# FIELD TRIP TO THE YPRESIAN/LUTETIAN BOUNDARY AT THE GORRONDATXE BEACH SECTION (BASQUE COUNTRY, W PYRENEES)

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## Summary

One of the Paleogene Stage boundaries still needing official definition is the Ypresian/Lutetain (Early-Middle Eocene) boundary. With the aim of contributing to attain this definition, a high-resolution multi-disciplinary study, including physical stratigraphy (lithostratigraphy, sequence stratigraphy and magnetostratigraphy) and biostratigraphy (calcareous nannofossil, planktic foraminifer and larger foraminifer), has been carried out over the 700 m thick uppermost Ypresian – lower Lutetian Gorrondatxe section. The results show that the different events traditionally used to place the Ypresian/Lutetian boundary, hitherto thought to be simultaneous (i.e., the planktic foraminifer P9 (=E7) / P10 (=E8) Zone boundary; the calcareous nannofossil CP12a / CP12b Subzone boundary; the larger foraminifer SBZ12 / SBZ13 Zone boundary; and the boundary between magnetic polarity chrons C22n and C21r), actually occur at very different levels. Therefore, before considering any section to place the Ypresian/Lutetian boundary stratotype, the criterion to precisely define this boundary should be selected. To this end, the succession of events pinpointed in the Ypresian/Lutetian boundary interval of the Gorrondatxe beach section might prove a useful database.

The Gorrondatxe section fulfils most of the requirements demanded of a prospective stratotype section. In addition, the great sedimentary thickness, which implies a very high deep-marine sedimentation rate, provides the Gorrondatxe section an additional value, as it offers the opportunity to chronologically order successive biomagnetostratigraphic events more precisely than elsewhere. Therefore, we consider that, once the criterion to define the Ypresian/Lutetian boundary is selected, the Gorrondatxe beach section should be deemed a firm candidate to place the Global Stratotype Section and Point of the base of the Lutetian Stage.

## INTRODUCTION

The International Commission on Stratigraphy (ICS) aims to define Global Boundary Stratotype Sections and Points (GSSP) of all Stages. To this end, appropriate boundary marker events must first be defined (Remane et al., 1996). One of the boundaries still needing definition is the Ypresian/Lutetain (Y/L; =Early-Middle Eocene) boundary. For the time being two sections, the Agost section (MOLINA et al., 2000) and the Fortuna section (GONZALVO et al., 2001) in southern Spain, have been proposed as candidates to be selected as GSSP of the base of the Lutetian.

Originally, the Lutetian was defined by DE LAPPARENT (1883) to refer to the so-called "Calcaire Grossier" of the Paris Basin. Later, BLONDEAU et al. (1980) proposed two neostratotypes 50 km North of Paris, namely the Saint-Leu d'Esserent and Saint-Vaast-Les-Mellos sections. However, the Lutetian sections around Paris, and even elsewhere in northern Europe, are not suitable candidates to be designated as the GSSP since they display shallow-marine deposits and/or the base of those sections corresponds to a regional unconformity (e.g., AUBRY, 1986, 1995; STEURBAUT, 1988).

The lower part of the Lutetian "Calcaire Grossier" is best typified by the occurrence of abundant specimens of *Nummulites laevigatus*, a species whose range coincides with Zone SBZ13 of SERRA-KIEL et al. (1998). In addition, AUBRY (1986) demonstrated that, in terms of calcareous nannofossils, the base of the "Calcaire Grossier" pertains to Subzone CP12b of OKADA & BUKRY (1980). AUBRY et al. (1986) carried out the correlation of the Lutetian strata in Paris with those of the Hampshire-London basin based on calcareous nannofossil and *Nummulites* faunas. There, they integrated biostratigraphic and magnetostratigraphic data and proposed that the Lutetian strata correspond to magnetic polarity chron C21.

Although planktic foraminifera are rare in these north European sections, the criterion most commonly used during the last half century to place the base of the Lutetian has been the first appearance of specimens belonging to the planktic foraminifer genus *Hantkenina*, which also mark the base of Zone P10 of BERGGREN et al. (1995). Unfortunately, Eocene hantkeninids were restricted to lower and middle latitudes. In addition, they were not abundant at their inception and never reached high percentages in well-preserved Eocene faunas (PREMOLI SILVA & BOERSMA, 1988, p. 323; COXALL et al., 2003, p. 237). BERGGREN & PEARSON (2005) indicated that the

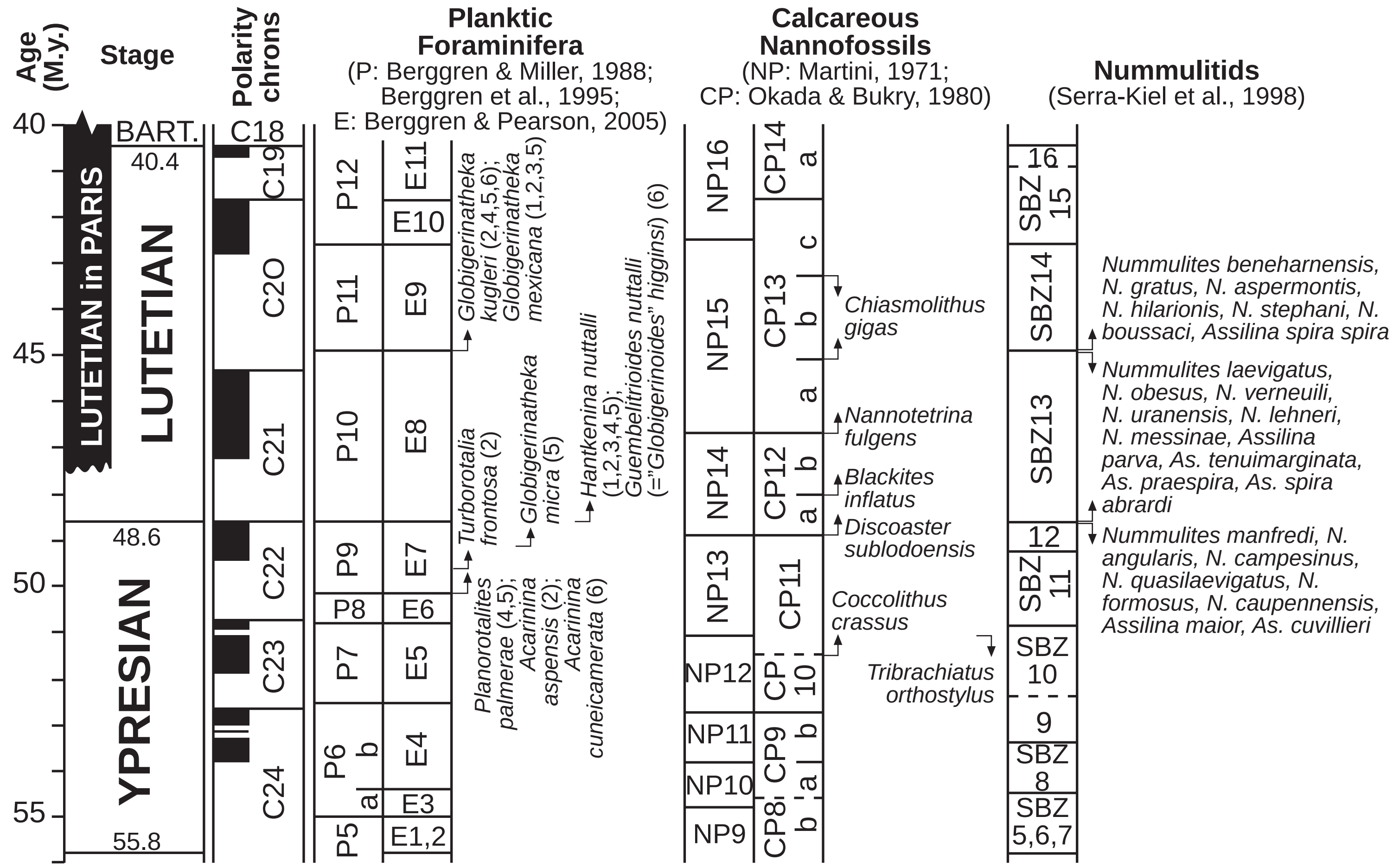



**Fig. 1.** Ypresian – Lutetian standard biomagnetochronostratigraphic framework. The extent of the Lutetian strata in Paris is shown for comparison purposes. Absolute ages are from LUTERBACHER et al. (2004). Correlation between magnetic polarity chrons, planktic foraminiferal zones, and calcareous nannofossil zones is from BERGGREN et al. (1995) and BERGGREN & PEARSON (2005). Planktic foraminiferal events are as follow: (1) STAINFORTH et al., 1975; (2) BLOW, 1979; (3) TOUMARKINE & LUTERBACHER, 1985); (4) BERGGREN et al., 1995; (5) PREMOLI SILVA et al. (2003); (6) BERGGREN & PEARSON (2005); correlation of events by (1), (2) and (3) with magnetic polarity chrons is based on BERGGREN & MILLER (1988).

first appearance of *Guembelitrioides nuttalli* (="*Globigerinoides*" *higginsi*, which marks the base of their Zone E8, equivalent to Zone P10 of BERGGREN et al., 1995) occurs at a very similar level to the first appearance of hantkeninids and, therefore, that it can be used to denote the base of the Middle Eocene. The correlation between magnetostratigraphic and different biostratigraphic scales has improved over time (e.g., BERGGREN, 1972; HARDENBOL & BERGGREN, 1978; BERGGREN & MILLER, 1988; BERGGREN et al., 1995; LUTERBACHER et al., 2004), and today it is considered that the first appearances of the first specimens of the genus *Hantkenina* and of the taxon *Guembelitrioides nuttalli* coincide with the boundary between C22n and C21r magnetozones (BERGGREN et al., 1995; BERGGREN & PEARSON, 2005).
Taking everything into account, Figure 1 shows the currently most accepted biomagnetochronostratigraphic correlation scheme for the Y/L boundary.

