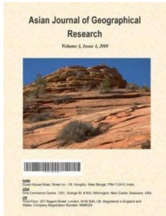

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Biostratigraphic and Paleoenvironmental Characterization of Cretaceous Carbonate Deposits in the Ivorian Offshore Sedimentary Basin, Côte d'Ivoire

Yao Kouadio Cyrille[1], Gbangbot Jean-Michel Kouadio[2*], Diangone Eric[1], Monde Sylvain[1], Digbehi Zéli Bruno[1] and N'da Loukou Victor[3]

[1]UFR Earth Sciences and Mineral Resources, Laboratory of Marine Geology and Sedimentology, University Félix Houphouët-Boigny, 22 BP 582 Abidjan 22, Côte d'Ivoire.
[2]UFR Environment, Laboratory of Environmental Science and Technology, University Jean Lorougnon of Daloa, BP 150 Daloa, Côte d'Ivoire.
[3]National Company of Petroleum Operations of Côte d'Ivoire (PETROCI), Côte d'Ivoire.

Authors' contributions

This work was carried out in collaboration among all authors. Author YKC designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors GJMK and DE reviewed the first draft of the manuscript and helped with the revision. Authors MS, DZB and NLV managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The biostratigraphic characterization of the Cretaceous carbonate levels of the offshore sedimentary basin of Côte d'Ivoire was made possible by a palynological and micropaleontological study of two drilling cutting (SN-X and DH-X). These sediments provided a rich microfauna consisting of species such as *Ticinella madecassiana*, *Ticinella primula*, *Ticinella raynaudi* and *Ticinella roberti* associated

**Corresponding author: E-mail: gbangbotjeanmichel@yahoo.fr;*

with a rich microflora composed of spores and pollen grains such as *Appendicisporites potomacensis*, *Cicatricosisporites venustus, Appendicisporites baconicus*, *Ephedripites* sp., *Schizea certa* and *Elaterosporites klaszi* characterizing the upper Albian.

This study highlights several stages including the Cenomanian foraminifera *Globigerinelloides bentonensis, Globigerinelloides caseyi*, and pollen grains *Steevesipollenites cupuliformis*, and *Ephedripites barghornii* and Turonian by the planktonic foraminifera *Heterohelix moremani*, *Hedbergella planispira, Whiteinella archaeocretacea, Whiteinella baltica*.

The lower Senonian is marked by the planktonic foraminifera *Hedbergella delrioensis, Heterohelix globulosa, Heterohelix reussi*, and the dynocyst *Oligosphaeridium* complex and *Dinogymnium westralium*. The Campanian is evidenced by the presence of the dinocysts *Circulodinium distinctum* and *Hystrichodinium pulchrum*.

Thanks to the lithological and biostratigraphic analysis of these carbonate sediments, the palaeo-provinces have been determined and are located in the internal, medium or external neritic domains. Massive limestones were established between the upper Albian and the lower Senonian. The matrix is generally present in the lower and medium Albian. The full carbonate sedimentation occurs between the medium Albian and the lower Senonian, with a maximum in the upper Albian.

Keywords: Biostratigraphy; cretaceous; Foraminifera; paleoprovince; carbonate.

1. INTRODUCTION

Knowledge of the sedimentary, biological, chemical and environmental mechanisms in a sedimentary basin is a real asset. Especially since the mastery of these processes helps to better understand and evaluate oil systems. The Ivorian sedimentary basin has been the subject of numerous research programs aimed at determining its sedimentological and biostratigraphic characteristics. The aim of this work was to know the major sedimentary processes, to determine the sequences and the depositional environment. It is also to indicate the stratigraphic stages and give the paleoenvironment of deposit.

Increasingly, researchers are aiming for reconstitution of palaeobotany. Digbehi et al. [1] identified the main Cretaceous foraminifera and palynomorphs of the Ivorian sedimentary basin. Bie [2] through a palynostratigraphic study identified in the Abidjan margin. The age of the main Cenozoic formations as well as their depositional environment.

Assale [3] and recently Guede [4] also used palynomorphs to characterize the biostratigraphy of the onshore formations of the Abidjan and San Pedro margins.

Other works, in particular, those of [5,6], combined the study of the microflora and that of the microfauna (foraminifera) to determine the age of the studied formations but also their depositional environments. The present article is part of this dynamic study and its main objective is the biostratigraphic characterization and determination of paleoenvironments of carbonate deposits in the Ivorian offshore basin from two wells drilled off Jacqueville and San-pedro.

2. GEOLOGICAL AND STRUCTURAL SETTING OF THE STUDY AREA

The Ivorian sedimentary basin represents the northern part of the basins of the Gulf of Guinée. It has an emergent part (Onshore basin) and a submerged part (Offshore basin).

The Cretaceous-Cenozoic onshore basin is traversed from east to west by an important normal fault more or less parallel to the coast, the "lagoon fault" [7,8,9]. In this part of the basin, sedimentation is less thick north of the fault and thicker in the south.

