. The aim of the present paper is to provide taxonomic attributions for the vertebrate fauna recovered from Puerto de la Cadena, as well as to accurately date this site based on a synthesis of geological, magnetostratigraphic and paleontological data.

2. Geological setting

The Neogene outcrop of Puerto de la Cadena (Murcia Region, SE Spain) is located 8 km SSW of the town of Murcia, and 2.5 km south of El Palmar, on the northern flank of the Carrascoy range mountain (Fig. 1). The location coordinates are 37° 55' 9" N, 1° 9' 41" W, with an altitude of 160 m AMSL. This site was discovered in 2008 as a result of the construction of the MU-31 motorway in the vicinity of Puerto de la Cadena, which is an open natural pass between the mountains of Carrascoy and Cresta del Gallo, connecting the cities of Murcia and Cartagena.

Some geological units with great lateral continuity are located in Puerto de la Cadena

area, and their position is influenced by the neotectonic activity. In 2008, the construction works of the MU-31 motorway began to affect some of these units, which led to the recovery of large vertebrate remains.

2.1. Regional context

One of the best sites for describing the Neogene stratigraphic record on the northern side of the Carrascoy mountain range is Barranco del Cigarrón, where we have documented a stratigraphic succession that includes at least five lithostratigraphic units (Figs. 1-2). The lower three units are clearly recognizable and equivalent to those described in the Bajo Segura Basin: Columbares Formation, Torremendo Formation and La Virgen Formation (Montenat, 1990; Soria et al. 2008). The two uppermost units, identified here as Cigarrón Unit and La Paloma Unit, have not been previously described.

The fossiliferous outcrop of Puerto de la Cadena is located on the upper part of the Cigarrón Unit, which might be the lateral equivalent to the Rojas and Variegated Marl formations of Montenat (1977), both early Pliocene in age (Soria et al., 2008). On the north side of the Carrascoy range, Montenat (1977) described these units as composed of marls and gray calcareous sands, with conglomeratic levels, cross stratification and reactivation surfaces. He further reported the presence of bone debris in yellow sandy outcrops (such as at the La Alberca and La Paloma paleontological sites).

The lower stratigraphic boundary of the Cigarrón Unit, which hosts the Puerto de la Cadena site in the upper part, corresponds to a surface of marked erosion. This surface is present in both the La Virgen Fm. and Torremendo Fm. (see geological map in Fig. 1). This stratigraphic discontinuity is immediately overlain with sands and sandy marls, which include large-sized clasts bored by lithobiont bivalves and abundant shells of

small ostreids similar to those of the genus *Pycnodonte*. The marls are finely laminated and contain a diversified microfossil assemblage, represented by foraminiferans, ostracodes bryozoans, bivalves, carbonate sponge spicules, and sea urchin spicules. All the macro and micropaleontological data indicate that sedimentation of the Cigarrón Unit began under normal salinity marine conditions in a shallow water depositional environment, and a subsequent transgressive event can be recognized at the top of La Virgen Fm. This transgressive event is recorded in the same way in numerous places in the Bajo Segura Basin, coinciding with the beginning of the Pliocene (Corbí and Soria, 2016). This implies that the erosive surface documented at the base of the Cigarrón Unit corresponds to the end-Messinian discontinuity (Soria et al., 2005 and 2008).

2.2. Sedimentary record at the fossil site

The Cigarrón Unit at the Puerto de la Cadena site is represented by a sand and lutite alternating succession (Fig. 2). The sandy facies association is characterized by coarse sediments (mainly sands, but also microconglomerates and conglomerates), that are mainly organized in sets of trough and planar cross-stratification. These sets have a thickness of between a few centimeters and a meter, and most of them have an erosive base that exhibits a basal lag with intraformational mud clasts, fragmentary bones and plant fossil remains. They fine upwards, with frequent reactivation surfaces.

The macrovertebrate fossil remains are mainly located in the conglomeratic layers of the sands or in the basal lag of the sedimentary sets. The sand components are medium-sized to coarse siliciclastic grains with very little matrix and no cement. Cross-bedding in the sedimentary sets exhibits internal lamina that are variably inclined, from quasi-horizontal to 30°, and in most cases points towards N55°E.

The lutitic intercalations display different features. Some of them are thick lutitic intercalations (metric scale) with a concave base and a planar top. Bioturbation frequently occurs at the top of these bodies, consisting of 5-7 cm long (vertical development) traces with a characteristic U-shape and circular cross-section of about 0.5 cm (*Arenicolites* isp.; Simo and Olsavsky, 2007). In contrast, other thinner (centimetric to metric) lutitic intercalations have an irregular morphology. Most of the micromammal remains (about 5% of the total fossil remains) were obtained from the latter lutitic levels.

2.3. Geological interpretation

Mancheño et al. (2001) provided an interpretation of the depositional context for a tortoise carapace found in geological units similar to those described above, and concluded that fluvial transport would have brought the carapace to the sea. However, stratigraphical and sedimentological information from the different subunits at the top of the Cigarrón Unit leads us to favor a continental depositional context related to fluvial systems near the coast.

We agree with Mancheño et al. (2001) about the fluvial context for the upper part of the Cigarrón Unit, where the Puerto de la Cadena site is located. Sand and gravel beds with unidirectional cross-stratification correspond to channels through which dunes and megaripples migrate. The fluctuating flow regime causes the frequent reactivation of surfaces that separate the sets of cross-stratification. The lutitic interbeds between sandy bodies represent floodplain deposits of the fluvial system, dominated by channel overbank processes. The presence of micromammal fossils in the lutites indicates that there were episodes of vegetation development. The inferred depositional context for the Puerto de la Cadena site shows certain similarities to the fluvial system described

for the Rojas micromammal site (early Pliocene) located in the Bajo Segura Basin (Soria et al., 1996). In this case, as in the Puerto de la Cadena, microfossils are concentrated in vegetated areas of the floodplain.

2.4. The age of the Cigarrón Unit

The basal marine sediments of the Cigarrón Unit contain a varied assemblage of foraminifera in which benthic forms dominate (ca. 80%) over planktonic forms. The benthic foraminifera association includes the genera *Ammonia*, *Amphicoryna*, *Biasterigerina*, *Bigenerina*, *Bolivina*, *Bulimina*, *Cibicides*, *Elphidium*, *Fursenkoina*, *Globulina*, *Nonion*, *Pullenia*, *Reussella*, *Siphonina*, *Textularia*, and *Trifarina*. The dominant planktonic association includes *Globigerinoides extremus*, *Globigerinoides obliquus*, *Globigerinoides trilobus*, *Neogloboquadrina* spp., *Globorotalia scitula*, *Globigerina bulloides*, *Globoturborotalita* spp., and *Orbulina universa*. This marine microfossil biofacies is similar to that of the transgressive deposits at the base of the Pliocene Unit (P Unit; Soria et al., 2005) in the Bajo Segura Basin. This implies that the two units are correlative and that the underlying erosive surface corresponds to the end-Messinian discontinuity described by Soria et al. (2005). More specifically, there are four significant features at the beginning of the Pliocene Unit from the Bajo Segura Basin that coincide with those in the Cigarrón Unit: (a) abundant ostreids (*Pycnodonte* sp.) and clasts bored by lithobionts (Montenat, 1990; Soria et al., 2005; Caracuel et al., 2011); (b) prevalence of benthic foraminiferans (70–90%) over planktonic ones (Corbí, 2010); (c) abundant and diversified content of benthic foraminiferans, most of them represented by the genera *Ammonia*, *Bolivina*, *Bulimina*, *Cibicides*, *Elphidium*, *Nonion*, and *Textularia* (Corbí et al., 2016); and (d) an association of normal-sized planktonic

foraminiferans, typical of oligotrophic warm water, dominated by *Globigerinoides* (mainly *G. trilobus* and *G. obliquus/extremus*; Corbí et al., 2016).

Assigning the Cigarrón Unit to the Pliocene implies a post-MSC (Messinian Salinity Crisis) sedimentation, i.e., it occurred after the Mediterranean flooded with normal marine water from the Atlantic Ocean. In this basin, under high-level sea conditions, the Mediterranean margins were progressively filled with sediments, leading to regressive or shallowing sequences (Caracuel et al., 2004, 2009; Soria et al., 2005). The Cigarrón Unit represents one of these sequences, and displays an evolution from shallow marine to continental environments over time. The latter are represented by fluvial systems with channels and floodplain development, which is the depositional context in which the sediments of the Puerto de la Cadena site were accumulated.

3. Material and methods

Systematic excavations were carried out at the Puerto de la Cadena site in 2009, 2010 and 2011. They yielded about 2,000 well-preserved fossil remains of a diverse fauna of continental vertebrates (Figs. 5-9). Large amounts of sediment were also screen-washed using superimposed 4.0, 1.0 and 0.5 mm mesh screens. The recovered fossils represent at least 26 species and are currently housed at the Museo Arqueológico de Murcia (MAM; Murcia, Spain).

In this work, we update the systematic of the vertebrate taxa found so far in the early Pliocene levels of the Puerto de la Cadena area. We both review previously found remains and analyze and discuss recently found material (see Supplementary Information and Table 1).

