Defining MN-units and magnetobiostratigraphic correlation of the Spanish sections

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The main problem in the biostratigraphic system of mammalian MN-units is that these units are not well defined and lack strict boundaries, but this system can be enhanced by boundary definitions. In this way, small mammals are an excellent tool to achieve high resolution standards, but they rarely migrate over large distances.
The Spanish Neogene basins include the highest density of large and small mammal localities in Europe, and therefore the highest resolution level may be found there. With the exception of the Messinian, no direct connection existed between Iberia and Africa during the Miocene, and therefore the occurrence of new mammals in Iberia often resulted from a previous route through France and Central Europe.

In Spain the following definitions for MN-zones are proposed (AGUSTÍ et al. 2001); the calibration of the MN boundaries is shown in Figs. 1 and 2.

MN1 (Oligocene-Miocene transition): FAD of *Vasseuromys* in the Ebro basin, where the Oligocene-Miocene boundary was calibrated by magnetostratigraphic correlations. Base: 23.8 Ma, base of chron C6Cn.2n
MN2: FAD of *Andegameryx* and *Amphitragulus* (moschoid artiodactyls).
Among rodents a distinction is only possible by particular stages of evolution of cricetids (*Eucricetodon*) and eomyids (*Ritteneria*). The younger part of this unit is characterized by *Ligerimys* (eomyids), *Pseudaelurus, Xenohyus* and *Teruelia* (giraffid). Problems of age constraint occur because there are no well-calibrated sections in the Iberian basins. Two different dates for the base exist, 22.4 Ma or 22.1 Ma. Further work is needed to place the MN1 - MN2 boundary with more precision.
MN3 can be easiliy recognized. A large number of herbivores entered Europe during this time, including equids (*Anchitherium*), anthracotherids (*Brachyodus*), suids (*Aureliachoerus*), cervids (*Procervulus, Lagomeryx, Acteocemas*), palaeomerycids (*Palaeomeryx*) and proboscideans (Gomphotheridae). Among carnivores this unit is characterized by the genus *Hemicyon.* The age calibration of this unit is made in the North Alpine Foreland Basin, the oldest part of MN3 is correlated to the lower part of chron C6n, and places the base of MN3 at a minimum age of 20 Ma.
MN4 is characterized by the entry of the following large mammals: *Prodeinotherium, Bunolistriodon, Dorcatherium, Eotragus, Megacricetodon* and the disappearance of *Acteocemas* and *Andegameryx.* The MN3 - MN4 boundary has no good age constraint in the Iberian basins, magnetostratigraphic correlations are made in the Schwändigraben-Fontannen section (Swiss), and placed between chrons C5Cn.2r and C5Cr between 16.6 Ma to 17.2 Ma.
A distinction between MN4 and MN5 in Central Europe can be made on the basis of the FAD of the cricetid *Cricetodon.* In Western Europe *Cricetodon* appears in association with *Megacricetodon collongensis.* In Spain *Cricetodon* is missing in most sections with *M. collongensis.* The lower boundary of MN5 is placed now at 16 Ma, at the base of C5Br.
The lower part of MN6 is characterized by the FAD of a second *Megacricetodon* lineage and the replacement of *Bunolistriodon* by *Listriodon.* The upper subunit of MN6 shows the FAD of *Tethytragus, Hispanomeryx* and *Euprox.* The lower boundary of MN6 is placed at 13.7 Ma, at the base of chron C5ABr.

The lower boundary of the MN7 and MN8 unit is placed between chrons C5Ar.1n and C5Ar.3r, between 13 and 12.5 Ma. MN7-like faunas are found in the Valles-Penedes basin characterized by *Cricetodon albanensis, Cricetodon lavocati, Fahlbuschia crusafonti*, the FAD of *Propotamochoerus, Parachleuastochoerus* and *Protragocerus*. The MN8 unit is originally defined by *Hispanomys, Palaeotragus, Protragocerus, Tetralophodon.* The characteristic species *Deperetomys hagni* and *Democricetodon freisingensis* are not recorded in the Spanish basins.