As for the offshore basin, it is dependent on two structural features (the Romanche fault and the Saint-Paul fault), the nature and importance of the erosion and sedimentation mechanisms since the opening of the Atlantic Ocean [10]. The relatively narrow continental shelf (20-30 km) occupies two geologically very different zones from West to East:

- the margin of San Pedro which extends from the maritime border with Liberia to the city of Grand-Lahou. This continental shelf is covered with sediments that thicken to the south where they reach 700-800 m thick at the edge of the continental shelf [10].

- the margin of Abidjan constitutes the eastern part of the offshore basin. Its base is about 6 to 8 km deep under thick sedimentary layers whose thickness increases towards the east. This margin is cut south of Abidjan by a large underwater canyon called "bottomless hole" which starts flush with the coast and reaches a depth of 1000 m at the embankment. It ends in the abyssal plain at about 5000 m depth [8].

The present study is based on two (2) soundings (SN-X and DH-X) located in the submerged sedimentary basin (offshore) on an east-west transect of the margin of San-Pédro and Abidjan (Fig. 1).

3. MATERIALS AND METHODS

The material used consists mainly of cuttings from two oil wells on which micropaleontological, paleontological and lithological analyzes were carried out.

For micropaleontological analyzes, 40 g of each sample was taken, crushed in a mortar and then treated with hydrogen peroxide (10%) for at least two hours to destroy the organic matter. After washing on a column of three calibrated sieves (250 µm, 100 µm and 63 µm) and drying in an oven at 80°C, the foraminifera were sorted under a binocular magnifying glass with a needle and placed in a micropaleontological cell by separating agglutinated foraminifera from limestone benthic foraminifera and planktonic foraminifera.

The taxonomic identification of foraminifera was done through specialized documentation. The biostratigraphic division was based on the stratigraphic markers of the international scale, [11]. Biozonation was specified from the bibliographic data of [12].

For palynological preparations, 20 g of sample was treated with strong acids (hydrochloric and hydrofluoric) under a fume hood to destroy all the mineral matter and to preserve the organic matter. After washing on a 10 µm fabric, the resulting residue was mounted between the lamella and coverslip and then observed under a light microscope Motic BA300 brand coupled to a camera for shooting.

Taxonomic identification was based on biozones determined by Digbehi et al. [1], from palynological markers.

The determination of deposition environments results from the integrated study of several parameters including microfauna, microflora, lithology and the production of organic matter. Most taxa have specific living conditions and can serve as environmental indicators (bathymetry, turbidity, salinity, brightness, etc.) [13]. The criteria for identifying depositional environments are by biological, lithological, petrographic, geochemical [14].

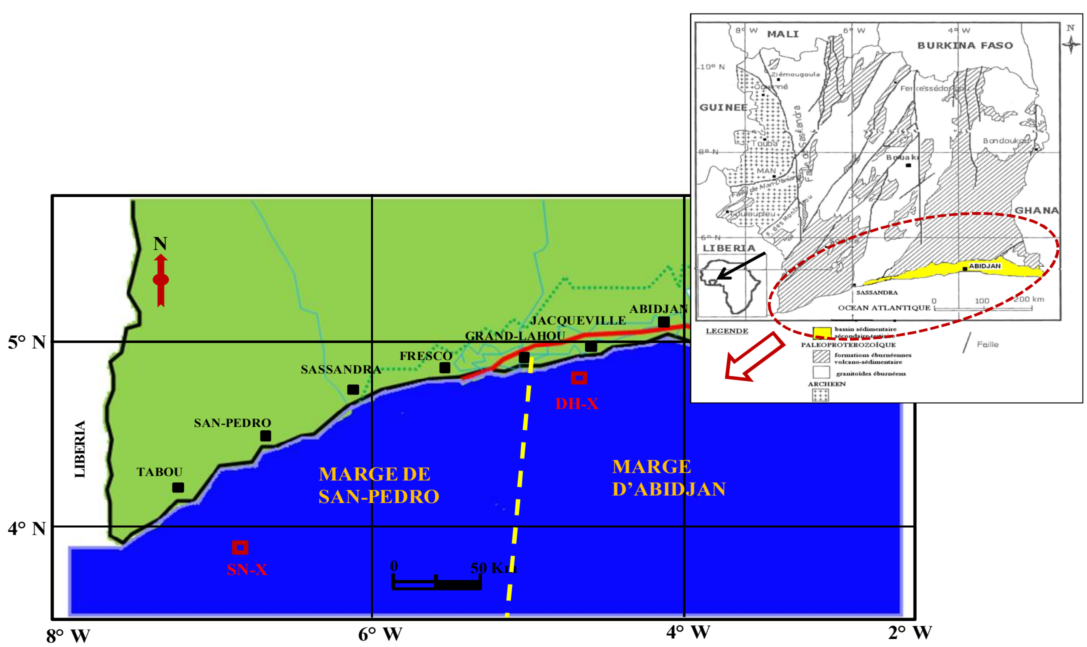

Fig. 1. Geological and structural map of the study area. Location of sounding (SN-X et DH-X)

4. RESULTS

4.1 Biostratigraphy of the SN-X Sounding

Figs. 2 and 3 present the biostratigraphic distribution of the benthic and planktonic foraminifera of the SN-X sounding.

