

PLANKTIC FORAMINIFERAL FAUNAL TURNOVER AND BIO-CHRONOSTRATIGRAPHY OF THE PALEOCENE-EOCENE BOUNDARY AT ZUMAYA, NORTHERN SPAIN

J.I.Canudo (1) and E.Molina (1)

(1) Área de Paleontología. Departamento de Geología. Universidad de Zaragoza. E-50009 ZARAGOZA.

ABSTRACT

A quantitative study of the planktic foraminifera from the Paleocene-Eocene boundary in the Zumaya section has been carried out. Most of the characteristic datum events have been recognized, including the first occurrence of *Pseudohastigerina*, the last occurrence of *Morozovella velascoensis* and the last occurrence of *Planorotalites pseudomenardii*. The stratigraphic positions of these biohorizons, however, show some differences in relation to the tropical areas, including a stratigraphic separation between the last occurrence of *Morozovella velascoensis* and the first occurrence of *Pseudohastigerina wilcoxensis*.

Quantitative analyses of the planktic foraminifera indicate a relatively cold climatic interval in the lower part of the *Morozovella aequa* Biozone. A warm climatic interval characterizes the upper part of *Morozovella aequa* Biozone at and above a carbonate dissolution interval. The earlier cooler period may be correlated with the initial rifting and spreading of the NE Atlantic, the dissolution interval with a flooding of CO₂ caused by volcanism, and the warm period could be related to the maximum warming of the Cenozoic.

At present a working group of the International Subcommission on Paleogene Stratigraphy is searching for a Paleocene/Eocene boundary stratotype. In this context the Zumaya section has been proposed as one of the Spanish candidates, since it is excellently exposed, very accessible, of marine character with no facies change, and good paleontological control as its relatively continuous planktic foraminiferal record indicates. The exact stratigraphical position of the Paleocene/Eocene boundary need an agreement in the working group, by now we define a boundary time span, which comprises from the base of the Ilerdian to the base of the Ypresian.

Key words: Planktic foraminifera, Biostratigraphy, Chronostratigraphy, Faunal Turnover, Paleocene, Eocene, Zumaya, Pyrenees.

RESUMEN

Se ha realizado un estudio cuantitativo de los foraminíferos planctónicos del límite Paleoceno-Eoceno en el perfil de Zumaya. Se han reconocido los biohorizontes más utilizados con este grupo de microfósiles para situar dicho límite: primera aparición de *Pseudohastigerina*, última aparición de *Morozovella velascoensis* y última aparición de *Planorotalites pseudomenardii*. La posición bioestratigráfica de estos biohorizontes presenta diferencias respecto a las áreas tropicales, ya que existe un intervalo entre la última aparición de *M. velascoensis* y la primera aparición de *Pseudohastigerina wilcoxensis*.

El análisis cuantitativo de los foraminíferos planctónicos ha permitido poner de manifiesto un periodo relativamente frío en la parte inferior de la Biozona de *Morozovella aequa* y un periodo cálido, que se inicia con un nivel de disolución de carbonatos durante la parte superior de la Biozona de *Morozovella aequa*. El periodo relativamente más frío, se podría relacionar con el momento de abertura del Atlántico Norte, el nivel de disolución con una gran producción de CO₂ causada por vulcanismo, y el periodo cálido con el máximo calentamiento climático de todo el Cenozoico.

Actualmente existe un grupo de trabajo de la Subcomisión Internacional de Estratigrafía del Paleógeno que tiene como objetivo definir el estratotipo de límite para el Paleoceno-Eoceno. En este contexto se ha propuesto el perfil de Zumaya como uno de los candidatos españoles, puesto que tiene una exposición excelente, es muy accesible, de carácter marino, sin cambio de facies, y con un buen control paleontológico como indica su registro de foraminíferos planctónicos relativamente continuo. La posición estratigráfica exacta del límite Paleoceno/Eoceno requiere un acuerdo en el grupo de trabajo, por el momento definimos un intervalo de límite, el cual abarca desde la base del Ilerdiense a la base del Ypresiense.

Palabras clave: Foraminíferos planctónicos, Bioestratigrafía, Cronoestratigrafía, Cambio faunístico, Paleoceno, Eoceno, Pirineos.

Canudo, J.I. and Molina, E. (1992): Planktic foraminifera faunal turnover and bio-chronostratigraphy of the Paleocene-Eocene boundary at Zumaya section (Northern Spain). *Rev. Soc. Geol. España.*, 5: 145-157.

Canudo, J.I. y Molina, E. (1992): Cambios faunísticos de los foraminíferos planctónicos y bio-cronoestratigrafía del límite Paleoceno-Eoceno en el corte de Zumaya (Norte de España). *Rev. Soc. Geol. España.*, 5: 145-157.

1. INTRODUCTION

This study reports on the planktic foraminifera across the Paleocene-Eocene boundary in the Zumaya section (Basque-Cantabrian basin), and discusses the biostratigraphic and paleoceanographic implications of the Paleocene-Eocene boundary events in the Pyrenees.

The Paleocene/Eocene boundary events are usually difficult to observe due to the presence of frequent hiatuses and dissolution intervals which characterize this transition world wide. Relatively continuous sequences across this boundary are present in a few sections in Spain, as for example the Campo section (Pyrenees) a shallow water facies, the Caravaca section (Betics) and the Zumaya section (Pyrenees) a deeper water facies. These three sections have been proposed as potential Paleocene-Eocene boundary stratotypes to the International Subcomission on Paleogene Stratigraphy by the spanish working group on the Paleocene-Eocene boundary.

Sedimentation across the Paleocene-Eocene boundary in the Pyrenean Basin appears relatively continuous although there are differences between the sections. The Zumaya section was deposited in the deep part of a basin which outcrops in sections along the beaches at the northern Coast Range of the Basque country. The lithology and geologic setting of the Zumaya section has been described in detail by Hillebrant (1965) and Pujalte *et al.* (1989). The stratigraphic section chosen for this study is easily accesible and exposure occur along San Telmo beach, just north of the Township of Zumaya. (Fig. 1).

Hillebrandt (1965) first published a significant biostratigraphic analysis of the planktic foraminiferal fauna from the Zumaya section but did not discuss details across the Paleocene / Eocene boundary. Likewise, Orue-Etxebarria (1983-84) and Orue-Etxebarria *et al.* (1984a, b) later published a biostratigraphy based on Paleogene planktic foraminifera in other sections of the Basque Country. Besides, Orue-Etxebarria and Lamolda (1985) studied the paleogeography of the Basque-cantabrian basin by means of planktic foraminifera from the Paleocene to Middle Eocene and they concluded that deposition occurred in a tropical to temperate province during the Paleogene.

This study details the stratigraphic and faunal aspects across the Paleocene-Eocene boundary based on quantitative planktic foraminiferal analysis in order to elucidate this transition event. Planktic foraminifera and calcareous nannofossils are the major fossil components in the sediments across the Paleocene-Eocene boundary

in the Zumaya section. Benthic foraminifera and ostracodes occur in low percentages (less to 10%). Large foraminifera and other macrofossils are extremely rare. Reworked Cretaceous and Lower Paleocene planktic foraminifera only occur in isolated samples and in very low abundance (less to 1%).

2. MATERIALS AND METHODOLOGY

Samples were obtained from fresh unweathered bedrock after removing surface contamination. A total of 29 samples were analyzed for this study. Samples were immersed in water and dilute H₂O₂ (10%). Some samples proved difficult to break down and a light detergent (Calgon) was added to the water and the sample heated to speed up the process. After the sample was disaggregated it was washed through a 63 micron screen and dried in the oven. In general, samples were not easy to disaggregate and this procedure was repeated until a clean foraminiferal residue was recovered. Preservation of planktic foraminifera for this section is generally good although recrystallization of original calcite shells is evident in all samples.

