The Ypresian/Lutetian transition in the Gorrondatxe Beach (Getxo, Western Pyrenees): Review, recent advances and future prospects

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Designed by: Fernando Caballero Logo Image: Aitor Payros On the Cover photograph: Ypresian/Lutetian strata exposed at the Gorrondatxe beach cliff. Photo by: Fernando Caballero

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THE YPRESIAN/LUTETIAN TRANSITION IN THE GORRONDATXE BEACH (GETXO, WESTERN PYRENEES): REVIEW, RECENT ADVANCES AND FUTURE PROSPECTS

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INTRODUCTION

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The definition of chronostratigraphic units through their boundaries is being accomplished following the International Commission on Stratigraphy (ICS) Guidelines (Cowie et al, 1986). Stages originally defined by their contents are now defined by their lower boundary: Global Stratotype Standard-section and Point (GSSP). Stages may be characterized by their contents, but precise definitions of stages can only be attained by boundary definitions. The emphasis has therefore been placed on the precise definition of boundaries. ICS groups do not look any longer for the unit-stratotype but for the succession offering the most detailed documentation of the transition from one stage to the next one (Remane, 2003).

The International Commission on Stratigraphy requires that its Subcommissions organize working groups to choose a GSSP for each international chronostratigraphy boundary. According to the ICS revised Guidelines (Remane et al. 1996) a suitable candidate section has to fulfil a series of requirements since the function of the type-section is to give an unbiased and complete record of the most relevant marker events. However, the absolutely perfect typesection will often not exist and the requirements enumerated below are intended to characterize the ideal type-section and most of them must be, but not all of them can be fulfilled in every case. The Geological requirements are: exposure over an adequate thickness of sediments, continuous sedimentation, the rate of sedimentation should be high enough, absence of synsedimentary and tectonic disturbances, absence of metamorphism and strong diagenetic alteration. The Biostratigraphic requirements are: abundance and diversity of well preserved fossils, absence of vertical facies changes and favourable facies for long range biostratigraphic correlations (open marine environment). Other requirements are: amenability to radiometric dating, magnetostratigraphy and chemostratigraphy, possibility to fix a permanent marker, accessibility, free access and permanent protection of the site.

The Ypresian/Lutetian boundary statotype has to be defined in an event correlable with the base of the Lutetian, which is the lowermost standard stage of the Middle Eocene (Jenkins and Luterbacher, 1992). The boundary stratotype must be defined by a lithological level in a stratigraphic section, coinciding with an easily correlable event, in a suitable marine continuous section, preferably out of the Paris basin where the Lutetian stage was defined, since the Lutetian in the Paris basin is a sedimentary sequence between two hiatuses. An important problem is the

scarcity of continuous sections at the Ypresian/Lutetian transition due to the large offlap/sea level fall event that cuts out part or the entire NP13/14 calcareous nannofossil interval in many sections. This hiatus is very frequent in the Atlantic Ocean (Aubry, 1995). Consequently, the GSSP will have to be located in a deep water section with minimal evidence of disturbance, transport and erosion.

According to Luterbacher et al. (2004) the Ypresian stage was introduced by Dumont in 1849 to include the shelf-facies strata lying between the terrestrial to marginally marine Landenian and the marine Brusselian in Belgium. Later Dumont in 1851 assigned the upper sandy part of the stage to the Paniselian, apart from the Ypresian *sensu stricto*, which is typified by the Yper Clay of western Belgium. Biostratigraphically, the Ypresian is well restrained by its dinocyst and calcareous nannoplankton associations (e.g. Vandenberghe et al., 1998). It is characterized by nannoplankton zones NP11, NP12 and NP13 (Martini 1971) and possibly the base of NP14 in the Aalter Sands. Magnetostratigraphic studies (Ali and Hailwood, 1995) correlate the Ypresian interval with polarity Chrons C24r-C22r. According to Cavelier and Pomerol (1986) the Ypresian covers the whole of the Cuisian, extending beyond the Cuisian to include zone NP13 and possibly the base of zone NP14. In its lower part the Ypresian also covers the middle and late Ilerdian.

The Lutetian was defined by De Laparent in 1883 and is typified by the "Calcaire grossier" of the Paris Basin. The stratotype was selected by Blondeau (1981) approximately 50 km north of Paris at St. Leud'Esseret and St. Vaast-less-Mello. Biostratigraphically, the Lutetian stratotype contains larger foraminifera, palynomorphs and calcareous nannoplankton. According to Aubry (1983, 1995) the base of the Lutetian falls in the upper part of the nannoplankton NP14 Zone of Martini (1971) and in the CP12b Zone of Okada y Bukry (1980), extending to zones NP15 and the lower part of NP16. And in terms of shallow benthic foraminifera the base of the Lutetian is approximately placed at the base of the SBZ13 Zone of Serra-Kiel et al. (1998). According to Cavelier and Pomerol (1986) the early and middle Lutetian correspond to the *Nummulites laevigatus* and *Alveolina stipes* Zones, while the late Lutetian is already in the *Alveolina elongata* Zone characteristic of the Biarritzian s.s., which is entirely contained whithin the Lutetian.