- Interval (3010-3080 m)

The markers *Ephedripites* spp. and *Cicatricocisporites* spp. indicate a lower Albian age.

- Interval (2530-2590 m)

It contains sandstone intercalated with clay and past limestone. This interval is dated by *Classopollis* palynoflores at 2530 m, which indicate the Cenomanian roof. The species *Ephedripites ambiguous* (Fig. 8K), *Ephedripites.* sp., *Galeacornea clavis* (Fig. 8.M), *Pemphixipollenites inequiexinius*, *Steevesipollenites cupuliformis* and *Triorites africaensis* (Fig. 8O) present at 2535 m characterize the upper Cenomanian.

- Interval (2498-2530 m)

It presents the same lithological composition as the previous interval. The association of planktonic foraminifera with *Hedbergella planispira* (Figs. 6-3), *Whiteinella baltica, Whiteinella archaeocretacea, Hedbergella cf. simplex, Archaeoglobigerina cf. blowi, Hedbergella delrioensis* (Figs. 6-4), *Hedbergella. globulosa* (Figs. 6-5), *Hedbergella. reussi* and *Hedbergella. glabrans* date the Turonian. The appearance of *Classopollis brasiliensis* (Fig. 8I) at 2530 m allows fixing the Cenomanian / Turonian limit.

- Interval (2460-2498 m)

This interval contains sandstone interbedding clay and crystalline limestone past. The lower Senonian is marked by the planktonic species *Hedbergella delrioensis* (2475 m), *Heterohelix globulosa* (2485 m) and *Heterohelix reussi* (2490 m). The appearance of palynoflora like *Parasyncolpites* sp. (Fig. 8A) at 2460 m allows fixation of the upper limit of the Santonian.

- Interval (2440 -2460 m)

Sedimentation was essentially clay. Foraminifera includes calcareous and agglutinated test forms at higher levels. The dinocysts *Circulodinium distinctum* and *Hystrichodinium pulchrum* abound. The abundant presence of these dinocysts makes it possible to date this interval of the Campanian.

4.2 Biostratigraphy of the DH-X Sounding

Figs. 4 and 5 show the vertical distribution of benthic and planktonic foraminifera and palynomorphs of the DH-X sounding.

- Interval (2472-2703 m)

The summit of the interval is composed of limestone and the base consists of an alternation of clay and sandstone. The spores and pollen *Appendicisporites potomacensis* (Fig. 8C), *Cicatricosisporites venustus, Appendicisporites baconicus, Ephedripites sp., Schizea certa* (Fig. 8D), *Elaterosporites klaszi, Elaterosporites. protensus* (Fig. 8. B) and *Elaterosporites. verrucatus* present characterizes the upper Albian.

- Interval (2377 - 2463 m)

This interval contains limestone calcisphere interspersed with clay. *Ticinellae* (Fig. 7. 2-4) including *Ticinella madecassiana, Ticinella primula, Ticinella raynaudi* and *Ticinella roberti* associated with *Globigerinelloides bentonensis* (Figs. 6-1), *Globigerinelloides caseyi, Hedbergella angolae, Hedbergella gorbachikae* (Figs. 7-1), *Praeglobotruncana delrioensis* and *Costellagerina libyca* allow to date the upper Albian (100 Ma) from 2377 m.

- Interval (2335 - 2371 m)

Sedimentation is marly. The abundant presence of *Hedbergella cf. brittonensis* from 2341 m, allowing to date the Cenomanian. This age is confirmed by the planktonic association at *Hedbergella / Globigerinelloides*. The Palynoflora *Classopollis classoides* (Fig. 8H) and *Classopollis jardinei* appeared at 2335 m and *Classopollis brasiliensis* (2341 m) date Cenomanian and *Triorites africaensis* (2353 m) date the upper Cenomanian.

- Interval (2319 - 2335 m)

The sediment is also composed of marl. The planktonic foraminifera *Heterohelix moremani* and *Hedbergella planispira, Whiteinella archaeocretacea*, and *Whiteinella. baltica*, appeared at 2319 m to fix the roof of the Turonian.

