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Micromammal biostratigraphy of the Upper Miocene to lowest Pleistocene continental deposits of the Guadix basin, southern Spain

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Recent study of the small mammals (rodents and insectivores) from several fossil-bearing sites situated in the central sector of the Guadix Basin (Southern Spain) has notably increased the knowledge of the mammal assemblages that existed in Southern Iberia from the latest Miocene to the earliest Pleistocene. On the basis of this new information, we propose a biozonation for the continental deposits of the Guadix Basin, which consists of six biozones ranging in age from the late Turolian (MN13) to the early Villanyian (MN17). These biozones, defined according to the rules of the *International Stratigraphical Guide*, include not only the mentioned recently discovered fossil sites, but also other, previously known, localities of the basin. Finally, we integrate the described biozones in the Neogene Mammal units and the European Land Mammal Ages, correlate them with several classical mammal sites from other Iberian basins and the rest of Europe, and establish an approximate numerical age for the lower and upper limits of each biozone.

☐ *Biostratigraphy, Guadix Basin, rodents, insectivores, Upper Miocene, Pliocene, Pleistocene.*

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Fossil micromammals (mainly rodents) are a basic tool for the establishment of biostratigraphical and chronostratigraphical scales in the Neogene and Quaternary continental deposits, thanks to their rapid evolution and the relative abundance of their remains. However, the scales based on fossil mammals present some problems, because the discontinuity of their record makes the situation of the boundaries between different biostratigraphical units difficult (Fahlbusch 1991; Hernández Fernández *et al.* 2004). Other difficulties derive from the biogeographical patterns of terrestrial mammals, more complex than those of marine organisms, and from the problems of preservation in subaerial environments (Walsh 1998; van Dam *et al.* 2001; Gómez Cano *et al.* 2011). The particularities of the continental mammal record have led to the description of various systems of subdivision, which are sometimes quite different from those used for marine deposits.

From the 1970s onwards, several studies have focused on the biostratigraphical division of the European Neogene and Quaternary, the most remarkable being the definition and subsequent revisions of the Neogene Mammal (MN) units (Mein 1975, 1990, 1999; de Bruijn *et al.* 1992), Rodent Zones and Superzones (Fejfar & Heinrich 1990; Fejfar *et al.* 1998) and European Land Mammal Ages (ELMA) (Fahlbusch 1976; Steininger 1999), as well as the description of different continental stages (Daams *et al.* 1977, 1987). Besides these systems of European or even Eurasian scale, several works have established local biozones based on the stratigraphical distribution of rodents. For the Spanish Upper Miocene and Pliocene, some of the most significant studies defining local zonations are those of van de Weerd (1976), Mein *et al.* (1990) and van Dam *et al.* (2001) in the Teruel-Alfambra region, Agustí *et al.* (1997) and Casanovas-Vilar *et al.* (2011) in the Vallès-Penedès Basin, Martín Suárez & Freudenthal (1998) in the area of Crevillente, and García-Alix *et al.* (2008a) in the Granada Basin. Recently, Cuenca-Bescós *et al.* (2010), on the basis of the small mammal record of the different fossil bearing levels of the Sierra de Atapuerca complex, formally

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defined several rodent biozones with validity for the Iberian Pleistocene. Regarding the Guadix Basin, the main biostratigraphical studies (Agustí 1986, 1990; Martín Suárez 1988; Agustí & Martín Suárez 1994) are in need of a thorough revision in the light of new discoveries, or are focused only on the most recent (Pleistocene) deposits found in the basin (Oms *et al.* 2000).

In previous years, the exhaustive study of the small mammals (rodents and insectivores) from several sites located in the central sector of the Guadix Basin (Minwer-Barakat *et al.* 2004, 2005, 2007, 2008a, b, c, 2009a, b, 2010; García-Alix *et al.* 2007a, 2008b) has increased notably the knowledge of the mammal faunas that inhabited the south of the Iberian Peninsula from the Late Miocene to the earliest Pleistocene. These fossiliferous levels, distributed along a very complete stratigraphical succession, represent the most complete sequence of micromammal sites found in the Guadix Basin. Moreover, the extensive sampling of each level has yielded large fossil collections and led to the establishment of complete faunal lists for most localities, showing notable changes in the faunal composition from the oldest to the youngest sites. Thus, the study of these levels represents an important increase in the information on the micromammal assemblages from this area during a long time interval, which can be very useful for the establishment of biostratigraphical units of local value.

In this work, we propose a new local biozonation for the continental deposits of the Guadix Basin based on all these recent findings and taking also into consideration the previously established local zonations. The defined biozones include not only the fossil sites studied by our team, but also other formerly known localities of this basin. Moreover, we correlate this biozonation with the MN and ELMA systems, with other local biozonations established in different Iberian areas, as well as with several European fossil localities. We also intend to give an approximate numerical age for the lower and upper limits of each biozone, by comparison with the faunal content of other continental sections calibrated with the Geomagnetic Polarity Time Scale.

Although some previously described faunal assemblages from the basin need an exhaustive systematic revision that will allow their inclusion in this new biozonation, this work contributes to create a properly defined biostratigraphical framework, necessary for arranging the mammal fossil sites of one of the Iberian basins with a longest continental record.

Geological setting

The Guadix Basin (Fig. 1), situated in the central sector of the Betic Cordillera, was established as a separate intramontane basin in the late Miocene (Viseras *et al.* 2004, 2005). It seals the contact between the two main structural realms of the Betic Cordillera: the Internal Zones (or Alboran Block) and the External Zones (corresponding to the folded and faulted South Iberian palaeomargin). The sedimentary infill of this basin has been divided into six genetic units (Fernández *et al.* 1996a), of which the boundary unconformities are related to both tectonic events and eustatic changes (Soria *et al.* 1998). The two lower units (Units I and II) were deposited in a phase of marine sedimentation during the Tortonian, and the third one (Unit III) includes shallow marine sediments, deposited during the sea retreat from the central sector of the Betic Cordillera at the end of the Tortonian (García-García *et al.* 2009). The three youngest units (Units IV, V and VI) correspond to a phase of exclusively continental sedimentation in an endorheic basin context, from the late Turolian to the late Pleistocene. This sedimentary stage was interrupted in the late Pleistocene, when a stream piracy process triggered the change of the basin from endorheic to exorheic (Calvache & Viseras 1997). Since then, the basin has formed part of the catchment area of the Guadalquivir River, and has been subject to significant erosion.

Within the continental units, three main drainage systems can be distinguished (Fernández *et al.* 1996b). The so-called Axial System flowed parallel to the palaeogeographical axis of the basin, towards the NE (Viseras 1991). This fluvial-lacustrine longitudinal drainage system drained into a large shallow lake, located to the East, which acted as base level for the entire depression. The Axial System was fed by two transverse alluvial systems. The Internal Transverse System had large coalescent alluvial fans with their source area located on the Internal Zones of the Betic Cordillera (Viseras & Fernández 1994). The External Transverse System was composed of small isolated alluvial fans and fan deltas that received its input from the erosion of the External Zones of the Betic Cordillera (see Viseras *et al.* 2004 and references therein). In addition to these three drainage systems, the so-called Lacustrine System was developed when the valley of the main fluvial system (Axial System) was temporarily occupied by small shallow lakes that represented flooding of large areas of the floodplain (Viseras *et al.* 2006; Arribas *et al.* 2009; Pla-Pueyo *et al.* 2009).

Description of the studied sections and fossil sites

The studied area is situated in the central part of the basin, where fine-grained clastic deposits corresponding to distal alluvial and fluvial sedimentation

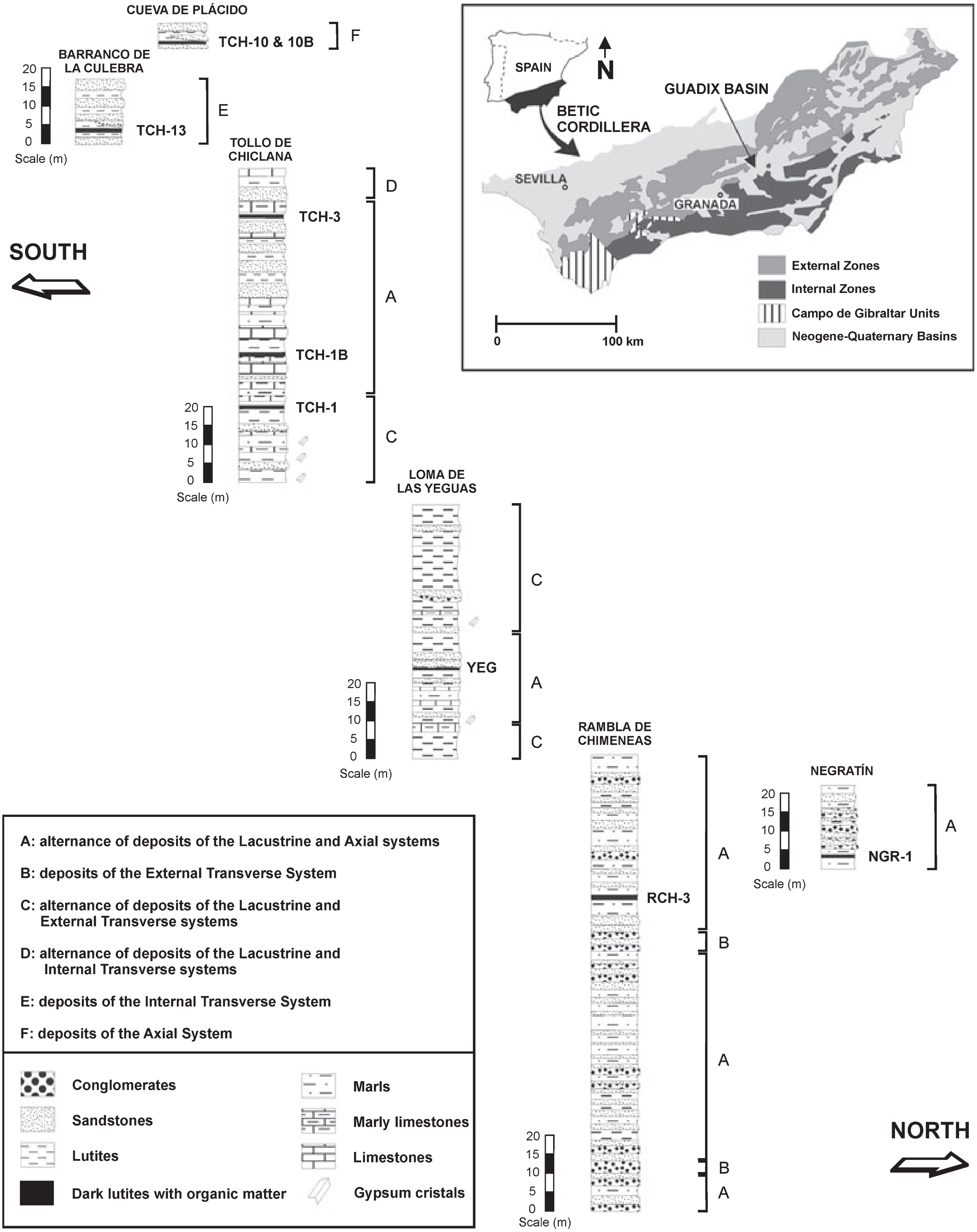


Fig. 1. Geographical and geological setting of the Guadix Basin, and synthetic stratigraphical columns of the studied sections.

alternate with lacustrine carbonates. It includes several sections, represented in Fig. 1 and succinctly described below. According to Viseras (1991), this is the area of the basin where sedimentation shows evidences of having been more continuous. This implies that the study area should contain the most complete fossil record of the entire basin for the studied time interval. Further details may be consulted in Minwer-Barakat (2005).

