

## Late Miocene and Pliocene small mammals from the Calatayud Basin (Central Spain)

### *Micromamíferos del Mioceno superior y Plioceno de la Cuenca de Calatayud (centro de España)*

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**Abstract:** A new series of late Neogene small mammal samples from the Calatayud Basin (Central Spain) is described. The samples were collected from the central part of the basin at Cortasogas and Maluenda under the supervision of Remmert Daams and Manuel Hoyos in the early eighties and more recently in 1998. On the basis of small mammal teeth, the age of Cortasogas 1 and 2 is estimated at 8.5-7.5 and 9.5-8.5 Ma, respectively. The age of Maluenda 1A and 1B is estimated at 11-9 and 5-4 Ma, respectively. These results provide new constraints on the age and nature of the regionally important sedimentary discontinuity between the Intermediate and Upper units in the basin. They indicate that in these areas, where sediments from the Intermediate unit and the basal red siliciclastic subunit of the Upper unit have their minimum thickness, a major part of the Upper Miocene is missing. The youngest locality Maluenda 3 has an age of 4.5-3 Ma, providing additional evidence for a Pliocene age of the upper carbonatic fluviolacustrine subunit of the Upper sedimentary unit.

**Resumen :** En este trabajo se realiza la descripción de una nueva serie de muestras con micromamíferos fósiles del Neógeno superior de la Cuenca de Calatayud (España central). Las muestras fueron recolectadas en los sectores centrales de la cuenca (Cortasogas y Maluenda) bajo la supervisión de Remmert Daams y Manolo Hoyos a principios de los años 80 y más recientemente, en una nueva ocasión, en 1998. Las edades de los yacimientos Cortasogas 1 y 2 han sido estimadas en 8.5-7.5 y 9.5-8.5 Ma respectivamente en función del análisis de dientes de micromamíferos. Por otra parte, las edades de los yacimientos de Maluenda 1A y 1B fueron estimadas en 11-9 y 5-4 Ma respectivamente. Estos resultados proporcionan un nuevo avance en la datación y el análisis de la naturaleza de la importante discontinuidad sedimentaria regional entre la Unidad Intermedia y Superior de la cuenca. Los datos indican que en las áreas donde los sedimentos de la Unidad Intermedia y la subunidad basal roja siliciclástica de la Unidad Superior tienen las menores potencias, una buena parte del Mioceno superior se encuentra ausente. El yacimiento más joven (Maluenda 3) tiene una edad de 4.5-3 Ma y proporciona una firme evidencia para atribuir una edad pliocena a la subunidad superior carbonática fluviolacustre de la Unidad Superior.

### INTRODUCTION

The Neogene Calatayud Basin is an elongated NW-SE oriented intramontane depression, filled by an up to 1,200 m - thick succession of lacustrine and alluvial sediments (Fig. 1). The basin infill is characterized by a concentric facies distribution with clastic deposits in the margins grading progressively into evaporites and carbonates in the central part. Three

main Miocene-Pliocene units, separated by two major sedimentary discontinuities, have been recognized in the basin (SANZ-RUBIO, 1999) (Fig. 2): the Lower and Intermediate units, both containing evaporites, and the Upper unit, mainly consisting of terrigenous deposits and fresh-water carbonates.

The evaporites (halite, anhydrite) of the Lower unit, which are Upper Oligocene to Middle Miocene in age, reach more than 500 m thickness in the cen-

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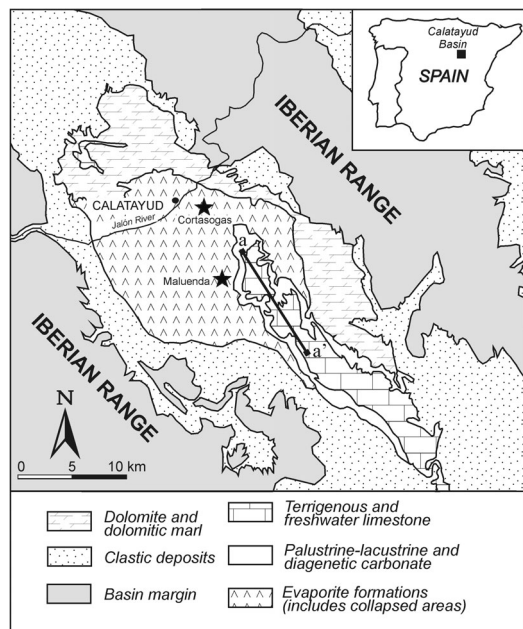


Figure 1.- Location and geological sketch map of the study area with mammal localities indicated. The a-a' profile corresponds to the stratigraphic cross section shown in Fig. 2.

Figura 1.- Localización y mapa esquemático geológico del área de estudio con indicación de los yacimientos de mamíferos. El perfil a-a' corresponde al corte estratigráfico mostrado en la Figura 2.

tral part of the basin. At the top the saline deposits are mainly composed of anhydrite and glauberite, which are replaced by secondary gypsum under near-surface conditions. The Intermediate unit (late Middle Miocene to early Late Miocene in age) shows an irregular thickness up to 120 m. Its central part predominantly contains laminated gypsum and dolostones, which are laterally associated with extensive dolomitic mudflats. Locally, particularly in the central areas of the basin, diagenetic carbonates form most of the sedimentary succession. The Upper unit (Late Miocene-Pliocene in age) ranges from 25 to 85 m in thickness and consists of terrigenous alluvial-fluvial deposits and fluvio-lacustrine carbonates.

