Journal of Al - Azhar University - Gaza

Natural Sciences

This special issue is released on the occasion of the International Conference on Basic and Aplied Sciences (ICBAS2010)
10-12 October 2010

A Refereed Scientific Journal

Published by
Deanship of Postgraduate Studies and Scientific Research
Al - Azhar University - Gaza
Palestine

ISSN 1810-6366

Volume: 12, ICBAS Special Issue

A Stratigraphic Lacuna Around the Ypresian / Lutetian Boundary (Early-Middle Eocene) in Arabia and Other Localities in the Tethys

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Abstract: The changes in the paleontology, stratigraphy and sedimentary facies around Ypresian/Lutetian boundary (YLB) or Early/Middle Eocene boundary (EMEB) have been documented in many sections in Arabia and some other localities in the Tethys (including Saudi Arabia, United Arab Emirates, Qatar, Kuwait, Iraq, Jordan, Palestine, Turkey, India, Egypt, Libya, Spain and France) which provides a good database for biostratigraphic subdivisions, that are marked by a stratigraphic lacuna in these areas. The event that produced this lacuna is believed to be primarily tectonic, which coincides tentatively with the pronounced eustatic lowering of the sea-level just before the close of Ypresian, which may place in apparent juxtaposition.

Key words: Lacuna, Ypresian, Lutetian, Eocene, Arabia, Tethys.

INTRODUCTION

A marked lacuna at YLB (or EMEB) has been recorded in many parts of the Tethyan Realm including India (Mohan & Soodan [1], Levitan [2], Rage *et al.* [3]), Turkey (Hrbek *et al.* [4]), Iraq (Al-Hashimi [5]), Kuwait (Boukhary & Alsharhan [6]), Qatar (Boukhary & Alsharhan [6], Al-Saad [7]), Saudi Arabia (Filatoff & Hughes [8]), United Arab Emirates (Anan *et al.* [9], Anan [10], Boukhary *et al.* [11]), Negev (Benjamini [12]), Egypt (El-Heiny & Morsi [13], Abul-Nasr & Thunell [14], Strougo *et al.* [15], Haggag & Luterbacher [16], Haggag [17]), Libya (Guiraud & Bosworth [18]), France (Janin *et al.* [19]), and Spain (Molina *et al.* [20], Orue-Etxebarria *et al.* [21]) (Fig. 1).

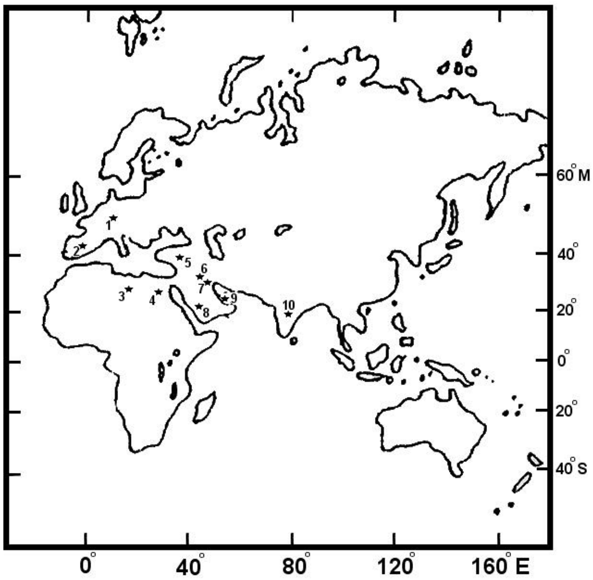

Fig. 1: Location map of the different localities in the Tethys that recorded the lacuna around YLB: 1. France, 2. Spain, 3. Libya, 4. Egypt, 5. Turkey, 6. Iraq, 7. Kuwait, 8. Saudi Arabia, 9. Qatar and United Arab Emirates 10. India.