The section of Negratín is situated 4 km south of Cuevas del Campo, close to the road connecting this village with the Negratín Dam. The section consists of an alternance of grey marls and black, laminated clays with vegetal remains and gastropods (corresponding to the lacustrine system), and channel bodies of clast-supported conglomerates, overlain by sands with clasts of different lithology (metamorphic rocks and limestones). These conglomerates and sands correspond to the Axial Fluvial System, which in its distal part incorporates an important amount of sediment supplied by the External Transverse System fans. The level of NGR-1 is found at 30SWG042591; it is a 50 cm thick level of black lutites with abundant organic matter, gastropods and root traces. Its faunal list includes *Apodemus gudrunae, Occitanomys alcalai, Stephanomys dubari*, *Paraethomys meini, Ruscinomys* sp., *Apocricetus alberti, Debruijnimys almenarensis, Myocricetodon jaegeri, Eliomys* sp., *Atlantoxerus* sp., *Parasorex ibericus* and Soricidae indet. (Minwer-Barakat *et al.* 2009a).

The section of Rambla de Chimeneas is situated 10 km east of Villanueva de las Torres and 6 km west of the Negratín Dam, on the left bank of the Guadiana Menor River. On the opposite riverside, close to the base of the section, late Miocene bioclastic calcarenites crop out, corresponding to the preceding phase of marine sedimentation. The section includes conglomerates and sands with mainly metamorphic clasts (corresponding to the Axial System), conglomerates with mostly limestone fragments (belonging to the External Transverse System), and grey marls, in decimetric to metric thick levels, which correspond to the Lacustrine System. The level of Rambla de Chimeneas-3 (RCH-3) is located at coordinates 30SVG997579; it is a 50-cm thick level of dark marls with abundant remains of gastropods. The faunal list of this fossiliferous level is the following: *Occitanomys alcalai, Stephanomys dubari*, *Paraethomys meini,* Cricetinae indet., Erinaceidae indet. and Soricidae indet (see Minwer-Barakat *et al.* 2009b for further details).

The section of Loma de las Yeguas is located 2 km southwest of the Rambla de Chimeneas section (Minwer-Barakat 2005). It includes red, laminated clays, often with gypsum cristals ('playa-lake' deposits), and scarce levels of red sands, which correspond to the most distal parts of the External Transverse System; dark sands (occasionally also gravels) with a high content of mica, silts and clays, belonging to the Axial System, and white limestones, corresponding to the Lacustrine System. This alternance of distal fluvial and lacustrine deposits also includes thin levels of gypsum. The fossil site called Yeguas (previously studied by Soria & Ruiz Bustos 1991), a 25-cm thick level of dark grey clays at coordinates 30SVG980567, has yielded remains of *Paraethomys meini, Stephanomys cordii, Apocricetus barrierei, Asoriculus gibberodon* and *Paenelimnoecus pannonicus* (Minwer-Barakat 2005).

The composite section of Tollo de Chiclana is the youngest of the studied sections and contains several fossiliferous levels, the fauna of which has been described in several previous papers (Minwer-Barakat *et al.* 2004, 2005, 2007, 2008a, b, c, 2010; Furió *et al.* 2007; García-Alix *et al.* 2007a, 2008b). Its base is situated 2.5 km southwest of the top of the section of Loma de las Yeguas. The section crops out along 4.5 km of a NNE-SSW ascending path; the deposits are arranged in virtually horizontal beds, so the youngest levels are situated to the south. In view of the irregular topography, we have divided the section in several subsections with a good exposure of the sediments; the northernmost and oldest one is the so-called subsection of Tollo de Chiclana. It consists of red-brown clays with gypsum and scarce intercalations of silts, sands and gravels with carbonate clasts, which correspond to floodplain deposits of the most distal part of the External Transverse System; white marls and limestones with root traces corresponding to the lacustrine system, and grey lutites and fine-grained sands, representing distal deposits of the Axial System. In the northernmost part, there are also some levels of brown sands of the Internal Transverse System.

In this subsection, three fossiliferous levels have been identified. The oldest one, called Tollo de Chiclana-1 (TCH-1), is a 50-cm thick level of dark clays with abundant gastropods, at 30SVG959553. Its faunal list includes *Castillomys crusafonti, Apodemus atavus, Paraethomys meini, Stephanomys* sp., *Dolomys adroveri, Eliomys intermedius, Asoriculus gibberodon, Paenelimnoecus pannonicus* and *Archaeodesmana elvirae*. Approximately 15 m above this level, the site of Tollo de Chiclana-1B (TCH-1B) crops out at coordinates 30SVG958552. It is a 45-cm thick bed of black clays with gastropods, which have yielded abundant remains of micromammals including *Stephanomys donnezani, Castillomys crusafonti, Apodemus atavus, Occitanomys brailloni, Rhagapodemus frequens, Mimomys hassiacus, Blancomys meini, Trilophomys vandeweerdi, Pliopetaurista pliocaenica, Eliomys intermedius, E. truci, Asoriculus gibberodon, Paenelimnoecus pannonicus, Myosorex meini* and *Archaeodesmana brailloni.* About 35 m upwards, the level of Tollo de Chiclana-3 (TCH-3) is found at coordinates 30SVG957549. This 25-cm thick bed of grey clays has yielded remains of *Stephanomys thaleri, S. minor, Castillomys crusafonti, Apodemus atavus, Mimomys stehlini, Kislangia ischus, Eliomys intermedius, Asoriculus* *gibberodon, Paenelimnoecus pannonicus, Myosorex meini, Blarinoides aliciae, Archaeodesmana* sp. 3 (according to Minwer-Barakat *et al.* 2008a) and Talpinae indet.

The subsection of Barranco de la Culebra, located 3.5 km to the south of the site TCH-3, includes gravels with clasts of schist, quartzite and dolostone, brown sands, silts and clays representing distal aluvial deposits of the Internal Transverse System. Only some centimetric beds of lacustrine carbonates appear in this subsection. The site called Tollo de Chiclana-13 (TCH-13) is a 35-cm thick level of dark clays situated at coordinates 30SVG955509, with the following faunal list: *Stephanomys thaleri, S. minor, Castillomys crusafonti, Apodemus atavus, Micromys caesaris, Mimomys stehlini, Eliomys truci, Asoriculus gibberodon, Paenelimnoecus pannonicus, Petenyia hungarica,* Desmaninae indet and Talpinae indet.

The uppermost subsection is the Cueva de Plácido subsection, in which the youngest deposits studied in this work crop out. It consists of gravels with mostly schist clasts, grey sands, silts and clays, corresponding (according to Viseras *et al.* 2009) to distal fluvial deposits of the Axial System. The sites Tollo de Chiclana-10 and 10B (TCH-10 and 10B) are situated at the same height and very close to each other, at the base of two low hills separated by a small ravine, at coordinates 30SVG942520. Both are 20-cm thick levels of greenish grey lutites, so they must correspond to the same stratigraphical level. The faunal list of these two levels is also equivalent, including *Stephanomys balcellsi, Castillomys rivas, Micromys* sp., *Mimomys medasensis, Myosorex meini,* Soricidae indet. and Desmaninae indet.

Previous biozonations for the Guadix Basin

From the 1980s onwards, several local biozonations have been proposed for the Guadix Basin (Agustí 1986, 1990; Agustí *et al.* 1987; Martín Suárez 1988; Agustí & Martín Suárez 1994; Oms *et al.* 2000). Fig. 2 shows the zones defined by different authors and their relationships with the MN (Mein 1975) and MmQ (Agustí *et al.* 1987) units; the biozones proposed in the present work are also included in the figure. Differences between these schemes are small and mainly caused by the changes of the species that give name to some biozones. The only biozone whose position with respect to the MN units has been modified is the *Kislangia gusii* Zone: this species was first identified as *Mimomys rex* and placed in the Lower Villanyian, MN16 (Martín Suárez 1988) and later situated in the Upper Villanyian, MN17 (Agustí & Martín Suárez 1994). Martín Suárez (1988) and Agustí & Martín Suárez (1994) formally defined a group of biozones (assemblage zones, taxon-range zones, concurrent-range zones, etc.), which included most of the mammal localities known in the basin at that moment. This scheme was slightly modified by Oms *et al.* (2000), but only for those zones corresponding to the Upper Pliocene and Pleistocene (although all of them correspond to the Pleistocene after Gibbard *et al.* 2010).

In the past decade, a significant increase in the knowledge of the micromammal faunas from this basin has occurred, by identifying several species previously unknown in the area, pointing out certain problems with the taxonomic ascription of some taxa, and discovering various localities (some of them studied in the present work) that are impossible to include in the previously defined biostratigraphical schemes. These problems are especially important regarding the biozones previously described for the Upper Ruscinian and the Lower Villanyian.

The '*Mimomys occitanus*' biozone (Agustí 1986, 1990; Martín Suárez 1988; Agustí & Martín Suárez 1994) was established on the basis of the faunal assemblages of the sites Gorafe-2, 3 and 5, being characterized by the presence of the mentioned species (which was transferred to the genus *Dolomys* by Maul 1996), considered as the taxon with highest biostratigraphical value. However, the arvicolid teeth from these levels are very scarce, and their ascription to the species *D. occitanus* is not conclusive. Other Spanish populations originally ascribed to this species were later assigned to other taxa such as *Mimomys gracilis, Mimomys hassiacus* or *Dolomys adroveri*. On the other hand, the assignation of the arvicolids from other Ruscinian localities of the Guadix Basin to the species *Mimomys stehlini* (Ruiz Bustos & Sesé 1985; Ruiz Bustos 1987) seems not to be correct (see Minwer-Barakat *et al.* 2008b and references therein). Therefore, a revision of the Ruscinian arvicolid faunas from this basin, as well as the definition of new biozones, becomes necessary. In this way, two of the localities studied in this work have yielded large samples of arvicolid teeth that have allowed precise specific determinations (*Dolomys adroveri* from TCH-1 and *Mimomys hassiacus* from TCH-1B, Minwer-Barakat *et al.* 2004, 2008b), and the definition of two new biozones for the Upper Ruscinian (see next section). Nevertheless, the revision of the arvicolids from other localities will probably lead to the identification of other species, which may permit the definition of more zones or subzones.

