

A stratigraphical framework for Miocene (MN4–MN13) continental sediments of Central Spain

Encadrement stratigraphique des sédiments continentaux miocènes (MN4–MN13) des bassins centraux d'Espagne

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Abstract—New bio- and magnetostratigraphic data from the Miocene continental sediments of Central Spain are used to update the existing stratigraphical framework. Our revised record is based on the study of more than two hundred mammal faunas, ranging from the Late Ramblian (ca 18 Ma) to the Late Turolian (ca 6 Ma). (© Académie des sciences / Elsevier, Paris.)

Miocene / mammals / Spain / biostratigraphy / MN units

Résumé — Les sédiments continentaux miocènes du Centre de l'Espagne ont livré des données nouvelles d'ordre bio- et magnétostratigraphique, qui sont utilisées ici pour mettre au point un encadrement stratigraphique en datations absolues. Notre étude est basée sur l'examen de plus de deux cents faunes de Mammifères dont l'âge va du Ramblien supérieur (environ 18 Ma) au Turolien supérieur (environ 6 Ma). (© Académie des sciences / Elsevier, Paris.)

Miocène / mammifères / Espagne / biostratigraphie / unités MN

Version abrégée (voir p. 629)

1. Introduction

New stratigraphic data have become available as a result of exhaustive sampling in the Miocene sediments of the Daroca-Calatayud, Teruel, Madrid, Duero, and Loranca Basins in the 1990s, although detailed palaeontological information is not yet available for all the sections.

Various fossiliferous sections were sampled magnetostratigraphically (Krijgsman et al., 1994; Krijgsman et al., 1996; van Dam, 1997; Daams et al., in press) and correlated with the GPTS (Cande and Kent, 1995). Over two hundred localities yielded micromammal faunas, and some forty of

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these contained large mammals as well. The oldest fauna, Agreda, is correlated to the base of local zone A (Late Ramblian) and its age is about 18 Ma. The youngest locality, El Arquillo 4, has an age of approximately 6.0 Ma (van Dam, 1997). This implies that the temporal resolution per fauna is some 60 000 years, and although some periods are better covered than others, we do not think that we have missed any important biostratigraphic, palaeoecological or palaeoclimatic event.

2. Biostratigraphy

The local biozones (*figure*) are based on rodents and have been defined in previous papers (Daams and Freudenthal, 1981, 1988 for the lower part, and van Dam, 1997 for the upper part) and will not be repeated here.

Zone A (= latest MN3). This zone is amongst others characterised by the First Occurrence (FO) of the Asiatic-North American horse *Anchitherium*, of cervids (*Procerulus*, *Acteocemas*) and of palaeomerycids, and consequently differentiate the faunas of this zone completely from the preceding zone Z. It also contains the FOs of *Dorcatherium crassum* (Moli Calopa) and of the Asiatic-North American Chalicotheriidae (Rubielos de Mora), whereas in other parts of Western Europe the FO of *Dorcatherium* and Chalicotheriidae have an early MN4 age. Although Eomyidae are quantitatively the predominant rodents of the main part of zone A, they are less frequent in the upper part, where Gliridae form the bulk of the fauna. Modern Cricetidae such as *Democricetodon* make their first appearance in the uppermost faunas, albeit in extremely low numbers.

Zone B (= early MN4). *Democricetodon* is the only modern cricetid and Gliridae predominate. Large mammals are not known from this zone.

Zone C (= late MN4). Immigrants of possible African origin, such as *Hyaenailouros*, *Prosansanosmilus*, *Prodeinotherium cuvieri* and *Gomphotherium angustidens*, are present. The zone contains the FO of *Hispanotherium* and *Triceromeryx*, but in one locality (Córcoles) only and in low numbers. *Eotragus artenensis* is present and it is the most primitive representative of the genus. This zone contains the LRO of *Ligerimys*.