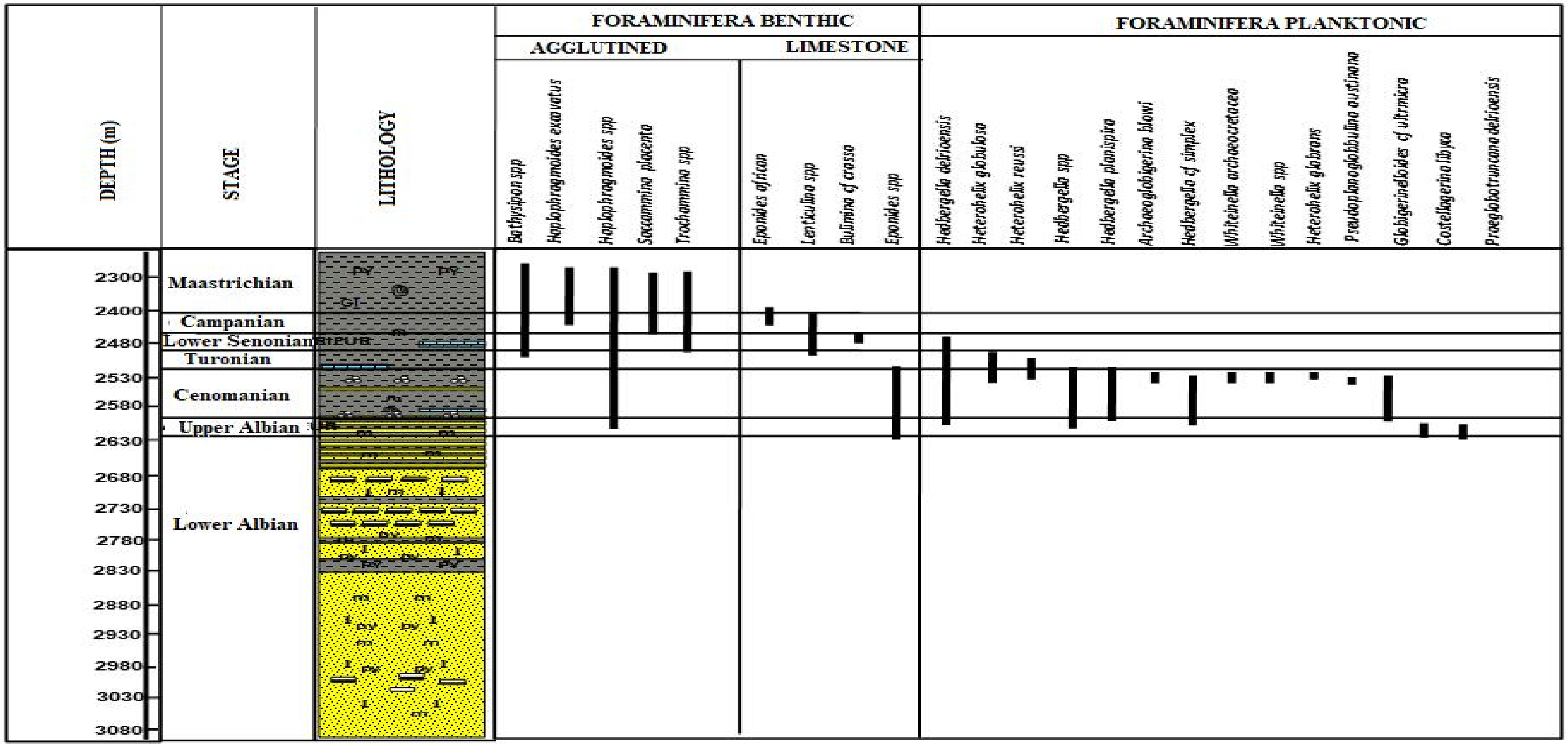

Fig. 2. Foraminifera distribution of sounding SN-X

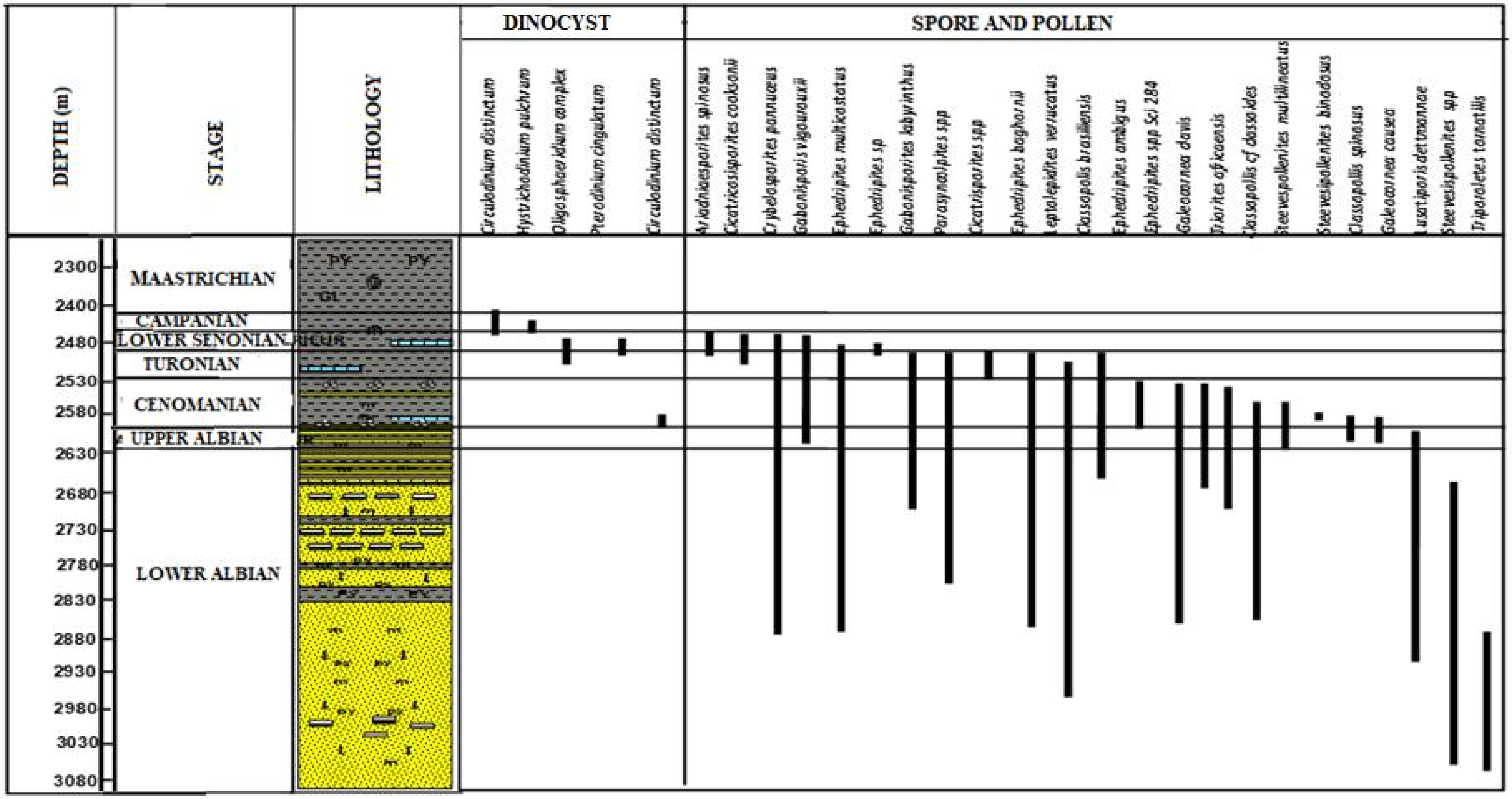

Fig. 3. Palynomorph distribution of sounding SN-X

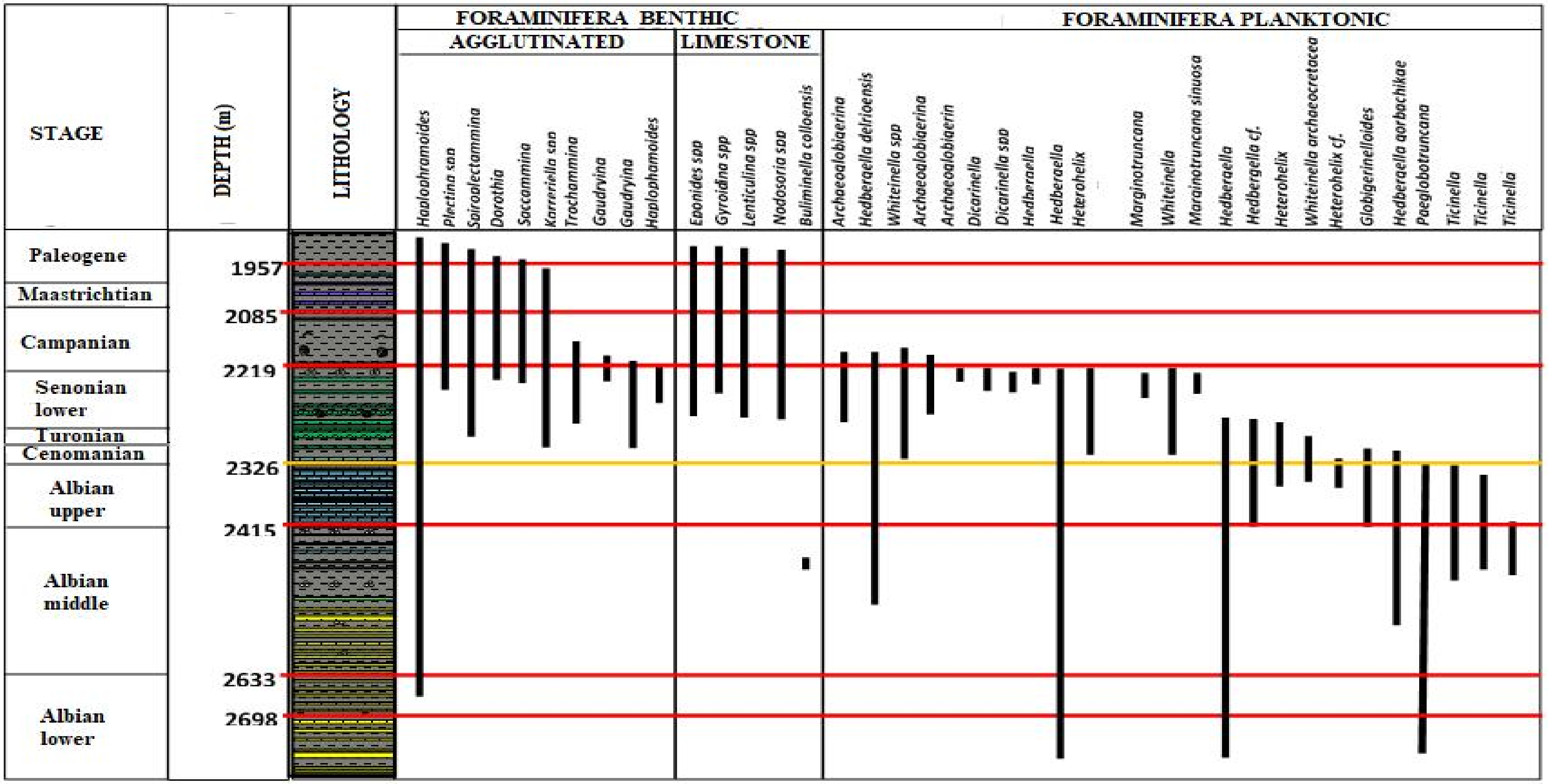

Fig. 4. Distribution of benthic and planktonic foraminifera of the sounding DH-X