A palaeokarstic surface marks the boundary between the Lower and Intermediate units in the central part of the basin, providing evidence of an episode of subaerial exposure. Palaeokarstic features indicating a sedimentary discontinuity are recognized as well at the boundary between the Intermediate and Upper units. The transition between the latter two units is characterized by an extensive net progradation of alluvial-fluvial deposits over lacustrine sediments, thus representing a major change in the paleogeography of the basin. This younger discontinuity is

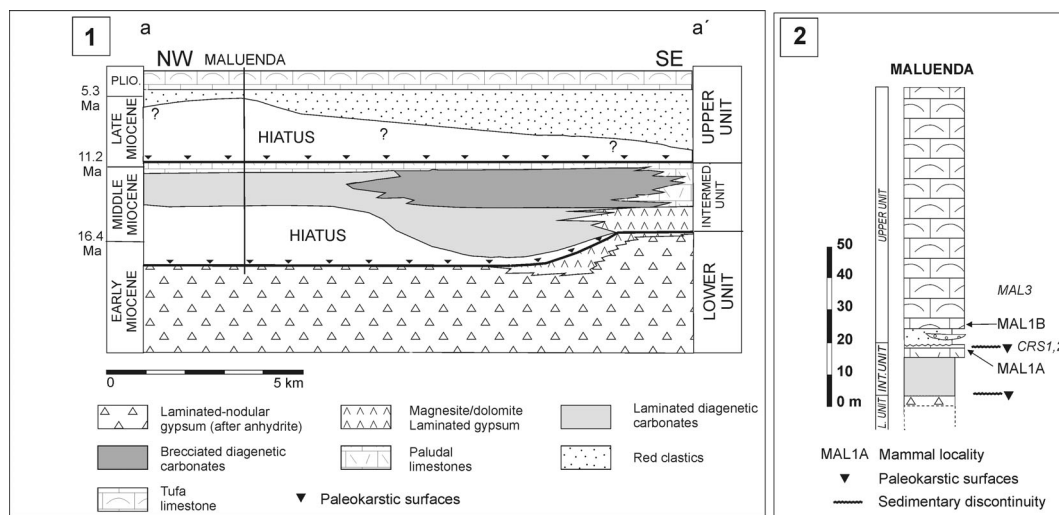


Figure 2.- 1) Stratigraphy of the Neogene deposits in the central sector of the Calatayud basin; 2) Maluenda section with stratigraphic positions of the mammal localities indicated. Italics represent approximate stratigraphic positions of mammal localities.

Figura 2.- 1) Estratigrafía de los sedimentos neógenos del sector central de la Cuenca de Calatayud; 2) Sección de Maluenda con la posición estratigráfica de los yacimientos paleontológicos indicados. En cursivas, se muestran algunos yacimientos de mamíferos con localización estratigráfica aproximada.

related to an important regional tectonic event that has also been recognized in other continental Tertiary basins of the Iberian Peninsula (CALVO *et al.*, 1993).

Until now, age estimations for the upper part of the basin infill have been highly tentative because of the lack of mammal localities. The paleontological site Cerro Grande (CANUDO & CUENCA, 1989) was used by SANZ-RUBIO (1999) to date the top of the Intermediate unit as "late Aragonian/early Vallesian" (latest Middle to earliest Late Miocene). In addition, the presence of middle Late Miocene to Pliocene (Turolian and Ruscinian) sediments has been demonstrated on the basis of samples from Fuentes and Velilla (IGME, 1983). Unfortunately, we have not been able to trace back the exact positions of these localities.

On 4 July 1998, a one-day fieldtrip was organized under the supervision of Remmert DAAMS and Manolo HOYOS to revisit the area and collect more test samples. Unfortunately, both passed away in 1999 within one month. We dedicate this paper, which contains the results of the fieldtrip, to our friends and teachers Remmert DAAMS and Manolo HOYOS.

## MATERIAL

The Cortasogas and Maluenda sites are located in highly collapsed areas between the parallel NW-SE oriented Perejiles and Jiloca rivers. The collapse features are the result of evaporite dissolution at the top of the Lower Unit. This process, which may have repeated itself during different stages of sedimentation of overlying units, has resulted in spectacular collapse morphologies. Stratigraphic sections at both Cortasogas and Maluenda areas are quite similar, although collapse was more intense in the Cortasogas area. For this reason, we have considered the Maluenda section (Fig. 2) as a reference for correlation.