Zone D (= major part of MN5). The running rhinoceros *Hispanotherium* is the predominant large mammal, and it is accompanied by *Triceromeryx* (Palaeomerycidae). *Anchitherium*, bovids, cervids and tragulids are irregularly present. Cricetidae are by far the most abundant rodent group. Four subzones are recognised on the basis of rodents. In a future paper these subzones will be defined. Large mammal faunas from local subzone Da are not significantly distinct from faunas of the upper part of local subzone C. Subzone Db is characterised by the FO of *Micromeryx* and of the bovids other than *Eotragus*. Subzone Dc contains the FO of *Tethytragus*, and subzone Dd that of *Hispanomeryx*, a small ruminant with hypsodont teeth.

Zone E (= latest MN5). This zone is characterised by a major change in the large mammal fauna; *Anchitherium* predominates together with *Tethytragus langai* and the new cervid *Heteroprox*. The large mammal faunas of this zone resemble more the ones of zone F than those of zone D. The most important rodent event is the FO of *Cricetodon*. *Hispanotherium* is not present in this zone anymore. In Portugal the fauna of Amor contains *Hispanotherium* and was originally correlated to Las Planas 4A (zone E) by Antunes and Mein (1981). Van der Meulen and Daams (1992) disagreed with this correlation and correlated Amor to zone D.

Zone F (= early MN6). The only important large mammal event is the FO of *Listriodon splendens*. The FO of two hamsters, *Megacricetodon rafaelli* and *M. gersii*, characterise this zone.

Zone G (= rest MN6–MN7/8). This zone has been subdivided into three subzones by Daams and Freudenthal (1988) on the basis of the successive evolutionary stages of the *Megacricetodon gersii-ibericus* lineage. No other remarkable small mammal events occur during this time. This is not true for the large mammals, although subzone G1 lacks a large mammal record. The remainder of the zone is characterised by the FO and successive abundance of *Alicornops simorreense*; this browsing, short-legged, rhinoceros is also common in the Vallesian. Faunas of subzone G2 are homogeneous all over the Iberian peninsula. The subzone is characterised by the abundance of *Tethytragus langai*, *Heteroprox larteti*, and *Hispanomeryx aragonensis*, and by the FO of true-antlered deer (*Euprox furcatus*). *Anchitherium* is less frequent. Subzone G3 is nearly void of previously abundant bovids. G3 is also characterised by the presence of the oldest Oiocerine *Samotragus pilgrimi* (Azanza et al., 1998). Towards the end of the Aragonian a new group of bovids (Boselaphini; *Miotragocerus*, *Protragocerus*) appears in Catalunya, accompanied by a wave of immigrants that reach their optimum during the Early Vallesian. Amongst these Late Aragonian immigrants are the Primates *Dryopithecus* and *Pliopithecus* who stayed in Catalunya and never reached central Spain (Moyá Solá et al., 1990). The date of their entry may be between 11.1 and 11.5 Ma. *Anchitherium* may be abundant towards the end of the Aragonian.

Zone H (= early MN9). The zone is characterised by the co-occurrence of *Hispanomys* and *Megacricetodon ibericus* (Cricetidae). The FO of *Hipparion* defines the lower boundary and the giraffids (*Decennatherium pachecoi*) are also present for the first time.

Zone I (= late MN9). The zone is defined by the FO of *Cricetulodon* and by the presence of one single species of *Megacricetodon* (*M. debruijini*). The first and very scarce remains of murids are present in the upper part of this zone. Large mammal faunas are scarce in the central basins. The zone contains the LO of Palaeomerycidae and the FO of *Amphiprox*. Large mammal faunas of this zone of Catalunya are the most diverse of the Spanish Neogene.