Measurements of the small mammal teeth were taken on the occlusal plane of the molars with the software DinoCapture 2.0, using photographs from the Digital Microscope AM4115TL Dino-Lite Edge. Micromammal teeth are illustrated by means of micrographs taken with Environmental Scanning Electron Microscopy (ESEM) at the Servei de Recursos Científics i Tècnics de la Universitat Rovira i Virgili (Tarragona). Upper and lower teeth are denoted by capital letters ('P' for premolars and 'M' for molars) followed by superscripts and subscripts respectively, whereas deciduous premolars are denoted with the letter 'D'.

The descriptions and measurements of murid molars follow van de Weerd (1976) and Martín Suárez and Freudenthal (1993) respectively. The terminology used to describe gerbillid teeth is that of Wood and Wilson (1936), and length and width were measured as defined by Minwer-Barakat (2005). Mein and Freudenthal (1971) were followed when we described and measured cricetid teeth. The term "prelophid" is taken from Freudenthal (1985). The terms used to describe prolagid teeth follow Angelone and Sesé (2009). The descriptions and measurements of leporid remains follow the nomenclature and methods proposed by López Martínez et al. (2007) and Angelone and Sesé (2009) respectively.

A magnetostratigraphic study was performed based on 22 paleomagnetism stations distributed along a 60 m-thick composite series of the Puerto de la Cadena. Rock samples were extracted both with a portable drilling machine and by hand shaping of oriented blocs. Analytics were carried out at the Paleomagnetism Laboratory of SCT-Universitat de Barcelona-CSIC. A minimum of one sample per paleomagnetism station underwent a stepwise thermal demagnetization. The demagnetization included up to 15 steps, from room temperature to 700 °C. A few alternating field demagnetizations were

also carried out, and bulk susceptibility was measured during the whole process to detect any mineralogical changes. The results were correlated to the latest Astronomical Tuned Neogene Time Scale (ATNTS; Hilgen et al., 2012).

4. Magnetostratigraphy

A magnetostratigraphic survey was carried out in order to date the Puerto de la cadena site based on the correlation with both the magnetostratigraphy-calibrated mammal scale for the Iberian Peninsula (Agustí et al., 2001) and the magnetostratigraphically dated successions of nearby sections with the same age and stratigraphic units (Krijnsman et al., 2006; Soria et al., 2008). The limited stratigraphic context of the Puerto de la Cadena site (relatively thin Isleta section) made it necessary to also include the thicker Barranco del Cigarrón section in the magnetostratigraphic study. Thus, a first sampling was focused on the Cigarrón Unit in the two sections, and a second sampling was focused on the uppermost part of the La Virgen Units.

Thermally demagnetized samples displayed a stable demagnetization plot (see examples in Fig. 3) with high magnetization intensity values. A high temperature interval from around 300 °C to full demagnetization was considered to calculate a primary component. At lower temperatures, a normal polarity component was observed, and is considered to be a recent overprint of the geomagnetic field. The high temperature component provided both normal and reversed polarities (Fig. 4). In the Cigarrón Unit, normal polarities are recorded from meter 100 to 120, while in the upper remaining section only reversed polarities have been found. In the Isleta section only reversed polarities are observed. Samples from the La Virgen Unit provided unreliable results due to the low intensities and the instability of the magnetization.

5. Biostratigraphic correlations

5.1. Small mammals

The micromammal list of Puerto de la Cadena includes *Stephanomys* cf. *dubari*, *Paraethomys* cf. *meini*, *Apocricetus* cf. *barrierei*, *Ruscinomys lasallei*, *Debruijnimys* sp., *Prolagus* cf. *michauxi*, and *Trischizolagus maritsae* (See Figs. 5-6, Table 1, and Supplementary Information), and can be assigned to the base of MN14 (earliest Ruscinian).

Mein et al. (1990) defined the base of MN14 in the Teruel Basin as the entry of *Celadensia*. However, Agustí et al. (2001) considered the base of MN14 to be the first appearance of the arvicolid *Promimomys* due to the occurrence of *Celadensia* in Baccinello (Italy), a MN13 locality (Rook and Torre, 1995). The range of *Promimomys* within the Iberian Peninsula is limited to the Teruel region (Mein et al., 1990), so correlations with southern Iberian basins are difficult to establish. In the absence of arvicolids, Agustí et al. (2001) proposed differentiating MN13 and MN14 based on the evolutionary stages of *Apodemus*, *Stephanomys*, *Paraethomys*, *Ruscinomys* and *Apocricetus*. In agreement with Morales et al (2013), the appearance of a large-sized *Paraethomys* (*P.* aff. *abaigari*, *P. abaigari*) with a smaller one (*P. meini*) marks the beginning of the subzone N2. Mansino et al. (in press) considered this subzone to be early Ruscinian (MN14). The remains of *Stephanomys* from Puerto de la Cadena display a more derived evolutionary stage than those of *S. ramblensis*, the most characteristic late Turolian taxon in Spanish basins (Agustí and Llenas, 1996). In contrast, its descendant, *Stephanomys dubari*, is common in latest Turolian and earliest Ruscinian assemblages (García-Alix et al., 2008; Mansino et al., 2015). *Apocricetus*

barrierei is a typical taxon of early Rusinian or MN14 unit (Mein, 1975; Mein et al., 1990; Freudenthal et al., 1998; Kälin, 1999; García-Alix et al., 2008). Therefore, the joint occurrence of *Apocricetus* cf. *barrierei* and *Stephanomys* cf. *dubari*, lead us to assign Puerto de la Cadena to the base of the MN14 unit.

We can compare the small mammal record of Puerto de la Cadena with that of some nearby late Turolian localities. Librilla 1, Molina de Segura 9, Sifón 61, and Sifón 79, located in the Fortuna Basin (Agustí et al., 1983, 2006), and Crevillente 6, situated in the Crevillente Basin (Martín Suárez and Freudenthal, 1998), share with Puerto de la Cadena the presence of *Paraethomys meini* as well as a Cricetodontinae like *Ruscinomys* sp. In addition, *Prolagus michauxi* is present in the Fortuna Basin levels. However, these localities differ from Puerto de la Cadena due to the presence of *Stephanomys ramblensis* and *Apocricetus alberti*, suggesting that they have an older age. In spite of the great faunal similarity, the absence of the gerbil *Debruijnimys* in Molina de Segura 9, Sifón 61, Sifón 79, and Crevillente 6 has a biostratigraphic interest. Following Agustí et al. (2006), the so named “Gerbil Event” (third Messinian Mammalian Event, MME 3) took place between 5.96 and 5.33 Ma, when rodents of African affinities came into the Western Mediterranean, such as members of the genera *Myocricetodon* and *Debruijnimys*. This dispersal event clearly occurred after the arrival of *Paraethomys*, and is directly related to the MSC. Therefore, all the cited localities were deposited before the onset of MME 3, as they have a lower stratigraphical position than Puerto de la Cadena. In contrast, the studied small mammal assemblage is very similar to that of the Sifón 413 locality (Agustí et al., 2006). Similar taxa have been recognized in this level: *Debruijnimys* sp., *Paraethomys miocaenicus* (= *P. meini*), *Stephanomys medius* (= *S. dubari*, *S. cordii*), *Ruscinomys lasallei* and *Prolagus michauxi*.

The nearby site of La Alberca has also yielded a similar small mammal association, with the occurrence of *Stephanomys medius* (= *S. dubari*, *S. cordii*), *Ruscinomys lasallei*, *Paraethomys meini*, *Prolagus michauxi*, and the genus *Trischizolagus* (Montenat, 1973; López Martínez, 1989; Freudenthal et al., 1998). Following Bruijn et al. (1975), the La Alberca site is late Miocene in age. They based their dating on the association of planktonic foraminiferan association found in higher and lower marine sediments, between which the continental site is intercalated. If this dating is correct, then La Alberca would be older than Puerto de la Cadena. This is consistent with the absence of gerbils in La Alberca and the presence of *Apocricetus alberti*.

The joint presence of *Stephanomys* cf. *dubari*, *Paraethomys* cf. *meini*, *Ruscinomys lasallei*, *Apocricetus* cf. *barrierei* and *Debruijnimys* sp. leads us to correlate the Puerto de la Cadena site with the subzone N1 of the Ventian proposed by Morales et al. (2013), in further agreement with the large-mammal association.