The population counts were based on representative splits (using an Otto microsplitter) of 300-500 individuals in the size fraction bigger than 103 μ m. The smaller size (63-103 μ m) was also examined for small species. All specimens picked were mounted on micros-

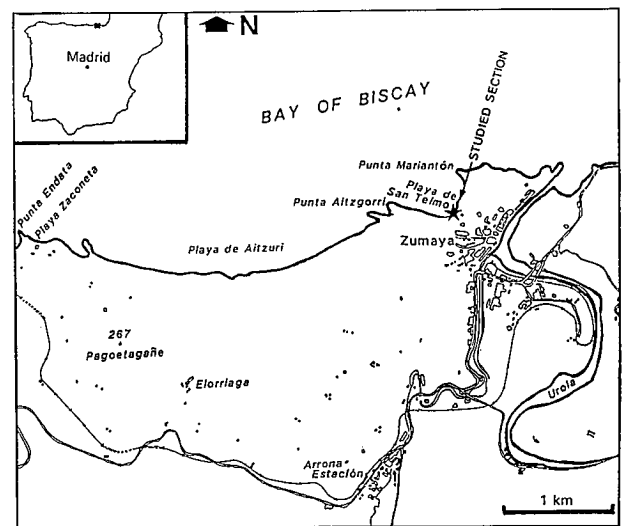


Fig. 1.-Location map of the section across the Paleocene-Eocene boundary at Zumaya (modified of Wiedmann, 1986).

Fig. 1.-Situación geográfica del tránsito Paleoceno-Eoceno en la sección de Zumaya (modificado de Wiedmann, 1986).

MURICATED WALL

1. Large *Morozovella*

- Morozovella acuta* (Toulmin)
- Morozovella angulata* (White)
- Morozovella gracilis* (Bolli)
- Morozovella* aff. *lensiformis* (Subbotina)
- Morozovella marginodentata* (Subbotina)
- Morozovella oclusa* (Loeblich & Tappan)
- Morozovella subbotinae* (Morozova)
- Morozovella velascoensis* (Cushman)

2. Small *Morozovella*

- Morozovella crosswickensis* (Olsson)
- Morozovella edgari* (Premoli Silva & Bolli)

3. Weakly muricinate *Morozovella*

- Morozovella aequa* (Cushman & Renz)
- Morozovella lacerti* (Cushman & Renz)

4. *Igorina* (Biconvex morozovellids)

- Igorina albeari* (Cushman & Bermudez)
- Igorina laevigata* (Bolli)
- Igorina lodoensis* (Mallory)
- Igorina nicoli* (Martin)
- Igorina pusilla* (Bolli)

5. *Acarinina spinuloinflata* lineage

- Acarinina nitida* (Martin)

6. Subquadrate acarininids

- Acarinina strabocella* (Loeblich & Tappan)
- Acarinina triplex* Subbotina
- Acarinina wilcoxensis* (Cushman & Ponton)

7. Finely muricate acarininids (*Muricoglobigerina*)

- Muricoglobigerina angulosa* (Bolli)
- Muricoglobigerina esnehensis* (Nakkady)
- Muricoglobigerina soldadoensis* (Brönniman)
- Muricoglobigerina mckennai* (White)
- Muricoglobigerina chascanona* (Loeblich & Tappan)

RETICULATED WALL

8. Low-spined subbotined

- Subbotina patagonica* (Todd)
- Subbotina finlayi* (Brönniman)
- Subbotina hornibrooki* (Brönniman)
- Subbotina triangularis* (White) sensu Bolli, 1957
- Subbotina velascoensis* (Cushman) sensu Bolli, 1957

9. *Globorotaloides*

- Globorotaloides pseudoimitata* (Blow)

SMOOTHED WALL

10. *Planorotalites*

- Planorotalites elongata* (Glaessner)
- Planorotalites pseudomenardii* (Bolli)
- Planorotalites* aff. *pseudoscitula*
- Planorotalites troelseni* (Loeblich & Tappan)

11. *Globanomalina*

- Globanomalina ovalis* Haque

12. *Pseudohastigerina*

- Pseudohastigerina wilcoxensis* (Cushman & Ponton)

13. Biseriate heterohelicids

- Chiloguembelina crinita* (Glaessner)
- Chiloguembelina subtriangularis* Bekmann

14. Other heterohelids

- Guembeltria* spp.

Table 2.- Planktic foraminifera groups and their constituent species considered in this study.

Tabla 2.- Grupos de foraminíferos planctónicos y las especies que los componen estudiadas en este trabajo.

Paleocene-Eocene boundary at Zumaya are shown in figure 2. A brief discussion of the major zonal characteristics is given below.

3.1. *Planorotalites pseudomenardii* Biozone

Definition: This biozone spans the interval between the first and last occurrence of *Planorotalites pseudomenardii*. This biozone was originally proposed by Bolli (1957a).

Remarks: The interval which has been studied (1 m) extends only into the upper part of the *Planorotalites pseudomenardii* Biozone. The lithology is an alternation of grey limestones and marls. Representatives of *Morozovella* and *Acarinina* and low spired subbotinids attain relatively high numbers in the upper part of this biozone. Species which are more than 5 % abundant in the *Planorotalites pseudomenardii* Biozone are: *Morozovella acuta* (Toulmin), *Morozovella angulata* (white), *Morozovella crosswickensis* (Olsson), *Globorotaloides pseudoimitata* (Blow), *Morozovella edgari* (Premoli Silva & Bolli) *Acarinina nitida* (Martin) and *Subbotina triangularis* (White, sensu Bolli, 1957a). The last occurrence of *Acarinina subsphaerica* took place near the top of this biozone. Bolli (1957a) used the last occurrence of *P. pseudomenardii* to mark the top of this biozone. Toumarkine and Luterbacher (1985) and Berggren and Miller (1988), using the same criterion, defined the upper boundary of the *Planorotalites pseudomenardii* Biozone, and found the first occurrence of *M. subbotinae* in a younger level than the last occurrence of *P. pseudomenardii*.

3.2. *Morozovella aequa* Biozone

Definition: This biozone defines the interval between the last occurrence of *Planorotalites pseudomenardii* and the first occurrence of *Pseudohastigerina wilcoxensis*. It was originally proposed by Luterbacher (1964) and modified for the Pyrenees by Canudo and Molina (*in press*).

Remarks: This biozone spans 39 m at the Zumaya section. In the lower part the lithology consists of a predominantly homogeneous grey marl intercalated with calcarenitic levels. However, the upper part of the biozone is characterized by grey limestones alternating with thin levels of marls. Representatives of *Morozovella* and low spired subbotinids attain relatively high numbers in the lower part of the biozone, whereas the species of *Morozovella*, *Acarina* and *Chiloguembelina* are most abundant in the upper part of the biozone.

Species which are more than 5% abundant in the *Morozovella aequa* Biozone are: *Morozovella subbotinae* (Morozova), *Morozovella edgari*, *Morozovella crosswickensis* (except in the middle part), *Acarinina nitida* (except in the middle part), *Subbotina triangularis*, *Subbotina hornibrooki* (Bronnimann), *Subbotina velascoensis* (lower and middle part), *Subbotina patagonica* (upper part).

The *Morozovella aequa* Biozone in the Pyrenees represents a distinct but gradual faunal change in planktic foraminifera with 10 species disappearing: *Morozovella acuta* (Toulmin), *Morozovella velascoensis* (Cus-