The criteria employed for the establishment of the *Apodemus agustii* biozone are also imprecise. Agustí & Martín Suárez (1994) characterized this zone by the association of taxa that have a long stratigraphical distribution: '*Apodemus dominans*' (= *A. atavus*, see

MN (Mein, 1975) and MmQ (Agustí et al., 1987) units	**Guadix Basin Biozones**					
	Agustí (1986)	**Agustí (1990)**	**Martín Suárez (1988)**	**Agustí and Martín Suárez (1994)**	**Oms et al. (2000)**	**This work**
MmQ-4	*Arvicola cantiana*	*Arvicola cantiana*			*Arvicola cantiana*	
MmQ-3	*Pitimys* cf. *arvalidens*	*Pitimys arvalidens*			*Terricola arvalidens*	
	Mimomys savini	*Allophaiomys nutiensis* ssp.	*Mimomys savini*	*Mimomys savini*	*Allophaiomys burgondiae*	
MmQ-2	*Allophaiomys pliocaenicus*	*Allophaiomys pliocaenicus*	*Allophaiomys pliocaenicus*	*Allophaiomys pliocaenicus*	*Allophaiomys pliocaenicus*	
MmQ-1	*Mimomys ostramosensis*	*Mimomys* sp. A	*Mimomys ostramosensis*	*Mimomys ostramosensis*	*Mimomys oswaldoreigi*	
MN17	*Mimomys* cf. *reidi*	*Mimomys* cf. *reidi*	*Mimomys* cf. *reidi*	*Kislangia gusii*	*Mimomys* cf. *reidi*	
					Kislangia gusii	*Mimomys medasensis*
MN16	*Mimomys cappettai*	*Kislangia* aff. *cappettai*	*Mimomys rex*	*Kislangia cappettai*		*Stephanomys minor*
			Mimomys cappettai			
MN15	*Mimomys occitanus*	*Mimomys occitanus*	*Apodemus agustii*	*Apodemus agustii*		*Mimomys hassiacus - Stephanomys donnezani*
			Mimomys occitanus	*Mimomys occitanus*		*Dolomys adroveri*
MN14	*Trilophomys castroi*	*Trilophomys castroi*	*Trilophomys*	*Trilophomys*		*Trilophomys*
MN13			*Apodemus gudrunae*	*Apodemus gudrunae*		*Apodemus gudrunae*

Fig. 2. Previous local biozonations defined by different authors for the Guadix Basin, and their relationship with the biozones proposed in this work and the MN (Mein 1975) and MmQ (Agustí *et al.* 1987) units.

Fejfar & Storch 1990; Minwer-Barakat *et al.* 2005; García-Alix *et al.* 2008c), *Stephanomys thaleri*, *Castillomys* and *Paraethomys jaegeri*. Therefore, it is difficult to distinguish this biozone from other units of similar age. Since its definition, this biozone included a single locality, Cañada del Castaño-1 (Martín Suárez 1988), in which no arvicolid was recovered, but only taxa of scarce biostratigraphical value. The only species of which the stratigraphical distribution is restricted to this biozone is *A. agustii*, so this zone could be defined by its range (as a taxon-range zone); however, this murid has only been found in Cañada del Castaño-1, so the inclusion of other sites in this biozone results impossible.

The only local biozone defined for the Lower Villanyian in previous works is the *Kislangia cappettai* taxon-range zone. In the reference section, Cañada del Castaño (Martín Suárez 1988; Agustí & Martín Suárez 1994), this species is only found in the level CC-2, which has only yielded two complete teeth. In addition to the difficulty of the specific determination of such a scarce material, the species *K. cappetai* is not common in the basin, so the definition of a biozone based on it seems inadequate.

Lower Villanyian sites in the Guadix Basin are really scarce. The levels Zújar-10 and 11, with few identified micromammal species, may be assigned to this age (Oms *et al.* 1999). The finding of the sites TCH-3 and 13 represents by far the most complete rodent and insectivore record of the Lower Villanyian found in the basin until now; therefore, in the next section, we define a new biozone on the basis of the faunal assemblages from these localities, which substitute the *K. cappettai* zone.

Besides, the most important problem of the previously defined biozonations is that, in many cases, the criteria employed for their establishment were not in agreement with the rules of the *International*

Stratigraphic Guide (Salvador 1994); for instance, several assemblage zones were characterized by the presence of only two taxa. In other cases, modification of the defining criteria is needed to include recently discovered localities. For all these reasons, we consider it necessary to propose a new biozonation, which we describe below together with its relationship with previous biostratigraphical schemes and with the MN and ELMA systems.

New biozonation for the Upper Miocene–Lower Pleistocene of the Guadix Basin

Figure 3 shows the distribution of micromammals (Rodentia and Lipotyphla) in the studied levels from the Guadix Basin, which has led to the definition of six biozones ranging from the Upper Turolian to the Upper Villanyian. In the studied sections, the faunal record is excellent for all the considered intervals except for the Lower Ruscinian, as the level of Yeguas has yielded very scarce material. For this reason, we have included in the figure the taxa identified in the nearby site Gorafe-4 (GO-4, Martín Suárez 1988), which is in fact the locality selected as the reference level of the only biozone corresponding to the Lower Ruscinian (see below).

Following the *International Stratigraphic Guide*, which recommends considering the potentiality of the correlation of the new described biozones, we have chosen for the definition of zones those criteria that allow the inclusion of most localities previously found in the basin. Moreover, we have selected characteristic taxa with wide geographical distributions, avoiding the use of uncommon or not well-known species.

The definition of biozones according to the *International Stratigraphic Guide* is particularly problematic in the case of units based on fossil mammals, due to the discontinuity of the record of this group and the scarcity of remains in most sites. The establishment of some types of interval zones (‘highest-occurrence zones’, ‘lowest-occurrence zones’, Salvador 1994) results especially complicated, because of the difficulty of knowing precisely the stratigraphical position of a mammal site with respect to the biohorizons of first or last occurrence of taxa that are not present in that site. For this reason, we have preferred the definition of assemblage zones, except for those intervals in which one or two taxa with abundant remains and short stratigraphical distributions occur, allowing the establishment of range zones (taxon-range zones and concurrent-range zones).

According to the *International Stratigraphic Guide*, it is recommended (although not mandatory) that the definition of a biostratigraphical unit includes the designation of one or more specific reference sections in which the diagnostic taxon or taxa can be found (Salvador 1994). However, in the case of mammals, it is also useful to designate a concrete reference level due to the scarcity and discontinuity of the record within a section. Therefore, we have assigned a reference section and reference level for each described biozone, this latter including the most representative fauna of the unit. Fig. 4 shows some of the most representative taxa of the described biozones, which are, from oldest to youngest, the following:

Apodemus gudrunae *Assemblage Zone*

Definition. – Assemblage zone defined by the association of *Apodemus gudrunae*, *Apocricetus alberti, Occitanomys alcalai, Paraethomys meini, Myocricetodon jaegeri, Debruijnimys almenarensis* and *Parasorex ibericus*.

Reference section and level. – Section of Negratín, level NGR-1.

Other included fossil sites in the Guadix Basin. – Rambla de Chimeneas-3 (RCH-3), Pino Mojón, Bacochas 1 (Sesé 1989).

Remarks. – We have kept the name of the biozone proposed in previous biozonations (Martín Suárez 1988; Agustí & Martín Suárez 1994), which was originally characterized by the presence of *Apodemus gudrunae,* ‘*Cricetus* cf. *kormosi*’ and ‘*Galerix* sp.’. The Spanish samples previously assigned to ‘*Cricetus* cf. *kormosi*’ are now included in the species *Apocricetus alberti* (see Freudenthal *et al.* 1998), while ‘*Galerix* sp.’ identified in several localities of the basin corresponds in fact to *Parasorex ibericus.*

The increase in the number of species integrating the assemblage that characterizes this biozone allows the inclusion of those sites where few taxa are recorded because, according to the *International Stratigraphical Guide*, not all members of the assemblage need to occur for a section (or, in this case, a fossil-bearing level) to be assigned to an assemblage zone (Salvador 1994). Besides NGR-1 and RCH-3, the localities of Pino Mojón, with *Apodemus gudrunae* and *Myocricetodon*, and Bacochas 1, with *Apocricetus alberti, Paraethomys meini* and a large gerbillid most probably belonging to *Debruijnimys* (see Minwer-Barakat *et al.* 2009a) can be included in this biozone too. A

