

by Eustoquio Molina¹, Laia Alegret¹, Estibaliz Apellaniz², Gilen Bernaola², Fernando Caballero², Jaume Dinarès-Turell³, Jan Hardenbol⁴, Claus Heilmann-Clausen⁵, Juan C. Larrasoana⁶, Hanspeter Luterbacher⁷, Simonetta Monechi⁸, Silvia Ortiz^{1,9}, Xabier Orue-Etxebarria², Aitor Payros², Victoriano Pujalte², Francisco J. Rodríguez-Tovar¹⁰, Flavia Tori⁸, Josep Tosquella¹¹ and Alfred Uchman¹²

The Global Stratotype Section and Point (GSSP) for the base of the Lutetian Stage at the Gorrondatxe section, Spain

1 Departamento de Ciencias de la Tierra, Universidad de Zaragoza, E-50009 Zaragoza, Spain. E-mail: emolina@unizar.es

2 Departamento de Estratigrafía y Paleontología, Universidad del País Vasco, E-48080 Bilbao, Spain.

3 Laboratorio di Paleomagnetismo, Istituto Nazionale di Geofisica e Vulcanologia, Roma, I-00143, Italy.

4 Global Sequence, Chronostratigraphy Inc., 826, Plainwood Drive, Houston, Texas 77079-4227, USA.

5 Department of Earth Sciences, Aarhus University, Dk-8000, Aarhus C, Denmark.

6 Instituto Geológico y Minero de España, Unidad de Zaragoza, E-50006, Zaragoza, Spain.

7 Museo Geológico, Seminario Conciliar, E-08007, Barcelona, Spain.

8 Dipartimento di Scienze della Terra, Università di Firenze, I-50121 Firenze, Italy.

9 Department of Earth Sciences, University College London, WC1E 6BT, London, UK.

10 Departamento de Estratigrafía y Paleontología, Universidad de Granada, E-18002 Granada, Spain.

11 Departamento de Geodinámica y Paleontología, Universidad de Huelva, E-21071 Huelva, Spain.

12 Institute of Geological Sciences, Jagiellonian University, Kraków, PL-30063, Poland.

The GSSP for the base of the Lutetian Stage (early/middle Eocene boundary) is defined at 167.85 metres in the Gorrondatxe sea-cliff section (NW of Bilbao city, Basque Country, northern Spain; 43°22'46.47" N, 3° 00' 51.61" W). This dark marly level coincides with the lowest occurrence of the calcareous nannofossil Blackites inflatus (CP12a/b boundary), is in the middle of polarity Chron C21r, and has been interpreted as the maximum-flooding surface of a depositional sequence that may be global in extent. The GSSP age is approximately 800 kyr (39 precession cycles) younger than the beginning of polarity Chron C21r, or ~47.8 Ma in the GTS04 time scale. The proposal was approved by the International Subcommission on Paleogene Stratigraphy in February 2010, approved by the International Commission of Stratigraphy in January 2011, and ratified by the International Union of Geological Sciences in April 2011.

Introduction: The Ypresian and Lutetian Standard Stage Stratotypes

The Ypresian and Lutetian are the global standard stages of the lower and middle Eocene (Jenkins and Luterbacher, 1992). Other

European regional stages, such as the Cuisian, Paniselian, Bruxellian and Biarritzian, were defined at, or close to, the lower–middle Eocene transition, but are now disused (De Geyter et al., 2006).

According to Luterbacher et al. (2004) and Steurbaut (2006), the Ypresian Stage was introduced by Dumont in 1849 to include the clayey and sandy shelf-facies strata lying between the terrestrial to marginally marine Landenian deposits and the marine Brusselian sands in Belgium (Figure 1). Later, in 1851 Dumont attributed the upper sandy part of the historical Ypresian to the Paniselian and restricted the Ypresian *sensu stricto* to the Yper Clay of western Belgium and its equivalents. Consequently, the extent of the Ypresian-Paniselian has been a major point of discussion for over a century. Whether Dumont (1850) included the Aalter Sand Formation in the historical Ypresian cannot be ascertained. However, according to Steurbaut (2006) today the Aalter Formation is included within the Paniselian and thus in the standard Ypresian Stage. Biostratigraphically, the Ypresian is well constrained by its dinoflagellate cyst and calcareous nannoplankton associations (e.g. Vandenberghe et al., 1998). It is characterized by the Martini (1971) nannoplankton zones NP11, NP12, NP13 and the base of NP14, including an acme of *Discoaster sublodoensis* in the Aalter Sands (Steurbaud, 1988, 2006). Steurbaut (1988) also found the acme of *D. sublodoensis* in the basal deposits of the Brussels Sand Formation, showing that the lower part of this unit is also included within the Ypresian. Hooyberghs (1992) studied two sections of the basal Brussels Formation in the Brussels-Leuven area, which yielded planktic foraminifera attributable to P9 (= *Acarinina aspensis*) of Blow (1979) in one of the sections and to P10 (= *Turborotalia frontosa*) in the other. Magnetostratigraphic

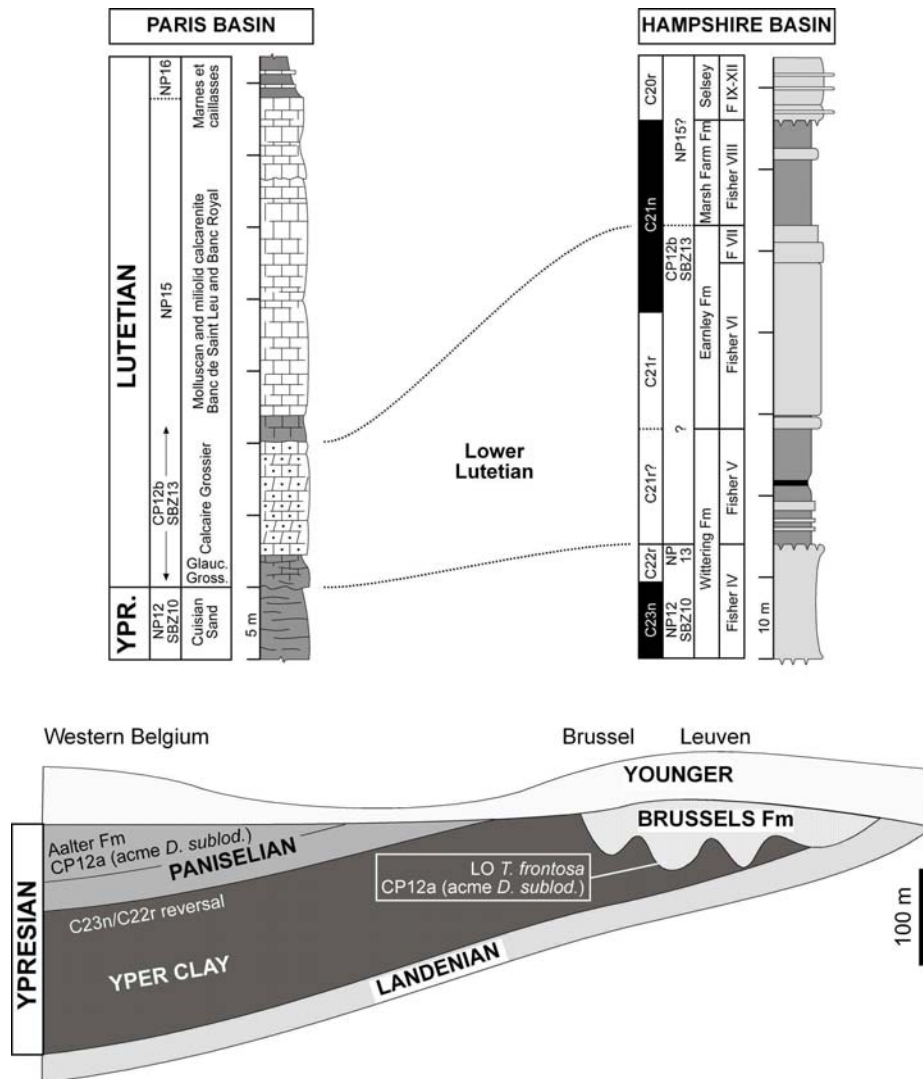


Figure 1. Chronostratigraphic framework of historical, stratotypic Ypresian/Lutetian areas in Northern Europe.

studies (Ali and Hailwood, 1995) correlate the lower and middle Ypresian interval with polarity Chrons C24r-C22r; unfortunately, the uppermost deposits of the Ypresian interval did not yield reliable magneto-stratigraphic results. According to Cavelier and Pomerol (1986) the lower part of the Ypresian correlates with the middle and late Ilerdian, whereas its upper part includes the entire Cuisian and extends beyond it.

The Lutetian was defined by De Lapparent in 1883 and is typified by the “Calcaire grossier” of the Paris Basin (Fig. 1). The stratotype was selected by Blondeau (1981) approximately 50 km north of Paris at St. Leu d’Esserent and St. Vaast-les-Mello. The Lutetian stratotype contains larger foraminifera, palynomorphs and calcareous nannoplankton. According to Aubry (1983, 1995) the base of the Lutetian is within the nannoplankton NP14 Zone of Martini (1971) and near the boundary between CP12a/CP12b Zones of Okada and Bukry (1980), extending to zones NP15 and the lower part of NP16. According to Aubry (1986), only very poorly preserved calcareous nannofossil assemblages were recovered from the beds that represent the Lutetian neostatotype. Better-preserved and richer assemblages were recovered from correlative sections (Blondeau et al., 1965). The Lutetian is well exposed in the inactive quarry of Chaumont-en-Vexin

(Oise, Paris Basin), where common and well-preserved calcareous nannoflora were recovered except from the upper levels. In this section *Discoaster subloboensis* occurs with *Rhabdosphaera inflata* (= *Blackites inflatus*) in the lowermost sample, thus defining Subzone CP12b. Nevertheless, according to Steurbaut (1988) the basal Lutetian “Glaucanie Grossière” is part of nannofossil Subzone CP12a, as defined in Berggren et al. (1995), because it contains *D. subloboensis*, but no *B. inflatus*. The same is true for the so-called “Brusselian” deposits of Belgium, which have been equated with the “Glaucanie Grossière”. In the Shallow Benthic foraminifera Zonation (Serra-Kiel et al., 1998) the base of the Lutetian is placed at the base of the SBZ13 Zone. According to Cavelier and Pomerol (1986) the lower Lutetian corresponds to the *Nummulites laevigatus* and *Alveolina stipes* zones, and the middle Lutetian is in the *Alveolina munieri* and *Alveolina prorecta* zones. According to the same authors, the *Alveolina elongata* Zone characteristic of the Biarritzian s.s. (Hottinger and Schaub, 1960) is entirely within the upper Lutetian. However, most authors place now the Biarritzian s.s. (i.e. the *Alveolina elongata* Zone, SBZ17) in the basal part of the Bartonian (e.g. Serra-Kiel et al., 1998; Serra-Kiel et al. in Hardenbol et al., 1998; Luterbacher et al., 2004). With regard to magnetostratigraphy, no data are available from the historical Lutetian stratotype area, but its basal deposits were correlated with the Earnley Formation of England (Fig. 1), the base of which corresponds to Chron C21r (Aubry et al., 1986).

The Ypresian/Lutetian Boundary Working Group

The International Commission on Stratigraphy (ICS) requires that its Subcommissions organize working groups to choose a Global Stratotype Section and Point (GSSP) for each international chronostratigraphic boundary. 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. The Ypresian/Lutetian boundary stratotype has to be defined at a level equivalent 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 lithostratigraphic level coinciding with an easily correlatable event that allows correlation, 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. Consequently, the GSSP has to be located in a deep-water section with minimal evidence of disturbance, transport and erosion.

Since 1992 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 Cordillera (Alamedilla, Agost, Fortuna, etc.) and in the Pyrenees (Anotz, Campo, Erro, Gorrondatxe, Getaria, Osinaga, Otsakar, etc.). Most of these Betic and Pyrenean sections are not ideal, as they have hiatuses, restricted facies, tectonic complications and other problems (Gonzalvo et al., 2001; Payros et al., 2006). The Fortuna section was considered a leading candidate for some years, but the boundary interval is very condensed (Molina et al., 2006) and later it was not considered a suitable section to define a GSSP.

Finally, we focused our effort on the study of the two most suitable sections to define the Lutetian GSSP: the Agost and Gorrondatxe sections. In both sections, the different events traditionally used to place the Ypresian/Lutetian boundary, previously thought to be almost simultaneous, occur at very different levels. The lowest occurrence of *Hantkenina nuttalli*, frequently used by planktic foraminiferal specialists to mark this boundary (Berggren et al., 1995), is younger than the base of the Lutetian in the Paris Basin, according to the new data from the Agost section (Molina et al., 2000; Larrasoana et al., 2008; Ortiz et al., 2008) and the Gorrondatxe section (Orue-Etxebarria et al., 2006; Bernaola et al., 2006b; Payros et al., 2006, 2007, 2009a, 2009b). The closest event to the base of the historical Lutetian Stage seemed to be the lowest occurrence (LO) 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 provided conclusive evidence that both sections are almost continuous and contain diverse and well-preserved fossil groups.

The Getxo-2009 Final Workshop

After nearly 20 years of active research on the Ypresian/Lutetian boundary, a Workshop was held in Getxo (Biscay province, Basque Country, northern Spain) in September 2009, which was attended by 17 researchers of the Working Group (Orue-Etxebarria et al., 2009; <http://www.ehu.es/paleogene/getxo2009/Home.html>). Three main topics were presented and discussed in the workshop.

The Ypresian/Lutetian boundary interval

The first objective of the workshop was the delimitation of the time interval in which the GSSP should be defined. It was conceptually agreed that the Lutetian GSSP should be placed somewhere in the interval between the top of the historical Ypresian Stage defined in Belgium and the bottom of the historical Lutetian Stage stratotype defined in Paris. A major problem to this end 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 all of the NP13/14 calcareous nannofossil interval in many sections. Consequently, the Ypresian/Lutetian boundary interval is represented by a hiatus in most sections worldwide. For example, this hiatus is very common in the

Atlantic Ocean and in northern Europe (Aubry, 1995; Payros et al., 2009b).

Using the biomagnetostratigraphic information available from the Ypresian deposits of Belgium (see above), it was concluded that the upper part of the Ypresian corresponds to the calcareous nannofossil Subzone CP12a (including an acme of *Discoaster subloboensis*) and that it is coeval with part of the Brussels Formation, which yielded planktic foraminifera attributable to P9 (= *Acarinina aspensis*) and P10 (= *Turborotalia frontosa*) of Blow (1979). Consequently, the base of the time interval in which the Lutetian GSSP should be defined is delimited by the acme of *D. subloboensis* and by the lowest occurrence of *T. frontosa*.

The upper limit of the boundary interval should be the base of the Lutetian Stage stratotype, which is typified by the SBZ13 (= *Nummulites laevigatus*) Zone of larger foraminifera. Its age on the calcareous nannofossil scale is more ambiguous, as the basal Lutetian deposits from Chaumont-en-Vexin were included in the CP12b (= *Rhabdosphaera inflata* = *Blackites inflatus*) Subzone by Aubry (1986), but those from the "Glauconie Grossière" were included in the CP12a Subzone by Steurbaut (1988). The presence or absence of *B. inflatus* in the basal Lutetian was long discussed during the Getxo Workshop. Due to the methodological principle that an absence is not as certain and rigorous as a presence ("absence of evidence is not evidence of absence"), it was considered that the absence of *B. inflatus* in the "Glauconie Grossière", as reported by Steurbaut (1988), is not as significant as the presence of *B. inflatus* in the lowermost sample of Aubry (1986) in Chaumont-en-Vexin.

Taking everything into account, it was concluded that the Lutetian GSSP should be defined within, or preferable at the top of, the short interval (ca. 550 kyr, according to Payros et al., 2009a and 2011) between the top of the Ypresian (near the LO of *Turborotalia frontosa* and acme of *Discoaster subloboensis*) and the base of the Lutetian (near the LO of *Blackites inflatus*), being therefore fully included within Chron C21r. This implies that some of the criteria traditionally used to approach the Ypresian/Lutetian boundary (e.g. the C22n/C21r Chron boundary and the first occurrences of hantkeninids and *Guembelirioides nuttalli*) have to be definitely abandoned.

Primary and secondary correlation criteria

In order to fulfil the chronostratigraphic principle that the base of the upper stage defines the boundary, it was decided that the Lutetian GSSP should preferably coincide with an event that, being included within the Ypresian/Lutetian boundary interval, is as close as possible to the base of the Lutetian Stage stratotype.

All the events near the base of the Lutetian stratotype were discussed and it was finally concluded that the LO of *Blackites inflatus*, marker of the base of CP12b Subzone, best defines the Ypresian/Lutetian Stage boundary because this event is the closest to the base of the Lutetian historical stratotype of Paris. In support of this conclusion, *Nummulites laevigatus* occurs in the lower Lutetian deposits of Paris and, similarly, in Gorrondatxe the first larger foraminifera sample above the LO of *B. inflatus* also contains the first *N. laevigatus*. Even in the case that it is eventually demonstrated that *B. inflatus* appears above the base of the Lutetian Stage stratotype, using this species as a marker would not be a problem because the GSSP would be defined very close to the base of the Lutetian Stage.

It was also concluded that the LO of *B. inflatus* allows reliable global correlation of the base of the Lutetian, actually being the best

correlation criterion around the Ypresian/Lutetian transition, as *Blackites inflatus* occurs in different paleogeographic areas (Tori and Monechi, submitted) and in numerous sections and deep-sea holes (i.e. Monechi and Thierstein, 1985; Bown, 2005; Larrasoana et al., 2008; Payros et al., 2011; Siesser and Bralower, 1992; McGonigal and Wise, 2001; Mita, 2001; Bralower, 2005). Due to its wide distribution *B. inflatus* seems to be present in near-shore and deep sea sediments. Furthermore, in agreement with Wei and Wise (1990) the *Blackites spinosus* group (including any species of *Blackites* and *Rhabdosphaera*) is not a latitudinally controlled group and may be affected by factors other than temperature. The LO of *B. inflatus* has the additional advantage of coinciding with an interval that corresponds to the maximum flooding of a depositional sequence that may be eustatic in origin and global in extent, allowing thus sequence stratigraphic correlation of the Lutetian GSSP level with shallow-marine, transitional and even terrestrial successions (Payros et al., 2009b).