## THE GORRONDATXE BEACH SECTION

The aim of this field trip is to present new biomagnetostratigraphic data of the Y/L transition at the Gorrondatxe beach section (Basque Country, western Pyrenees), and to propose this section as a candidate to locate the GSSP of the base of the Lutetian Stage (i.e., Y/L boundary). The section is exposed on the cliffs of an easily accessible beach (named Gorrondatxe but also known as Azkorri owing to the so-called cape on the NE side of the beach) just NW of Bilbao (Latitude: 43°23'N; Longitude: 3°01'50"W; Figs 2 and 3). 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.bizkaia.net/ingurugiroa_Lurraldea/Hondartzak/in_home3.htm).
In the light of the geological, biostratigraphic and infrastructure requirements specified by the ICS for any prospective GSSP and the different criteria used so far to define the base of the Lutetian Stage, the study of the Gorrondatxe section was undertaken from the viewpoint of the general stratigraphic context (paleogeography, lithostratigraphy and sequence stratigraphy), biostratigraphy (calcareous nannofossils, planktic foraminifera and nummulitids) and magnetostratigraphy.

## GEOLOGICAL SETTING

During Eocene times the studied area formed part of the bottom of a 1500 m deep marine gulf that opened into the Atlantic ocean at approximately 35°N latitude (Fig. 2A). More than 2300 m of lower Ypresian-upper Lutetian deep-marine deposits accumulated on the bottom of this gulf. These deposits were uplifted and tilted during the Alpine Orogeny, and are now exposed in coastal cliffs that extend from the town of Sopela to the Galea Cape (Fig. 3).

The Gorrondatxe beach section, 700 m thick, is mostly composed of hemipelagic marls and limestones, but thin-bedded (<10 cm) siliciclastic turbidites are also common. In addition, some thick-bedded (10-240 cm) mixed turbidites (siliciclastic and carbonate) occur at certain levels of the succession. PAYROS et al. (2006) investigated the sedimentary features of every turbidite bed thicker than 15 cm in order to assess volumetric variations of turbidites throughout the Sopela-Galea section (Fig. 3). They obtained a semiquantitative estimation of the vertical variations in turbidite abundance by plotting their composite thickness in 10 m thick intervals. This procedure made evident that the Sopela-Galea succession consists of three turbidite-poor intervals (average turbidite content < 10%) and three turbidite-rich intervals (average > 20%, occasionally reaching 80%). PAYROS et al. (2006) noted that the ages of the turbidite-rich intervals correlate precisely with those of resedimentation units of the Pamplona area, 200 km southeast of the study area, where sequence stratigraphic studies were carried out by PAYROS (1997) and PUJALTE et al. (2000). The lowstand turbiditic deposits of their fourth (Cu-2), fifth (Cu-Lt) and sixth together with seventh (Lu-1 + Lu-2) sequences correlate with the turbidite-rich intervals of the Sopela-Galea succession, supporting the interpretation of the latter as regional lowstand deposits (Fig. 3).

## BIOMAGNETOSTRATIGRAPHIC DATABASE

Figure 4 summarizes the most significant results of the biomagnetostratigraphic study of the Gorrondatxe beach section. Specific details on the number, location and quality of samples studied, methods, taxonomic terminology and interpretations are given below for those who might be interested.

### Calcareous Nannofossils

The calcareous nannofossil study is based on the analysis of a total of 56 samples (Fig. 5). Samples were taken every 20 m with closer intervals near the main biostratigraphic events. Smear slides of samples were prepared from raw material using the pipete method for calcareous nannofossils (BOWN, 1998),

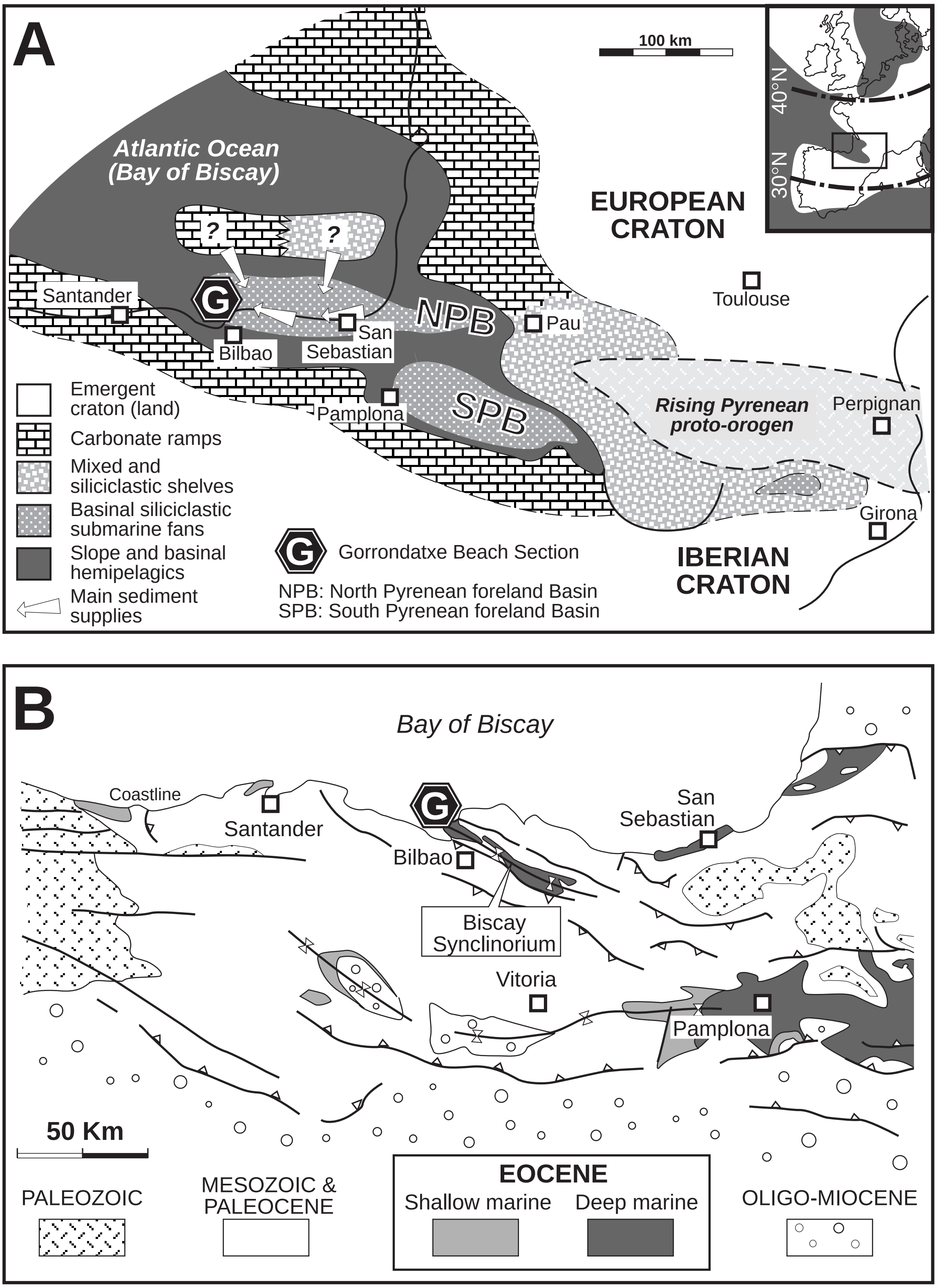



**Fig. 2.** (A) Early Palaeogene paleogeography of the Pyrenean area without palinspastic restoration (party based on PLAZIAT, 1981, PUJALTE et al., 2002, and our own data). (B) Simplified geological map of the Western Pyrenees showing the most important Eocene outcrops. The location of the Gorrondatxe section (G) is shown on both maps.

