Up-to-date Spanish continental Neogene synthesis and paleoclimatic interpretation

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Abstract: A synthesis of the Spanish continental Neogene is presented by designing an integrated correlative chart of the Neogene successions of the Iberian Peninsula. Nine main sedimentary breaks have been distinguished in most of the basins. They are considered a valuable criteria for correlation as they occur in similar time intervals from basin to basin. The determined sedimentary breaks occur in the Agenian, Ramblian, Middle Aragonian, Late Aragonian, Late Vallesian, Middle Turolian, Late Turolian, Late Ruscinian-Early Villafranchian, and Villafranchian ages. The larger interior basins (Ebro, Tajo, Duero) show a fairly complete Neogene sedimentary record in which the above mentioned sedimentary breaks are usually well recognized. A good correlation may be established from basin to basin. Likewise, there is a fairly good correlation among the Upper Miocene-Pliocene sedimentary record of basins spreading out in Levante and southeastern Spain. However, the correlation is not as clear in those basins located within the Iberian and Catalan Coastal Ranges, which usually do not show a similar sedimentary pattern. The comparison between Neogene stratigraphic logs in most of the Spanish continental basins and the pattern of global events from currently accepted Cenozoic Cycle Charts allows recognition of chronological coincidences, especially with regard to the age of seven major sedimentary ruptures (those developed at about 24.5 Ma, 22 Ma, 16 Ma, 13.5 Ma, 9.5 Ma, 5.5 Ma, 3.3 Ma). Evolutionary sedimentary trends in both offshore Mediterranean areas and inland peripheral zones of the Iberian Peninsula show also striking coincidences regarding the chronology of major sedimentary breaks observed in continental successions. Paleoclimatic curves for the Spanish continental Neogene display four relative temperature peaks indicative of warm climatic conditions (Late Agenian, Early-Middle Aragonian, Vallesian-Turolian, and Late Villafranchian) as well as five relatively dry periods (Early Ramblian, Middle-Late Aragonian, Middle Turolian, Late Ruscinian, and Middle Villafranchian ages).

Key words: Neogene, Continental basins, Stratigraphic correlation, Sedimentary discontinuities, Paleoclimates, Spain.

Resumen: Se presenta en este trabajo una síntesis del Neógeno continental español mediante la elaboración de un esquema de correlación general de las sucesiones neógenas en la Península Ibérica. Se reconocen nueve rupturas o discontinuidades mayores dentro del registro sedimentario de un total de 16 áreas que cubren la mayor parte de las cuencas continentales terciarias de la Península. Las rupturas, denominadas de acuerdo con su posición cronológica, son las siguientes: Ageniense, Rambliense, Aragoniense medio, Aragoniense superior, Vallesiense superior, Turoliense medio, Turoliense superior, Rusciniense superior-Villafranquiense inferior y Villafranquiense. Las grandes cuencas interiores (Ebro, Tajo, Duero) presentan un registro muy completo de las sucesiones neógenas y de las rupturas arriba señaladas, las cuales tienen buena correlación de una cuenca a otra. De igual modo, existe una correlación notable entre los registros sedimentarios del Mioceno superior-Plioceno de las cuencas de Levante y el Sudeste. Sin embargo, la correlación es menor con las cuencas situadas en la Cadena Ibérica y la Cadena Costero Catalana. La comparación entre el registro sedimentario Neógeno obtenido en gran parte de las cuencas continentales españolas y la secuencia de eventos globales a partir de los cuadros de ciclicidad para el Cenozoico actualmente aceptados permite reconocer coincidencias cronológicas entre ambos, especialmente en lo que se refiere a siete de las rupturas sedimentarias mayores (las definidas a 24.5 Ma, 22 Ma, 16 Ma, 13.5 Ma, 9.5 Ma, 5.5. Ma, 3.3 Ma). Las tendencias en la evolución sedimentaria de las sucesiones Neógenas, tanto en áreas del "offshore" Mediterráneo como en zonas periféricas de la Península Ibérica, muestran igualmente notables coincidencias en lo que se refiere a la cronología de rupturas sedimentarias mayores observadas en sucesiones continentales. La interpretación paleoclimática, resumida en las curvas de humedad y temperatura que acompañan el cuadro de correlación, permite definir varios cambios climáticos a lo largo del Neógeno en España. Destacan cuatro picos relativos de temperatura (Ageniense superior, Aragoniense inferior-medio, Vallesiense-Turoliense y Villafranquiense superior), los tres primeros indicando posiblemente condiciones subtropicales. De igual modo, son detectables cinco períodos de sequedad relativa (Rambliense inferior, Aragoniense medio-superior, Turoliense medio, Rusciniense superior y Villafranquiense medio). Estas tendencias paleoclimáticas son en buena parte contrastables con las observadas a partir de sucesiones marinas.

Palabras clave: Neógeno, Cuencas continentales, Correlación estratigráfica, Discontinuidades sedimentarias, Paleoclimas, España.

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Seven years ago, an overview of the Neogene basins of Spain was presented at the VIIIth Congress of the Regional Committee of the Mediterranean Neogene Stratigraphy in Budapest under the title "Approach to the Spanish Continental Neogene Synthesis and Paleoclimatic Interpretation". This contribution was authored by 16 researchers, specialists in different fields of the Neogene geology, who were helped by 23 other researchers yielding specific information in some areas. The workshop was instigated and coordinated by Dr. López-Martínez. The final draft of the Spanish Neogene Synthesis can be found in López-Martínez *et al.* (1987).

The methodology of the synthesis written in 1985 was based on modern techniques of basin analysis, especially the conceptual background derived from the tectono-sedimentary basin analysis (Megías, 1982) as well as the development of sequential stratigraphy of basins (Mitchum *et al.*, 1977; Vail *et al.*, 1984). Later contributions on this topic may be found in Wilgus *et al.* (1988) and Vera (1989), among others. The use of these techniques allowed the overcome of previous syntheses that had been outlined mainly on the basis of vertebrate paleontology (e.g., Aguirre *et al.*, 1976). As a result, a general scheme of correlation was established among the Neogene stratigraphic records of seven major areas within the Iberian Peninsula which, in turn, grouped sixteen basins and/or sectors of larger basins. Two curves indicative of the evolution of humidity and temperature throughout the Neogene in Spain accompanied the correlation chart.