The International Subcommission on Paleogene Stratigraphy (ISPS) decided to set up a working group to select a GSSP for the base of the Lutetian Stage and appointed Eustoquio Molina to be its chairman in 1992. Since then the most active members of the working group visited and sampled several sections in Italy, Israel, Tunisia, Morocco, Mexico and Argentina, but unfortunately none of the studied sections was considered a good candidate. In Spain many sections were visited and sampled in the Betic Cordilleras (Alamedilla, Agost, Fortuna, etc.) and in the Pyrenees (Anotz, Campo, Erro, Gorrondatxe, Guetaria, Osinaga, Otsakar, etc.). Most of these Betic and Pyrenean sections are not ideal, as they are plagued with hiatuses, restricted facies, tectonic complications and other problems (Gonzalvo et al., 2001; Payros et al., 2006).The Fortuna section was considered a leading candidate, but the boundary interval is very condensed (Molina et al., 2006) and consequently now is not considered a suitable section to define a GSSP.

Lately, the research has been focused on the study of the two more suitable sections to define the Lutetian GSSP, which are the Agost and Gorrondatxe sections. The results of both sections show that the different events traditionally used to place the Ypresian/Lutetian boundary, previously thought to be almost simultaneous, actually occur at very different levels. The first appearance of *Hantkenina nuttalli*, frequently used by planktic foraminifera specialists to mark this boundary (Berggren et al., 1995), is younger than the Lutetian strata in Paris, according to the new data from the Agost section (Molina et al., 2000; Larrasoaña et al., 2008; Ortiz et al., 2008) and the Gorrondatxe section (Bernaola et al., 2006; Payros et al., 2007). The closest event to the base of the original Lutetian stage seems to be the first occurrence of the calcareous nannofossil *Blackites inflatus* at the base of Subzone CP12b (Aubry, 1986). The integrated magnetobiostratigraphic studies carried out at the Agost and Gorrondatxe sections provide conclusive evidence that both sections are almost continuous and contain diverse and wellpreserved fossil groups. However, the Gorrondatxe section seems to be more suitable than the Agost section and it is now the leading candidate.

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ICHNOLOGICAL ANALYSIS THROUGH THE YPRESIAN/LUTETIAN BOUNDARY INTERVAL AT THE GORRONDATXE SECTION*

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From the beginning of the twenty-first century, ichnology underwent rapid growth, showing the potential of trace fossils analysis in a wide range of fields (i.e., palaeobiology, palaeoecology, and sequence stratigraphy, among others). This important expansion is reflected in several symposium volumes, books, and monographs published recently (i.e., Pemberton et al. 2001; Buatois et al. 2002; Hasiotis, 2002; McIlroy, 2004; Bromley et al. 2007; Miller, 2007; Seilacher, 2007; MacEachern et al. 2008). In the last years ichnological analysis has been revealed as a very valuable tool in the interpretation of palaeoceanographic changes affecting benthic biota, during different range extinctions events. On this basis, part of the presented research (Rodríguez-Tovar and Uchman) has been focused on the recognition, characterization and interpretation of stratigraphic intervals of special incidence in the macrobenthic biota, determining relevant changes and even extinctions in the community. Trace fossil composition and distribution, including cross-cutting relationship and tiering, together with the ichnofabric approach, have been used to determine how severe the macroinfaunal crisis was during the impact event at the Cretaceous-Palaeogene boundary interval (Rodríguez-Tovar et al., 2002, 2004, 2006; Rodríguez-Tovar and Uchman, 2004a, b, 2006, 2008; Rodríguez-Tovar, 2005), the importance of oxygenation changes and nutrients availability during the Oceanic Anoxic Event at the Cenomanian-Turonian boundary interval (Rodríguez-Tovar et al., 2009a, b), or the incidence of variations in palaeobathymetry, sedimentation changes and organic matter flux on benthic assemblages during the Ypresian/Lutetian transition (Ortiz et al., 2008). All of this allows us to corroborate the potential of the ichnological analysis in basin research, including its integration to define stratigraphic boundaries related to macrobenthic changes. In this context, integration of trace fossil data to precisely define the Ypresian/Lutetian boundary at the Gorrondatxe section will be of especial interest.

^{*} Expanded abstract of: Rodríguez-Tovar J.F. et al. (2009). See-level and palaeoecological factors affecting trace fossil distribution in Eocene turbiditic deposits (Gorrondatxe section, N Spain). Palaeogrography, Palaeoclimatology, Palaeoecology (under review).