Alternative correlation events were also considered. The LO of *Discoaster subloadoensis* was considered too low to define the Ypresian/Lutetian boundary because it appears within Chron 22n, which is clearly Ypresian. The C22n/C21r Chron boundary was ruled out on the same basis. The LO of *Turborotalia frontosa*, which is slightly younger (basal C21r), was also demonstrated to be included in the historical Ypresian stratotype (see above) and, therefore, is too low to mark the base of the Lutetian. Planktic foraminifera were not considered decisive because of their scarcity in the Lutetian Stage stratotype in Paris. However, the sequence of planktic foraminiferal events at the Ypresian/Lutetian transition was established. Interestingly, the studies of the Ypresian/Lutetian Boundary Working Group have demonstrated that the lowest occurrence of *Hantkenina*, frequently used by planktic foraminifera specialists to approach the base of the Lutetian, is about 4.5 Myr younger than the LO of *Blackites inflatus* and therefore much younger than the true base of the Lutetian (Bernaola et al., 2006b; Orue-Etxebarria et al., 2006; Payros et al., 2006, 2007, 2009a, 2009b, 2011; Larrasoana et al., 2008; Ortiz et al., 2008; Rögl and Egger, 2010; Jovane et al., 2010; Wade et al., 2011).

Selection of the Lutetian GSSP

The discussion sessions during the Getxo Workshop showed that the series of events across the Ypresian/Lutetian boundary is similar in the two proposed candidate sections: Agost and Gorrondatxe. Few of the other aforementioned sections and deep-sea holes report a good biomagnetostratigraphic correlation, but largely support and confirm the Gorrondatxe results. Furthermore, a new biostratigraphic revision of the Bottaccione reference section in Italy confirms, as observed in the Gorrondatxe section, the position of the LO of *B. inflatus* in the second half of the C21r (Tori and Monechi, pers. comm.). The same sequence was also found in many other sections worldwide (Payros et al., 2007), showing that all the events found at the Agost and Gorrondatxe sections are coeval (there is no interregional diachrony) and that both sections are continuous (no hiatus). Nevertheless, some events that appear as almost coeval at Agost are actually far separated at Gorrondatxe, demonstrating that the Gorrondatxe section is more expanded. In fact, the c. 11 cm/kyr sedimentation rate of the Ypresian/Lutetian boundary interval at Gorrondatxe is the highest ever recorded by the Ypresian/Lutetian Working Group members (Bernaola et al., 2006b). Furthermore, this section allows sequence stratigraphic and cyclostratigraphic calibration of all the events that characterize the

Ypresian/Lutetian boundary interval. The advantages and disadvantages of both sections were discussed, concluding that the Gorrondatxe section is more suitable to define the GSSP. The voting was organized on September 26, 2009 and the result was unanimous in favour of Gorrondatxe. Consequently, the proposal was accepted by the 17 members of the Ypresian/Lutetian Working Group who attended the Workshop, defining the GSSP for the base of the Lutetian at meter 167.85 of the Gorrondatxe section in a dark marly level where the nannofossil *Blackites inflatus* has its lowest occurrence, approximately 47.76 Ma ago according to Payros et al. (2011).

The Gorrondatxe Section

Located just northwest of the city of Bilbao (Biscay Province, Basque Country, Spain), the Gorrondatxe beach section (Lat. 43° 22' 46"N, Long. 3°00'51"W) is part of a 2300-m-thick lower Ypresian to upper Lutetian succession (from 800 m to 1500 m). The 700-m-thick Gorrondatxe section is affected by a fault 100 m above its base, but the Ypresian/Lutetian boundary interval (as defined above) is completely preserved above the fault, as it extends from 109 m to 167.85 m, the latter corresponding to the GSSP level. The whole succession is well exposed in coastal cliffs about 50 m high, where the beds dip approximately 60° SW. Some parts are partly covered by scattered vegetation, but a complete composite section can be easily reconstructed by correlating characteristic key beds that can be traced and/or recognized along the outcrops from both the bottom and the top of the cliffs (Fig. 2).

During Eocene times the area formed part of the bottom of a 1500 m deep marine gulf that opened into the Atlantic Ocean at approximately 35° N latitude. This area received sediments from several sources, notably pelagic carbonates, calciclastic turbidites derived from northern sources, and siliciclastic turbidites coming from northern and eastern sources. Thus, distinctive lithostratigraphic units were formed (Fig. 2A). The 700-m-thick succession exposed at the Gorrondatxe beach is part of the so-called Sandy Flysch and is composed of alternating pelagic limestones and marls, interspersed with thin-bedded (<15 cm) siliciclastic turbidites and thick-bedded mixed calciclastic-siliciclastic turbidites. The stratigraphic interval that contains the GSSP of the base of the Lutetian (from 100 m to 220 m as measured from the base of the succession exposed at the Gorrondatxe beach) is mainly characterized by alternations of pelagic limestones and marls, turbidites commonly being just a few millimetres thick (Payros et al., 2009a). This allowed identification of the sedimentary signal of astronomical eccentricity and precession cycles.

The pelagic deposits are very rich in well-preserved microfossils and yield a primary paleomagnetic signal suitable for magnetostratigraphic interpretation. Therefore, this succession has previously been the subject of several sedimentological, sequence stratigraphic, cyclostratigraphic, magnetostratigraphic and paleontological studies, including calcareous nannofossils, planktic foraminifera, larger foraminifera, smaller benthic foraminifera, ostracods, dinoflagellates and ichnofossils (Orue-Etxebarria et al., 1984, 2006, 2009; Orue-Etxebarria, 1985; Orue-Etxebarria and Apellaniz, 1985; Rodríguez-Lazaro and García-Zarraga, 1996; Bernaola et al., 2006a, 2009b; Payros et al., 2006, 2007, 2009a, 2009b, 2011; Rodríguez-Tovar et al., 2010; Ortiz et al., 2011). Clay mineral and stable isotope analyses are currently in progress.

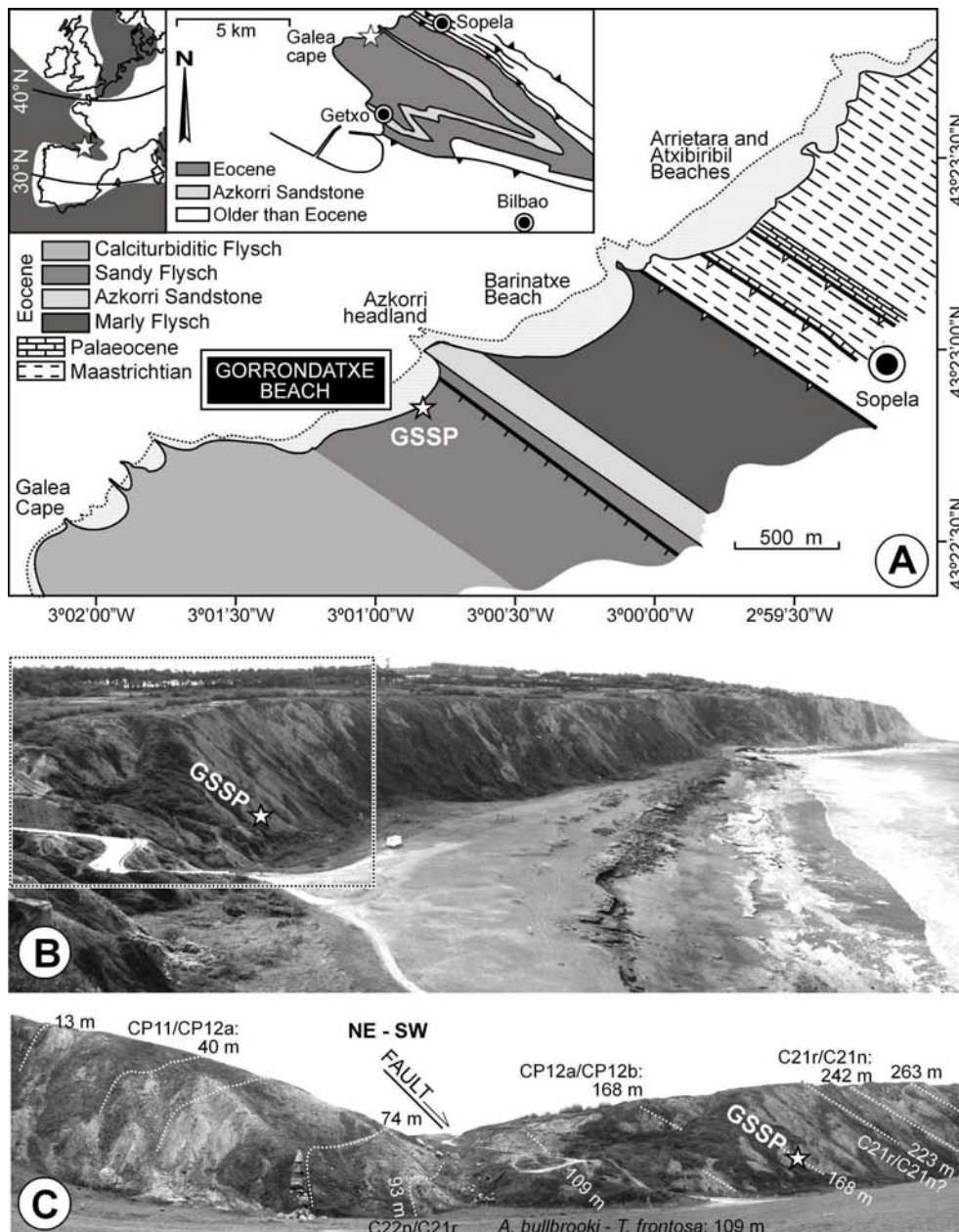


Figure 2. (A) Location of the Gorrondatxe area (B) General view of the Gorrondatxe beach. The framed area shows the lower part of the succession. (C) Lower part of the Gorrondatxe section, showing the main biomagnetostratigraphic events.

Sequence stratigraphy and cyclostratigraphy

Payros et al. (2006) showed that the 2300-m-thick lower Ypresian to upper Lutetian succession consists of six distinct intervals with variable amounts of turbidites (Fig. 3). The turbidite content of three intervals is low and they are called consequently “turbidite-poor”. The other three intervals are named “turbidite-rich”. The Lutetian GSSP is included in the middle part of the 2nd turbidite-poor interval (967.85 m of the complete Eocene succession shown in Fig. 3, which corresponds to 167.85 m of the partial succession exposed at the Gorrondatxe beach). This interval is mainly characterized by alternations of pelagic limestones and marls, the intercalated turbidites commonly being tabular-shaped, flat-based and just a few millimetres thick (Payros et al., 2009a). These turbidites are therefore very distal

and record the effect of turbidity currents with low erosive capacity that did not scour the pelagic deposits.

Payros et al. (2006) observed that the turbidite-poor deposits are typified by warm-water planktic foraminiferal assemblages, whereas the turbidite-rich deposits are characterized by cosmopolitan, cool-water associations. This correlation points towards climatic variations as a plausible driving mechanism for both sedimentary and biotic changes (Payros et al., 2009b), and allows interpretation of the Lutetian GSSP succession in terms of an Ypresian/Lutetian depositional sequence driven by sea-level changes (Fig. 3). Payros et al. (2009b) further showed that the Ypresian/Lutetian depositional sequence can reasonably be correlated throughout marine, coastal and terrestrial deposits of the Pyrenees, and with depositional sequences worldwide (Haq et al., 1988; Plint, 1988; Vandenberghe et al., 1998, 2004; Miller et al., 1998; Pekar et al., 2005), corresponding to sequences 3.1 of Haq et al. (1988) and Yp10 of Hardenbol et al. (1998). Furthermore, these depositional sequences possibly correlate with oceanic temperature variations in several deep-sea sites (oxygen isotope events Ei5 and Ei6). These correlations suggest that the Ypresian/Lutetian depositional sequences might be the result of climatically-driven eustatic sea-level changes, therefore being global. This implies that the position of the GSSP-based Ypresian/Lutetian boundary can now be approached by means of sequence stratigraphy. The Lutetian GSSP coincides with the maximum flooding surface of the Ypresian/Lutetian depositional sequence (Payros et al., 2009b).

High-frequency sedimentary cycles were also identified in the Gorrondatxe section (Payros et al., 2007, 2009a). Recurrent pelagic limestone-marl couplets and bundles were driven by 21 kiloyear (kyr) precession and 100 kyr eccentricity astronomical cycles, respectively (Payros et al., 2009a). This allowed precise age dating of the multiple biomagnetostratigraphic events pinpointed at the Gorrondatxe section (Fig. 4). The lowest occurrence of *Turborotalia frontosa* and the acme of *Discoaster subloboensis*, the two coeval events that mark the top of the historical Ypresian stratotype of Belgium, were found 26 precession couplets and 5.5 eccentricity bundles (546 kyr) below the Lutetian GSSP (LO of *Blackites inflatus*, CP12a/b). The lowest occurrence of *Blackites piriformis* was found to be 105 kyr (5 precession couplets) older than the CP12a/b boundary, and the highest

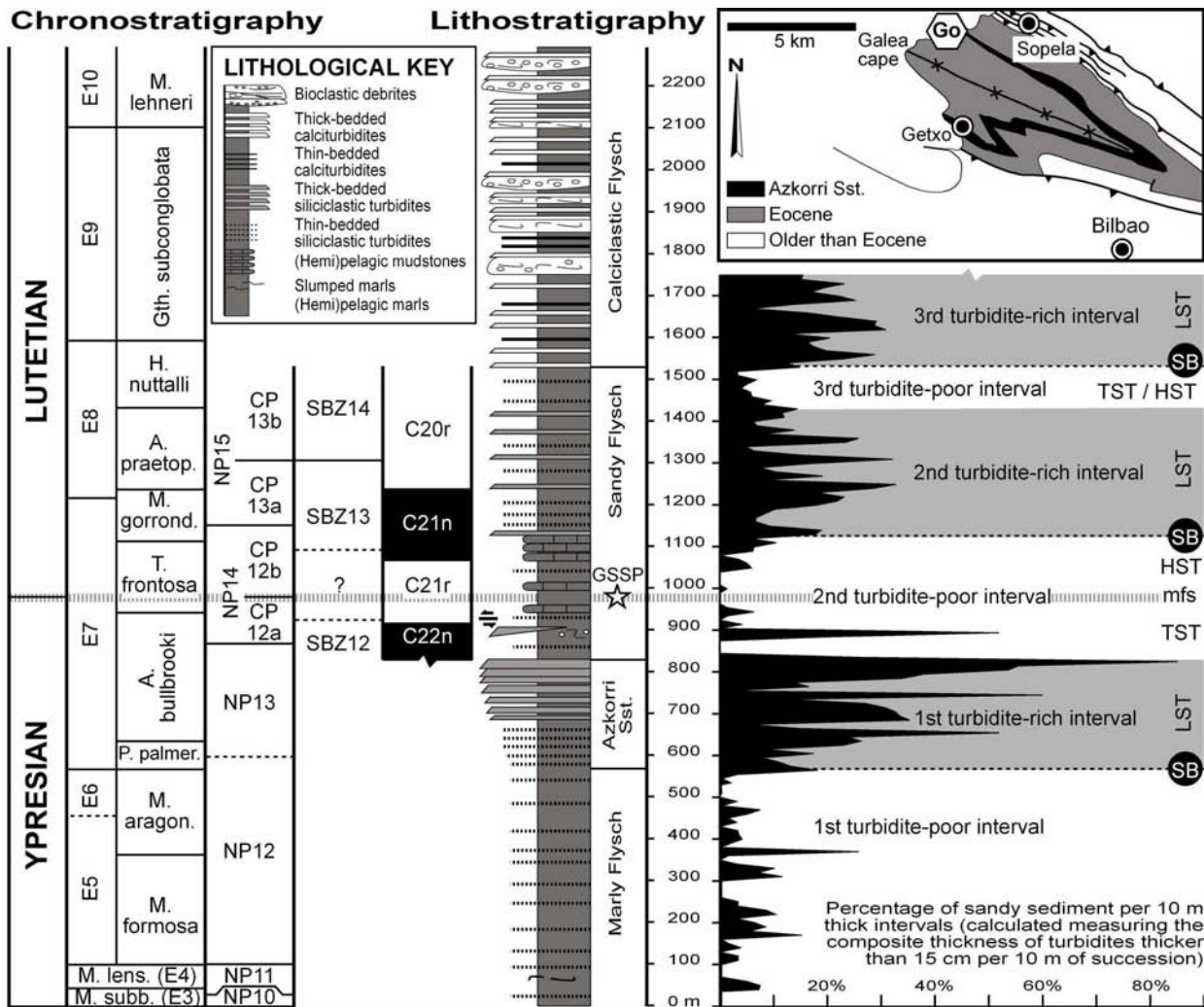


Figure 3. Litholog of the Eocene succession exposed between Sopela and the Galea Cape (location in inset), which contains the Ypresian/Lutetian boundary succession exposed at Gorrondatxe (Go). Vertical variations in abundance of pelagic and turbiditic deposits (right-hand graph; Payros et al., 2006) allow definition of depositional sequences and systems tracts (SB: sequence boundary; LST: lowstand systems tract; TST: transgressive systems tract; mfs: maximum flooding surface; HST: highstand systems tract).

occurrence of *B. piriformis* and the lowest occurrence of *Nannotetrina cristata* approximately 115 kyr younger. The C21r/C21n magnetic polarity reversal was tentatively placed 15 precession couplets (315 kyr) above the lowest occurrence of *B. inflatus*; however, another 24 m of succession are ambiguous magnetostratigraphically, which most likely imply another 192 kyr for Chron C21r and, hence, an age difference of 507 kyr between the Lutetian GSSP and the C21r/C21n Chron boundary. Other much younger events dated with respect to the CP12a/b boundary are the LO of *Morozovella gorrondatxensis* and *Globigerinatheka micra* (1.25 Myr younger), the LO of *Nannotetrina fulgens* (CP12b/13a boundary, 2 Myr younger), the LO of *Guembelirioides nuttalli* (E7/E8 boundary, 2.5 Myr younger), the C21n/C20r boundary and the LO of *Acarinina praetopilensis* (2.7 Myr younger), the LO of *Chiasmolithus gigas* (CP13a/b boundary, 2.9 Myr younger), the highest occurrence (HO) of *Morozovella caucasica* (3.4 Myr younger), the HO of *M. gorrondatxensis* (3.6 Myr younger) and the LO of *Hantkenina* sp. (P9/P10 boundary of Berggren et al., 1995; 4.5 Myr younger).

The Lutetian GSSP at the LO of *Blackites inflatus* in Gorrondatxe cannot be cyclostratigraphically calibrated with the underlying C22n/

C21r magnetic polarity reversal and other older events, as these are separated by an unsolvable fault 68 m below the GSSP. Therefore, minimum age estimates can only be provided for these events. The C22n/C21r magnetic polarity Chron boundary, located 4 m below the fault (Fig. 4), was found to be more than 80 kyr older than the top of the historical Ypresian stratotype (defined by the acme of *Discoaster subloensis*), as it was found more than 30 precession couplets (630 kyr) below the CP12a/b boundary. The LO of *D. subloensis* (marker of Subzone CP12a), an older event clearly placed within the age range of the historical Ypresian stratotype of Belgium, was found to be more than 900 kyr older than the lowest occurrence of *B. inflatus*. In order to solve these uncertainties and integrate the Ypresian/Lutetian cyclostratigraphic framework within the geomagnetic polarity time scale of Gradstein et al. (2004), Payros et al. (2011) correlated the Gorrondatxe section with the nearby Otsakar section. This section had previously been rejected as candidate for the Lutetian GSSP due to some tectonic problems. However, after solving the tectonic disturbance, a continuous record of pelagic limestone-marl couplets was reconstructed between the C22n/C21r Chron boundary and the lowest occurrences of *Turborotalia frontosa* and *B. inflatus*.