Although the results of that paper seemed to be conclusive and the correlation chart fairly well fixed, the authors did not hesitate to offer this approach with criticism and assessed their work as a starting point which should be improved by future developments. However, some major conclusions could be pointed out as quite consistent: 1) the lack of coincidence between main sedimentary breaks and classic chronostratigraphical limits (these limits being characteristically located within Tectonosedimentary Units (TSU)); 2) limits between TSU are not coincident with limits between mammal-based biostratigraphic zones; and 3) according to the established marine-continental correlation chart, the sedimentary breaks identified in continental sedimentary sequences seem to be chronologically equivalent to those related to major events in the marine realm. This latter observation is probably the most controversial.

The aim of this present paper, which is conceived as an updating of the previous synthesis, is to test the current validity of that contribution in view of the new data provided by: 1) recent findings of mammal localities and the biostratigraphical information supplied by them, 2) advances in our stratigraphic and sedimentological knowledge of basins, and 3) new proposals on the Neogene structural evolution of the Iberian plate, considered either as a whole or in particular areas. Unfortunately, available information from magnetostratigraphy, radiochronology or systematic chronostratigraphical studies is far from being sufficient to supplement the fossil mammal biochronological background; therefore, this information will be offered in a restricted manner.

An initial change with regard to the previous synthesis concerns the division and terminology of the Neogene Mammal Ages on which the stratigraphic chart is based. For instance, the Ramblian (Daams *et al.*, 1987) and Alfambrian (Moissenet *et al.*, 1990) continental stages are included in the new chart in order to integrate recent proposals for the biostratigraphy of the Lower Miocene and Lower Pliocene, respectively. Other changes concern the chronology of the stratigraphical divisions as well as the correlation between Neogene Mammal Ages and the Marine Neogene Mediterranean Chronostratigraphy. Such changes are considered provisional as they will surely undergo modifications in the future.

We assume the validity of the methodology of basin analysis used in the paper by López-Martínez *et al.* (1987). Although this methodology is viewed with criticism by some researchers (see Santanach, 1989), even by co-authors of this paper, the establishement and further correlation of major stratigraphic events in the diverse basins supports it as an acceptable working method.

We take into account some valuable suggestions on problems for recognition of sedimentary breaks in continental basins (González *et al.*, 1988; Pardo *et al.*, 1989). Most of the sedimentary ruptures described in this paper fit with the major types (1, 2, or 3-types) of sedimentary breaks defined by these authors. Accordingly, the breaks are outlined either by sharp erosional surfaces, unconformities, paleokarst surfaces or significant changes of the evolutionary trend of the sedimentary filling in the basins. Overall, they constitute major sedimentary discontinuities which are related to tectonic activity in the basin margins. Although some ambiguity may remain, the term 'sedimentary break' will be used for major sedimentary discontinuities that can be recognized in an entire basin.

Geochronology, bio- and chronostratigraphy

The geochronological scale presented in this paper is that of López-Martínez *et al.* (1987) with some modifications. First of all, we separated the left column of the marine chronostratigraphy from the continental stratigraphy because there exist few points of correlation between the marine and continental realm in Spain. Two dashed lines between the marine chronostratigraphical scale and the continental one are drawn. The first dashed line represents the correlation between the mammal locality of Crevillente 6 and the *Globorotalia conomiozea* zone of the Lower Messinian (Bruijn *et al.*, 1975). The second dashed line represents the correlation between the mammal locality of La Alberca from upper MN13, intercalated between marine sediments, to the Late Messinian (Mein *et al.*, 1973). Tie-points of lesser order are also taken into account for the construction of our chronological framework. Reinterpretation of the paleomagnetic data of Dijksman (1977) of the Armantes section near Calatayud situates the Armantes 7 fauna (Zone F of the Upper Aragonian) at 13.7 Ma (Daams *et al.*, *in prep.*). Another tie-point is that between the Early Serravallian and the upper part of Zone D of the Middle Aragonian. This correlation is based on the first indications of a cooling of the surface waters of the Mediterranean (Chamley *et al.*, 1986) and the cooling on the continent interpreted by Van der Meulen and Daams (1992). Another correlation is that of the Aragonian/Vallesian boundary as evidenced by the *Hipparion*-datum in the Mediterranean area. Sen (1990) argues that there is no radiometric data available that can prove that the *Hipparion*-datum is older than 11 Ma, and that magnetostratigraphical data situates its age at a maximum of 11.5 Ma. In this paper we follow Sen's suggestion and we set the datum at 11.5 Ma.

In the following columns we prefer to distinguish between truly defined continental stages and mammal ages, such as was done by Steininger *et al.* (1990), but again with a modification. These authors mention a gap between the Orleanian and Astaracian, a suggestion not followed by us.

The MN subdivision presented in this paper does not have a/b subdivisions of zones 2, 3, 4 and 16, and zones 7 and 8 are fused. Bruijn *et al.* (1992) suppressed these subdivisions as they are not useful at european scale. Distinction between zone 7 and 8 is not possible either at larger distance from the reference level.

The local zones are those of Daams and Freudenthal (1981) who defined zones A to I in Calatayud - Teruel basins; Daams and Van der Meulen (1984) who defined zones X, Y and Z in Ebro, Almazán and Calatayud-Teruel basins, respectively; and Alvarez *et al.* (1987) who defined zone W for the Upper Oligocene in the Loranca basin. Most of the local zones are defined in the type areas of the Ramblian and Aragonian. The use of the proposed local fauna subdivisions allows a more precise correlation than the biochronological framework of the MN system (Daams and Freudenthal, 1990). The local zones can be used independently for both micromammal and macromammal faunas.

Summary of the Spanish continental basins and their neogene sedimentary record

General characteristics

Three main Tertiary continental basins are located in the interior of the Iberian Peninsula (Fig.1). The Duero basin, in the north-central part, is bounded by the Cantabrian Range, the Hesperic Massif and the Central System. The Tajo basin is located exactly in the centre and is bordered by the Toledo Mountains, the Iberian Range and the southern side of the Central System. Finally, the Ebro basin is bordered by the Pyrenees, the Iberian Range and the Catalan Coastal Range. Each of these basins exceeds 15,000 km2 in extent, and together they occupy a large portion of the total area of Spain. In addition to these large Tertiary basins, other minor intramountanous basins occur within the bordering ranges or in areas which were covered by the sea throughout most of the Neogene. This is the case of Late Neogene basins of the Betic domain and some other peripheral basins.