Trace fossil assemblage at the Gorrondatxe section

Recent ichnological analysis of the Gorrondatxe section revealed a moderate diversity in the trace-fossil assemblage, which contains 41 ichnospecies belonging to 28 ichnogenera, arranged in morphological groups according to Książkiewicz (1977) with further modifications by Uchman (1995) (Table I). This trace-fossil assemblage is typical of the deep-sea *Nereites* ichnofacies, with a significant contribution of shallow-tier, pre-depositional structures, mainly graphoglyptids (winding and meandering *Helminthorhaphe* and *Cosmorhaphe*, branched winding and meandering *Desmograpton*, *Urohelminthoida*, *Acanthorhaphe*, *Paleomeandron* and *Protopaleodictyon incompositum*, and networks *Paleodictyon* and *Megagrapton*), and shallow to deep-tier post-depositional forms (*Planolites*, *Nereites*, *Multina*, *Thalassinoides*, *Ophiomorpha*, *Chondrites*, *Zoophycos*, *Scolicia*, *Trichichnus*). The generalized presence of graphoglyptids through the section is typical of the *Paleodictyon* ichnosubfacies, which is common in distal flysch deposits (Seilacher, 1974; Uchman, 1999, 2001, 2004). The general ichnofacies characterization corroborated previous interpretations for the sedimentary environment, of a submarine fan fringe or basin plain, with occasional lateral sediment supply (Payros et al., 2006).

Some ichnotaxa are continuously recorded through the section, with Chondrites intricatus, Ch. targionii, Ophiomorpha annulata and Scolicia strozzii being the most common and relatively abundant, and considered as the background components of the trace-fossil assemblage. Planolites, Thalassinoides, and Zoophycos also occur throughout the section, but less frequently and less continuously. Spirophycus also shows punctual record in practically the entire section, except for the lowermost part, and the same is true for Ophiomorpha rudis but it is absent in the lowermost and uppermost parts of the section. Trace fossils composition, diversity and abundance of the remaining ichnotaxa (graphoglyptids, and other post-depositional ichnotaxa) fluctuate significantly throughout the section, irrespective at least in part to frequency of turbidites, allowing distinction of five intervals. The fluctuations are related foremost to changes of trophic level, and additionally to temperature, quality of substrate and ecological disturbances, which in turn are partly controlled by the sea-level dynamics according to the sequence-stratigraphy proposal. Increased diversity of trace fossils and particularly of graphoglyptids is interpreted as an occurrence of moderate oligotrophy and stabilization of ecological conditions. The change of substrate from siliciclastic to marly or limy mud during stillstand, eutrophisation, lowered oxygenation and drop of temperature, typical of low sea level, can limit diversity of graphoglyptids and trace fossils in general.

Trace fossil assemblage through the Ypresian/Lutetian boundary interval

From the five intervals differentiated, especially significant are the changes occurred in the trace-fossil assemblage at the upper part of the interval A and the base of the interval B, around the Ypresian/Lutetian boundary interval (Fig. 1):

Interval A, distinguished in the lower part of the section, corresponds to the second turbiditic-poor interval, and is dominated by hemipelagic marlstones. This interval shows a moderate diversity and abundance of pre- and post-depositional trace fossils; apart from the 9 ichnospecies continuously recorded through the section, another 13 are also recognized (Table I, Fig. 1). Some of them are exclusive of this interval, including *Alcyonidiopsis* isp. A, *?Urohelminthoida, Helminthorhaphe japonica, Multina, Protopaleodictyon,* and *Paleodictyon miocenicum*. Others like *Helminthopsis, Helicodromites* and *Trichichnus* also occur in the middle part of the section, while *Desmograpton* and *Phycosiphon,* only with punctual record in the interval A, also appear in the

Table I.Ichnotaxa of the Gorrondatxe section (in black those from intervals A or B), their ethology, relation to
turbiditic beds, morphological affiliation with indication of graphoglyptids, and location in intervals A
or B. BWM - branched winding and meandering; WM - winding and meandering; N - Network; SpH -
spiral and helical.

