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Biostratigraphic and Palaeoenvironmental Study of the Tobène Phosphatic Series (Western Senegal)

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Abstract: ***The geological section of the phosphate quarry of Tobène associated with the boreholes of prospecting, carried out by miners, confirms the Tobène's lithostratigraphic and biostratigraphic settings. A lithostratigraphic analysis [1], [2] highlights three sedimentary formations, in agreement with previous results [3]. From a biostratigraphic point of view, the planktonic microfauna highlighted E8 to E13 biozones in the phosphatic group, dating it to the early Lutetian to Bartonian age and helping to develop a more complete biozonation throughout the deposit. The pelagism index indicates an evolution of sedimentary environment between a slightly opened internal platform, favourable to detrital and siliceous deposits, and an intermediate platform more conducive to calcium phosphate deposits.***

Keywords: Tobène, Taïba, phosphate, lithostratigraphy, biostratigraphy

1. Introduction

The Tobène panel forms with those of the Ndomor Mor Diop and Keur Fall, the large phosphates deposit of Taïba. It is situated between Mboro and Tivaouane, approximately 80 km northeast of Dakar (Fig. 1).

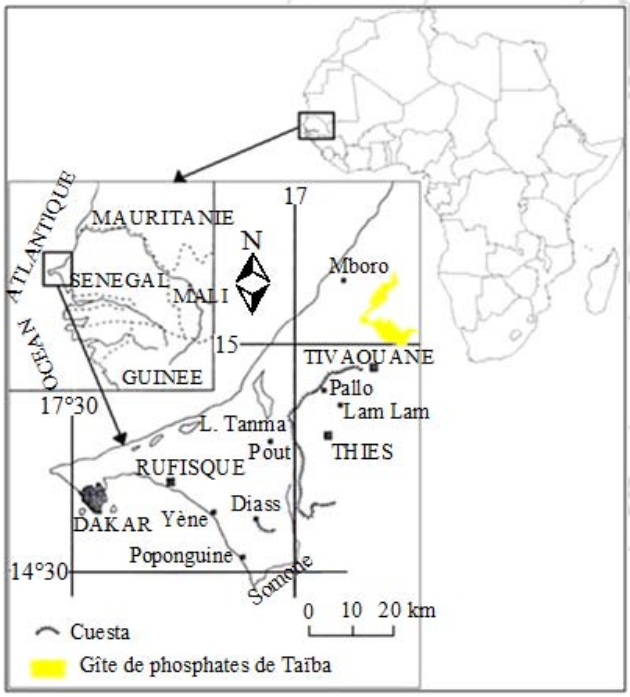

Figure 1: Location map of the Taïba deposit [4]

The first biostratigraphic study of the Taïba deposit, on the basis of macrofauna [5], dated the phosphate to the late Lutetian age. Subsequent biostratigraphic work on planktonic foraminifera [6]–[10] dated the phosphate deposit to the late Lutetian to Bartonian age.

Recently, biostratigraphic studies of Tobène [11]–[13] have helped establish a more detailed biozonation. However, these studies are often sectorial.

The aim of this synthesis study is to extend the biostratigraphic research on the eastern sector of the Tobène panel, with AOBJ and EIGQ boreholes, to establish a more complete biozonation across the Tobène deposit and to clarify the environment of the phosphate deposit, particularly in the eastern sector.

2. Literature Survey

The relevance of this synthesis research, taken from the thesis of Diagne [1], rests on the fact that it covers all the sectors of Tobène deposit and completes the previous studies on western, north and central sectors [11]–[13]. Consequently, it allows, with AOBJ and EIGQ boreholes in the eastern sector, to establish a more complete biozonation across the whole of Tobène deposit and a reconstruction of phosphates depositional environment.

3. Materials and methods

The studied samples came from the Tobène quarry and the borehole cores (AOBJ and EIGQ) of the east-central and eastern sectors of the deposit.

Each sample was disintegrated in a solution of hydrogen peroxide at 110 volumes to eliminate organic matter, washed with water, and then sifted with 1-mm, 125-µm and 63-µm sieves. The arenic fraction was then isolated, dried in a drying oven and sorted under a binocular lump to extract the fossils before the determination of the species [14]–[16]

4. Results and Discussion

4.1 Study of the boreholes

4.1.1 EESD borehole (Fig. 2)

a. Lithologic description

This borehole presented four lithologic units, which are, from the bottom to the top:

- from 40.75 to 40.55 m: foliated attapulgite clay, representing the wall of the phosphate layer; this unit is attached to the Lam-Lam formation [3];

- from 40.55 to 34.60 m: locally silicified heterogeneous phosphate (18.5 to 19.5m) belonging to the formation with large flint nodules;
- from 34.60 to 33.95 m: little phosphatic and ferruginous brown clays representing the roof of the phosphatic layer; and
- from 33.95 to 27.10 m: ferruginous phosphatic sandstone changing in the lower third of the unit into phosphate that contains numerous silicified and ferruginous enclaves then into heterogeneous phosphate at the base.

The last two units were assembled in a single formation of platy flint rich in Daucina and variegated clays [3].

b. Biozonation

The biozonation scale used is the one used by [17]. The genus names of the foraminifera and author names are given only in the first quotation.

The presence of *Truncorotaloides rohri* Brönnimann between 39.9 m and 33 m deep (lithologic units 2 to 4) characterizes E7 to E13 biozones. However, the association of the species *Truncorotaloides* cf. *libyaensis* El Khoudary, *T.* cf. *haynesi* Samanta, and *Morozovella lehneri* Cushman and Jarvis, between 39 and 33 m deep, characterizes the E9 to E13 biozones. Finally, the presence of *Orbulinoides beckmanni* Saito from 33.94 m to 34.7 m (lithologic unit 3) placed this interval in the E12 biozone.

Due to the presence of E9 biozone, overlying E8 biozone at the base of calcareous phosphate (lithologic unit 2), these planktonic foraminifera characterize the E8 to E14 biozones of the early Lutetian to Bartonian age.

c. Palaeoenvironmental evolution

The palaeoenvironmental interpretation is based on the values of the pelagism index calculated along each borehole, the associations of molluscs and the Lithology, among others.

Despite the frequent fluctuations, the values of the pelagism index remain relatively high (27.77 to 55.55%). The marine environment is thus opened and characterizes an intermediate platform. The absence of molluscs in most samples seems to be explained by the larger depth of the depositional environment.