THE LACUNA AT YLB IN ARABIA

Saudi Arabia (SA): Filatoff & Hughes [8] noted that the episode of Early Eocene-Early Oligocene in the Saudi Arabian Red Sea is based on the apparent absence of sediments of Middle to Upper Eocene age and is interpreted as a period of erosion and/or non deposition. and the exposure is likely to have been related to gradual eustatic fall. A stratigraphical lacuna at YLB in SA was also recorded by Boukhary & Alsharhan [6].

United Arab Emirates (UAE): The YLB is located in the core of the Jabal Hafit, UAE (at Kilometer 4, about 47 m thick, along the right and left sides of the asphalted road climbing to the top of the Jabal (Fig. 2). Anan *et al.* [9] noted that the Early Eocene Hili Member of the Rus Formation in J. Hafit (after the Umm ArRuus Hill in Saudi Arabia) ends by an early

Middle Eocene intraformational conglomeratic bed which underlies the Middle Eocene marl and marly limestone of Wadi Al Nahayan Member (of Hamdan & Bahr [22]) of the Dammam Formation (of Bramkamp [23]). This Middle Eocene stratigraphic situation of the intraformational conglomeratic bed was also presented by Boukhary *et al.* [11] by means of large foraminiferal assemblage and located the EMEB within the Early Eocene Rus Formation by nannofossil assemblage. The latter conclusion about the YLB mainly agrees with the conclusion that previously noted by Anan [10] by means of planktic foraminiferal assemblage at the top of the Early Eocene (P9, *Acarinina pentacamerata* Zone) after the planktic foraminiferal zones of Stainforth *et al.* [24] and Toumarkine & Luterbacher [25] (= *Subbotina inaequispira* of Berggren & Miller [26]) directly after the conglomeratic bed (Fig. 2, bed no. 10).

Qatar: Boukhary & Alsharhan [6] and Al-Saad [7] marked an unconformity between the Early Eocene Rus Formation and the Middle Eocene Midra Member of the Dammam Formation (which represents a gap in the Eocene spans P10 and P12 in the west, and the whole early Lutetian P10-P12 in the east) and represented by a degradation vacuity in the stratigraphic record. This gap is due to the epirogenic uplift of Qatar Peninsula from the close of the late Ypresian (P9) until the beginning of the middle Lutetian (*Globigerinatheka subconglobata* Zone, P11).

Kuwait: Boukhary & Alsharhan [6] figured an unconformity in Kuwait at the YLB which is represented between the Early Eocene Rus Formation and the Middle Eocene Midra Member of the Dammam Formation.

Iraq: Al-Hashimi [5] noted that the Lower-Middle Eocene contact in Wadi Hauran (west of Iraq) is marked by one meter thick bed of conglomerate (consists of nodular phosphate, glauconitic and fish teeth), which indicates a break in sedimentation prior to the Middle Eocene transgression. He also added that the similar Lower-Middle Eocene unconformity of the Dammam Formation is encountered throughout the south and southwestern Iraq. Boukhary & Alsharhan [6] also figured an unconformity in south Iraq around the YLB. On the other hand, Krumbein [27] has edited that the phosphate and glauconitic materials as criteria for recognition of submarine unconformities. Abul-Nasr & Thunell [14] noted that the concentration of clastic phosphatic sediments being a function of reworking during times of lowered sea level. Moreover, Abul-Nasr [28] noted that the genesis of phosphorite and glauconite is simply controlled by the prevalence of anoxic condition combined with slow rate of sedimentation.

Jordan: Abul-Nasr & Thunell [14] noted that a reworked material has been found to be widely distributed and coeval with lag deposits in Jordan and Palestine that coincides stratigraphically with global low sea level stand near the upper part of the Early Eocene (P9).