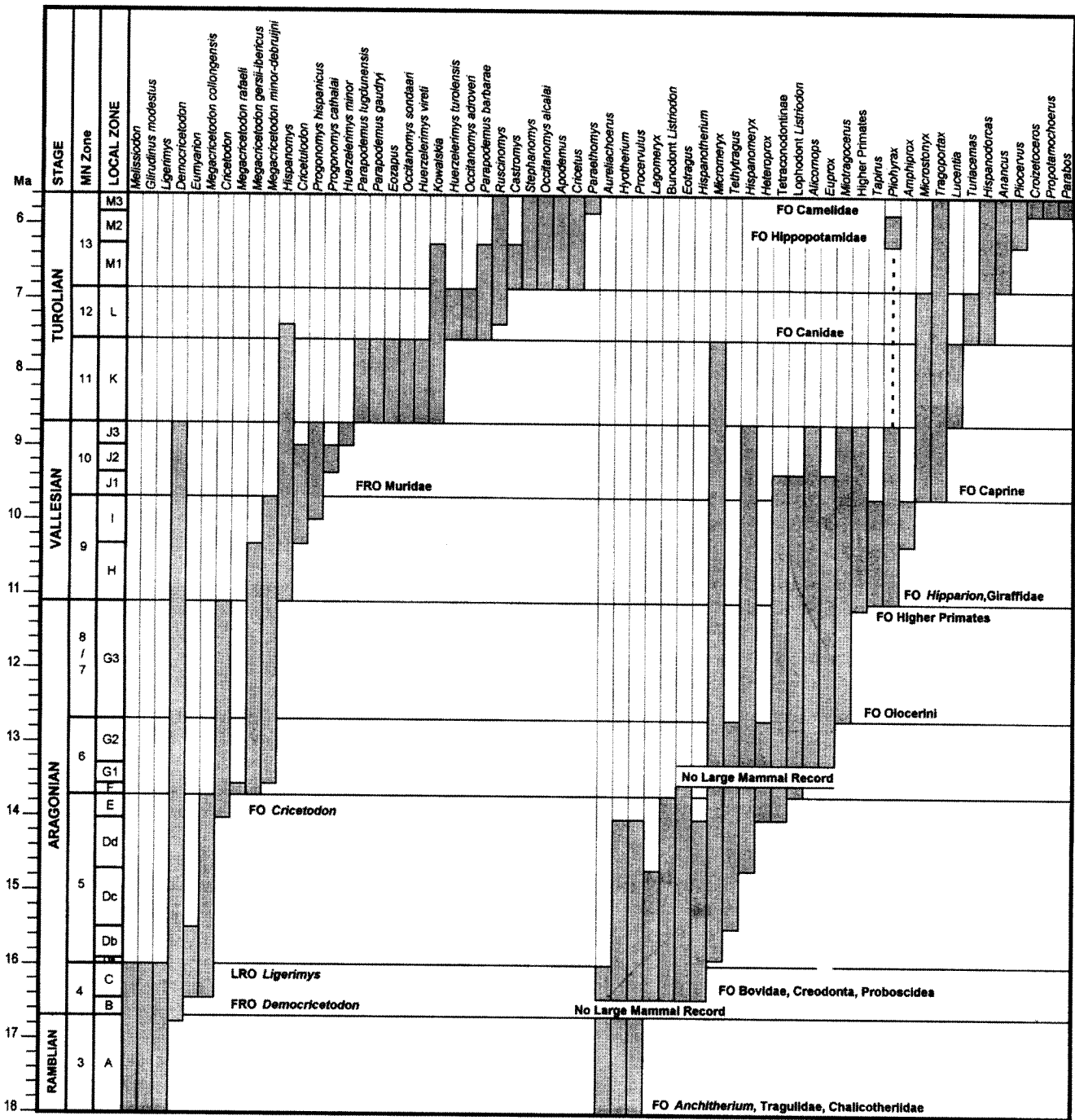


Figure. Distribution chart of selected large and small mammals from the Miocene of the Iberian Peninsula that are most useful for long-distance correlation. FO = First Occurrence. LO = Last Occurrence. FRO = First Regular Occurrence. LRO = Last Regular Occurrence.

Répartition stratigraphique des grands et petits mammifères du Miocène de la péninsule Ibérique les plus appropriés à la corrélation à grandes distances. FO = enregistrement le plus ancien, LO = enregistrement le plus récent, FRO = enregistrement généralisé le plus ancien, LRO = enregistrement généralisé le plus récent.