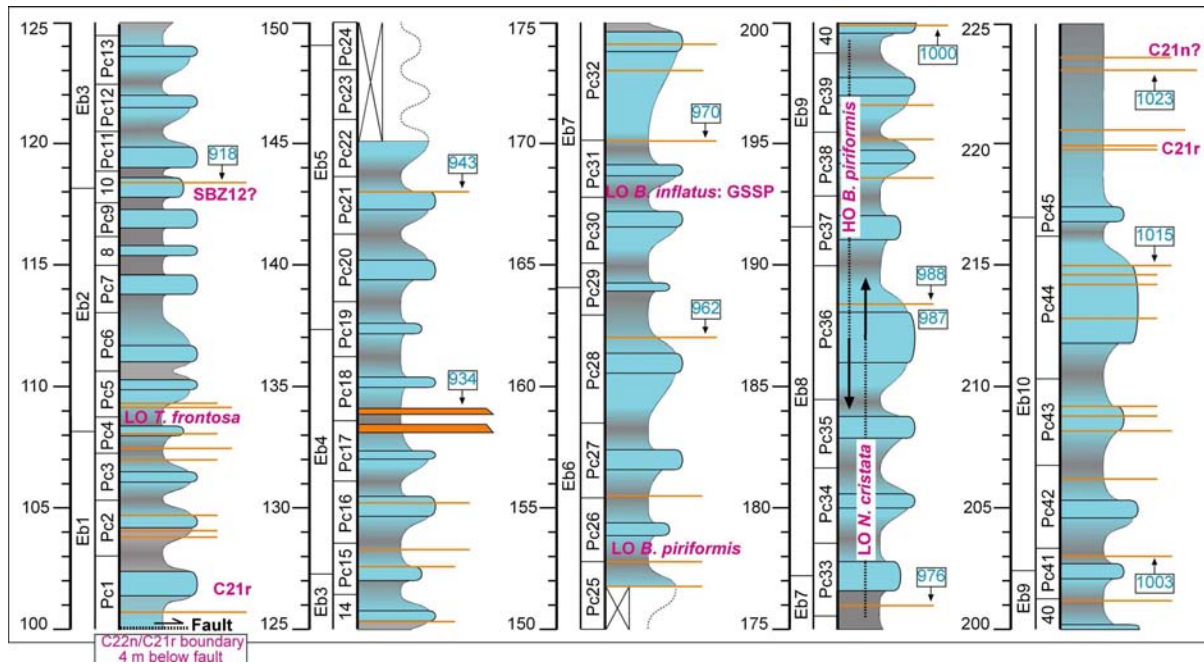


Figure 4. Detailed cyclostratigraphic log of the Gorrondatxe succession that includes the Ypresian/Lutetian boundary, which is marked by the LO of *B. inflatus* (updated from Payros et al., 2009a). Grey beds: pelagic marl; blue beds: pelagic limestone; orange beds: turbidites (only those thicker than 5 cm are depicted; the wider the bed, the thicker the turbidite, up to a maximum thickness of 20 cm in the 133 m turbidite). Pc: 21 kyr precession couplet; Eb: 100 kyr eccentricity bundle. Biomagnetostratigraphic events are shown in pink. Boxed blue numbers are reference numbers painted on the outcrop in blue, and show the position of the numbered bed in the Eocene succession, the base of which lies 900 m below this log.

Comparison of bioevents and couplet counts show that the limestone-marl couplets had the same astronomical precession origin in Gorrondatxe and Otsakar. Thirty-nine precession couplets were counted between the C22n/C21r Chron boundary and the lowest occurrence of *B. inflatus* in Otsakar, suggesting a timelapse of approximately 819 kyr. Given the 48,599 Ma age reported by Gradstein et al. (2004) for the base of Chron C21r, an age of 47.76 Ma can now be calculated for the CP12a/b boundary, being approximately 250 kyr younger than shown in Gradstein et al. (2004). Interestingly, according to the precession cycle count combined from Gorrondatxe and Otsakar (Payros et al., 2011) Chron C21r lasted 1.326 Myr, a figure that is very similar to previous estimates by Gradstein et al. (2004) and Westerhold and Röhl (2009).

Elements of Correlation

Calcareous nannofossils

A high-resolution sampling was carried out to detect with accuracy the lowest occurrences of key calcareous nannofossil taxa, with special attention to that of *Blackites inflatus*, the main correlation criterion of the Lutetian GSSP. All the studied samples from the Gorrondatxe section yielded moderately to well-preserved calcareous nannofossil assemblages that occasionally show traces of dissolution and in lesser extent re-crystallization. Preservation of calcareous nannofossils is frequently excellent and delicate structures and coccospheres are usually present (Plate 1).

The high diversity and total abundance of calcareous nannofossils are remarkably regular throughout the succession with an average of 45 species per sample and 17 specimens per field of view. The

assemblages are dominated by common to abundant *Reticulofenestra* and *Coccolithus*, with less common *Ericsonia*, *Sphenolithus*, *Zygrhablithus* and *Chiasmolithus*, the latter increasing up section in abundance and size.

The studied interval spans from the upper part of Zone CP11 to Subzone CP13b where the following main biohorizons have been found (Fig. 5):

- LO of *Discoaster sublodoensis* (CP11/CP12a; NP13/NP14): At the Gorrondatxe section the LO of *D. sublodoensis* was recorded 40 m above the base of the succession and 128 m below the Lutetian GSSP. From 40 to 90 m this taxon is rare to very rare, its preservation is usually poor, and transitional forms between *D. lodoensis* and *D. sublodoensis* have also been found. From 103.5 m upwards, *D. sublodoensis* is more common and the specimens are better preserved. A similar abundance trend was also observed by several authors and confirms that *D. sublodoensis* is usually rare in its lower range in many sections (Romein, 1979; Backman, 1986; Steurbaut, 1988; Agnini et al., 2006; Larrasoana et al., 2008; Payros et al., 2011).
- The LO of *Blackites piriformis* precedes the LO of *Blackites inflatus*, the CP12b marker, by 14 m. These two taxa could be confused in poorly preserved material, especially in samples where re-crystallization is strong. At the Gorrondatxe section, the range of *B. piriformis* is very short. It first appears at 153 m and disappears 34 m higher, 20 m above the GSSP. This species is also rare and sporadic in other well-preserved successions (Bown, 2005; Payros et al., 2011).
- LO of *Blackites inflatus* (CP12a/CP12b): At Gorrondatxe section we found the LO of *Blackites inflatus* at the selected GSSP level, 128 m above the base of Subzone CP12a and just 14 m above the LO of *Blackites piriformis*. Considering the sedimentation rate of

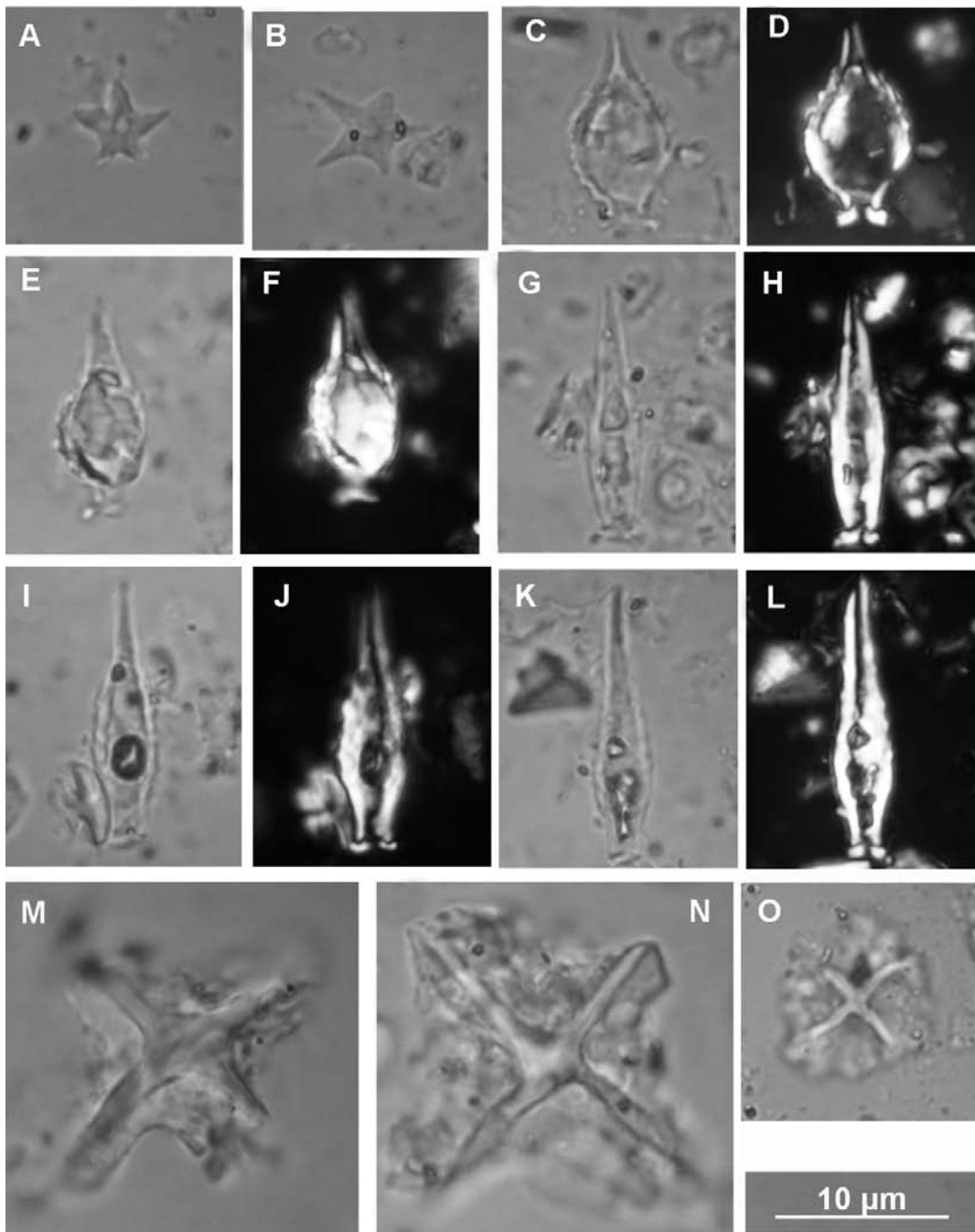


Plate 1. Microphotographs of key calcareous nannofossil taxa for the biostratigraphic characterization of the Ypresian/Lutetian transition in Gorrondatxe; scale bar is 10 µm in all cases. **A, B:** *Discoaster subloidoensis* (from 65 m and 25 m below the GSSP, respectively). **C-F:** *Blackites piriformis* (**C-D:** 1 m above the GSSP; **E-F:** 7 m below the GSSP). **G-L:** *Blackites inflatus* (**G-H:** 1 m above the GSSP; **I-J:** 19 m above the GSSP; **K-L:** 35 m above the GSSP). **M-N:** *Nannotetrina fulgens* (**M:** 241 m above the GSSP; **N:** 278 m above the GSSP). **O:** *Nannotetrina cristata* (20 m above the GSSP).

the Gorrondatxe section and the precession cycle count these 14 m represent about 100 kyr. The bed-by-bed sampling carried out to detect the LO of *Blackites inflatus* implies a sampling resolution of about 2 kyr.

d) LO of *Nannotetrina* spp.: This biohorizon has occasionally been used to define the base of CP13 in sections where its marker taxon *Nannotetrina fulgens* is very rare or absent, but the first occurrence of *Nannotetrina* (*N. cristata*) is usually reported in CP12b (Perch-Nielsen, 1985). Thus, we advise against the use of this biohorizon

to mark the base of Zone CP13. The LO of *Nannotetrina* spp., *N. cristata* was found 20 m above the LO of *Blackites inflatus*, hence in the lower part of Subzone CP12b. In the Agost section the LO of *Nannotetrina* spp. was found together with the LO of *B. inflatus* and the LO of *N. cristata* in the sample above (Larrasoña et al., 2008).

e) LO of *Nannotetrina fulgens* (CP12b/CP13a; NP14/NP15): In the Gorrondatxe section the LO of *N. fulgens* is recorded at 311 m, 143 m above the Lutetian GSSP. This taxon is rare in the lower part of its range, but increases in abundance from 446 m upwards. Other biohorizons, such as the HO of *Blackites inflatus* (Bukry, 1973; Aubry, 1983; Varol, 1989; Larrasoña et al., 2008) or the HO of *Discoaster subloidoensis* (Lyle et al., 2002), have been used as alternatives to approximate the base of CP13 Zone.

f) LO of *Chiasmolithus gigas* (CP13a/CP13b): This biohorizon, marked by the first *Chiasmolithus* larger than 19 µm with a broad distal shield and restricted central opening spanned by a relatively small x-shaped structure with sigmoid bars, is located at 474 m, 306 m above the Lutetian GSSP. The highest occurrence of *Ch. gigas* has not been detected, its presence

being continuous up to the top of the studied interval (Fig. 5).

Planktic foraminifera

A total of 127 samples were collected, which were more closely spaced around the main biostratigraphic events. All levels contain a diversified assemblage of well-preserved planktic foraminifers (Plate 2), which represent more than 90% of the total (planktic plus benthic) foraminiferal content.

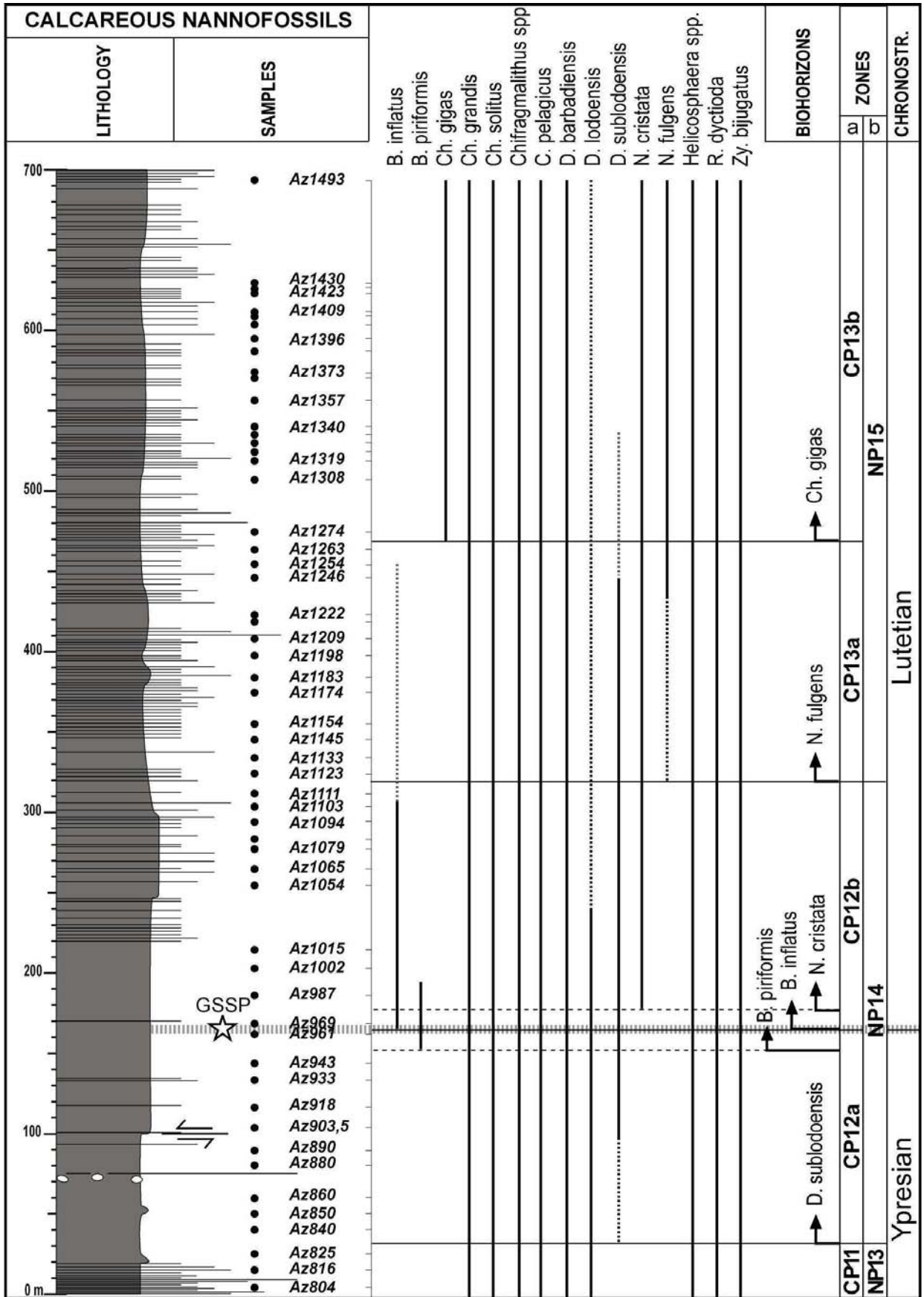


Figure 5. Selected calcareous nannofossil species ranges and location of the main biohorizons across the Ypresian/Lutetian transition at the Gorrondatxe section. Broken lines indicate very rare occurrences. Zones in column (a) follow Okada and Bukry (1980); those in column (b) follow Martini (1971).