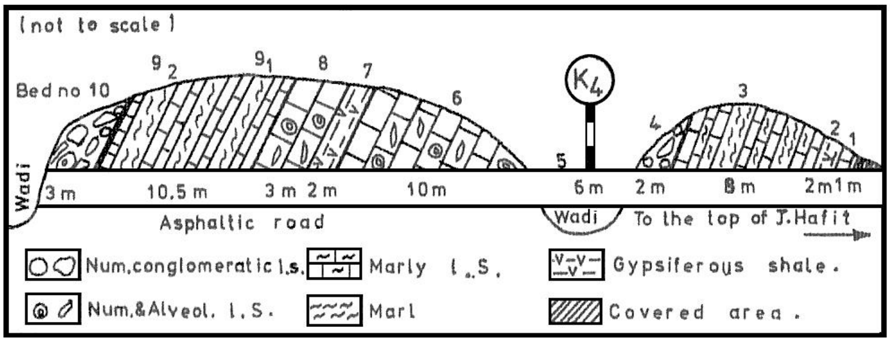

Fig. 2: Top Lower Eocene succession at K4 in Jabal Hafit, UAE including the nine alternated soft and hard limestone beds which ends by the intraformational conglomeratic bed no. 10 (after Anan [10]).

THE LACUNA AT THE YLB IN OTHER SITES OF THE TETHYS

Egypt: El-Heiny & Morsi [13] noted that the hiatus which was recognized in Wadi Qattar section (south central Sinai) near the top of the Thebes Formation and the missing interval in this section compared to Wadi Nukhul section (to the south), are equivalent to the top part of the Early Eocene *Acarinina pentacamerata* Zone (P9) and the lowermost part of the Middle Eocene *Hantkenina aragonensis* (= *H. nuttalli* Zone, P10). Abul-Nasr & Thunell [14] traced a major horizon of reworked material (lag deposit of disseminated fish teeth, phosphatic nodules, coprolites and phosphatic grains) lies within the Thebes Formation near the top of the upper part of the Lower Eocene (P9) in western Sinai. This reworked material has been found to be widely distributed and coeval with similar deposits in Palestione and Jordan and coincides stratigraphically with global low sea level stand. According to these authors, this phase of shallowing is attributed to eustatic sea level falls and not to tectonic movements. They also noted that the tectonic uplift of the Syrian Arc can be ruled out as the major factor responsible for the wide-spread distribution of the observed lag deposits. Haggag [17] detected an unconformity in Wadi Ed Dakhl (South Galala, Eastern Desert of Egypt) which represents a gap across the Early/Middle Eocene boundary, where the Lower Eocene (the upper part of the *Morozovella aragonensis* Zone, P8 and the *Acarinina pentacamerata* Zone, P9) and the basal part of the Middle Eocene (lowest portion of the *A. bullbrooki* Zone = *Hantkenina nuttalli* Zone, P10) are missing.

Libya: Guiraud & Bosworth [18] noted that the shorelines during the Early Eocene slightly regressed and a gentle tectonic activity occurred, mainly characterized by the continued subsidence of the Sirt Basin (Libya), Abu Gharadig, Gindi and Assiut troughs (Egypt). The Early-Middle Eocene transition is often marked by a gap in the series, especially along the Unstable Shelf and Sirt basin.

Turkey: Hrbek *et al.* [4] noted that much agglomeration of the geological regions in central Anatolia began in the early-middle Eocene (~50 Ma)

Spain: Molina *et al.* [20] noted that the base of *Hantkenina nuttalli* Zone (P10 = E8 of Berggren & Pearson [29] at an exposed section near Agost (southern Spain) is often used to set the boundary between the Lower and the Middle Eocene (Ypresian/Lutetian) which falls at a facies changes from a limestone bank to marls just below the first occurrence of *H. nuttalli* implying a short hiatus at the lithological boundary. Orue-Etxebarria *et al.* [21] noted that the different events traditionally used to place the YLB hitherto thought to be simultaneous (planktonic foraminifera, calcareous nannoplankton, large foraminifera), but actually occur at very different levels (Fig. 3).