The Neogene sedimentary record is fairly complete in several Spanish basins. With regard to the continental Neogene, the sedimentary sequences are especially well developed within the three large interior basins which were separated from the marine realm since their formation in the Paleogene. The thickness of the continental Neogene successions in these basins ranges from 500m to 1,500m. In the other basins the thickness of the continental Neogene successions is highly variable but in a few cases it reaches up 1,500 m, particularly in those generated as a consequence of rifting processes (Anadón *et al.*, 1989a).

The formation and evolution of the Tertiary basins in Spain are closely related to the upbuilding of the Pyrenean and Betic orogens and the internal deformation which affected the Iberian microplate (Vegas and Banda, 1982; Anadón *et al.*, 1989a). The Ebro basin developed as a foreland basin resulting from the upthrusting of the southern Pyrenean zones. A rather similar situation is recognized in the northern margin of the Duero basin whereas the Central System bounds the

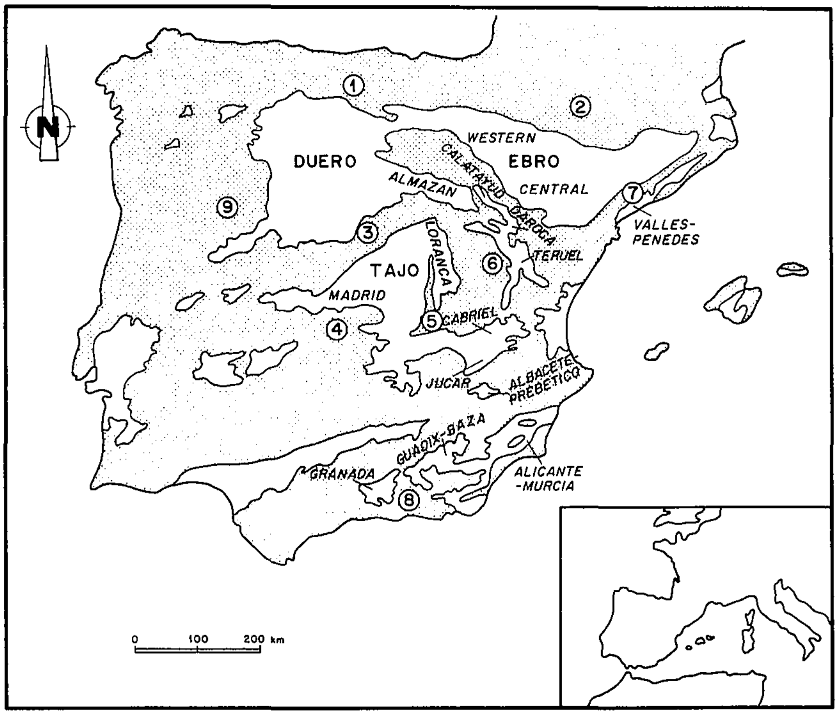

Figure 1.- Map of the Iberian Peninsula with location of the Tertiary basins included in this synthesis. Larger Tertiary basins are written in capitals; the several subbasins or minor basins are indicated with italics. Encircled numbers indicate major structural chains bounding the basins: 1, Cantabrian Range; 2, Pyrenees; 3, Central System; 4, Toledo Mountains; 5, Altomira Range; 6, Iberian Range; 7, Catalan Coastal Range; 8, Betic Ranges; 9, Hesperic Massif.

basin to the south. This latter major structure has been interpreted as a big arch bounded by reverse faults resulting from the compressive deformation of rigid intraplate areas (Vegas and Banda, 1982; Vegas *et al.*, 1990) or as a crustal thickening due to basement thrusting (Warburton and Alvarez, 1989). Whichever the case, the Madrid basin, located to the south of the Central System, received huge volumes of terrigenous deposits which account for Tertiary sediments nearly 3,500m thick.

In general, all the compressional processes leading to the formation of the large Spanish Tertiary basins were active throughout the Paleogene and, locally, into the Lower and Middle Miocene. Synchronously, several minor or medium-size basins (Vallés-Penedés, Calatayud, Teruel, Rubielos de Mora, ..) developed in the eastern part of Iberia as a result of extensional processes (Anadón *et al.*, 1989b). In a similar way, a number of extensional or strike-slip small basins were formed in the Betic Zones during and after the emplacement of the Betic nappes (Vegas and Banda, 1982; Sanz de Galdeano, 1990; Sanz de Galdeano and Vera, 1992). Most of these basins were filled with marine sediments in their first stages but in many cases show later continental successions of considerable thickness (Granada, Guadix-Baza, Fortuna,...)

In spite of the extreme complexity of the structural framework of the Tertiary basins of Spain, some common trends in vertical evolution of terrestrial successions (both alluvial and lacustrine deposits) are observed from basin to basin. Thus, in the Duero, Ebro and Tajo basins the sequential evolution throughout the Neogene is marked by progradations and retreatments of the peripheral alluvial systems which show striking similarities in the three areas (IGCP-219 Spanish Group, 1990). The infilling of the smaller basins (those located in the Iberian Range, Betic domain or elsewhere) displays different sedimentary patterns and a wider spectrum of both alluvial and lacustrine facies. Nevertheless, many of the sedimentary breaks recognized within these basins are chronologically equivalent to those detected in the larger ones.

Figure 2 shows several simplified stratigraphic logs from all the basins included in this study. In practice, they cover most of the continental Neogene record in Spain (Fig.1). Emphasis is put on the position of the sedimentary breaks. Some comments on these sedimentary breaks, ordered by time intervals, are given below. Mammal sites included in Figure 2 are listed in Appendix A.