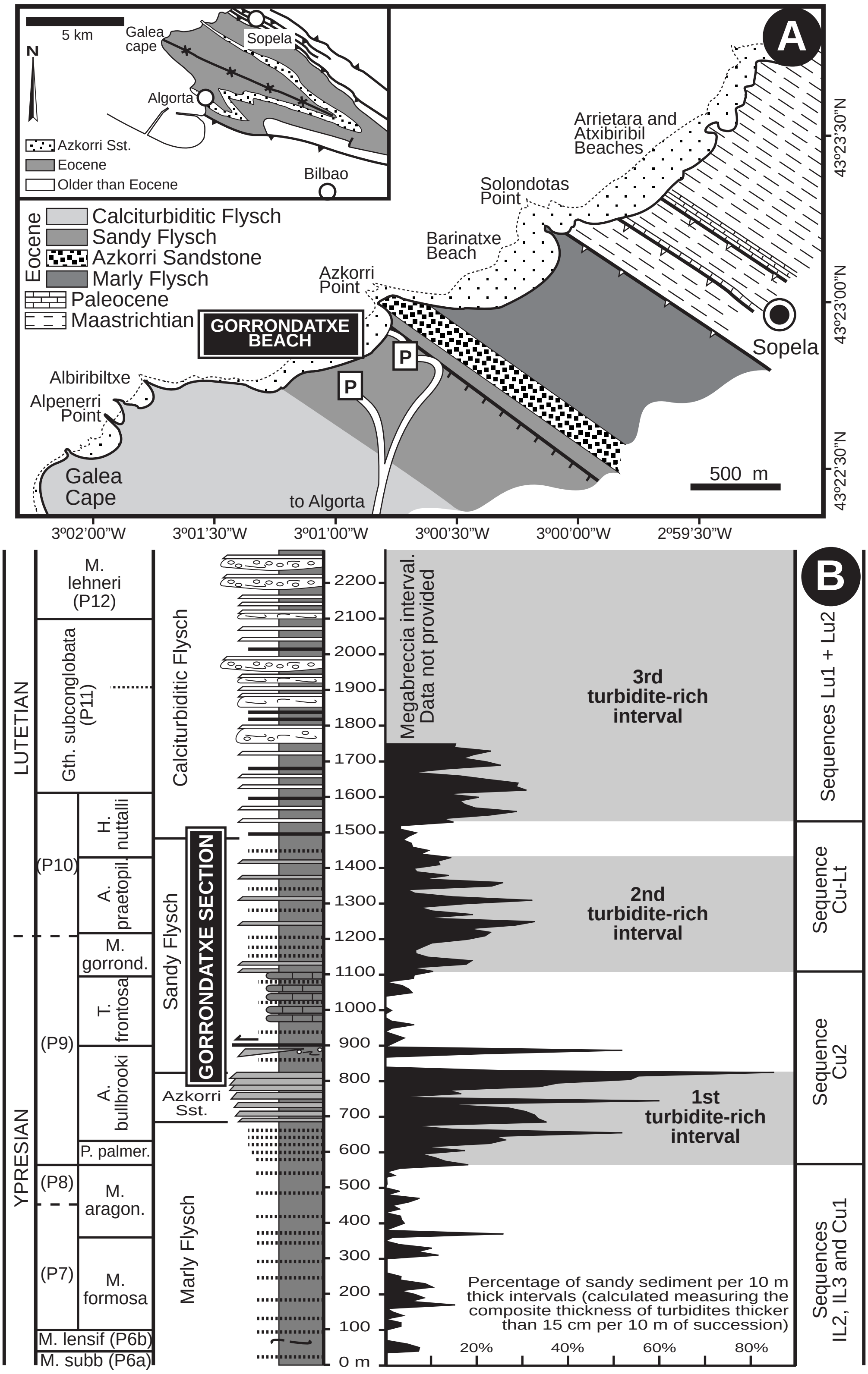



**Fig. 3.** (A) Simplified geological map of the study area, showing the location of the Gorrondatxe beach section. (B) Simplified litholog of the Sopela-Galea succession, showing the extent of the Gorrondatxe beach section. Planktic foraminifera biostratigraphy (left-hand column) is from ORUE-ETXEBARRIA et al. (1984); informal lithostratigraphic units are mostly based on RAT (1959); vertical variations in turbidite content (right-hand graph) are from PAYROS et al. (2006); depositional sequences are those defined by PAYROS (1997) and PUJALTE et al. (2000) in the Pamplona area.

avoiding mechanical of physical processes that could modify the original composition of the assemblage. All the smear slides were analyzed under a Leica DMLP petrographic microscope at 1500X magnification. In order to investigate the smallest species, to observe details of bigger forms and to take pictures, smear-slides were examined at 2000X magnification. At least 300 nannofossil specimens per sample were counted along a random traverse on the slide. Moreover, in order to detect rare species with key biostratigraphic value, three additional tracks were studied per sample.

According to the preservation criteria proposed by ROTH & THIERSTEIN (1972) 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.

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 latest increasing in abundance and size upsection.

Reworked nannofossils occur in all the samples. Most of them are Cretaceous and in lesser quantity Paleocene, and early Eocene. The reworking results from the nature of the sediments, limestone-marlstone alternations with a high number of interbedded turbidites. The presence of reworked nannofossils can occasionally obscure the location of the latest occurrence (LO) of some taxa. Taking into account that the reworking is not very intense and is not equally present throughout the succession, the LO of a species was tentatively located at the end of its continuous occurrence. In this work, however, in order to minimize the possible error of considering the end of the continuous occurrence of a species as its latest occurrence, we only use the first occurrence (FO) of selected species.

The studied interval spans from the upper part of the Zone CP11 to the Subzone CP13b of OKADA & BUKRY (1980).

**Planktic Foraminifera**

To analyze the planktic foraminifera of the Gorrondatxe section 96 samples (each of about 1kg) were collected, which were very close-spaced near the main biostratigraphic events (Fig. 6). The samples were washed and screened to obtain residues of a 100-630 $\mu$m size range, which were studied under binocular microscope. The full assemblage of planktic foraminifers was recorded to species level. After a separation with an Otto microspliter, relative abundances of the different species were estimated based on counts of about 300 individuals.

All of these residues contained a diversified assemblage of well-preserved planktic foraminifers, which represents more than 90% of the total foraminifer content (planktic plus benthic). Thus, the quantity and degree of preservation permitted a semiquantitative study designed to determine the FO and LO of planktic foraminifer species. On the basis of this data, and taking into account the great thickness of the Gorrondatxe succession, a new high-resolution planktic foraminifer biostratigraphic scale, composed of five Biozones, is proposed for the studied interval (Fig. 6).

(1) *Acarinina bullbrooki* Interval Zone (emended herein; =part of P9 of BERGGREN et al., 1995, and of E7 of BERGGREN & PEARSON, 2005).

Definition: Biostratigraphic interval between the FO of *Acarinina bullbrooki* and the FO of *Turborotalia frontosa*.

Remarks: Just the upper part of the Biozone is represented in the lower 100 m of the Gorrondatxe section. The most common species are *A. bullbrooki, Globanomalina planoconica, Morozovella caucasica* and *Pseudohastigerina micra*.

(2) *Turborotalia frontosa* Interval Zone (emended herein; =part of P9 of BERGGREN et al., 1995, and of E7 of BERGGREN & PEARSON, 2005).

Definition: Biostratigraphic interval between the FO of *Turborotalia frontosa* and the FO of *Morozovella gorrondatxensis*.

Remarks: This Biozone, 183 m thick, contains an assemblage similar to the preceding Biozone, with the addition of *Turborotalia frontosa*.

(3) *Morozovella gorrondatxensis* Interval Zone (herein defined; =upper part of P9 of BERGGREN et al., 1995, and of E7 of BERGGREN & PEARSON, 2005; and lowermost part of P10 of BERGGREN et al., 1995, and of E8 of BERGGREN & PEARSON, 2005).

Definition: Biostratigraphic interval between the FO of *Morozovella gorrondatxensis* and the FO of *Acarinina praetopilensis*.

Remarks: The first specimens of *Globigerinatheka micra* occur at the same level as the FO of *Morozovella gorrondatxensis*. Thus, the FO of both taxa defines the base of this 125 m thick Biozone. The FO of *Guembelitrioides nuttalli*, proposed as marker event of the Y/L boundary by BERGGREN &