The approximate position of the two Cortasogas localities CRS 1 and 2A sampled in the early eighties could be re-located in the field. New test samples (CRS 1A, 1B & 2B) were taken from or around these sites (Figs. 3, 4). Three fossiliferous levels were found near Maluenda: MAL 1A and 1B (Fig. 5), and MAL3 (Fig. 6). For additional sample information the reader is referred to Table 1. The material belongs to the Diputación General de Aragón.

locality	code	kg sediment	no of teeth	taxa	Teruel biozone range	age estimation (Ma)
Maluenda 3	MAL3	~ 80	1	<i>Stephanomys</i> sp. (advanced)	Tr-MgMh*	4.5 - 3
			4	<i>Oryctolagus</i> cf. <i>laynensis</i>		
Maluenda 1B	MAL1B	~ 100	1	<i>Promimomys</i> sp. / <i>Mimomys davakosi</i>	2PaPr-arM*	5 - 4
			1	<i>Prolagus</i> sp.		
			1	Soricidae indet.		
			1	Chiroptera indet.		
Cortasogas 1A	CRS1A	~ 100	2	<i>Occitanomys sondaari</i>	K	8.5 - 7.5
			2	<i>Prolagus</i> sp.		
Cortasogas 1	CRS1	unknown	4	<i>Occitanomys sondaari</i>	K	8.5 - 7.5
			1	<i>Prolagus</i> sp.		
Cortasogas 2B	CRS2B	~ 100	3	<i>Progonomys hispanicus</i>	J	10 - 8.5
			1	<i>Hispanomys</i> cf. <i>peralensis</i>		
			1	<i>Paenelimoecus</i> sp.		
			1	<i>Galerix</i> sp.		
Cortasogas 2A	CRS2A	unknown	1	<i>Hispanomys</i> cf. <i>peralensis</i>	J	10 - 8.5
			fragm.	Murinae indet.		
			fragm.	<i>Prolagus</i> sp.		
Maluenda 1A	MAL1A	~ 100	3	<i>Muscardinus hispanicus</i>	I-J	11 - 9 (8?)
			fragm.	<i>Prolagus</i> sp.		

\* 2PaPr = 2 *Paraethomys* and *Promimomys* Zone, Tr = *Trilophomys* Zone, aM = Archaic *Mimomys* Zone, MgMh = *Mimomys gracilis* + *M. haynackensis* Zone.

Table 1.- Locality, sampling, taxon and age information. The localities are biostratigraphically correlated to the Teruel biozones of MEIN *et al.* (1990) and VAN DAM *et al.* (2001), which are paleomagnetically calibrated (KRIJGSMAN *et al.*, 1996; OPDYKE *et al.*, 1997; VAN DAM *et al.*, 2001).

Tabla 1.- Localidades, muestreo, taxón e información de la edad. Las localidades están correlacionadas bioestratigráficamente con las biozonas de Teruel, las cuales están calibradas magnetoestratigráficamente.

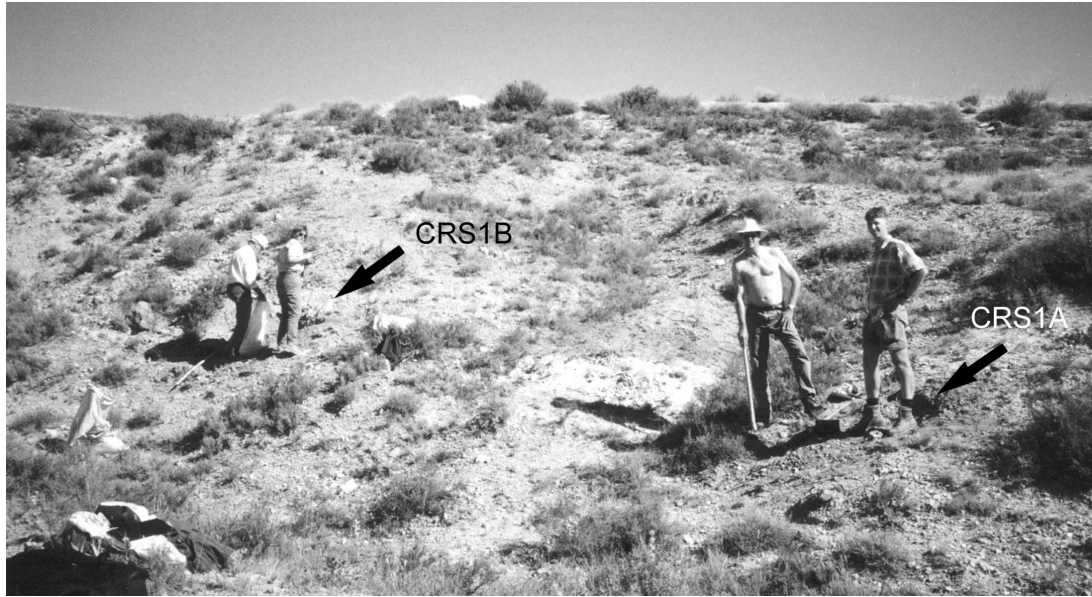


Figure 3.- Outcrop view of the mammal localities Cortasogas 1A and 1B (CRS1A/1B). CRS1A probably corresponds to the old locality CRS1 sampled in the early eighties. 100 kg of sediment from CRS1B did not yield any dental material. Second from the right: Remmert DAAMS.

*Figura 3.- Yacimientos de mamíferos Cortasogas 1A y 1B (CRS1A/1B). Estos yacimientos corresponden posiblemente al antiguo yacimiento CRS1. No se encontró ningún material dentario en los 100 kg de sedimento lavados de CRS1B. Remmert DAAMS es el segundo por la derecha.*



Figure 4.- Outcrop view of the mammal locality Cortasogas 2B (CRS2B). This locality probably corresponds to the old locality CRS2A. Second from the left: Manuel HOYOS.