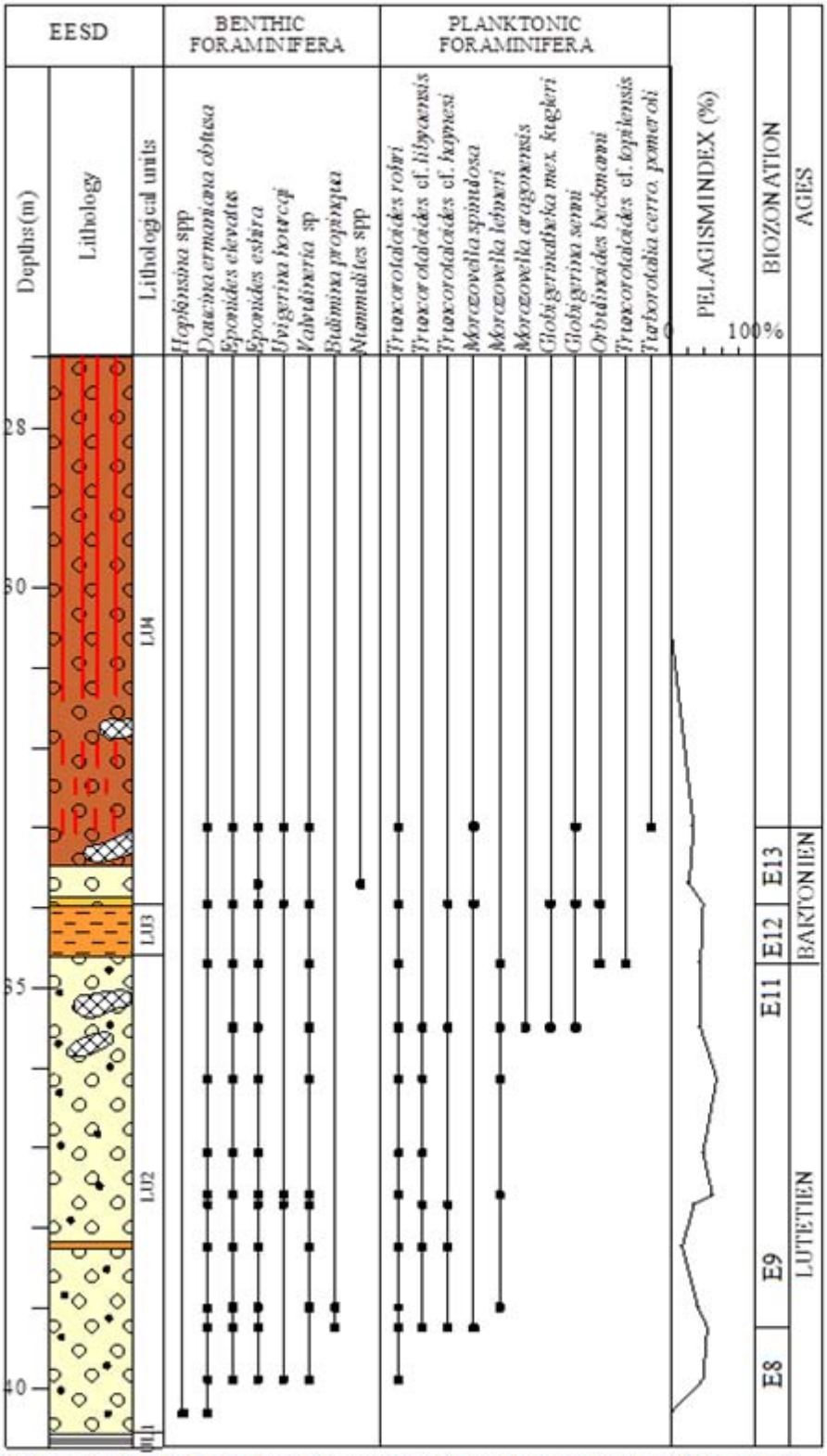

Figure 2: Lithology of phosphatic series and vertical distribution of planktonic and benthic foraminifera in order of appearance in the EESD borehole

Figure 3: Legend of lithologic symbols of the Tobène deposit

4.2 AYNS borehole (Fig. 4)

a. Lithologic description

Five lithologic units follow each other, in this borehole, upwards:

- from 43.20 to 42.50 m: karstified limestone at the top, corresponding to the wall of the phosphatic layer;
- from 42.50 to 37.90 m: pulverulent calcareous phosphate with silicified levels in the upper half of the unit; the base, having intercalations of phosphatic limestone, is more carbonated;
- from 37.90 to 34.10 m: clayey homogeneous phosphate and pulverulent on the top of the unit, becoming more or less ferruginous with ferruginous veinlets as it moves upwards;

- from 34.10 to 33.70 m: slightly phosphatic and ferruginous green clays; and
- from 33.70 to 28.40 m: gritty and ferruginous phosphate (29.9 to 31.4 m deep); at the base of the unit, it changes into a sandy phosphate that is more or less ferruginous, which overlies the homogeneous phosphate.

b. Biozonation

The association of planktonic foraminifera between 42.25 and 28.88 m deep (lithologic units 2 to 5), including *Truncorotaloides haynesi*, *T. libyaensis*, and *T. rohri*, locates this interval in E9 to E13 biozones. The presence of *Orbulinoides beckmanni* at 33.18 m (unit 5) indicates E12 biozone. Therefore, these planktonic foraminifera highlight E8 to E13 biozones of the early Lutetian to Bartonian age.

c. Palaeoenvironmental evolution

The evolution of the pelagism index shows a fluctuation between the domain type intermediate platform (index between 15 and 47%) and the littoral to the infralittoral domain (0 and 15%). The presence of molluscs confirms the existence of a marine environment, type continental shelf. (Ly *et al.*, 2003)

4.2.1 Borehole UAND (Fig. 5)

a. Lithologic description

This borehole presents four lithologic units, which are, moving upwards:

- from 43.50 to 43.40 m: foliated attapulgite clays;
- from 43.40 to 34.60 m: sandy phosphate, changing into a clayey phosphate overlaid by sand with ferruginous hardening interbedded by phosphate; the unit ends by phosphate with siliceous or phosphatic clay intercalations;
- from 34.60 to 34.25 m: brown clays; and
- from 34.25 to 31.45 m: hardened phosphate topped by sandy phosphate more or less hardened.

b. Biozonation

The association of planktonic species *Truncorotaloides* aff. *haynesi*, *T. libyaensis*, *T. topilensis* Cushman, *T. Rohri*, *Morozovella spinulosa* Cushman, and *Globigerina eocaena* Guembel, between 41.30 and 34.35 m deep, locates this interval in E7 to E13 biozones. The presence of *Orbulinoides beckmanni* at 34.35 m allows for the placement of this level in E12 biozone.

According to Flicoteaux in [3], who located attapulgites in the early Lutetian, this phosphate series may have been deposited in the early Lutetian to the Bartonian age, corresponding to E8 to E13 biozones.