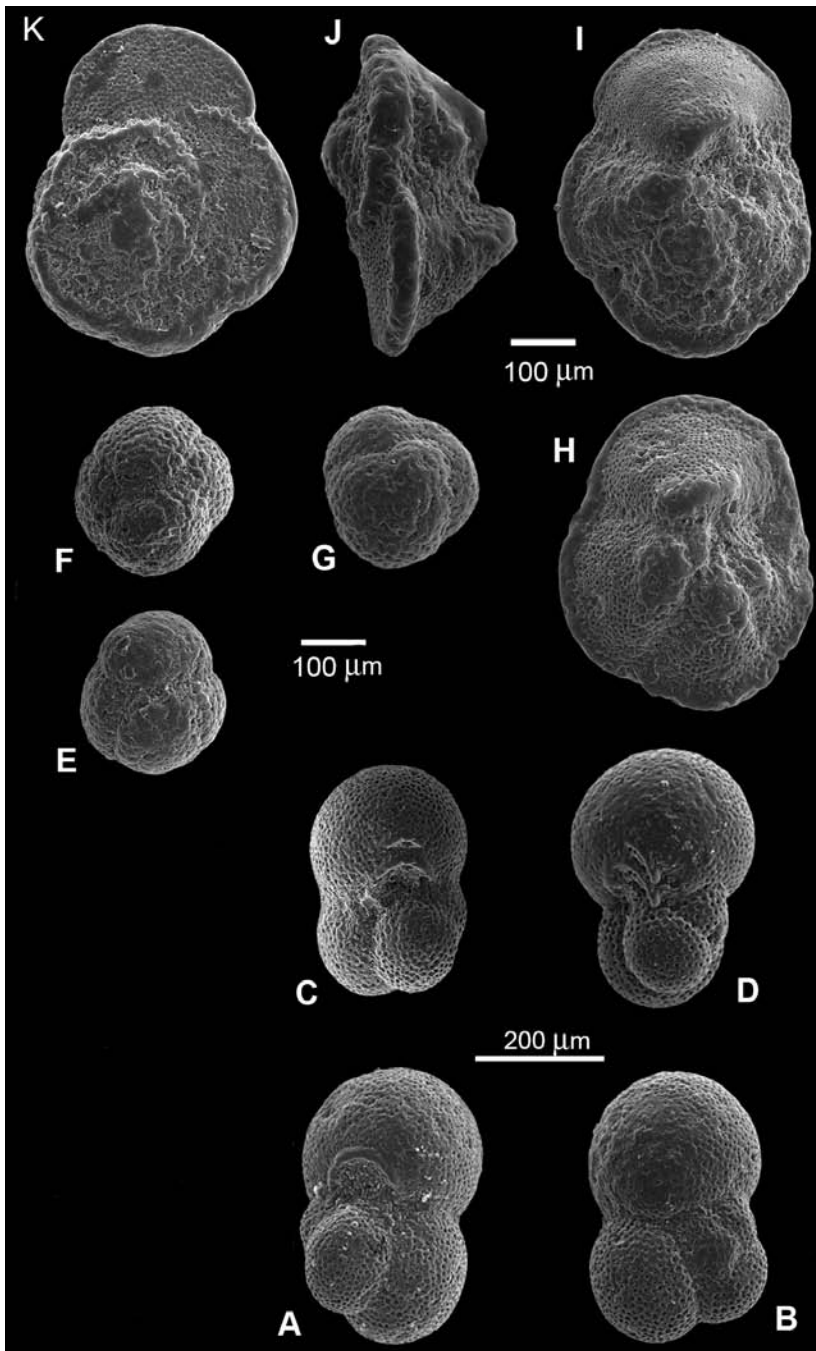


Plate 2. Microphotographs of key planktic foraminiferal taxa for the biostratigraphic characterization of the Ypresian/Lutetian transition in Gorrondatxe. A-D: *Turborotalia frontosa* (A and C: umbilical views of specimens that correspond, respectively, to the normal morphotypes and to the most primitive morphotypes found at the lowermost stratigraphic range of the species, 60 m below the GSSP; B: spiral view; D: lateral view); scale bar is 200 µm in all cases. E-G: *Globigerinatheka micra* (E-F: umbilical views; G: spiral view); scale bar is 100 µm in all cases. H-K: *Morozovella gorrondatxensis* (H-I: umbilical views; J: lateral view; K: spiral view); scale bar is 100 µm in all cases.

The lower 109 m of the succession present an assemblage typified by *Subbotina linaperta*, “*Guembeltrioides*” *lozanoi*, *Globanomalina planoconica*, *Pseudohastigerina micra*, *Morozovella aragonensis*, *Morozovella caucasica*, *Igorina broedermanni* and *Acarinina bullbrooki* (Fig. 6). Specimens similar in shape to *Guembeltrioides*

nuttalli, albeit smaller in size and lacking supplementary sutural apertures, occur throughout this interval, which might correspond to intermediate forms between “*G.*” *lozanoi* and *G. nuttalli* (Toumarkine and Luterbacher, 1985). This assemblage is included in the *Acarinina bullbrooki* Biozone, and is considered equivalent to part of zones P9 of Berggren et al. (1995), E7 of Berggren and Pearson (2005) and E7a of Wade et al. (2011). This interpretation is supported by the occurrence of *Planorotalites palmerae*, marker taxon of Zone P9, 250 m lower in the succession (see Orue-Etxebarria et al., 1984; Orue-Etxebarria and Apellaniz, 1985; Payros et al., 2006).

The assemblage from the interval between 109 and 283 m (hence, including the Lutetian GSSP level at 167.85 m) is characterized by *Turborotalia frontosa*, *Acarinina bullbrooki*, *Pseudohastigerina micra*, *Igorina broedermanni*, *Subbotina linaperta*, *Subbotina senni*, *Globanomalina indiscriminata*, *Globanomalina planoconica*, *Morozovella caucasica*, *Morozovella crater* and *Morozovella aragonensis*. Accordingly, this interval has been included in the *Turborotalia frontosa* Zone and is regarded as equivalent to the upper part of Zone E7 of Berggren and Pearson (2005) and to the lower part of Zone E7b of Wade et al. (2011). The lowest specimens of *T. frontosa* are very rare, their size is smaller than that of the holotype and show a slightly lower aperture than the typical morphotype (Plate 2C). These characteristics change from 126 m upwards, as specimens of *T. frontosa* become progressively bigger, more abundant and their aperture becomes higher. In this study, the species *Globigerina frontosa* Subbotina, 1953 and *Globigerina bowyeri* Bolli, 1957 are regarded as synonymous, as in Stainforth et al. (1975) and Pearson et al. (2006), and included within *T. frontosa*. The lowest occurrence of *T. frontosa* is the planktic foraminiferal event that is closest to the base of the historical Lutetian stratotype, therefore being the best planktic foraminiferal proxy to approach the position of the Ypresian/Lutetian boundary. In Gorrondatxe this event lies 58 m (approx. 550 kyr) below the Lutetian GSSP.

The simultaneous LOs of *Morozovella gorrondatxensis* and *Globigerinatheka micra* at 283 m (115 above the Lutetian GSSP) mark the base of the *Morozovella gorrondatxensis* Biozone, which extends over 125 m. Pearson et al. (2006) included *M. gorrondatxensis* in synonymy with *Morozovella crater*. However, the *M. gorrondatxensis* specimens differ from the *M. crater* specimens found in the underlying *Turborotalia frontosa* Biozone. *Morozovella gorrondatxensis* shows a lower umbilical side, less marked muricae on the circumumbilical collar, and a smaller umbilicus than *M. crater*. Given these characteristics, Orue-Etxebarria (1985) suggested that *M. gorrondatxensis* is homeomorph of the older *Morozovella gracilis*. Pearson et al. (2006) considered that the small-sized *Gth. micra* might be a junior synonym of the larger *Subbotina senni*. However, *Gth. micra* is here regarded as an intermediate species between *S. senni* and *Globigerinatheka subconglobata*, as its aperture is very different

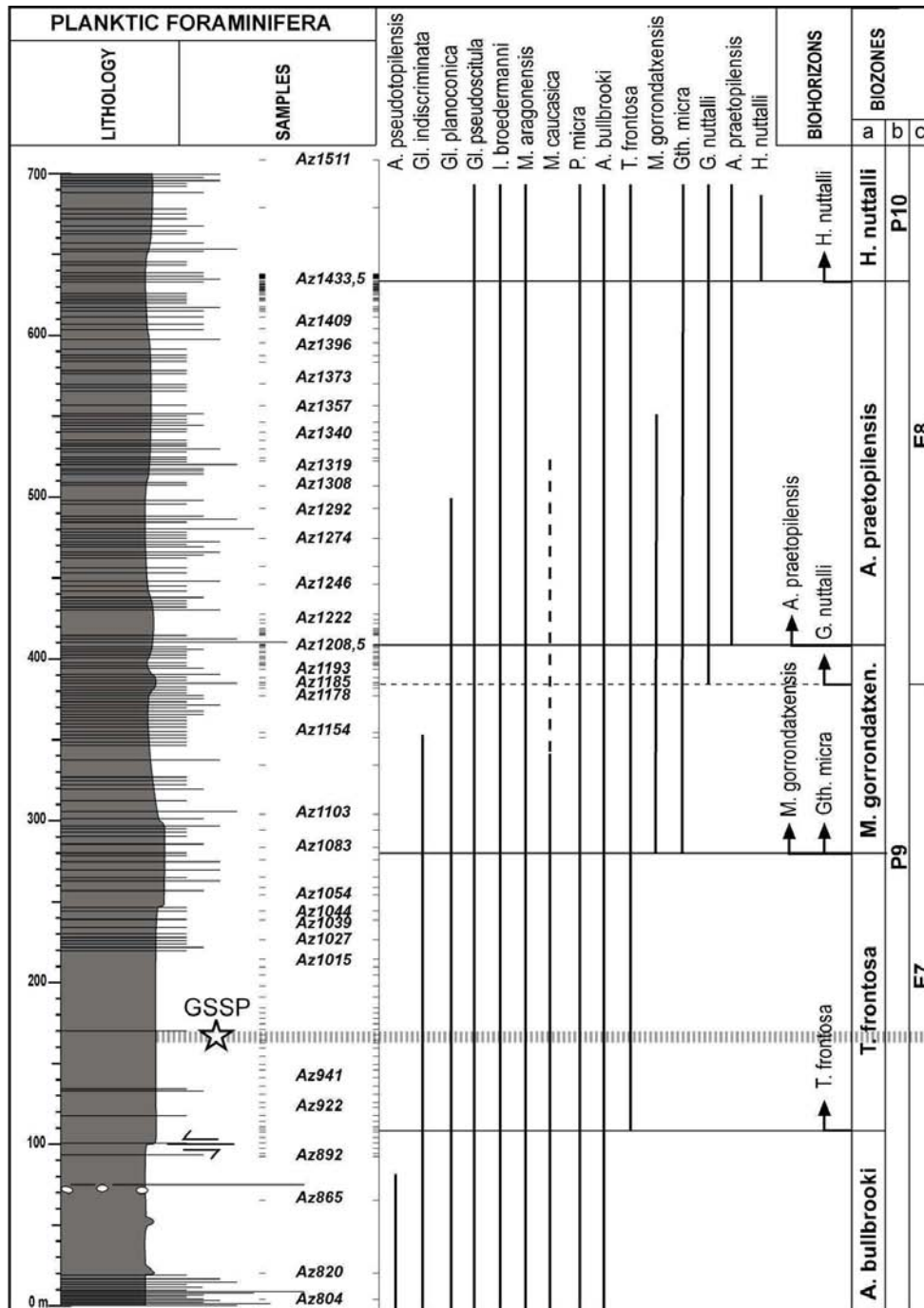


Figure 6. Selected planktic foraminifera species ranges and location of the main biohorizons across the Ypresian/Lutetian transition at the Gorrondatxe section. Biozones in column "a" are as described in Bernaola et al. (2006b), with later modifications by Payros et al. (2009a); those in column "b" (P scale) follow Berggren et al. (1995), and those in column "c" (E scale) follow Berggren and Pearson (2005).

from that of the former, being similar to that of *Gth. subconglobata*, but lacks the typical secondary apertures of the latter. The HO of *Pseudohastigerina wilcoxensis* and *Globanomalina indiscriminata* are recorded at the upper part of the *Morozovella gorrondatxensis* Biozone. Relatively large-sized specimens of *Guembeltrioides nuttalli* with secondary sutural apertures, which mark the E7/E8 zonal boundary (Berggren and Pearson, 2005; Wade et al., 2011), appear in the uppermost part of this biozone, at 385 m (217 m above the Lutetian GSSP). All these characteristics suggest that the *Morozovella*

gorrondatxensis Zone mainly correlates with the upper part of zones E7b of Wade et al. (2011) and E7 of Berggren and Pearson (2005) (equivalent to Zone P9 of Berggren et al., 1995), although its uppermost part corresponds to Zone E8 (=P10). The LO of *Gth. micra* in the upper part of Zone P9 was also reported by Premoli Silva et al. (2003).

The LO of *Acarinina praetopilensis* at 408 m (240 m above the Lutetian GSSP) marks the base of the homonymous biozone, which extends over 225 m. The first specimens of the nominate taxon differ from the holotype (Blow, 1979) in that they are slightly smaller and have a less distinct circum-cameral muricocarina. The HO of *Morozovella caucasica* is recorded in the middle part of this zone (522 m), whereas those of *Subbotina inaequispira* and *M. gorrondatxensis* were found in the upper part (574 m). The *Acarinina praetopilensis* Zone correlates with the lower part of Zone E8 of Berggren and Pearson (2005) and Wade et al. (2011).

Finally, the base of the *Hantkenina nuttalli* Zone is defined by the LO of the nominate taxon at 635 m (467 m above the Lutetian GSSP). Hantkeninids are rare in all samples and their tubulospines are systematically broken, making it impossible to distinguish between *H. nuttalli* and *Hantkenina singanoae* (Pearson et al., 2006). As the LO of hantkeninids is located higher than the HO of *M. caucasica*, it might not correspond to their lowest occurrence in the stratigraphic record. The LO of *Truncorotaloides topilensis* is recorded in the lower part of the *Hantkenina nuttalli* Biozone. Globigerinathekids, including *Gth. mexicana*, become very abundant 80 m higher up in the succession (see Orue-Etxebarria et al., 1984; Orue-Etxebarria and Apellaniz, 1985; Payros et al., 2006). For all these arguments,

the *Hantkenina nuttalli* Zone is correlated with the upper part of Zone E8 of Berggren and Pearson (2005) and Wade et al. (2011) (Fig. 6).

Larger foraminifera

Larger foraminifera, mostly represented by nummulitids (*Nummulites* and *Assilina* specimens) but also by orthophragminids (not studied in this work), and other shallow marine water organisms (e.g. red algae) occur in some turbidite levels, but only sixteen

provided positive results (Bernaola et al., 2006b and Orue-Etxebarria et al., 2006).

Most specimens were classified at species level and are suitable for biostratigraphic determination. However, in some samples the systematic study was hindered by the poverty of the nummulitid assemblage. Despite these difficulties, it was possible to date the minimum age of the levels containing nummulitids, which extends from SBZ12 to SBZ14 zones of Serra-Kiel et al. (1998).

We differentiated several stratigraphic intervals (Fig. 7), which are characteristic of several ages according to data from Hottinger (1977), Schaub (1981) and Serra-Kiel et al. (1998):

The first interval is represented by only one sample in the basal part of the section (meter 69), with a nummulitid assemblage that belongs to the upper Cuisian (SBZ12). It provided the zone defining species *Nummulites manfredi*, *N. campesinus*, *Assilina maior*, and other less characteristic forms, with a group of reworked species from older ages.

A second interval (meters 105-134), with the presence of some forms belonging to the *N. perforatus*, *N. laevigatus* and *A. praespira* groups, does not allow discrimination between zones SBZ12 and SBZ13.

A third interval (meters 270-410) above the Lutetian GSSP (167.85 m), contains a nummulitid assemblage characterized by the lowest occurrence of *N. laevigatus* and other fauna representative of the latter part of Zone SBZ13 (early Lutetian), such as *N. britannicus*, *N. messinae*, *N. gallensis*, *N. obesus*, *N. lehneri*, *N. variolarius* and *A. bericensis*, with some reworked species belonging to previous zones.

Finally, the upper part of the section (meters 473-654) shows a lower Lutetian nummulitid assemblage similar to that of the previous

group, some species with a chronostratigraphic range between the lower and middle Lutetian (SBZ13-14), such as *N. uranensis*, *N. alponensis*, *N. aff. millecaput*, and other species representative of the lower middle Lutetian (SBZ14), such as *N. boussaci* or even species like *N. lorioli*, which characterizes the transition to the upper middle Lutetian (SBZ15).

All data considered, the age of the Lutetian GSSP level could not be accurately determined by means of larger foraminifera but must correspond to the transition between zones SBZ12 and SBZ13. A similar result was obtained in Otsakar (Payros et al., 2011), confirming that the SBZ12/13 boundary does not correlate with the calcareous nannofossil subzone CP12a and the C22n/C21r Chron boundary (Serra-Kiel et al., 1998), but is slightly younger than in previous calibrations.

Smaller benthic foraminifera

Benthic foraminiferal assemblages from Gorrondatxe were quantitatively analyzed by Ortiz et al. (2011), with samples more closely spaced near the main biostratigraphic events (Fig. 8).

The common occurrence of typically bathyal and abyssal species (e.g., *Nuttallides truempyi*, *Bulimina trinitatensis*, *Cibicidoides eoacaenus*), and the presence of some neritic to upper bathyal taxa such as *Anomalinoidea acutus*, *Osangularia plummerae* and *Lenticulina* species, match with the estimated palaeodepth for this area of about 1500 m (Payros et al., 2006).