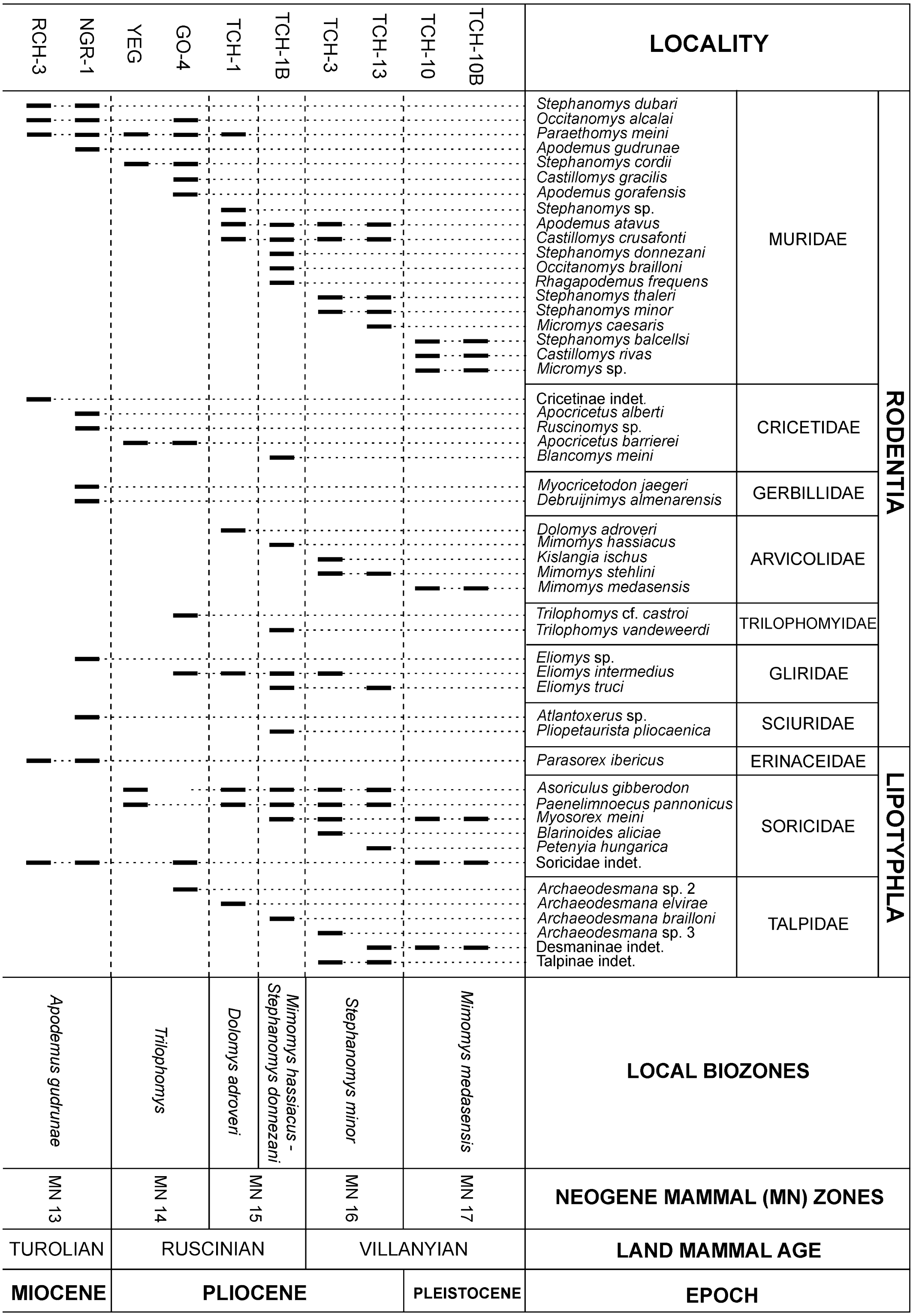
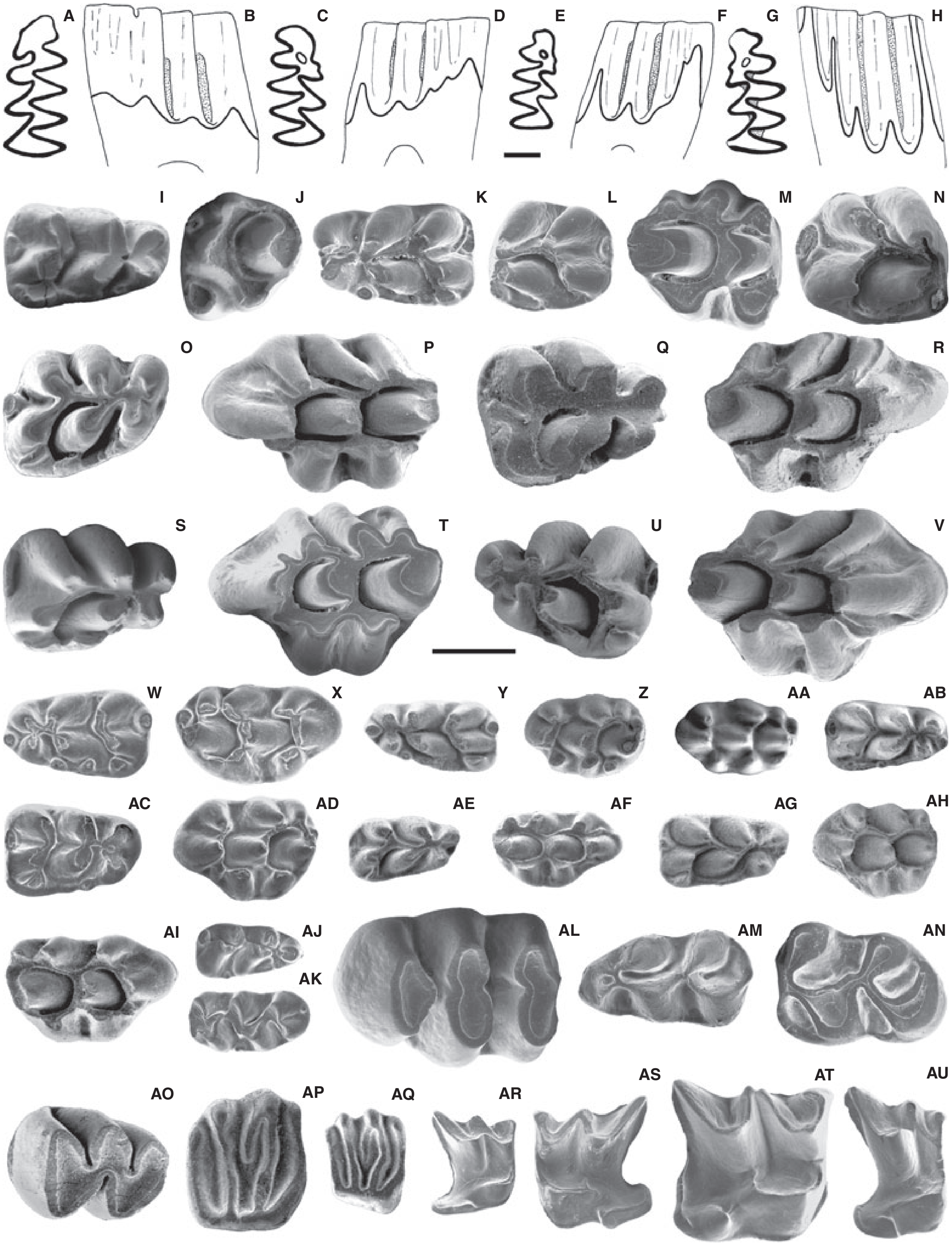


Fig. 3. Distribution of rodents and insectivores in the studied sites. Species are grouped in families and, among each family, they are arranged in order of appearance. Localities are stratigraphically arranged. *Archaeodesmana* sp. 2 and sp. 3, after Minwer-Barakat *et al.* (2008a).

review of the fauna from these two sites is necessary, as many rodent species have been described in the Spanish Upper Miocene after the publication of the faunal lists by Sesé (1989).

Trilophomys *Assemblage Zone*

Definition. – Assemblage zone defined by the association of *Apocricetus barrierei, Stephanomys cordii,*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Castillomys gracilis, Apodemus gorafensis, Paraethomys meini and *Trilophomys*.

Reference section and level. – Section of Gorafe, level GO-4 (Martín Suárez 1988).

Other included fossil sites in the Guadix Basin. – Yeguas (Soria & Ruiz Bustos 1991; Minwer-Barakat 2005), Gorafe-1 (de Bruijn 1974), Gorafe-A (Ruiz Bustos *et al.* 1984), Colorado 2, Aljibe 2 and 3 (Guerra Merchán *et al.* 1991).

Remarks. – Martín Suárez (1988) defined the *Trilophomys* Interval zone with a lower limit marked by the first appearance of *Trilophomys* and an upper limit characterized by the first occurrence of *Mimomys*. Later Agustí & Martín Suárez (1994) named the *Trilophomys* Assemblage Zone characterized by the presence of the species *Trilophomys castroi* and *'Cricetus barrierei'* (now transferred to the genus *Apocricetus*). This definition does not comply with the rules of the *International Stratigraphical Guide*, according to which an assemblage biozone must be characterized by the presence of at least three taxa (Salvador 1994). In the present work, we have maintained the same name, modifying the characteristic assemblage, as noted above.

In this zone, the first appearances of *Trilophomys, Paenelimnoecus pannonicus* and *Asoriculus gibberodon* are recorded. Some of the characteristic taxa of the *Apodemus gudrunae* Biozone, such as *Apodemus gudrunae*, *Apocricetus alberti* y *Myocricetodon jaegeri*, are no longer present in the *Trilophomys* Biozone.

Dolomys adroveri *Taxon-range Zone*

Definition. – Taxon-range Zone that corresponds to the total range of *Dolomys adroveri*. Its lower and upper boundaries are the first appearance datum (FAD) and last appearance datum (LAD) of *D. adroveri*, respectively.

Reference section and level. – Section of Tollo de Chiclana, level TCH-1.

Other included fossil sites in the Guadix Basin. – Galera-C (Garcés *et al.* 1997).

Remarks. – TCH-1 and Galera-C are the only sites of the Guadix Basin where *D. adroveri* has been recognized. The relative position of these two sites cannot be established by lithostratigraphical criteria. However, the faunal list of Galera-C seems to indicate a slightly younger age, because it includes some taxa that are not present in TCH-1, but occur in the next younger zone (*Mimomys hassiacus-Stephanomys donnezani* Biozone), such as *Occitanomys brailloni* (Garcés *et al.* 1997). The presence of another arvicolid, *Dolomys occitanus*, in Galera-C (Garcés *et al.* 1997) is doubtful. In the Teruel region, samples originally assigned to that species (some of them found in levels that also contain *D. adroveri*) have later been ascribed to *Mimomys gracilis*. Therefore, revision of the material is necessary to check the presence of this species in the Guadix Basin.

This biozone records the FAD of *Castillomys crusafonti* (TCH-1) and *Stephanomys donnezani* (Galera-C). The water-mole *Archaeodesmana elvirae* has only been mentioned up to now from the type-locality, TCH-1 (Minwer-Barakat *et al.* 2008a); therefore, its known range is restricted to this biozone. The species *Apocricetus barrierei, Castillomys gracilis* and *Stephanomys cordii*, which characterized the *Trilophomys* Zone, are no longer present in the *Dolomys adroveri* Zone.

Mimomys hassiacus-Stephanomys donnezani *Concurrent-range Zone*

Definition. – Concurrent-range Zone defined by the simultaneous occurrence of *Mimomys hassiacus* and *Stephanomys donnezani*. Its lower limit is marked by the FAD of *M. hassiacus* and its upper limit is characterized by the LAD of *S. donnezani*.

Fig. 4. Some significant small mammals recognized in the described biozones. A, B, left m1 of *Dolomys adroveri*, TCH-1 131, in occlusal (A) and labial (B) views. C, D, right m1 of *Mimomys hassiacus*, TCH-1B 511, in occlusal (C) and labial (D) views. E, F, right m1 of *Mimomys stehlini*, TCH-13 39, in occlusal (E) and labial (F) views. G, H, left m1 of *Mimomys medasensis*, TCH-10 13, in occlusal (G) and labial (H) views. I–J, *Paraethomys meini*, right m1, RCH-3 2 (I) and left M2, RCH-3 9 (J). K, L, *Stephanomys dubari*, left m1, NGR-1 1 (K) and left m2, NGR-1 6 (L). M, N, *Stephanomys cordii*, right M2, YEG 5 (M) and right m2, YEG 2 (N). O, P, *Stephanomys donnezani*, right m1, TCH-1B 30 (O) and left M1, TCH-1B 135 (P). Q, R, *Stephanomys thaleri*, right m1, TCH-3 71 (Q) and right M1, TCH-3 108 (R). S, T, *Stephanomys minor*, right m1, TCH-13 59 (S) and left M1, TCH-13 2 (T). U, V, *Stephanomys balcellsi*, left m1, TCH-10B 1 (U) and right M1, TCH-10B 22 (V). W, X, *Apodemus gudrunae*, left m1, NGR-1 16 (W) and right M1, NGR-1 31 (X). Y, Z, *Apodemus atavus*, left m1, TCH-1 58 (Y) and left M1, TCH-1 107 (Z). AA, AB, *Micromys caesaris*, left M1, TCH-13 27 (AA) and right m1, TCH-13 20 (AB). AC, AD, *Occitanomys alcalai*, right m1, NGR-1 44 (AC) and left M1, NGR-1 51 (AD). AE, AF, *Castillomys crusafonti*, right m1, TCH-1B 280 (AE) and right M1, TCH-1B 356 (AF). AG–AH, *Castillomys rivas*, right m1, TCH-10B 42 (AG) and left M1, TCH-10B 57 (AH). AI, right M1 of *Occitanomys brailloni*, TCH-1B 487. AJ, AK, *Myocricetodon jaegeri*, right m1, NGR-1 86 (AJ) and right M1, NGR-1 91 (AK). AL, left M1 of *Debruijnimys almenarensis*, NGR-1 78. AM, left m1 of *Apocricetus alberti*, NGR-1 119. AN, left m3 of *Apocricetus barrierei*, YEG 7. AO, left M2 of *Trilophomys vandeweerdi*, TCH-1B 619. AP, right M1-2 of *Eliomys intermedius*, TCH-1B 601. AQ, right M1-2 of *Eliomys truci*, TCH-1B 562. AR, right M1 of *Paenelimnoecus pannonicus*, TCH-1B 714. AS, left M1 of *Asoriculus gibberodon*, TCH-1B 785. AT, right M1 of *Blarinoides aliciae*, TCH-3 278. AU, right M1 of *Myosorex meini*, TCH-10B 106. All the figured specimens are deposited at the Departamento de Estratigrafía y Paleontología, Universidad de Granada, Spain. Scale bars equal 1 mm.