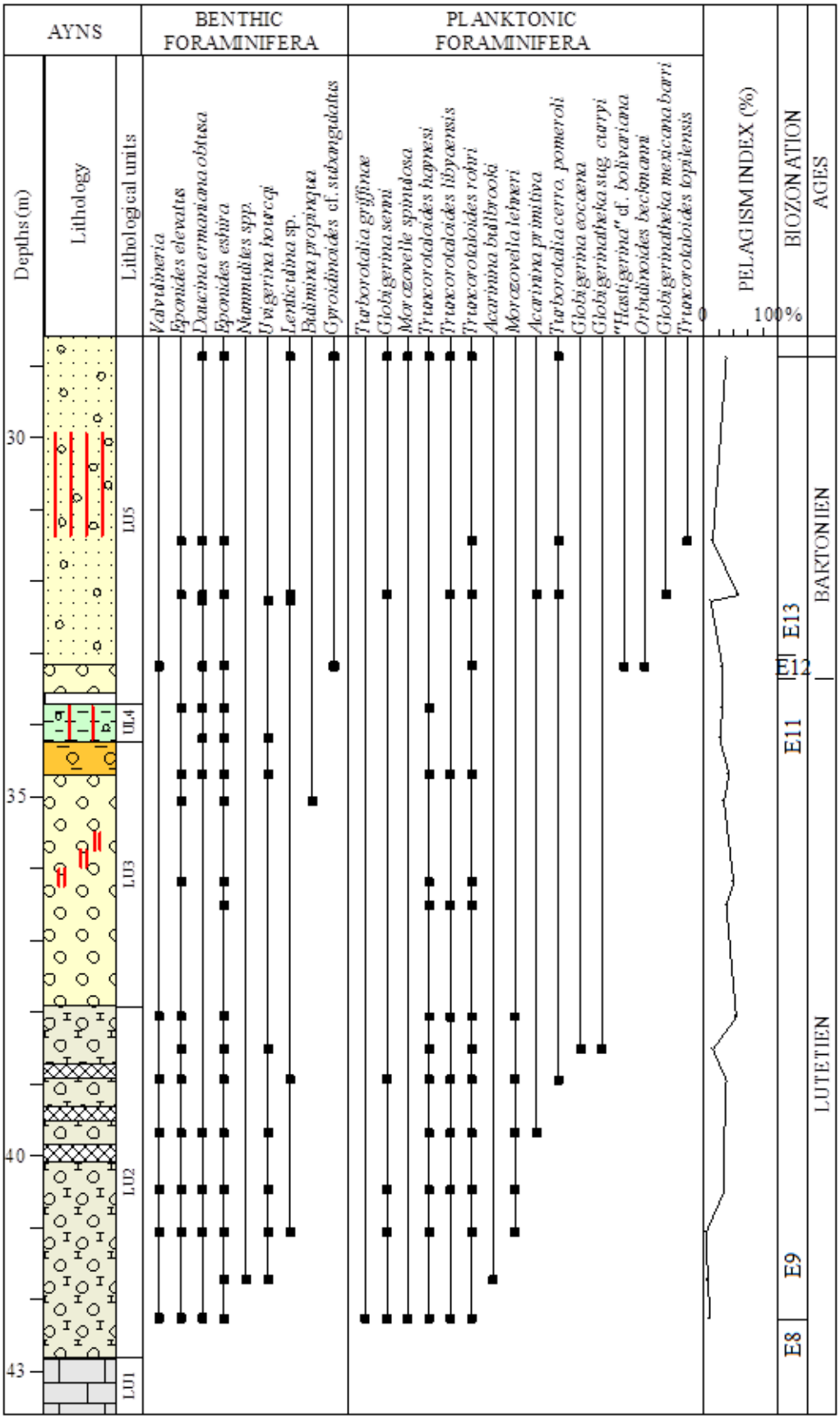

Figure 4: Lithology of the phosphatic series and vertical distribution of planktonic and benthic foraminifera in order of appearance in the AYNS borehole