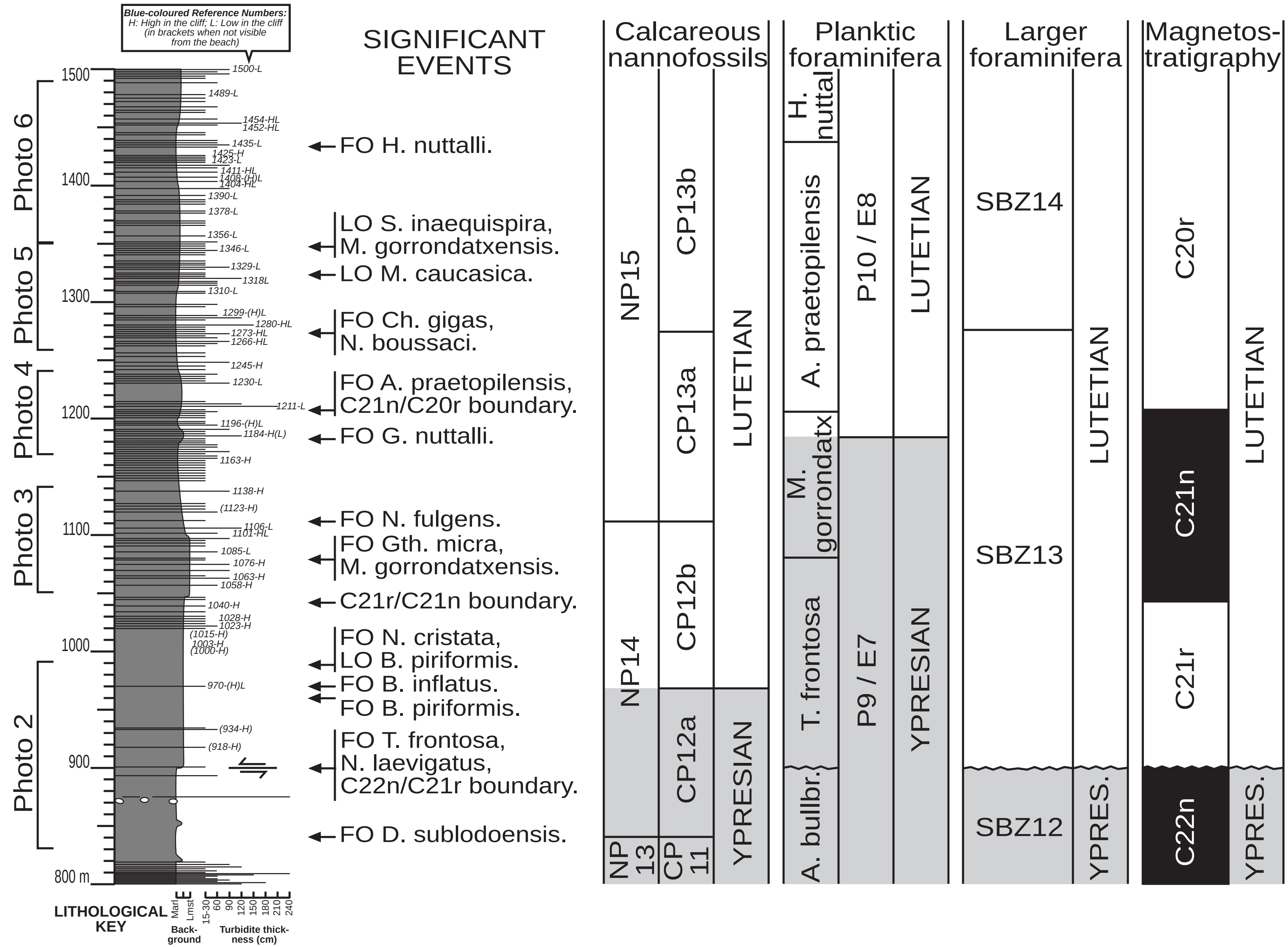



**Fig. 4.** Lithological log of the Gorrondatxe beach section showing the location of the most significant biomagnetostratigraphic events and theresultant biostratigraphy (calcareous nannofossils, planktic foraminifera and larger foraminifera) and magnetostratigraphy. The position of the boundary between the Ypresian (grey) and Lutetian (white) Stages varies depending on the scale.

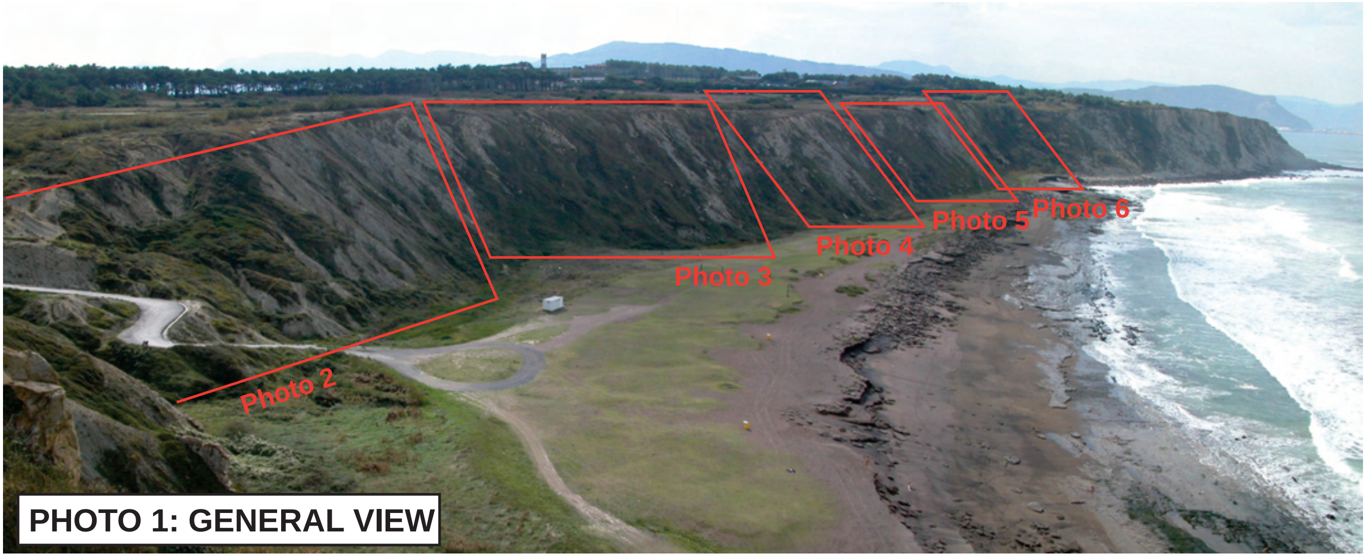
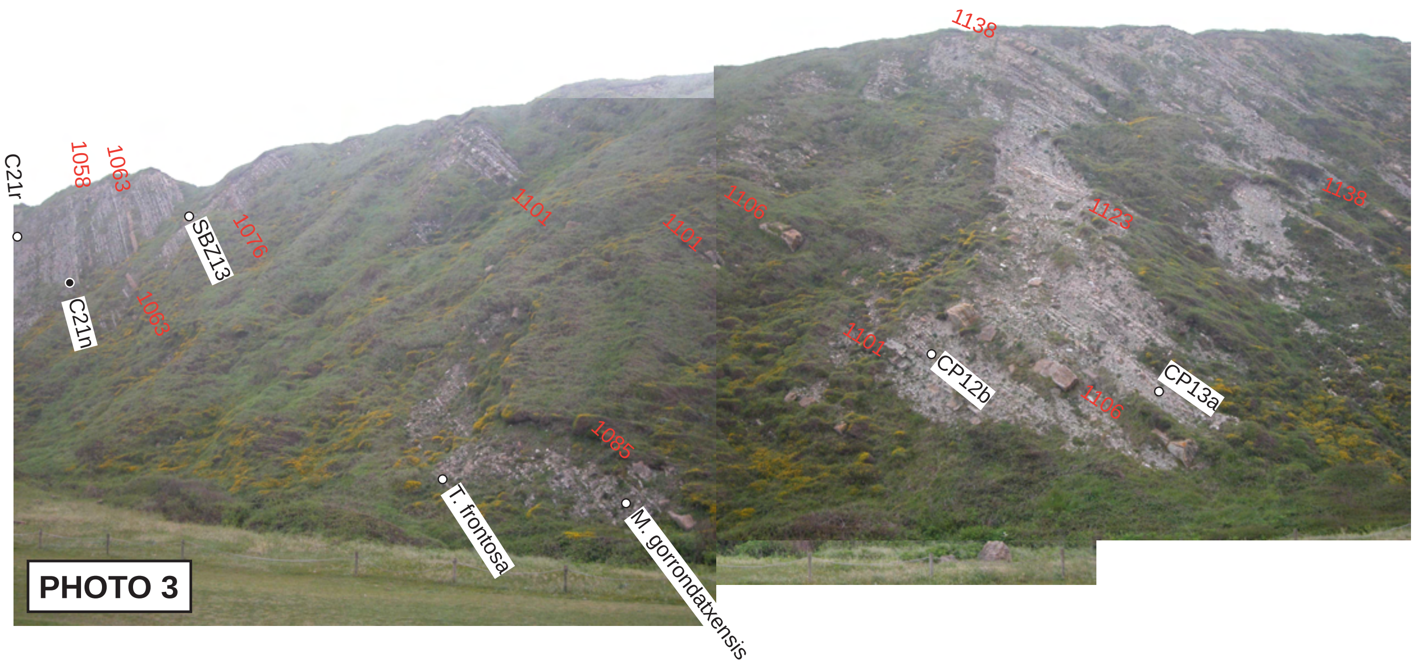