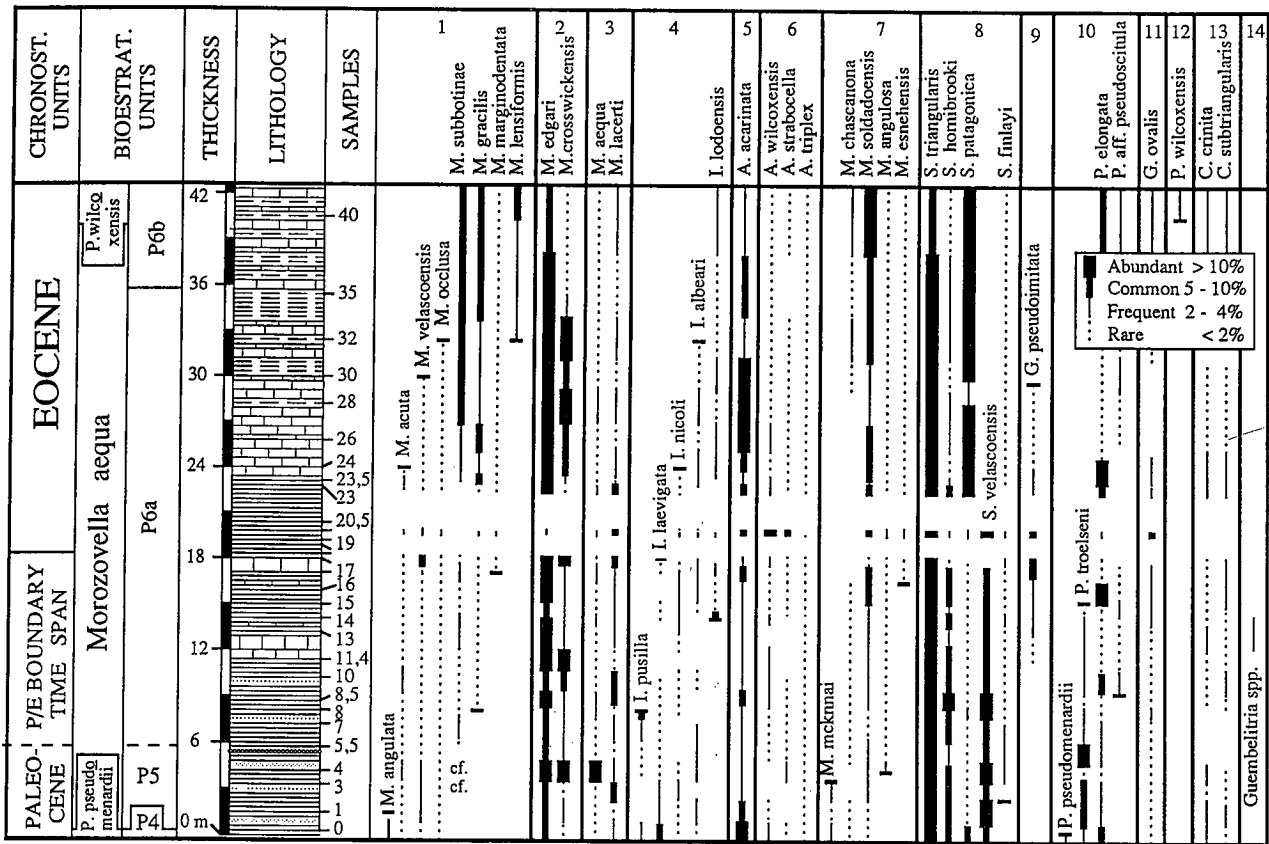


Fig. 2.-Semi-quantitative species ranges of planktic foraminifera of the uppermost Paleocene and lowermost Eocene of the Zumaya section.
 Fig. 2.-Distribución semicuantitativa de los foraminíferos planctónicos en el tránsito Paleoceno-Eoceno de la sección de Zumaya.

CHRON. UNITS	First and Last Appearance at the Zumaya Section	BIOZONATIONS						
		Canudo & Molina (in press)	Bolli, 1957 Toumarkine & Luterbacher, 1985	Berggren & Miller, 1988	Blow 1979	Orue Etxebarria et al. 1984a, b	Hillebrandt 1965	
EOCENE	<i>M. edgari</i>	Pseudohastigerina wilcoxensis	<i>Morozovella subbotinae</i>	P 6b	P.7	<i>Globorotalia (Morozovella) lensiformis</i>	<i>Globorotalia (Morozovella) subbotinae</i>	<i>Globorotalia subbotinae</i>
	<i>P. wilcoxensis</i>		<i>Morozovella edgari</i>					
	<i>M. velascoensis</i>	Morozovella aqua	<i>Morozovella velascoensis</i>	P 6a	P.6	<i>Globorotalia (Morozovella) subbotinae</i>	<i>Globorotalia velascoensis</i>	
	<i>M. gracilis</i>							
PALEOCENE	<i>M. subbotinae</i>	Planorotalites pseudomenardii	<i>Planorotalites pseudomenardii</i>	P 4	P.5	<i>Globorotalia (Planorotalites) pseudomenardii</i>	<i>Globorotalia pseudomenardii</i>	
	<i>P. pseudomenardii</i>							
	<i>M. soldadoensis</i>							
	<i>P. pseudomenardii</i>							

Fig. 3.-Comparison of uppermost Paleocene and lowermost Eocene planktic foraminiferal biozonations with biozonation used in this paper.
 Fig. 3.-Comparación de las biozonaciones del tránsito Paleoceno-Eoceno con la utilizada en este trabajo.

man), *Morozovella oclusa* (Loeblich & Tappan), *Igorina pusilla* (Bolli), *Igorina laevigata* (Bolli), *Igorina nicoli* (Martin), *Igorina albeari* (Cushman & Renz), *Muricoglobigerina mckanaii* (White), *Subbotina velascoensis* (Cushman sensu Bolli, 1957) and *Planorotalites troelseni* (Loeblich & Tappan). In addition, this biozone marks the first occurrence of many typical species of the Lower Eocene including *Morozovella subbotinae*, *Morozovella marginodentata* (Subbotina), *Morozovella gracilis* (Bolli), *Morozovella cf. lensiformis*, *Igorina lodoensis* (Mallory), *Muricoglobigerina soldadoensis* (Bronniman), *Muricoglobigerina angulosa* (Bolli), *Muricoglobigerina esnehensis* (El Nakkady) *Subbotina finlayi*, *Planorotalites elongata* (Glaessner) *Planorotalites aff. pseudocitula* and *Chiloguembelina subtriangularis* Beckmann.

For the interval between the last occurrence of *P. pseudomenardii* and the first occurrence of *M. subbotinae*, Berggren and Miller (1988) used the *Morozovella velascoensis* Biozone (P.5). *M. velascoensis* is not suitable as index fossil in the Pyrenees because this species is rare at these latitudes and in other more shallow Pyrenees sections *M. velascoensis* has not been found (Ca-

nudo, 1991). The original concept of the “*Globorotalia*” *aequa* Biozone of Luterbacher (1964) corresponds to the P6a Biozone of Berggren and Miller (1988). For the Pyrenees the *Morozovella aequa* Biozone has been modified by Canudo and Molina (*in press*) corresponding approximately to P5 and P6a Biozones.

3.3. *Pseudohastigerina wilcoxensis* Biozone

Definition: This biozone defines the interval between the first occurrence of *Pseudohastigerina wilcoxensis* and the first occurrence of *Morozovella aragonensis*. This biozone was originally proposed by Berggren (1971) and modified by Canudo and Molina (*in press*) for the Pyrenees.

Remarks: The studied interval extends only into the lower part of the *Pseudohastigerina wilcoxensis* Biozone. The lithology consists of alternating grey limestone and marl layers in the lower part. *Morozovella*, *Acarinina spinuloinflata* lineage, *Planorotalites* and low spire subbotinids attain relative highly numbers in the lower part of the biozone. Species with greater than 5% abundance in the lower part of the *Pseudohastigerina*

