

Field trip guide to the Paleocene and Early Eocene of Zumaya section

Eustoquio MOLINA¹, Ignacio ARENILLAS¹ and Birger SCHMITZ²

¹ Departamento de Ciencias de la Tierra, Universidad de Zaragoza, E-50009 Zaragoza. SPAIN.

² Department of Marine Geology, Earth Sciences Centre, University of Göteborg, S-41381. SWEDEN.

INTRODUCTION

The stratigraphic section chosen for the field trip is easily accesible since exposure occurs along San Telmo beach, just north of the township of Zumaya (Guipúzcoa province, northern Spain). (Fig. 1). Lithologically the lower Paleocene consist of about 50 metres of limestones with intercalated thin marl layers, the upper Paleocene is composed of about 120 metres of marls with interbedded limestones and calcarenite strata, and marls in the uppermost part. Turbidite strata are rare across the Paleocene stage boundaries and Paleocene/Eocene boundary, but become common in the upper part of the section from the *M. subbotinae* Biozone (Early Eocene) and in the upper Cretaceous.

The Paleocene and Early Eocene sedimentation 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 along the beaches at the northern coast range of the iberian peninsula. The lithology and geologic setting of the Zumaya section was described in detail by Hillebrandt (1965) and Pujalte *et al.*, (1989). The depositional sequences have been established by Pujalte *et al.* (1993; 1994; 1995). 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. Futhermore, Orue-Etxebarria *et al.* (1996) have published an integrated biostratigraphy in other sections of the Basque Country (Ermua and Trabakua Pass), which are reference sections for the Paleocene/Eocene boundary. Excellent reference sections are also the Campo and Tremp sections in the area of the Ilerdian stratotype (Molina, 1994; 1996; Molina *et al.*, 1992; 1995; 1996).

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 stage boundaries and Paleocene/Eocene boundary. Planktic foraminifera and calcareous nannofossils are the major fossil components in the sediments across the Paleocene-Eocene boundary at Zumaya section. Benthic foraminifera and ostracodes occur in low percentage (<10%). Larger foraminifera and other macrofossils are very rare. Reworked fossils are extremely rare and only occur in the turbiditic levels, which are very well localized.

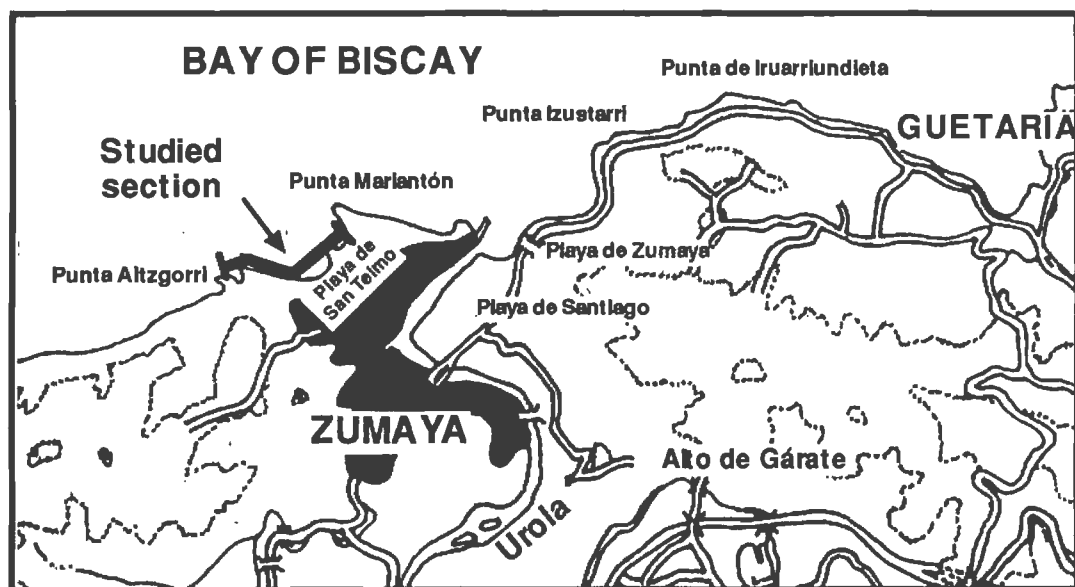
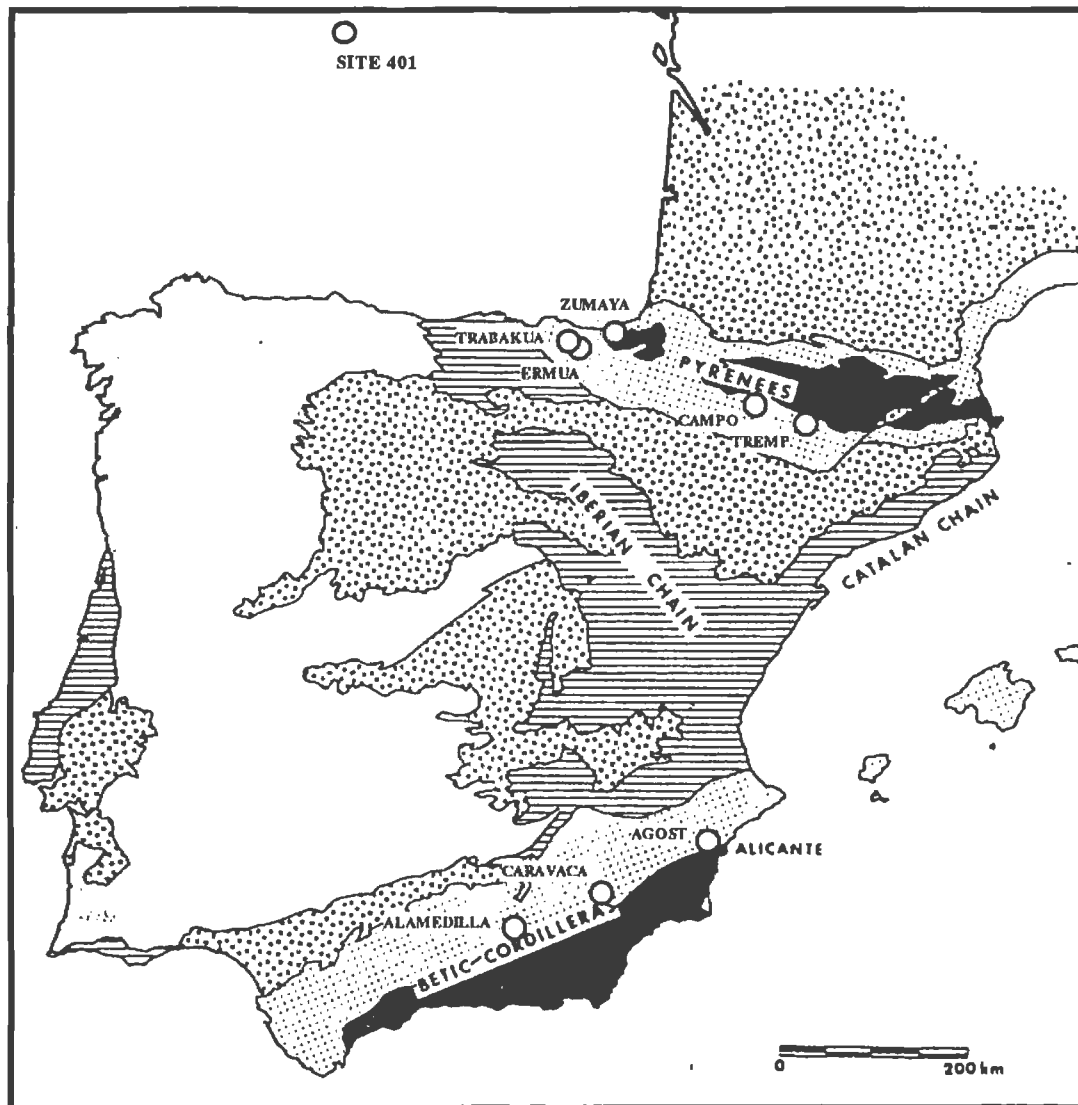