Photo 2
Photo 3
Photo 4
Photo 5
Photo 6
PHOTO 1: GENERAL VIEW


C21r
1058
1063
SBZ13
1076
C21n
1063
1101
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T. frontosa
M. gorrondatxensis
1106
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1123
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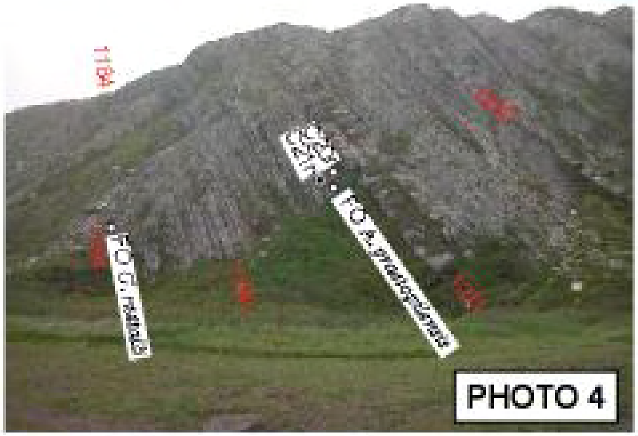
CP12b
1106
CP13a
PHOTO 3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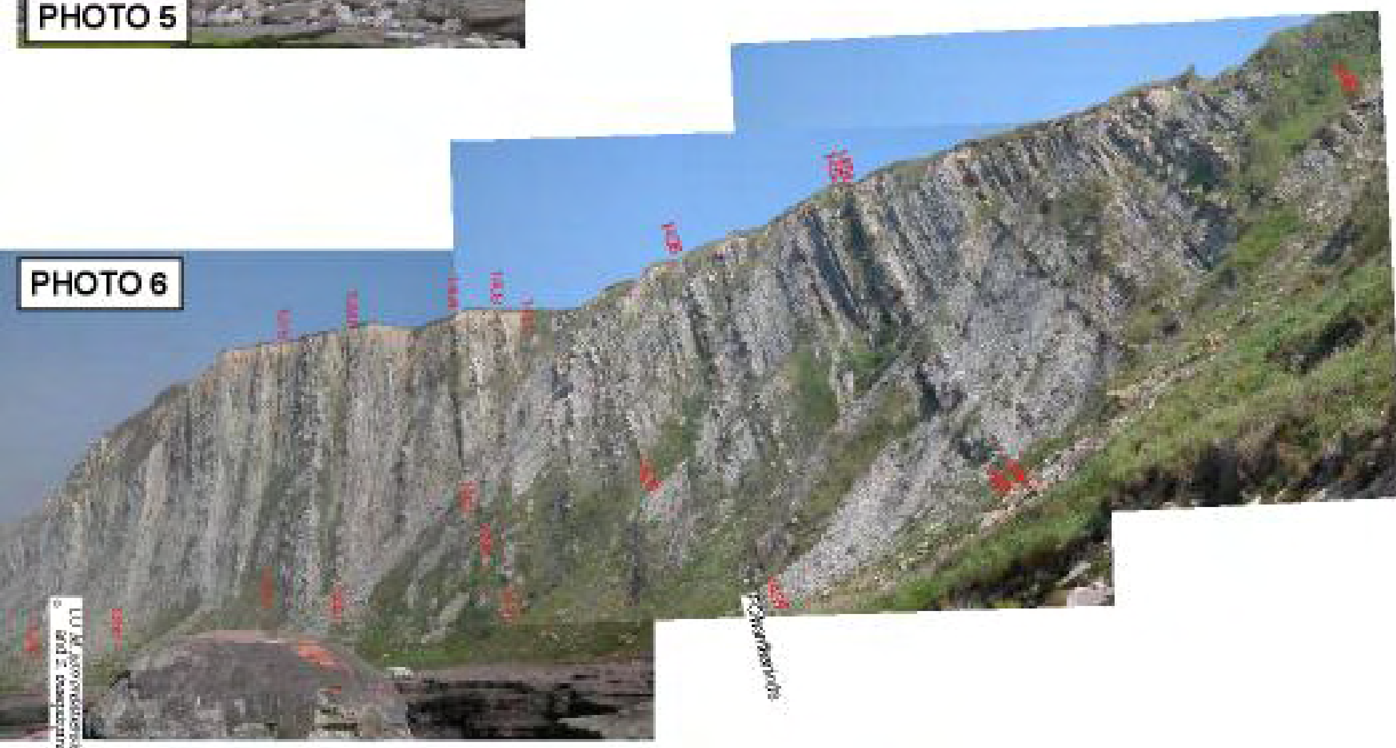
PHOTO 6

PEARSON (2005), was found slightly before the top of this Biozone.

(4) *Acarinina praetopilensis* Interval Zone (defined by ORUE-ETXEBARRIA & APELLANIZ, 1985; =lower part of P10 of BERGGREN et al., 1995, and of E8 of BERGGREN & PEARSON, 2005).

Definition: Biostratigraphic interval between the FO of *Acarinina praetopilensis* and the FO of *Hantkenina nuttalli*.

Remarks: The LO of *M. caucasica* and *M. gorrondatxensis* are recorded in the middle and upper part, respectively, of this 225 m thick Biozone.

(5) *Hantkenina nuttalli* Interval Zone (upper part of P10 of BERGGREN et al., 1995, and of E8 of BERGGREN & PEARSON, 2005).

Definition: Biostratigraphic interval between the FO of *Hantkenina nuttalli* and the FO of *Globigerinatheka mexicana*.

Remarks: Given the rarity of *Hantkenina nuttalli* in the Gorrondatxe section and the assemblage in the previous Biozone, the FO of *H. nuttalli* in the Gorrondatxe section might not correspond to its first appearance in the stratigraphic record. The FO of *Truncorotaloides topilensis* is recorded in the lower part of this Biozone.

**Nummulitids**

Larger foraminifera, mostly *Nummulites* and *Assilina* specimens, as well as fragments of other shallow-water organisms (e.g., red algae and corals), occur in the basal part of many thick-bedded, mixed carbonate-siliciclastic turbidites. All of the turbidites in the Gorrondatxe section were examined for nummulitids, but only sixteen provided positive results (Fig. 7). Nummulitid specimens were extracted from these turbidites and studied following a two-step procedure. First, their outer test features (diameter and shape, morphology and arrangement of septal filaments and granules, etc.) were examined with a binocular microscope. Then, they were split along the equatorial section to study their inner features, such as number of whorls, rate of opening of the spire (whorl radius), number of chambers per whorl, septal and chamber shape, and the proloculus diameter of megalospheric forms.

Four out of sixteen samples did not provide reliable results, since nummulitid specimens were poorly preserved. The remaining twelve samples yielded a wealth of nummulitid specimens, with a total of 45 different taxa representing a mixture of resedimented and displaced faunas (Fig. 7). Most of the specimens could be classified at the specific level and proved suitable for biostratigraphic determination. However, the systematic study was sometimes hindered because of the not fully diversified character of some samples. On the one hand, most of the samples contained megalospheric nummulitids but lacked microspheric forms. This situation is probably the result of the hydrodynamic sorting (i.e., grain-size classification) of the sediment involved in turbidity currents, which made large microspheric and small megalospheric nummulitid tests accumulate separately. On the other hand, the most evolved morphotypes of a phylogenetic series were easy to recognize. In general, the most modern specimens are larger and show more complex test ornamentation. However, it is not straightforward to apply this rule to small-sized microspheric nummulitids, since small test size and simple ornamentation might be related either to a lower phylogenetic level (i.e., older specimens) or, alternatively, to the young ontogenetic stage of more modern specimens. Despite these difficultities sometimes hampered the precise reconstruction of the paleobiocenosis at specific level, it was still possible to date the minimum age of the turbidites containing nummulitids (Fig. 7), which extend from SBZ12 to SBZ14 of SERRA-KIEL et al. (1998).

**Magnetostratigraphy**

A total of 65 unique sampling sites were obtained, comprising 2 to 3 hand-samples per site (Fig. 8). Paleomagnetic sampling was basically restricted to the hemipelagic lithologies (mostly grey marls and marly limestones), which are potentially more suitable facies regarding paleomagnetic behaviour in comparison with turbidites. Hand-samples were oriented *in situ* with a compass and subsequently standard cubic specimens were cut in the laboratory for analysis. Natural remanent magnetization (NRM) and remanence through demagnetization were measured on a 2G Enterprises DC SQUID high-resolution pass-through cryogenic magnetometer (manufacturer noise level of $10^{-12}$ $Am^2$) operated in a shielded room at the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Rome, Italy. A Pyrox oven in the shielded room was used for thermal demagnetizations and alternating field (AF) demagnetization was performed with three orthogonal coils installed inline with the cryogenic magnetometer.

Paleomagnetic analysis was conducted on 116 specimens corresponding to 1 or 2 specimens per sampling 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,