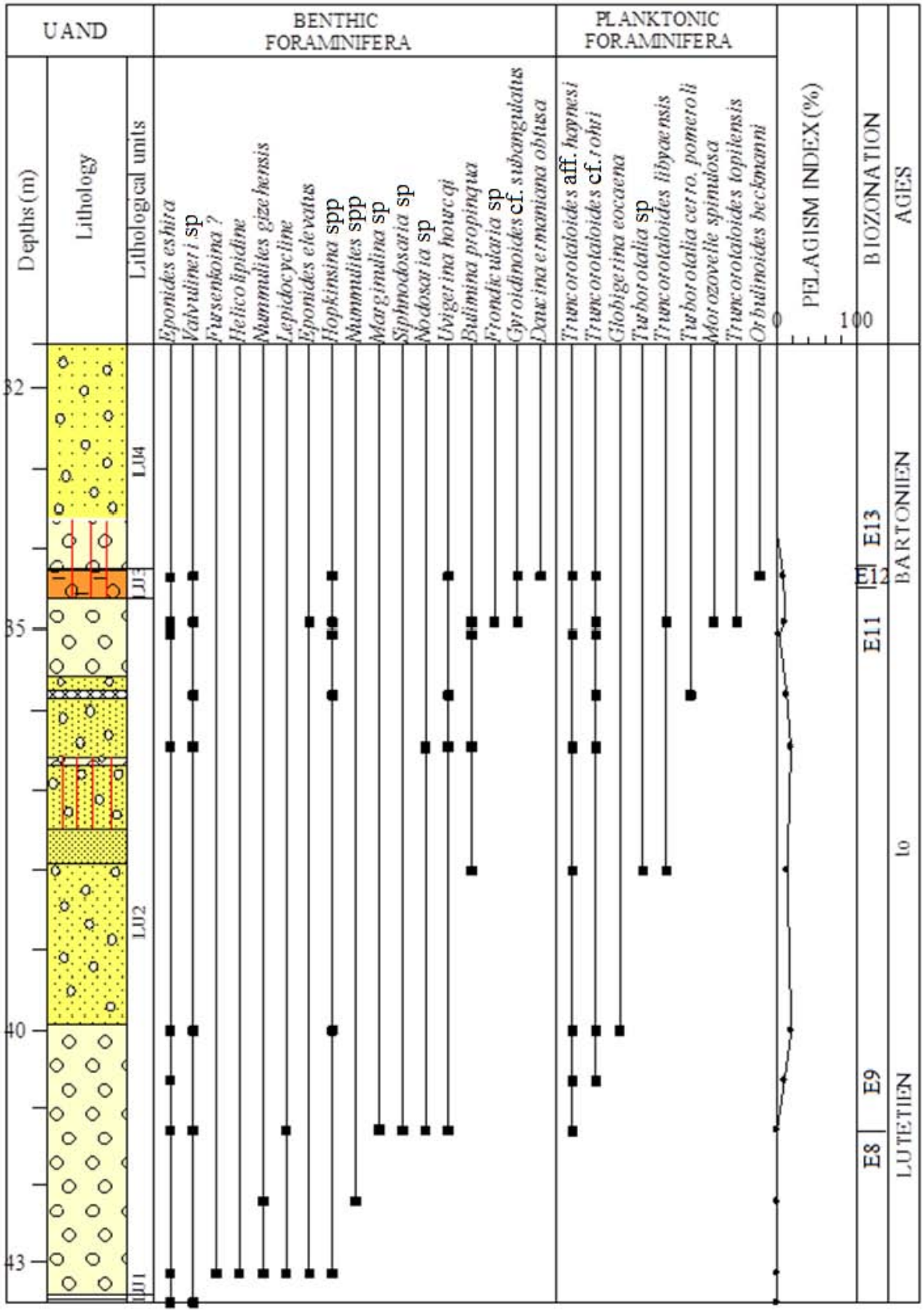

Figure 5: Lithology of phosphate series and vertical distribution of planktonic and benthic foraminifera in order of appearance in the UAND borehole

c. Palaeoenvironmental evolution

Throughout the borehole, the low values of the pelagism index (0 to 18.4%) reflect low marine influences and an infralittoral to littoral depositional environment.

4.2.3 IINS borehole (Fig. 6)

a. Lithologic description

This borehole shows five lithologic units, which follow each other from bottom to top:

- from 37.60 to 37.45 m: attapulgites;

- from 37.45 to 32.80 m: beige heterogeneous phosphate hardened in several places; it presents at the base flint benches, and the phosphate beds are more or less clayey;
- from 32.80 to 31.45 m: beige to grey homogeneous phosphate, which is silicified in places;
- from 31.45 to 30.47 m: phosphatic clay; and

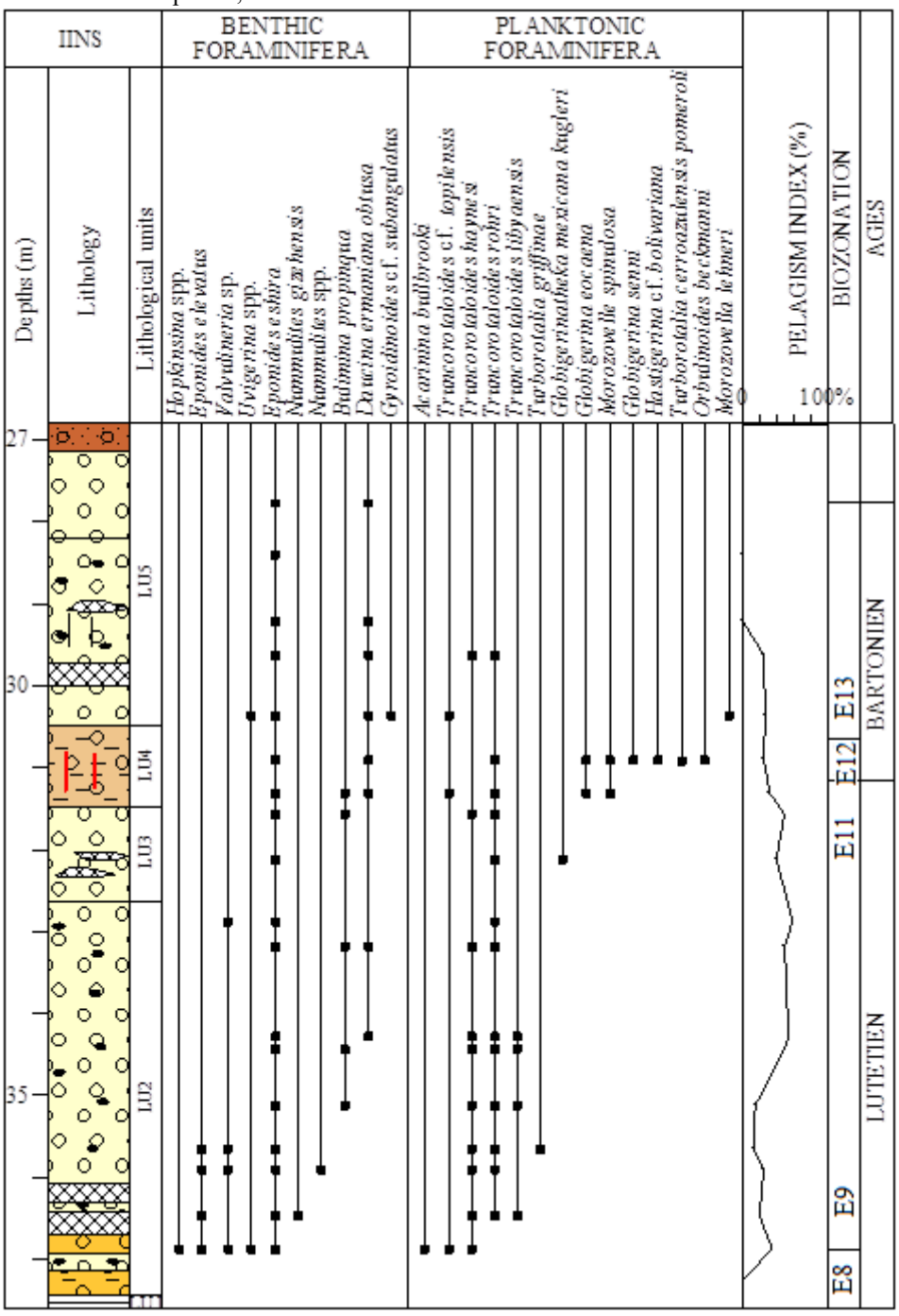

Figure 6: Lithology of phosphate series and vertical distribution of planktonic and benthic foraminifera in order of appearance in the IINS borehole

- From 30.47 to 26.80 m: oxidized, silicified homogeneous phosphate, more or less hardened; at the summit of the unit, it passes to badly hardened phosphatic sandstone.

b. Biozonation

The planktonic foraminifera *Truncorotaloides* cf. *topilensis* and *T. haynesi* in the interval 36.85 to 29.6 m (lithologic units 2 to 5) characterize E9 to E13 biozones. The spices *Orbulinoides beckmanni* at 30.90 m deep (lithologic unit 4) places this level in E12 biozone. The presence of E9 biozone at the base of the heterogeneous phosphate (lithologic unit 2) overlying attapulgite clays locates the phosphate series of this borehole between E8 and E13 biozones and places it in the early Lutetian to Bartonian age.

c. Palaeoenvironmental Evolution

The evolution of the pelagism index in this borehole reflects a fluctuation ranging from the infralittoral and littoral domains, which are slightly opened with a low pelagism index (0 to 15%), to an intermediate to external platform,

where the index is higher (20 to 60%). Furthermore, the presence of molluscs in some samples indicates a marine environment-type continental shelf.