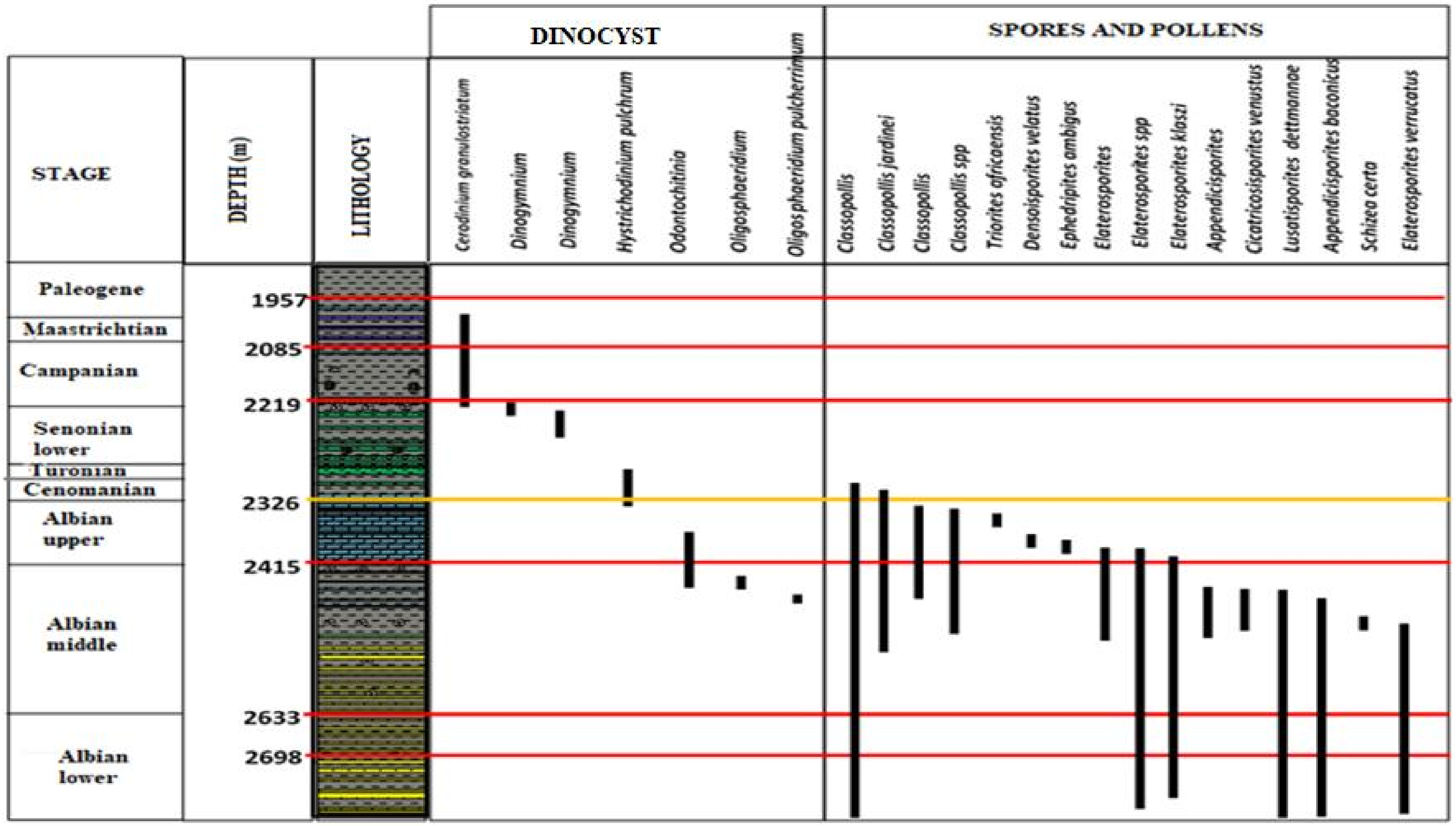

Fig. 5. Distribution of palynomorphs of the sounding DH-X

- Interval (2223-2301 m)

It consists of marl with limestone and dolomite. The planktonic species *Hedbergella delrioensis* and *Archaeoglobigerina blowi* make it possible to place the lower Senonian roof (83.5 Ma). The lower Senonian age is confirmed by the presence of *Gaudryina ellisorea* at 2225 m and by the planktonic species *Dicarinella primitiva, Archaeoglobigerina cretacea, Heterohelix reussi, Heterohelix globulosa, Whiteinella baltica.*

The *Oligosphaeridium complex* and *Dinogymnium westralium* dinokyste appearing at 2225 m also date back to the lower Senonian.