India: Mohan & Soodan [1] noted that the Middle to upper Eocene sedimentary sequence of Babia Stage of the Berwail Series in the Kutch of India disconformably overlies the Ypresian sediments, and also the Lutetian sediments are disconformably overlain by Oligocene sediments. Jauhri & Agarwal [30] recorded an unconformity between Ypresian and upper Lutetian (rock record missing) in the Shillong, NE India. Rage *et al.* [3] noted that the top of the Naredi Formation in the Kutch of western India consists of lateritic clay that is believed to represent a late Early Eocene unconformity of regional extent.

Fig. 3: The intraformational conglomeratic bed (no. 10) in the top Lower Eocene at K4 of J. Hafit consists of highly compacted pebble and cobble fragmented limestone cemented by fine reddish matrix of marly limestone. This bed rests horizontally on hard ground layer and overlies the alternating beds of the Early Eocene sequence.

TECTONOSEDIMENTARY EVOLUTION AT YLB IN THE TETHYS

1. Said [31] noted that a worldwide high-stand of sea-level during late Cretaceous and early Tertiary time resulted in the transgression of a broad epicontinental sea across a large area of the northeast margin of the Arabo-Nubian Craton.
2. Moore *et al.* [32] recorded a hiatus occurs near the base of the Middle Eocene (48-50 Ma), and it is seen only as a shoulder in the hiatus abundance curves of the World Ocean.
3. The YLB was predicted by Haq *et al.* [33] at top C22n (49 Ma), at P9/P10 boundary.
4. Warrak [34] noted that the development of Hafit anticline (UAE) as a positive relief feature must have started just before the Middle Eocene, and at the beginning of that time it was definitely a ridge. Warrak [35] concluded that J. Hafit and other foreland folds in the Northern Oman Mountains were formed prior to the main Zagaros deformation which started in very Late Miocene and culminated in the Late Plio-Pleistocene.

5. Snavely *et al.* [36] noted that a late Ypresian abrupt sea-level drop (recognized by Vail *et al.* [37]) caused a rapid and widespread regression of the epicontinental sea. Carbonate platforms in the eastern part of the Egyptian basin became suddenly exposed and eroded with localized shallow-marine deposition being restricted to structurally low regions between fault blocks.
6. Berggren & Miller [26] noted that the global sea-level lowering (and associated hiatus / unconformity) characteristics of the LMEB interval which may place in apparent juxtaposition or overlap, biostratigraphic events are normally separated in space and time.
7. Janin *et al.* [19] announced about the well known hiatus between the Cuisian (Early Eocene) and Lutetian (Middle Eocene) in the French type-localities.
8. Haggag [17] detected an unconformity in Wadi Ed Dakhl (South Galala, Eastern Desert of Egypt) represents a gap across the EMEB.
9. Levitan [2] noted that the 'soft' collision between India and Asia began in the Early-Middle Eocene and spreading system of the Indian Ocean changed conguration.
10. Sissingh [38] noted that an imported event affecting the northern Peri-Tethys platform was the inception of rifting in Western Europe at about the beginning of the Middle Eocene, 50 Ma ago.
11. Jauhri & Agarwal [30] in the Shillong Plateau, NE India recorded clastic influx major regression at the top Ypresian (represents major cooling) and followed unconformably by an upper Lutetian limestone succession (represents warming Khirthar transgression). An event of modest tectonic and climatic fluctuations bringing about an appreciable amount of change in the depositional environment and biota occurred across the early Eocene-middle Eocene boundary (upper Zone P9-lowermost Zone P12).
12. Meulenkamp & Sissingh [39] noted that the Tertiary evolution of the Peri-Tethys platforms was primarily controlled by the enhanced coupling of the African/Arabian, Apulian, Iberian, Eurasian and Indian plates. The northward motion of the African block relative to Eurasia was fastest in the east in accordance with the overall anticlockwise rotation of Africa/Arabia, whereas the position of the of northern margin of the African Plate relative to Iberian remained fairly stable throughout the Cainozoic. They also added that the Arabian Platform, still largely covered by the sea in Early to Middle Eocene times, was subject to a major regression in the Middle to Late Eocene.
13. Akosy *et al.* [40] noted that the Middle-Upper Eocene deposits of the Elaziğ Basin at Eastern Turkey accumulated when the basin subsided rapidly during the Middle Eocene by block faulting. Due to uplift of a footwall block the sea could not inundated the area south of this fault.
14. Zaineldeen & Fowler [41] interpreted that the most faults in the Early Eocene succession of J. Hafit were erected during the Late Cretaceous and reactivated in the Early Eocene and later times and two generation of folds affected the Lower Eocene.