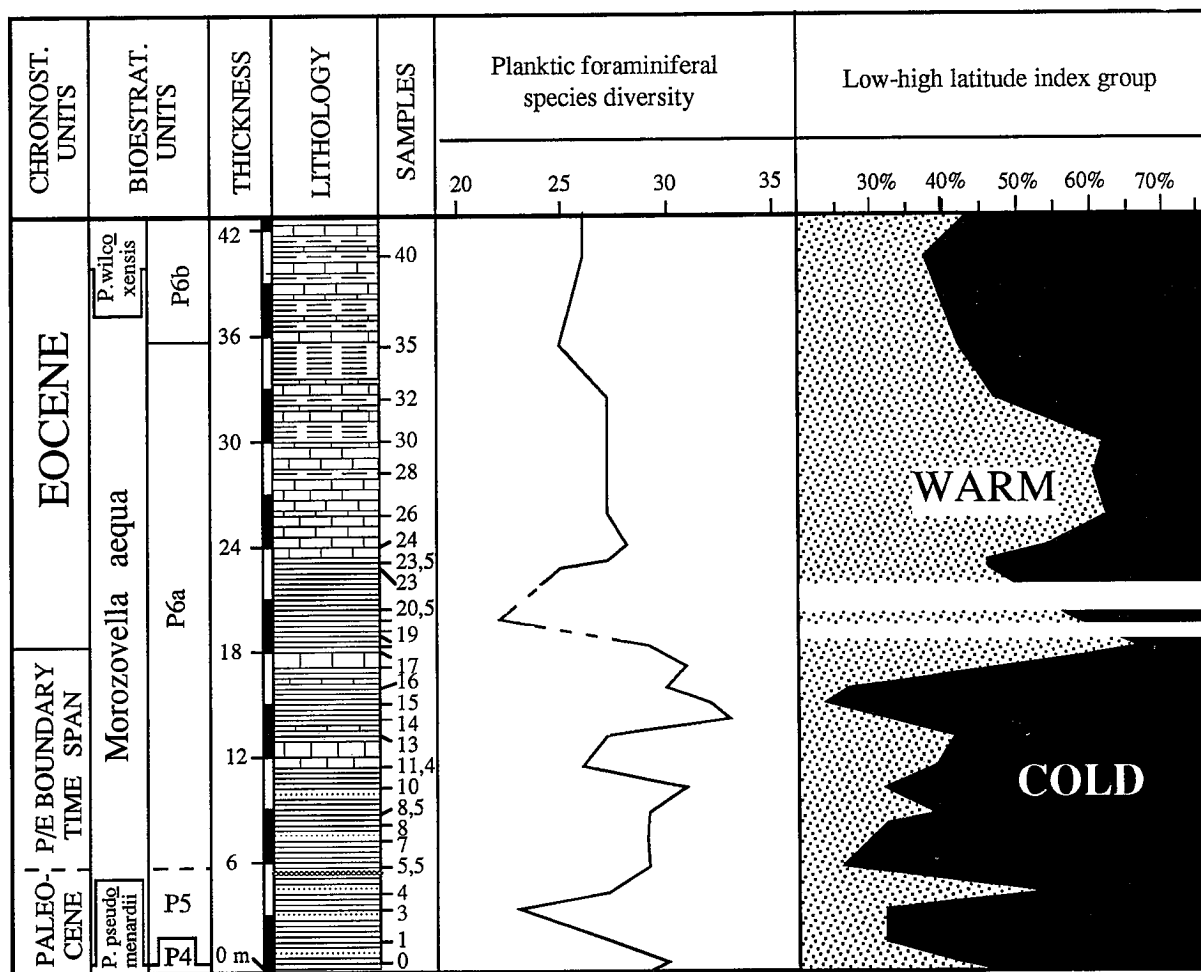


Fig. 4.-Planktic foraminiferal biozonation, planktic foraminiferal diversity and lower-higher latitude index group in the size bigger than 103 μm from Zumaya section.
 Fig. 4.-Biozonación de foraminíferos planctónicos, número de especies de foraminíferos planctónicos y variación del índice baja-altas latitudes de la fracción mayor de 103 μm en la sección de Zumaya.

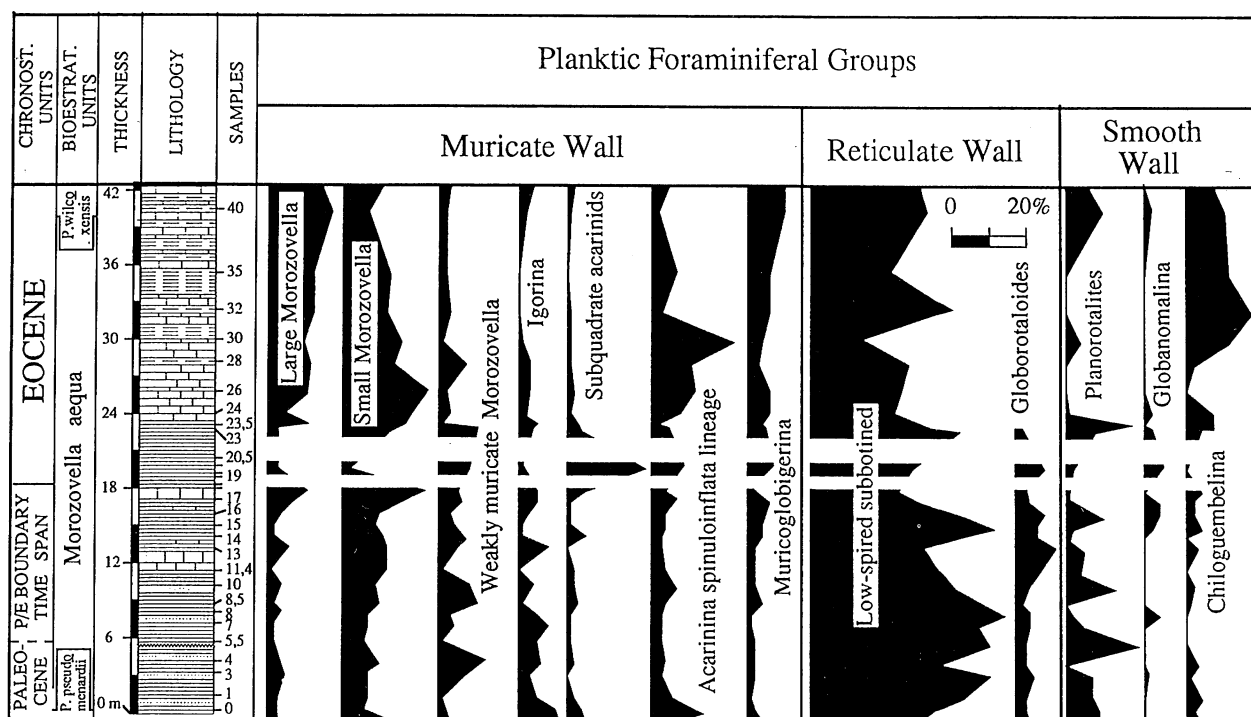


Fig. 5.-Planktic foraminiferal biozonation, relative population abundances of species in the size fraction bigger than 103 μm from the Paleocene-Eocene Zumaya section.

Fig. 5.-Estudio cuantitativo y bioestratigrafía de los foraminíferos planctónicos de la fracción mayor de 103 μm en el límite Paleoceno-Eoceno en la sección de Zumaya.

wilcoxensis Biozone are: *Morozovella edgari*, *Morozovella cf. lensiformis*, *Morozovella gracilis*, *Acarinina nitida*, *Subbotina triangularis*, *Muricoglobigerina soldadoensis*, *Subbotina patagonica* and *Planorotalites elongata*.

The *Pseudohastigerina wilcoxensis* first appearance datum (FAD) is easy to recognise in the Pyrennes and is therefore a good index taxon in the North Atlantic. The *Pseudohastigerina wilcoxensis* Biozone is equivalent to biozones which have been generally regarded to be of early Eocene age and usually its boundary with the underlying *Morozovella subbotinae* / *Morozovella velascoensis* (P6a) Biozone to coincide with the Paleocene - Eocene boundary (Toumarkine and Luterbacher, 1985; Berggren and Miller, 1988); this criteria was based on the classic correlation in which the last occurrence of *M. velascoensis* coincides with first occurrence of *P. wilcoxensis*, but in the Pyrenees *P. wilcoxensis* could appear later than in low latitudes.