Calcareous taxa are dominated by bolivinids, cibicids, *Globobulimina* species and allochthonous taxa (removed from the foraminiferal counts), which are noticeably more abundant in the upper turbidite-rich interval. Other calcareous taxa such as buliminids,

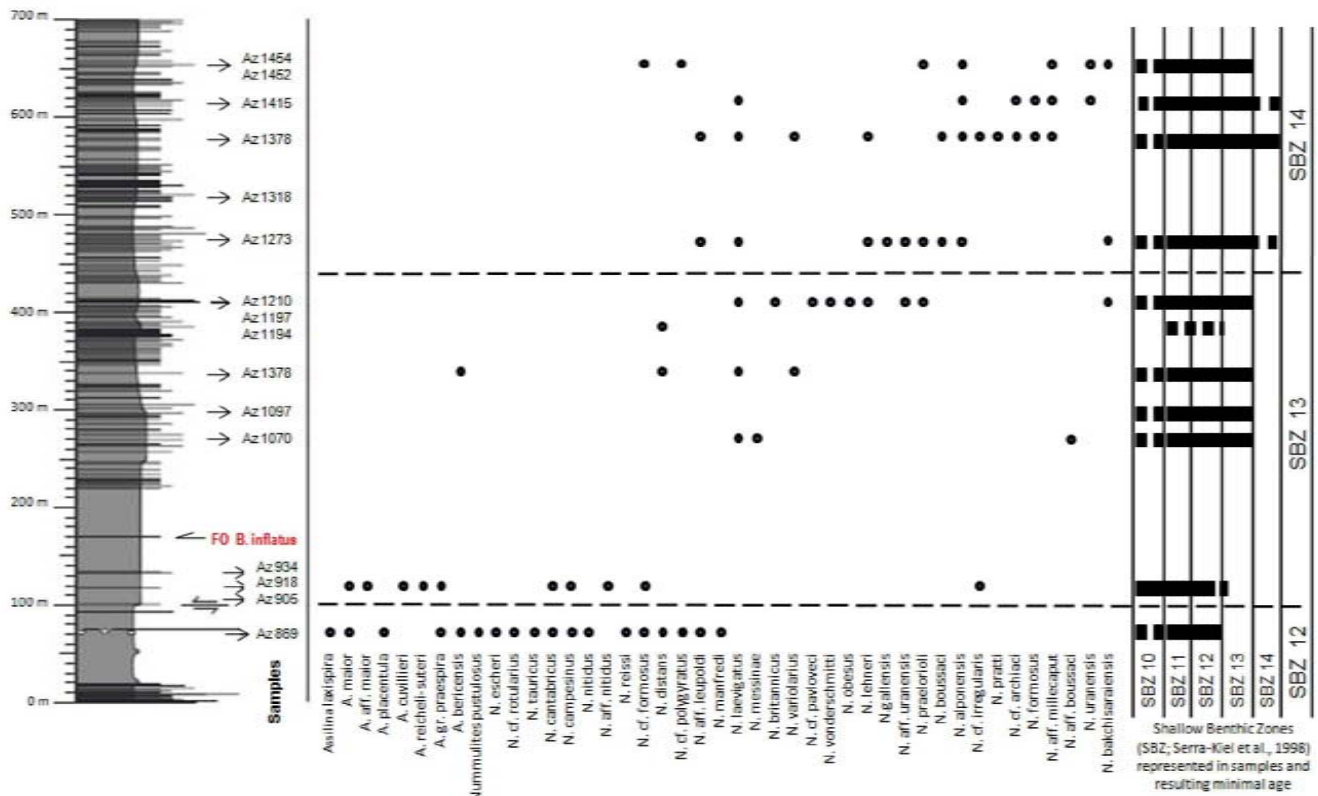


Figure 7. Nummulitid species occurrences in the Gorrondatxe section. Broken lines on the right-hand columns indicate that the corresponding Shallow Benthic Zone (SBZ) is probably represented in the sample, whereas continuous lines indicate verified occurrences.

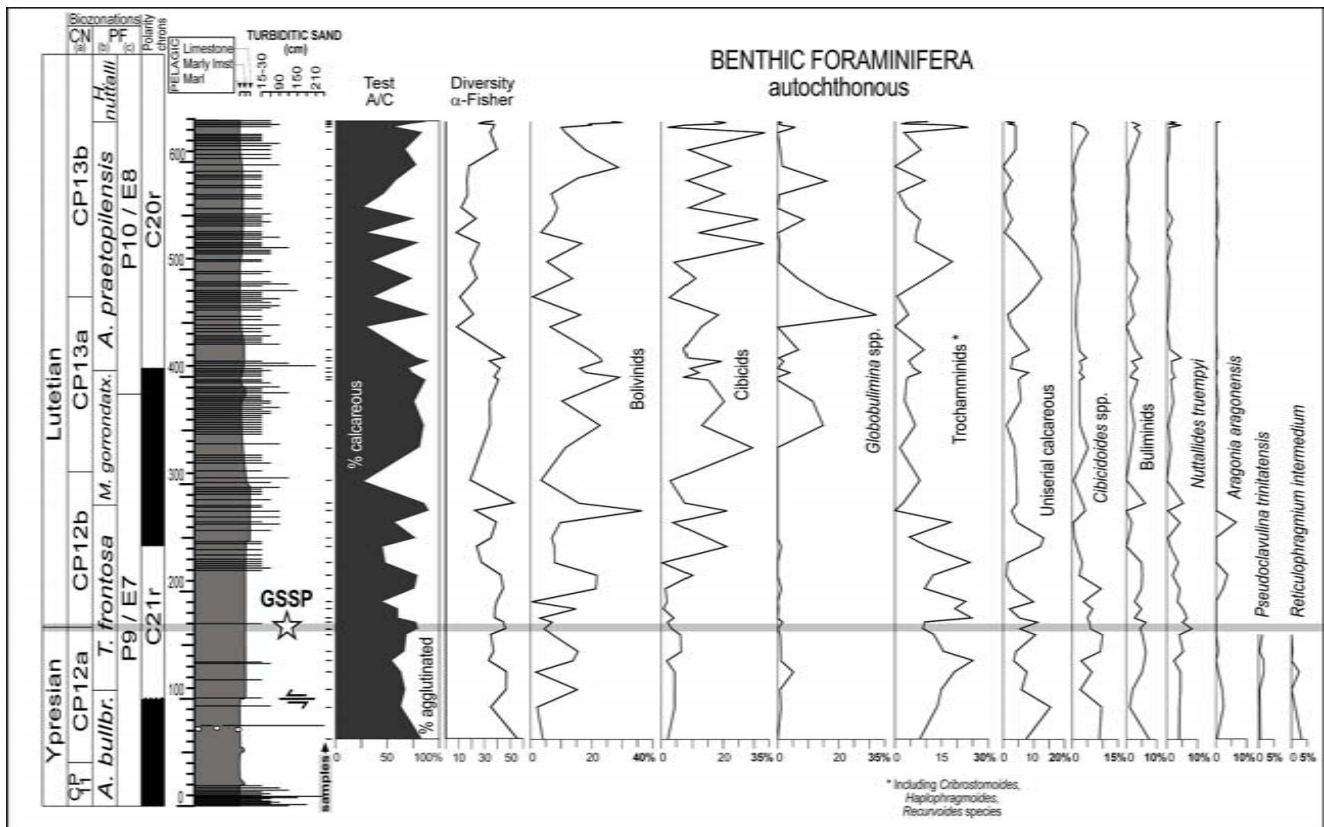


Figure 8. Benthic foraminifera quantitative analysis across the Ypresian/Lutetian transition at the Gorrondatxe section (modified from Ortiz et al., 2011). (a) calcareous nannofossil zonation (Okada and Bukry, 1980). (b) and (c), planktic foraminiferal zonation described in Bernaola et al. (2006b), with later modifications by Payros et al. (2009a), Berggren et al. (1995) and Berggren and Pearson (2005).

uniserial calcareous taxa, *Cibicidoides* species and *Nuttallides truempyi* characterize the high-diversity assemblages in the lower turbidite-poor interval where the GSSP for the base of the Lutetian stage is defined. Agglutinated taxa are also common at the former interval, particularly trochamminids (up to 23%).

Typical lower and middle Eocene *Cibicidoides* species such as *Cibicidoides eoacenus*, *C. praemundulus* and *C. subspiratus* (e.g., Van Morkhoven et al., 1986) are abundant at the lower part of the section (Fig. 8). *Cibicidoides mexicanus*, which was primarily an Oligocene species, is roughly limited to the upper part of the section. *C. subspiratus*, whose total range defines the late early Eocene and middle Eocene Zone BB3 at bathyal depths (Berggren and Miller, 1989), has been recorded throughout the section. Few *Reticulophragmium* specimens were identified at Gorrondatxe, which are limited to metre 65 to 143.9 (CP12a biozone, below the Lutetian GSSP) (Fig. 8). We tentatively assigned them to *R. intermedium*, a species from the early Eocene and possible ancestral to *R. amplexans*, traditionally used in biostratigraphic zonations for the middle and late Eocene (e.g., Kaminski and Gradstein, 2005). *Pseudoclavulina trinitatis* shows a similar occurrence to *R. intermedium*, recorded from metre 65 to 160.8 (CP12a biozone). The highest observed occurrence of this species at CP12a is probably a local disappearance since its HO is recorded at the Eocene/Oligocene boundary in Trinidad and in the Betic Cordillera (Bulli et al., 1994; Molina et al., 2006).

Aragonia aragonensis shows several peaks in relative abundance under and, more distinctively, above the Lutetian GSSP (Fig. 8). Peaks of this opportunistic species have been recorded close to the P9/P10 boundary of Berggren et al. (1995) (Ortiz and Thomas, 2006; Ortiz et

al., 2008), i.e., in an upper stratigraphic position than at Gorrondatxe. These data suggest that peaks in *A. aragonensis* may not be a valid marker for global correlation of the Ypresian/Lutetian boundary, although they may provide some important paleoclimatic information.

Ostracods

Ostracods of the Eocene succession, including the Gorrondatxe section, were studied by Rodríguez-Lázaro and García-Zárraga (1996). As their results remain valid, only a summary of the most significant characteristics is presented herein.

The Gorrondatxe ostracod assemblages possess a cosmopolitan, circumglobal, deep water (mesobathyal), cool-to-cold water temperature distribution. The assemblages of the Sandy Flysch contain the following species: *Protoargilloecia angulata*, *P. trapezoida*, *Aratrocypis* aff. *maddocksa*, *Krithe luyensis*, *K. parvula*, *Cytherella* spp., *Platyleberis* spp., *Trachyleberidea prestwichiana* and *Agenocythere ordinata*. In this interval species like *Abysso Bairdia anisovalva*, *Profundobythere bathyatos*, *Henryhowella* gr. *asperima*, and *Parakrithe* sp. 3 also occur, among other species that are characteristic of the North Atlantic Paleogene (Whatley and Coles, 1991). In fact, the Gorrondatxe assemblages compare well with those described from the Paleogene of Aquitaine (Ducasse, 1975), Italy (Ascoli, 1975), Moravia (Pokorný, 1975), Trinidad (Bold, 1960), North Atlantic Ocean (Coles and Whatley, 1989) and Bahamas (Guernet, 1982).

The biostratigraphic analysis allows a good characterization even at generic level. Certain genera such as *Abysso Bairida* and

Rimacytheropteron, previously described from the Middle Eocene, first appear in Lower Eocene deposits in the study area. The biostratigraphic index for the lowermost Eocene (*Rimacytheropteron* cf. *rotundapunctata*) found in the underlying Marly Flysch deposits is missing from the Gorrondatxe section. The Azkorri Sandstone shows an increase of thanatocoenotical forms derived from the continental shelf. Species like *Agrenocythere ordinata*, *Cytheropteron* sp. 1, *Cardobairdia* sp. 3, *Legitimocythere* aff. *presenquenta* are characteristic of the planktic foraminiferal E7 Zone in the Gorrondatxe section and thus of the Lutetian GSSP interval. The transition to the E8 Zone is defined by the presence of *Heinia* cf. *dryppa*, *Heinia* sp. 2, *Australoecia* cf. *posteroacuta*, *Parakrithe* sp. 2 and *Hanryhowella* gr. *asperrima*. Finally the lowest occurrences of *Rimacytheropteron* ? sp. 2 and *Dutoitella* sp. 2 represent the beginning of Zone E8 in Gorrondatxe.

Dinoflagellate cysts

Dinoflagellate cysts have been studied in six samples from the interval 63 m – 184 m (Table 1). The preservation varies from fairly good to moderate. The assemblages are moderately diverse and almost entirely consist of gonyaulacacean taxa. The dominant taxa are *Cleistosphaeridium diversispinosum* (14–89% of total organic-walled microplankton) and *Spiniferites* spp. (1–30%). *Homotryblium tenuispinosum*, *Operculodinium centrocarpum* and *Glaphyrocysta*

spp. are usually less common (1–5%). *Polysphaeridium zoharyi* is usually rare, but in one sample accounts for 10%.

Regarding paleoecology, the assemblages seem to be derived from mixed waters typical for a mid-outer shelf setting. Cysts indicating nutrient-rich and brackish environments, such as peridiniacean cysts, *Lingulodinium machaerophorum* and *Paralecaniella indentata* are generally rare. Two locally common cysts, *Homotryblium tenuispinosum* and *Polysphaeridium zoharyi*, may have been transported from warm lagoonal palaeoenvironments. A few reworked Cretaceous cysts were recognised.

Assemblages differ from those of NW Europe by a lower diversity and rarity or absence of species used for biozonation in the North Sea Basin. Closest similarity is with assemblages from southern England (Eaton, 1976; Bujak et al., 1980). Noteworthy is the strong reduction of the *Eatonicysta-Areosphaeridium* group, although the group is still present. This group was probably favoured by cooler waters than prevailing in the Bay of Biscay during the Eocene. Based on the present, limited studied material the following biostratigraphical comparison with NW Europe and the Norwegian-Greenland Sea can be given:

1. The highest occurrence of *Charlesdowniea columna* occurs in the uppermost part of Chron 22n in the Norwegian-Greenland Sea (Eldrett et al., 2004; Brinkhuis et al., 2006) and is probably synchronous in NW Europe (cf. discussion in Eldrett et al. 2004). At Gorrondatxe the highest in situ occurrence of *C. columna* takes

Table 1. Dinoflagellate cysts in studied samples from Gorrondatxe. Figures are percentages of total organic-walled microplankton. X = present outside count. The GSSP lies at 167.85 m, 1.9 m below sample 969.75m-2897.

GORRONDATXE BEACH SECTION Dinoflagellate cysts, part 1 C. Heilmann-Clausen 2009	<i>Achilleodinium biformoides</i>	<i>Adnatosphaeridium multispinosum</i>	<i>Adnatosphaeridium robustum</i>	<i>Areosphaeridium michoudii</i>	<i>Charlesdowniea aculeata</i>	<i>Charlesdowniea columna</i>	<i>Cleistosphaeridium diversispinosum</i>	<i>Cordosphaeridium fibrospinosum</i>	<i>Cordosphaeridium funiculatum</i>	<i>Citrioperidinium giuseppi</i>	<i>Damassadrinium impages</i>	<i>Diropterygium</i> cf. <i>clacoides</i>	<i>Duosphaeridium nudum</i>	<i>Eatonicysta glabra-ursulae</i> group	<i>Glaphyrocysta</i> spp.	<i>Homotryblium abbreviatum</i>	<i>Homotryblium tenuispinosum</i>	<i>Impagidinium</i> spp.	<i>Muratodinium fimbriatum</i>	<i>Nematosphaeropsis</i> spp.	<i>Operculodinium centrocarpum</i>	<i>Operculodinium divergens</i>	<i>Phthianoperidinium comatum</i>	<i>Phthianoperidinium crenulatum</i>	<i>Polysphaeridium zoharyi</i> s.l.	<i>Samlandia chlamydophora</i>	<i>Selenopemphix nephroides</i>	<i>Spiniferites</i> spp.
984m - 2899		3	x	x			36					2	x		1		3		0.5	4	2			0.5	x	2	30	
981m - 2898	0.5	1	0.5			?	34					1			2	5	0.5		0.5	4	3	1	1	1	1		x	29
969.75m - 2897							25					0.5				21			1		3		0.5	0.5		0.5	0.5	11
955.5m - 2896	0.5	0.5		0.5	x		32			x	0.5			5		1	0.5	1	0.5	5	0.5	8	0.5	2	x			27
c. 910m - 2895	x	x	?	?	?	?	89					1		0.3	x	6		0.3	0.3	0.3	x	0.3			x	x	x	1
c. 863m - 2894	2	2	x	?	x	1	14	2	1	2	x	1	x	x	3	6	6	2	5	1	3	1	1	x	10	x	?	20

GORRONDATXE BEACH SECTION Dinoflagellate cysts, part 2 C. Heilmann-Clausen 2009	<i>Thalassiphora pelagica</i>	<i>Cerebrocysta bartomensis</i>	<i>Diphyes fuscoides</i>	<i>Lingulodinium machaerophorum</i>	<i>Proximochorot</i> sp. 1	<i>Wetzelia</i> aff. <i>meckelfeldensis</i> in Michoux	<i>Melittasphaeridium</i> cf. <i>asterium</i>	<i>Diphyes colligatum</i>	<i>Hystriocholopoma salacia</i>	<i>Impletosphaeridium rugosum-cracens</i> group	<i>Melittasphaeridium pseudorecurvatum</i>	<i>Paralecaniella indentata</i>	<i>Pentadinium latirostratum</i>	<i>Wetzelia articulata-ovalis</i> s. De Coninck	<i>Palambages</i> sp. 1 in HC & Costa 89	<i>Areosphaeridium diktyoplokum</i>	<i>Areosphaeridium</i> cf. <i>polytelum</i>	<i>Cordosphaeridium inodes</i>	<i>Homotryblium</i> sp. 1	<i>Wetzelia</i> cf. <i>uncinata</i>	<i>Wetzelia</i> cf. <i>meckelfeldensis</i>	<i>Apertodinium</i> spp.	<i>Charlesdowniea colechthrypta-columna</i>	<i>Turbosphaera magnifica</i>	OTHER SPECIES	<i>Nypa</i> pollen (mangrove palm)	<i>Azolla</i> spores (aquatic fern)
984m - 2899				1				5	0.5							x		3								3	0.5
981m - 2898				0.5				2				1	x			x	1	0.5	3	0.5	x	x				7	0.5
969.75m - 2897				1	1			1	0.5	0.5				29	x											4	1
955.5m - 2896	0.5	x		0.5				0.5	x	1	x	1	x	3												8	0.5
c. 910m - 2895		x	x	0.3	x	x																				1	
c. 863m - 2894	1																									16	x

place between samples at 63 m and 110 m, well below the Lutetian GSSP level, and may therefore be synchronous with north Europe.

2. The highest occurrence of *Eatonicysta ursulae* is a major event in NW Europe and the Norwegian-Greenland Sea where it takes place in Chron 21r shortly above the highest occurrence of *Charlesdowniea columna*. At Gorrondatxe typical *E. ursulae* have not been observed, but the highest occurrence of intermediate forms between *E. ursulae* and its close relative *E. glabra* takes place between samples at 63 m and 110 m, and may be synchronous with the highest occurrence of *E. ursulae* in north Europe.

3. *Duosphaeridium nudum* is restricted to a narrow interval at the Ypresian-Lutetian transition in Aquitaine, NW Europe, Rockall Plateau and W Siberia (cf. discussions in Michoux, 1985, and Iakovleva and Heilmann-Clausen, 2010). *Duosphaeridium nudum* is present, although very rare, at Gorrondatxe.

4. The lowest occurrence of the important boreal dinoflagellate cyst *Areosphaeridium diktyoplokum* almost coincides with the NP12/NP13 boundary in NW Europe. The lowest occurrence of *A. diktyoplokum*

is recorded at 181 m in the Gorrondatxe section and thus appears to be delayed relative to North Europe (Table 1).

Ichnofossils

The Gorrondatxe section reveals a moderate diversity of trace fossils. It contains 41 ichnospecies belonging to 28 ichnogenera (Rodríguez-Tovar et al., 2010). This trace-fossil assemblage is typical of the deep-sea *Nereites* ichnofacies, with a significant contribution of shallow-tier, pre-depositional structures, mainly graphoglyptids, and shallow to deep-tier post-depositional forms. 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). Some ichnotaxa are continuously recorded through the section, which can be considered the background assemblage, while the remaining ichnotaxa (graphoglyptids, and other post-depositional structures) show significant fluctuations in composition, diversity and abundance throughout the section, allowing distinction of five intervals (Rodríguez-Tovar et al., 2010); however, only the lowermost intervals A and B are relevant to the Lutetian GSSP (Fig. 9):

Interval A, which includes the Lutetian GSSP level, shows a moderate diversity and abundance of pre- and post-depositional trace fossils; apart from the background assemblage, another 13 are also identified. Some of them are exclusive of this interval, including *Alcyonidiopsis* isp. A, *?Urohelminthoidea*, *Helminthorhapse japonica*, *Multina*, *Protopaleodictyon*, and *Paleodictyon miocenicum*. 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, fodinicchnia and chemichnia are rare.