Reference section and level. – Section of Tollo de Chiclana, level TCH-1B.

Other included fossil sites in the Guadix Basin. – Moreda1-A (Castillo 1990).

Remarks. – TCH-1B and Moreda1-A, with very similar faunal lists, represent the only citations of the species *M. hassiacus* in the basin. However, the definition of a taxon-range Zone characterized by this species could be confusing, because there are other previously defined biozones in other areas characterized by the co-occurrence of *M. hassiacus* and other taxa (*M. hassiacus* and *M. gracilis* Zone; *M. hassiacus* and *M. stehlini* Zone; Fejfar *et al.* 1998). In other European areas, *Mimomys hassiacus* is still present in the Villanyian; therefore, this biozone is more precisely defined by its concurrent range with *S. donnezani*, a very common species in the Ibero-Occitan province.

This biozone records the FAD of *Myosorex meini*, which will be present in the basin until the late Villanyian (in TCH-10 and 10B), and the LAD of *Archaeodesmana brailloni, Blancomys meini* and *Pliopetaurista pliocaenica*.

It is not possible to include in the *Dolomys adroveri* and *Mimomys hassiacus-Stephanomys donnezani* biozones other Upper Ruscinian localities from the basin, apart from Galera-C, Moreda1-A and the reference levels of both zones, TCH-1 and 1B. Remains of arvicolids are too scarce to allow a precise determination in Gorafe-2, 3 and 5, and absent in Cañada del Castaño-1 (Martín Suárez 1988). Otherwise, the inclusion in the biozones defined in this work of other localities such as Huéscar 3 (Mazo *et al.* 1985), Barranco de Quebradas 1, Barranco de Cañuelas 2, 3 and 5 (Sesé 1989) and Nuca-1 (Ruiz Bustos 1991) is also impossible. These authors considered the species *D. occitanus, M. gracilis* and *M. hassiacus* to be synonyms of *M. stehlini* (Ruiz Bustos & Sesé 1985; Ruiz Bustos 1987) and ascribed the arvicolids recovered from all these sites to this latter species. As noted by Minwer-Barakat *et al.* (2008b), all the mentioned species show significant differences and must be considered as different taxa. Moreover, the first occurrence of *M. stehlini* corresponds to the Lower Villanyian (Mein 1975; Fejfar & Heinrich 1990; Mein *et al.* 1990; Fejfar *et al.* 1998), so the citations of this species in Upper Ruscinian levels of the Guadix Basin seem to be incorrect. Anyhow, the presence in these sites of *Stephanomys donnezani* allows their assignation to the Upper Ruscinian, with an age similar to that of TCH-1 and 1B; their relative stratigraphical position cannot be known with more detail.

In summary, the taxonomic determination of the arvicolids from many Upper Ruscinian localities of this basin must be revised. After a proper determination, probably some sites might be included in one of the biozones defined in this work. It is also possible that such a revision will lead to the identification of arvicolid species recognized in similar-aged levels in other Spanish basins (*Mimomys davakosi, M. vandermeuleni, M. gracilis*), which would permit the definition of other biozones within the Ruscinian.

Stephanomys minor *Assemblage Zone*

Definition. – Assemblage zone defined by the association of *Stephanomys minor, S. thaleri, Castillomys crusafonti, Mimomys stehlini* and *Kislangia ischus*.

Reference section and level. – Section of Tollo de Chiclana, level TCH-3.

Other included fossil sites in the Guadix Basin. – TCH-13, Zújar-11 (Oms *et al.* 1999), Moreda1-B (Castillo 1990).

Remarks. – This biozone coincides with the range of *M. stehlini* in the Guadix Basin. However, the definition of a taxon-range zone would be problematic due to the controversy about the synonymy of this species with other arvicolids. Moreover, the establishment of an assemblage Zone allows the inclusion of those sites where this arvicolid is not identified, but the species *S. thaleri, S. minor, C. crusafonti* and *K. ischus* are present, such as Zújar-11 (Oms *et al.* 1999).

The discovery of the species *Micromys caesaris* in TCH-13 may have certain biostratigraphical interest. *Micromys* is a very rare genus in the Guadix Basin. Apart from a few cases without specific ascription in some Ruscinian localities (Guerra Merchán *et al.* 1991; Ruiz Bustos 1991), the species *M. minutus* is well represented in the Pleistocene site of Loma Quemada-1 (Martín Suárez 1988 and unpublished collections stored in the University of Granada). The genus is neither recorded in Moreda1-B nor in TCH-3, despite the abundant remains recovered from both sites. On the contrary, in TCH-13 (younger than TCH-3), *Micromys caesaris* is the most abundant murid. In other southeastern Spanish areas, such as the Valdeganga section in the Júcar Basin (Opdyke *et al.* 1997), *Micromys* is absent in the lowermost Villanyian levels. On the contrary, in higher sites within the Lower Villanyian (Valdeganga 9b), some teeth, very similar to those from TCH-13, allow ascription to *M. caesaris* (see Minwer-Barakat *et al.* 2008c). In any case, more records would be necessary to concrete the range of *M. caesaris* and to prove its biostratigraphical value. Up to now, in the Guadix Basin, the species has only been identified in TCH-13, very similar in faunal content to TCH-3; therefore, we prefer not to use this species for the definition of a different biozone, and we have included both TCH-3 and 13 in the *Stephanomys minor* Biozone.

In this biozone, two lineages of *Stephanomys* coexist, represented by the species *S. minor* and *S. thaleri*, identified both in karstic (Moreda1-B) and fluvio-lacustrine levels (Zújar-11, TCH-3 and 13). This biozone includes the total range of *K. ischus*. The level TCH-3, type locality of the species *Blarinoides aliciae*, represents the only record of the genus in southern Spain (Minwer-Barakat *et al.* 2007).

Mimomys stehlini, the most abundant arvicolid in TCH-3 and Moreda1-B and the only one identified in TCH-13, characterizes the lower limit of the Villanyian in Europe according to Fejfar *et al.* (1998). This species has a very broad geographical distribution and allows a precise correlation with several sites from France, Italy and eastern Europe.

Mimomys medasensis *Taxon-range Zone*

Definition. – Taxon-range Zone that corresponds to the total range of *Mimomys medasensis*. Its lower and upper boundaries are the FAD and LAD of *M. medasensis*, respectively.

Reference section and level. – Section of Tollo de Chiclana, level TCH-10B.

Other included fossil sites in the Guadix Basin. – TCH-10 (stratigraphically equivalent to TCH-10B), Galera-2 (Martín Suárez 1988; Agustí *et al.* 2010), Galera-G (Garcés *et al.* 1997), Cortes de Baza-1 (Peña *et al.* 1977).

Remarks. – Agustí & Martín Suárez (1994) defined the *Kislangia gusii* Biozone, characterized by the occurrence of two arvicolid species: *K. gusii* and *Mimomys medasensis*, found together in Galera-2. In that and later works (Oms *et al.* 2000), other localities, where only one of these two species (*M. medasensis*) occurs, were assigned to this biozone, such as Cortes de Baza-1 (Peña *et al.* 1977) and Galera-G (Garcés *et al.* 1997), which is not in agreement with the criteria used for the definition of the biozone. The description in the present work of a new biozone characterized exclusively by the range of the species *M. medasensis* solves this question, allowing the inclusion of all the mentioned localities, in addition to the recently discovered TCH-10 and 10B.

This biozone records the total range of the murid *Stephanomys balcellsi* and the first occurrence of *Castillomys rivas*. In this zone, some of the common species of the *Stephanomys minor* Assemblage Zone, such as *S. minor, S. thaleri, Castillomys crusafonti, Mimomys stehlini, Kislangia ischus, Paenelimnoecus pannonicus* and *Blarinoides aliciae*, are no longer present.

This is the youngest biozone defined in this work. It is older than the *Mimomys* cf. *reidi* Biozone (Agustí 1986, 1990; Martín Suárez 1988; Oms *et al.* 2000), characterized by the presence of a small and hypsodont arvicolid provisionally determined as *Mimomys* cf. *reidi*, which includes the sites of Alquería (Martín Suárez 1988), Fuentenueva-1 (Moyà-Solà *et al.* 1987; Agustí *et al.* 2010), Galera-H (Garcés *et al.* 1997) and Nuca-3 (Ruiz Bustos 1991). The fossil record of the eastern sector of the basin (Orce area) allows the definition of several Pleistocene biozones based on the total ranges of several species of arvicolids (Oms *et al.* 2000; Agustí *et al.* 2010), but these units are clearly younger than the zones defined in the present study.

Correlations

In this section, we assign the six new biozones to the corresponding MN units (Mein 1975, 1990, 1999) and European Land Mammal Ages (ELMAs, Fahlbusch 1976; Steininger 1999), and correlate them, when possible, with the Rodent Zones and Superzones (Fejfar *et al.* 1998). Fig. 5 shows the main criteria employed by several authors for the characterization of the mentioned units.

Moreover, we correlate the proposed biozones with other mammal sites (Fig. 6). Correlations are more accurate with other Iberian localities, due to the great similitude in faunal content with the levels studied in this work, and less precise with more distant European sites. However, in some cases, the presence of widespread species allows precise correlation with distant mammal sites. To avoid a too long list of references, we defer to Mein *et al.* (1990) and Hernández Fernández *et al.* (2004) for additional references about Iberian localities, and to de Bruijn *et al.* (1992) for further information about the main classical European sites.

Finally, we provide an approximate numerical age for the lower and upper limits of each biozone, based on comparison with other Iberian sections well calibrated with the Geomagnetic Polarity Time Scale (Lourens *et al.* 2004; Ogg *et al.* 2008). Many of these palaeomagnetic studies in the Iberian record were focused on the estimation of the age of the limits of the MN units (see Agustí *et al.* 2001 and references therein). Although some recent works have proposed the MN boundaries as time intervals rather than specific ages (Hernández Fernández *et al.* 2004; Domingo *et al.* 2007; Gómez Cano *et al.* 2011), we have preferred to keep using the numerical ages available in the literature.