4. THE PALEOCENE-EOCENE BOUNDARY

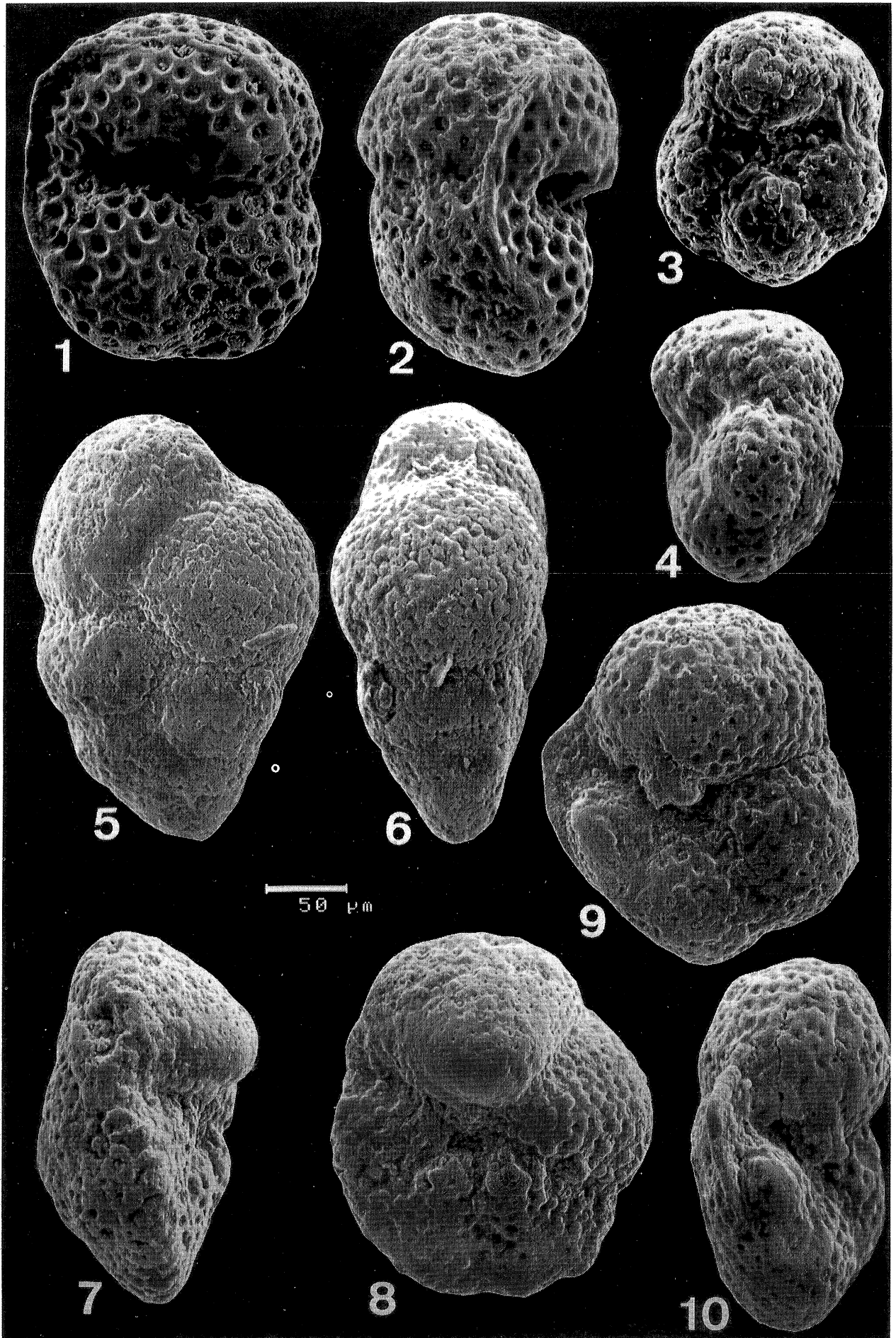
In current publications there are distinct and consistent differences in the definition of the Paleocene-Eocene boundary and there is not a definitive criterion that is internationally accepted. Thus, different criteria for recognizing the base of the Eocene have been used (as listed below), most of them we consider, for the purpose of this study as part of the Paleocene-

Eocene boundary time span from the base of the Ilerdian to the base of the Ypresian.

- Top of *Morozovella velascoensis* Biozone (In Bolli, 1957a)
- Top of the Ilerdian stage (In Hottinger and Schaub, 1960)
- Pseudohastigerina* datum plane (In Berggren *et al.*, 1967)
- Base of NP 10 Biozone (In Martini, 1971)
- Base of the Ilerdian stage (In Pomerol, 1975)
- Base of the Ypresian stage (In Berggren *et al.*, 1985)
- Base of Chron 24 (In Berggren and Miller, 1988)
- Base of BB2 (In Berggren and Miller, 1989).

The problems associated with the determination of the position of the Paleocene-Eocene boundary based on planktic foraminifera and other criteria, could be due primarily to different interpretations of paleontologic data and unsolved biostratigraphic and chronostratigraphic correlations. In order to find a reasonable solution to these problems, it is necessary to evaluate these different options.

Generally, planktic foraminiferal workers use the extinction of *M. velascoensis* as one of the criteria for recognizing the Paleocene-Eocene boundary and this datum was assumed to coincide with the FAD of *P. wilcoxensis* (Bolli, 1957a; Toumarkine and Luterbacher, 1985; Berggren and Miller, 1988). However, the FAD of



Pseudohastigerina as index datum for the Paleocene-Eocene boundary does not appear to be very synchronous between low and high latitude regions (Caro *et al.*, 1973), and whereas *M. velascoensis* occurs commonly in the Paleocene-Eocene transition of the tropical areas and it is not common outside of equatorial regions.

Calcareous nannofossil workers have placed the Paleocene-Eocene boundary at the NP9-NP10 boundary, which correlates to the top of the *Morozovella velascoensis* Biozone (Bolli *et al.*, 1985). In the Campo (Canudo *et al.*, 1989) and Zumaya sections, the NP9-NP10 boundary occurs below the first occurrence of *Pseudohastigerina* and near the last occurrence of *M. velascoensis* (top of *Morozovella velascoensis* Biozone of Toumarkine and Luterbacher, 1985).

There is an important bathyal and abyssal benthic foraminiferal extinction, near the Paleocene-Eocene boundary (Tjalsma and Lohmann, 1983) coincident with the BB1-BB2 boundary of Berggren and Miller (1989). This event is present at Zumaya (Ortiz and McDougall, personal communication) at the sample (sample 18) immediately below the dissolution level. This biohorizon is coincident with significant changes in planktic foraminifer abundances (Fig. 4) and the last occurrence of *Igorina laevigata* in the Zumaya section.

The placement for the Paleocene-Eocene boundary should be at the base of an international standard stage. However the stratotypes of Paleogene stages were not originally established on the basis of planktic microfossils, and it is difficult to recognize precisely these stages worldwide. These chronostratigraphic units represent the formal basis for relating rock and time; assignment of strata to a chronostratigraphic unit such as the Paleocene or Eocene or one of its subdivisions, for instance Ypresian or Ilerdian stage, requires consideration of all independent evidence (biostratigraphic, magnetostratigraphic and chemostratigraphic).

Traditionally three chronostratigraphic units have been recognized in the marine Paleocene-Eocene transition: 1. The Ypresian stage was defined in Belgium in shallow to moderately deepwater sand and clay deposits (Dumont, 1849; Willems *et al.*, 1981), 2. The Thanetian stage was defined in England in shallow clay and clastic deposits (Renevier, 1873; Cavalier and Pomerol, 1986), and 3. The Ilerdian stage was defined in Spain (Pyrenees) in shallow clays and limestones (Hottinger and Schaub, 1960; Luterbacher, 1973).

The Ilerdian stage is very useful for Tethyan stratigraphy (Luterbacher, 1973). Recently, Molina *et al.* (1989, *in press*) has presented new micropaleontologic and magnetostratigraphic data of the Ilerdian stratotype

(Tresp section) and parastratotype (Campo section). Planktic foraminifera typical of *Morozovella subbotinae* / *Morozovella velascoensis* Biozone (P.6a) of Berggren and Miller (1988) have been recognized in the Middle Ilerdian stratotype (Canudo, 1991; Molina *et al.*, *in press*). The Ilerdian in the parastratotype of Campo corresponds to two biozones: *Morozovella aequa* and *Pseudohastigerina wilcoxensis*.

Nevertheless, it is difficult to recognize exactly the Ilerdian base in the Zumaya section, because large foraminifers have not been found, and there is no independent evidence from faunistic or sedimentological studies which would support direct correlation. However, the micropaleontological data indicate that the base of the Ilerdian is probably placed at the lower part of the *Morozovella aequa* Biozone and in the middle part of *Discoaster multiradiatus* Biozone.

Currently, the International Subcommission on Paleogene Stratigraphy placed the Paleocene-Eocene boundary between the Thanetian and Ypresian stages. The Ilerdian is not used as a standard stage since the Middle and Late Ilerdian overlap with the Ypresian but the Early Ilerdian spans a gap between the Thanetian and Ypresian that is not represented in any of the European marine classical stages (Molina *et al.*, *in press*).