Main Neogene sedimentary breaks

Agenian sedimentary break.- This sedimentary break has been recognized in the Ebro (both central and western sectors) and Tajo basins. In this latter basin the sedimentary break is recorded as Castellana Phase by Aguirre *et al.* (1976). The age of the sedimentary break has been well determined in the Loranca basin but elements are lacking for a solid age determination of the discontinuity throughout the Oligocene-Miocene boundary in the Madrid basin. *Rhodanomys* faunas are present below and above the break. Its age corresponds to the Y zone (Daams *et al.*, 1987) or to the limit between X and Y zones (probably to the Upper Oligocene) (López Martínez and Torres, 1991).

The sedimentary break is marked in the Ebro basin by a net progradation of alluvial systems over alluvial and laterally related lacustrine sequences which show a

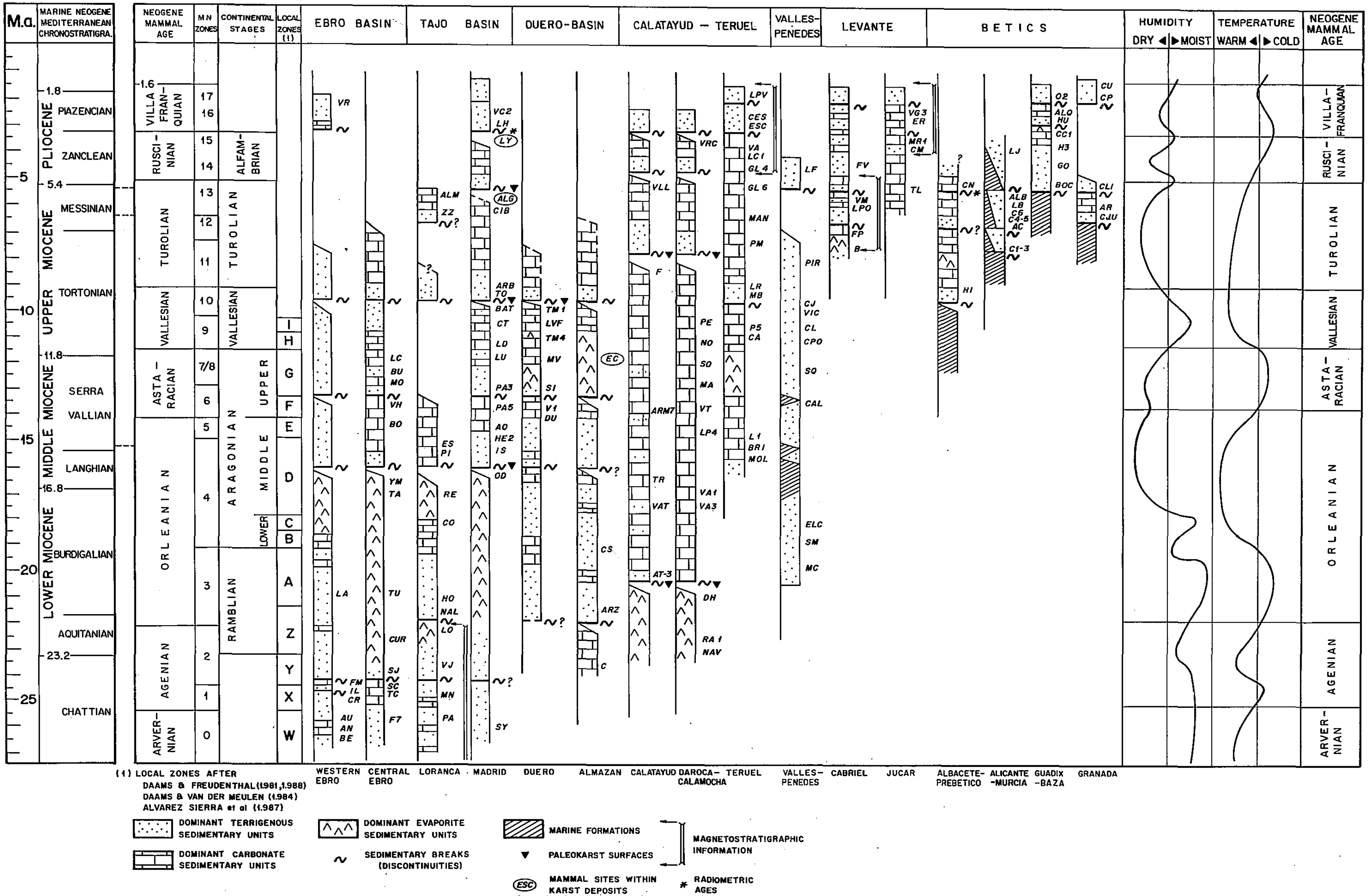

Figure 2.- Integrated Correlation Chart of Spanish Neogene continental basins. Lithostratigraphic logs for some basins are separated in different sectors. The graphic is accompanied by paleoclimatic curves for the Spanish Neogene. Meaning of codes for fossil mammal sites is included in Appendix A.

positive sedimentary trend (González, 1989; Pérez García, 1989; Muñoz, 1991).To the north of the central Ebro area (Huesca province), this sedimentary break is represented by an angular unconformity between mammal sites of zone X (Santa Cilia) and zone Y2-Z (San Juan-La Galocha) (Alvarez *et al.*, 1990). In Loranca the sedimentary break resulted from the reactivation of alluvial fan systems (Díaz-Molina *et al.*, 1989).

Ramblian sedimentary break.- Formerly defined as Late Agenian-Early Aragonian (López-Martínez *et al.*, 1987), this sedimentary break has been clearly recognized in the Loranca basin (Tajo) where it is dated by faunas of the Loranca and Navalón mammal sites, below and above the discontinuity, respectively. In Almazán, the sedimentary break is marked by an angular unconformity near the basin margin and by a drastic sedimentary change in central parts of the basin where alluvial deposits overlie lacustrine carbonate sequences which contain the Cetina mammal site. An intra Z zone biostratigraphic position is postulated for this event. *Ligerimys* (one species) and *Eucricetodon* are recorded below and above the sedimentary break.

The relative chronological proximity of the two aforementioned sedimentary breaks is consistent with the remarkable tectonic activity developed throughout the Late Paleogene and Early Miocene in the Iberian Plate and other zones of the western Mediterranean (Vegas and Banda, 1982; Letouzey, 1986; Anadón *et al.*, 1989). Unfortunately, the available biostratigraphic information from some ranges, such as a number of small basins of the Iberian Ranges, is not as complete as needed for dating accurately the periods of basin formation and initial evolutionary stages (Simón, 1984).