Fig. 1.- Location of the Zumaya section

PALEOCENE STAGE BOUNDARIES

One of the most promising sections for providing GSSP's for the Paleocene stage boundaries is the Zumaya section (Molina, 1994; 1996, Schmitz *et al.*, 1996). This section consists of an expanded about 160 metres thick and biostratigraphically complete Paleocene record (Fig. 2). The Zumaya section is an important link between the historical stratotype sections and the expanded Paleocene sections at low-middle latitudes in the Tethys and Atlantic Ocean.

According to Rosenkrantz (1924) (*fide* Schmitz *et al.*, 1996) the original basal Selandian in Denmark was defined at a major lithological shift, from greyish white, oxic limestone/chalk to suboxic greensand overlain by grey marl and clay. The limestone/chalk deposition prevailed throughout the entire Maastrichtian and Danian. After the Danian-Selandian transition, grey marls and clays dominated the sedimentation in Denmark for several million years. In terms of calcareous nannoplankton zonations, the basal Selandian in Denmark falls in the upper part of Zone NP4 or lower NP5 (Thomsen, 1994).

Consequently, at Zumaya the base of the Selandian appears to correspond to a package of red marls forming a 3.4 metres thick transition interval from reddish limestone-marl couplets below to grey marls above, about 55 metres above the Cretaceous/Tertiary boundary. This lithological shift is one of the most prominent in the Zumaya section. Thick reddish limestones with some marl layers dominate the lower 45 metres of the Danian. They are followed by some 10 metres of reddish limestone-marl couplets. The overlying 3.4 metres of red marls change abruptly into grey marls, which thereafter persist for some 25 metres. A varied grey marl-limestone lithology characterizes the remainder of the Paleocene.

The entire Paleocene of Zumaya section has been analyzed for stable isotopes in whole-rock samples (0.25 to 0.5 metres spacings). In the interval in which the basal Selandian may be defined, there is a negative $\delta^{13}\text{C}$ shift of about 1 per mil (Schmitz *et al.*, 1996). The Danian/Selandian boundary is a prominent event in term of $\delta^{13}\text{C}$, nannofossils and foraminifera (Fig. 3).

Planktic foraminifera were studied by Arenillas *et al.* (1993), Arenillas and Molina (1995; 1996) and Arenillas (unpublish Ph. D. thesis). (Fig. 4). Near or at the base of the red marls four species have their last appearance (*Eoglobigerina trivialis*, *Acarinina indolensis*, *Acarinina kubanensis* and *Morozovella tadjikistanensis*), and two species have their first occurrence (*Morozovella crosswickensis* and *Chiloguembelina crinita*). In the red marls, or just above these, *Subbotina velascoensis* has its first appearance. Genus *Morozovella* strongly decreases at the Danian/Selandian transition that is characterised by three levels in which the percentage of planktic foraminifera decreases and the percentage of the small benthic foraminifera increases (Arenillas and Molina, 1996). In coincidence with the upper two levels there is an increase of the genus *Chiloguembelina* which proliferates when oxygen minimum zones are well developed (Arenillas and Molina, 1995). Consequently, these data support the correlation of the Zumaya grey marls with the basal Selandian stratotype grey suboxic clay/marl. As the upper part of *Morozovella angulata* Biozone (P3a) does not correspond to the Danian we have used a new biozone called *Morozovella crosswickensis* to divide the *M. angulata* Biozone. The base of the new biozone approximately coincides with the base of the red marls. This is the main event in term of planktic foraminifera, but one meter above, in coincidence with the appearance of the nannofossil *F. tympaniformis*,

Subbotina velascoensis has its first appearance, which could be also used to define the Danian/Selandian boundary.