Interval B is characterized by a highly significant decrease in trace fossil diversity and abundance. Only punctual records of *?Helminthopsis*, *Trichichnus*, *Nereites irregularis*, *Protopaleodictyon* are noted, mainly in the upper part of the interval. In the base of interval B, close to the interval A-B transition, only *Nereites* isp. is found. Most of the interval B ichnotaxa are post-depositional, winding and meandering structures, showing a dominant pascichnial behaviour.

Relatively frequent pre-depositional trace fossils at interval A,

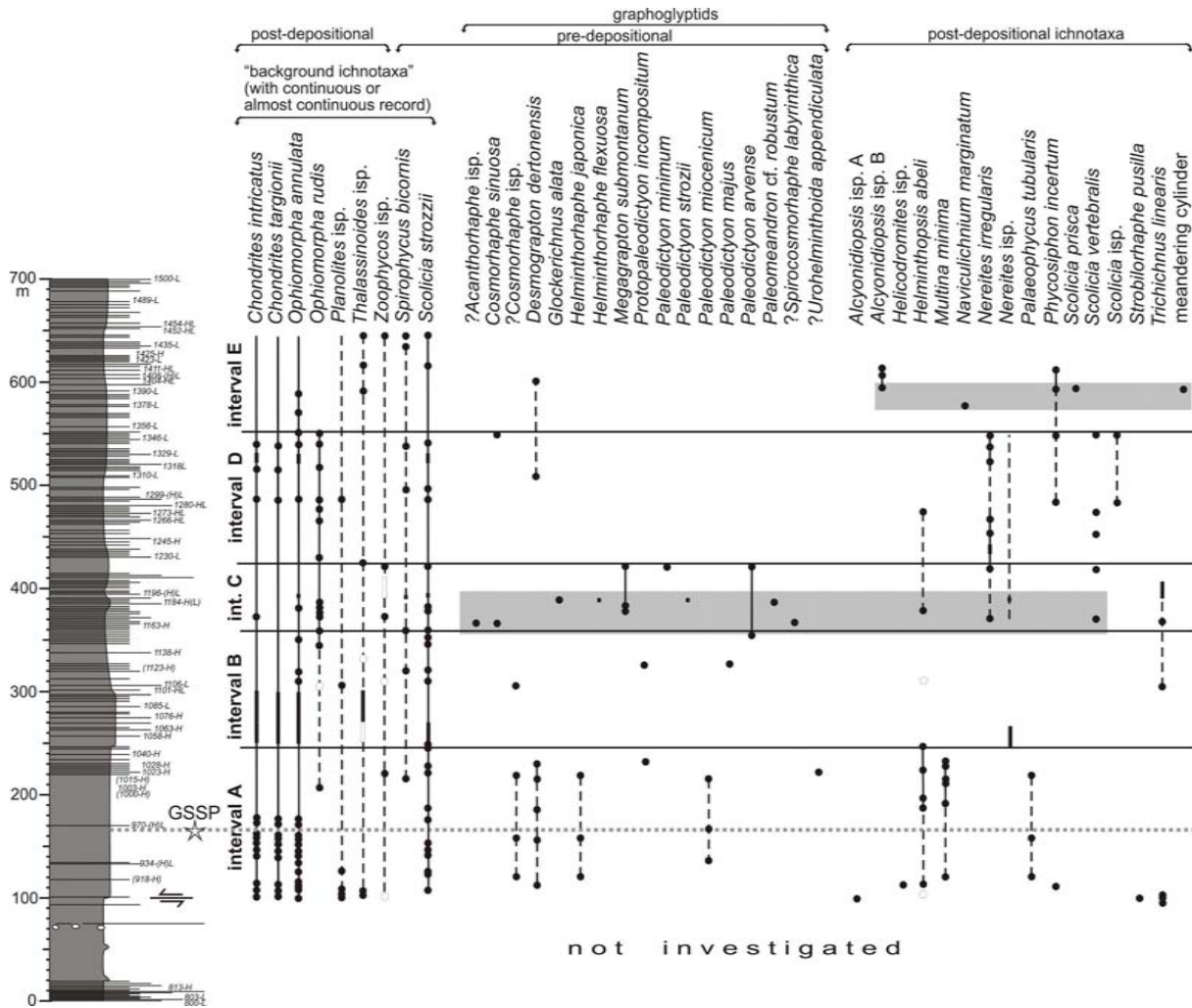


Figure 9. Synthetic log of the Gorrondatxe section with the vertical distribution of trace fossils and subdivisions into ichnological intervals A-E (after Rodríguez-Tovar et al., 2010). Continuous lines and rectangles for more or less continuous record, and filled points for punctual one. Dashed lines for discontinuous record. White rectangles and points for uncertain record (?) of a particular ichnotaxon. Grey bands for horizons with abundance of lowest occurrences in the section.

including several types of graphoglyptids, were 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 transgressive system tract and the lower-middle part of the subsequent highstand system tract. Limited lateral flux of nutrients due to the scarcity of turbidites and limited flux of nutrients from the water column promoted variable trace maker behaviours in competition for food, resulting in variable morphologies of trace fossils. The sharp near-disappearance of trace fossils in Interval B, including some graphoglyptids, indicates a worsening of ecological conditions.

Magnetostratigraphy

Sampling for magnetostratigraphy was conducted throughout a 700 m thick interval of the Gorrondatxe section (Dinarès-Turell in Bernaola et al., 2006b). Paleomagnetic sampling was basically restricted to the hemipelagic lithologies (mostly grey marls and marly limestones), which are potentially more suitable facies regarding palaeomagnetic behaviour. A total of 89 unique sampling sites were obtained, comprising 2 to 3 hand-samples per site.

Progressive stepwise alternating field (AF) demagnetization was routinely used and applied after a single heating step to 150°C. AF demagnetization included 14 steps (4, 8, 13, 17, 21, 25, 30, 35, 40, 45, 50, 60, 80, 100 mT). Characteristic remanent magnetizations (ChRM) were computed by least-squares fitting on the orthogonal demagnetization plots. The ChRM declination and inclination for each sample was used to derive the latitude of the virtual geomagnetic pole (VGP). This parameter was used as an indicator of the polarity (normal polarity for positive VGP latitudes and reverse polarity for negative VGP latitudes).

The ChRM components present either normal or reverse polarity in bedding-corrected coordinates. In a few cases, the calculated ChRM was regarded as unreliable (class B samples). We consider the demagnetization behaviour unsuitable for magnetostratigraphic interpretation in 30% of the analyzed specimens (class C samples) which mostly relate to very weak samples. The magnetostratigraphy is based on Class A samples (Fig. 10).

The primary nature of the ChRM is supported by: (1) the presence of a dual-polarity ChRM in addition to the low temperature present-day field overprint; (2) an unrealistic shallow inclination before bedding correction (e.g. not compatible with any geomagnetic Cenozoic field direction for Iberia); (3) changes in polarity do not seem to be lithologically controlled.

The VGP latitude derived from the ChRM directions yields a

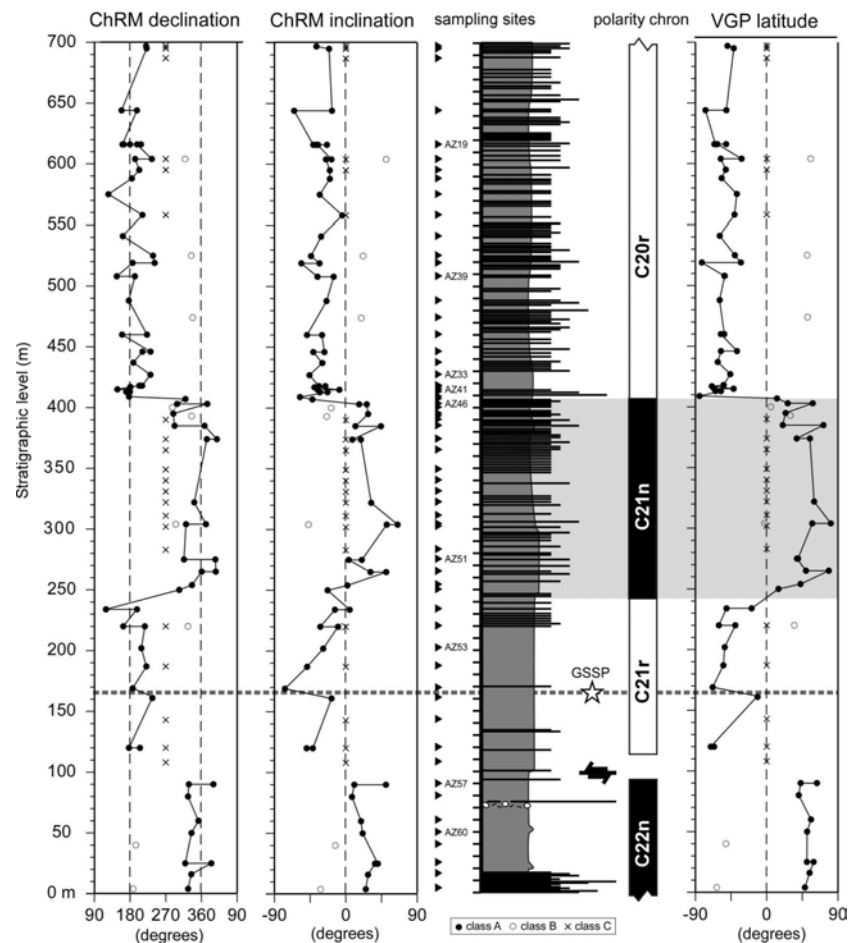
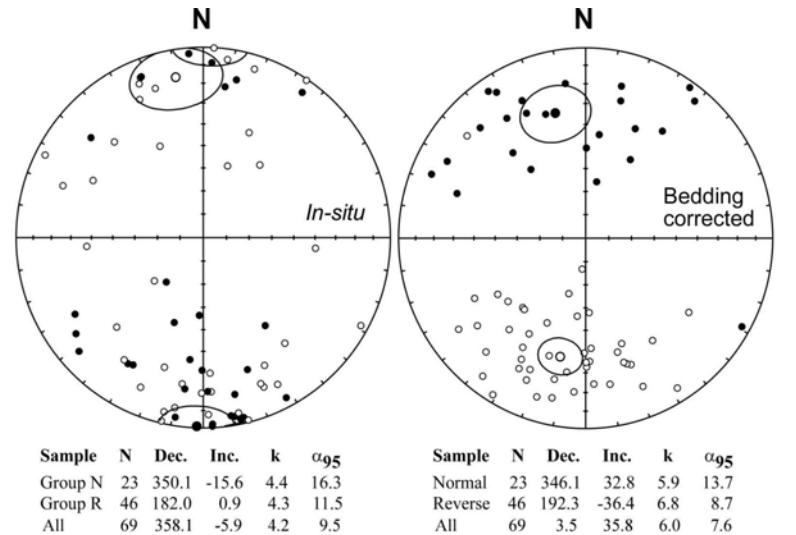


Figure 10. Above, equal-area projections of the ChRM directions before (in situ) and after bedding correction. The 95% confidence ellipse for the normal and reverse mean directions is indicated and statistical information is given. Below, stratigraphic variation of the ChRM directions and virtual geomagnetic pole (VGP) latitude and interpreted magnetic polarity stratigraphy plotted on a lithologic log of the Gorrondatxe section.

succession of four magnetozones (two normal and two reverse). The lower normal magnetozone, which correlates with planktic foraminifer *Acarinina bullbrooki* Zone (lower part of P9 and E7), calcareous nannofossil zones CP11-CP12a, and larger foraminifer Zone SBZ12

can be directly correlated to Chron C22n. The overlying reverse magnetozone, which includes the Lutetian GSSP level, is correlated to Chron C21r based on its stratigraphic position above the interval interpreted as Chron C22n and on the basis of calcareous nannofossil and nummulitid biostratigraphic data. The succeeding normal and reverse magnetozones correspond to chrons C21n and C20r, respectively, on the same basis (Fig. 10). Unfortunately, it was not possible to pinpoint unequivocally the C21r/C21n Chron boundary, as the interval between 223 and 242 m is ambiguous magnetostratigraphically. A plausible interpretation is that this ambiguous magnetic polarity does not record the original magnetic polarity, but a delayed re-magnetization. Similar palaeomagnetic uncertainties elsewhere have been interpreted as a result of delayed acquisition mechanisms during early diagenesis (Payros et al., 2011). In such scenarios, magnetic minerals can be formed at different times at different sedimentary levels due to early diagenetic diffusion of iron from anoxic layers into suboxic-oxic zones, where secondary magnetic minerals would then form, resulting in delayed remanence acquisition. The delayed signature typically extends by only a limited stratigraphic thickness below the true chron boundary. In consequence,

it is likely that the magnetostratigraphically ambiguous interval of Gorrondatxe actually corresponds to Chron C21r.

Summary of the Proposal of the GSSP for the Base of the Lutetian

Name of the Boundary: Base of Lutetian

Rank and status of the Boundary: Stage/Age GSSP

Position of the defined unit: Base of the lower middle Stage of the Eocene Series, between the Ypresian Stage and the Bartonian Stage.

Type locality of the GSSP: A section exposed on the cliffs of an easily accessible beach (named Gorrondatxe but also known as Azkorri) near the Getxo village in the western Pyrenees (province of Biscay, Basque Country, N Spain). The Gorrondatxe section fulfills most of the GSSP requisites demanded by the ICS (Table 2). The Gorrondatxe section is 700 m thick and is mostly composed of hemipelagic marls and limestones, but thin-bedded (<10 cm) siliciclastic turbidites are also common, with the

Table 2. Summary of evaluation of the Gorrondatxe section for holding the Lutetian GSSP.

REQUISITES TO BE FULFILLED BY A GSSP	PROPOSED LUTETIAN GSSP AT GORRONDATXE
Exposure over an adequate thickness of sediments.	Yes. The Ypresian-upper Lutetian succession is 2300 m thick; the upper Ypresian-lower Lutetian Gorrondatxe beach section is 700 m thick; the Ypresian/Lutetian transition interval is completely exposed and is almost 60 m thick.
Continuous sedimentation.	Yes, no hiatus was detected.
High sedimentation rate.	Yes, c. 11 cm/kyr for the Ypresian/Lutetian boundary interval, which lasted c. 550 kyr (the highest ever recorded by the Ypresian/Lutetian Working Group members).
Absence of syndimentary and tectonic disturbances.	Yes. The Ypresian/Lutetian Gorrondatxe turbidites are generally a few mm thick, tabular-shaped and flat-based, recording the effect of distal turbidity currents with low erosive capacity. The Gorrondatxe fault at 100 m from the base of the section does not affect the 60 m thick Ypresian/Lutetian boundary interval.
Absence of metamorphism and strong diagenetic alteration.	Yes. Ongoing clay mineral and stable isotope analyses suggest no metamorphism and little diagenetic overprinting.
Abundance and diversity of well-preserved fossils.	Yes. Up to date calcareous nannofossils, planktic foraminifers, larger foraminifers, smaller benthic foraminifers, ostracods, dinoflagellate cysts and ichnofossils have been studied.
Absence of vertical facies changes.	Yes. Although turbidite abundance varies along the section, it remains low within the Ypresian/Lutetian boundary interval.
Favourable facies for long-range biostratigraphic correlations (open marine environment).	Yes. Estimated paleo-sea depth is 1500 m; being located at a paleo-latitude of 35°N, correlations with both Boreal and Tethysian pelagic regions are possible. The combination of sequence stratigraphy, cyclostratigraphy and magnetostratigraphy allow correlation with shallow-marine and terrestrial deposits.
Amenability to radiometric dating.	Unknown, but absolute cyclostratigraphic dating is possible.
Amenability to magnetostratigraphy.	Yes, chrons C22n, C21r, C21n and C20r have been identified.
Amenability to chemostratigraphy.	Yes, but work is still in progress.
Accessibility.	Excellent.
Free access.	Yes, the section is located in a public beach.
Permanent protection of the site.	Yes. The whole coast is protected by the Spanish Littoral Law (22/1988, July 28); the Gorrondatxe beach is specially protected in order to preserve the endangered Natterjack toad (<i>Epidalea calamita</i>) from regional extinction. Local institutions (town and regional councils, University of the Basque Country) are willing to cooperate.
Possibility to fix a permanent marker.	Yes. Once the GSSP is approved, a permanent marker (a metal plate) will be fixed. Local institutions (town and regional councils, University of the Basque Country) are willing to cooperate.

exception of the Ypresian/Lutetian boundary interval that is mainly composed of hemipelagic marls (Fig. 11).

Geological setting: During the Eocene Epoch the Gorrondatxe area formed part of the bottom of a 1500 m deep marine gulf that opened into the Atlantic Ocean at approximately 35°N latitude. More than 2300 m of lower Ypresian to upper Lutetian deep-marine deposits accumulated on the bottom of this gulf. These deposits were uplifted and tilted during the Alpine Orogeny as part of the western Pyrenees Cordillera, and are now exposed in coastal cliffs that extend from the town of Sopela to the Galea Cape (Fig. 2).

Geographic location: The Gorrondatxe stratotype section is located 3 km from the centre of the Getxo village, 25 km NW of Bilbao, the capital city of the Biscay province, Basque Country, N of Spain.

Coordinates: Latitude: 43°22'46.47" N. Longitude: 3°00'51.61"W. Altitude: 20 m.

Map: The Gorrondatxe stratotype section is represented on the IGME Geological Map of Spain, number 37, sheet of Algorta (Getxo), 1:50,000, and the Geological Map of the Basque Country (EVE, Basque Government), number 37-IV, sheet of Getxo, scale 1:25,000 (available at <http://www.eve.es/publicaciones/cartografia/Mapas/37-IV.pdf>).

Accessibility: The Gorrondatxe beach section is easily accessible. The beach, awarded the European Union Blue Flag for water cleanliness and beach services, is equipped with a car park, fountains, bars and bus services (further details at <http://www.ehu.es/paleogene/getxo2009/GORRONDATXE.html>). The GSSP site was cleaned eliminating some vegetation and a path was cleared to access the precise level of the GSSP (Fig. 12).