Author		Mein (1975)	Mein (1990, 1999)		Fejfar et al. (1998)		Agustí et al. (2001)	
Units		Neogene Mammal Zones	Neogene Mammal Zones		Rodent Superzones	Rodent Zones	Neogene Mammal Zones	
Definition criteria		Characteristic species	First appearances	Last appearances	Concurrent ranges of genera	Total or concurrent ranges of species	First appearances	Last appearances
VILLANYIAN	MN17	*Mimomys pliocaenicus*	*Lagurodon* *Clethrionomys*	*Stephanomys*	*Borsodia* *Villanyia*	*Mimomys pliocaenicus*	*Kislangia gusii* *Mimomys reidi* *M. pliocaenicus* *M. tornensis*	
	MN16	*Mimomys stehlini* *M. polonicus*	*Kislangia*	*Trilophomys* *Blancomys*		*Mimomys polonicus*	*Mimomys polonicus* *Kislangia ischus*	
						Mimomys hassiacus + *Mimomys stehlini*		
RUSCINIAN	MN15	*"Mimomys" occitanus* *Apocricetus angustidens* *Ruscinomys europaeus* *Trilophomys pyrenaicus*	*Mimomys* *Dolomys*	*Occitanomys* *Paraethomys* *Galerix*	*Trilophomys* *Ruscinomys*	*Mimomys hassiacus* + *Mimomys gracilis*	*"Mimomys" occitanus* *Mimomys davakosi* *M. vandermeuleni*	*Occitanomys* *Paraethomys* *Ruscinomys* *Apocricetus*
						Mimomys davakosi		
	MN14	*Apocricetus barrierei* *Promimomys insuliferus*	*Promimomys* *Trilophomys* *Blarinoides*	*Promimomys*		*Promimomys cor*	*Promimomys* *Trilophomys* *Castor*	
						Promimomys insuliferus		
TUROLIAN	MN13	*"Cricetus kormosi"* *(=Apocricetus alberti)* *Ruscinomys lasallei*	*Apocricetus* *Blancomys* *Paraethomys* *Myocricetodon* *Protatera*	*Myocricetodon* *Heteroxerus* *Hispanomys*	*Valerimys* *Hispanomys*	*Stephanomys ramblensis*	*Paraethomys* *Apocricetus* *Blancomys*	

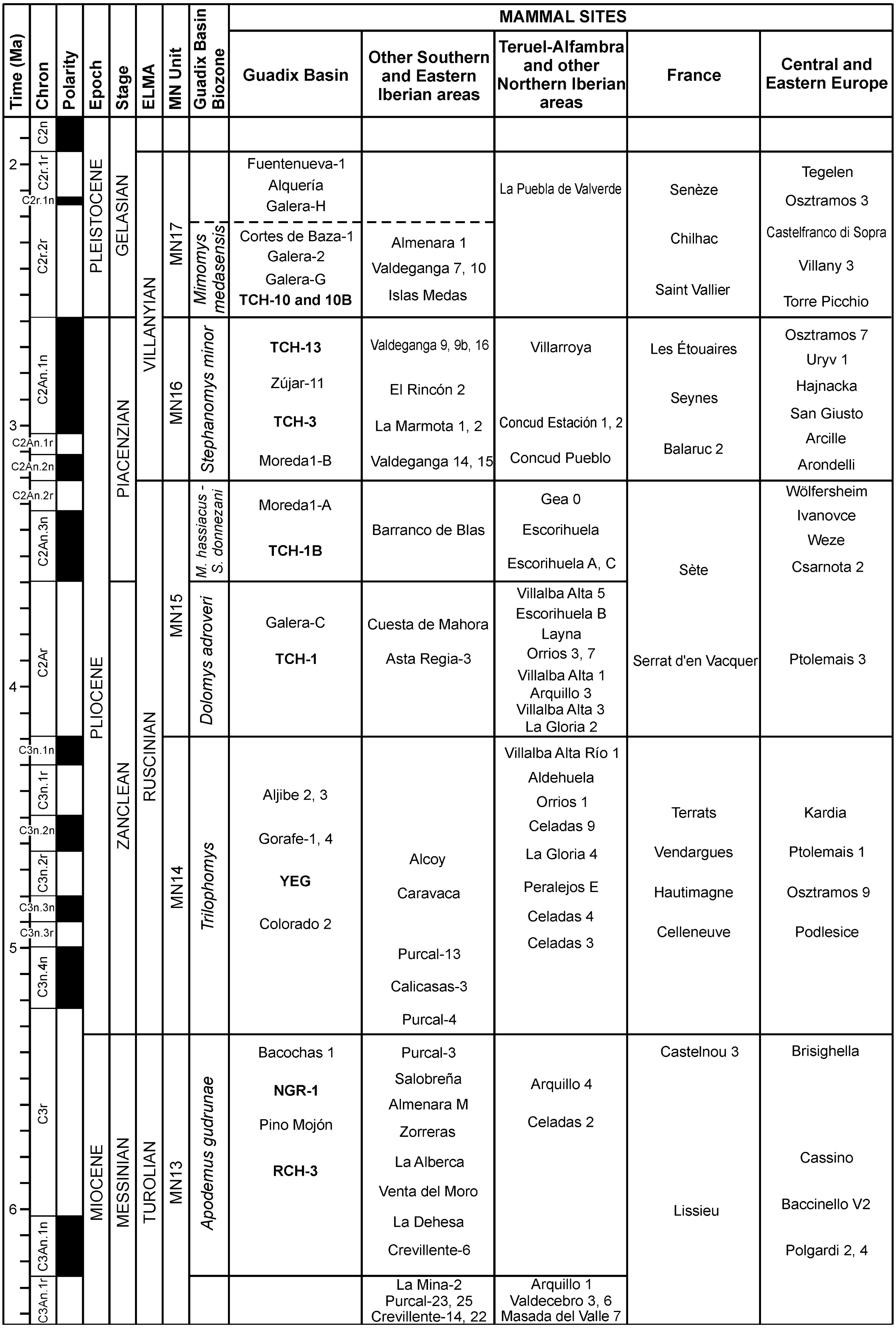
Fig. 5. Criteria used by different authors for characterizing several units of subdivision of the Neogene continental record. To simplify, only those micromammal taxa useful for the assignation of the biozones described in the present work to these systems of subdivision are indicated.

Apodemus gudrunae *Assemblage Zone*

The first occurrences of *Paraethomys meini* and *Occitanomys alcalai* are documented in the Upper Turolian (MN13); these species persist during the Ruscinian (Mein 1999). The presence of *Myocricetodon*, restricted in Europe to the Upper Turolian, and the species *Apocricetus alberti* and *Apodemus gudrunae*, characteristic of this unit (Mein 1975; Fejfar & Heinrich 1990), allows a doubtless assignation of the *Apodemus gudrunae* Biozone to MN13.

Upper Turolian localities are numerous in other Iberian areas such as the Granada Basin (García-Alix *et al.* 2008a), the Fortuna Basin (Garcés *et al.* 1998), the Crevillente area (Martín Suárez & Freudenthal 1998) and the Teruel region (Mein *et al.* 1990; van Dam *et al.* 2001). In all these areas, a set of localities with typical Upper Turolian species (*Apodemus gudrunae, Occitanomys alcalai, S. ramblensis)* previous to the occurrence of *Paraethomys meini* may be distinguished from another group of levels in which this latter species is present. Thus, the localities RCH-3 and NGR-1 are younger than La Mina-2, Purcal-23 and 25, Crevillente-14, 22 and 31, La Gloria 6, Masada del Valle 7, Valdecebro 3 and 6, Arquillo 1 and Villastar, where *Paraethomys* is still absent. On the other hand, the sites Purcal-3, La Dehesa, Arquillo 4, Celadas 2, Crevillente-6, Librilla, Venta del Moro and La Alberca, with *P. meini*, are equivalent in age to RCH-3 and NGR-1. The *Apodemus gudrunae* Biozone can be correlated with the *Paraethomys meini* Zone described in the Granada Basin (García-Alix *et al.* 2008a), the *Paraethomys* Zone defined in Crevillente (Martín Suárez & Freudenthal 1998) and the Zone M3 of the Teruel-Alfambra area (van Dam *et al.* 2001).

In the Sorbas Basin, the levels Zorreras 2B and 3A (Martín Suárez *et al.* 2000), with *O. alcalai, P. meini, S. dubari* and *D. almenarensis*, can be also correlated with NGR-1 and RCH-3. The faunal lists of the main karstic infillings of the Spanish Late Turolian, Salobreña (Aguilar *et al.* 1984) and Almenara M (Agustí *et al.* 2011), are very similar to that of NGR-1, so we interpret that they have the same age. These two karstic sites represent, together with Pino Mojón and NGR-1 in the Guadix Basin, the only citations of the genus *Myocricetodon* in Spain. In addition, the presence of a large gerbillid belonging to *Debruijnimys* in the site of Ses Fontanelles (Ibiza Island, Spain) allows correlation with NGR-1;



Epoch	Stage	ELMA	MN Unit	Guadix Basin Biozone	MAMMAL SITES				
					Guadix Basin	Other Southern and Eastern Iberian areas	Teruel-Alfambra and other Northern Iberian areas	France	Central and Eastern Europe
PLEISTOCENE	GELASIAN								
		VILLANYIAN	MN17		Fuentenueva-1 Alquería Galera-H		La Puebla de Valverde	Senèze Chilhac Saint Vallier	Tegelen Osztramos 3 Castelfranco di Sopra Villany 3 Torre Picchio
				Mimomys medasensis	Cortes de Baza-1 Galera-2 Galera-G **TCH-10 and 10B**	Almenara 1 Valdeganga 7, 10 Islas Medas			
PLIOCENE	PIACENZIAN		MN16	*Stephanomys minor*	**TCH-13** Zújar-11 **TCH-3** Moreda1-B	Valdeganga 9, 9b, 16 El Rincón 2 La Marmota 1, 2 Valdeganga 14, 15	Villarroya Concud Estación 1, 2 Concud Pueblo	Les Étouaires Seynes Balaruc 2	Osztramos 7 Uryv 1 Hajnacka San Giusto Arcille Arondelli
		RUSCINIAN	MN15	*M. hassiacus - S. donnezani*	Moreda1-A **TCH-1B**	Barranco de Blas	Gea 0 Escorihuela Escorihuela A, C	Sète	Wölfersheim Ivanovce Weze Csarnota 2
	ZANCLEAN			*Dolomys adroveri*	Galera-C **TCH-1**	Cuesta de Mahora Asta Regia-3	Villalba Alta 5 Escorihuela B Layna Orrios 3, 7 Villalba Alta 1 Arquillo 3 Villalba Alta 3 La Gloria 2	Serrat d'en Vacquer	Ptolemais 3
			MN14	*Trilophomys*	Aljibe 2, 3 Gorafe-1, 4 **YEG** Colorado 2	Alcoy Caravaca Purcal-13 Calicasas-3 Purcal-4	Villalba Alta Río 1 Aldehuela Orrios 1 Celadas 9 La Gloria 4 Peralejos E Celadas 4 Celadas 3	Terrats Vendargues Hautimagne Celleneuve	Kardia Ptolemais 1 Osztramos 9 Podlesice
MIOCENE	MESSINIAN	TUROLIAN	MN13	*Apodemus gudrunae*	Bacochas 1 **NGR-1** Pino Mojón **RCH-3**	Purcal-3 Salobreña Almenara M Zorreras La Alberca Venta del Moro La Dehesa Crevillente-6	Arquillo 4 Celadas 2	Castelnou 3 Lissieu	Brisighella Cassino Baccinello V2 Polgardi 2, 4
						La Mina-2 Purcal-23, 25 Crevillente-14, 22	Arquillo 1 Valdecebro 3, 6 Masada del Valle 7		

Fig. 6. Correlation of the studied localities and the biozones defined in this work with other European mammal sites. The figure also shows the relationship of the proposed biozones with the chronological and geomagnetic scales.

this record proves the dispersion of this rodent far for the continent in relationship with the Messinian Salinity Crisis (Moyà-Solà *et al.* 1984).