The calcareous nannofossils at Zumaya were studied by Kapellos (1974) and restudied by Von Salis in Schmitz *et al.* (1996). The first representatives of the genera *Sphenolithus* and *Fasciculithus* were found in the red limestone-marl couplets, that also include occasional *Ellipsolithus macellus*, and thus can be assigned to the upper part of NP4 Zone. The lowermost *Fasciculithus tympaniformis*, the marker for the base of NP5 Zone, was observed 75 centimetres above the lithologic change to the red marls, while the lowermost occurrence of typical *Neochiastozygus perfectus* was noted at the very base of the red marls. A sharp decrease of *Braarudosphaera bigelowi* s.l. accompanies the lithologic shift from the reddish limestone-marl couplets to the red marl. No major change in nannofossil flora was found at the shift from red to grey marl, however, a sharp increase in the abundance of microscopic dolomite rhombs was observed (Fig. 3).

Consequently, there are a number of arguments in favor of that the transitions from dominantly oxic limestones to grey suboxic marls or clays in Denmark and Spain reflect the same event. The nannofossil data show that at both sites the lithological shifts occur near or at the transition from Zone NP4 to NP5. Moreover, the finding of *Neochiastozygus perfectus* at the base of the red marls at Zumaya concurs with its first appearance in Denmark in the uppermost metres of the Danian (Thomsen, 1994). Pujalte *et al.* (1994) suggest that one of the most important sequence boundaries in the Zumaya section occurs in the interval in which we think that the basal Selandian occurs. This is the boundary between depositional sequences DS4 and DS5 according to their sequence boundary as the one marking the unconformity at the Danian-Selandian boundary in Denmark, and which represents the Se-1 sequence boundary in the chart of Hardenbol (1974). The sequence boundaries may not be correlatable worldwide, it is likely that at least regionally, along the northeastern Atlantic coast the same sea-level changes are registered by the strata. Magnetostratigraphy shows that the upper part of the limestone-clay couplets at Zumaya belongs to the Chron C26r (Roggenthen, 1976), which is the same chron preliminarily assigned for the basal Selandian in Denmark (Ali *et al.*, 1994). It is noteworthy that the basal Selandian interval at Zumaya is situated about 10 metres above the boundary between the *P. uncinata* (P2)/*M. angulata* (P3a) planktic foraminiferal zones, which in the general stratigraphic scheme of Berggren *et al.* (1995) is considered to correspond to the Danian/Selandian boundary.

The base of the Thanetian in its original type area is an unconformity dated to the upper part of Zone NP6 (Aubry, 1994; Knox, 1994). The preliminary nannofossil data suggest that the NP6 zone corresponds approximately to the interval around 100 metres above the Cretaceous/Tertiary boundary at Zumaya section. In terms of planktic foraminifera the base of the Thanetian has been classically placed in the lower part of *P. pseudomenardii* Zone (P4).

Apparently, in Zumaya there is no important sequence boundary near or within this interval (Pujalte *et al.*, 1994). The closed sequence boundaries are the above mentioned DS4/DS5 (Danian/Selandian) boundary and the DS5/DS6 boundary at about 145 metres above the Cretaceous/Tertiary boundary. The DS5/DS6 boundary occurs in NP9 Zone above the Thanetian in England and corresponding to the basal Ilerdian in Spain. According to Arenillas and Molina