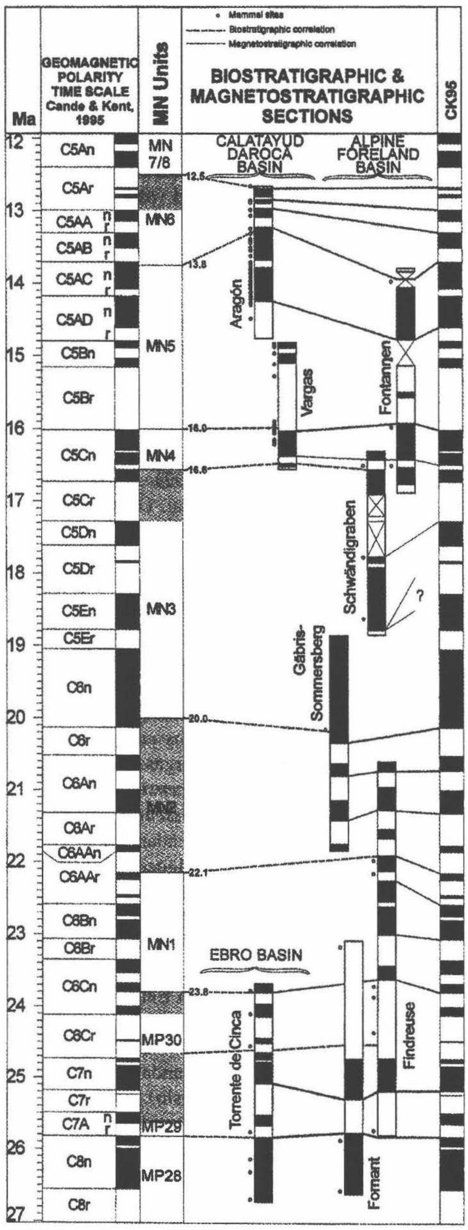

Fig. 1: Biostratigraphic and magnetostratigraphic correlations across the different Lower to Middle Miocene sections of the Calatayud-Daroca, Ebro and Alpine Foreland Basins. Biostratigraphic (magnetostratigraphic) boundary lines correlate towards the time scale on the left (*right*). Shaded time slices in the MN units column represent uncertainities of MN boundary ages. Crosses in the magnetostratigraphic logs represent significant sampling gaps. Correlation of the Fornant-Findreuse and Schwändigraben-Fontannen sections to the GPTS has been reinterpreted (from AGUSTÌ et al. 2001).

The beginning of the Late Neogene is defined by the entry of *Hippotherium.* The base of MN9 is placed at 11.1 Ma (GARCÉS et al. 1997). Small mammal changes include the replacement *of Megacricetodon* and *Fahlbuschia* faunas *by Cricetulodon.*

The lower boundary of MN10 is established in the Valles-Pendes basin at 9.7 Ma in chron C4Ar.3r. In this unit an important faunal change took place at the Early/Late Vallesian boundary, the so-called "Mid-Vallesian Crisis" (MVC), with the disappearance of *Conohyus, Amphiprox, Hispanomeryx, Miotragocerus, Prottragocerus, Lartethotherium sansaniense, Dicerorhinus steinheimensis, Megacricetodon, Eumyarion, Bransatoglis, Myoglis, Paraglirulus, Eomuscardinus, Albanensia, Miopetaurista, Chalicomys* and *Euroxenomys*

(AGUSTÍ & MOYÀ-SOLÀ 1990, AGUSTÍ et al. 1999). In Western Europe this disappearance coincides with the spread of murids.
The lower boundary of MN11 is placed at 8.7 Ma in the upper part of chron C4An. In this unit the extinction of *Rotundomys* and *Anomalomys* occurs. Some artiodactyl taxa disappear and are replaced by *Lucentia* and *Birgerbohlina.*
For the MN11/MN12 boundary two different age calibrations exist, one placing the boundary at 8.0 Ma (base of chron C4n), the second at 7.5 Ma (in chron C4n.1). The unit is characterized by the entry of *Pliocervus, Hispanodorcas, Palaeoryx, Gazella* and *Procapreolus*, while *Dorcatherium, Micromeryx* and *Lucentia* disappear (KRIJGSMAN et al. 1996).