6.2. Large mammals

The large mammal assemblage from Puerto de la Cadena (Fig. 7 and Table 1) includes taxa that, in Spain, either (a) first appear in MN13 (*Eucyon*, *Macaca*, *Parabos*); (b) are as yet only known from MN14 (*Sivatherium*, *Gazella* aff. *baturra*, *Hipparion fissurae*); (c) are recorded for the first time (*Gazella* aff. *lydekkeri*); or (d) occur in both MN13 and MN14 (see Supplementary Information). Taken as a whole, the large mammal association from Puerto de la Cadena suggests an age close to the MN13-MN14 transition, which is another important novelty for the Spanish fossil record of the Miocene/Pliocene boundary. In fact, in the Iberian Peninsula there are nearly no fossil localities with ages comprised between those of Venta del Moro (Valencia; local biozone M3; Morales, 1984; Montoya et al., 2006) and La Gloria 4 (Teruel; biozone O;

Alcalá, 1994). The very few localities in between have yielded a small number of large mammal fossils: Arenas del Rey (Granada; Aguirre, 1963; Alberdi and Boné, 1978), Almenara-Casablanca M (Castellon; Agustí et al., 1989, 2011; Köhler et al., 2000), La Alberca (Murcia; Montenat and Crusafont, 1970) and Baza-1 (Granada; Piñero et al., in press; Ros-Montoya et al., in press). In contrast, the micromammal record is abundant, although it is difficult to interpret (Morales et al., 2013). Therefore, it is not surprising that Puerto de la Cadena contains so many taxa not previously recorded in this geographical area: *Eucyon monticinis*, *Hipparion* aff. *fissurae*, *Sivatherium* cf. *hendeyi*, *Gazella* aff. *baturra*, *Gazella* aff. *lydekkeri*, and the possible presence of the caprine *Norbertia hellenica*. *Macaca* sp. which was already known from Almenara-M (Köhler et al., 2000), although the new record from Puerto de La Cadena confirms its presence in the early Pliocene of Spain (see Supplementary Information). The remaining large mammal remains from Puerto de la Cadena either cannot be assigned to a species (as is the case with the sole remain of a deer antler and the rhinoceros *Dihoplus*). The proboscidean *Anancus* appears in MN12 and the bovine *Parabos* at the end of MN13 (in local zone M3). These new appearances are framed within the major faunal turnover that took place at the end of the Miocene, which in part is related to the Messinian Salinity Crisis (Agustí et al., 2006; Van der Made et al., 2006; Gibert et al., 2013, Morales et al., 2013). The appearance of several of these species is also recorded in other Mediterranean localities, namely: *Eucyon monticinesis*, which was described from Brisighella, Italy (Rook, 1992); *Sivatherium*, which in Macedonia was described as *Sivatherium garevskii* (see Geraads, 2009) and in Turkish Thrace (Edirne = Adrianopolis) as *Sivatherium giganteum* (see Abel, 1904); *Gazella* aff. *lydekkeri* and likely the possible caprine dentition, which could correspond to the *Gazella* sp. and *Norbertia hellenica* from Maramena (Köhler et al., 1995).

6. Magnetobiostratigraphic correlation

The correlation of the obtained polarities with the Geomagnetic Polarity Time Scale (Fig. 10) is based on the available geological and biostratigraphic data. First, the regional geological and magnetostratigraphic context of Krijgsman et al. (2006) and Soria et al. (2008) indicates that the Cigarrón Unit is equivalent to the Pliocene Unit in Soria et al. (2005). Both units correspond to the infilling of the post end-Messinian erosion by transitional environments in which the Puerto de la Cadena paleontological remains accumulated.

The entire Puerto de la Cadena section records a reversed polarity chron, whereas the Cigarrón Unit, whose upper part includes the Puerto de la Cadena site, records a normal-reversed polarity sequence (Fig. 4). According to the above-mentioned end-Messinian discontinuity at the base of the Cigarrón Unit, correlation with the reversed chron C3r is discounted because it covers the Mio-Pliocene boundary. Therefore, the normal polarity interval at the base of the Cigarrón section must be correlated with chron C3n.4n (or younger).

In turn, the correlation among Iberian micromammal sites that have been magnostratigraphically dated and the Puerto de la Cadena site supports that the correlation of the latter must be older than C3.2n. This is the case of Sifón P (correlated to C3.2n by Garcés et al., 2001), a site which has a more derived *Stephanomys* than that from Puerto de la Cadena. Such constraints indicate that the reversed polarity span at Puerto de la Cadena is likely correlated to C3n.3r or C3n.2r. A correlation to C3n.3r is preferred based on the large similarity in the small mammal association with Fuente del Viso (see Supplementary Information), which is correlated with that chron (Opdyke et

al., 1997; Freudenthal et al., 1998). Therefore, we correlate the normal interval at the Cigarrón section with chron C3n.4n, and the upper reverse span at the upper part with C3n.3r. The Puerto de la Cadena site is therefore dated between 4.997 and 4.896 Ma (Fig. 10).

Our interpretation is consistent with other well-dated sites. The older age indicated for Venta del Moro and Sifón 79 is in line with their assignment to the normal chron C3An.1n (6.252–6.033 Ma; Garcés et al., 2001; Agustí et al., 2006; Gibert et al., 2013). Similarly, the somewhat older Purcal 3, 4, and Zorreras 3A were correlated to chron C3r, ranging from 5.235 to 6.033 Ma (Martín-Suárez et al., 1998, 2000). Finally, the Sifón 413 level was situated in the Pliocene span of chron C3r (5.330–5.235 Ma; Garcés et al., 2001), and although its small mammal association resembles that of Puerto de la Cadena, considering the chronostratigraphic information, Sifón 413 is at least 200 kyr older.

Martín-Suárez et al. (2000) and Agustí et al. (2001) considered the Fuente del Viso faunal association as MN14, instead of latest MN13 as indicated by Opdyke et al. (1997). The faunal assemblage of Puerto de la Cadena has been interpreted in this work as earliest MN14. Considering these data, a minimum age for the base of MN14 is established within the chron C3n.3r. This permits bracketing the MN13/MN14 boundary between 4.997 and 4.896 Ma. This correlation is consistent with that of Opdyke et al. (1997) and Agustí et al. (2001), who supported an MN13/MN14 limit younger than its traditional position at the marine Miocene/Pliocene boundary.

Therefore, according to this correlation, Puerto de la Cadena is closely coeval of the Tomea Eksi 3 level, at the other edge of the Mediterranean Basin, in the Pliocene lacustrine deposits of the Florina-Ptolemais-Servia Basin (Greece; Hordijk and Bruijn,

2009), also placed within chron C3n.3r. However, when we compare the two small mammal assemblages, striking differences are evident. The rodent fauna from Tomea Eksi 3 is composed of a diversified fauna of murids related to *Apodemus* (*Micromys bendai*, *Rhagapodemus primaevus*, *Apodemus atavus*, *Apodemus dominans*?) together with an archaic arvicolid (*Mimomys* aff. *davakosi*). This association suggests a forested environment, with predominant humid conditions, which is confirmed by the other rodent associations present in closer levels of the basin, including, among others, flying squirrels of the species *Pliopetaurista dehneli* (Vorio 3/3a; Hordijk and Bruijn, 2009).

In contrast, Puerto de la Cadena has a very different small mammal association, with most of the rodent species indicating open-dry conditions. This is the case of the hamsters *Apocricetus* cf. *barrierei* and *Ruscinomys lasallei* (a selenodont/hypsodont cricetid), the gerbil *Debruijnimys* sp. and the stephanodont murid *Stephanomys* cf. *dubari*. These evidences point to the existence of very different environmental conditions at the two extremes of the Mediterranean. In the Western Mediterranean there is the persistence of an open landscape, with prevalent dry conditions, which most possibly are reminiscent of the Messinian Salinity Crisis (as indicated by the persistence of gerbils of African origin). In contrast, the conditions in South Eastern Europe suggest a forested environment in a humid context. This difference can be explained by the influence of the neighboring Black Sea, which possibly increased precipitation due to lake effect.

7. Conclusions

The Puerto de la Cadena site, in the upper part of the Cigarrón Unit, at the northern flank of the Carrascoy range mountain (Murcia, Spain), has yielded diverse vertebrate

continental fauna, and up to 26 different species were recorded. The recovered assemblage can be correlated to the base of MN14 (earliest Ruscinian of the early Pliocene). The small mammal association consists of *Stephanomys* cf. *dubari*, *Paraethomys* cf. *meini*, *Debruijnmys* sp., *Apocricetus* cf. *barrierei*, *Ruscinomys lasallei*, *Trischizolagus maritsae*, and *Prolagus* cf. *michauxi*. The large mammal record comprises *Macaca* sp., *Eucyon monticinensis*, *Anancus arvernensis*, *Hipparion* aff. *fissurae*, *Dihoplus schleiermacheri* vel *Dihoplus megarhinus*, Cervidae indet., *Sivatherium* cf. *hendeyi*, *Gazella* aff. *baturrea*, *Gazella* aff. *lydekkeri*, *Parabos* sp., and three additional indeterminate bovids. Among the reptiles, Puerto de la Cadena records *Crocodylia* indet., *Malpolon* gr. *monspessulanus-mlynarski*, *Vipera* sp., Trionychidae indet., *Titanochelon* sp., and one indeterminate testudinid. This fauna includes a number of elements of African origin, such as *Debruijnmys* sp., *Macaca* sp., and *Sivatherium* cf. *hendeyi*, which most likely settled on the Iberian Peninsula during the Messinian Salinity Crisis (as has been reported in previous studies).

Puerto de la Cadena is one of the youngest localities of the MN14 (early Pliocene), with the joint presence of typical elements of this unit, like *Apocricetus* cf. *barrierei*, *Sivatherium*, *Gazella* aff. *baturrea*, and *Hipparion fissurae*. According to the magnetostratigraphic correlation proposed in this work, the faunal association from Puerto de la Cadena is dated to the early Pliocene. Our results allow us to establish the boundary between MN13 and MN14 within the reversed polarity interval C3n.3r (4.997–4.896 Ma). In addition, this study confirms the persistence of crocodiles in the early Pliocene of Europe.