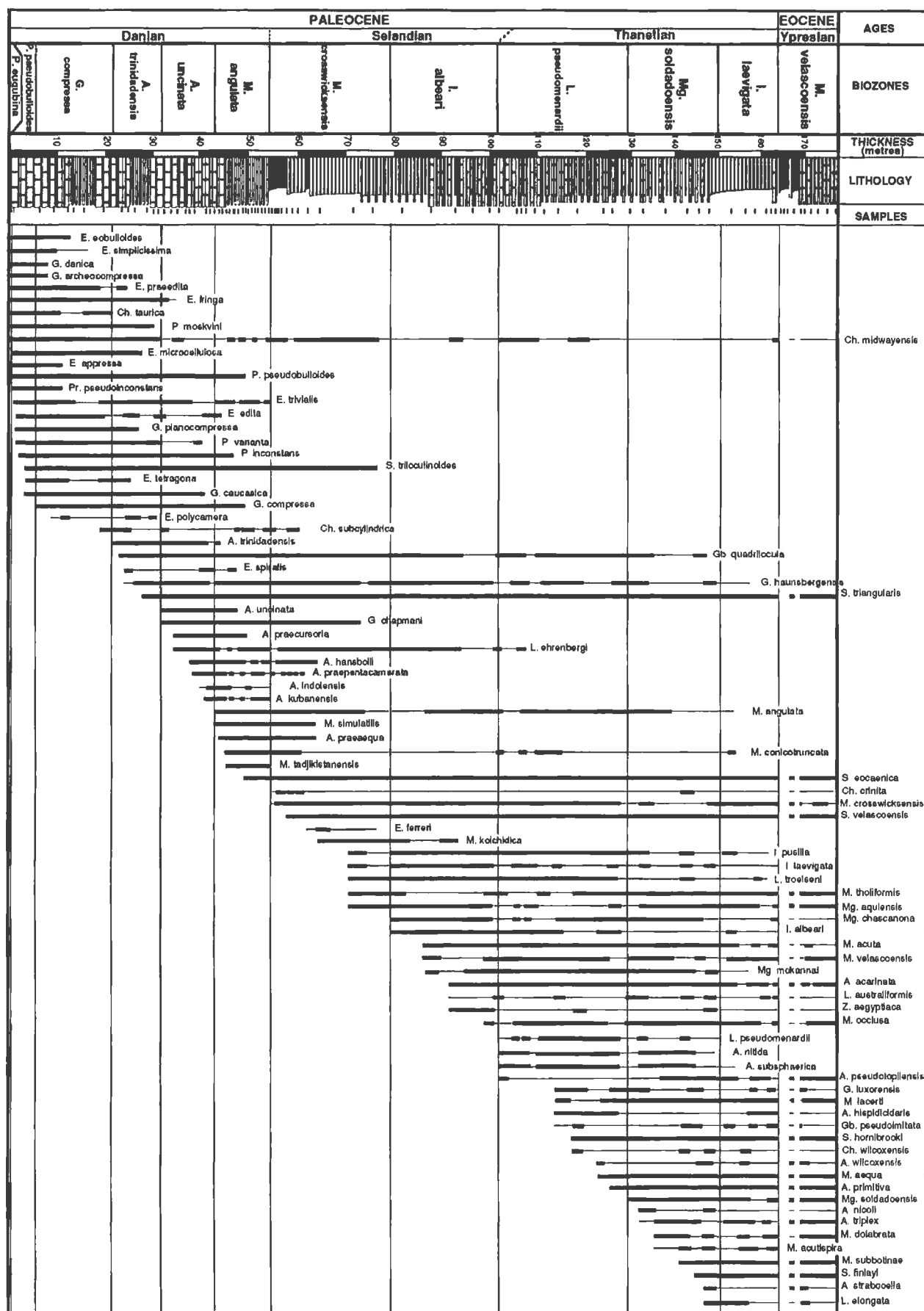


Fig. 4.-Planktic foraminiferal biostratigraphy of the Paleocene at Zumaya section (modified from Arenillas, unpubl. Ph. D. thesis)

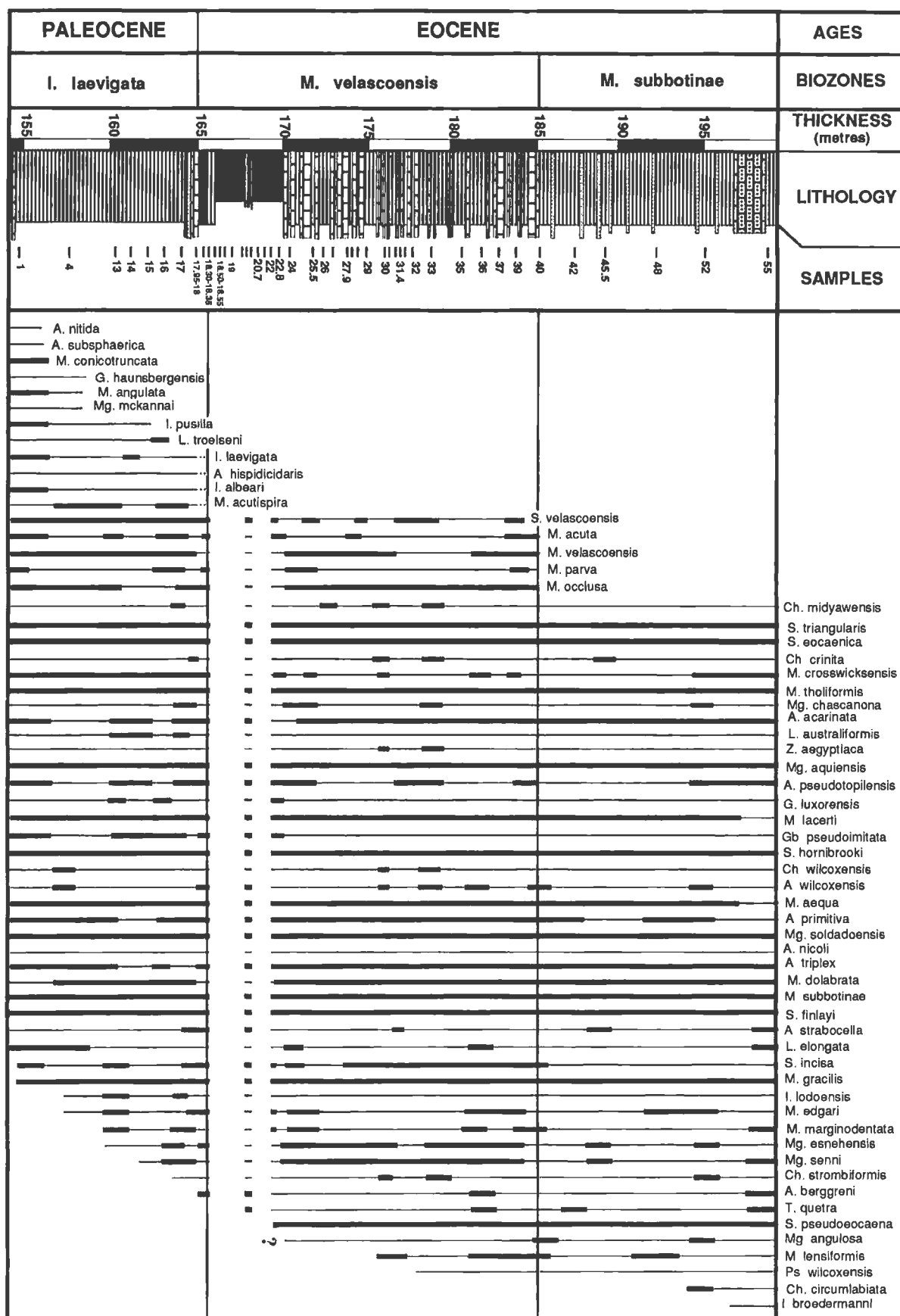


Fig. 7.- Planktic foraminiferal biostratigraphy across Paleocene/Eocene boundary at Zumaya section (modified from Canudo y Molina, 1996, and Arenillas, unpubl. Ph. D. thesis)

(1995) and Arenillas (unpublished Ph. D. thesis) in the lower part of *L. pseudomenardii* Biozone there are very relevant changes in the planktic foraminifera warm/cold index at Zumaya section, indicating an increase in temperature across the Selandian/Thanetian boundary (Fig. 5).