PALEONTOLOGICAL SETTING OF THE EARLY/MIDDLE EOCENE IN JABAL HAFIT

The well preserved planktic and benthic foraminiferal assemblages around YLB in J. Hafit anticline, UAE provide a good database for biostratigraphic subdivisions and identification of faunal changes. Below the conglomeratic bed (Fig. 3), Anan *et al.* [9] recorded 17 planktic foraminiferal species from the Early Eocene succession related to the Rus Formation, and one large species *Nummulites bassiounii* Boukhary and Blondeau [42] (belongs to the *N. perplxus* lineage) was recorded in the crest of J. Hafit. Anan [10] recorded 24 planktic foraminiferal species, 23 small benthic foraminiferal species and 1 large foraminiferal species *Davisina langhami* were also recorded in the conglomeratic bed, as well as 23 nannofossil species by Boukhary *et al.* [11]. The latter authors found rich large benthic foraminiferal species in the fine reddish matrix of marly limestone carbonates which cements the conglomerate clasts in the conglomeratic bed, including *Assilina spira abrardi, Somalina praestefanini* and *Nummulites perplxus*, which is similar to the basal Lutetian assemblage of Italy. For that, they considered this intraformational conglomeratic bed representing the basal part of the Middle Eocene, as noted previously by Anan *et al.* [9] (but not the upper part of Early Eocene as noted by Anan [10]). The latter conclusion is in accordance with the nannofossil assemblage recorded by Boukhary *et al.* [6]. This results considered the EMEB within the Early Eocene Rus Formation, which supports the idea that previously presented by Anan [10] to locate the intraformational bed in the Early Eocene Rus Formation, not to the basal Lutetian Wadi Al Nahayan Formation (as noted before by Anan *et al.* [9] and Boukhary *et al.* [11]).

Based on the stratigraphic distribution of the relevant index planktic foraminiferal fossils *Morozovella caucasica* and *Hantkenina nuttalli*, the YLB can be detected as follows (Table 1):

1) The diagnostic planktic foraminiferal species *M. caucasica* has been recorded around the YLB (P9/P10) in some regional studies (Blow [43], Krasheninnikov & Pflaumann [44], Toumarkine & Luterbacher [25], Pearson [47], while it has been found only up to the top of the Early Eocene horizon (P9) by some other authors (i.e. Stainforth *et al.* [24], Toumarkine [48], Benjamini [12], Haggag & Luterbacher [16], Anan *et al.* [9], Anan [10] Molina *et al.* [20]. Its absence in the Middle Eocene horizon

most probably an indication of a local diastem more than ecological factors.

2) The YLB is usually placed at the base of the Middle Eocene *H. nuttalli* Zone (P10, based on the marker species). It has not been found in some studied sections in Egypt (Haggag [45], [17], Haggag & Luterbacher [16], Marzouk & Soliman [47]) and J. Hafit, UAE (Anan *et al.* [9], Anan [10], but appears only in younger levels than recorded, in some regional literatures (Blow [43], Toumarkine & Luterbacher [25], Pearson [47]. These authors noted that the absence of this marker species prevents the direct recognition of the homonymous zone.