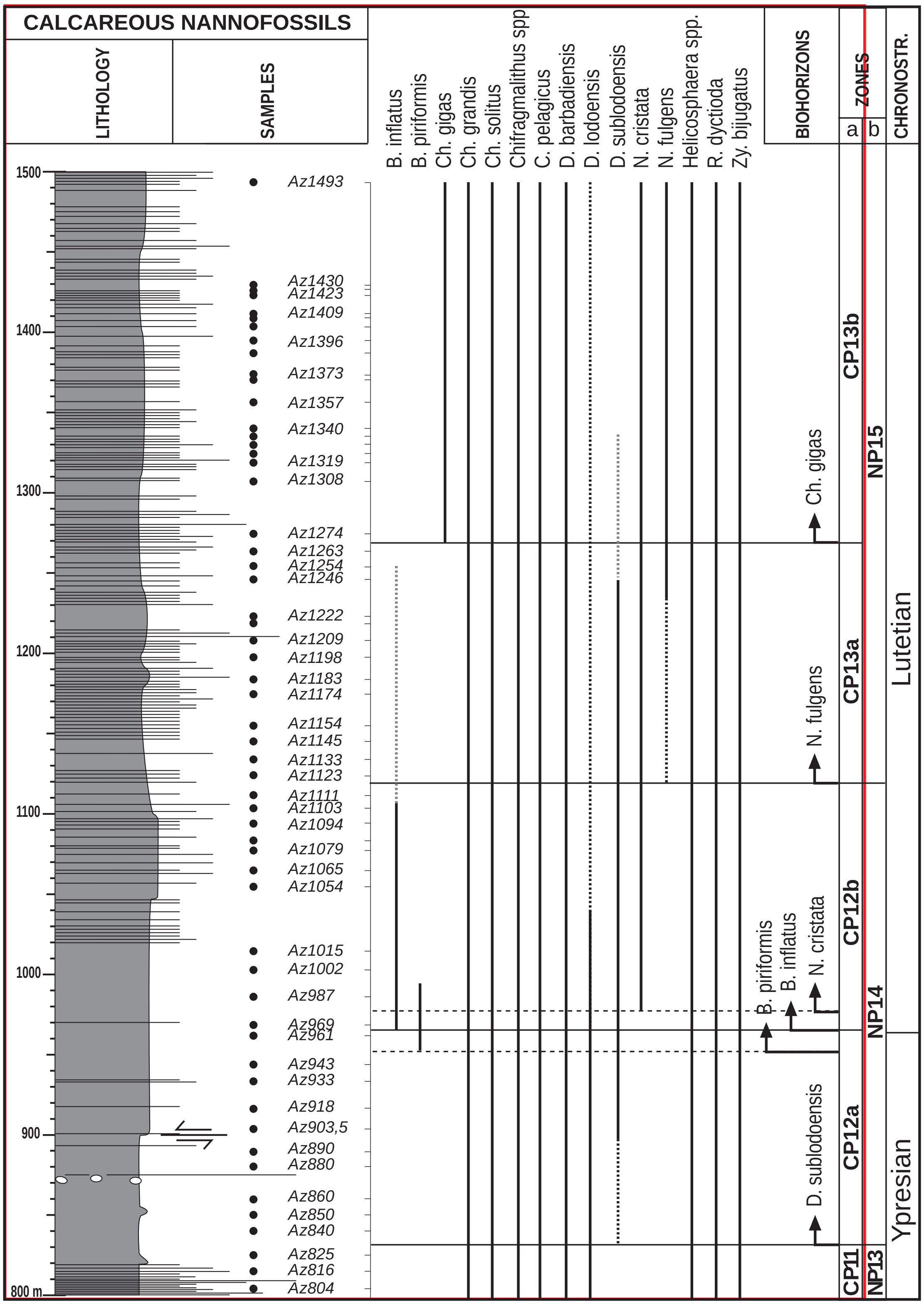


**Fig. 5.** Selected calcareous nannofossil species ranges and location of the main biohorizons across the Ypresian/Lutetian transition at the Gorrondatxe section. Broken lines indicate very rare occurrences. Zones in column (a) are following OKADA & BUKRY (1980); those in column (b) are following MARTINI (1971).

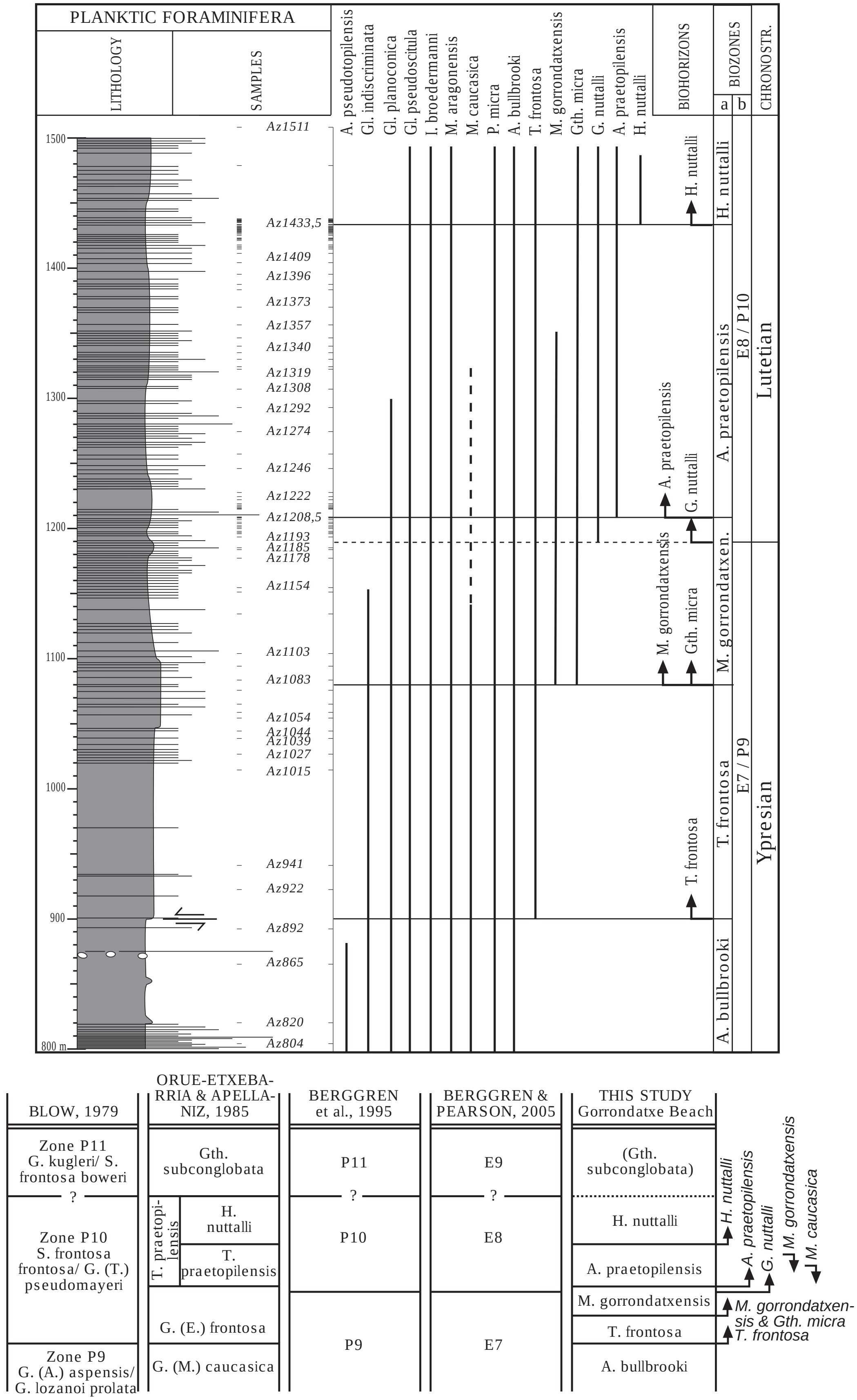


**Fig. 6.** Selected planktic foraminifer species ranges and location of the main biohorizons across the Y/L transition at the Gorrondatxe section. Biozones in column (a) are as described in this study; those in column (b) are following BERGGREN et al. (1995) (P scale) and BERGGREN & PEARSON (2005) (E scale). Correlation with other scales is shown in the lower Table.

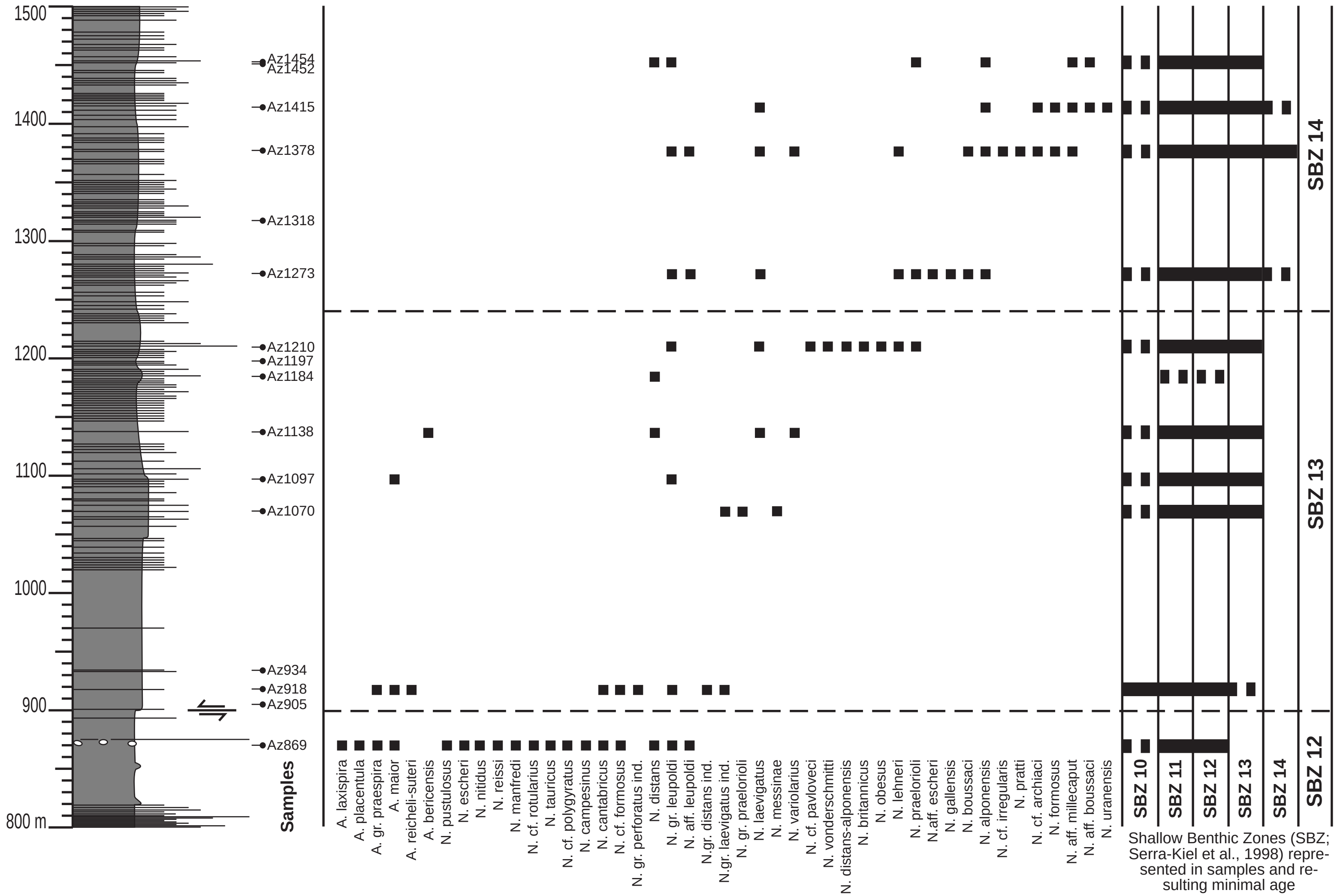

**Fig. 7.** Nummulitid species occurrences in the Gorrondatxe section. Broken lines on the right-hand columns indicate that the corresponding Shallow Benthic Zone (SBZ) is probably represented in the sample, whereas continuous lines indicate verified occurrences.