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References

Abel, O., 1904. Über einen Fund von *Sivatherium giganteum* bei Adrianopel. Sitzungsberichte der Mathematisch Naturwissenschaftlichen Klasse der kaiserlichen Akademie der Wissenschaften 113, 1–22.

Aguirre, E., 1963. Situación de las capas con *Hipparion* de Granada en la serie Neógena Mediterránea. N. Com. Inst. Geol. Min. 69, 239–246.

- Aguirre, E., Alberdi, M.T., Thaler, L., López Martínez, N., Ruiz Bustos, A., 1974. Murcia-Granada. In: Aguirre, E., Morales, J., (Eds.), *Coloquio Internacional sobre Biostratigrafía Continental del Neógeno Superior y Cuaternario Inferior. Libro-Guía*, Madrid, pp. 87–133.
- Aguirre, E., López N., Morales J., 1976. Continental faunas in Southeast Spain related to the Messinian. In: Cita, M.B., (Ed.), *Il significato geodinamico della crisi di Salinità del Miocene Terminale nel Mediterraneo. Messinian Seminar (2)*, Gargano, pp. 62–63.
- Agustí, J., Moyà-Solà, S., Gibert, J., Guillén, J., Labrador, M., 1983. Nuevos datos sobre la bioestratigrafía del Neógeno continental de Murcia. *Paleontol. Evol.* 18, 83–94.
- Agustí, J., Moyà-Solà, S., Martín-Suárez, E., 1989. Review of the late Miocene–early Pliocene mammalian faunas from eastern Spain. *B. Soc. Paleontol. Ital.* 28 (2–3), 155–160.
- Agustí, J., Llenas, M., 1996. The late Turolian muroid rodent succession in eastern Spain. *Acta Zool. Cracov.* 39 (1), 47–56.
- Agustí, J., Cabrera, L., Garcés, M., Krijgsman, W., Oms, O., Parés, J.M., 2001. A calibrated mammal scale for the Neogene of Western Europe. State of the art. *Earth-Sci. Rev.* 52 (4), 47–260.
- Agustí, J., Garcés, M., Krijgsman, W., 2006. Evidence for African–Iberian exchanges during the Messinian in the Spanish mammalian record. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 238 (1), 5–14.
- Agustí, J., Santos-Cubedo, A., Furió, M., De Marfá, R., Blain, H.-A., Oms, O., Sevilla, P., 2011. The late Neogene-early Quaternary small vertebrate succession from the

Almenara-Casablanca karst complex (Castellón, Eastern Spain): Chronologic and paleoclimatic context. *Quat. Int.* 243 (1), 183–191.

Alberdi, M.T., Boné, E., 1978. Macrovertébrés du gisement d'Arenas del Rey (Miocène Supérieur du bassin de Grenade, Andalousie, Espagne). *Bull. Soc. Belge Géol.* 87 (4), 199–214.

Alcalá, L., 1994. Macromamíferos Neógenos de la fosa de Alfambra-Teruel. *Inst. Est. Tur.*, Museo Nacional de Ciencias Naturales, Teruel, 1–554 pp.

Angelone, C., Sesé, C., 2009. New characters for species discrimination within the genus *Prolagus* (Ochotonidae, Lagomorpha, Mammalia). *J. Paleo.* 83 (1), 80–88.

Caracuel, J.E., Soria, J.M., Yébenes, A., 2004. Early Pliocene transgressive coastal lags (Bajo Segura Basin, Spain): a marker of the flooding after the Messinian salinity crisis. *Sediment. Geol.* 169 (3), 121–128.

Caracuel, J.E., Corbí, H., Estévez, A., Giannetti, A., Monaco, P., Pina, J.A., Soria, J., Tent-Manclús, J.E., Yébenes, A., 2009. Pistas fósiles asociadas a la discontinuidad finimessiniense en el margen norte de la Cuenca del Bajo Segura (SE España). *Geogaceta* 47, 37–40.

Caracuel, J.E., Corbí, H., Giannetti, A., Monaco, P., Soria, J.M., Tent-Manclus, J.E., Yébenes, A., 2011. Paleoenvironmental changes during the late Miocene (Messinian)–Pliocene transition (Bajo Segura Basin, southeastern Spain): sedimentological and ichnological evidence. *Palaios* 26 (12), 754–766.

Corbí, H.A., 2010. Los foraminíferos de la Cuenca neógena del Bajo Segura (Sureste de España): biostratigrafía y cambios paleoambientales en relación con la crisis de

salinidad del Mediterráneo. PhD dissertation, Universidad de Alicante, Alicante, pp. 1–280.

Corbí, H., Soria, J., 2016. Late Miocene-early Pliocene planktonic foraminifer event-stratigraphy of the Bajo Segura basin: A complete record of the western Mediterranean. *Mar. Petrol. Geol.* 77, 1010–1027.

Corbí, H., Asensio-Montesinos, F., Ramos-Esplá, A.A., 2016. The Littoral Bottoms of Benidorm Island (Western Mediterranean Sea): Eco-Sedimentological Characterization Through Benthic Foraminifera. *Thalassas* 32 (2), 105–115.

de Bruijn, H., Mein, P., Montenat, C., van de Weerd, A., 1975. Correlations entre les gisements de rongeurs et les formations marines du Miocène terminal d'Espagne méridionale (provinces d'Alicante et de Murcia). *Proc. Kon. Ned. Akad. Wetensch.* 78 (4), 1–31.

Fejfar, O., Heinrich, W.D., 1990. Muroid rodent biochronology of the Neogene and Quaternary in Europe. In: Lindsay, E.H., Fahlbusch, V., Mein, P. (Eds.), *European Neogene Mammal Chronology*. Plenum Press, New York, pp. 91–117.

Freudenthal, M. 1985. Cricetidae (Rodentia) from the Neogene of Gargano (Prov. Of Foggia, Italy). *Scripta Geol.* 77, 29–76.

Freudenthal, M., Mein, P., Suárez, E.M., 1998. Revision of Late Miocene and Pliocene Cricetinae (Rodentia, Mammalia) from Spain and France. *Treb. Mus. Geol. Barcelona* 7, 11–93.

Garcés, M., Krijgsman, W., Agustí, J., 2001. Chronostratigraphic framework and evolution of the Fortuna Basin (Eastern Betics) since the late Miocene. *Basin Res.* 13 (2), 199–217.

- García-Alix, A., Minwer-Barakat, R., Martín, J.M., Martín-Suárez, E., Freudenthal, M., 2008. Biostratigraphy and sedimentary evolution of Late Miocene and Pliocene continental deposits of the Granada Basin (southern Spain). *Lethaia* 41 (4), 431–446.
- Geraads, D., 2009. Giraffidae (Mammalia) de la fin du Néogène de la République de Macédoine (ARYM). *Geodiversitas* 31 (4), 893–908.
- Gibert, L., Scott, G.R., Montoya, P., Ruiz-Sánchez, F.J., Morales, J., Luque, L., Abella, J., Lería, M., 2013. Evidence for an African-Iberian mammal dispersal during the pre-evaporitic Messinian. *Geology* 41 (6), 691–694.
- Hilgen, F.J., Lourens, L.J., Van Dam, J.A., 2012. The Neogene period. In: Gradstein, F., Ogg, J., Schmitz, M., Ogg, G. (Eds.), *The Geological Time Scale 2012*. Elsevier, Amsterdam, pp. 923–978.
- Hordijk, K., de Bruijn, H., 2009. The succession of rodent faunas from the Mio/Pliocene lacustrine deposits of the Florina-Ptolemais-Servia Basin (Greece). *Hellenic J. Geosci.* 44, 21–103.
- Kälin, D., 1999. Tribe Cricetini. In: Rössner, G.E., Heissig, K. (Eds.), *The Miocene Land Mammals of Europe*. Verlag Dr. Friedrich Pfeil, München, pp. 373–388.
- Krijgsman, W., Leewis, M.E., Garcés, M., Kouwenhoven, T.J., Kuiper, K.F., Sierro, F.J., 2006. Tectonic control for evaporite formation in the Eastern Betics (Tortonian; Spain). *Sediment. Geol.* 188–189, 155–170.
- Köhler, M., Moyà-Solà, S., Morales, J., 1995. The vertebrate locality Maramena (Macedonia, Greece) at the Turolian–Ruscinian boundary (Neogene). 15. Bovidae and Giraffidae (Artiodactyla, Mammalia). *Münch. Geowiss. Abh. A* 25, 167–180.

Köhler, M., Moyà-Solà, S., Alba, D.M., 2000. *Macaca* (Primates, Cercopithecidae) from the Late Miocene of Spain. *J. Hum. Evol.* 38 (3), 447–452.

López Martínez, N., 1989. Revisión sistemática de los Lagomorpha (Mammalia) del Terciario y Cuaternario de España. *Mem. Mus. Paleontol. Univ. Zaragoza* 3 (3), 1–344.

López-Martínez, N., Likius, A., Mackaye, H.T., Vignaud, P., Brunet, M., 2007. A new Lagomorph from the Late Miocene of Chad (Central Africa). *Rev. Esp. Paleontol.* 22 (1), 1–20.

Mancheño, M.A., Rodríguez Estrella, T., Pérez Varela, F., Jiménez Fuentes, E., Serrano Lozano, F., Romero Sánchez, G., 2001. Las tortugas gigantes del Puerto de la Cadena (Murcia, España). *Stud. Geol. Salmant.* 37, 11–23.