*Figura 4.- Yacimiento de mamíferos Cortasogas 2B (CRS2B). Este yacimiento se corresponde probablemente con el antiguo yacimiento CRS2A. Manuel HOYOS es el segundo por la izquierda.*



Figure 5.- Outcrop view of the mammal localities Maluenda 1A and 1B. The sedimentary discontinuity between the Intermediate and Upper units is located on top of the whitish-grey marls and carbonates that contain the Maluenda 1A locality. Second from the left: Manuel HOYOS. Fifth from the left: Remmert DAAMS.

*Figura 5.- Yacimientos de mamíferos Maluenda 1A y 1B. La discontinuidad sedimentaria entre la Unidad Intermedia y Superior se localiza sobre las margas y carbonatos blanquecinos y grisáceos, donde se encuentra Maluenda 1A. 4 millones de años separan ambos yacimientos paleontológicos. Manolo HOYOS es el segundo por la izquierda, mientras que Remmert DAAMS es el quinto por la izquierda*

Cortasogas 1 and 1A (X: 617.731, Y: 4.578.329) are positioned in a marly interval, situated below recrystallized palustrine carbonates. The marl is partially cemented by secondary gypsum. Cortasogas 1A predominantly consists of grey marls and is overlain by a greenish marly bed with gastropod fragments. Cortasogas 2B (X: 617.982, Y: 4.578.043) is a dark marly bed with gastropod fragments that is positioned between palustrine carbonates belonging to the lower part of the Upper unit.

Maluenda 1A (X: 616.822, Y: 4.571.824) is a grey bed located just above diagenetic carbonates that replaced the laminated gypsum of the Lower unit and below a thin bed of palustrine carbonates belonging to the Intermediate unit. These beds are overlaid by the red silts and clays that form the basis of Upper unit. The beds show a uniform dip of about 50°. Maluenda 1B (X: 616.822, Y: 4.571.824) is located in

a carbonate interval 4.5 m above the red silts and clays. The carbonates mainly consist of oncolithic channels and autochthonous tufa deposits. The site is included in a light grey and powdery marly bed with gastropod fragments. Maluenda 3 (X: 617.459, Y: 4.572.110) is a thin grey marly bed in a folded part, about 600 m from the Maluenda 1 sites. The beds around the locality show a dip of about 70°. The local sedimentary sequence consists of an alternation of grey marls rich in gastropods and oncolithic beds.

## RESULTS

### CORTASOGAS 1 AND 1A

The murine M1 from CRS1 (L= 1.89, W= 1.25) and CRS1A (L= 1.91, W= 1.22, Fig 7.3) show a t1,



Figure 6.- Outcrop view of the mammal locality Maluenda 3. Dissolution of the Lower unit evaporites resulted in collapse, leading to folding and faulting of the overlying materials. (Folded laminated carbonates of the Upper unit are visible in the background.)

Figura 6.- Yacimiento de mamíferos Maluenda 3. La disolución de las evaporitas de Unidad Inferior genera colapsos que provocan el plegamiento y fracturación de los materiales suprayacentes (ver en la fotografía el plegamiento de los carbonatos laminados de la Unidad Superior).

which is placed backwards, and a strong t6-t9 connection. The CRS1A specimen shows a t1 bis as well. The murine m1 from CRS1 (L= 1.70, W= 1.07) shows a weakly developed buccal ridge and a longitudinal spur. The m2 from CRS1A (L= 1.38, W= 1.20) shows a longitudinal spur as well. In addition two non-diagnostic m3 (L= .90, W= .85; L= .97, W= .90) were found. Morphologically all specimens fit very well the *Progonomys hispanicus* - *Occitanomys sondaari* lineage. *Occitanomys adroveri* and *O. alcalai* can virtually be excluded because these species show relatively large and high cusps. In addition, in *Occitanomys alcalai* the buccal ridge of the m1 is stronger developed (ADROVER *et al.*, 1988). The relatively large size of the m2 practically excludes the possibility that the Cortasogas 1 material belongs to the small and primitive species *P. hispanicus* (VAN DAM, 1997: table 3.2). This observation is consistent with the advanced morphology of the M1, which excludes almost certainly the most primitive

*Progonomys hispanicus* stages belonging to Teruel bio-zones J1 and J2 (VAN DAM *et al.*, 2001).

#### CORTASOGAS 2A AND 2B

The two murine teeth from CRS2A and 2B are very primitive (Figs. 7.4, 7.5). The M1 from CRS2B has a very small width (W= 1.07). (No length could be measured because of a missing anterior part). Considering the slenderness and the lack t6-t9 connection, the specimen can with certainty be assigned to *Progonomys hispanicus*. Also the m2 fits this assignment, both on the basis of size (L= 1.24, W= 1.07) and morphology (no longitudinal spur).

The two *Hispanomys* m1 (CRS2A: L= 2.54, L=1.52; CRS2B: L= 2.43, W= 1.62, Fig. 7.6) are too small to be assigned to *H. freudenthali* (VAN DE WEERD, 1976) and fit very well *H. peralensis*. Because of the limited amount of material, we list these specimens as *H. cf. peralensis*.