Ichnotaxa	Ethological category	Pre-, Post- depositional origin	Morphological group	Graph	Interval A - B
?Acanthorhaphe isp.	agrichnia	pre	BWM	x	
Alcyonidiopsis isp. A	pascichnia	post	simple		А
Alcyonidiopsis isp. B	pascichnia	post	simple		
Chondrites intricatus	chemichnia	post	branched		A-B
Chondrites targionii	chemichnia	post	branched		A-B
Cosmorhaphe sinuosa	agrichnia	pre	WM	х	
?Cosmorhaphe isp.	agrichnia	pre	WM	x	A-B
Desmograpton dertonensis	agrichnia	pre	BWM	x	А
Glockerichnus alata	agrichnia?	pre	radial	x	
Helicodromites isp.	?chemichnia.	post	SpH		А
K.	?fodinichnia	1	1		
Helminthopsis abeli	pascichnia	Dre	WM		A-B
Helminthorhaphe japonica	agrichnia	DLE	WM	x	Α
Megagrapton submontanum	agrichnia	1) TP	network	x	
Multina minima	pascichnia	post	N-BWM	~	А
Naniculichnium maroinatum	?nascichnia	post	WM		
Nereites irregularis	nascichnia	post	WM		
Nervites isp	pascichnia	post	WM		в
Onhiomornha annulata	domichnia	post	branched		A-R
Onkiomorpha nudis	domichnia	post	branched		A-B
Dalaganhucus tuhularis	fodinichnia/	post	simple		Δ
r utueophycus tuouturis	domichnia	post	simple		А
Paleodictyon minimum	agrichnia	pre	network	x	
Paleodictyon strozzii	agrichnia	pre	network	x	
Paleodictuon miocenicum	agrichnia	Dre	network	x	А
Paleodictvon maius	agrichnia	pre	network	x	В
Paleodictyon arvense	agrichnia	pre	network	x	_
Paleomeandron cf. robustum	agrichnia	pre	BWM		
Phycosiphon incertum	fodinichnia	post	spreiten		А
Planolites isp.	pascichnia	post	simple		A-B
Protovaleodictyon incompositum	agrichnia	pre	BWM	x	A-B
Scolicia prisca	pascichnia	post	WM		
Scolicia strozzii	pascichnia	pre	WM		A-B
Scolicia vertebralis	pascichnia	post	WM		
Scolicia isp.	pascichnia	post	WM		
2Spirocosmorhanhe laburinthica	agrichnia	prest	WM	x	
Spirophycus bicornis	nascichnia?	pre	SnH	<u>^</u>	A-B
Strohilorhanke nusille	fodinichnia?	pre	branched		A
Thalassinoides inn	fodinichnia/	post	branched		A-B
TIMMODUIDINCO TON	domichnia	post	Francied		
Trichichnus linearis	chemichnia	post	branched		A-B
?Urohelminthoida annendiculata	agrichnia	DTP	BWM	¥	A
Zoophucos isp.	fodinichnia	nost	spreiten	~	A-B
meandering cylinder	?pascichnia	nost	WM		
	- F and a state of the	P			

upper part of the section. Trace fossil morphologies are variable, including simple (*Alcyonidiopsis* isp. A), spreite (*Phycosiphon*), and helical (*Helicodromites*) forms, together with branched, winding and meandering forms, and occasional networks (*Multina, Paleodictyon*). Agrichnial behaviour dominates, and others like pascichnia, fodinichnia and chemichnia are rare.

Interval B, differentiated in the lower-middle part of the section, corresponds to the uppermost part of the second turbidite-poor interval, with the increase of hemipelagic limestones upwards, and the beginning of the second turbidite-rich-interval. Interval B is characterized by a highly significant decrease in trace fossil diversity and abundance (Table I, Fig. 1). Apart from the background ichnotaxa, only punctual records of *?Helminthopsis, Trichichnus, Nereites irregularis, Protopaleodictyon* are noted, being, moreover, mainly registered in the upper part of the interval. In the base of the interval B, close to the interval A-B transition, only *Nereites* isp. is recognized. Most of the interval B ichnotaxa are post-depositional, winding and meandering structures, showing a dominant pascichnial behaviour.

The significant changes registered in the trace-fossil assemblage in the intervals A-B transition were interpreted as caused by variations in palaeoecological features (e.g., oxygenation, nutrients), probably conditioned by the sea-level dynamics. Interval A is characterized by a high diversity and abundance of pre-depositional trace fossils, which show a high morphological variability, with punctual record of networks. The abundance of agrichnia (all graphoglyptids) is significant. Relatively frequent pre-depositional trace fossils at the interval A, including several types of graphoglyptids, could be related to the generally interpreted well oxygenated, moderately oligotrophic environment, in which the feeding strategy (microbe gardening or trapping) is a successful adaptation to nutrient-poor, stable environments (Seilacher, 1977; Miller, 1991; Uchman, 1999, 2003). Interval A corresponds to a general sea-level rise during a TST and the lower-middle part of the subsequent HST, including the maximum flooding surface between both systems tracts. Limited lateral flux of nutrients due to the scarcity of turbidites and limited flux of nutrients from the water column enhanced the general Eocene oligotrophy, and promoted variable trace maker behaviours in competition for food, resulting in variable morphologies of trace fossils. Interval B shows a significant change in the trace-fossil assemblage. The diversity and abundance decreased, with the lowest values in the section. The sharp near-disappearance of trace fossils, including some graphoglyptids, indicates a worsening of ecological conditions, which can be caused by several factors. The beginning of the interval is correlated with the progressive increase in hemipelagic limestones deposited during the high sea-level stillstand corresponding to the late sea-level highstand. The substrate of the background sediments was changed from siliciclastic mud to marly or limy mud. This change can influence graphoglyptids, which generally are rare in marly flysch deposits (Uchman, 1999, 2007). The stillstand at the beginning of this interval could increase the oligotrophy and lower the oxygenation in sediment. Strong oligotrophy negatively influences trace fossil diversity (Leszczyński and Uchman, 1993). Higher organic matter content can shift up the redox boundary. Thinner oxygenated layer of sediment is also a limiting factor. Burrows produced in shallower tiers have less chance to be preserved as trace fossils (e.g., Bromley, 1996). It is probable that this possible set of changes disturbed the ecological stability and caused a general worsening of deep-sea floor life conditions. As a result trace fossil diversity dropped. The changes of trace fossils correlate partly with planktic foraminifera fluctuations and both groups are related to trophic level changes. However, the crisis of ichnofauna (intervals A-B transition) precedes incursion of cold-water groups. It is not excluded that incursion of cold water was earlier in the deep-sea than in shallow zones.