5. FAUNAL TURNOVER

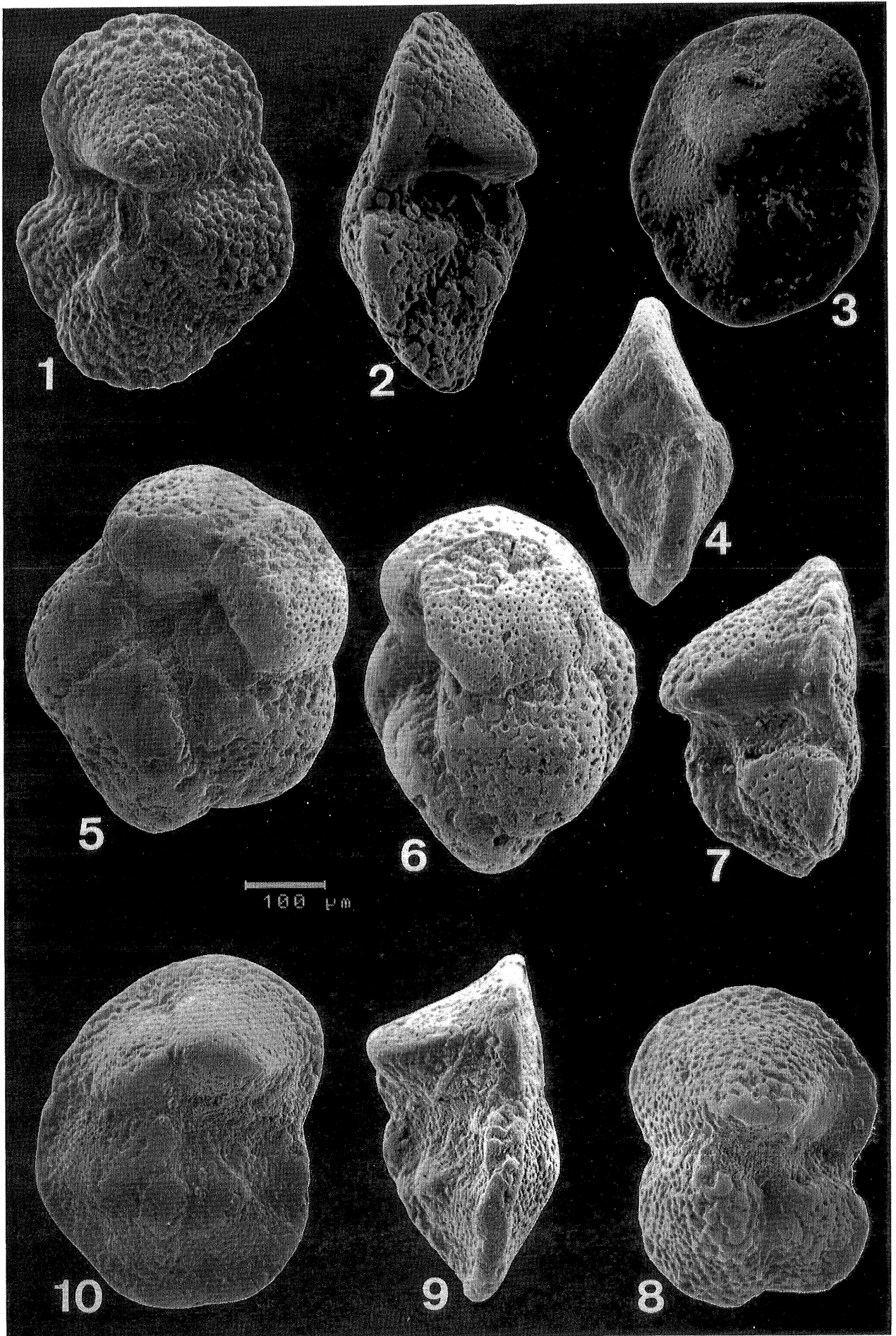
Planktic foraminifera indicate significant environmental changes during the Paleogene as the geographic distribution studies carried out by Boersma and Premoli-Silva (1983) and Premoli-Silva and Boersma (1988) indicated. Species diversity patterns can also be used as indicators of environmental change with low species diversity generally associated with cool water and high diversity with warmer temperate to tropical environments. We examined species diversity patterns in the Zumaya section as discussed below. Comparison with other studies, however is difficult, because of differing species concepts by different authors and the preservational conditions which prevent direct comparison. Figure 5 shows species richness changes across the Late Paleocene and Early Eocene of Zumaya. No clear trend in species richness is seen for the Paleocene-Eocene boundary time span except in the middle part of the *Morozovella aequa* Biozone, in which an abrupt decrease in species richness occurs at a dissolution level.

Premoli-Silva and Boersma (1988) grouped planktic foraminifera of the Atlantic into 3 latitudinal assemblages (low, middle, high). They showed that different

Fig. 6.-Planktic foraminifera

- 1 and 2: *Subbotina patagonica* (Todd) Muestra (Sample) Zumaya-17
- 3 and 4: *Acarinina nitida* (Martin). Muestra Zumaya-17
- 5 and 6: *Chiloguembelina crinita*. (Glaessner) Muestra Zumaya-28
- 7 and 8: *Morozovella edgari* (Premoli Silva y Bolli). Muestra Zumaya-28
- 9 and 10: *Globorotaloides pseudoimitata* (Blow); Muestra Zumaya-28

Fig. 6.-Foraminíferos planctónicos.



species have different temperature ranges and that their distributional patterns are related to latitudinal thermal gradients and water mass properties. These authors characterized the temperate Atlantic Eocene water mass by variable planktic foraminiferal high diversity and dominance. We have used their species groupings to interpret environmental conditions and this data suggests that the lower part of Paleocene-Eocene transition interval was characterized by relatively cool to temperate water mass as implied by the high abundance of low-spined subbotinid (high latitude species) and the upper part of the P/E transition by warm to temperate water mass as indicated the *Morozovella* (tropical species) and the relatively high planktic foraminiferal species diversity (25-30) (Figs. 4 and 5).

The faunal composition across the Paleocene-Eocene boundary transition time span at Zumaya is characterized by a relatively gradual change between disappearing typical Paleocene taxa and appearing typical Eocene taxa. In general, there are the same number of species per genera, except for *Igorina* which has 4 species (*I. pusilla*, *I. laevigata*, *I. nicoli* and *I. albeari*), in the *Planorotalites pseudomenardii* Biozone, as in *Morozovella aequa* Biozone and only 1 (*I. lodoensis*) at *Pseudohastigerina wilcoxensis* Biozone.

It is interesting that the major amplitude variation in this ratio of low/high latitude index group of Premoli Silva and Boersma (1988) coincides with the Paleocene-Eocene transition in the Zumaya section. Low latitude warm-water species vary between 20% and 60% of the planktic foraminifera assemblage. High latitude cool-water species vary between 20% and 40% in the lower part of the *Morozovella aequa* Biozone, but drop sharply from 75% to less 45% in the middle part of *Morozovella aequa* Biozone. These warm-water species increase in abundance probably indicate warmings in the Atlantic mid-latitudes.

Figure 5 indicates that one of these low/high latitude ratio changes is related to a major decrease in the low-spined subbotinids (group 8), that represent cooler water temperatures (Premoli Silva and Boersma, 1988, Boersma and Premoli Silva, 1991). At the Zumaya section there is a sharp decrease in abundance coincident with the carbonate dissolution level. At the same time the warm water small morozovellids peak in abundance. The decline in low spined subbotinids coincides with the disappearance of the *Globorotaloides* (group 9) which suggest that they may thrive in cooler water environments similar to subbotinids and their disappearance may be related to global warming. The *Chiloguembelina* abundance in the Zumaya section is generally less

than 5%, except in the upper part of *Morozovella aequa* Biozone, where peak abundance of 20% is reached near the top of *Morozovella aequa* Biozone. In the middle part of this biozone there is an interval of strong carbonate dissolution, that could indicate a relatively shallow CCD. The Late Paleocene global warming trend that culminated in the early Eocene is the warmest interval of the entire Cenozoic (Miller and Fairbanks, 1985), but the fluctuations in the abundance of planktic foraminifera suggest climatic variations in this trend.

The base of *Morozovella aequa* Biozone is characterized by the relative changes in the dominant species. Most remarkable are the decline of small *Morozovella* followed by increasing abundances of low-spined subbotinids. This pattern suggests a time of change and the injection of relatively cool waters. A short warm period can be identified in the lower part of *Morozovella aequa* Biozone.