Conservation: Being located in a public beach, the site is protected by the Spanish Littoral Law (22/1988, July 28). In addition, the site is specially protected in order to preserve the endangered Natterjack toad (*Epidalea calamita*) from regional extinction. Once the GSSP is approved, the Gorrondatxe section will be

protected as a Natural Park under the supervision of the Department of Stratigraphy and Paleontology of the University of the Basque Country.

GSSP definition: Meter 167.85 of the Gorrondatxe section in a dark marly level where the nannofossil *Blackites inflatus* has its lowest occurrence, approximately 47.76 Ma.

Identification in the field: The dark marly level, where the nannofossil *Blackites inflatus* lowest occurs, can be unmistakably identified in a mainly marly interval, 2.15 m below a 15 cm prominent turbidite at meter 170 (Fig. 4). Once the GSSP is approved, a permanent marker (a metal plate) will be fixed.

Completeness of the section: All the events that characterize the Ypresian/Lutetian transition worldwide were identified in the expected chronostratigraphic order in Gorrondatxe, showing that the succession is complete and continuous (Fig. 11). The great sedimentary thickness is one of the most outstanding features of the Gorrondatxe section, which is much thicker than in all the other Ypresian/Lutetian sections studied by the

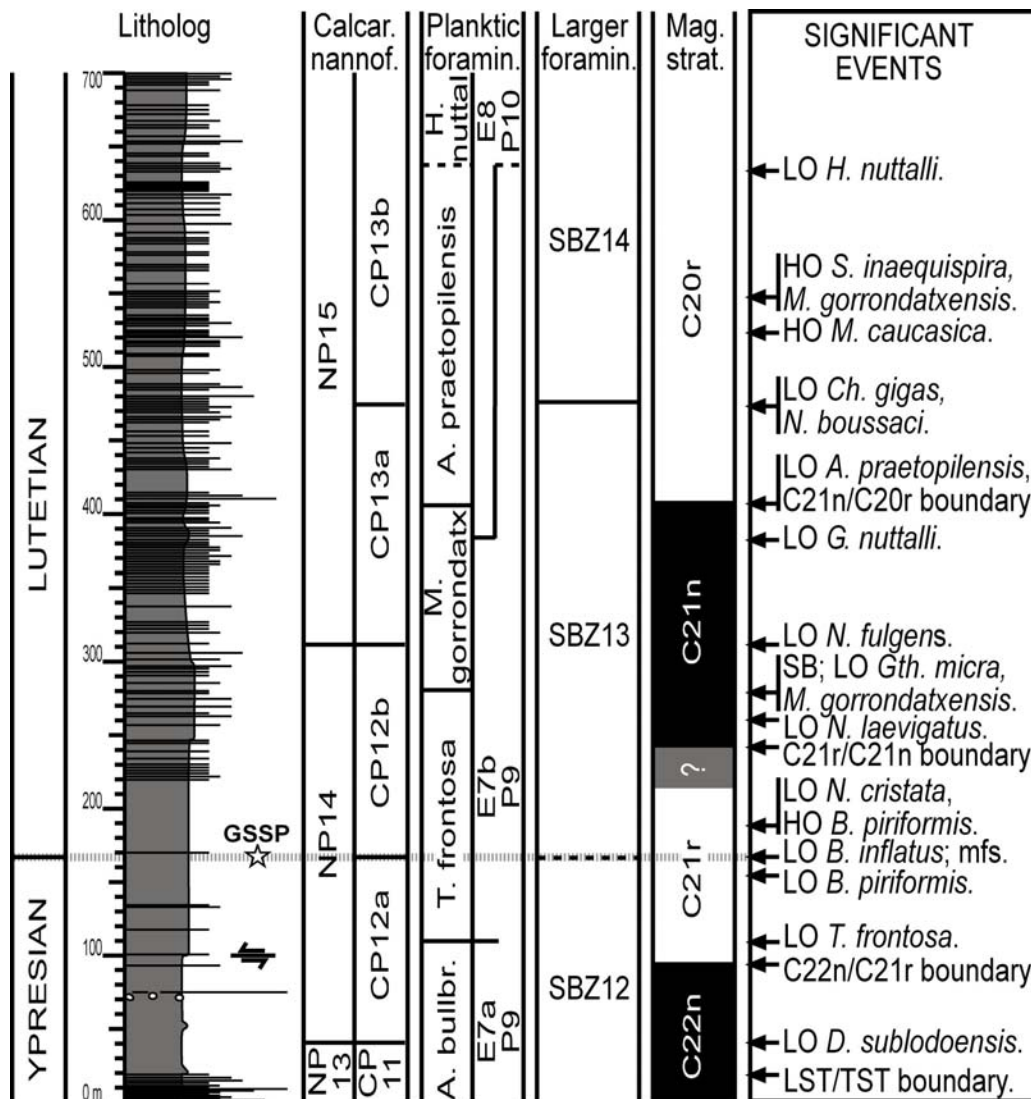


Figure 11. Summary of the biostratigraphy (calcareous nannofossils, planktic foraminifera and larger foraminifera), magnetostratigraphy and sequence stratigraphy in the Gorrondatxe section. The most important events around the Ypresian/Lutetian boundary are depicted in the right-hand box (SB: sequence boundary; LST: lowstand systems tract; TST: transgressive systems tract; mfs: maximum flooding surface; HST: highstand systems tract).



Figure 12. Panoramic view of the Gorrondatxe section from meter 100 to 400 and detail view of the Ypresian-Lutetian transition in which the Lutetian GSSP is marked.

Ypresian/Lutetian Boundary Working Group. Hence, successive biostratigraphic and magnetostratigraphic events are more separate in the Gorrondatxe section than in other sections. Such a great thickness is the result of frequent turbiditic beds, which are generally distal, tabular-shaped and flat-based, recording therefore the effect of turbidity currents with low erosive capacity. Luckily, some of these turbidity currents supplied penecontemporaneous larger foraminifera, allowing thus correlation with coeval shelfal deposits. Despite the turbidite content, the astronomical Milankovitch signal can be readily recognized in the pelagic sediments, which allows cyclostratigraphic calibration of all the events that characterize the Ypresian/Lutetian transition (Fig. 4).

Global correlation: Multiple elements for global correlation across the Ypresian/Lutetian boundary were identified, allowing global correlation (Fig. 11). The following elements have been studied: calcareous nannofossils, planktic foraminifera, small benthic foraminifera, larger foraminifera, ostracods, dinoflagellate cysts,

ichnofossils, magnetostratigraphy, cyclostratigraphy and sequence stratigraphy. One major advantage of Gorrondatxe is its intermediate location between the North Sea (boreal) region, where the historical Ypresian and Lutetian stratotype sections were defined, and the more southerly Tethys region. The Gorrondatxe section thus contains faunal and floral elements representative of both regions and this facilitates correlation between high- and low-latitude regions worldwide. The occurrence of reworked shallow-marine taxa allows approaching the position of the GSSP in such settings. The Gorrondatxe section appears to have been affected by the same sea-level changes as other sites worldwide. In the Pyrenean region where the Gorrondatxe section is located correlations can be made with coeval successions that represent a wide range of sedimentary environments, including submarine slopes, shallow-marine shelves, coastal areas and even terrestrial environments. This potential opens the prospect for improving the correlation of events represented in different geological time

scales. The potential for precise global correlation of the GSSP is further enhanced by the combination of biostratigraphic, magnetostratigraphic and sequence stratigraphic information with cyclostratigraphy.

Primary correlation marker: The best event for global marine correlation is the lowest occurrence of the calcareous nannofossil *Blackites inflatus*.

Secondary correlation markers: The highest occurrences of the dinoflagellate cyst *Charlesdowniea columna* and of intermediate forms between *Eatonicysta ursulae* and *Eatonicysta glabra* take place between 63 m and 110 m which may be synchronous with their HO's in high-latitude sections (Norwegian-Greenland Sea and NW Europe). The C22n/C21r magnetic reversal lies 39 precession-related mudstone-marl couplets below the Lutetian GSSP, which represent 819 kyr (assuming a modern mean precession period of 21 kyr); by the same means the C21r/C21n magnetic reversal is 507 kyr younger than the GSSP. The acme of the calcareous nannofossil *Discoaster subloedoensis* and the lowest occurrence of the planktic foraminifer *Turborotalia frontosa* were found 26 precession couplets (546 kyr) below the GSSP. The lowest occurrence of the calcareous nannofossil *Blackites piriformis* was found to be 105 kyr (five precession couplets) older than the GSSP, whereas its highest occurrence, as well as the lowest occurrence of *Nannotetrina cristata*, is 115 kyr younger than the GSSP. The lowest occurrences of the planktic foraminifers *Morozovella gorrondatxensis* and *Globigerinatheka micra* are 1.25 Myr younger than the GSSP. The shallow-marine larger foraminiferal SBZ12/13 boundary is located close to the GSSP, although this needs further refinements. The GSSP corresponds to the maximum flooding surface of a possibly global depositional sequence, the lower and upper boundaries of which correlate with oxygen isotope events Ei5 and Ei6 (Pekar et al., 2005). In relationship with the maximum flooding surface, an increase in the abundance of the opportunistic, smaller benthic foraminifera *Aragonia aragonensis* starts nine precession cycles (189 kyr) above the GSSP. The correlation of the maximum flooding surface between marine and coastal/terrestrial successions showed that the Lutetian GSSP is younger than the base of mammal Zone MP10 and older than MP14 (Payros et al., 2009b).

Acknowledgements

We would like to thank all people that collaborated in the long process of defining the base of the Lutetian. We greatly acknowledge those members of the Ypresian/Lutetian Working Group that could not attend the final Workshop in Getxo 2009, who actively participated studying the Gorrondatxe section and could not vote, but agree with the proposal. Furthermore, we are grateful to Stan Finney, Jim Ogg, Isabella Premoli Silva, Birger Schmitz, Paul Pearson, Hellen Coxall and Bridget Wade for constructive comments and suggestions, which improved the original proposal. Financial support was mainly provided by different projects of the Ministry of Science and Innovation of Spain, the Town Council of Getxo and the Basque Government.

References

Agnini, C., Muttoni, G., Kent, D.V. and Rio, D., 2006. Eocene biostratigraphy

and magnetic stratigraphy from Possagno, Italy: the calcareous nannofossil response to climate variability. *Earth and Planetary Science Letters*, v. 241, pp. 815-830.

Ali, J.R. and Hailwood, E.A., 1995, Magnetostratigraphy of upper Paleocene through lower middle Eocene strata of NW Europe. *Society of Economic Paleontologists and Mineralogists. Special Publication*, v. 54, pp. 271-274.

Ascoli, P., 1975, Gli ostracodi della sezione paleocenico-eocenica di Possagno. *Schweizer. Paläont. Abhandl.*, v. 97, pp. 137-139; 213-214.

Aubry, M.P., 1983, Biostratigraphie du Paléogène épicontinental de l'Europe du Nord-Ouest. Etude fondée sur les nannofossiles calcaires. Doctoral thesis, Laboratoire Géologie Faculté Sciences, Lyon, v. 89, pp. 320.

Aubry, M.P., 1986, Paleogene calcareous nannoplankton biostratigraphy of North-western Europe. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 55, pp. 267-334.

Aubry, M.P., 1995, From Chronology to Stratigraphy: interpreting the lower and middle Eocene stratigraphic record in the Atlantic Ocean. *In* Berggren, W.A., Kent, D.V., Aubry, M.P. and Hardenbol, J., eds. *Geochronology, time scales and global stratigraphic correlation*. *SEPM Special Publication*, v. 54, pp. 213-274.

Aubry, M.P., Hailwood, E.A. and Townsend, H.A., 1986. Magnetic and calcareous-nannofossil stratigraphy of the lower Palaeogene formations of the Hampshire and London basins. *Jour. Geol. Soc. London*, v. 143, pp. 729-735.

Backman, J., 1986, Late Paleocene to middle Eocene calcareous nannofossil biochronology from the Shatsky Rise, Walvis Ridge and Italy. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 57, pp. 43-59.

Berggren, W. A. and Miller, K. G., 1989. Cenozoic bathyal and abyssal calcareous benthic foraminiferal zonation. *Micropaleontology*, v. 35, pp. 308-320.

Berggren, W.A. and Pearson, P.N., 2005, A revised tropical to subtropical Paleogene planktonic foraminiferal zonation. *Journal of Foraminiferal Research*, v. 35, pp. 279-298.

Berggren, W.A., Kent, D.V., Swisher, C.C. and Aubry, M.A., 1995, A revised Paleogene geochronology and chronostratigraphy. *In* Berggren, W.A., Kent, D.V., Aubry, M.P. and Hardenbol, J., eds. *Geochronology, time scales and global stratigraphic correlation*. *SEPM Special Publication* v. 54, pp. 129-212.

Bernaola, G., Nuño-Arana, Y. and Payros, A., 2006a. Análisis bioestratigráfico del Eoceno Inferior de la sección de Barinatxe (Pirineos occidentales) mediante nanofósiles calcáreos. *Geogaceta*, v. 40, pp. 175-178.

Bernaola, G., Orue-Etxebarria, X., Payros, A., Dinarès-Turell, J., Tosquella, J., Apellaniz, E. and Caballero, F., 2006b, Biomagnetostratigraphic analysis of the Gorrondatxe section (Basque Country, Western Pyrenees): Its significance for the definition of the Ypresian/Lutetian boundary stratotype. *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, v. 241, pp. 67-109.

Blondeau, A., 1981, Lutetian. *In* Pomerol, Ch., ed. *Stratotypes of Paleogene Stages*. *Bulletin d'Information des Géologues du Bassin de Paris, Mémoire hors série 2*, pp. 167-180.

Blondeau, A. Cavellier, C., Feugueur, L. and Pomerol, Ch., 1965, Stratigraphie du Paléogène du Bassin de Paris en relation avec les bassins avoisinants. *Bulletin de la Société géologique de France*, v. 7 (7), pp. 200-221.

Blow, W.H., 1979, The Cenozoic Globigerinida: A Study of the Morphology, Taxonomy, Evolutionary Relationships and the Stratigraphical Distribution of Some Globigerinida (Mainly Globigerinacea), 3 vols, 1413 pp. E.J. Brill, Leiden, The Netherlands.

Bold, W.A., van den, 1960, Eocene and Oligocene ostracoda of Trinidad. *Micropaleontology*, v. 6, pp. 231-254.

Bolli, H. M., Beckmann, J. P. and Saunders, J. B., 1994. Benthic foraminiferal biostratigraphy of the South Caribbean region. *Cambridge University Press*, 408 pp.

Bown, P.R., 2005. Palaeogene calcareous nannofossils from the Kilwa and Lindi areas of coastal Tanzania (Tanzania Drilling Project 2003-4). *Journal of Nannoplankton Research*, v. 27(1), pp. 21-95.