Figure 1. Synthetic log of the Gorrondatxe section with the vertical distribution of trace fossils in ichnological intervals A and B. Continuous lines and rectangles for more or less continuous record, and filled points for punctual one. Dashed lines for discontinuous record. White rectangles and points for uncertain record (?) of a particular ichnotaxa.

Thus, according to trace fossil analysis, a significant change in the eco-sedimentary environment for macrobenthic tracemakers can be envisaged around the Ypresian/Lutetian boundary interval at the Gorrondatxe section. Trace fossil data support the relevance of this boundary, as well as its location in this part of the section.

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BENTHIC FORAMINIFERAL TURNOVER ACROSS THE YPRESIAN-LUTETIAN TRANSITION AT THE GORRONDATXE SECTION (N SPAIN): RESPONSE TO SEDIMENTARY DISTURBANCE*

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Benthic foraminiferal assemblages across the Ypresian-Lutetian transition from the Gorrondatxe section have been analyzed quantitatively. Benthic foraminifera have been picked from the 100-630 mm fraction from samples distributed unevenly, more closely-spaced near the main biostratigraphic events (Fig. 1).

At the lowermost part of the succession, mostly composed of marls, hemipelagic limestones and very thin-bedded turbidites, benthic foraminifera are fairly well preserved. A subsequent increase in turbidite accumulation occurs from metre 300 upwards (upper part of calcareous nannofossil Subzone CP12b), where benthic foraminifera are less well preserved. However, the high number of samples available from the marly levels (same samples used for the planktic foraminiferal analyses) allowed us to select the best preserved ones for the benthic foraminiferal studies, and to obtain representative assemblages from this part of the succession. From hereafter, we will refer to the lowermost part of the succession (0-300 m) as the turbidite-poor interval, and from metre 300 upwards as the 2nd turbidite-rich interval (see Payros et al., 2006).

Benthic foraminiferal assemblages contain representatives of the Midway-type fauna described from the sublittoral Midway formation in Texas (Berggren and Aubert, 1975). These fauna include such taxa as *Anomalinoides acutus*, *Lenticulina* species and several lagenids and polymorphinids. Other taxa common at sublittoral depths (e.g., asterigerinids) are also common but they are probably related to transport by turbidity currents. Species described from the cosmopolitan deep bathyal Velasco Formation in Mexico (Berggren and Aubert, 1975), such as *Nuttallides truempyi* are also recorded at Gorrondatxe. Other typical bathyal taxa such as *Cibicidoides eocaenus*, *C. subspiratus*, and buliminids species (e.g., *B. jarvisi/semicostata*) are common. These data match with the estimated palaeodepth for this area of about 1500 m (Payros et al., 2006).

The number of benthic foraminiferal species is high at the Gorrondatxe section. However, assemblages are usually dominated by a few taxa that make about half of them (Fig. 1). Agglutinated and calcareous taxa are both abundant, with the latter dominating the assemblages in the 2nd turbidite-rich interval. Trochamminids are the most abundant agglutinated taxa.

^{*} Expanded abstract of an article in preparation for Journal of Foraminiferal Research.

Astrorhizids (e.g., *Bathysiphon, Nothia, Rhabdammina*), *Karrerulina* species and *Spiroplectammina navarroana* are also abundant, and *Ammodiscus, Glomospira* species (including *G. charoides*), *Ammosphaeroidina pseudopauciloculata* and *Spiroplectammina spectabilis* are common. Most of these taxa are more abundant in the turbidite-poor interval, particularly the trochamminids (up to 23%). Calcareous taxa are strongly dominated by bolivinids (mainly *Bolivinoides crenulata*), asterigerinids and *Cibicides* species. Buliminids, calcareous uniserial (e.g., laevidental-inids) and unilocular taxa (e.g., *Fissurina, Palliolatella*), *Nuttallides truempyi*, and *Cibicidoides*, *Osangularia, Anomalinoides* and *Gyroidinoides* species are also common. *Globobulimina* species (mainly *G. ovata*) show a very uneven distribution, making up 12% and 24% of the assemblages in two samples in the 2nd turbidite-rich interval. Calcareous taxa distribution is also related to the lithological intervals. Bolivinids, asterigerinids, *Cibicides* and *Globobulimina* species are noticeably more abundant in the 2nd turbidite-rich interval, while the other calcareous taxa mentioned above, are more abundant in the turbidite-poor interval.