Middle Aragonian sedimentary break.- This sedimentary break seems to be generalized in most of the analyzed basins. It has been recognized clearly in the Ebro basin as well as in Loranca and Madrid basins. In this latter basin the discontinuity is recorded as Neocastellana Phase by Aguirre *et al.* (1976). The biostratigraphic position of the sedimentary break is fixed by the occurrence of mammal sites containing *Hispanotherium* below and above the break. A significant lithological change between thick lacustrine evaporite successions and sequences dominated by alluvial, carbonate and gypsum deposits is recognized in the Ebro and Madrid basins. This change is related to the tectonic reactivation of the basin margins combined with the exhaustion of previous evaporite source areas (Calvo *et al.*, 1989; Anadón *et al.*, 1989a). In addition, the discontinuity may be marked locally, e.g., in the Madrid basin, by paleokarst surfaces (Calvo *et al.*, 1984).

In areas where marine and continental interfingering is recorded, such as the Vallés-Penedés area, the sedimentary break may correspond to the progradation of continental clastic facies over Upper Langhian coastal marine sediments.

Late Aragonian sedimentary break.- This sedimentary break was not outlined in the previous synthesis by López-Martínez *et al.* (1987). Further studies have demonstrated that a Late Aragonian sedimentary break, first observed in the Madrid basin, can be also recognized in western and central areas of the Ebro basin as well as in the Duero. In all these cases the sedimentary break is marked by a net progradation of coarser alluvial deposits over alluvial and/or lacustrine sequences showing a positive depositional trend.

The sedimentary break is located between the F and G zones as indicated by Paracuellos-5 and Paracuellos-3 mammal sites in the Madrid basin, Villanueva de Huerva and Moyuela in the Ebro, and Valladolid-1 and Simancas in the Duero. This event is correlated with a second tectonic pulse included in the Guadarrama Phase that affected the Central System in the northern margin of the Madrid basin (De Vicente *et al.*, 1990).

Late Vallesian sedimentary break.- This is a relevant event because of two reasons: 1) the sedimentary break can be accurately recognized in the large basins (Ebro, Duero and Tajo); 2) as some recent investigations seem to indicate (Sanz de Galdeano, 1990; De Vicente *et al.*, 1990), the Late Vallesian sedimentary break records a major change in the tectonic strains affecting the Iberian microplate by that period. A generalised extensional phase lead to the development of grabens and strike-slip basins in both internal and external zones of the Betics (Calvo *et al.*, 1978; Sanz de Galdeano, 1990). Likewise, a drastic change of the paleogeography of the large interior basins (Ebro and Madrid) is recorded (Calvo *et al.*, 1989; Pérez García, 1989; De Vicente *et al.*, 1990).

The precise age of this discontinuity is still a matter of controversy. Both Lower and Upper Vallesian faunas are recorded below the discontinuity in the Duero and Madrid basins (López-Martínez *et al.*, 1987; Alvarez *et al.*, 1990; Sesé *et al.*, 1990) but there is a lack of agreement with regard to the lithostratigraphic position of mammal sites of Vallesian age in some areas, particularly in the Duero basin (Corrochano and Armenteros, 1989; Portero *et al.*, 1991).

Middle Turolian sedimentary break.- This sedimentary break is significant as it may be correlated with the intra-Messinian regional sedimentary break (Santisteban, 1981; Megías *et al.*, 1983; Agustí *et al.*, 1985a). The relationships between continental and marine deposits can be observed in the Alicante-Murcia area. Therein, the Middle Turolian site of Casa del Acero overlies marine deposits of Messinian age (Agustí *et al.*, 1985b; López-Martínez *et al.*, 1987). The correlation between marine-continental may be also established on the basis of several mammal sites in Crevillente. *Parapodemus* faunas are recorded both below and above the sedimentary break.

An additional event related to the Middle Turolian sedimentary break is probably represented by relevant depositional changes recorded in lacustrine basins of the Prebetic area (Elizaga, 1990). Data from the Cabriel and Granada basins also support the existence of this discontinuity which may be dated as an intra MN12 zone. In the Cabriel basin, the Fuente Podrida mammal site dated at 7.2 Ma (Opdyke *et al.*, 1990) is located below the discontinuity.

Late Turolian sedimentary break.- Whereas this sedimentary break is not well defined within the large interior basins (the Madrid basin may be considered an exception as the Algora mammal site of Late Turolian age would be located above the rupture), the peripheral Levantine and Betic basins offer a good choice for determining its chronostratigraphic position. Thus, a Late Turolian sedimentary break (intra-MN13) can be defined in the Granada, Guadix-Baza (Agustí *et al.*, 1988), Prebetic, Cabriel and Vallés-Penedés basins. *Apodemus* faunas are recorded below and above the discontinuity. In most cases the sedimentary break is represented by an erosional surface and/or the overlying of terrigenous deposits on lacustrine carbonates.

This sedimentary break has a probable absolute age of about 5.7 +/-0.3 Ma as recorded by the Monagrillo volcanic event (Bellon *et al.*, 1981) in the Las Minas basin (Prebetic) (Elizaga and Calvo, 1989). This is also supported by paleomagnethostratigraphic insight from the Cabriel succession where the Venta del Moro mammal locality dated over 5.47 or 5.78 Ma (Opdyke *et al.*, 1990) is located below the discontinuity.

Late Ruscinian - Early Villafranchian sedimentary break.- The sedimentary break is located approximately in the Ruscinian (Alfambrian) - Villafranchian boundary. It has been related to the Ibero-Manchega I phase (Pérez-González, 1979, 1982) in the Tajo, Júcar, and La Mancha areas. The sedimentary break has been also recognized in Teruel, where the Alfambrian stage has been defined (Moissenet *et al.*, 1990), and in nearby interior basins. In all these cases the rupture is related to tectonic reactivation resulting on both tilting and, locally (e.g., Loranca basin), strong deformation of previously deposited Neogene formations. The recognition of this sedimentary break in Guadix-Baza is controversial (Agustí *et al.*, 1988).
Mimomys ischus (Esteban and Martínez Salanova, 1987) as well as the last *Hipparion* faunas have been recorded both below and above the discontinuity, which has been dated c.a. 3.5 +/- 0.3 Ma according to the volcanic event of Campo de Calatrava (Alberdi *et al.*, 1984). This event may be correlated with the Las Higueruelas mammal locality.