Zone J (= MN10). The Upper Vallesian contains three local subzones (J1, J2, J3) based on murids (van Dam, 1997). Zone J1 is characterised by the FRO (First Regular Occurrence) and expansion of the murids, and by the FOs of the Boselaphini *Tragoportax* and the suid *Microstonyx*. Large-mammal faunas from subzones J2 and J3 have been

recognised in the Teruel Basin only and are correlative with late MN10. Subzone J2 contains the FO of a real Caprini (*Aragoral mudejar*, Alcalá and Morales, 1997). Subzones J2 and J3 are characterised by a reduction of both small and large mammal faunas with respect to early MN10 faunas (van Dam, 1997).

The Turolian has been subdivided into five local zones on the basis of evolutionary stages of various murid lineages (van Dam, 1997).

Zone K (= MN11). *Parapodemus lugdunensis* and the zapodid *Eozapus* have their FO early in MN11 (Early Turolian), and both are restricted to this zone. The first Turolian large-mammal faunas of MN11 are characterised by a progressive impoverishment such as is evidenced by the absence of *Alicornops*, *Listriodon* and *Miotragocerus*. These are also characterised by the FO of modern cervids (*Lucentia*), and of the first representative of the Cervinae + Odocoileinae clade which replaces the Munciacinae (Azanza and Montoya, 1955). *Hipparion* and *Tragoptax* are abundant.

Zone L (= MN12). The micromammal faunas are characterised by *Parapodemus barbara*, *Occitanomys adroveri* and *Huerzelerimys turoloensis*, of which the latter two species are restricted to this zone. Various representatives of Sciuridae and Talpidae occur for the first time. *Tragoptax gaudryi* and *Hipparion* are still the predominant large mammals, and the zone contains the FOs of *Canis*, *Protorix* and *Hispanodorcas*.

Zone M (= MN13). The zone is defined by the presence of the murid *Stephanomys ramblensis*. Three subzones (M1, M2, M3) are recognised on the basis of the distribution of *Castromys* and *Paraethomys*. Zone M1 is characterised by a high diversification of *Hipparion* which may be present with three species. Furthermore the zone contains the FOs of *Anancus*, *Pliocervus*, *Hexaprotodon* (M2) and *Croizetoceros*, *Parabos*, and *Paracamelus* and *Protopotamochoerus* (M3) amongst the large mammals and those of *Apodemus* and *Cricetus* amongst the rodents.

3. Ages of the European Mammal units

3.1. Ramblian (MN2B-MN3)

The base of the Ramblian stage is dated in the Ebro Basin at 19.3 ± 0.2 Ma (Odin et al., 1997), but no other numerical ages are available for Ramblian faunas in Spain. The age of the Ramblian-Aragonian (= MN3–4) boundary can be estimated on the basis of the average sedimentation rate of the Aragonian type area. The result would be approximately 17 Ma. Aguilar et al. (1996) gave an age estimate of 17.5 ± 0.3 Ma for the fauna of Beaulieu (South of France) on the basis of Ar–Ar dating of volcanic rocks underlying the fossiliferous level but subcontemporaneously associated with the formation of the fossiliferous beds (Aguilar et al., op cit.). The rodent fauna of Beaulieu was correlated to MN3 and according to the above mentioned authors the evolutionary stage of *Ligerimys antiquus* (Eomyidae) would agree with that of the same species from Moratilla (late MN3, Teruel Province). The MN3–4 boundary is younger than the faunas of Beaulieu and Moratilla and consequently it is younger than 17.5 ± 0.3 Ma. Here, the data from the Spanish succession

and from the first order tie-point of Beaulieu in the South of France do not appear to contradict each other.

3.2. Aragonian (MN4–MN8)

The immigration wave from Africa to Europe of large mammals such as *Deinotherium*, other elephants, and several carnivores during MN4 occurs approximately around 16.5 Ma and is probably related to a global temperature rise (van der Meulen and Daams, 1992). A major faunal change similarly related to a temperature rise took place in East Africa, and appears to occur around 16.5 Ma as well (Pickford, 1991).