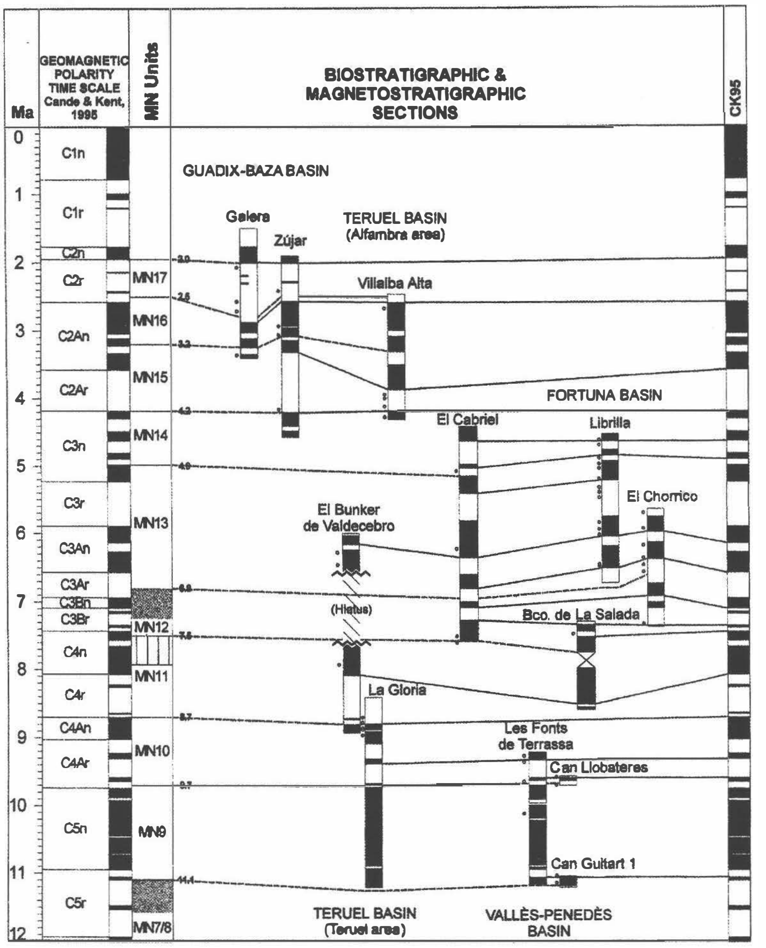

Fig. 2: Biostratigraphic and magnetostratigraphic correlations across the different Upper Miocene and Pliocene sections of the Iberian basins. Stripped rectangle between MN 11 and MN 12 in the MN units log represents the uncertainty of this boundary age due to alternate correlations of the lower part of the Cabriel section (OPDYKE et al. 1997), partly reinterpreted in this paper (from AGUSTÌ et al. 2001).

The MN13 unit records an important turnover: dissapearance of *Parapodemus, Huerzelerimys, Microstonyx, "Procapreolus"*; dispersal and first occurrence of *Macaca* and *Nyctereutes, Hexaprotodon, Paracamelus, Parabos, Paraethomys, Blancomys, Protatera, Calomyscus.*
Recent studies in the Fortuna basin place the boundary between MN12 and MN13 between 6.8-7.2 Ma (between chrons C3Ar and C3Br; KRIJGSMAN et al. 1996, GARCÉS et al. 1998).
MN14 defines the transition from Miocene to Pliocene. The best estimate of the base of MN14 is found in the Cabriel section where a correlation to chron C3n.3r at 4.9 Ma is possible.

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Spanish sections: Correlation of magnetozones and MN-zones

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High resolution mammal data from Spain point out the specific problem of MN4, MN5 and MN6 correlations. Especially in the Aragonian area with the Aragonian type section, a good correlation between mammal MN-zones and magnetostratigraphy was constructed. The following table shows the correspondence between the local mammal zones A - I and the MN-zones:

Local zonation	MN zonation
A	3
B	4
C	4
D (Da, Db, Dc, Dd, De)	5
E	5
F	6/7
G	7/8
H	9
I	9

Tab. 1: Correlation of Spanish local mammalia zonation with European MN-zonation.

The Armantes section provided very good magnetostratigraphic results, allowing an unambiguous correlation to the GPTS of CANDE & KENT (1995). The magnetostratigraphy of the Aragonian type section fits quite well to the magnetic record of the Armantes section. The MN4 - MN5 boundary was placed at the top of chron C5 Cn.1n (about 16 Ma), and the MN5