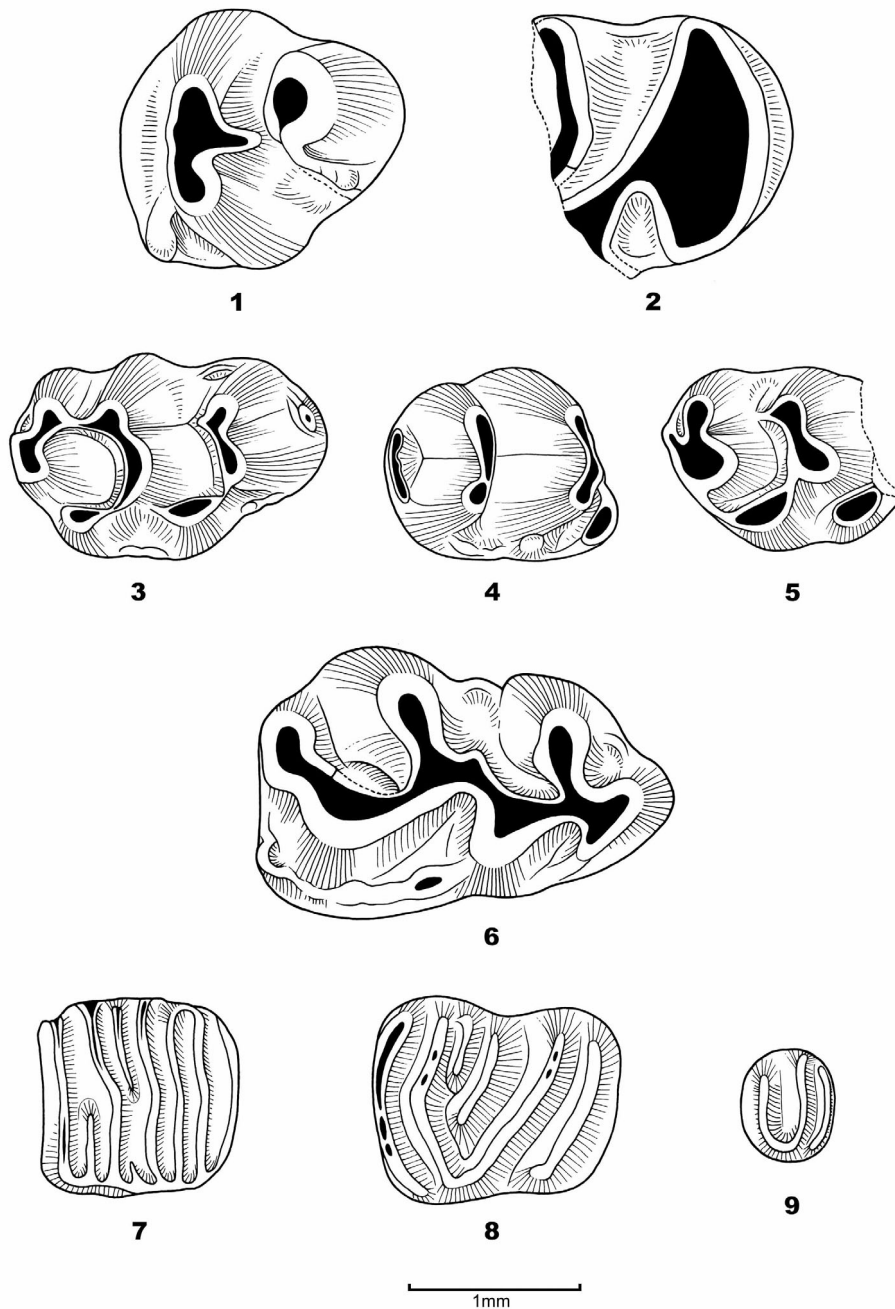


Figure 7.- 1) M3 sin. of *Stephanomys* sp. from MAL3; 2) Anterior part of M1 dex. of *Promimomys* sp. / *Mimomys davakosi* from MAL1B; 3) M1 dex. of *Occitanomys sondaari* from CRS1A; 4) m2 dex. of *Progonomys hispanicus* from CRS2B; 5) M1 dex. of *Progonomys hispanicus* from CRS2B; 6) m1 dex. of *Hispanomys* cf. *peralensis* from CRS 2B; 7) M2 sin. of *Muscardinus hispanicus* from MAL1A; 8) M1 dex. of *Muscardinus hispanicus* from MAL1A; 9) P4 dex. of *Muscardinus hispanicus* from MAL1A.

Figura 7.- 1) M3 sin. de *Stephanomys* sp. de MAL3; 2) parte anterior de M1 dex. de *Promimomys* sp. / *Mimomys davakosi* de MAL1B; 3) M1 dex. de *Occitanomys sondaari* de CRS1A; 4) m2 dex. de *Progonomys hispanicus* de CRS2B; 5) M1 dex. de *Progonomys hispanicus* de CRS2B; 6) m1 dex. de *Hispanomys* cf. *peralensis* de CRS 2B; 7) M2 sin. de *Muscardinus hispanicus* de MAL1A; 8) M1 dex. de *Muscardinus hispanicus* de MAL1A; 9) P4 dex. de *Muscardinus hispanicus* de MAL1A.