PALEOCENE/EOCENE BOUNDARY

The lower part of the Paleocene-Eocene (P-E) transition at Zumaya consists of about 17 metres of homogenous grey marls; the upper part consists of more than 30 metres of grey marls alternating with grey limestone beds. A prominent one-meter-thick grey sandy limestone bed interrupts the marl sequence. A turbidite (8 centimetres thick) is found in the lower part of the grey limestone bed. Such turbidites are very rare in the Paleocene-Eocene interval. The limestone is overlain by 45 centimetres thick dark marl layer, which is succeeded by a 4 metres interval of red clay that marks the benthic foraminiferal mass extinction and $\delta^{13}\text{C}$ shift. The clay interval is devoid of original calcite except for a thin calcareous interval in the middle part.

Placement of the Paleocene/Eocene (P/E) boundary has not been officially defined. By convention, many biostratigraphers used to place this boundary at the extinction of *Morozovella velascoensis* that marks the P5/P6a boundary and is assigned an age estimate of 54.7 Ma (Berggren *et al.*, 1995). Since the last occurrence of *M. velascoensis* appears diachronous and this species is not present in high latitudes or in shallow sections, this datum is a very poor marker for a major series boundary. The *Pseudoshastigerina* "datum" has also been used by some authors to define the Paleocene/Eocene boundary, but the *Pseudoshastigerina* first appearance is very diachronous (Molina *et al.*, 1992; Canudo & Molina, 1992; Pardo *et al.*, 1994). The *Pseudoshastigerina wilcoxensis* first appearance is not a reliable datum, since it appears later in high latitudes and because of the difficulty in discriminating it from its ancestor *Globanomalina ovalis*. The $\delta^{13}\text{C}$ excursion, which has been determined to be globally synchronous and coincides with a major mass extinction in benthic foraminifera (Kennett and Stott, 1991; Kaiho, 1991; Pak and Miller, 1992) appears to be the best and most reliable marker horizon for the Paleocene/Eocene boundary. Consequently, we have placed the P/E boundary at this $\delta^{13}\text{C}$ excursion and extinction in benthic foraminifera (BB1/BB2 Zone of Berggren and Miller, 1989).

The Zumaya section contains the most biostratigraphically complete Paleocene-Eocene transition known to date, with about 30 metres representing Zones P5 and P6a of Berggren and Miller (1988), which correspond to Zone P5 of Berggren *et al.* (1995) and to the *Igorina laevigata* and *Morozovella velascoensis* Biozones of Arenillas and Molina (1996). This represents the most expanded interval for this zone known to date in deep sea sections. By comparison, Zone P6a is represented only by 1.2 m in the Pacific Ocean deep-sea Site 577 (Miller *et al.*, 1987), by 6.4 m in the Bay of Biscay Site 401 (Pardo *et al.*, 1995; 1996; Arenillas *et al.*, 1996) and by 6.5 m for Zones P5 and P6a combined (Pak and Miller, 1992).

Ranges of selected index species and the planktic foraminiferal biozonations are illustrated in Figure 6 along with the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ curves. The $\delta^{13}\text{C}$ excursion coincides with a 45 centimetres thick dark grey shale layer,

increased carbonate dissolution and the extinction of over 50% of the benthic foraminifera (Ortiz, 1993; 1995; Canudo *et al.*, 1995; Schmitz *et al.*, in press). No significant planktic foraminifera species turnover is apparent across the clay. The most important change across the P/E boundary is the strong increase in the relative abundance of *Acarinina*, reaching the highest values just above the benthic extinction in the marl interval interbedded in the clay. It is notable that the *Acaninina* increase is already apparent 20 centimetres below the benthic extinction.

The ranges and relative abundances of all planktic foraminiferal species are illustrated in Figure 7. The Paleocene-Eocene transition is characterized by a gradual species turnover with about 30% (17 species) of the taxa terminating and about 20% (12 species) originating primarily in this interval. The lower 10 metres (*I. laevigata* Biozone) is characterized by the gradual disappearance of 8 species and the appearance of 6 species. The Paleocene/Eocene boundary is marked by the simultaneous disappearance of 4 species. The upper 20 metres (*M. velascoensis* Biozone) is characterized by the gradual appearance of 6 species and the disappearance of 5 species at the top of this zone (Fig. 7).

Biostratigraphic interpretation of Zumaya is based on planktic foraminifera following numerical zonations of Blow (1979), Berggren and Miller (1988) and the last revision of Berggren *et al.* (1995). In order to avoid confusion inherent to successive changes in numerical zonations we recognized the classical biozonations of Hillebrandt (1965), Tourmarkine and Luterbacher (1985) and the new biozonation of Arenillas and Molina (1996). It has been proposed that Zone P5 be eliminated because the defining datum events, *L. pseudomenardii* LO and *M. subbotinae* FO, may even overlap due to diachroneity (Blow, 1979, Canudo and Molina, 1992a). This may give the erroneous impression of a hiatus with Zone P5 missing. Since the Spanish sections must be correlated to coeval sections worldwide where the P-zonation of Berggren and Miller (1988) has been used, our biostratigraphic interpretation here also follows this zonation. Nevertheless, in order to improve the biostratigraphical resolution we have further divided the classical *M. velascoensis* Biozone: *Igorina laevigata* Biozone and *Morozovella velascoensis* Biozone (Arenillas and Molina, 1996). This division has the advantage of a higher resolution and the coincidence of the zonal boundary with the small benthic foraminiferal extinction.