Most of the mammals recorded in RCH-3 and NGR-1 are rare outside the Iberian Peninsula. Due to the lack of shared species, correlation with other Upper Turolian localities such as Lissieu (France), Cassino, Baccinello V2 (Italy) and Polgardi 2 and 4 (Hungary) is approximated and based on the use of the MN system. The faunas from Brisighella (de Giuli 1989) and Castelnou 3 (Aguilar *et al.* 1991), assigned to the latest Turolian, share some taxa with RCH-3 and NGR-1, but also include other typical Ruscinian species; thus, they must be somewhat more recent than RCH-3 and NGR-1.

The lower limit of MN13 has been estimated between 6.6 and 7.2 Ma, according to several authors (Opdyke *et al.* 1997; Garcés *et al.* 1998; Steininger 1999; Agustí *et al.* 2001). In any case, the age of the *Apodemus gudrunae* Biozone is more recent. According to the study by Garcés *et al.* (1998) in the Fortuna Basin, the first occurrence of the murid *Paraethomys* in Europe is correlated with chron C3An.1n, providing a maximum age of 6.25 Ma for the sites in which *P. meini* is present. This datum agrees with that from the Teruel-Alfambra region, where the last locality previous to the entry of *Paraethomys* is dated at 6.2 Ma (van Dam *et al.* 2001). Therefore, the maximum age of the lower limit of the *Apodemus gudrunae* Biozone can be placed at 6.25 Ma.

The upper limit of this biozone coincides with the MN13-MN14 boundary. Opdyke *et al.* (1997) estimated the minimum age of this boundary at 4.9 Ma, the age of the locality of Fuente del Viso in the Júcar Basin, an opinion followed by other authors (Steininger 1999; Berger *et al.* 2005) who consider that this boundary is considerably younger than the Miocene–Pliocene limit. These authors assigned the site of Fuente del Viso to MN13, but the presence of *Stephanomys cordii*, *Apodemus gorafensis* and *Apocricetus barrierei* allows ascription to MN14; therefore, the MN13-MN14 limit must be older than 4.9 Ma (Agustí *et al.* 2001; García-Alix *et al.* 2008a). Martín Suárez *et al.* (1998) and García-Alix *et al.* (2008a) provided a more precise estimation for this limit on the basis of the magnetostratigraphical data from the Purcal section (Granada Basin), where latest Turolian (Purcal-3) and earliest Ruscinian (Purcal-4) levels are correlated with chron C3r. According to these authors, the MN13-MN14 boundary is slightly older than the limit between chrons C3r and C3n, estimated at 5.23 Ma, and therefore very close to the Messinian-Zanclean (Miocene-Pliocene) boundary, estimated at 5.33 Ma (Lourens *et al.* 2004).

Trilophomys Assemblage Zone

The rodents *Trilophomys*, *Stephanomys cordii* and *Apocricetus barrierei*, identified in the reference site (Gorafe-4) and in other localities included in this zone (Yeguas, Gorafe-A), are considered to be characteristic of MN14 (Mein 1975; Fejfar & Heinrich 1990), and allow assignation of the *Trilophomys* Zone to this unit.

The two rodent zones distinguished by Fejfar *et al.* (1998) in the Lower Ruscinian are based on the range of two different species of *Promimomys*, a common genus in central and eastern Europe, but very scarce in the Iberian Peninsula, only being mentioned in the Teruel region (Fejfar *et al.* 1990; Mein *et al.* 1990). Therefore, the *Trilophomys* Biozone cannot be correlated with these rodent zones.

The sites of Gorafe-4 and Yeguas, with *S. cordii*, are younger than those lowermost Ruscinian localities of the Granada Basin in which *S. dubari* is identified: Purcal-4 and 13, Calicasas-3 and 5A (García-Alix *et al.* 2008a). The teeth of *A. barrierei* from Yeguas are larger than those of the same species from PUR-4 (García-Alix *et al.* 2008b), which is consistent with a younger age for Yeguas, as the size of this species increases from older to younger localities. The faunal content of Gorafe-4 and Yeguas is very similar to that of other southeastern Spanish localities, such as Alcoy and Caravaca, which can be considered equivalent in age.

In the Guadix Basin, there is no record of the taxa used for the establishment of Lower Ruscinian biozones in the Teruel area, such as *Celadensia* and *Promimomys* (Mein *et al.* 1990). The localities of Yeguas and Gorafe-4 can be correlated without great precision with MN14 sites like Peralejos E, Celadas 4, 5 and 9, Cerro Gordo and La Gloria 4. The presence of *Stephanomys margaritae*, a descendant of *S. cordii*, in Orrios 1, Lomas de Casares 1, Villalba Alta Río 1 and Aldehuela, allows us to consider that those sites are slightly younger than Yeguas and Gorafe-4.

Apocricetus barrierei, identified in Yeguas and Gorafe-4 and in the French localities of Celleneuve, Hautimagne, Vendargues and Terrats, indicates a similar age for all these sites. The taxa recognized in the *Trilophomys* Biozone are uncommon in Eastern Europe. Therefore, an indirect correlation (based on the allocation in the same MN unit) can be established with Lower Ruscinian localities with *Promimomys*, such as Podlesice, Osztramos 9, Ptolemais 1 and Kardia.

The lower limit of the *Trilophomys* Biozone is considered equivalent to the MN13-MN14 boundary, established, as noted above, in ~5.33 Ma. The upper limit coincides with the MN14-MN15 boundary, calibrated in the Alfambra area with the C3n-C2Ar transition (Opdyke *et al.* 1997; Agustí *et al.* 2001), with an age of 4.19 Ma. The palaeomagnetic data obtained in the Guadix Basin for the estimation of the age of MN15 (Oms *et al.* 1999) are coherent with this interpretation.

Dolomys adroveri *Taxon-range Zone*

The fauna from TCH-1 and Galera-C allows an undoubtful assignation to the Upper Ruscinian (MN15). According to Mein (1990), the first occurrence of *Dolomys* corresponds to MN15, and the last record of *Paraethomys* is also found in this unit. Moreover, the species *D. adroveri* has been only identified in localities belonging to MN15. These two sites are clearly younger than the Ruscinian localities in the Teruel area where 'archaic *Mimomys*' are found: La Gloria 2, Villalba Alta Río 2, Villalba Alta 3, Lomas de Casares 1 (with *M. vandermeuleni*), Villalba Alta 1 and Arquillo 3 (with *M. davakosi*, Fejfar *et al.* 1990; Mein *et al.* 1990). Serrat d'en Vacquer (reference level of MN15) and Ptolemais 3, where *M. davakosi* is found, are also older than TCH-1 and Galera-C.

The presence of *Dolomys adroveri* allows a precise correlation of this biozone with Spanish localities such as Asta Regia-3 in the Jerez Basin (Castillo & Agustí 1996), Cuesta de Mahora in the Júcar Basin (Opdyke *et al.* 1997) and the karstic infilling of Layna (Fejfar *et al.* 1990), which have yielded the same species. In the Teruel region, where *D. adroveri* is a common species, Mein *et al.* (1990) defined a *Dolomys* Biozone with two subzones. The lower one, in which *D. adroveri* is the only arvicolid, includes sites such as Orrios 3, 4, 7 and Villalba Alta 4. The upper one, in which this species occurs together with *Mimomys gracilis*, includes the localities of Escorihuela B, Villalba Alta 5 and Poblado Ibérico. The level TCH-1, which has only yielded the arvicolid *D. adroveri*, would be similar in age to the sites belonging to the former one of these subzones. The teeth of *D. adroveri* from TCH-1 resemble those of the same species from Orrios 7 (Minwer-Barakat *et al.* 2004, 2008b), suggesting an equivalent age for both sites. The exhaustive revision and determination of another arvicolid present in Galera-C, originally ascribed to '*Mimomys occitanus*', would be necessary for a more precise correlation of the local *Dolomys adroveri* Biozone from the Guadix Basin and the *Dolomys* Biozone from Teruel. This revision and future findings will probably lead to the subdivision of the biozone defined in the present work.

The *Dolomys adroveri* Biozone cannot be correlated with the two Upper Ruscinian rodent zones defined by Fejfar *et al.* (1998) (*M. davakosi* Zone and *M. gracilis* + *M. hassiacus* Zone). According to Fejfar & Heinrich (1990), the upper part of MN15 is characterized by an important arvicolid radiation that involves, among other taxa, the first occurrence of *Dolomys* and *M. gracilis*. Nevertheless, in Teruel, *D. adroveri* is identified in several localities older than the first record of *Mimomys gracilis*. This observation seems to indicate that *M. davakosi* Zone and *M. gracilis* + *M. hassiacus* Zone are not strictly successive. Probably, the establishment of another biozone would be necessary for the inclusion of those sites younger than the last occurrence of *M. davakosi* and older than the first appearance of *M. gracilis*, which, in the Iberian Peninsula, are characterized by the presence of a unique arvicolid, *D. adroveri*.

The maximum age of the lower limit of this biozone is that of the MN14-MN15 boundary, dated around 4.19 Ma, as explained. The estimation of the age of the upper limit of this biozone is difficult. However, the site of Galera-C is correlated with chron C2An.3n. (Garcés *et al.* 1997); therefore, the upper limit of the *Dolomys adroveri* Biozone must be younger than the base of this chron, dated at 3.60 Ma.

Mimomys hassiacus-Stephanomys donnezani *Concurrent-range Zone*

The only arvicolid identified in this biozone, *Mimomys hassiacus*, is not useful for correlation with the MN units, European rodent zones and ELMAs. According to Fejfar *et al.* (1998), this species is present in the Upper Ruscinian (*M. hassiacus* + *M. gracilis* Zone) and also in the Lower Villanyian (*M. hassiacus* + *M. stehlini* Zone). However, the presence of *Occitanomys brailloni* and *Stephanomys donnezani* in TCH-B and Moreda1-A allows the correlation of the *Mimomys hassiacus-Stephanomys donnezani* Biozone with the Upper Ruscinian (MN15). The genus *Occitanomys* becomes extinct at the end of the Ruscinian (Agustí 1986; Mein 1990; Agustí *et al.* 2001), while *S. donnezani* is only present in MN15 localities such as Serrat d'en Vacquer (reference locality) and Sète, and has not been found in Villanyian levels.