80, 100 mT). Characteristic remanent magnetizations (ChRM) were computed by least-squares fitting (KIRSCHVINK, 1980) on the orthogonal demagnetization plots (ZIJDERVELD, 1967). The ChRM declination and inclination for each sample has been used to derive the latitude of the virtual geomagnetic pole (VGP). This parameter has been used as an indicator of the polarity (normal polarity for positive VGP latitudes and reverse polarity for negative VGP latitudes).

The NRM intensities are on the order of 0.1 mA/m, usually decreasing to 50% or less at 150°C. The characteristic remanent magnetization (ChRM) is conventionally defined as the linear segment trending towards the origin of the demagnetization diagram. Normally (class A samples), the ChRM component can be isolated above 13-17 mT after removal of a viscous secondary component at low fields that conforms to the recent Earth's magnetic field in geographic (*in-situ*) coordinates. The ChRM component most likely resides in a low-coercivity mineral like maghemite or magnetite although a minor contribution of a higher coercivity mineral (iron-sulphide, hematite?) cannot be ruled out considering that in some instances the ChRM is not fully demagnetized at the highest applied magnetic field (100 mT). The ChRM components present either normal or reverse polarity in bedding-corrected coordinates. In a few cases, the calculated ChRM has been regarded as unreliable (class B samples). We consider the demagnetization behavior as unsuitable for magnetostratigraphic interpretation in 30% of the analyzed specimens (class C samples), which mostly relate to very week samples. The magnetostratigraphy is based on Class A samples (Fig. 8).

The reversal test of McFADDEN & McELHINNY (1990) has been performed on the ChRM components in order to assess the antipodality of the normal and reverse populations (Fig. 8). This test classifies a 'positive' reversal test on the basis of the angle $g_c$ between the mean directions of the two sets of observations at which the null hypothesis of a common mean direction would be rejected with 95% confidence (class 'A' if $g_c \leq 5^o$ as 'B' if $5^o < g_c \leq 10^o$, as 'C' if $10^o \leq g_c \leq 20^o$, and 'Indeterminate' if $g_c > 20^o$). The ChRM data for the Gorrondatxe section passes the reversal test as class C ($g_c = 16.2\ ^o$).

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 succession of four magnetozones (two normal and two reverse). The lower normal magnetozone, which correlates with planktic foraminifer Zones P9 and E7, calcareous nannofossil Zones CP11-CP12a, and larger foraminifer Zone SBZ12 can be directly correlated to Chron C22n. The overlying reverse magnetozone 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.

## POSITIONING THE Y/L BOUNDARY

All the events traditionally used to place the Y/L boundary (i.e., the planktic foraminifer P9 (=E7) / P10 (=E8) Zone boundary; the calcareous nannofossil CP12a / CP12b Subzone boundary; the larger foraminifer SBZ12 / SBZ13 Zone boundary; and the boundary between magnetic polarity Chrons C22n and C21r) have been identified in the Gorrondatxe section (Fig. 4). However, a comparison of the Gorrondatxe data with the standard biomagnetostratigraphic scheme shown in Figure 1 evidences that all these events, previously considered as simultaneous, actually occur at very different levels. A concomitant consequence arising from that observation is that before selecting a section

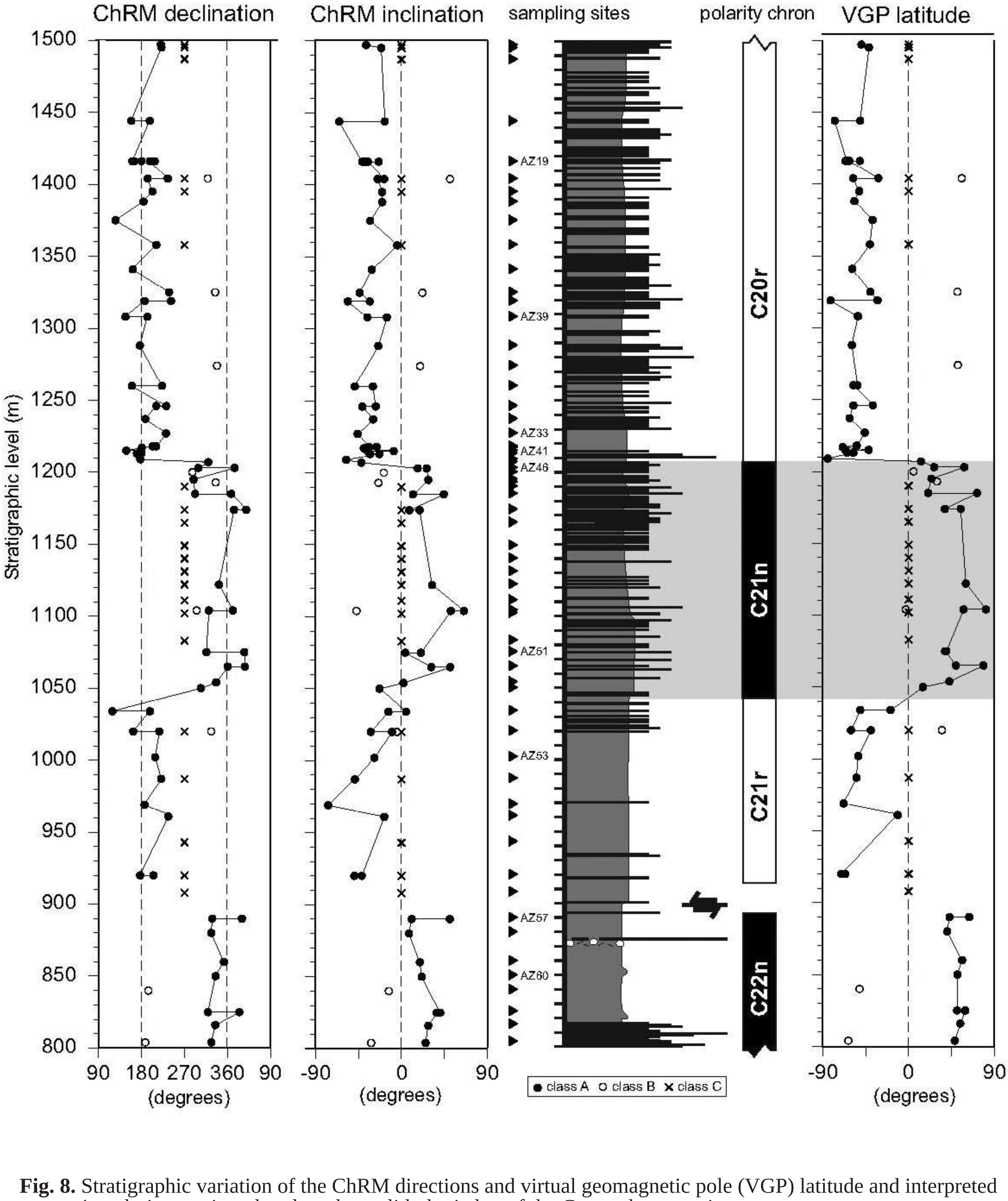


**Fig. 8.** Stratigraphic variation of the ChRM directions and virtual geomagnetic pole (VGP) latitude and interpreted magnetic polarity stratigraphy plotted on a lithologic log of the Gorrondatxe section.

to place the Stratotype of the Lutetian, the criterion to identify the base of this Stage should be precisely defined.

With regard to the Gorrondatxe section, the position of the different events traditionally used to mark the Y/L boundary are highlighted below and will be shown during the field trip (Figs. 4 and 5). In addition, their correlation with other zonal scales is explained below.

**(A) Larger foraminifer criterion**

The lower part of the Lutetian "Calcaire Grossier" around Paris is typified by the occurrence of specimens of *Nummulites laevigatus*, a species whose range coincides with Zone SBZ13 of SERRA-KIEL et al. (1998).

The **base of SBZ13** is not preserved in the Gorrondatxe section due to a fault at 900 m of the succession (Fig. 4). However, the Gorrondatxe data demonstrate that this event occurs within calcareous nannofossil Zone CP12a, as already shown in the standard correlation scheme (Fig. 1), within planktic foraminifera Zone E7 (=P9), and seems to be approximately coeval with the FO of the planktic foraminifer *T. frontosa* and with the boundary between Chrons C22n and C21r.