Table 1: Stratigraphic ranges of *Morozovella caucasica* (Glaessner) as recorded by some authors: 1. Stainforth *et al* [24], 2. Toumarkine & Luterbacher [25], 3. Krasheninnikov & Pflaumann[44], 4. Hillebrandt [48], 5. Benjamini [12], 6. Toumarkine [25], 7. Blow [43], 8. Haggag & Luterbacher [16], 9. Anan *et al.* [9], and Anan [10], 10. Molina *et al.* [20] , 11. Pearson [46].

Age	Planktonic Foraminiferal Zonation / Authors		1	2	3	4	5	6	7	8	9	10	11
Middle Eocene	*Hantkenina nuttalli or Acarinina bullbrooki or Subbotina inaequispira*	P10											
Early Eocene	*A. pentacamerata*	P9											
	Morozovella aragonensis	P8											

THE YLB LACUNA IN JABAL HAFIT, UAE – A CASE STUDY

1. Cherif & El Deeb [49] started the base rocks of Jabal Hafit with the Middle Eocene age and remarked four unconformities in the Tertiary sequence of J. Hafit. These are, in ascending order: (1) within the Middle Eocene, (2) between the Middle Eocene (P13) and the Late Eocene (P16/P17), (3) at the Late Eocene/Oligocene contact, and (4) at the Oligocene/Miocene contact.
2. Warrak [35] presented four local diastems in J. Hafit anticline, which are in ascending order: (1) on the crest between Tle1 (Paleocene-Middle Eocene limestone) and Tle 2 (Middle Eocene cherty limestone), (2) bands of pebble and boulders limestone conglomerate near the top of Tle 2 and along the hinge zone of the structure, (3) at the basal contact of Tle 4 (Middle Eocene buff limestone) and (4) the Late Eocene/Oligocene contact in the northern part of J. Hafit.
3. Anan *et al.* [9] related the Early Eocene rocks, for the first time, to the Hili Member of the Rus Formation. The YLB is located in the core of the Jabal Hafit (at Kilometer 4 along both sides of the asphalted road climbing to the top of the Jabal). They also added that the Early Eocene succession belongs to the Early Eocene *Acarinina pentacamerata* Zone, P9 (= E7 of Berggren & Pearson [29] and ends by an early Middle Eocene intraformational conglomeratic bed, which underlies unconformably the marl and marly limestone of early Middle Eocene? *Hantkenina nuttalli* Zone, P10 (= E8 of Berggren & Pearson [29] of Wadi Al Nahayan Member of the Dammam Formation.
4. Anan [10] noted that the top Lower Eocene consists of nine alternating soft gypsiferous shale, marl and marly limestone beds with hard nummulitic and/or alveolinid limestone beds (Fig. 2) which ended with an intraformational conglomeratic bed (Fig. 2, no. 10, Fig. 3) around the YLB. The sedimentary facies of this conglomeratic bed coincides with the marked fall in sea level that took place just before the close of the Early Eocene (as noted by Vail *et al.* [37] and Haq *et al.* [33], about 48/49 Ma). This bed is barren of small foraminifera, but yields large foraminiferal species. Accordingly, this intraformational conglomeratic bed belongs to the Early Eocene. It was most probably deposited as submarine debris flows in the basin, not as subaerial denudation due to the occurrence of angular to subangular limestone detritus in different sizes of fragments with fine grained matrix in the small and nearly homogenous thickness. This conglomeratic bed

suggests a minimal reworking and accumulation in low-energy environment in a short distance of transportation on a slightly steepening paleoslope from the positive localized source area during the time of active tectonic.