Mansino, S., Fierro, I., Montoya, P., Ruiz-Sánchez, F.J., 2015. Micromammal faunas from the Mio-Pliocene boundary in the Alcoy Basin (SE Spain): biostratigraphical and palaeoecological inferences. *Bull. Geosci.* 90 (3), 555–576.

Mansino, S., Fierro, I., Tosal, A., Montoya, P., Ruiz-Sánchez, F.J., in press. Micromammal biostratigraphy of the Alcoy Basin (Eastern Spain): remarks on the Pliocene record of the Iberian Peninsula. *Geol. Acta*.

Martín Suárez, E., Freudenthal, M., 1993. Muridae (Rodentia) from the lower Turolian of Crevillente (Alicante, Spain). *Scripta Geol.* 103, 65–118.

Martín Suárez, E., Freudenthal, M., 1998. Biostratigraphy of the continental upper Miocene of Crevillente (Alicante, SE Spain). *Geobios* 31 (6), 839–847.

Martín-suárez, E., Oms, O., Freudenthal, M., Agustí, J., Parés, J.M., 1998. Continental Mio-Pliocene transition in the Granada Basin. *Lethaia* 31 (2), 61–166.

- Martín-Suárez, E., Freudenthal, M., Krijgsman, W., Rutger Fortuin, A., 2000. On the age of the continental deposits of the Zorreras Member (Sorbas Basin, SE Spain). *Geobios* 33 (4), 505–512.
- Mein, P., 1975. Résultats du Groupe de Travail des Vertébrés, p. 78–81. In: Senes, J., (Ed.), Report on Activity on the RCMNS Working Groups (1971–1975). Regional Committee of the Mediterranean Neogene Stratigraphy, Bratislava, pp. 78–81.
- Mein, P., Freudenthal, M., 1971. Une nouvelle classification des Cricetidae (Mammalia, Rodentia) du Tertiaire de l'Europe. *Scripta Geol.* 2, 1–37.
- Mein, P., Bizon, G., Bizon, J.-J., Montenat, C., 1973. Le gisement de mammifères de La Alberca (Murcia, Espagne méridionale). Corrélations avec les formations maritimes du Miocène terminal. *C. R. Acad. Sci., Paris, Sér. D* 276, 3077–3080.
- Mein, P., Moissenet, E., Adrover, R., 1990. Biostratigraphie du Néogène Supérieur du bassin de Teruel. *Paleontol. Evol.* 23, 121–139.
- Minwer-Barakat, R., 2005. Roedores e insectívoros del Turoliense Superior y el Plioceno del sector central de la cuenca de Guadix. PhD dissertation, Universidad de Granada, Granada, Spain, pp. 1–535.
- Montenat, C., 1973. Les formations néogènes et quaternaires du Levant espagnol. PhD dissertation, Univ. Orsay, Orsay, pp. 1–1170.
- Montenat, C., 1977. Les bassins néogènes du levant d'Alicante et de Murcia (Cordillères bétiques orientales, Espagne). *Docum. Lab. Géol. Fac. Sci. Lyon* 69, pp. 1–345 pp.

Montenat, C., 1990. Les bassins Néogènes du domaine bétique oriental (Espagne): tectonique et sédimentation dans un couloir de d´crochement. Doc. Trav. IGAL, Paris, 12–13, 1–392.

Montenat, C., Crusafont, M., 1970. Découverte de Mammifères dans le Néogène et le Pléistocène du Levant espagnol (Provinces d'Alicante et de Murcia). C. R. Acad. Sci., Paris, Sér. D 270, 2434–2437.

Montoya, P., Morales, J., Robles, F., Abella, J., Benavent, J.V., Marín, M.D., Ruiz Sánchez, F.J., 2006. Las Nuevas excavaciones (1995-2006) en el yacimiento del Mioceno final de Venta del Moro, Valencia. *Estud. Geol.* 62 (1), 313–326.

Morales, J., 1984. Venta del Moro: su macrofauna de mamíferos y biostratigrafía continental del Mioceno terminal mediterráneo. PhD dissertation, Edit. Univ. Complut. Madrid, pp. 1–340 pp.

Morales, J., Peláez-Campomanes, P., Abella, J., Montoya, P., Gibert, L., Scott, G., Cantalapiedra, J.L., Sanisidro, O., 2013. The Ventian mammal age (Latest Miocene): present state. *Span. J. Pal.* 28 (2), 149–160.

Murelaga, X., Mancheño, M.A., Carlos Calero, J.A., Romero, G., Rodríguez-Estrella, T., Montolla, P., 2007. Restos fósiles de Quelonios en la Región de Murcia. In: Braga, J.C., Checa, A., Company, M., (Eds.), XXIII Jornadas de la Sociedad Española de Paleontología. Libro de resúmenes, Caravaca de la Cruz, pp. 165–166.

Opdyke, N., Mein, P., Lindsay, E., Perez-Gonzales, A., Moissenet, E., Norton, V.L., 1997. Continental deposits, magnetostratigraphy and vertebrate paleontology, late Neogene of Eastern Spain. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 133 (3), 129–148.

Pérez-García, A., Murelaga, X., Mancheño, M.A., Fierro, I., 2011. Nuevos datos sobre las tortugas del Puerto de la Cadena (Mioceno superior de Murcia). *Geogaceta* 50 (2), 185–188.

Piñero, P., Agustí, J., Oms, O., Blain, H.A., Laplana, C., Ros-Montoya, S., Martínez-Navarro, B., in press. Rodents from Baza-1 (Guadix-Baza Basin, SE Spain). Filling the gap of the early Pliocene succession in the Betics. *J. Vert. Paleontol.*

Romero, G., Fierro, I., 2010. Intervenciones paleontológicas en el Puerto de la Cadena (Murcia). In: Ediciones Tres Fronteras, Consejería de Cultura y Turismo, Dirección General de Bellas Artes y Bienes Culturales (Eds.), XXI Jornadas de Patrimonio Cultural de la Región de Murcia, Comunidad Autónoma de la Región de Murcia, pp. 161–170.

Rook, L., 1992. «*Canis*» *monticinensis* sp. nov., a new Canidae (Carnivora, Mammalia) from the late Messinian of Italy. *B. Soc. Paleontol. Ital.* 30 (1), 7–22.

Rook, L., Torre, D., 1995. *Celadensia grossetana* n. Sp. (Cricetidae, Rodentia) from the Late Turolian Baccinello-Cinigiano Basin (Italy). *Geobios* 28 (3), 379–382.

Ros-Montoya, S., Martínez-Navarro, B., Espigares, M.P., Guerra-Merchán, A., García-Aguilar, J.M., Piñero, P., Rodríguez-Rueda, A., Agustí, J., Oms, O., Palmqvist, P., in press. A new Ruscinian site in Europe: Baza-1 (Baza Basin, Andalusia, Spain). *C. R. Paleovol.*

Simo, V., Olsavsky, M., 2007. *Diplocraterion parallelum* Torell, 1870, and other trace fossils from the Lower Triassic succession of the Drienok Nappe in the Western Carpathians, Slovakia. *Bull. Geosci.* 82 (2), 165–173.

Soria, J.M., Caracuel, J.E., Yébenes, A., Fernández, J., Viseras, C., 2005. The stratigraphic record of the Messinian salinity crisis in the northern margin of the Bajo Segura Basin (SE Spain). *Sediment. Geol.* 179 (3), 225–247.

Soria, J.M., Caracuel, J.E., Corbí, H., Dinarès-Turrel, J., Lancis, C., Tent-Manclús, J.E., Viseras, C., Yébenes, A., 2008. The Messinian-early Pliocene record in the southern Bajo Segura Basin (Betic Cordillera, Spain): Implications for the Mediterranean salinity crisis. *Sediment. Geol.* 203 (3), 267–288.

van de Weerd, A., 1976. Rodent faunas of the Mio-Pliocene continental sediments of the Teruel-Alfambra region, Spain. *Utrecht Micropaleontol. Bull.* 2, 1–217.

Van der Made, J., Montoya, P., Morales, J., 2006. Late Miocene Turnover in the Spanish mammal record in relation to palaeoclimate and the Messinian Salinity Crisis. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 238 (1), 228–246.

Wood, A.E., Wilson, R.W., 1936. A suggested nomenclature for the cusps of the cheek teeth of rodents. *J. Paleo.* 10 (5), 388–391.