**(B) Magnetostratigraphic criterion**

AUBRY et al. (1986) carried out the correlation of the Lutetian strata in Paris with those of the Hampshire-London basin based on calcareous nannofossil and *Nummulites* faunas. There, they integrated biostratigraphic and magnetostratigraphic data and proposed that the Lutetian strata correspond to magnetic polarity chron C21.

The **base of Chron C21r** is not preserved in the Gorrondatxe section due to the fault at 900 m (Fig. 4). However, the Gorrondatxe data demonstrate that this event occurs within calcareous nannofossil Zone CP12a, as already shown in the standard correlation scheme (Fig. 1), within planktic foraminifera Zone E7 (=P9), and seems to be approximately coeval with the FO of the planktic foraminifer *T. frontosa* and with the base of SBZ13.

**(C) Calcareous nannofossil criterion**

AUBRY (1986) demonstrated that, in terms of calcareous nannofossils, the base of the Lutetian "Calcaire Grossier" around Paris pertains to Subzone CP12b of OKADA &

BUKRY (1980), which is defined by the FO of *B. inflatus*. Therefore, this is the most suitable calcareous nannofossil marker event to characterize the Y/L boundary.

The **FO of *B. inflatus*** is well constrained at 969 m in the Gorrondatxe section, and occurs within the upper part of Chron C21r, the planktic foraminifer Biozone *T. frontosa* (upper part of E7), and within larger foraminifer SBZ13 (Fig. 4). Several additional calcareous nannofossil events have been identified slightly lower and higher in the succession (Fig. 4). Relatively close to the FO of *B. inflatus* we found the FO of *T. frontosa*, poorly documented in the Gorrondatxe section due to the fault at 900 m, and the FOs of *Gth. micra* and *M. gorrondatxensis* at 1083 m.

**(D) Planktic foraminifer criteria**

Different criteria have been used to approximate the Y/L boundary using planktic foraminifers.

The **FO of *G. nuttalli*** was proposed by BERGGREN & PEARSON (2005) as marker event to define the Y/L boundary. In the Gorrondatxe section this event occurs at 1185 m, and is located at the uppermost part of Chron C21n, in the mid part of calcareous nannofossil Zone CP13a, and within the upper part of larger foraminifer Zone SBZ13.

The **FO of *A. praetopilensis*** was proposed by ORUE-ETXEBARRIA & APELLANIZ (1985) as marker event to define the Y/L boundary. In the Gorrondatxe section this event occurs at 1208.5 m, and is located at the upper boundary of Chron C21n, in the mid part of calcareous nannofossil Zone CP13a, and within the upper part of larger foraminifer Zone SBZ13.

The **FO of hantkeninids** was proposed by BERGGREN et al. (1995) as marker event to define the Y/L boundary. Although this event is supposedly simultaneous to the FO of *G. nuttalli* (BERGGREN & PEARSON, 2005), in the Gorrondatxe section the FO of hantkeninids occurs at a much higher level (1433.5 m), being correlatable with Chron C20r, calcareous nannofossil Zone CP13b, and larger foraminifer Zone SBZ14. However, it is acknowledged that the FO of hantkeninids in the Gorrondatxe section might probably not represent their onset in the stratigraphic record.

## SUITABILITY OF THE GORRONDATXE SECTION FOR THE GSSP OF THE BASE OF THE LUTETIAN

It should first be noted that most of the infrastructure, biostratigraphic and geological requirements mentioned by the ICS (REMANE et al., 1996) are fulfilled by the Gorrondatxe section. Especially, the great sedimentary thickness is one of the most outstanding features in favour of selecting the Gorrondatxe section as the Y/L GSSP. Table 1 shows the thicknesses of selected biostratigraphic and magnetostratigraphic zones around the Y/L boundary in the Gorrondatxe section and in other well-documented successions, some of which have already been proposed as candidates for the GSSP of the base of the Lutetian Stage. Table 1 readily demonstrates that the Gorrondatxe section is much thicker than all the other sections, a feature that indicates a much higher sedimentation rate. Hence, successive biostratigraphic and magnetostratigraphic events are more separate in the Gorrondatxe section and can thus be chronologically ordered more easily than anywhere else (Fig. 4). Such a great thickness is the result of abundant intercalations of turbiditic beds. However, these turbidites do not diminish the suitability of the Gorrondatxe section for the GSSP of the base of the Lutetian Stage, since they are generally extensive, tabular-shaped and flat-based, recording therefore the effect of turbidity currents with low erosive capacity, which did not cause any significant disturbance on the sea floor. Quite the opposite, some of these turbidity currents supplied abundant nummulitids, allowing thus the improvement of the correlation scheme between larger foraminifer and calcareous planktic biostratigraphic scales. Since larger foraminifera are transitional between open marine and terrestrial faunas, they could eventually prove invaluable to help correlating biostratigraphic zonal schemes based on open marine planktonic organisms with those from continental areas.

The only problem with the Gorrondatxe section is the fault located at 900 m. In fact, the tops of chron C22n and larger foraminifer Zone SBZ12 are not preserved in the Gorrondatxe section due to that fault (Fig. 4). Therefore, if either of these two events were eventually selected as marker event for the Y/L boundary, the Gorrondatxe section would not be an appropriate candidate for the corresponding GSSP. It should be noted, however, that these two events are now known to be older than the base of the original Lutetian stratotype in Paris.

If the base of Zone CP12b (marked by the FO of *B. inflatus*) were chosen as the Y/L boundary marker event, the Gorrondatxe section should be considered as a firm candidate for the GSSP of the base of the Lutetian Stage, since that event has been accurately located and correlated with other scales (Fig. 4). On the basis of the same

**Table. 1.** Stratigraphic characteristics of selected sections displaying the Ypresian/Lutetian boundary interval. Duration of magnetic and biostratigraphic zones from LUTERBACHER et al. (2004).

| SECTION | C21n (1.889 m.y.) | CP12a (1.0 m.y.) | CP12b (1.2 m.y.) | CP13a (1.6 m.y.) | P10 / E8 (3.7 m.y.) |
|---|---|---|---|---|---|
| Gorrondatxe | Thickness: 166 m; sedimentation rate: 87.88 m/m.y. | Thickness > 129 m; sedimentation rate > 129 m/m.y. | Thickness: 142 m; sedimentation rate: 118.33 m/m.y. | Thickness: 162 m; sedimentation rate: 101.25 m/m.y. | Thickness: 538 m; sedimentation rate: 145.41 m/m.y. |
| Chaumont-en-Vexin, Oise, Paris Basin (Aubry, 1986) | Not specified | Not preserved | Thickness: 9.5 m (base is probably missing); sedimentation rate: 7.3 m/m.y. | Not specified | Not specified |
| Whitecliff Bay, Hampshire-London Basin | Thickness: 18.5 m; sedimentation rate: 9.79 m/m.y. (Townsend & Hailwood, 1985; Aubry et al., 1986) | Not preserved | Identified, but thickness not specified (Aubry, 1986) | Not specified | Not specified |
| Contessa Highway, Italy (Lowrie et al., 1982) | Thickness: 13 m; sedimentation rate: 6.88 m/m.y. | Not specified | Not specified | Not specified | Thickness: 26 m; sedimentation rate: 7.03 m/m.y. |
| Contessa Road, Italy (Lowrie et al., 1982) | Thickness: 11.3 m; sedimentation rate: 5.98 m/m.y. | Not specified | Not specified | Not specified | Not specified |
| Bottaccione, Italy | Thickness: 8.25 m (Napoleone et al., 1983); sedimentation rate: 4.37 m/m.y. | Thickness: 25.5 m (Monechi & Thierstein, 1985); sedimentation rate: 25.5 m/m.y. | Thickness: 2 m, but FO of *B. inflatus* does probably not coincide with FAD (Monechi & Thierstein, 1985); sedimentation rate: 1.54 m/m.y. | Not specified | Thickness: 24 m (Napoleone et al., 1983); sedimentation rate: 6.49 m/m.y. |
| Agost, Spain (Molina et al., 2000) | Not specified | Thickness: 16.9 m; sedimentation rate: 16.9 m/m.y. | Thickness: 15.83 m; sedimentation rate: 12.18 m/m.y. | Not precisely defined; maximum possible thickness: 11 m; sedimentation rate: 6.67 m/m.y. | Thickness 23.75 m; sedimentation rate: 6.42 m/m.y. Composite thickness of *A. praetopilensis* and P10 *sensu stricto* zones: 47.5 m; sedimentation rate: 12.84 m/m.y. |
| Fortuna, Spain (Gonzalvo et al., 2001) | Not specified | Not specified | Not specified | Not specified | Thickness of *H. nuttalli* Zone: 21.42 m; sedimentation rate: 5.79 m/m.y. Composite thickness of *A. praetopilensis* and *H. nutalli* zones: 28.05 m; sedimentation rate: 7.58 m/m.y. |
| Possagno, Italy (Agnini et al., 2006) | Thickness: 18 m; sedimentation rate: 9.63 m/m.y. | Thickness: 22.8-27.4 m; sedimentation rate: 10.36-12.45 m/m.y. | | Thickness: 6.9 m; sedimentation rate: 4.18 m/m.y. | Not specified |

line of reasoning, the same conclusion would be reached if the base of planktic foraminifer Zone E8 (marked by the FO of *G. nuttalli*, and supposedly correlatable with Zone P10 as marked by the FO of hantkeninids) were the selected marker event.

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