Villafranchian sedimentary break.- The Villafranchian sedimentary break is widespread in most of the basins, where it records the terminal Neogene event prior to the development of recent fluvial systems. This sedimentary break has been related to the Ibero-Manchega II phase (Pérez-González, 1979, 1982) in the Tajo, Júcar and La Mancha areas. *Equus* and *Mammuthus* as well as the typical Villafranchian ruminant faunas (*Gazella, Gazellospira, Leptobos, Croizetoceros*) occur both below and above the discontinuity. The biostratigraphic position of the discontinuity is well determined in Guadix-Baza basins (Agustí *et al.*, 1988) where it occurs between the Alquería and Orce-2 mammal localities.

Discussion

Several preliminary conclusions may be derived from the correlative lithostratigraphic chart presented in Fig.2:

a) There is a fairly good correlation among main sedimentary sedimentary breaks recognized in the studied basins. Moreover, the sedimentary evolutionary trends of lithostratigraphic units defined between sedimentary breaks show, in general, similar patterns from basin to basin. In many cases, the morphological characteristics of the breaks (paleokarst surfaces, erosional surfaces) is similar in a same time slice for different basins.

b) The correlation among sedimentary breaks is clear in the largest interior basins, especially within the Lower and Middle Miocene interval as well as the lower part of the Upper Miocene (Vallesian). However, the correlation is poor among these large basins and those located within the Iberian and Catalonian Coastal Ranges. On the other hand, basins of the Levante and Betic areas show fairly good correlative patterns through Upper Miocene and Pliocene.

c) López-Martínez *et al.*(1987) made emphasis on the chronological coincidence of most of the sedimentary breaks in both marine and continental series by comparing the Spanish continental Neogene record with previously established charts of Neogene Global Cycles (Vail and Handerbol, 1983; Keller and Barron, 1983; and, in a regional scale, Soler *et al.*, 1983). The updated synthesis confirms this impression. Further refining based on sequence stratigraphy (Haq *et al.*, 1987, 1988) has led to the proposal of modified Cenozoic Cycle Charts which are currently accepted as a reference by most of the authors. According Haq *et al.*(1988), the Neogene marine series record a highly complex history of sea level changes with marked relative rises and falls in several periods. The timing of these eustatic sea level changes has been precisely fixed in Haq *et al.*'s curves (Fig.3).

The comparison between stratigraphic logs from the Neogene in most of the Spanish continental basins (Fig.2) and the pattern of global cycles allows to recognize chronological coincidences, especially with regard to the age of seven major sedimentary sedimentary breaks (Fig.3). This conclusion is considered to be valid even if uncertainities in continental biostratigraphy and marine-continental correlations in Spain oblige to make only a tentative assessment.

The agreement in the sequence boundary correlations between marine basins lies in most cases on approximate chronological coincidence, as deduced from biostratigraphic, paleomagnetic and isotopic data. Many authors use sequence boundary ages established in Global Cycle Charts as a chronological reference for dating discontinuities elsewhere. Instead of, we have obtained independent evidence for regional discontinuity correlations as well as to date them.