Figure captions

Figure 1. Geographical and geological setting of the Puerto de la Cadena site. [planned for 2 columns]

Figure 2. Stratigraphic log on Barranco del Cigarrón with detailed of the Puerto de la Cadena paleontological site. [planned for 2 columns]

Figure 3. Demagnetization plots of the Barranco del Cigarrón section. Top: sample with normal polarity zone from the La Virgen formation. Bottom: sample with reversed polarity from the Cigarrón Unit. [planned for single-column]

Figure 4. Magnetostratigraphic results from the studied sections. Top: Isleta section, encompassing the Puerto de la Cadena site. Bottom: Upper part of Barranco del Cigarrón section. P indicates polarity (normal in black and reversed in white). [planned for 2 columns]

Figure 5. Rodent teeth collection from Puerto de la Cadena. *Stepanomys* cf. *dubari*: A. partial right M¹, MAM/DA/2012-0019/A5-2; B. right M₁, MAM/DA/2012-0019/A5-1. *Paraethomys* cf. *meini*: C. right M₂, MAM/DA/2012-0019/A27'06-9; D. right M₁, MAM/DA/2012-0019/A26-2; *Debruijnmys* sp.: E. right M¹, MAM/DA/2012-0019/A5'06-1. *Apocricetus* cf. *alberti*: F. left M₃, MAM/DA/2012-0019/VLP2-831a; G. left M₂, MAM/DA/2012-0019/VLP2-831b; H. left M₁, MAM/DA/2012-0019/VLP2-831c. *Ruscinomys lasallei*: I) right M¹, MAM/DA/2012-0019/VLP2-799; J. left M₂, MAM/DA/2012-0019/A5'06-4; K. right M₂, MAM/DA/2012-0019/VLP2-869b; L. right M₁, MAM/DA/2012-0019/VLP2-869a; M. left M₃, MAM/DA/2012-0019/Puerto-de-la-Cadena. Scale bar equals 1mm. [planned for 1.5 column]

Figure 6. Lagomorph teeth from Puerto de la Cadena. *Trischizolagus maritsae*: A. left P₃, MAM/DA/2012-0019/VLP2-593; B. left lower molariform, MAM/DA/2012-0019/VLP2-626; C. left P², MAM/DA/2012-0019/A-27; D. right upper molariform, MAM/DA/2012-0019/VLP2-656. *Prolagus* cf. *michauxi*: E. left P₃, MAM/DA/2012-0019/A-26. Scale bar equals 1 mm. [planned for single column]

Figure 8. Crocodylia indet. from the early Pliocene of Puerto de la Cadena. A-C. Anterior maxillary tooth (MAM/DA/2012/VLP2-63) in lateral, posterior and dorsal views; D-E. Posterior maxillary tooth (MAM/DA/2012/VLP2-513) in anterior and lateral views. [planned for 1.5 column]

Figure 7. Large mammals from the early Pliocene locality of Puerto de la Cadena. *Dihoplus schleiermacheri/megarhinus*: A. anterior part of mandible, MAM/DA/2012/VLP3-682; E. left $D_{3/4}$, occlusal (1) and lingual (2) views, MAM/DA/2012/VLP2-507. *Hipparion* aff. *fissurae*: B. right $P_{3/4}$, occlusal view, MAM/DA/2012/VLP2-446; O. left $M^{1/2}$, occlusal view, MAM/DA/2012/VLP3-579. *Anancus arvernensis*: C. left $D^{3/4}$, occlusal (1) and buccal (2) views, MAM/DA/2012/VLP2-234; L. left D^2 , lingual (1), occlusal (2) and buccal (3) views, MAM/DA/2012/VLP2-282. Bovidae indet. sp. 3: D. maxilla with D^2 - M^2 , occlusal view, MAM/DA/2012/VLP2-212. Bovidae indet. sp. 2: F. right M_3 , lingual (1), occlusal (2) and buccal (3) views, MAM/DA/2012/VLP2-563. Cervidae indet.: G. antler fragment, MAM/DA/2012/VLP4-79. Bovidae indet. sp. 1: H. right metatarsus, anterior view, MAM/DA/2012/VLP2-272. *Sivatherium* cf. *hendeyi*: I. right lower canine, lingual (1), distal (2) and labial (3) views, MAM/DA/2012/VLP2-543. *Eucyon monticinensis*: J. left M_1 , buccal (1), occlusal (2) and lingual (3) views, MAM/DA/2012/VLP2-51. *Gazella* aff. *lydekkeri*: K. right metacarpus, anterior view, MAM/DA/2012/VLP2-103. *Gazella* aff. *baturra*: M. left female horn core, anterior (1) and lateral (2) views, MAM/DA/2012/VLP2-325. *Parabos* sp.: N. right M^2 , occlusal (1) and buccal (2) views, MAM/DA/2012/VLP2-464. The 1.5 cm scale bar goes with figure J, the 6 cm scale bar goes with figures H and K, and the 3 cm scale bar goes with the remaining figures. [planned for 2 columns]

Figure 9. The two clades of turtles identified in the early Pliocene site of Puerto de la Cadena (Murcia). A. Carapace of *Titanochelon* sp. “in situ”; B-C. VLP2-269, nuchal plate of Trionychidae indet. (Cryptodira), in dorsal (B) and ventral (C) views. [planned for 1.5- column]

Figure 10. Magnetobiostratigraphic correlation of the studied locality and other reference sites, with the magnetic polarity time scale. [planned for 1.5 columns]

Table caption

Table 1. Vertebrate faunal list of the site of Puerto de la Cadena.

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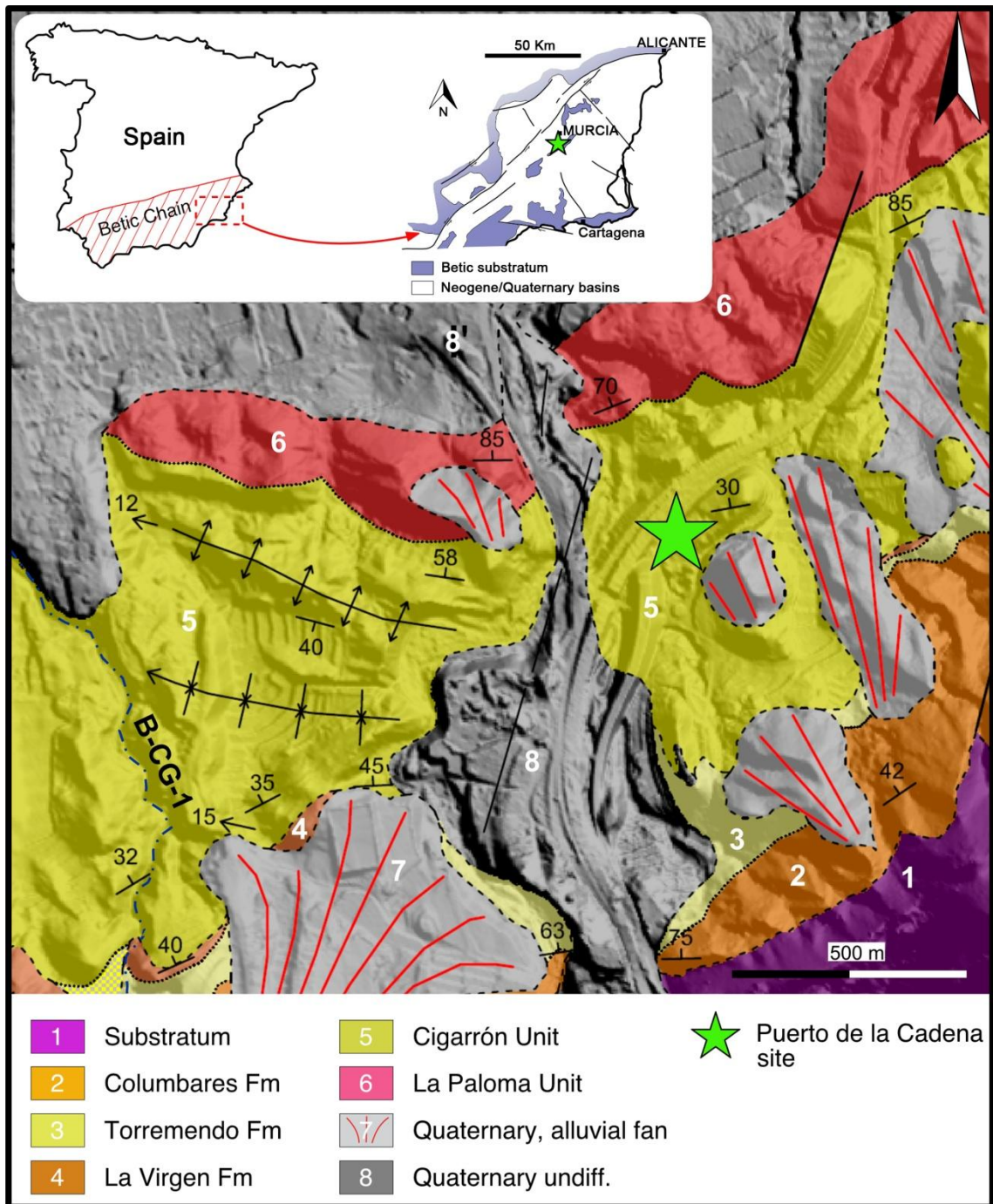