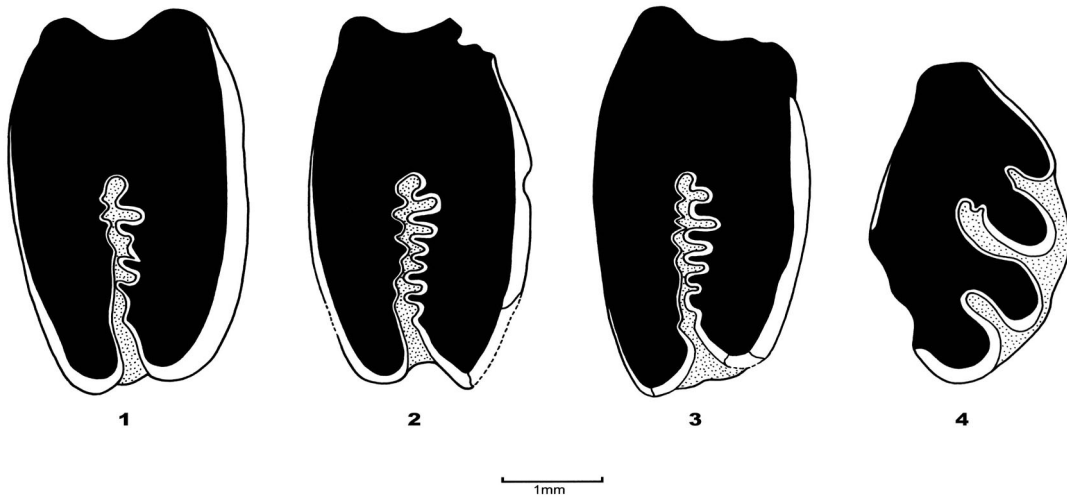


Figure 8.- *Oryctolagus* cf. *laynensis* from MAL3. 1. M1 dex; 2. P4 dex; 3. P3 dex; 4. P2 dex.

Figura 8.- *Oryctolagus* cf. *laynensis* de MAL3. 1. M1 dex; 2. P4 dex; 3. P3 dex; 4. P2 dex.

#### MALUENDA 1A

Only three teeth of *Muscardinus* were recovered from this locality, a P4 (L= .56; W= .67), M1 (L= 1.40; W= 1.20), and M2 (damaged) (Figs. 7.7-7.9). These elements show 3, 6 and 8 transverse ridges, respectively. The anteroloph of the P4 is very thin. The two centrolophs of M1 are short. No extra, third centroloph is present. The M1 is three-rooted, whereas the roots of M2 are broken off, but three scars are visible on the crown base. The specimens fall well into the variation of *M. hispanicus* DE BRUIJN, 1966 (compare also VAN DE WEERD, 1976: table 50). The M1 is too long for the more primitive *M. thaleri* DE BRUIJN, 1966. *M. aff. crusafonti* from Conclud 3 in the Teruel basin (VAN DE WEERD, 1976) can be excluded because of its larger size, whereas *M. vireti* HUGUENEY & MEIN, 1965 can be excluded because its M1 is four-rooted. *M. pliocaenicus* KOWALSKI, 1963, shows a simpler dental pattern: it has only two ridges in the P4 and six ridges in the M2.

#### MALUENDA 1B

The level of MAL1B has produced a worn-down anterior part of an arvicoline M1 (Fig. 7.2), lacking enamel differentiation and cement. Both size and

morphology of this fragment either fits the *Promiomys* or *Miomys davakosi* stage of evolution. (E.g. *M. occitanus* can be excluded because this species already has enamel differentiation.)

The level has also yielded a *Prolagus* d3 (crown top: L= 1.23, W= 1.00; crown base: L= 1.57, W= 1.11), which unfortunately could not be identified to the species level, because size and morphology of the d3 remain fairly constant during *Prolagus* evolution.

#### MALUENDA 3

The murine m3 found in MAL3 (Fig. 7.1) resembles *S. donnezani* (e.g. from Layna; CORDY, 1976). The anterior-buccal cusp is reduced and low relative to the protoconid. Its size (L= 1.63, W= 1.52) is at the lower boundary of the Layna population, but fits quite well the size range of Sète (both localities have been correlated to MN15). However, size is also at the upper boundary of *S. margaritae*, which has been defined by ADROVER (1986) as a species with a size intermediate between *S. medius* and *S. donnezani*. *S. calveti* BACHELET AND CASTILLO-RUIZ, 1990, from Belmèz and Plà-de-la-Ville (correlated to MN15 and 16, respectively), cannot be excluded either on the basis of size and morphology. The specimen cannot belong to *S. medius* (too small, crown too low) and *S.*