Infaunal and epifaunal morphogroups are abundant in the turbidite-poor interval, while infaunal morphogroups are dominant through most of the 2nd tubidite-rich interval. Bolivinids and Globobulimina species are infaunal taxa that are abundant under high organic carbon flux rates at the seafloor. The strong dominance of this group has been generally correlated with low-oxygen conditions (e.g., Murray, 2006). However, bolivinids and other deep infaunal taxa have also been recorded in environments with well-oxygenated bottom waters (e.g., Fontanier et al., 2005). Asterigerinids are another dominant group in the 2nd turbidite-rich interval that mainly occurs epiphytically in shallow-water environments (e.g., Murray 2006). We consider asterigerinids to be allochthonous taxa at Gorrondatxe, having been transported downslope due to the turbidity currents or by floating plant material. The high abundance of *Cibicides* spp. in our samples could also be a consequence of the turbidity currents and therefore, allochthonous taxa, but they are usually found attached to hard substrates in high-energy settings (e.g., Murray, 2006). We consider that turbidity currents may have played a major role in the composition of the benthic foraminiferal assemblages in Gorrondatxe. Therefore, we suggest that turbidity currents were responsible for the high abundance of allochtonous groups and probably for the transport of refractory organic matter, which could explain the high abundance of bolivinids and Globobulimina species (e.g., Jorissen et al., 2007).

A peak of *Aragonia aragonensis* is recorded in the upper part of the turbidite-poor interval (CP12b biozone). *Aragonia aragonensis*, which has been suggested to be an opportunistic species (Steineck and Thomas, 1996), shows peaks in abundance just after the PETM (e.g., Alegret et al., 2009) and the Y/L boundary (e.g., Ortiz and Thomas, 2006). However, the peak of *A. aragonensis* is not as distinct as in other sections and it is recorded in an older stratigraphic position than in other Y/L sections. These data suggest that the peak in *A. aragonensis* may not be a valid marker for global correlation of the Y/L boundary.

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THE YPRESIAN/LUTETIAN TRANSITION IN THE GORRONDATXE BEACH (GETXO, WESTERN PYRENEES)



Figure 1. Occurrence and relative abundances of the benthic foraminiferal taxa across the Ypresian-Lutetian transition at Gorrondatxe.

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GORRONDATXE SECTION

25-27 September

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YPRESIAN/LUTETIAN

BENTHIC FORAMINIFERAL TURNOVER ACROSS THE YPRESIAN-LUTETIAN TRANSITION IN NORTHERN AND SOUTHEASTERN SPAIN: RESPONSE TO SEDIMENTARY DISTURBANCE

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The study of the Ypresian–Lutetian (Y–L) or early-middle Eocene transition has traditionally been overshadowed by detailed studies on different events related to the Paleogene Epoch boundaries. The occurrence of a hiatus across the Y-L transition in many northern European sections, including those in which the classic Ypresian and Lutetian stratotypes were originally defined, has also hindered the development of a precise chronostratigraphic framework. Not surprisingly, the stratotype for the base of the Lutetian Stage is one of the few Paleogene Stages whose Global Stratotype Section and Point (GSSP) is still pending definition.

An International Working Group set to select the GSSP for the base of the Lutetian Stage has recently amended the Standard chronostratigraphic scheme of Gradstein et al. (2004) for the Y-L transition (Payros et al., 2007; 2009a; Larrasoaña et al., 2008). The sections used for this purpose are the Gorrondatxe (Basque-Cantabrian Basin, northern Spain) and Agost (Betic Cordillera, southeastern Spain) sections. In order to infer paleoenvironmental and paleobathymetric turnovers across the Y-L transition, we analysed and compared benthic foraminiferal assemblages at these two sections as well as at the Fortuna section (Betic Cordillera, southeastern Spain) (Fig. 1).

Benthic foraminiferal assemblages are largely dominated by calcareous taxa at the Agost and Fortuna sections. In contrast, flysch-type agglutinated taxa are abundant at the Gorrondatxe section, as in the nearby Zumaia section (GSSP for the Selandian and Thanetian Stages); the flysch-type fauna is typical of the deep-water and low-middle latitude Slope-type biofacies of Kuhnt et al. (1989).

Bathyal species such as *Nuttallides truempyi*, *Bulimina trinitatensis* and *Cibicidoides eocaenus* are common at Gorrondatxe, Agost and Fortuna. Benthic foraminiferal assemblages representative of the Midway-type fauna (described from the sublittoral Midway Formation in Texas by Berggren and Aubert, 1975) are more abundant at the Agost and Fortuna sections than in the Gorrondatxe section. Therefore, upper-middle bathyal depths were inferred for the former, while a lower bathyal depth of deposition has been inferred for the Gorrondatxe section.



Figure 1. Paleogeographic location of the Gorrondatxe, Agost and Fortuna sections (modified from Martín-Algarra and Vera, 2004).