Figure 1

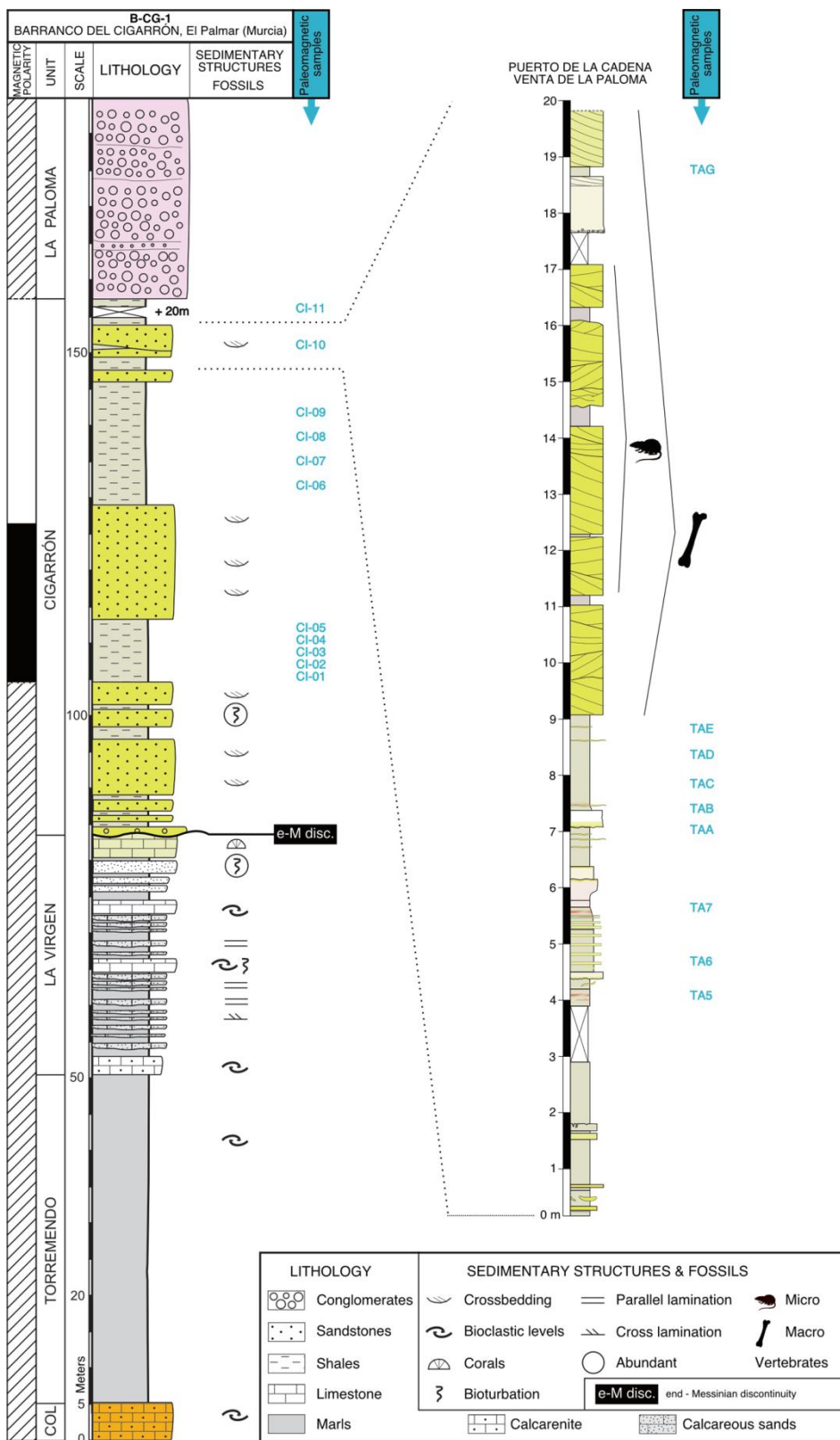


Figure 2

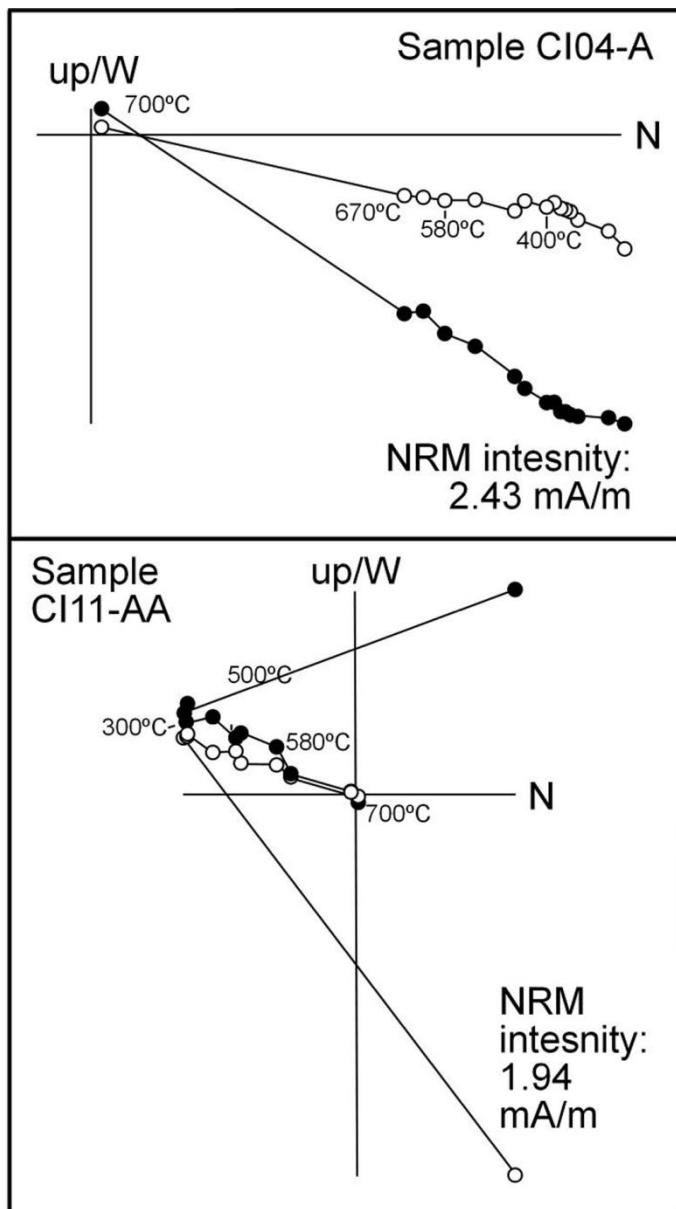


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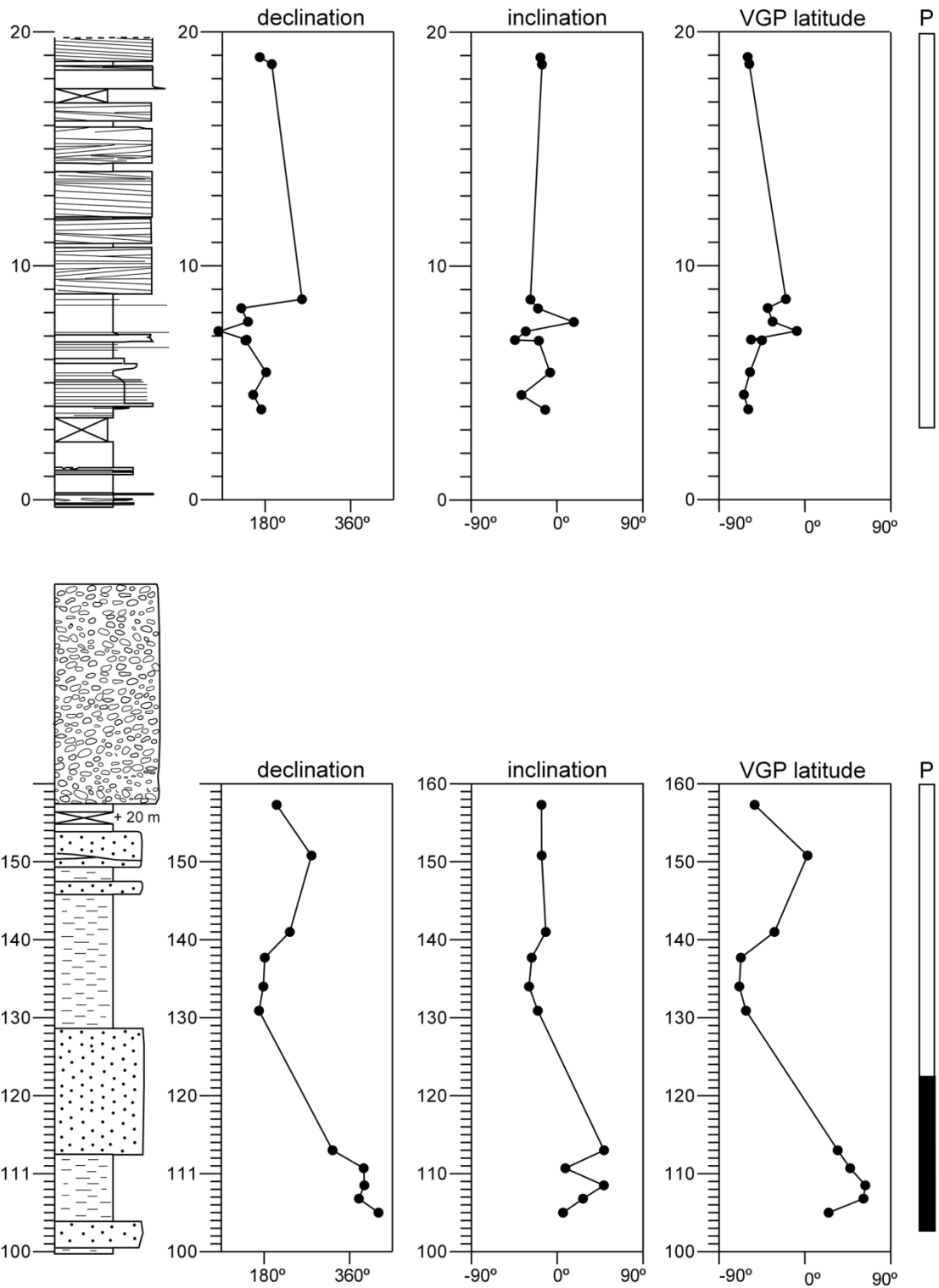