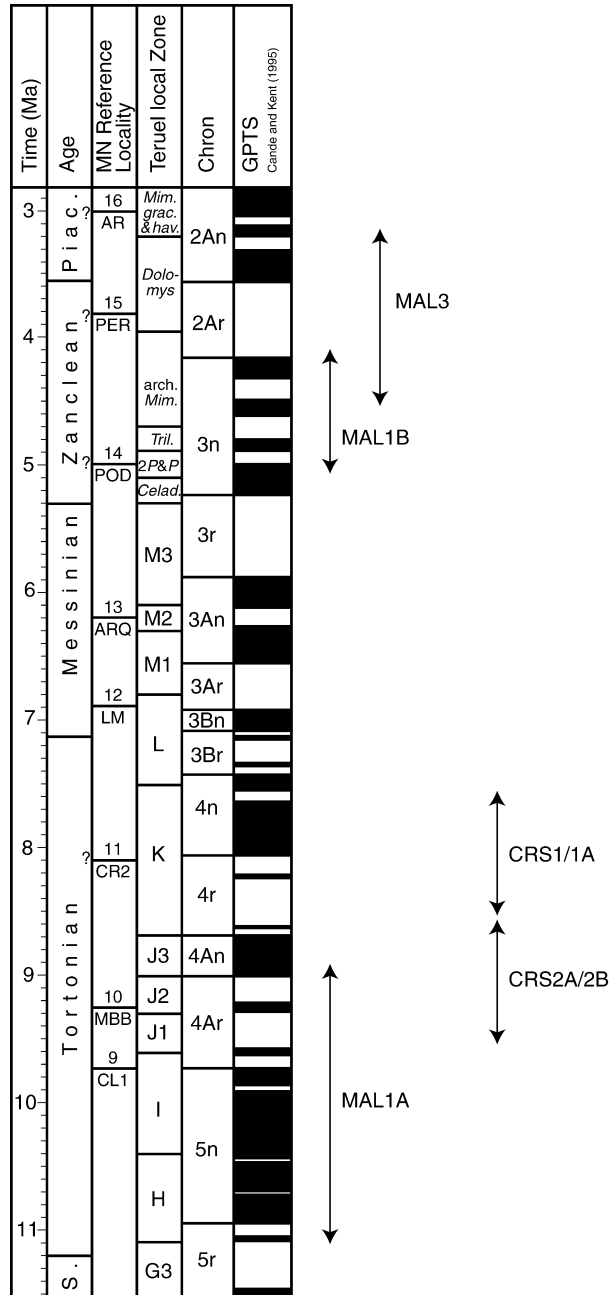


Figure 9.- Correlation of the Cortasogas and Maluenda localities to the numerical time scale, marine Ages, MN reference localities, Teruel local Zones, and Geomagnetic Polarity Time Scale. Local Zones and their chronology after MEIN *et al.* (1990), KRIGSMAN *et al.* (1996), OPDYKE *et al.* (1997) and VAN DAM *et al.* (2001). Reinterpretation of the base of the *Mimomys gracilis* & *M. haynackensis* Zone (MEIN *et al.*, 1990) after AGUSTÍ *et al.* (2001). The arrows indicate the age uncertainties of the localities.

Figura 9.- Correlación de los yacimientos de Cortasogas y Maluenda con la escala temporal numérica, pisos marinos, localidades MN de referencia, Zonas Locales de Teruel y la Escala Temporal de Polaridad Geomagnética. Las Zonas Locales y su cronología son posteriores a MEIN *et al.* (1990), KRIGSMAN *et al.* (1996), OPDYKE *et al.* (1997) y VAN DAM *et al.* (2001). La reinterpretación del base de la Zona de *Mimomys gracilis* & *M. haynackensis* (MEIN *et al.*, 1990) es posterior a AGUSTÍ *et al.* (2001). Las flechas indican el rango de variabilidad temporal de los yacimientos.

*thaleri* (too large, crown too high). *S. minor* can be excluded because it has its anterior-buccal cusp at an equal height as the other cusps, and it shows a pronounced inflection in the buccal enamel-dentine boundary in lateral view (CORDY, 1976).

Four leporine teeth (P2-M1, Fig. 8), belonging to one individual, were spotted in the field by Remmert Daams. The P2 (Fig. 8.4; L= 1.66, W= 3.27) shows four anterior lobes. The paraflexus represents the deepest inflection. Both hypo- and mesoflexus are well developed. The mesial hypercone and the lagi-cone are equally sized. The P3 (Fig. 8.3) and P4 (Fig. 8.2) are moderately damaged, but the occlusal surface of the M1 (Fig. 8.1; L= 2.31, W= 4.48) is complete. P3, P4 and M1 show a well-developed hyperflexus extending more than halfway with regard to the tooth width. The enamel ridge bordering the hypoflexus in these elements shows about six crenulations on the anterior side and three crenulations on the anterior side.

The presence of both mesoflexus and hyperflexus on the P2 excludes *Alilepus* and *Trischizolagus*. Generally, the size is that of *Oryctolagus* and not of *Lepus*. The small *Lepus granatensis*, as described from the middle Pleistocene of S. Spain (LÓPEZ-MARTÍNEZ, 1989), can be excluded on the basis of its P2, which has a very short meso- and hypoflexus. With an equal size of mesial hypercone and the lagi-cone the P2 could fit both *Oryctolagus laynensis* and *O. cuniculus*. The particular pointed shape of the buccal outline of the distal hypercone (LÓPEZ-MARTÍNEZ, 1989: fig. 56) fits better the former species. *O. cf. laynensis* (as we list it) from Maluenda 3 differs from the type population Layna (LÓPEZ-MARTÍNEZ, 1989) in having more crenulations in the hypoflexus border of P3-M1.

## DISCUSSION

### BIOSTRATIGRAPHY AND CHRONOLOGY

We have biostratigraphically correlated the Cortasogas and Maluenda localities to the dense small sequence of Teruel Basin, situated about 150 km in SSE direction, on the basis of which detailed Miocene (VAN DAM *et al.*, 2001) and Pliocene (MEIN *et al.*, 1990) zonations have been constructed (Table 1, Fig. 9). The age estimations are based on magnetostratigraphic studies in the Teruel and other Spanish basins (KRIJGSMAN *et al.*, 1996; OPDYKE *et al.*, 1997, AGUS-

TÍ *et al.*, 2001; VAN DAM *et al.*, 2001). Age estimations for the Calatayud localities are rounded to values of 0.5 Myr, because of age uncertainty of some zone boundaries and the expected geographic differences in faunal events and composition.