The Y/L boundary interval corresponds to a period of low sea-level in the classic areas (Belgian, Hampshire and Paris basins) (for a review, see Payros et al., 2009b). Benthic foraminiferal assemblages indicate a relative sea-level fall, probably of regional scale, in the Agost (supported by trace fossils evidence) and Fortuna sections, which has been related to the P9/P10 transition (Ortiz and Thomas, 2006; Ortiz et al., 2008). There is no evidence for sea-level changes at the Gorrondatxe section based on benthic foraminifera. This is probably due to the paleobathymetry of the Gorrondatxe section. Sea-level shifts during the Eocene were of a magnitude of around 20-30 m (Pekar et al., 2005) so it is unlikely that benthic foraminiferal assemblages underwent any significant change.

Benthic foraminiferal assemblages from the Gorrondatxe and Agost sections are characterized by the high dominance of reworked and epiphytic benthic foraminifera. This is consistent with the abundant intercalated turbidites and the paleogeographical location of both sections along a continental slope, with deep-water settings very close to the coastal photic zones (Fig. 1). We suggest that the abundant epiphytic taxa might also have been brought in floating plant material, reaching the seafloor when the floating algal matter decayed. Bolivinids are very abundant at the Gorrondatxe and Agost sections; these taxa have an infaunal mode of life, and their high abundance may be related to increased organic carbon flux rates to the seafloor. Turbidity currents are responsible for the transport of particulate organic carbon (often aged, i.e., refractory organic matter) to the seafloor. We suggest that this type of organic matter, and not its quantity, could account for the high abundance of bolivinids and other groups at the Gorrondatxe and Agost sections.

Agost section

Standard calibration

Larrasoaa et al. Gradstein et al. (2008)(2004)41 41 C19r C19r P12 E10 CP CP 1P1 SBZ1 14a 14a NP16 S E10 SBZ1 130 P12 P11 6 C19n C19n 42 42 Gorrondatxe section 30 P10 CP1 Payros et al. SBZ1 **CP13b** NP15 (2007) 43 43 Ać **B** SBZ14 6 P11 SBZ14 **CP13b** C20r **CP13b** 220r 320r 44 44 44 NP15 NP15 8 13a 3 SBZ1 45 45 45 3a CP1 3a CP1 46 46 46 C21n C21n C21n 2 SBZ1 SBZ13 6 SBZ13 6 P10 CP12b CP12b 8 47 CP12b 47 47 Ać NP14 NP14 NP14 L C21 55 021 48 48 48 SBZ11 CP12a 2a 2a CP1 SB2 SB7 C22r 5 12 12 NP 13 49 49 49 CP 64 13 11 A a= Aragonia aragonensis peak

Figure 2. Comparison between the standard biomagnetochronological time scale and the amended correlation scheme proposed by Payros et al. (2007) and Larrasoaña et al. (2008) on the basis of the Gorrondatxe and Agost sections data, respectively. Note the anachronic position of the *A. aragonensis* peaks.

We identified peaks in relative abundance of *Aragonia aragonensis* at the Gorrondatxe, Agost and Fortuna sections. *Aragonia aragonensis* has been suggested to be an opportunistic species (Steineck and Thomas, 1996) and it shows peaks in abundance at several deep oceans just after the PETM (e.g., Thomas, 2003). The peak recorded in Gorrondatxe is, interestingly, placed within highstand deposits which are typified by warm-water planktic foraminiferal assemblages (Payros et al., 2006; 2009b). However, these quantitative peaks at Gorrondatxe, Agost and Fortuna occur at different stratigraphic intervals, close to the P9/P10 boundary at the Agost and Fortuna sections, but at an older stratigraphical interval at the Gorrondatxe section (Fig. 2). This mismatch suggests that the peak in *A. aragonensis* may not be useful to locate the P9/P10 boundary.

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GORRONDATXE SECTION

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WORKSHOP ON THE YPRESIAN/LUTETIAN BOUNDARY STRATOTYPE

THE AGOST SECTION (SE SPAIN): A CANDIDATE SECTION TO DEFINE THE STRATOTYPE FOR THE BASE OF THE LUTETIAN STAGE

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The Agost section is located in the Betic Cordillera of southeastern Spain, ca. 1 km to the north of the village of Agost (Alicante), in the so-called Lomas de la Beata area (Fig. 1). This section is located in the vicinity of the section studied previously by Molina et al. (2000), but offers better outcrop and fossil preservation conditions (Fig. 1). The 115-m-thick section has been the subject of an integrated study including magnetostratigraphic and mineralogical analyses, and biostratigraphic and paleoenvironmental data derived from planktic foraminifera, calcareous nannofossils, small and larger benthic foraminifera and trace fossils (Larrasoaña et al., 2008; Ortiz et al., 2008).