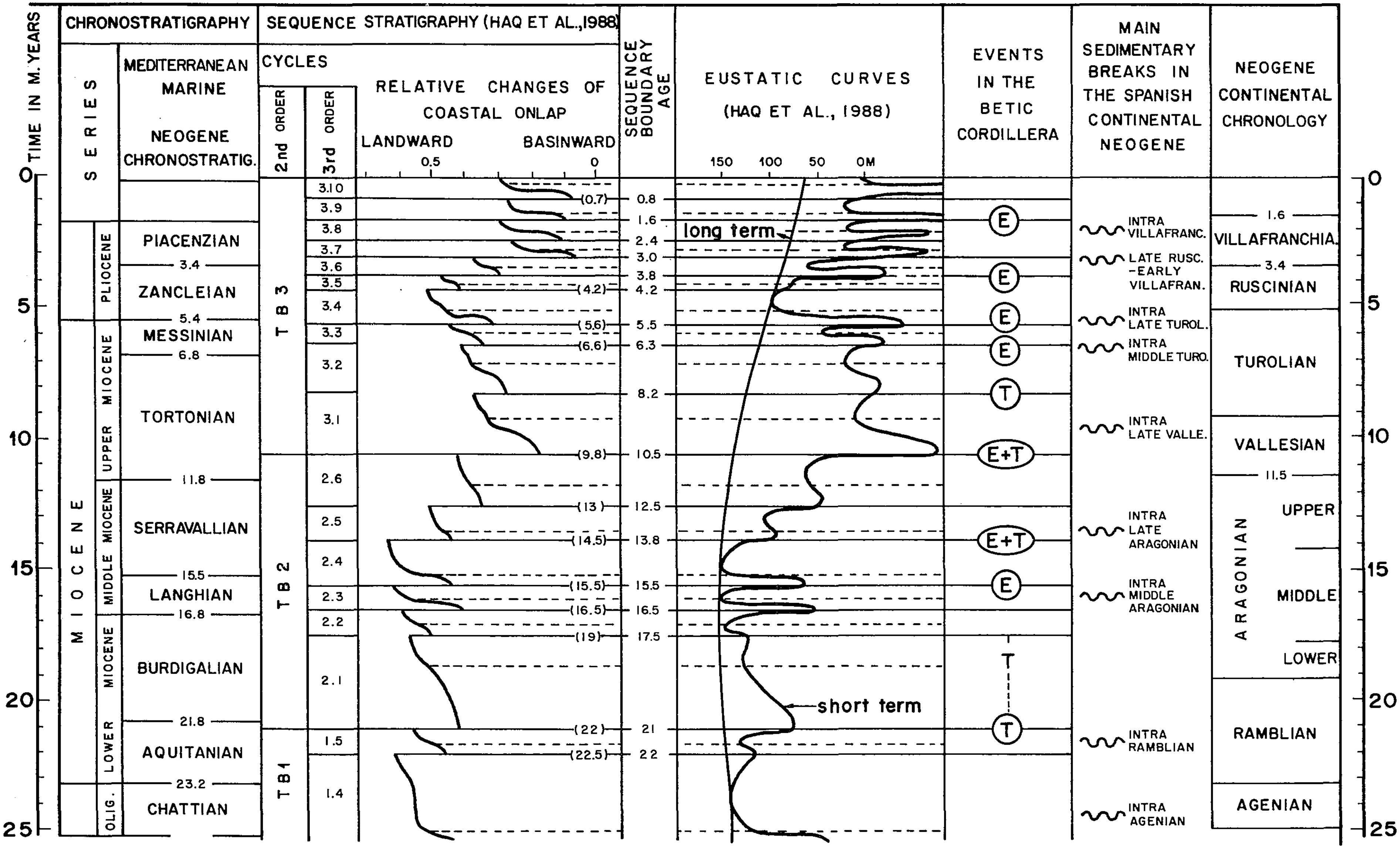

Figure 3.- Chart for comparison of the chronology of major sedimentary breaks determined in Spanish continental Neogene successions and curves showing relative changes of coastal onlap during the Neogene (Haq *et al.*, 1988). A comparison is also established with chronology of major events recorded in the Betic Cordillera (after Pascual *et al.*, 1991).

The coincidence of discontinuity ages between the Spanish continental Neogene record and Global Marine Charts show even better fitness than was previously stated (López-Martínez *et al.*, 1987). In the Spanish continental Neogene chart (Fig.2), major sedimentary breaks are at about 24.5 Ma (intra-Agenian), 22 Ma (intra-Ramblian), 16 Ma (intra-Middle Aragonian), 13.5 Ma (intra-Late Aragonian), 9.5 Ma (intra-Late Vallesian), 6.5 Ma (intra-Middle Turolian), 5.5 Ma (intra-Late Turolian), 3.3 Ma (Late Ruscinian-Early Villafranchian), and 2 Ma (intra-Villafranchian). Main similarities with Haq *et al.*(1988)'s curve are twofold (Fig.3): a) increase in frequency of relative changes of coastal onlap (i.e., reduction of the time spacing of eustatic events) and continental sedimentary breaks in more recent Neogene times, especially since the Messinian (Middle to Late Turolian); b) chronological coincidence between many sedimentary breaks in both marine and continental series. This is particularly clear for global changes recognized in the Aquitanian, Langhian, Middle Serravallian, Middle Tortonian, Messinian, and in several periods throughout the Pliocene.

Main sedimentary breaks defined within the Spanish continental Neogene record appear to be delayed in time in relation to Neogene sequence boundaries (Fig.3). Although this displacement might be unreal as precise dating of the sedimentary ruptures in the continental realm is difficult, a "cause-effect process" of the sea level falls on inland basins (perhaps a climatic effect as well?) may be postulated for explaining this stratigraphic relationship. Whichever the case, our understanding of how global changes recorded from marine series would be represented in the inland realm is so far incomplete.

Regional studies of the Neogene sedimentary record in offshore Mediterranean areas (Soler *et al.*, 1983) and inland peripheral zones of the Iberian Peninsula (Pascual *et al.*, 1991; Sanz de Galdeano and Vera, 1992) provide evidence that the sedimentary breaks recognized in these nearby areas may be interpreted as a result of eustatic and/or tectonic events (Sanz de Galdeano and Vera, 1992). This latter work makes emphasis on tectonism (or tectonism associated with eustatism) as a main cause for sequence boundaries through most of the Lower, Middle and Upper Miocene in SE Spain; eustatism would be properly a relevant factor for detected coastal onlap during Langhian. The Spanish continental basins, mostly having evolved like closed terrestrial basins, have had their sedimentary filling controlled by tectonic readjustments during the Miocene (IGCP-219 Spanish Group, 1990). In contrast, the geologic evolution of many basins, even the largest interior ones, during Late Miocene and Pliocene underwent changes from closed to open conditions that probably made them more sensitive to frequent eustatic sea level variations which are characteristic for this period.

Palaeoclimatology

The palaeoclimatic interpretation of this synthesis is based on the composition and compositional shift in time of micromammal faunas. The followed criteria are those of Van der Weerd and Daams (1978), Daams and Van der Meulen (1984), Daams *et al.*(1987), Sesé (1991), and Van der Meulen and Daams (1992), and will not be repeated in this paper. The temperature and humidity curves are precised with regard to the previous ones in López-Martínez *et al.*(1987) which is due to an increase of information and new treatment of data by Van der Meulen and Daams (1992).

The recognized climatic changes are demonstrated by humidity and temperature oscillations. Humidity and temperature trends are not necessarily simultaneous.

Four relative high temperature peaks, of which the first three may indicate (sub)tropical conditions, are recognized during the Spanish Neogene. The first one is that of the Early Agenian, during which tropical large mammals like tapirs and pangolins are present in various faunas in central Spain. The second one is that of the Early and Middle Aragonian, during which *Deinotherium* (a tropical African proboscidian) entered the Iberian Peninsula and *Hispanotherium* (a running rhinoceros with cement-filled teeth) spread widely. The third relatively warm interval is that of the Vallesian-Turolian. In the Lower Vallesian of Catalonia, Pongidae (apes) and again tapirs are present and in the entire Iberian Peninsula the tropical chevrotains (Tragulidae) have their maximum abundance during the Early Vallesian. The fourth warm interval is that of the Late Villafranchian and it is previous to the inmigration of rootless voles like *Allophaiomys*. Several of the temperature trends are recognized in the marine realm as well (Muller, 1984; Demarcq *et al.*, 1990).

Five relatively dry periods are recognized. The first one is that of the Early Ramblian during which running rhinoceroses and hypsodont ruminants (giraffes) are abundant. The second dry period is that of the Middle Aragonian characterized by the so-called Hispanotherium-faunas (see above) and those of the first hypsodont bovid (*Caprotragoides*). The third and the fourth dry periods are those of the Middle Turolian and Late Ruscinian, respectively, during which antilopes (high-crowned savannah-dwellers) are abundant. The fifth relatively dry period is that of the Middle Villafranchian during which the horse *Equus* and the steppe-elephant *Mammuthus* inmigrated into Europe.