In our sections various 'boundaries' of MN units are present. Daams et al. (in press) reinterpreted the biostratigraphical and palaeomagnetic data of the Calatayud–Teruel Basin (Krijgsman et al., 1994, 1996) and set the lower boundary of MN5 at approximately 16 Ma. The MN5–6 and MN6–7/8 boundaries are maintained at 13.75 and 12.5–13.0 Ma respectively (Krijgsman et al., 1994). Pickford (1991) set the MN5–6 boundary in East Africa at about 14 Ma, which is close to our estimation for Central Spain.

Our estimations for the MN4–5 and MN5–6 boundaries are different from the ones in Steininger et al. (1996) who estimate the MN4–5 boundary at 17.0 Ma on the basis of extremely conflictive tie-points (Steininger et al., 1996). Their estimated age for the MN5–6 boundary fluctuates between 16.5 and 15.2 Ma.

One of the tie-points for the MN4–5 boundary is the faunal succession of the Belchatow lignite mine in Poland. Three superposed levels (C, B, A) were correlated to MN4, MN5/6 and MN9 respectively (Kowalski, 1993). Two tuffite layers are present in the mine, one (TS3) between level C and B, and the other (TS2) above level B. The ages of the TS3 and TS2 samples are 18.1 ± 1.7 Ma and 16.5 ± 1.3 Ma, respectively (Steininger et al., 1996). We consider these ranges too wide to attempt an age determination for the MN4–5 boundary.

Another tie-point for the MN4–5 boundary cited by Steininger et al. (1996) is the Gemerek section in Turkey. The age of the Gemerek fauna would be constrained to 14.9 ± 0.7 Ma (Langereis et al., 1990). However, Krijgsman et al. (1996) showed that this estimate is a calculated mean age of four separate, and very different age determinations and that it cannot be used as an age constraint.

The recently published age of 15.2–15.0 Ma for the French Sansan fauna (basal MN6) (Sen, 1996, 1997) differs from our age determinations of early MN6 faunas (Daams et al., in press). Biostratigraphically we correlate Sansan to the Las Planas 5B fauna from the Aragonian type section (*Megacricetodon gersii* and *M. minor* are common components), and consequently its age would be approximately 13.6 Ma. This implies that the MN5–6 boundary in France would approach the value obtained in the Calatayud–Daroca Basin (ca. 13.75 Ma). Sen (1997) argues that the Sansan fauna is much more diverse (it contains more species) than any MN6 fauna from Spain and continues by saying that MN6 faunas from the South of

France on the one hand, and those from Central Spain on the other, are diachronous. Although it is true that Sansan contains 19 rodent species, Manchones 14 (and not 10 according to Sen, *op. cit.*), and Las Planas 5B 9, sample sizes are not comparable. Las Planas 5B contains 484 M12, Manchones 2397, and Sansan tens of thousands. A test sample from Sansan taken by us several years ago yielded 248 M12 from 10 rodent species and consequently the species richness is comparable to that of Las Planas 5B taking the relationship between sample size and species number in account. With an age of ca 15.2 Ma, Sansan would be time-equivalent to the Spanish and French *Hispanotherium* faunas, such as suggested by Sen (1997). In our opinion this is not an acceptable alternative.

In addition, the quality of the magnetostratigraphic data is different. Sansan is the only fauna in an approximately 45 m lithological section of which the upper 10 m only give reliable palaeomagnetic results. The Aragonian type section has a thickness of some 170 m and it contains 37 superposed faunas covering seven local zones and three MN units (MN5–6–7/8), and seven normal and eight reversed magnetozones. The Armantes section contains two superposed faunas, measures 280 m, and has twelve normal and thirteen reversed magnetozones (Krijgsman et al., 1994). We ascribe a higher reliability to the data from such long successions than to those from one isolated fauna in a short and difficult, interpretable section.

3.3. Vallesian (MN9–10)

The lower boundary of the stage is set at ca 11.1 Ma (Krijgsman et al., 1996; Agustí et al., 1997). The Early–Late Vallesian boundary (MN9–10) has been dated at 9.7 Ma by Garcés et al. (1996) and Agustí et al. (1997) in the Vallés-Penedés Basin. This age is consistent with the age estimates of basal MN10 faunas in the Masía de la Roma section (Krijgsman et al., 1996; van Dam, 1997).