Benthic foraminiferal data from Zumaya indicate that deposition across the P-E transition occurred probably in a middle or lower bathyal environment. This is indicated by the presence of many species which have upper depth limits between 600 m. and 1500 m. (e.g. *Spiroplectammina spectabilis*, *B. jarvisi*, *Cibicidoides hyphalus*, *Stensioina beccariiiformis*, *Bulimina velascoensis*, *B. trinitatensis*, *B. tuxpamensis*, *C. pseudoperlucidus*, *Nuttallides truempyi*, *Oridorsalis umbonatus*, Morkoven *et al.*, 1986). Planktic foraminifera represent more than 85% of the foraminiferal fauna. The presence of common *C. pseudoperlucidus* and *S. beccariiiformis* in the *L. pseudomenardii* and *I. laevigata* Biozones prior to the $\delta^{13}\text{C}$ shift indicates well oxygenated waters (Kaiho, 1991) and the common occurrence of *Cibicidoides* spp. suggests a high influx of terrestrial organic carbon (Boersma, 1985, Ortiz, 1993;1994).

The extinction of over 50% of the benthic taxa coincides with the $\delta^{13}\text{C}$ excursion and deposition of dark grey to brown shale layers with low carbonate content and strong foraminiferal dissolution. At Zumaya, a low diversity agglutinated assemblage and high abundance of *Bulimina tuxpamensis* suggest low oxygen conditions and waters undersaturated in calcium carbonate during

the $\delta^{13}\text{C}$ excursion. During the following interval of low $\delta^{13}\text{C}$ values, high abundance of *N. truempyi* (47%) suggests a return to more oxygenated waters (Ortiz, 1993; 1995, Canudo *et al.*, 1995).

Calcareous nannofossil were studied by Kapellos (1974) establishing the biozonation from the uppermost Cretaceous to the upper part of the Early Eocene. The Paleocene-Eocene transition is being studied in detail by Angori and Monechi and a preliminary biozonation was previously established by Aubry. According to Angori and Monechi the NP9/NP10 boundary is located 5 metres above the benthic foraminiferal mass extinction (Angori and Monechi, 1995, pers. comm.) and according to Aubry the same boundary is placed more than 20 metres above the benthic foraminiferal mass extinction (Aubry, 1990, pers. comm.) in coincidence with the CP8/CP9 boundary, but this boundary does not coincide with the NP9/NP10 boundary. This divergence is due to a different interpretation of the index species and not to a hiatus or condensation above the Paleocene/Eocene boundary at Zumaya section.

Dinoflagellates were studied by Nuñez-Betelu (1993, in press) establishing the biozonation of the Paleocene-Eocene transition at Zumaya section. The following zones were recognized: *A. hiperacanthum* Biozone across the Paleocene/Eocene boundary and *W. astra* Biozone above the dissolution interval in the lower Eocene. These results are similar and can be easily correlated to the nearby sections of Ermua and Trabakua Pass (Orue-etxebarria *et al.*, 1996).

Chemical element (Ir, Fe, Sc, Ni, Co, Se, Sb, Cr, Rb, Cs, Ce, Hf, and Th) concentration were analyzed with the Luis W. Alvarez-Iridium Coincidence Spectrometer. The stable isotope analyses were performed on bulk samples, using a VG Prism Series II mas spectrometer with an Isocarb automated carbonate preparation system (Schmitz *et al.*, in press). It appears that at Zumaya the negative $\delta^{13}\text{C}$ shift associated with the benthic extinction begins to evolve gradually somewhere between 20 to 40 centimetres below the base of the dissolution clay (Fig. 6). Based on sedimentation rate calculations it appears that the benthic mass extinction event at Zumaya occurred about 6 to 25 kyrs after the initiation of the sea-water $\delta^{13}\text{C}$ shifts.

There are two paleontological arguments in favor of that the $\delta^{13}\text{C}$ gradual change reflect the initiation of the events leading to the benthic mass extinction. According to Speijer in Schmitz *et al.* (in press) at Zumaya there is a 15 centimetres offset between the LAD's of *G. beccariiiformis* and the other benthics. Secondly, in the calcareous intervals of the dissolution clay an unusual planktic foraminiferal fauna exists, with acariniids, in particular *A. wilcosensis* and *A. acarinata*, showing major abundance peaks. These two species, however, already show their first strong abundance increase in a sample from the greenish marls at 20 centimetres below the benthic extinction. The $\delta^{18}\text{O}$ values lie relatively stable throughout the marl and limestone part of the section, with most values in the range -3.5 to -4 per mil. In the clay interval, however, $\delta^{18}\text{O}$ shows a widely scattered distribution, ranging between -2.6 to -6.6 per mil. These isotopic shifts has been attributed to a change in the source regions of global deep-water from the high latitudes to subtropical regions in connection with a high-latitude warming event. Warm, saline surface water began to spread all over the global sea floor, leading to benthic faunal turnovers (Kennett and Stott, 1991; Schmitz *et al.*, in press) and producing a major sea level rise (Molina *et al.*, 1994).

In conclusion, the Zumaya section is located in a very accesible place, has a very continuos, expanded, well exposed, and very good paleontological and geochemical records. Consequently, this section is considered as one of the best candidates to define the Paleocene/Eocene boundary stratotype. Futhermore, the definition of the Paleocene stage boundaries (Selandian and/or Thanetian) in the same section represents a unique and advantageous opportunity.