5. Boukhary *et al.* [11] noted that the conglomeratic bed around YLB yields large foraminiferal assemblage as *Assilina spira abrardi, Somalina praestefanini* and *Nummulites perplxus* similar to the basal Lutetian assemblage of Italy and presented this conglomeratic bed as a new member (Mibazara Member) in the Middle Eocene Wadi Al Nahayan Formation of the Dammam Group. According to the same authors the nannofossil assemblage the Lower/Middle Eocene boundary coincides with the NP 13/NP 14 boundary, lies within the top Lower Eocene Rus Formation.
6. As noted by many authors in many different locations in the Tethys (Hillebrandt [48], Cherif & El Deeb [49], Boukhary & Abdelmalik [50], Molina *et al.* [20], Orue-Etxebarria *et al.* [21] (Fig. 3) the biostratigraphical zonations of planktic and/or larger foraminifera at YLB are not coincident.
7. Accordingly, the stratigraphical position of the conglomeratic bed is still a matter of controversy. How, then, is it belonging to the top Ypresian or base Lutetian? and also by any tool of faunal assemblage?. Considering the problems outlined here, the late Early to early Middle Eocene is subject to independent verification. Whether this horizon can be used for locating the YLB it seems that we must await further studies. Until now, it is not equivocally or clear to us.

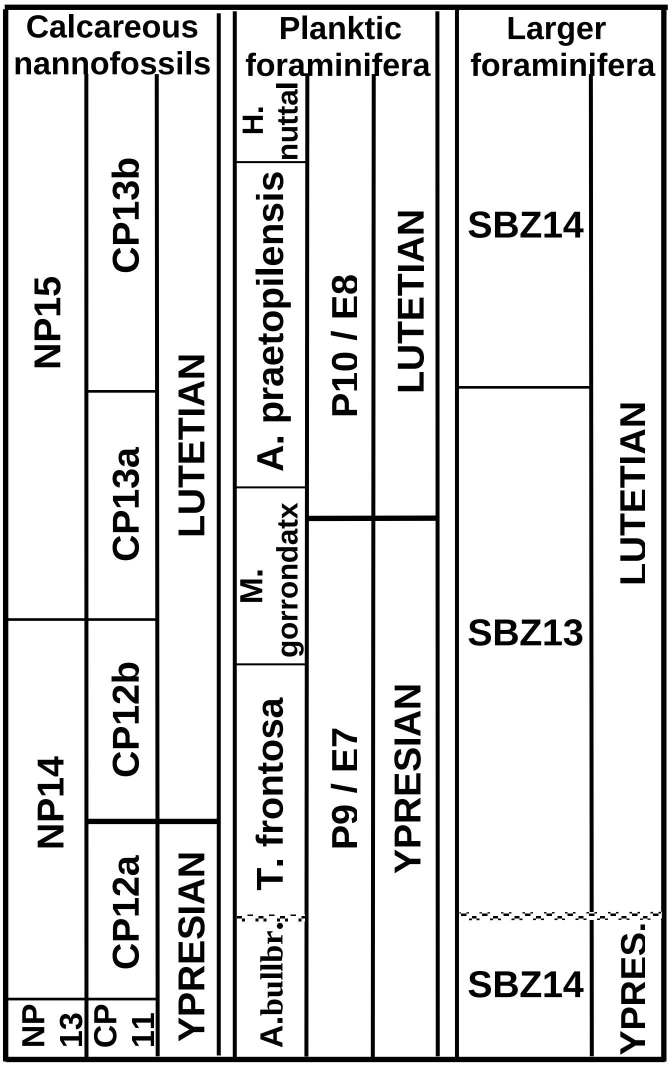

Fig. 3: The position of the boundary between the Ypresian and Lutetian based on different biostratigraphic zones of Calcareous Nannofossils, Planktonic Foraminifera and Larger Foraminifera in Gorrondatxe beach section, (Basque Country, W. Pyrenees), northwest Spain (after Orue-Etxebarria *et al.* [21].

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عدد خاص بالمؤتمر الدولي الأول للعلوم الأساسية والتطبيقية
من ١٠-١٢ أكتوبر ٢٠١٠

مجلة علمية محكمة

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عمادة الدراسات العليا والبحث العلمي

جامعة الأزهر- غزة

فلسطين

ISSN 1810-6366

المجلد ١٢، عدد خاص