The major benthic faunal turnover at the Paleocene/Eocene transition interval, in the Zumaya section is immediately below the dissolution level, coinciding with the maximum peak of the low latitude species. This important benthic extinction in the middle part of *Morozovella aequa* Biozone (BB1-BB2 boundary) according to Tjalsma and Lohmann (1983) implies a dramatic change that took place without any apparent significant temperature changes in surface waters of the Atlantic. According to Berggren and Olsson (1986) this event could be caused by the disruption in the equilibrium-adaptation of bathyal and abyssal benthic foraminifera by sinking of relatively cooler surface waters formed in the nascent Norwegian-Greenland Sea. The result of those events may be the eustatic sea-level fluctuations that occurred in a short time period between the uppermost Paleocene and lowest Eocene (Haq *et al.*, 1987). The more important warmer period took place in the upper part of *Morozovella aequa* Biozone (Fig. 5), where abundance of low-spined subbotinids decrease and there is a peak abundance in *Morozovella*, and *Acarinina spinuloinflata* lineage. These taxa are tropical indices and their migrations into high latitudes can be correlated with climatic warmings (Premoli Silva and Boersma, 1988). According to Rea *et al.*, (1990) the extinction event among benthic foraminifera was probably a response to the new low nutrient and chemically changed bottom waters, related to enhanced sea-floor hydrothermal activity occasioned by global tectonism that resulted in a flooding of the atmosphere with CO₂. In fact, volcanism and the flooding of CO₂ could be the cause of the carbonate dissolution interval and a reduced pole to equator temperature gradient could be the

Fig. 7.-Planktic foraminifera

- 1 and 2: *Morozovella subbotinae* (Morozova). Muestra (Sample) Zumaya-17
- 3 and 4: *Morozovella crosswickensis* (Olsson). Muestra Zumaya-6
- 5 and 6: *Muricoglobigerina soldadoensis* (Brönniman). Muestra Zumaya-28
- 7 and 8: *Morozovella aequa* (Cushman y Renz). Muestra Zumaya-28
- 9 and 10: *Morozovella velascoensis* (Cushman). Muestra Zumaya-28

Fig. 7.-Foraminíferos planctónicos.

cause of the relative abundance of the planktic foraminifera species of low latitudes in the upper part of *Morozovella aequa* Biozone. In another scenario, Kennett and Stott (1991) claim that injection of warm saline bottom water could have caused benthic extinction at the end of the Paleocene in an Antarctic sedimentary sequences.

The Chiloumbelinid species (group 13) record enriched oxygen isotopic values and the most depleted carbon isotopic ratios, for this reason its abundance can be used as indices for an oxygen minimum habitat (Boersma and Premoli Silva, 1988, 1989). Near the top of *Morozovella aequa* Biozone there was an important peak of this group (Fig. 4). This sharp increase indicates that an oxygen minimum environment was present in this part of the Paleocene-Eocene boundary time span at Zumaya section. This oxygen minimum environment could be related to the warming and increased stratification of the surface watermass in this interval.

6. CONCLUSIONS

1) Three planktic foraminiferal biozones have been used in the Zumaya section for the Paleocene - Eocene boundary transition interval: *Planorotalites pseudonardii* Biozone, *Morozovella aequa* Biozone and *Pseudohastigerina wilcoxensis* Biozone. The Paleocene / Eocene boundary time span (from base of the Ilerdian to base of the Ypresian) has been recognized in the *Morozovella aequa* Biozone.

2) The last appearance of *M. velascoensis* occurs several meters below the first appearance of *Pseudohastigerina* and correlation with other events indicates that the "datum plane" of *Pseudohastigerina* is very diachronous, showing a late arrival of *Pseudohastigerina wilcoxensis* to these latitudes.

3) Cool climatic intervals in the lower part of *Mo-*

rozovella aequa Biozone are characterized by abundance of, high-latitude low spired subbotinids. These cool intervals are probably related to injection of cool waters concomitant with the initial rifting and spreading of the NE Atlantic. In the middle part of the *Morozovella aequa* Biozone the low-latitude species group peak in abundance coinciding with a major benthic extinction caused by the initiation of a dissolution interval.

4) There is not a major extinction event in planktic foraminifera in the Paleocene-Eocene boundary time span. Nevertheless, 10 species gradually disappear in the *Morozovella aequa* Biozone, and the quantitative analysis shows a significant faunal turnover. The abundance increase in small *Morozovella* and *Acarinina spinuloinflata* in the upper part of *Morozovella aequa* Biozone reflects a warm climatic period. This warm period can be related to the maximum warming of the Cenozoic.

5) The Zumaya section is excellently exposed, very accessible, of marine character with no facies change, and good paleontological control as its relatively continuous planktic foraminiferal record indicates. Consequently, it is a good section for the study of the Paleocene-Eocene transition in the Pyrenees and the International Subcommission of Paleogene Stratigraphy should consider this section as a potential candidate to establish the Paleocene/Eocene boundary stratotype.

ACKNOWLEDGEMENTS

We thank Prof. Gerta Keller from Princeton University and two anonymous referees for helpful critical comments. This study was supported by the project PB88-0389-C02-01 (DGICYT). The SEM photos were taken at Universidad de Granada. This is publication number 2 of IGCP Project 308 (Paleocene/Eocene boundary events).

REFERENCES

- Berggren, W.A. (1969): Paleogene biostratigraphy of planktic foraminifera of Northern Europe. *Proc. I Intern. Conf. Plank. Microfossils*: 121-160.
- Berggren, W.A. (1971): Multiple phylogenetic zonation of the Cenozoic based on planktonic foraminifera of Northern Europe. *Proc. II Intern. Conf. Plank. Microfossils*: 41-56.
- Berggren, W.A., Kent, D.V. and Flynn, J.J. (1985): Jurassic to Paleogene. Part 2, Paleogene geochronology and chronostratigraphy. *Geol. Soc. Lond. Mém.* 10: 1411-195.
- Berggren, W.A. and Miller, K.G. (1988): Paleogene planktonic foraminiferal biostratigraphy and magnetobiochronology. *Micropaleontology*, 34: 362-380.
- Berggren, W.A. and Miller, K.G. (1989): Cenozoic bathyal and abyssal calcareous benthic foraminiferal zonation. *Micropaleontology*, 35: 308-320.
- Berggren, W.A. and Olsson, R.K. (1986): North Atlantic Mesozoic and Cenozoic paleobiogeography. In: Vogt, P. R. and Tucholke, B. E. (Eds.): *The Geology of North America*, Volume M, The Western North Atlantic Region: *Geological Society of America*: 565-587.
- Berggren, W.A., Olsson, R.K. and Reymont, R.A. (1967): Origin and development of the foraminiferal genus *Pseudohastigerina* Banner and Blow, 1959. *Micropaleontology*, 13: 265-288.
- Blow, W.A. (1979): *The Cainozoic globigerinida: a study of the morphology evolutionary relationships and the stratigraphical distribution of some globigerinacea*. E. J. Brill (eds.): 1413 p.
- Boersma, A. and Premoli-Silva, I. (1983): Paleocene planktonic foraminiferal biogeography and paleoceanography of the Atlantic Ocean. *Micropaleontology*, 24: 355-381.
- Boersma, A. and Premoli-Silva, I. (1989): Atlantic Paleogene biserial heterohelicids and oxygen minimum. *Paleoceanography*, 4: 271-286.
- Boersma, A. and Premoli-Silva, I. (1991): Distribution of Paleogene planktonic foraminifera, analogies with the re-