REFERENCES

- Ali, J, Heilmann-Clausen, C., Thomsen, E. and Abrahamsen, N. Magnetostratigraphy of the type Selandian: preliminary results. *GFF*, 116(1):43.
- Arenillas, I. 1996. *Los foraminíferos planctónicos del Paleoceno-Eoceno inferior: sistemática, bioestratigrafía, cronoestratigrafía y paleocenografía*. Doctoral thesis, Universidad de Zaragoza. (unpublished).
- Arenillas, I. and Molina, E. 1995. Análisis cuantitativo de los foraminíferos planctónicos del Paleoceno en Zumaya: implicaciones paleambientales y eventos paleoceanográficos. *Geogaceta*, 17:23-26.
- Arenillas, I. and Molina, E. 1996. Bioestratigrafía con foraminíferos planctónicos y eventos paleoceanográficos del tránsito Daniense/Selandiense del corte de Zumaya (Guipúzcoa). *Actas XII Bienal de la Real Sociedad Española de Historia Natural*. 272-276.
- Arenillas, I., Canudo, J.I. and Molina, E. 1993. Correlación entre la magnetoestratigrafía y la bioestratigrafía con foraminíferos planctónicos del Paleoceno inferior en Agost (Béticas) y Zumaya (Pirineos). *Actas IX Jornadas de Paleontología*, 1-6.
- Arenillas, I., Molina, E. and Pardo, A. 1996. Correlación cuantitativa con foraminíferos planctónicos del tránsito Paleoceno-Eoceno en Alamedilla (Béticas), Zumaya (Pirineos) y Site 402 (Golfo de Vizcaya): implicaciones paleoceanográficas. *Geogaceta*. 20(1):172-175.
- Aubry, M.P. 1994. The Thanetian Stage in NW Europe and its significance in terms of global events. *GFF*. 116(1): 43-44.
- 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, Kent, D.V., Swisher, C.C. and Aubry, M.P., 1995, A revised Cenozoic Geochronology and Chronostratigraphy. In Berggren et al. (Eds.), *Geochronology, time scales and global stratigraphic correlation*. SEPM Special Publication, 54:129-212.
- 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 pp.
- Boersma, A., 1985, Oligocene benthic foraminifers from North Atlantic Sites: benthic foraminifers as water-mass indexes in the North and South Atlantic. *Init. Rep. DSDP*, 82: 611-627.
- Canudo, J.I. and Molina, E., 1992a, Planktic foraminiferal faunal turnover and Bio-chronostratigraphy of the Paleocene-Eocene boundary at Zumaya, northern Spain, *Rev. Soc. Geol. España*, 5: 145-157.
- Canudo, J.I. and Molina, E., 1992b, Bioestratigrafía con foraminíferos planctónicos del Paleógeno del Pirineo. *N. Jb. Geol. Paläont. Abh.*, 186: 97-135.
- Canudo, J.I., Keller, G., Molina, E. and Ortiz, N. 1994. Planktic foraminiferal turnovers and $\delta^{13}\text{C}$ isotopes across the Paleocene-Eocene transition at Caravaca and Zumaya, Spain. *Paleogeogr., Paleoclimat., Paleoecol.*, 114:75-100.

- Hardenbol, J. 1994. Sequence stratigraphic calibration of Paleocene and Lower Eocene continental margin deposits in NW Europe and the Gulf Coast with the oceanic chronostratigraphic record. *GFF*, 116: 49-51.
- Hillebrandt, A. Von, 1965, Foraminiferen-Stratigraphie im Alttertiär von Zumaya (Prov. Guipuzcoa, Nw Spanien) und ein Vergleich mit anderen Tethys-Gebieten. *Bayer. Akad. Wiss., math., nat., Kl*, 123: 62pp.
- Kaiho, K., 1991, Global changes of Paleogene aerobic/anaerobic benthic foraminifera and deep-sea circulation. *Paleogeogr., Paleoclimat., Paleoecol.*, 83: 65-86.
- Kapellos, C., 1974. Über das Nannoplankton im Alttertiär des Profils von Zumaya-Getaria (Prov. Guipúzcoa, Nordspanien). *Eclogae geologicae Helvetiae*, 67: 435-444.
- Kennett, J.P. and Stott, L.D., 1991, Terminal Paleocene deep-sea benthic crisis: sharp deep-sea warming and paleoceanographic changes in Antarctica. *Nature*, 353: 225-229.
- Knox, R.W.O'B. 1994. The age and regional context of the Thanetian stratotype sections of SE England. *GFF*, 116(1): 55-56.
- Morkoven, F.P.C., Berggren, W.A., and Edwards, A.S., 1986, *Cenozoic cosmopolitan deep-water benthic foraminifera*. Elf-Aquitaine (Pan, France), 421 pp.
- Miller, K.G., Janecek, T.R., Katz, M.E., and Keil, D.K., 1987, Abyssal circulation and benthic foraminiferal changes near the Paleocene/Eocene boundary, *Paleoceanography*, 2: 741-761.
- Molina, E. 1994. Paleocene sections in Spain: chronostratigraphical problems and possibilities. *GFF. Geologiska Föreningens i Stockholm Förhandlingar*, 116:58-59.
- Molina, E. 1996. El límite Paleoceno/Eoceno en España: características y posibilidades. *Geogaceta*, 20(7): 210-213.
- Molina, E., Arenillas, I., Arz, J.A., Canudo, J.I., Gonzalvo, C. Ortiz, N. and Pardo, A. 1996. Síntesis biostratigráfica y eventos paleoceanográficos del Cretácico (Maastrichtense) al Mioceno (Langhiense) basada en foraminíferos. *Revista Española de Paleontología*. Nº extra: 192-200.
- Molina, E., Canudo, J. I., Guernet, C., McDougall, K., Ortiz, N., Pascual, J.O., Pares, J.M., Samso, J.M., Serra-Kiel, J. y Tosquella, J., 1992, The stratotypic Ilerdian revisited: integrated stratigraphy across the Paleocene/Eocene boundary. *Revue de Micropaléontologie*, 35(2): 143-156.
- Molina, E., Canudo, J.I., Martínez, F. and Ortiz, N., 1994. Integrated stratigraphy across the Paleocene/Eocene boundary at Caravaca, southern Spain. *Eclogae geologicae Helvetiae*, 87(1): 47-61.
- Molina, E., De Renzi, M. and Alvarez, G. 1995. El estratotipo del Ilerdiense y su registro fósil. *Actas XI Jornadas de Paleontología*, 211-220.
- Núñez-Betelu, L.K., 1993. Dinocyst delineation of the Paleocene/Eocene boundary in the basque basin, western Pyrenees. *Proceeding of the Fifth International Congress on Dinoflagellates* (in press).
- Ortiz, N. 1993, *Los microforaminíferos bentónicos del tránsito Paleoceno-Eoceno y sus implicaciones bioestratigráficas y paleoecológicas*. Tesis Universidad de Zaragoza: 274 pp.
- Ortiz, N. 1994. La extinción masiva de foraminíferos bentónicos batiales y abisales en el límite Paleoceno/Eoceno. In E. Molina (ed.) *Extinción y registro fósil*. Cuadernos Interdisciplinares, 5: 201-218.
- Ortiz, N. 1995. Differential patterns of benthic foraminiferal extinctions near the Paleocene/Eocene boundary in the North Atlantic and the western Tethys. *Marine Micropaleontology*. 26:341-359.
- Orue-etxebarria, X. and Lamolda, M. (1985): Caractéristiques paléobiogéographiques du Bassin Basco-Cantabrique pendant le Paléogène. *Rev. de Micropal.*, 27(4): 257-265.