4.2.4 AOBJ borehole (Fig. 7)

a. Lithologic description

Four lithologic units were identified in this borehole, which are, moving upwards:

- from 46.80 to 46 m: attapulgites;
- from 46 to 43.70 m: sand that is intercalated by clayey phosphate at the base and becomes clayey at the top;
- from 43.70 to 42.80 m: clay interbedded by clayey phosphate and flint benches; and
- from 42.80 to 38.40 m: ferruginous sandstone overlying clayey phosphate.

b. Biozonation

On the basis of planktonic foraminifera *Truncorotaloides topilensis*, *Globigerina eocaena* and *Morozovella lehneri* found at a depth between 45.15 and 40.11 m (lithologic units 2 to 4), the phosphate series was deposited in the early Lutetian to Bartonian, corresponding to E8 to E13 biozones. The rarity of planktonic species from 42 to 39 m does not allow for the establishment of a precise biozonation at this interval.

c. Palaeoenvironmental evolution

The fluctuations of the pelagism index (between 0 and 62%) indicate oscillations of the sea level between the littoral to infralittoral domain and the intermediate to external platform.

The frequency of molluscs and fish vertebrae characterizes the continental shelf. This conclusion agrees well with the results of the work in the western zone of Tobène [9 and 10].

4.2.5 EIGQ borehole (Fig. 8)

a. Lithologic description

This borehole highlights five lithologic units, which are, from bottom to top:

- from 49.10 to 48.85 m: attapulgites;
- from 48.85 to 44.88 m: ferruginous heterogeneous phosphate in its lower half; it is locally sandy and intercalated by flint benches;
- from 44.88 to 41.40 m: sandy homogeneous phosphate;
- from 41.40 to 40.18 m: green clay interbedded by flint benches; and
- from 40.18 to 38.57 m: homogeneous phosphate that is clayey at the base.

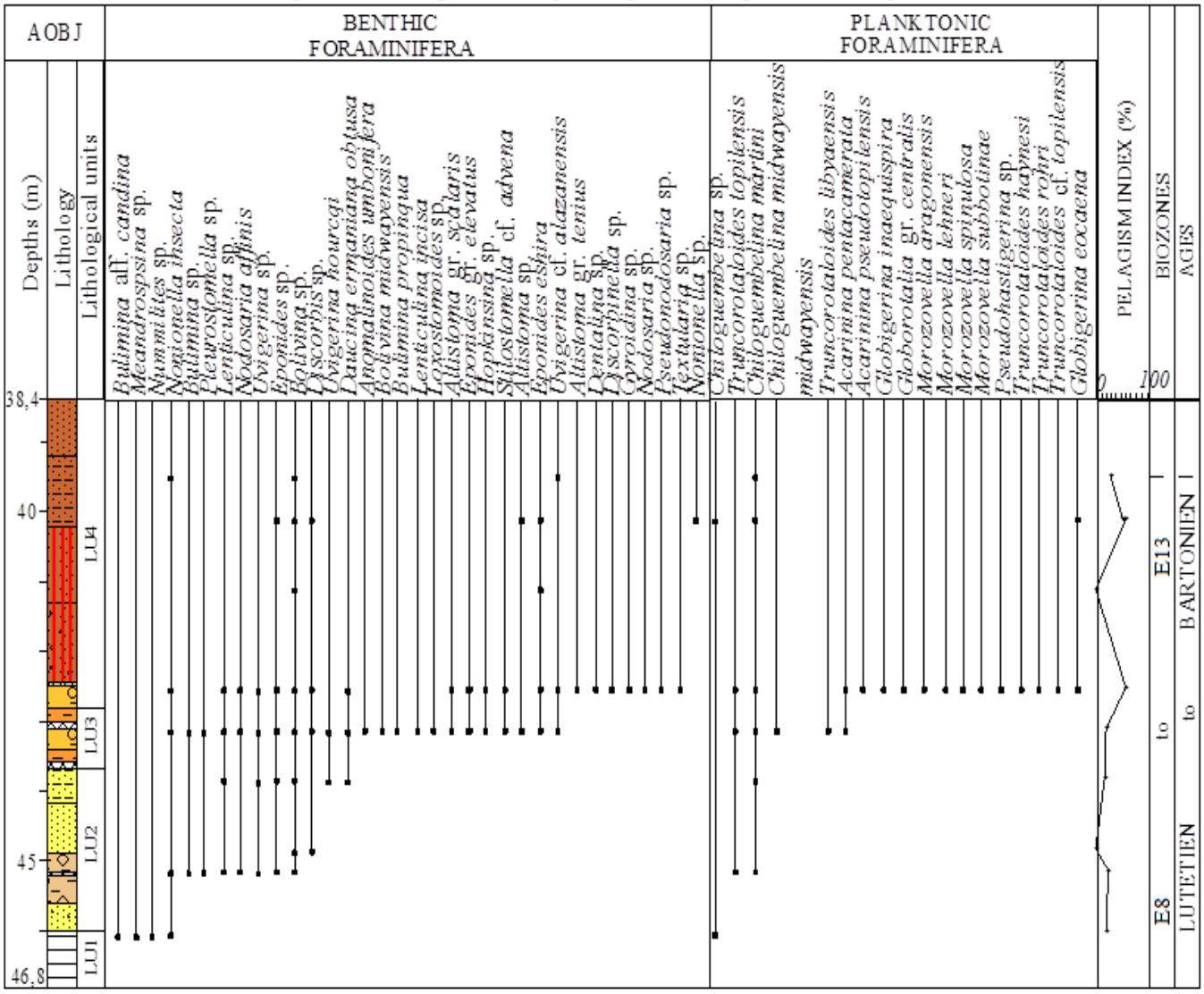

Figure 7: Lithology of phosphate series and vertical distribution of planktonic and benthic foraminifera in order of appearance in the AOBJ borehole