4.3 Paleoenvironmental Reconstitution

4.3.1 Paleoenvironment of the SN-X sounding

Fig. 9. Presents the statistical analysis results of the main faunistic and floristic groups of the sounding SN-X.

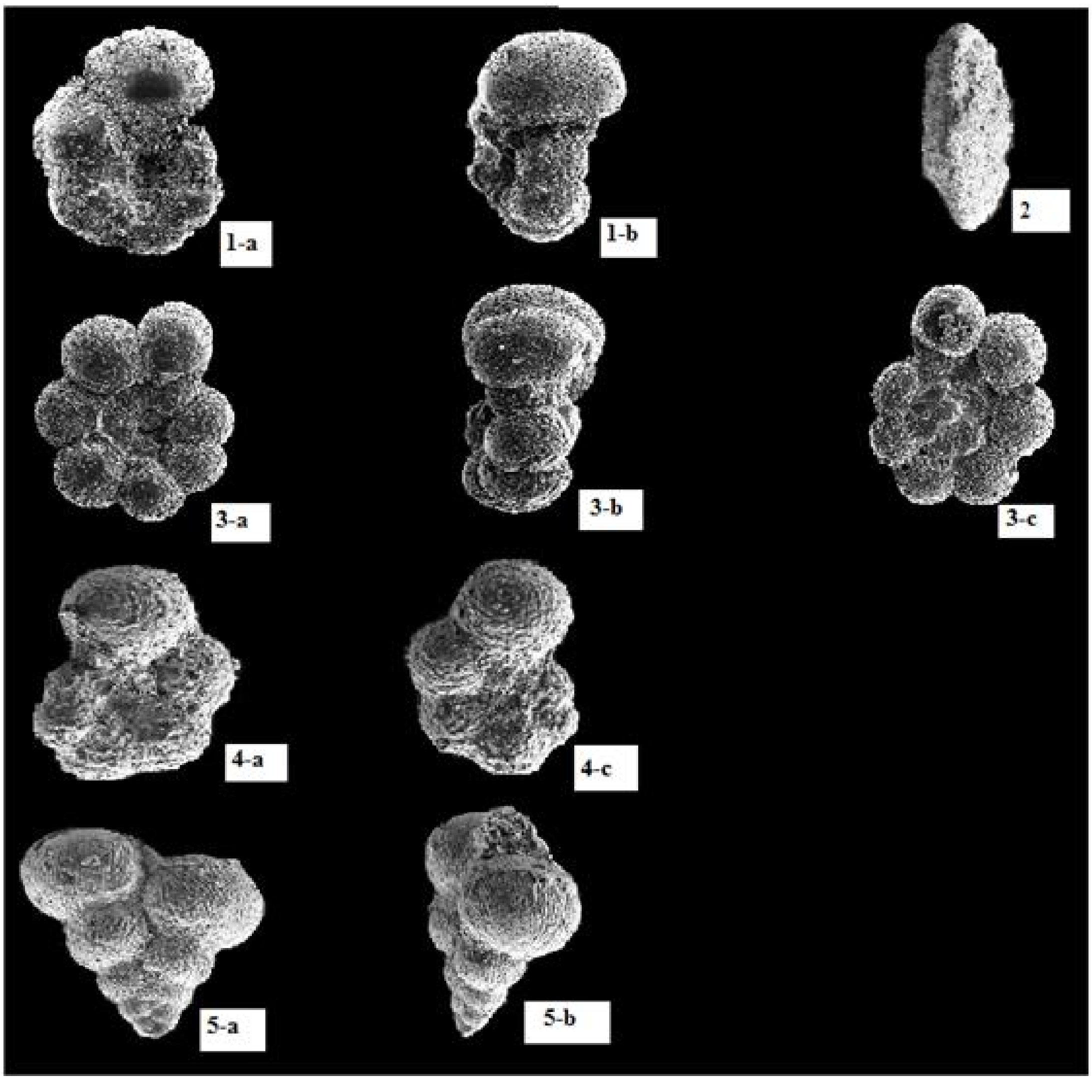

Fig. 6. Some planktonic foraminifera and benthic foraminifera agglutinated from the DH-X and SN-X sounding