Conclusions

This paper, based on that presented some years ago by López-Martínez *et al.* (1987) in Budapest, summarizes recent findings about the Neogene stratigraphy of most of the continental basins in Spain an updates the correlative chart for Neogene stratigraphic units. New findings of mammal localities and some, though sparse, recent radiometric and magnetostratigraphic data have been included in the synthesis.

Some modifications have been introduced by comparison with the geochronological scale used by López-Martínez *et al.* (1987). Main changes have been made in order to include new biostratigraphic terminology and more refined biostratigraphic local zones.

Nine main sedimentary breaks have been recognized as widespread occurring in the different basins. A good correlation is observed among the Neogene sedimentary record of the largest interior basins (Tajo, Duero, Ebro) through a time interval spanning Lower Miocene to Vallesian. In a similar way, a fairly good correlation has been determined for the Late Neogene sedimentary record in eastern and southern basins. However, the correlation is poorer in those basins located within the Iberian and Catalan Coastal Ranges, which usually do not show a similar sedimentary pattern.

There is chronological coincidence between the sedimentary breaks recognized within the Spanish continental Neogene record and sedimentary discontinuities resulting from global sea-level changes. The comparison with currently accepted Cenozoic Global Cycle Charts indicates that sedimentary disccontinuities occur at about 24.5 Ma, 22 Ma, 16 Ma, 13.5 Ma, 9.5 Ma, 5.5. Ma, and 3.3 Ma in both marine and continental successions. The chronological coincidence is also remarkable at a regional scale by comparing Spanish Neogene continental successions with those observed in offshore Mediterranean areas and inland peripheral zones of the Iberian Peninsula.

The palaeoclimatic curves inferred from mammal assemblages throughout the Neogene display four relative temperature peaks indicative of either (sub)tropical conditions or less marked warm intervals. Five relatively dry periods are inferred from the palaeoclimatic curves.

This paper fully corraborates most of the results achieved by López-Martínez *et al.* (1987), in particular the use of tectono-sedimentary analysis as a valid geological tool for this Neogene synthesis. On the other hand, this up-to-date confirms a main conclusion concerning the non-coincidence of global discontinuities with classic chronostratigraphic limits.

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One of the authors (Dr. Emilio Elizaga) died during the time in which this paper was written. All of us wish to devote this work for his memory, permanently reminding him as the best friend and scientific collaborator.

APPENDIX A

List of fossil mammal sites

Ebro basin

AN - Arnedo
AU - Autol
BE - Bergasa
BO - Borja
BU - El Buste
CR - Carretil
CUR - Cura
F7 - Fraga 7
FM - Fuenmayor
IL - Islallana
LA - Los Agudos
LC - La Ciesma
MO - Moyuela
SC - Santa Cilia
SJ - San Juan-La Galocha
TA - Tarazona
TC - Torrent de Cinca
TU - Tudela
VH - Villanueva de Huerva
VR - Villarroya
YM - Yesos de Monteagudo

Tajo basin

ALG - Algora
ALM - Almendros
AO - Arroyo del Olivar
ARB - Arbancones
BAT - Batallones
CIB - Canteras de Iberia
CO - Córcoles
CT - Cendejas de la Torre
ES - Escamilla
HE2 - Henares 2
HO - Huerta Obispalía
IS - San Isidro
LD - Ledanca
LH - Las Higueruelas
LO - Loranca
LU - Lupiana
LY - Layna
MN - Moncalvillo
NAL - Navalón
OD - O'Donnell
PA - Parrales
PA3 - Paracuellos 3
PA5 - Paracuellos 5
PI - Pineda
RE - Retama
SY - Sayatón
TO - Torija
VC2 - Valverde de Calatrava 2
VJ - Vallejo
ZZ - Zafra de Záncara

Duero basin

ARZ - Ariza
C - Cetina
CS - Carr.Soria
DU - Dueñas
EC - Escobosa de Calatañazor
LVF - Los Valles de Fuentidueña
MV - Montejo de la Vega
SI - Simancas
TM1 - Torremormojón 1
TM4 - Torremormojón 4
V1 - Valladolid 1

Calatayud - Teruel

ARM7 - Armantes 7
AT3 - Ateca 3
BRI - Brito
CA - Casas Altas
CES - Concud Estación
DH - La Dehesa
ESC - Escorihuela
F - Fuentes
GL4 - La Gloria 4
GL6 - La Gloria 6
L1 - Libros 1
LC1 - Loma de Casares 1
LP4 - Las Planas 4
LPV - La Puebla de Valverde
LR - La Roma
MA - Manchones
MAN - Los Mansuetos
MB - Masía del Barbo
MOL - Mas del Olmo
NAV - Navarrete
NO - Nombrevilla
P5 - Peralejos 5
PM - Puente Minero
RA1 - Ramblar 1
SO - La Solera
TR - Torralba de Ribota
VA - Villalba Alta
VA1 - Valdemoros 1
VA3 - Valdemoros 3
VAT - Valtorres
VLL - Velilla
VRC - Villarroya del Campo
VT - Valalto

Vallés Penedés

CAL - Can Almirall
CJ - Can Jofressa
CL - Can Llobateras
CPO - Can Ponsic
ELC - Els Casots
LF - La Fortesa
MC - Molí Calopa
PIR - Piera
SM - San Mamet
SQ - San Quirce
VIC - Viladecabals

Levante

B - Balneario
CM - Cuestas de Mahora
ER - El Rincón
FP - Fuente Podrida
FV - Fuente del Viso
LPO - La Portera
MR1 - Marmota 1
TL - Tolosa
VG3 - Valdeganga 3
VM - Venta del Moro

Betics

AC - Casa del Acero
ALB - La Alberca
ALQ - Alquería
AR - Arenas del Rey
BOC - Botardo
C1-3 - Crevillente 1,2,3
C4-5 - Crevillente 4,5
C6 - Crevillente 6
CC1 - Cañada del Castaño
CJU - Canteras de Jun
CLI - Cerro Limones
CN - Cenajo
CP - Cerro Parejo
CU - Cuarterones
GO - Gorafe
H3 - Huescar 3
HI - Híjar
HU - Huélago
LB - Librilla
LJ - La Juliana
O2 - Orce 2

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