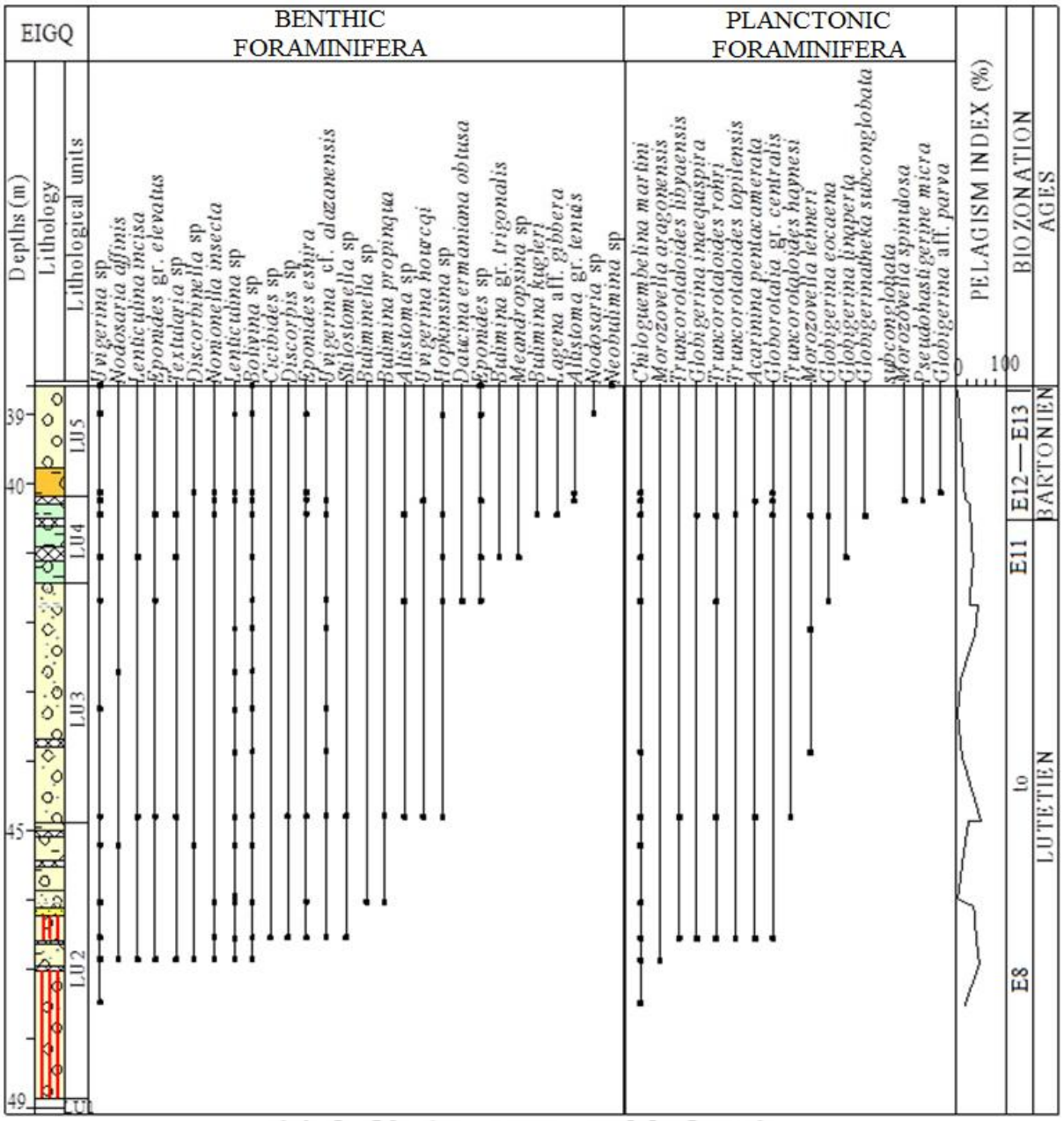

Figure 8: Lithology of phosphate series and vertical distribution of planktonic and benthic foraminifera in order of appearance in the EIGQ borehole

b. Biozonation

These planktonic species *Truncorotaloides libyaensis*, *T. rohri*, and *T. topilensis,* found between 46.55 to 40.45 m deep (lithologic units 2 to 4), situates the interval in E9 to E13 biozones. The presence of *Globigerina inaequispira* Subbotina between 46.55 to 40.45 m characterizes E6 to E11 biozones. Thus, the phosphatic series dates to the early Lutetian to the Bartonian age (E8 to E13 biozones).

c. Palaeoenvironmental evolution

The values of the pelagism index range from 5% to 48% and characterize an internal to intermediate platform. The presence of microgastropods, lamellibranchiata, fish vertebra and rare sea urchin debris, including units 2 and 3, indicate a continental shelf.