Figure 4

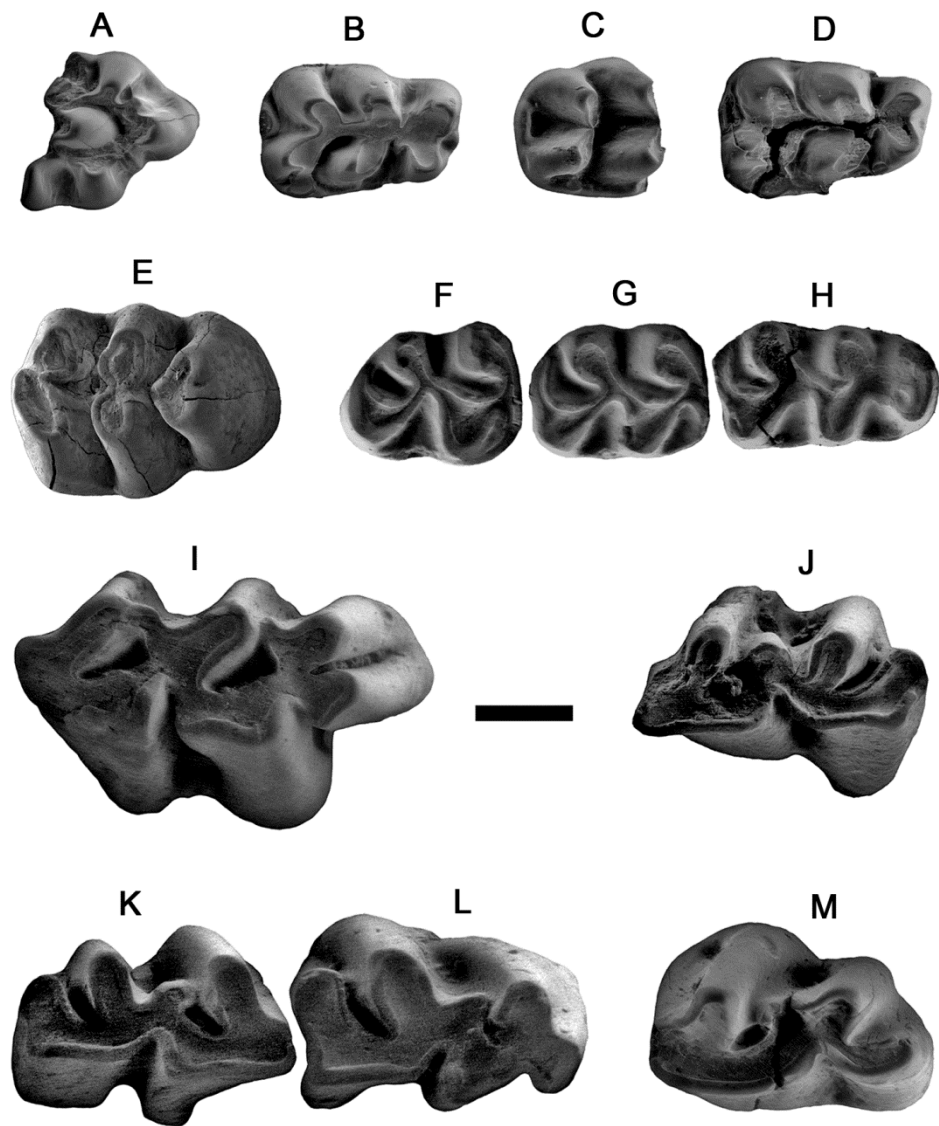


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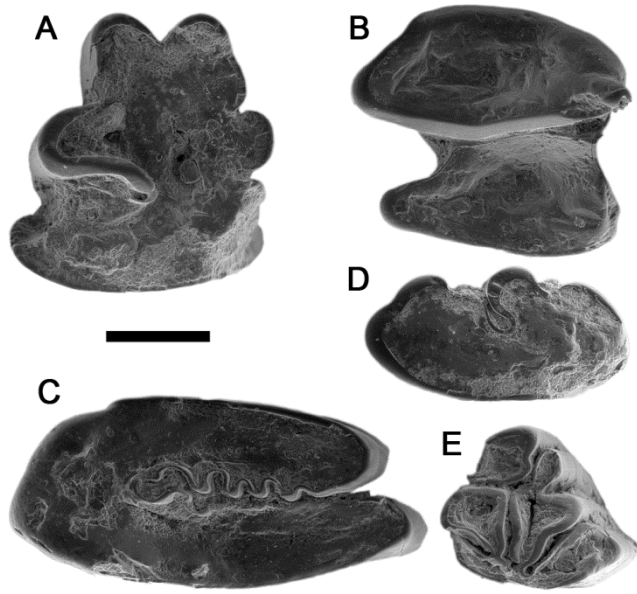


Figure 6



Figure 7



Figure 8

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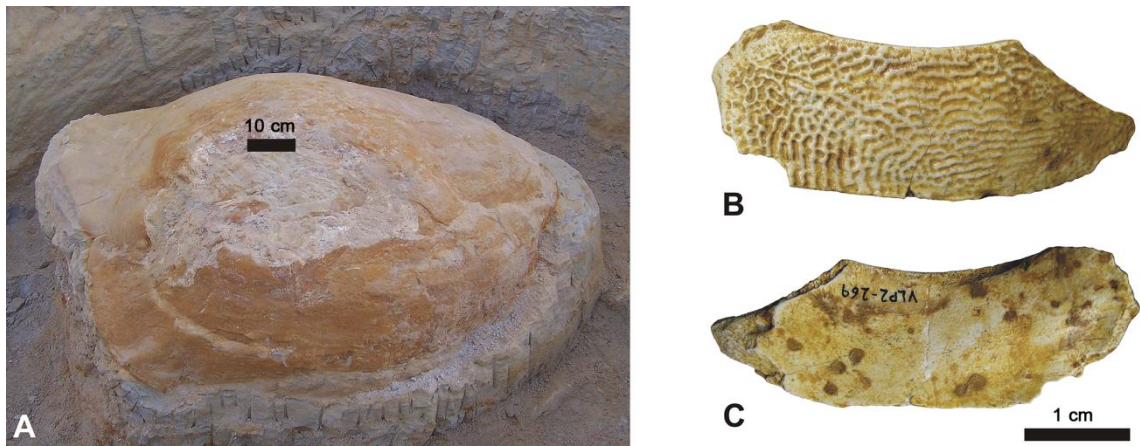


Figure 9

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Table 1

Order	Family	Species
Rodentia	Muridae	<i>Stephanomys</i> cf. <i>dubari</i> <i>Paraethomys</i> cf. <i>meini</i> <i>Debruijnimys</i> sp.
	Cricetidae	<i>Apocricetus</i> cf. <i>alberti</i> <i>Ruscinomys lasallei</i>
Lagomorpha	Leporidae	<i>Trischizolagus maritsae</i>
	Prolagidae	<i>Prolagus</i> cf. <i>michauxi</i>
Primates	Cercopithecidae	<i>Macaca</i> sp.
Carnivora	Canidae	<i>Eucyon monticinisensis</i>
Proboscidea	Gomphotheriidae	<i>Anancus arvernensis</i>
Perissodactyla	Equidae	<i>Hipparion</i> aff. <i>fissurae</i>
	Rhinocerotidae	<i>Dihoplus schleiermacheri</i> vel <i>Dihoplus megarhinus</i>
	Cervidae	Cervidae indet.
	Giraffidae	<i>Sivatherium</i> cf. <i>hendeyi</i> <i>Gazella</i> aff. <i>baturra</i> <i>Gazella</i> aff. <i>lydekkeri</i>
Artiodactyla	Bovidae	Bovidae indet. sp. 1
		Bovidae indet. sp. 2
		Bovidae indet. sp. 3
		<i>Parabos</i> sp.
Crocodylia		Crocodylia indet.
Testudines	Testudinidae	<i>Titanochelon</i> sp.
		Testudinidae indet.
	Trionychidae	Trionychidae indet.
Squamata	Viperidae	<i>Vipera</i> sp.
	Colubridae	<i>Malpolon</i> gr. <i>monspessulanus-mlynarski</i>

Highlights

- A synthesis of sedimentological, magnetostratigraphic and paleontological data has been carried out in the site of Puerto de la Cadena.
- This site is embedded in coastal facies, thus enabling a correlation between the marine and continental biostratigraphic scales.
- Puerto de la Cadena is correlated with the reverse polarity chron C3n.3r, which ranges from 4.997 to 4.896 Ma.
- Puerto de la Cadena has delivered a very diversified early Pliocene continental fauna, including large and small vertebrates.
- Many of the recorded elements are of African origin, their presence being a consequence of the Messinian Salinity Crisis.
- Crocodylia is a typical element of the latest Miocene terrestrial record persisting in the early Pliocene