- Orue-etxebarria, X., Apellaniz, E., Baceta, J.I. Coccioni, R. Di Leo, R. Dinares-Turell, J. Galeotti, S., Monechi, S., Nuñez-Betelu, K., Pares, J.M., Payros, A. Pujalte, V., Samso, J.M. Serra-Kiel, J. Schmitz, B. and Tosquella, J. 1996. Physical and biostratigraphic analysis of two prospective Paleocene-Eocene Boundary Stratotypes in the intermediate-deep water Basque Basin, western Pyrenees: The Trabakua Pass and Ermua sections. *N. Jb. Geol. Palaont. Abh.* 200 (in press).
- Pardo, A., Canudo, J.I. and Molina, E. 1994. Bioestratigrafía con foraminíferos planctónicos en la parte inferior de la Formación Ieper (Ypresiense estratotípico) en el sondeo Knokke (Bélgica). *Revista Española de Micropaleontología*, XXVI(1): 109-125.
- Pardo, A., Keller, G., Molina, E. and Canudo, J.I. 1995. Planktic foraminiferal paleoecology along the Paleocene-Eocene transition at Site 401 (Bay of Biscay, North Atlantic). *Actas XI Jornadas de Paleontología*, 129-134.
- Pardo, A., Keller, G., Molina, E. and Canudo, J.I. 1996. Planktic foraminiferal turnover across the Paleocene-Eocene transition at DSDP Site 401, Bay of Biscay, North Atlantic. *Marine Micropaleontology* (in press).
- Pak, D.K., and Miller, K.G., 1992, Paleocene to Eocene benthic foraminiferal isotopes and assemblages: Implications for deep-water circulation, *Paleoceanography*, 7: 405-422.
- Pujalte, V., Robles, S. Zapata, M., Orue-Etxebarria, X. y García Portero, J., 1989, Sistemas sedimentarios y fenómenos tectonoestratigráficos del Maastrichtiense superior-Eoceno inferior de la Cuenca Vasca (Guipuzcoa y Vizcaya). *XII Congreso Español de Sedimentología. Guía de Excursiones Geológicas*: 47-88.
- Pujalte, V., Robles, S., Robador, A., Baceta, J.I. and Orue-etxebarria, X. 1993. Shelf-to-basin Palaeocene palaeogeography and depositional sequences, western Pyrenees, north Spain. *Spec. Publs. Int. Ass. Sediment.* 18:369-395.
- Pujalte, V., Baceta, J.I. Payros, A. Orue-etxebarria, X. and Serra-Kiel. 1994. Late Cretaceous - Middle Eocene sequence stratigraphy and biostratigraphy of the SW. and W. Pyrenees (Pamplona and Basque Basins, Spain). *GEP and IGCP 286 Fiel Seminar*, 118 pp.
- Pujalte, V., Baceta, J.I. Dinarés, J., Orue-etxebarria, X., Pares, J.M. and Payros, A. 1995. Biostratigraphic and magnetostratigraphic intercalibration of latest Cretaceous and Paleocene depositional sequences from the deep-water Basque basin, western Pyrenees, Spain. *Earth and Planetary Science Letters*, 136:17-30.
- Roggenthen, W.M., 1976, Magnetic stratigraphy of the Paleocene a comparison between Spain and Italy. *Mem. Soc. Geol. It.*, 15: 73-82.
- Schmitz, B. Molina, E. and Von Salis, K. 1996. The Zumaya section in Spain: a possible global stratotype section for the Selandian and Thanetian stages. *Newsletter of the ISPS*, 6:15-21.
- Schmitz, B. Asaro, F., Molina, E. and Speijer, R.P. (in press) In search of the triggering mechanism for the latest Paleocene benthic extinction event: Iridium and $\delta^{13}\text{C}$ high-resolution profiles at Zumaya, Spain. *Paleogeogr., Paleoclimat., Paleoecol.*,
- Thomsen, E. 1994. Calcareous nannofossil stratigraphy across the Danian-Selandian boundary in Denmark. *GFF*, 116: 65-67.
- Toumarkine M. and Luterbacher, H., 1985. Paleocene and Eocene planktic foraminifera. In: Bolli et al. (eds) *Plankton Stratigraphy*. Cambridge University Press. 83-153.