Bralower, T.J., 2005. Data report: Paleocene-early Oligocene calcareous

- nannofossil biostratigraphy, ODP Leg 198 Sites 1209, 1210, and 1211 (Shatsky Rise, Pacific Ocean). In Bralower, T.J., Premoli Silva, I., and Malone, M.J. (Eds.), *Proc. ODP, Sci. Results*, v. 198, pp. 1–15.
- Bramlette, M.N. and Sullivan, F.R. 1961. Coccolithophorids and related nannoplankton of the early Tertiary in California. *Micropaleontology*, v. 7, pp. 129-174.
- Brinkhuis, H., Schouten, S., Collinson, M.E., et al. 2006. Episodic fresh surface waters in the Eocene Arctic Ocean. *Nature*, v. 441, pp. 606–609.
- Bujak, J.P., Downie, C., Eaton, G.L., and Williams, G.L. 1980. Dinoflagellate cysts and acritarchs from the Eocene of Southern England. *Special Papers in Palaeontology*, v. 24, 100 pp.
- Bukry, D., 1973. Low-latitude coccolith biostratigraphic zonation. In Edgar, N.T., Saunders, J.B., et al., *Init. Repts. DSDP*, v. 15: Washington (U.S. Govt. Printing Office), pp. 685-703.
- Cavelier, C. and Pomerol, Ch. 1986, *Stratigraphy of the Paleogene*. *Bulletin de la Société géologique de France*, v. 2, pp. 255-265.
- Coles, G.P. and Whatley, R.C., 1989, New Palaeocene to Miocene genera and species of ostracoda from DSDP sites in the North Atlantic. *Revista Española de Micropaleontología*, v. 21, pp. 81-124.
- De Geyter, G., De Man, E., Herman, J., Jacobs, P., Moorkens, T., Steurbaut, E. and Vandenberghe, N. 2006. Disused Paleogene regional stages from Belgium: Montian, Heersian, Landenian, Paniselian, Bruxellian, Laekenian, Ledian, Wemmelian and Tongrian. *Geologica Belgica*, v. 9(1-2), pp. 203-213.
- De Lapparent, A., 1883, *Traité de Géologie*, Savy, Paris, 1280 pp.
- Ducasse, O., 1975, Les associations fauniques d'ostracodes de l'Eocène moyen et supérieur dans le Sud du Bassin d'Aquitaine: distribution schématique et valeur paléocéologique. *Bull. Inst. Geol. Bassin Aquitaine*, v. 17, pp. 17-26.
- Dumont, A., 1850, Rapport sur la carte géologique du Royaume. *Bull. Acad. R. Sci. Lett. Beaux-Arts Belgique*, v. 16, pp. 351-371.
- Eaton, G.L. 1976. Dinoflagellate cysts from the Bracklesham Beds (Eocene) of the Isle of Wight, Southern England. *Bulletin of the British Museum of natural History (Geology)*, v. 26, pp. 227-332.
- Eldrett, J.S., Harding, I.C., Firth, J.V., and Roberts, A.P. 2004, Magnetostratigraphic calibration of Eocene-Oligocene dinoflagellate cyst biostratigraphy from the Norwegian-Greenland Sea. *Marine Geology*, v. 204, pp. 91-127.
- Gonzalvo, C., Mancheño, M.A., Molina, E., Rodríguez-Estrella, T. and Romero, G. 2001, El límite Ypresiense/Luteciense en la Región de Murcia (Cordillera Bética, España). *Geogaceta*, v. 29, pp. 65-68.
- Gradstein, F.M., Ogg, J.G. and Smith, A.G., 2004. *A geologic time scale 2004*. Cambridge, Cambridge University Press, 589 pp.
- Guernet, C., 1982, Contribution à l'étude des faunes abyssales: les ostracodes Paléogènes du bassin des Bahamas, Atlantique Nord (DSDP Leg 44) *Revue de Micropaleontologie*, v. 25, pp. 40-56.
- Haq, B.U., Hardenbol, J. and Vail, P.R., 1988, Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In: Wilgus, C.K., Posamentier, H., Ross, C.K., Kendall, C.G.St.C. (Eds.), *Sea-level changes: an integrated approach*. Soc. Econ. Paleontol. Mineral. (SEPM), Spec. Publ. v. 42, pp. 71-108.
- Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., De Graciansky, P.C. and Vail, P.R., 1998, Mesozoic and Cenozoic sequence chronostratigraphic framework of European Basins. In: De Graciansky, P.C., Hardenbol, J., Jacquin, T. and Vail, P.R. (Eds.), *Mesozoic and Cenozoic sequence stratigraphy of European basins*. SEPM (Society for Sedimentary Geology) special publication, v. 60, pp. 3-13.
- Hooyberghs, H.J.F., 1992, A new dating of the Brussels Sand Formation (Lower-Middle Eocene) on planktonic foraminifera from St-Stevens-Woluwe and Neerijse, Belgium. *Tertiary Research*, v. 14(1), pp. 33-49.
- Hottinger, L., 1977, Foraminifères operculiniformes. *Mém. Mus. Natl. Hist. Nat. Paris*, XL, 159 pp.
- Hottinger, L. and Schaub, H., 1960, Zur Stufeneinteilung des Paleozäns und Eozäns. Einführung der Stufen Ilerdien und Biarritzien. *Eclogae Geologicae Helvetica*, v. 53, pp. 453-480.
- Iakovleva, I.A. and Heilmann-Clausen, C., 2010, Eocene dinoflagellate cyst biostratigraphy of research borehole 011-BP, Omsk region, southwestern Siberia. *Palynology*, v. 34, pp. 195-232.
- Jenkins, D.J. and Luterbacher, H., 1992, Paleogene stages and their boundaries (Introductory remarks). *Neues Jahrbuch für Geologie und Paläontologie Abhandlungen*, v. 186, pp. 1-5.
- Jovane, L., Sprovieri, M., Coccioni, R., Florindo, F., Marsili, A., Laskar, J., 2010. Astronomical calibration of the middle Eocene Contessa Highway section (Gubbio, Italy). *Earth and Planetary Science Letters*, v.298, pp. 77-88.
- Kaminski, M.A. and Gradstein, F., 2005. *Atlas of Paleogene Cosmopolitan Deep-Water Agglutinated Foraminifera*. Grzybowski Foundation Special Publication, v. 10, pp. 1-548.
- Lapparent, A.D., 1883, *Traité de Géologie* Paris. Paris, Savy.
- Larrasoaña, J.C., Gonzalvo, C., Molina, E., Monechi, S., Ortiz, S., Tori, F. and Tosquella, J., 2008, Integrated magnetobiochronology of the Early/Middle Eocene transition at Agost (Spain): implications for defining the Ypresian/Lutetian boundary stratotype. *Lethaia*, v. 41, pp. 395-415.
- Leszczyński, S. and Uchman, A., 1993, Biogenic structures of organic-poor sediments: examples from the Paleogene variegated shales, Polish Outer Carpathians. *Ichnos*, v. 2, pp. 267-275.
- Liu, L., 1996. Eocene Calcareous Nannofossils from the Iberia Abyssal Plain. In Whitmarsh, R.B., Sawyer, D.S., Klaus, A., and Masson, D.G. (Eds.), 1996. *Proceedings of the Ocean Drilling Program, Scientific Results*, v. 149, p. 61-78.
- Luterbacher, H.P., Ali, J.R., Brinkhuis, H., Gradstein, F.M., Hooker, J.J., Monechi, S., Ogg, J.G., Powell, J., Röhl, U., Sanfilippo, A. and Schmitz, B., 2004, The Paleogene period. In: Gradstein, F.M., Ogg, J.G. and Smith, A.G. eds., *A Geologic Time Scale 2004*. Cambridge University Press, pp. 384-408.
- Lyle, M.W., Wilson, P.A., Janacek, T.R., Backman, J., Busch, W.H., Coxall, H., Faul, K., Gaillot, P., Howan, S.A., Knoop, P., Kruse, S., Lanci, L., Lear, C., Moore, T.C., Nigrini, C.A., Nishi, H., Nomura, R., Norris, R.D., Pälke, H., Pares, J.M., Quintin, L., Rafi, I., Rea, B.R., Rea, D.K., Steiger, T.H., Tripathi, A., Vandenberg, M.D. and Wade, B., 2002. Paleogene equatorial transect: sites, *Proceeding ODP, Initial Reports*, v. 199, pp. 1215-1222.
- McGonigal, K.L., and Wise, S.W., Jr., 2001. Eocene calcareous nannofossil biostratigraphy and sediment accumulation of turbidite sequences on the Iberia Abyssal Plain, ODP Sites 1067–1069. In Beslier, M.-O., Whitmarsh, R.B., Wallace, P.J., and Girardeau, J. (Eds.), *Proc. ODP, Sci. Results*, v. 173, pp. 1–35.
- Martini, E., 1971, Standard Tertiary and Quaternary calcareous nannoplankton zonation. In Farinacci, A. (Ed.) *Proceeding of the 2nd Planktonic Conference*, Roma, v. 2, pp. 739-785.
- Michoux, D., 1985, Palynostratigraphie de l'Éocène de Montford-en-Chalosse (Landes, France). *Revue de Micropaléontologie*, v. 28, pp. 138-153.
- Miller III, W., 1991, Paleocology of graphoglyptids. *Ichnos*, v. 1, pp. 305-312.
- Miller, K.G., Mountain, G.S., Browning, J.V., Kominz, M., Sugarman, P.J., Christie-Blick, N., Katz, M.E. and Wright, J.D., 1998, Cenozoic global sea level, sequences and the New Jersey transect: results from coastal plain and continental slope drilling. *Rev. Geophys.*, v. 36, pp. 569-601.
- Mita, I., 2001. Data Report: Early to late Eocene calcareous nannofossil assemblages of Sites 1051 and 1052, Blake Nose, northwestern Atlantic Ocean. In Kroon, D., Norris, R.D., and Klaus, A. (Eds.), *Proc. ODP, Sci. Results*, v. 171B, pp. 1–28.
- Molina, E., Cosovic, V., Gonzalvo, C. and Von Salis, K., 2000, Integrated biostratigraphy across the Ypresian/Lutetian boundary at Agost, Spain. *Revue de Micropaléontologie*, v. 43, pp. 381-391.
- Molina, E., Gonzalvo, C., Mancheño, M.A., Ortiz, S., Schmitz, B., Thomas, E. and von Salis, K., 2006, Integrated stratigraphy and chronostratigraphy across the Ypresian-Lutetian transition in the Fortuna Section (Betic Cordillera, Spain). *Newsletters on Stratigraphy*, v. 42(1), pp. 1-19.
- Monechi, S., and Thierstein, H.R., 1985, Late Cretaceous-Eocene nannofossil and magnetostratigraphic correlations near Gubbio, Italy. *Marine Micropaleontology*, v. 9, pp. 419-440.

- Okada, H. and Bukry, D., 1980, Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). *Marine Micropaleontology*, v. 5, pp. 321-325.
- Ortiz, S., and Thomas, E., 2006, Lower-middle Eocene benthic foraminifera from the Fortuna section (Betic Cordillera, southeastern Spain). *Micropaleontology*, v. 52, pp. 97-150.
- Ortiz, S., Gonzalvo, C., Molina, E., Rodríguez-Tovar, F.J., Uchman, A., Vandenberghe, N., and Zeelmaekers, E., 2008, Palaeoenvironmental turnover across the Ypresian-Lutetian transition at the Agost section, southeastern Spain: in search of a marker event to define the Stratotype for the base of the Lutetian Stage. *Marine Micropaleontology*, v. 69, pp. 297-313.
- Ortiz, S., Alegret, L., Payros, A., Orue-Etxebarria, X., Apellaniz, E. and Molina, E., 2011, Distribution patterns of benthic foraminifera across the Ypresian-Lutetian Gorrondatxe section, Northern Spain: response to sedimentary disturbance. *Marine Micropaleontology*, v. 78, pp. 1-13.
- Orue-Etxebarria, X., 1985, Descripción de dos nuevas especies de foraminíferos planctónicos en el Eoceno costero de la provincia de Bizkaia. *Revista Española de Micropaleontología*, v. 17, pp. 467-477.
- Orue-Etxebarria, X. and Apellaniz, E. 1985, Estudio del límite Cuisiense-Luteciense en la Costa Vizcaína por medio de foraminíferos planctónicos. *Newsletters on Stratigraphy*, v. 15(1), pp. 1-12.
- Orue-Etxebarria, X., Lamolda, M. and Apellaniz, E., 1984, Bioestratigrafía del Eoceno vizcaíno por medio de los foraminíferos planctónicos. *Revista Española de Micropaleontología*, v. 16, pp. 241-263.
- Orue-Etxebarria, X., Payros, A., Bernaola, G., Dinarès-Turell, J., Tosquella, J., Apellaniz, E. and Caballero, F., 2006, The Ypresian/Lutetian boundary at the Gorrondatxe beach section (Basque Country, W Pyrenees). *Climate and Biota of the Early Paleogene 2006. Mid Conference Field Excursion Guidebook, Bilbao*. 36 pp.
- Orue-Etxebarria, X., Payros, A., Caballero, F., Molina, E., Apellaniz, E. and Bernaola, G., 2009, The Ypresian/Lutetian transition in the Gorrondatxe beach (Getxo, western Pyrenees): review, recent advances and future prospects. *Compilation and Abstract Book of the International Workshop on the Ypresian/Lutetian Boundary Stratotype (Getxo, 25-27 september 2009)*, 215 pp. ISBN: 978-84-692-44876.
- Payros, A., Orue-Etxebarria, X. and Pujalte, V., 2006, Covarying sedimentary and biotic fluctuations in Lower-Middle Eocene Pyrenean deep-sea deposits: Palaeoenvironmental implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 234 (2-4), pp. 258-276.
- Payros, A., Bernaola, G., Orue-Etxebarria, X., Dinarès-Turell, J., Tosquella, J. and Apellaniz, E., 2007, Reassessment of the Early–Middle Eocene biomagnetostratigraphy based on evidence from the Gorrondatxe section (Basque Country, western Pyrenees). *Lethaia*, v. 40, pp. 183–195.
- Payros, A., Orue-Etxebarria, X., Bernaola, G., Apellaniz, E., Dinarès-Turell, J., Tosquella, J., and Caballero, F., 2009a, Characterization and astronomically calibrated age of the first occurrence of *Turborotalia frontosa* in the Gorrondatxe section, a prospective Lutetian GSSP: implications for the Eocene time scale. *Lethaia*, v. 42, pp. 255-264.
- Payros, A., Tosquella, J., Bernaola, G., Dinarès-Turell, J., Orue-Etxebarria, X. and Pujalte, V., 2009b, Filling the North European Early/Middle Eocene (Ypresian/Lutetian) boundary gap: Insights from the Pyrenean continental to deep-marine record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 280, pp. 313-332.
- Payros, A., Dinarès-Turell, J., Bernaola, G., Orue-Etxebarria, X., Apellaniz, E. and Tosquella, J., 2011, On the age of the Early/Middle Eocene boundary and other related events: cyclostratigraphic refinements from the Pyrenean Otsakar section and the Lutetian GSSP. *Geological Magazine*, v. 148, pp.442-460.
- Pearson, P.N., Nicholas, C.J., Singano, J.M., Bown, P.R., Coxall, H.K., van Dongen, B.E., Huber, B.T., Karega, A., Lees, J.A., Msaky, E., Pancost, R.D., Pearson, M. and Roberts, A.P., 2004: Paleogene and Cretaceous sediment cores from Kilwa and Lindi areas of coastal Tanzania: Tanzania Drilling Project Sites 1–5. *Journal of African Earth Sciences*, v. 39, pp. 25–62.
- Pearson, P.N., Olsson, R.K., Huber, B.T., Hemleben, C. and Berggren, W.A., 2006. *Atlas of Eocene planktonic foraminifera*. Cushman Foundation Special Publication No. 1, 514 pp.
- Pekar, S.F., Hucks, A., Fuller, M. and Li, S., 2005, Glacioeustatic changes in the early and middle Eocene (51-42 Ma): shallow-water stratigraphy from ODP Leg 189 Site 1171 (South Tasman Rise) and deep-sea ^{18}O records. *Geol. Soc. Amer. Bull.*, v. 117, pp. 1081-1093.
- Perch-Nielsen, K., 1971, Elektronenmikroskopische Untersuchungen an Coccolithen un verwandten Formen aus dem Eozän von Dänmark. *K. Dan. Vidensk. Selsk. Biol. Skr.*, v. 18, pp. 1-76.
- Perch-Nielsen, K., 1985, Cenozoic calcareous nannofossils. In: Bolli et al. (eds.) *Plankton Stratigraphy*. Cambridge University Press, pp. 427-554.
- Plint, A.G., 1988, Global eustacy and the Eocene sequence in the Hampshire basin, England. *Basin Res.*, v. 1, pp. 11-22.
- Pokorny, V., 1975, Discovery of deep-sea ostracodes in the Paleogene of the Czechoslovak Carpathians and its significance. *Vestník Ustredniho Ustavu Geologicweho*, v. 50, pp. 37-39.
- Premoli-Silva, I., Rettori, R. and Verga, D., 2003, Practical manual of Paleocene and Eocene planktonic foraminifera. In: Rettori, R. and Verga, D. (eds): *International School on planktonic foraminifera, 2nd course, Paleocene and Eocene*, 152 pp.; Perugia (Univ. Perugia, Tipografia Pontefelcino).
- Rodríguez-Lázaro, J. and García-Zarraga, E., 1996, Paleogene deep-marine ostracodes from the Basque Basin. In Keen, M.C. ed. *Proceedings of the 2nd European Ostracodologists Meeting at Glasgow, 1993*. British Micropaleontological Society, pp. 79-85.
- Rodríguez-Tovar F.J., Uchman A., Payros A., Orue-Etxebarria X., Apellaniz E. and Molina E., 2010, Sea-level dynamic and palaeoclimatological factors affecting trace fossil distribution in Eocene turbiditic deposits from the Gorrondatxe section, N Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 285, pp. 50-65.
- Rögl, F. and Egger, H., 2010, The missing link in the evolutionary origin of the foraminiferal genus *Hantkenina* and the problem of the lower-middle Eocene boundary. *Geology*, v. 38, pp. 23-26.
- Romein, A.J.T., 1979, Lineages in early Paleogene calcareous nannoplankton. *Utrecht Micropaleontological Bulletin*, v. 22, pp. 1-230.
- Schaub, H., 1981, Nummulites et Assilines de la Téthys paléogène. *Taxinomie, phylogénèse et biostratigraphie*. *Mém. suisses Paléontol.*, 104-106, 236 p.
- Seilacher, A., 1974, Flysch trace fossils: Evolution of behavioural diversity in the deep-sea. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte*, v. 1974, pp. 223-245.
- Seilacher, A., 1977, Pattern analysis of *Paleodictyon* and related trace fossils. *En: Trace fossils 2 (Crimes, T.P. and Harper, J.C., eds.)*. *Geological Journal, Special Issue*, v. 9, pp. 289-334.
- Serra-Kiel, J., Hottinger, L., Caus, E., Drobne, K., Ferrández, C., Jauhri, A.K., Less, G., Pavlovec, R., Pignatti, J., Samsó, J.M., Schaub, H., Sirel, E., Strougo, A., Tambareau, Y., Tosquella, J. and Zakrevskaya, E., 1998, Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. *Bulletin de la Société géologique de France*, v. 169, pp. 281–299.
- Stainforth, R.M., Lamb, J.L., Luterbacher, H., Beard, J.H. and Jeffers, R.M., 1975, Cenozoic planktonic foraminifera zonation and characteristics of index forms. *Lawrence (Univ. of Kansas), Paleont. Contr.*, v. 62, pp. 1-425.
- Sturbaut, E., 1988, New Early and Middle Eocene calcareous-nannoplankton events and correlation in middle to high latitudes of the northern hemisphere. *Newsletters on Stratigraphy*, v. 18(2), pp. 99-115.
- Sturbaut, E., 2006, Ypresian. *Geol. Belg.*, v. 9, pp. 73-93.
- Toumarkine, M. and Luterbacher, H., 1985, Paleocene and Eocene planktonic foraminifera. In: Bolli, H.M., Saunders, J.B. and Perch-Nielsen, K. (eds): *Plankton stratigraphy*, Cambridge University Press, pp. 85-154
- Tucholke, B.E., Sibuet, J.-C., Klaus, A., et al., 2004. *Proc. ODP, Init. Repts.*, 210: College Station, TX (Ocean Drilling Program). doi:10.2973/odp.proc.ir.210.2004
- Uchman, A. 1999, Ichnology of the Rhenodanubian Flysch (Lower Cretaceous-Eocene) in Austria and Germany. *Beringeria*, v. 25, pp. 67-173.
- Uchman, A., 2003, Trends in diversity, frequency and complexity of

- graphoglyptid trace fossils: evolutionary and palaeoenvironmental aspects. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 192, pp. 123-142.
- Vandenbergh, N., Laga, P., Steurbaut, E., Hardenbol, J. and Vail, P.R., 1998, Tertiary sequence stratigraphy at the southern border of the North Sea Basin in Belgium. *Society of Economic Paleontologists and Mineralogists. Special Publication*, v. 60, pp. 119-154.
- Vandenbergh, N., Van Simaey, S., Steurbaut, E., Jagt, J.W.M. and Felder, P.J., 2004, Stratigraphic architecture of Upper Cretaceous and Cenozoic along the southern border of the North Sea Basin in Belgium. *Netherlands Jour. Geosci.*, v. 83, pp. 155-171.
- Wade, B.S., Pearson, P.N., Berggren, W.A., and Pälike, H., 2011. Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the Geomagnetic Polarity and Astronomical Time Scale. *Earth-Science Reviews*, v. 104, pp. 111-142.
- Wei, W., and Wise, S.W., Jr., 1990. Biogeographic gradients of Middle Eocene–Oligocene calcareous nannoplankton in the South Atlantic Ocean. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 79, pp. 29–61.
- Westerhold, T., Röhl, U., 2009. High resolution cyclostratigraphy of the early Eocene: new insights into the origin of the Cenozoic cooling trend. *Clim. Past.*, v 5, pp. 309-327.
- Whatley, R.C. and Coles, G.P., 1991, Global change and the biostratigraphy of North Atlantic Cainozoic deep water ostracoda. *Journal of Micropaleontology*, v. 9, pp. 119-132.



Group photo of the most active working group members in the Lutetian GSSP at the Gorrondatxe section. From left to right in the upper row: Claus Heilmann-Clausen, Fernando Caballero, Eustoquio Molina, Laia Alegret, Silvia Ortiz, Estibaliz Apellaniz, Aitor Payros, Francisco J. Rodríguez-Tovar, Xabier Orue-Etxebarria; in the front row: Josep Tosquella, Simonetta Monechi, Hanspeter Luterbacher, Flavia Tori and Jan Hardenbol.