Several localities of the Teruel Basin with *M. hassiacus* and *M. gracilis* (Escorihuela, Escorihuela A and C, Gea 0) were assigned to the Villanyian by Mein *et al.* (1990) but, according to the biozonation of Fejfar *et al.* (1998), they must correspond to the Ruscinian. Although *M. gracilis* has not been identified in the Guadix Basin, the presence of *M. hassiacus* together with other typical Ruscinian species allows correlation of the *Mimomys hassiacus-Stephanomys donnezani* Biozone with the above-mentioned localities from Teruel, which must correspond to the uppermost Ruscinian. The lower crown and the less undulated *linea sinuosa* of *M. hassiacus* from TCH-1B (Minwer-Barakat *et al.* 2008b) indicate that this site is slightly older than Escorihuela. Other Upper Ruscinian localities where *M. hassiacus* is also found are Wölfersheim, Weze and Ivanovce. The site of Csarnota 2, where *M. gracilis* is present but *M. hassiacus* is still absent, would be somewhat older. The only Upper Ruscinian locality of the Granada Basin, Barranco de Blas (García-Alix *et al.* 2007b) has yielded few and incomplete arvicolid teeth that do not allow a specific determination; however, the presence of *S. donnezani* in this site permits correlation with TCH-1B and Moreda1-A.

The site of TCH-1B is clearly younger than Galera-C, correlated with chron C2An.3n. (Garcés *et al.* 1997). Hence, the lower limit of the *Mimoys hassiacus-Stephanomys donnezani* Biozone must be younger than the base of this chron (3.60 Ma). The upper limit of this biozone coincides with the MN15-MN16 boundary, situated in the Zújar section between chrons C2An.2r and C2An.2n (Oms *et al.* 1999; Agustí *et al.* 2001), with an estimated age of 3.21 Ma (Lourens *et al.* 2004). This datum is not in agreement with the studies developed in Teruel, where Opdyke *et al.* (1997) dated the MN15-MN16 boundary at 3.58 Ma. Nevertheless, this latter interpretation supposed that the sites of Escorihuela A and C, with *Mimomys hassiacus* and *M. gracilis*, belonged to MN16. According to Fejfar *et al.* (1998), this association corresponds to MN15, so the calibration of this boundary in Teruel would be incorrect. For this reason, we consider more reliable the estimate made in Zújar, and the age of 3.21 Ma for the MN15-16 limit.

Stephanomys minor *Assemblage Zone*

The species *Mimomys stehlini* permits an unambiguous assignation of this biozone to MN16, as it was one of the characteristic taxa considered in the original definition of this unit (Mein 1975). Following Fejfar *et al.* (1998), *M. stehlini* marks the beginning of the Villanyian, and its range is restricted to the Lower Villanyian. However, the correlation of the *Stephanomys minor* Biozone with one of the two rodent zones included by Fejfar *et al.* (1998) in MN16 is not possible. *Mimomys stehlini* is present in both the *M. stehlini + M. hassiacus* Zone and in the *M. polonicus* Zone, and appears together with *M. polonicus* in some sites such as Osztramos 7 and Les Étouaires.

The presence of *M. stehlini* in the *Stephanomys minor* Biozone allows correlation with a great number of localities in which this species is found, such as Concud Pueblo, Concud Estación 1 and 2 in the Teruel region, Balaruc 2, Seynes and Les Étouaires in France, Hajnacka (Slovakia), San Giusto, Arondelli, Arcille (Italy), Osztramos 7 (Hungary) and Uryv 1 (Russia). *Kislangia ischus* permits correlation with other Spanish localities such as Villarroya, La Marmota 1 and 2, El Carrasco and El Rincón 2 (Esteban & Martínez-Salanova 1987).

In the Valdeganga section, the oldest levels (Valdeganga 14 and 15), with *K. ischus* and *S. minor*, can be correlated with TCH-3. The site of Valdeganga 9b, somewhat younger but still belonging to the Lower Villanyian, can be considered equivalent in age to TCH-13 because of the presence of *Micromys caesaris*.

The lower limit of this Biozone coincides with the MN15-MN16 boundary, estimated, as stated above, at 3.21 Ma. The upper limit can be situated at the MN16-MN17 transition. The youngest Spanish locality assigned to MN16 is situated in the Villalba Alta section and correlates with the top of chron C2An (Opdyke *et al.* 1997). The oldest MN17 sites are found in the Galera (Garcés *et al.* 1997) and Zújar (Oms *et al.* 1999) sections, and can be correlated with the lower part of chron C2r. Agustí *et al.* (2001) placed the MN16-MN17 limit close to the C2An-C2r boundary (Gauss-Matuyama boundary), dated at 2.58 Ma (Lourens *et al.* 2004). This limit coincides, in fact, with the Pliocene–Pleistocene boundary after the change proposed by Gibbard *et al.* (2010). In this way, MN16 (and therefore the *Stephanomys minor* Biozone) corresponds to the Pliocene, whereas MN17 (and the *Mimomys medasensis* Biozone) belongs to the Pleistocene.

Mimomys medasensis *Taxon-range Zone*

The correlation of the *Mimomys medasensis* Biozone with the European biostratigraphical scales is only possible by means of indirect criteria. The only small mammal considered as a diagnostic taxon of MN17 by Mein (1975) is *Mimomys pliocaenicus*, which has been not recorded in the Guadix Basin. The range of this species is also used by Fejfar *et al.* (1998) for the definition of the only rodent zone corresponding to MN17. The genera that have their first appearance in MN17 (*Lagurodon, Clethrionomys, Lemmus*; Mein 1990) are also absent in the Guadix Basin. According to Fejfar & Heinrich (1990), other characteristic taxa of the *M. pliocaenicus* Zone are *Mimomys reidi, M. tornensis* and *Kislangia rex*. Agustí *et al.* (2001) added the species *K. gusii*, of which the range is restricted to MN17; this species is not present in TCH-10 and 10B, but has been found in Galera-2, a site included in the *Mimomys medasensis* Biozone, indicating a correspondence of this zone with MN17.

Moreover, the faunal list of TCH-10 and 10B, including *M. medasensis* and *Stephanomys balcellsi*, is very similar to that of other Spanish localities included in MN17, such as Islas Medas, Almenara 1 and the upper levels of the Valdeganga section (Fejfar & Heinrich 1990; de Bruijn *et al.* 1992; Opdyke *et al.* 1997).

In fact, all the sites where these two species have been recognized belong to MN17, so the correlation of the *Mimomys medasensis* Biozone with MN17 seems clear.

The age of TCH-10 and 10B would be very similar to that of Islas Medas. The smaller size of *S. balcellsi* and *M. medasensis* suggests a slightly older age than that of Almenara 1. There is no micromammal site corresponding to MN17 neither in other southern Spanish basins, nor in the Teruel region, where Upper Villanyian macromammals have been found in La Puebla de Valverde.

Mimomys medasensis and *S. balcellsi* have a quite limited geographical distribution: *S. balcellsi* is only known from Spain, whereas the only record of *M. medasensis* outside the Iberian Peninsula is from Torre Picchio in Italy (Girotti *et al.* 2003). Therefore, correlation of the *Mimomys medasensis* Biozone with the main Upper Villanyian European sites (Saint Vallier, Chilhac, Castelfranco di Sopra, Tegelen, Osztramos 3, Villany 3) is approximated.

The lower limit of the *Mimomys medasensis* Biozone can be considered coincident with the MN16-MN17 boundary (C2An-C2r boundary, 2.58 Ma). The level of Galera-H, with a clearly younger fauna than that of the *Mimomys medasensis* Biozone, is still correlated with chron C2r (Garcés *et al.* 1997); therefore, the entire biozone can be correlated with this chron. It is difficult to assign a numerical age to the upper limit of the *Mimomys medasensis* Biozone, but it must be notably older than the C2r-C2n boundary (base of the Olduvai chron), dated at 1.95 Ma.

Conclusions

The recent study of the rodents and insectivores identified in several fossil sites from the central sector of the Guadix Basin, together with other previously known small mammal assemblages from this basin, has allowed the definition of six local biozones.

The *Apodemus gudrunae* Assemblage Zone is defined by the association of *Apodemus gudrunae, Apocricetus alberti, Occitanomys alcalai, Paraethomys meini, Myocricetodon jaegeri, Debruijnimys almenarensis* and *Parasorex ibericus*. This biozone includes the sites of NGR-1 (reference level), RCH-3, Bacochas 1 and Pino Mojón. It can be included in the Upper Turolian (MN13). The maximum age of its lower limit can be placed at 6.25 Ma (the age of the first occurrence of *P. meini* in Spain); its upper limit coincides with the MN13-MN14 boundary, established at ~ 5.3 Ma.

The *Trilophomys* Assemblage Zone is defined by the association of *Apocricetus barrierei, Stephanomys cordii, Castillomys gracilis, Apodemus gorafensis, Paraethomys meini* and *Trilophomys*. It includes the sites of Gorafe-4 (reference level), Gorafe-1, Gorafe-A, YEG, Colorado 2, Aljibe 2 and 3. This biozone corresponds to the Lower Ruscinian (MN14), and therefore its lower and upper limits can be considered equivalent to the MN14 boundaries, dated at approximately 5.3 and 4.19 Ma.

The *Dolomys adroveri* Taxon-range Zone is defined by the total range of the arvicolid *Dolomys adroveri*. It includes the localities TCH-1 (reference level) and Galera-C; a careful revision of the arvicolids from other Ruscinian sites of the basin will probably lead to the inclusion of other sites in this biozone. It can be located in the Upper Ruscinian (MN15). The maximum age of its lower limit is 4.19 Ma (MN14-MN15 boundary), while its upper limit is younger than 3.60 Ma.

The *Mimomys hassiacus-Stephanomys donnezani* Concurrent-range Zone is defined by the simultaneous occurrence of *Mimomys hassiacus* and *Stephanomys donnezani*. It includes the sites TCH-1B (reference level) and Moreda1-A. As in the case of the *Dolomys adroveri* Zone, the revision of the arvicolid material from other Ruscinian localities of the basin is needed to allow their inclusion in the biozones described in this work or, alternatively, the definition of other biostratigraphical units. This biozone is assigned to the upper part of the Upper Ruscinian (MN15). Its age is constrained between 3.60 Ma and 3.21 (estimated age of the MN15-MN16 boundary).

The *Stephanomys minor* Assemblage Zone is defined by the association of *Stephanomys minor, S. thaleri, Castillomys crusafonti, Mimomys stehlini* and *Kislangia ischus*. This biozone includes the sites TCH-3 (reference level), TCH-13, Zújar-11 and Moreda1-B, and correspond to the Lower Villanyian (MN16). Its lower and upper limits coincide with the boundaries of MN16, estimated at 3.21 and 2.58 Ma.

Finally, the *Mimomys medasensis* Taxon-range Zone is defined by the total range of the arvicolid *Mimomys medasensis*. It includes the levels TCH-10B (reference level), TCH-10, Galera-2, Galera-G and Cortes de Baza-1. This biozone is correlated with the lower part of the Upper Villanyian (MN17). Its lower limit can be placed at the MN16-MN17 boundary (2.58 Ma). The age of its upper limit is difficult to establish, but it must be younger than the base of the Olduvai chron, dated at 1.95 Ma.

This is the first definition of local biozones according to the rules of the *International Stratigraphic Guide* for the continental deposits of the Guadix Basin. The proposed biozonation constitutes a solid framework for situating other localities from this basin whose faunal contents are in need of revision, and will also allow the inclusion of future finds.

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