During the Eocene, the study area belonged to the passive margin of Iberia. Carbonate sedimentation in the platform with abundant macroforaminifera gave way to pelagic sediments, turbidites and mass flow deposits in the continental slope located southwards. These sediments were folded and uplifted during the Miocene collision that led to formation of the Betic Cordillera in southern Spain. Nowadays, these sediments are exposed at the Agost section striking broadly north to south and displaying a gentle westward dipping of about 15-20°. The Agost section is composed of marls with intercalated limestone and sandstone beds. The marls and limestones correspond to hemipelagic sediments and predominate in the lower and upper parts of the section. The middle upper part of the section is mainly composed of sandstones that correspond to slope deposits such as turbidites and mass flows (Fig. 2). These processes are responsible for reworked material but they did not impede an accurate biostratigraphic analysis.

The integrated magnetobiostratigraphic studies evidence that the Agost section is continuous and spans from planktic foraminiferal zones P9 to P12 (E7 to E10), calcareous nannofossils zones CP11 to CP14a (NP13 to NP16), larger benthic foraminiferal zones SBZ11 to SBZ15, and Chrons C22n to C19r (Fig. 2; for more details see Larrasoaña et al., 2008). The results obtained in the Agost section indicate that, in agreement with the work of Bernaola et al. (2006) at the Gorrondatxe section, all the events that have traditionally been proposed to mark the Ypresian/Lutetian boundary appear at different stratigraphic levels. Thus, the FO of *H. mexicana*, a



Figure 1. Location of the Agost section. The asterisk indicates the location of the Ypresian/Lutetian section studied previously by Molina et al. (2000).

senior synonym of *H. nuttalli* (Pearson et al., 2006), (base of P10) and the FO of *G. nuttalli* (base of E8) are found within Chron C20r, at a much younger age (3–5 Myr) than previously considered in standard calibration schemes (e.g., Pearson et al., 2006). Similarly, the boundary between SBZ12 and SBZ13 is located within Chron C21n, also at a younger position than previously considered (Luterbacher et al., 2004). On the contrary, the FO of *B. inflatus* (base of CP12b) is found within Chron C21r, which conforms to the magnetostratigraphically calibrated age of ca. 48 Ma (middle part of C21r) considered in standard calibration schemes.

Benthic foraminiferal and trace fossil assemblages are highly influenced by turbidity currents and other gravity currents which probably added refractory organic matter to the sea floor. This pattern underscores the importance of the quality of organic matter as a main factor structuring benthic assemblages in the past. However, integrated study of benthic foraminiferal and trace fossil assemblages, the latter showing the succession *Nereites-Zoophycos-Cruziana* ichnofacies throughout the section, allows inference regarding the upper to middle bathyal palaeodepths for the lower part of the Agost section. A change to

sublittoral to circalittoral palaeodepths related to the P9-P10 transition is also inferred.

Mineralogical changes across the Agost section seem to be related to the lithological variations in the section rather than to climatic changes. However, it should be kept in mind that warmer or drier conditions may be indicated at the topmost part of the section.

Several marker events such as the peak of benthic foraminifera *Aragonia aragonensis* abundance and the co-occurrence across a short-interval of time of planktic foraminifera *Claviger-inella eocaenica* and *Cl. jarvisi* and warm-water calcareous nannofossils, suggest a transient warm event or hyperthermal event related to the FO of hantkeninids, i.e., the P9/P10 boundary (Fig. 2). This event could be a good criterion to enable widespread recognition of the base of the Lutetian Stage in support or in the absence of the primary marker if the FO of hantkeninids were selected as the primary marker. Nevertheless, this event should be further studied in deep marine successions and in other palaeobathymetric settings in order to test whether it represents a global event that could be used for worldwide correlation of the Y/L boundary. Besides, the first occurrence (FO) of the calcareous nannofossil *Blackites inflatus* (base of CP12b) is a synchronous event and well represented in most sections where reliable magnetobiostratigraphic



Figure 2. Integration of the most representative data from the Agost section. The grey bars indicate the position of the Ypresian according to different fossil groups, i.e., the Ypresian/Lutetian boundary. A. Aragonia; B. Blackites; Ch. Chiasmolithus; Cl. Clavigerinella; D. Discoaster; G. Guembelitrioides; H. Hantkenina; M. Morozovella; N. Nannotetrina; R. Reticulofenestra; T. Turborotalia; IS, illite-smectite. * Data by N. Vandenberghe and E. Zeelmaekers in Ortiz et al. (2008).

results have been obtained (e.g., Bernaola et al., 2006). Thus, of all the potential biostratigraphic markers, the choice of the FO of *B. inflatus* as a marker of the boundary might be the most suitable primary marker event to define the GSSP for the base of the Lutetian Stage.

In view of these results, the Agost section can be proposed as a suitable candidate to locate the GSSP for the Ypresian/Lutetian boundary because it fulfils most of the geological, biostratigraphic and accessibility requirements that any prospective GSSP should meet (see Remane et al., 1996): (i) it has a relatively high sedimentation rate, it is demonstrably continuous despite the presence of some turbidite deposits, and it is exposed over an adequate thickness of sediments; (ii) it includes diverse and well-preserved fossil groups, and enables the selection of the primary marker event from a bundle of well dated biostratigraphic events; and (iii) it is easily accessible and offers the possibility for protection of a permanent marker.

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