4.3 Biostratigraphic Correlations Between Study Boreholes

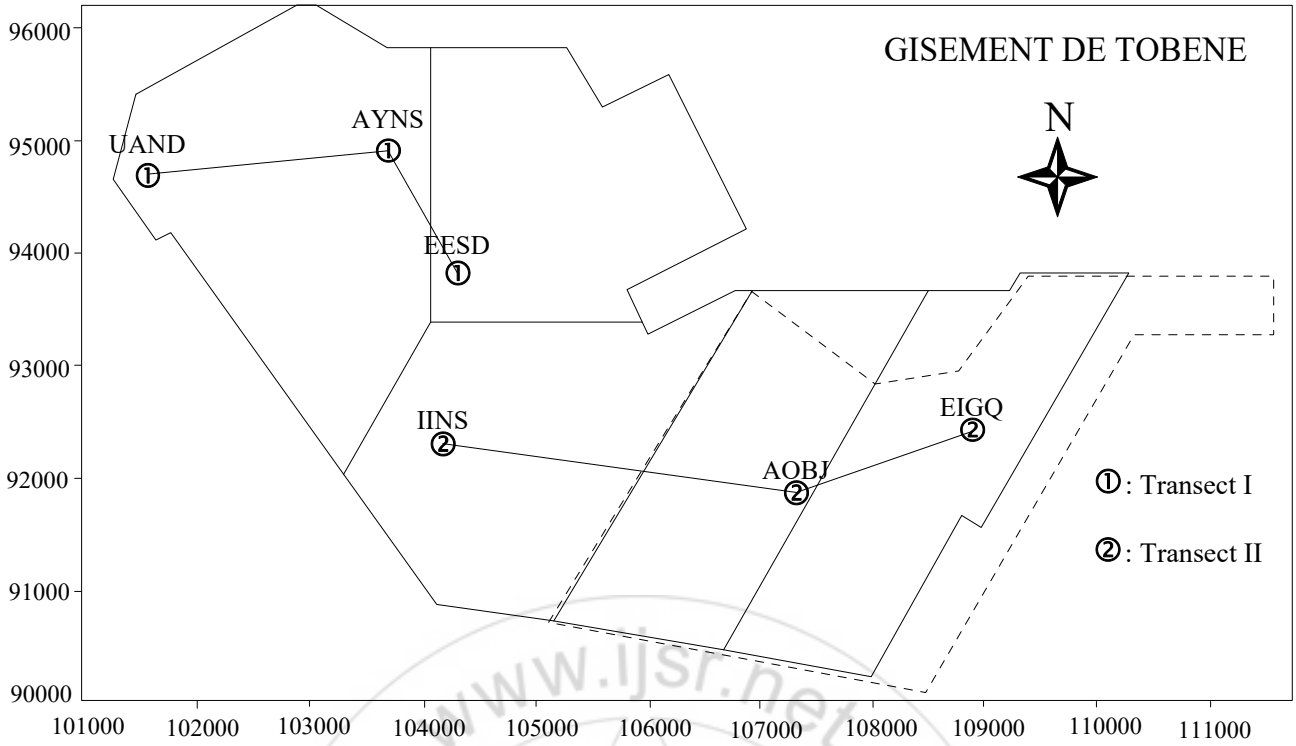

Figure 9: Map locating study boreholes and transects

4.3.1 Transect I (figs. 9 and 10)

a. Biostratigraphic correlations

This west-east transect goes through the UAND, AYNS and EESD boreholes. With the exception of the AYNS borehole, the base of the boreholes is comprised of foliated clays (attapulgite) and corresponds to E8 biozone, dated early Lutetian. This age is more consistent because E9 biozone was highlighted at the base of the lower phosphatic formation, which overcomes foliated clays in the boreholes. The rest of the phosphatic group (phosphatic formations 1 and 2) is characterized by the simultaneous presence of plankton species *Truncorotaloides haynesi*, *T. libyaensis*, *T. Rohri* and *Orbulinoides beckmanni*. This association places us in E9 to E13 biozones of the middle Lutetian to the Bartonian age. Thus, in the middle Eocene, calcium phosphate and the base of the phosphatic sandstone (lower and upper formations) were deposited. The summit of the upper formation of the series was not able to be dated due to the absence of fossils.

b. Palaeoenvironmental Synthesis

The planktonic and benthic foraminifera (pelagism index), the associated macrofauna and the data of lithofacies allowed for the characterization of the depositional environment of the whole of Tobène phosphatic deposit.

The evolution of the pelagism index in these boreholes shows low values (less than 3%) in the foliated clays of the early Lutetian, indicating a slightly opened marine depositional environment.

At the base of the lower phosphatic formation (Lutetian), the pelagism index reached 38% in the EESD borehole. This fact marks the beginning of a larger oceanic opening, and the depositional environment corresponds to an internal platform.

In the rest of the phosphate series, the values of the pelagism index, ranging from 0 and 56%, reflect sea-level oscillations between the littoral and the intermediate to external platform. The low values characterize the detrital levels (sands and clays), and the phosphatic levels correspond to high values.

At the summit of the phosphatic series, the disappearance of planktonic foraminifera and the importance of detrital deposits reflect a reduction of the oceanic influences related to the decrease in the sea level at the end of the middle Eocene.

Accordingly, phosphatic sedimentation occurred in a relatively open environment characterized by the highest values of the pelagism index.

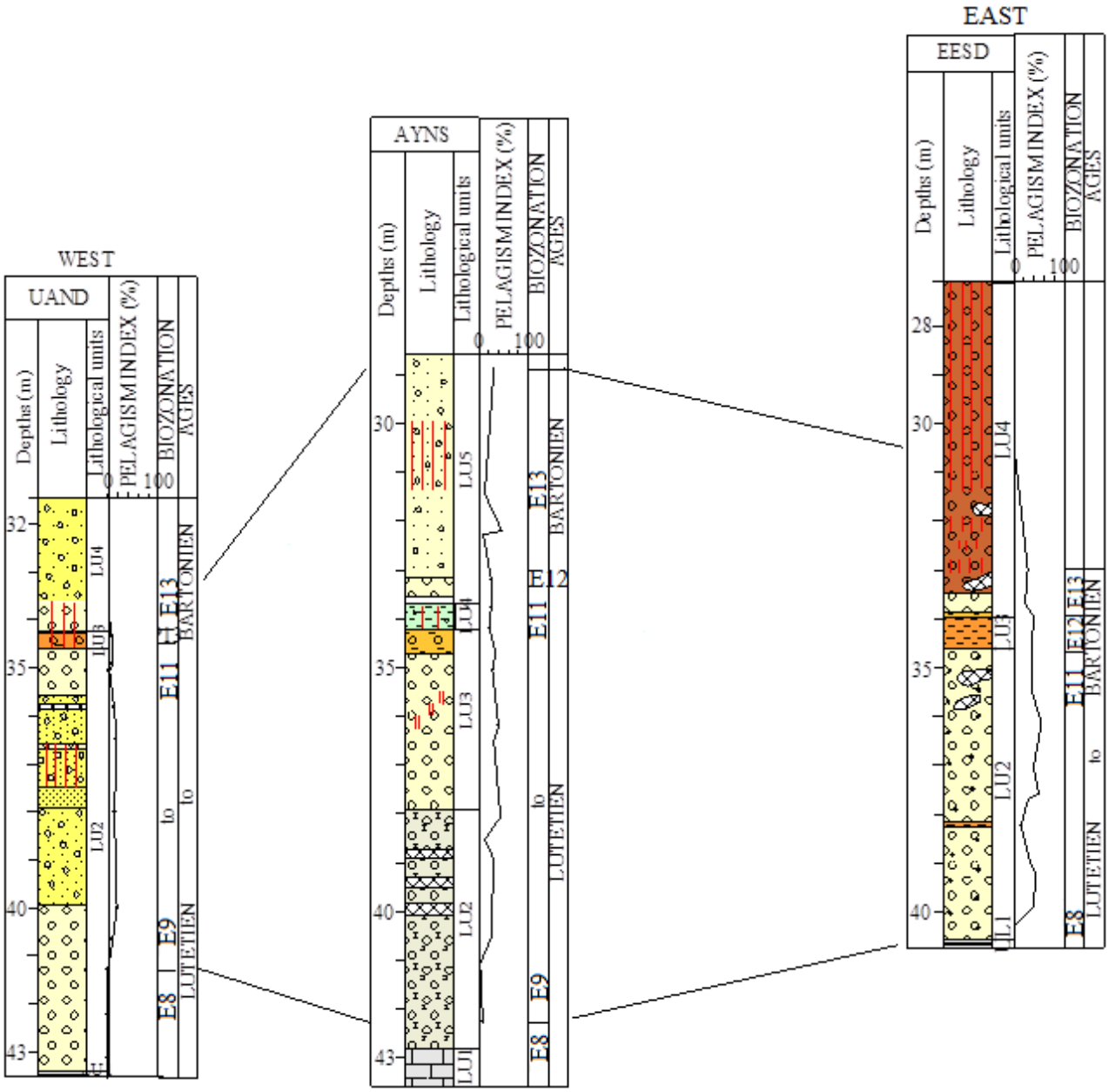

Figure 10: Correlations between biostratigraphic transect boreholes I

4.3.2 Transect II (Figs. 9 and 11)

a. Biostratigraphic correlations

This west-east transect goes through the IINS, AOBJ and EIGQ boreholes. The wall of the phosphatic formation is correlated to the "Marl of Lam-Lam" dated to the early Lutetian (E8 biozone).