3.4. Turolian (MN11–13)

The Vallesian–Turolian (MN10–11) boundary is estimated at 8.7 Ma in the La Gloria and El Bunker sections in Teruel (Krijgsman et al., 1996; van Dam, 1997). Magnetostratigraphic control for the MN11–12 and MN12–13 boundaries is poor in Central Spain. For the MN11–12 boundary we use 7.5 Ma on the basis of a reinterpretation by Krijgsman et al. (1996) of Opdyke et al.'s (1990) results for the Cabriel Basin in eastern Spain. The MN12–13 boundary is set tentatively at 6.8 Ma on the basis of the polarity pattern in the upper part of the El Bunker section (van Dam, 1997). This age is consistent with the post-Tortonian age (i.e. younger than 7.12 Ma according to Krijgsman et al., 1994a) for the MN12 mammal locality of Casa del Acero (Murcia, Spain) (Agustí et al., 1985).

Version abrégée

Les nombreuses fouilles effectuées au cours des dix dernières années dans le Miocène des bassins de Daroca-Calatayud, Teruel, Madrid, Duero et Loranca nous ont permis d'enregistrer de nouvelles données d'ordre stratigraphique. L'information paléontologique disponible aujourd'hui n'est cependant pas encore suffisamment précise pour tous les profils stratigraphiques. Sur quelques profils, des échantillons ont aussi été recueillis en vue de l'étude magnétostratigraphique, et une corrélation avec l'échelle GPTS (Cande et Kent, 1995) a été proposée (Krijgsman et al., 1994 ; Krijgsman et al., 1996 ; van Dam, 1997 ; Daams et al., sous presse). Sur 200 gisements qui ont fourni des faunes de petits mammifères, une quarantaine seulement a également livré des grands mammifères. Parmi eux, le plus ancien est celui d'Agreda, qui est placé à la base de la zone locale A (Ramblien supérieur), dont l'âge peut être estimé à environ 18 Ma, tandis que le gisement le plus récent, El Arquillo 4, est daté aux alentours de 6,0 Ma (Van Dam, 1997). En conséquence, la résolution d'âge par la faune est d'environ 60 000 années, en dépit du fait que certaines époques soient mieux représentées que d'autres. De plus, il ne semble pas que des événements biostratigraphiques, paléocologiques ou paléoclimatiques importants aient échappé à notre documentation.

Une biozonation locale a été établie sur la base des rongeurs dans des travaux précédents ; elle ne sera donc pas répétée ici.

La partie inférieure (zones A–G) a été définie par Daams et Freudenthal (1981, 1988), alors que la partie supérieure (zones J1–M3) l'a été par van Dam (1997). Les événements biostratigraphiques les plus importants sont signalés dans le texte en anglais et dans la figure.

Sur l'âge des unités mammaliennes européennes

Ramblien (MN2b–MN3)

La base du Ramblien est datée, dans le bassin de l'Ebre, à $19,3 \pm 0,2$ Ma (Odin et al., 1997) ; on ne dispose pas d'autres datations des faunes rambliennes espagnoles. Une estimation sur l'âge de la limite Ramblien–Aragonien peut être tentée sur la base du taux moyen de sédimentation dans la région du type Aragonien. L'âge obtenu est d'environ 16,7 Ma, mais ce chiffre doit être considéré comme une estimation minimale, car la valeur réelle est probablement plus élevée. En effet, la faune des rongeurs de Beaulieu (France), datée à $17,5 \pm 0,3$ Ma (Aguilar et al., 1996), est représentative de l'unité MN3 ; le stade évolutif de *Ligerimys antiquus* (Eomyidae) est, d'après Aguilar et al. (*op. cit.*), comparable à celui qui présente cette espèce à Moratilla (MN3 supérieure, Province de Teruel). La limite MN3–MN4, postérieure aux faunes de Beaulieu et de Moratilla,

est donc plus récente que $17,5 \pm 0,3$ Ma. Ici, les données provenant des profils espagnols et de la localité-clé de Beau-lieu ne semblent pas être en contradiction.