- cent?. *Palaeogeogr. Palaeoclimat. Palaeoecol.*, 83: 29-48.
- Bolli, H.M. (1957a): The genera Globigerina and Globorotalia in the Paleocene-Eocene Lizard Springs Formation of Trinidad. B.W.I., *U.S. Nat. Mus. Bull.*, 215: 155-172.
- Bolli, H.M. (1957b): Planktonic Foraminifera from the Eocene Navet and San Fernando Formations of Trinidad. B.W.I., *U.S. Nat. Mus. Bull.*, 215: 61-81.
- Bolli, H.M., Perch-Nielsen, K. and Saunders, J.B. (1985): Comparison of zonal schemes for different fossil groups. In: *Plankton Stratigraphy* (Bolli, H. M., Perch-Nielsen, K. and Saunders, J. B., Eds.): 3-10.
- Canudo, J.I. (1991): Posición bioestratigráfica (Foraminíferos planctónicos) del Ilerdiense en la Cuenca Surpirenaica Central (área tipo) y su situación respecto al límite Paleoceno-Eoceno. *I Congreso del Grupo Español del Terciario*, Vic: 63-66
- Canudo, J.I. (in press): Los foraminíferos planctónicos del Paleoceno-Eoceno en el Prepirineo meridional y su comparación con la Cordillera Bética. *Memorias del Museo de Paleontología de la Universidad de Zaragoza*, 6.
- Canudo, J.I. and Molina, E. (in press): Bioestratigrafía con foraminíferos planctónicos del Paleógeno del Pirineo. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*.
- Canudo, J.I., Molina, E. and Sucunza, M. (1989): Bioestratigrafía con Foraminíferos planctónicos y Nannoplanctón calcáreo de la sección de Campo (paraestratotipo del Ilerdiense). *Geogaceta*, 8: 81-84.
- Caro, Y., Luterbacher, H.P., Perch-Nielsen, K., Premoli-Silva, I., Riedel, W.R. and San Filippo, A. (1975): Zonations a l'aide de microfossiles pélagiques du Paléocène supérieur et de l'Eocène inférieur. *Bull. Soc. Géol. France*, (7) 17: 125-147.
- Cavelier, C. and Pomerol, Ch. (1986): Stratigraphy of the Paleogene. *Bull. Soc. Géol. France*, (8) 2: 255-265.
- Dumont, A. (1849): Rapport sur la carte géologique du Royaume. *Bull. Acad. Roy. Sciences*, Bruxelles, 16: 351-373.
- Haq, B.U., Hardenbol, J. and Vail, P.R. (1987): The new chronostratigraphic basis of Cenozoic and Mesozoic sea level cycles. *Cushman Foundation for foraminiferal Research*, Sp. Publ., 24: 7-13.
- Hillebrandt, A. Von. (1965): Foraminiferen-Stratigraphie im Alttertiar von Zumaya (Prov. Guipuzcoa, NW Spanien) und ein Vergleich mit anderen Tethys-Gebieten. *Bayer. Akad. Wiss., math., nat.*, Kl, Abh., 123: 1-62.
- Hottinger, L. and Schaub, H. (1960): Zur Stufeneinteilung des Paleocaens und des Eocaens. Einführung der Stufen Ilerdien und Biatrritzien. *Eclog. Geol. Helvet.*, 53: 453-479.
- Kennet, J.P. and Stott, L.S. (1991): Abrupt deep sea warming, palaeoceanographic changes and benthic extinctions at the end of the Paleocene. *Nature*, 353: 225-229.
- Luterbacher, H.P. (1964): Studies in some Globorotalia from the Paleocene and Lower Eocene of the Central Apennines. *Eclog. Geol. Helvet.*, 57: 631-730.
- Luterbacher, H.P. (1973): La sección-tipo del piso Ilerdiense. *13 Coloquio de Micropaleontología*: 113-140.
- Martini, E. (1971): Standard Tertiary and Quaternary calcareous nannoplankton zonation. *Proc. Second Inter. Conf. Plankt. Microfossils*, Roma. Tecnoscienza, 2: 739-785.
- Miller, K.G. and Fairbanks, R.G. (1985): Cainozoic $\delta^{18}O$ record of climate and sea level. *South African Journal of Science*, 81: 248-249.
- Molina, E., Canudo, J.I., Ortiz, N., Sucunza, M., Samsó, J.M., Serra-Kiel, J. and Tosquella, J.M. (1989): Integrated biostratigraphy of the Lower Eocene in Area of Ilerdian stratotype (Central Southpyrenean basin), *28th Int. Geol. Cong.*: 449-450.
- Molina, E., Canudo, J.I., Guernet, C., McDougall, K., Ortiz, N., Pascual, J.O., Pares, J.M., Samsó, J.M., Serra-Kiel, J. and Tosquella, J.M. (in press): The stratotypic Ilerdian revisited: Integrated Stratigraphy across the Paleocene-Eocene boundary. *Rev. Micropaleontologie*, 35: (inpress).
- Orue Etxebarria, X. (1983-84): Los foraminíferos planctónicos del Paleógeno del Sinclinatorio de Bizcaia (Corte de Sopolana-Punta de la Galea). *Kobie*, 13-14: 429 p.
- Orue Etxebarria, X. and Lamolda, M. (1985): Caractéristiques paléobiogéographiques du bassin basco-cantabrique pendant le Paléogène. *Rev. Micropaléontologie*, 27: 257-265.
- Orue Etxebarria, X., Lamolda, M. and Apaellaniz, E. (1984a): Los Foraminíferos planctónicos del Paleoceno vizcaino y su Bioestratigrafía. *Rev. Esp. Microp.*, 16: 59-74.
- Orue Etxebarria, X., Lamolda, M. and Apaellaniz, E. (1984b): Bioestratigrafía del Eoceno vizcaino por medio de foraminíferos planctónicos. *Rev. Esp. Microp.*, 16: 241-263.
- Pomerol, Ch. (1975): La signification de l'Ilerdien et l'intérêt de cet étage dans la stratigraphie du Paléogène mésogéen. *Bull. Soc. Geol. France*, (7) 17: 213-217.
- Premoli-Silva, I. and Boersma, A. (1988): Atlantic Eocene planktonic foraminiferal historical biogeography and paleohydrographic indices. *Palaeogeogr. Palaeoclimat. Palaeoecol.*, 67: 315-356.
- Pujalte, V., Robles, S., Zapata, M., Orue-Etxebarria, X. and García-Portero, J. (1989): Sistemas sedimentarios, secuencias deposicionales y fenómenos tectonoestratigráficos del Maastrichtiense superior-Eoceno inferior de la Cuenca Vasca (Guipúzcoa y Vizcaya). *XII Congreso Español de Sedimentología*, Guía de Excursiones Geológicas: 47-88.
- Rea, D.K., Zachos, J.C., Owen, R.M. and Gingerich, Ph.D. (1990): Global change at the Paleocene - Eocene boundary: climatic and evolutionary consequences of tectonic events. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 79: 117-128.
- Renevier, E. (1873): Thanetien. *Bull. Soc. Vaudoise Sc. Nat.* 12: 218-252.
- Steurbaut, E. (1988): New early and Middle Eocene calcareous nannoplankton events and correlations in middle to high latitudes of the northern hemisphere. *Newsl. Stratigr.* 18: 99-115.
- Thiede, J. (1980): Palaeoceanography, margin stratigraphy and paleophysiology of the Tertiary North Atlantic and Norwegian - Greenland Seas. *Phil. Trans. Roy. Soc. London*, A 295: 177-185.
- Tjalsma, R.C. and Lohmann, G.P. (1983): Paleocene-Eocene bathyal and abyssal benthic foraminifera from the North Atlantic. *Micropaleontology*, Sp. Publ., 4: 40p.
- Toumarkine, M. and Luterbacher, H.P. (1985): Paleocene and Eocene planktic foraminifera. In: *Plankton Stratigraphy*. (Bolli, H. M., Perch-Nielsen, K. and Saunders, J.B., Eds.): 87-154.
- Wei, W. and Wise, S.W. Jr. (1990): Biogeographic gradients of middle Eocene-Oligocene calcareous nannoplankton in the South Atlantic Ocean. *Palaeogeogr. Palaeoclimat. Palaeoecol.*, 79: 29-61.
- Weaver, P.P.E. and Bergsten, H. (1991): Assessing the Accuracy of Fossil Datum Levels: Globorotalia margaritae Foraminiferida, a Pliocene Test Case. *Jour. Micropaleont.*, 9: 225-232.
- Wiedmanm, J. (1986): Macro-invertebrates and the Cretaceous-Tertiary boundary. In: *Global Bio-Events*, Springer, Lecture Notes in Earth Sciences, 8: 397-409.
- Willems, W., Bignot, G. and Moorkens, Th. (1981): Ypresian. *Bull. Inf. Géol. Bassin de Paris*, 2: 267-299.

Recibido el 8 de septiembre de 1991

Aceptado el 11 de febrero de 1992