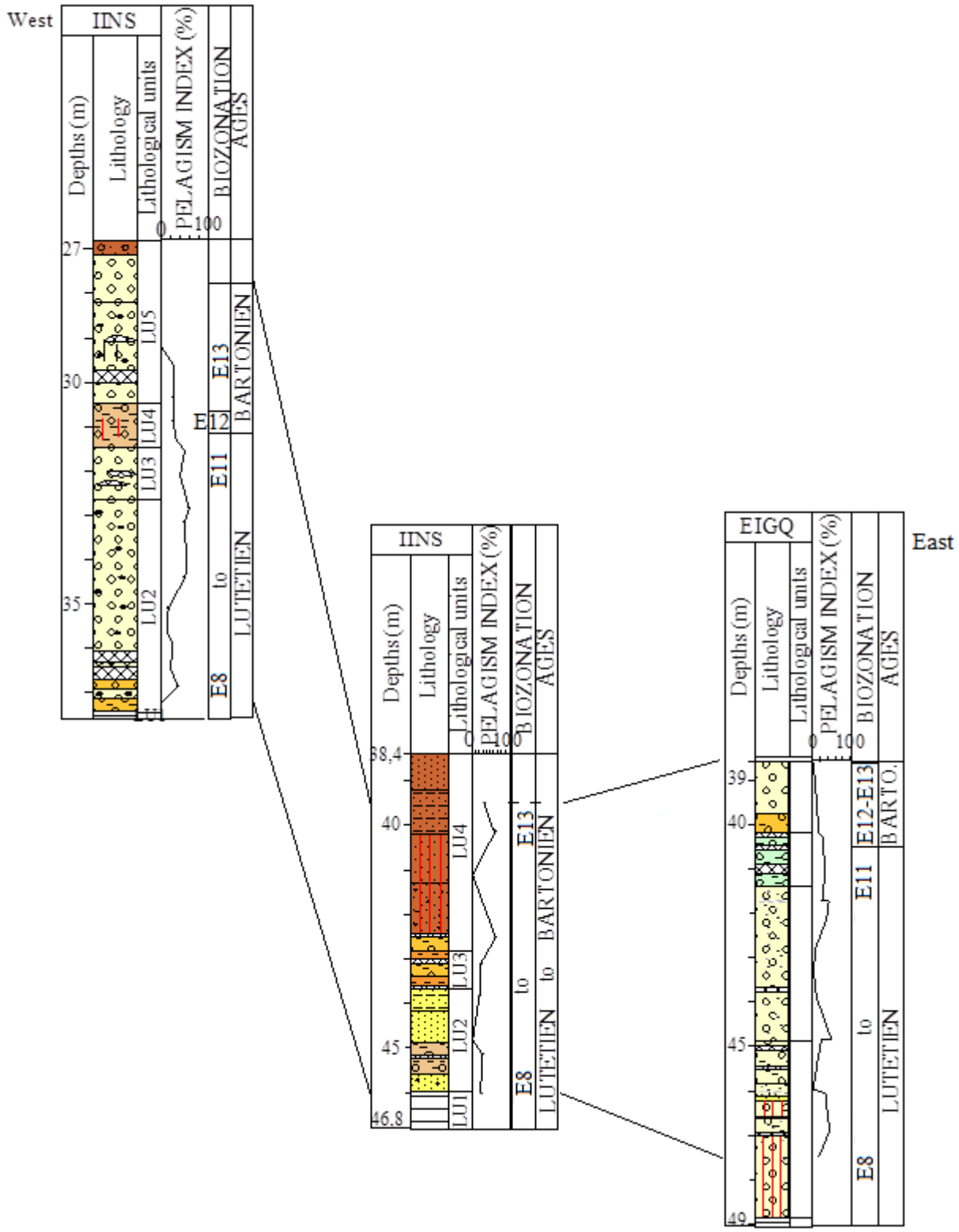

Figure 11: Correlations between biostratigraphic transect boreholes II

In all of these boreholes, the lower phosphate formation and the base the phosphatic sandstone unit are characterized by planktonic species *Truncorotaloides libyaensis*, *T. Rohri*, *T. topilensi*, *Globigerina eocaena* and *Morozovella lehneri*. This microfauna confers on these deposits a middle Lutetian to Bartonian age, corresponding to E9 to E13 biozones.

b. Palaeoenvironmental synthesis

The evolution of the values of the pelagism index in this transect is comparable to the previous transect. The early Lutetian, marked by low values of the index, indicates a marine depositional environment slightly opened to marine influences. In the late Lutetian and Bartonian age, the index ranges from 12 to 64%. With the exception of the IINS borehole, this index goes down at times under 5% and characterizes a slightly opened littoral environment.

As in the previous transect, the detrital supply in the littoral environment becomes more important at the top of the upper phosphatic formation.

5. Conclusions

The lithostratigraphic study allowed for the global identification of five lithologic units in the phosphatic group gathered in three sedimentary formations. Thus, we distinguish upwards: foliated clay's equivalent to Lam-Lam's formation, underlying the calcium phosphate formation on which rest on the variegated clays and silico-ferralitic units. These two last units were gathered by [3] in the upper phosphatic formation with flint benches rich in Daucina and variegated clays.

The biostratigraphic study helped highlight the following:

- E8 Biozone is dated to the early Lutetian, during which the foliated clays (attapulgite) of the wall equivalent to Lam-Lam's formation were deposited; and
- E9 to E13 Biozones are dated to the middle Lutetian to Bartonian age, during which both phosphatic formations were deposited.

Moreover, the pelagism index in the different boreholes helped clarify the depositional environment of the Tobène phosphatic series, which, moving upwards from the phosphatic series, oscillates between a littoral platform, where the detrital supply comes from, and an intermediate to external platform favourable to the deposit of calcium phosphate.

The summits of most boreholes were marked by a strong decrease in the pelagism index, reflecting a high reduction of the marine influences in this zone of Taïba close to the horst of Diass. It seems that this horst has worked as a threshold in the Tobène zone, which would explain the frequent fluctuations in the sea level [12].

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