Aragonien (MN4–MN8)

L'arrivée, au cours de l'unité MN4, d'immigrants africains comme *Deinotherium*, d'autres proboscidiens et de quelques carnivores, eut lieu approximativement vers 16,5 Ma ; elle est en relation avec un accroissement brusque de la température (van der Meulen et Daams, 1992). Un événement comparable a été signalé à la même époque en Afrique orientale (Pickford, 1991). La limite MN4–5 est située à environ 16 Ma par Daams et al. (sous presse), sur la base d'une réinterprétation des données paléomagnétiques et biostratigraphiques du bassin de Calatayud–Teruel (Krijgsman et al., 1994, 1996), alors que les limites MN5–6 et MN6–7/8 demeurent à 13,75 et 12,5–13,0 Ma respectivement (Krijgsman et al., 1994). À son tour, Pickford (1991) place la limite MN5–6 en Afrique orientale, à environ 14 Ma. Cet âge est comparable aux datations des bassins centraux espagnols. Néanmoins, notre échelle diffère de la dernière proposition de l'échelle du Miocène, où la limite MN4–5 est estimée à 17,0 Ma (Steininger et al., 1996) sur la base de localités-clé très conflictuelles, et la limite MN5–6 fluctue entre 16,5 et 15,2 Ma. De plus, la datation entre 15,2–15,0 Ma de la localité de Sansan (base de la MN6) en France (Sen, 1996, 1997) ne concorde pas non plus avec notre datation à environ 13,6 Ma pour les faunes de la base la MN6 (Daams et al., sous presse). L'hypothèse selon laquelle les faunes de la MN6 françaises et espagnoles sont diachroniques, fondée sur la plus grande diversité de la faune de Sansan (Sen, 1997), n'est pas soutenable, car les énormes différences entre le nombre de dents par échantillon n'ont pas été prises en considération. Par ailleurs, la possibilité que Sansan soit contemporaine des

faunes à *Hispanotherium*, comme le suggère Sen (1997), ne semble pas non plus pouvoir être acceptée. D'autre part, la fiabilité de séries longues, comme celles de l'Aragonien et d'Armantes, avec de nombreux gisements superposés est beaucoup plus grande que celle des données issues de localités isolées et de profils courts.

Vallésien (MN 9–10)

La limite inférieure de cet étage a été placée à environ 11,1 Ma (Krijgsman et al., 1996 ; Agustí et al., 1997) ; de nouvelles discussions ne sont pas nécessaires. La limite entre le Vallésien inférieur et le Vallésien supérieur (MN9–10) a été située à 9,7 Ma par Garcés et al. (1996) et Agustí et al. (1997) dans le bassin du Vallès–Penedès. Cet âge concorde avec celui estimé dans le profil de Masía de la Roma (van Dam, 1997).

Turolien (MN11–13)

D'après les polarités paléomagnétiques, la limite Vallésien–Turolien (MN10–11) est estimée à 8,7 Ma (Krijgsman et al., 1996 ; van Dam, 1997) dans les profils de La Gloria et El Bunker à Teruel. Le contrôle magnétostratigraphique des limites MN11–12 et MN12–13 est très insuffisant dans les bassins centraux d'Espagne. Pour la limite MN11–12, nous adoptons 7,5 Ma, en suivant la réinterprétation que Krijgsman et al. (1996) font des données obtenues par Opdyke et al. (1990) dans le bassin du Gabriel (Espagne orientale). Cependant, Opdyke et al. (1997) donnent 8,1 Ma pour cette même limite. D'autre part, la limite MN12–13 est située à 6,8 Ma (van Dam, 1997). Cet âge est en accord avec un âge post-Tortonien (plus récent que 7,12 Ma, d'après Krijgsman et al., 1994a) pour la localité de Casa del Acero (Murcia, Espagne) (Agustí et al., 1985).

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