The localities of Cortasogas 2A and 2B are correlated to Teruel Zone J (correlative to MN10), which is the *Progonomys hispanicus* - *Parapodemus lugdunensis* Zone. Cortasogas 1 and 1A are correlated to Zone K (correlative to MN11), the *Parapodemus lugdunensis* Zone, using the presence of *Occitanomys sondaari*. A "Vallesian" (Zone H or I) age is assigned to Maluenda 1A because *Muscardinus hispanicus* is restricted to this interval (DE BRUIJN, 1976; VAN DAM *et al.*, 2001). No *Muscardinus* is known from the well-sampled Zone K ("lower Turolian", correlates to MN11) in the Teruel basin, which is probably due to climatic conditions (aridity). Although a Zone K-equivalent age for Maluenda 1A is theoretically possible, we discard the possibility of a Zone L-equivalent age (correlative to MN12), because a more advanced form (*M. aff. hispanicus*) is known from this interval (VAN DE WEERD, 1976).

The presence of a species belonging to the *Promiomys* or *Miomys davakosi* stage of evolution in Maluenda 1B constrains the age of this locality to the early Pliocene (~5-4 Ma). The maximum age of 4.5 Ma for MAL3 is based on the range of *S. margaritae*, which enters the Teruel Basin in the *Trilophomys* Zone (MEIN *et al.* 1990). An upper limit of 3 Ma is based on the range of *S. calveti*, which has been found in levels correlative to "lower MN16" (BACHELET AND CASTILLO-RUIZ, 1990).

### IMPLICATIONS FOR THE STRATIGRAPHIC FRAMEWORK OF THE BASIN

The presence of an up to 45 m thick sequence of brecciated carbonates in the uppermost part of the Intermediate unit (particularly well-developed in the south-eastern part of the basin) points to a sedimentary discontinuity between the Intermediate and Upper units. These carbonates show widespread diagenetic fabrics formed at relatively shallow depth caused by downward circulation of sulphate-poor surface-derived ground waters of meteoric origin (SANZ-RUBIO *et al.*, 2001). They record a complex history of dissolution, collapse and infilling, responsible for typical karst structures, such as caves, collapse breccia and speleothems. Because of the

lack of biostratigraphic data, it was difficult so far to estimate the age and duration of the time interval represented by this sedimentary discontinuity. A rough estimation (interval corresponding to part of zones I-J, i.e. "Vallesian") was made by SANZ-RUBIO (1999) on the basis of distant paleontological sites. The new biostratigraphic data, however, demonstrate that the hiatus between the Intermediate and Upper units in the central areas of the basin includes a major part of the "Turolian" (late Tortonian and Messinian).

The evolution of the Middle Miocene to Pliocene sedimentation of the Calatayud Basin and the Maluenda and Cortasogas areas can shortly be summarised as follows:

Around the Early-Middle Miocene transition, sedimentation of the Lower unit ended, and was followed by subaerial exposure of the evaporites, development of paleokarstic features and a relative drop of the water table. Also the Maluenda and Cortasogas areas, which were main depocenters for Lower unit evaporite sedimentation (HOYOS *et al.*, 1996), became subaerially exposed. Sedimentation continued in the northwestern and southeastern areas and in new depocentres formed at the margins of the basin (SANZ-RUBIO *et al.*, 2001). The beginning of the deposition of the Intermediate unit was marked by a change in the hydrochemical composition of the brines, with increased input of  $\text{CaHCO}_3^-$  enriched meteoric waters and a drop in the salinity. Due to the differential loading caused by the deposition of the earliest sediments of the Intermediate unit, the burial was more extensive in the external parts than in the centre of the evaporitic basin (SANZ-RUBIO *et al.*, 2001).

At the end of deposition of the Intermediate unit, the process of evaporite dissolution and karstification migrated to the central parts of the basin, including Maluenda and Cortasogas. In these parts the Intermediate unit is represented by very thin deposits corresponding to the uppermost levels of the unit at basin scale. During the early Late Miocene (11-9 Ma), a new paleokarstic event occurs, which is particularly well-expressed in the southeastern parts of the basin, and which corresponds to the sedimentary discontinuity between the Intermediate and Upper unit. Central parts of the basin remained subaerially exposed between 9-8 and 5-4 Ma, as indicated by the mammal faunas. Sedimentation resumed with the deposition of red siliciclastics (beginning of the deposition of the Upper unit). Deposition started earlier in the southeastern part of the basin (thickness up

to 65 m) than in the central parts (e.g. 5 m at Maluenda). Finally, the Maluenda and Cortasogas areas subside as a result of the continuation of evaporite dissolution and collapse, resulting in the accumulation of thick Pliocene carbonatic series.

## CONCLUSION

The mammal sites of Cortasogas and Maluenda provide new age constraints for the upper part of the Neogene series of the Calatayud Basin. The new biostratigraphic data imply the presence of a major hiatus, probably including the complete "Turolian" (late Tortonian and Messinian), in some central parts of the basin. This sedimentary discontinuity between the Intermediate and Upper sedimentary units is associated with the occurrence of typical structures such as caves, collapse breccia and speleothems. With additional sampling of the studied localities, the chronology of the Late Miocene and Pliocene evolution of the Calatayud Basin can be further refined.

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