Légende : 1-a : Globigerinelloides bentonensis (umbilical face); 1-b : Globigerinelloides bentonensis (lateral face); 2 : Haplophragmoides excavatus (latéral face) ; 3-a : Hedbergella planispira (umbilical face); 3-b : Hedbergella planispira (latéral face); 3-c : Hedbergella planispira (spiral face); 4-a: Hedbergella delrioensis (umbilical face); 4-c: Hedbergella delrioensis (spiral face); 5-a : Heterohelix globulosa (front view); 5-b : Heterohelix globulosa (profile view)

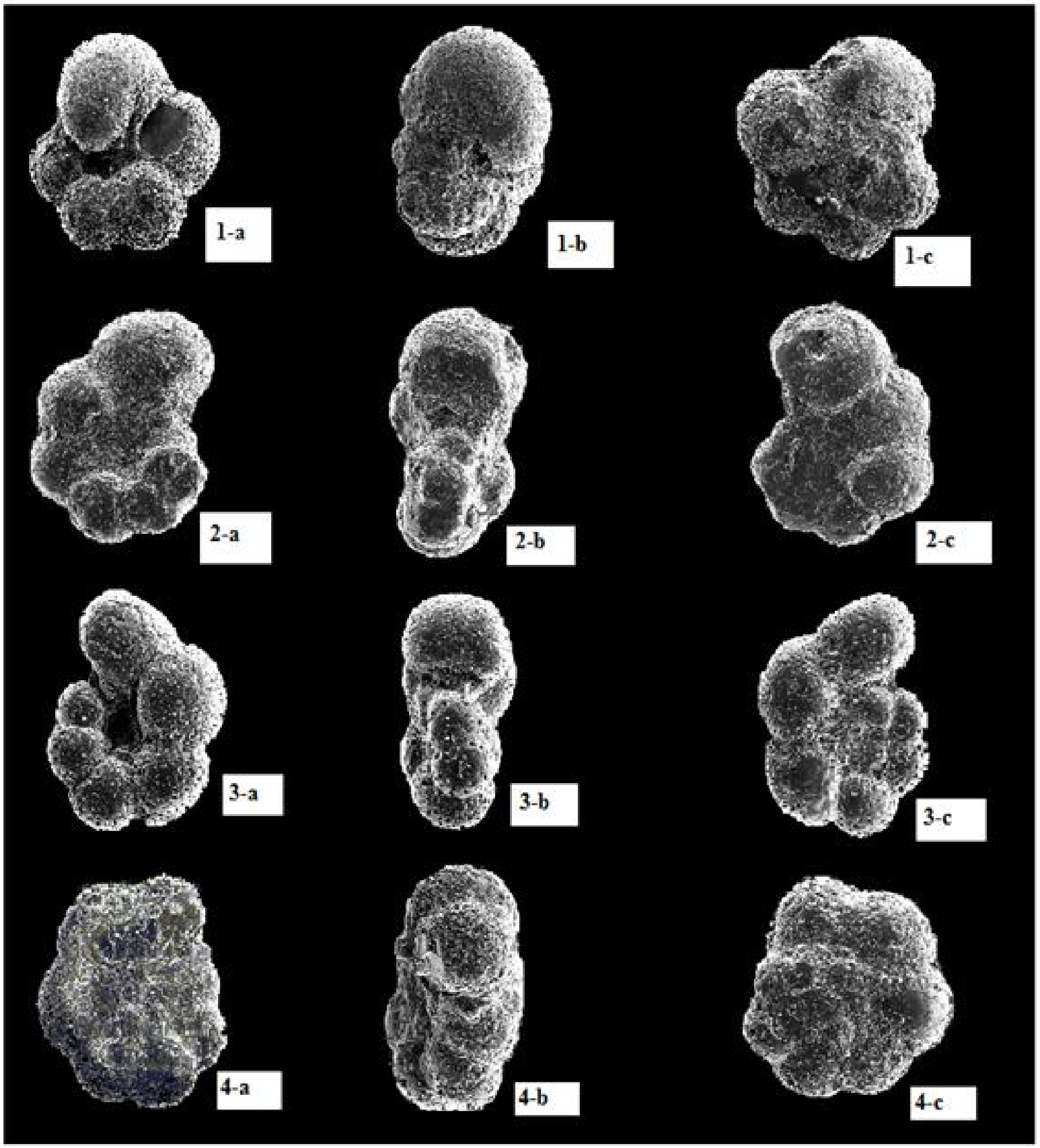

Fig. 7. Some planktonic foraminifera characteristic of Albian SN-X and DH-X sounding
Légende : 1-a- Hedbergella gorbachikae (umbilical face) ;1-b- Hedbergella gorbachikae (latéral face) ; 1-c- Hedbergella gorbachikae (spiral face) ; 2-a-Ticinella primula (umbilical face) ; 2-b- Ticinella primula (latéral face) ; 2-c-Ticinella primula (spiral face) ; 3-a- Ticinella raynaudi (umbilical face) ; 3-b-Ticinella raynaudi (latéral face) ; 3-c-Ticinella raynaudi (spiral face) ; 4-a-Ticinella roberti (umbilical face) ; 4-b- Ticinella roberti (latéral face) ; 4-c- Ticinella roberti (spiral face)

- Interval (3010-3080 m) of the Lower Albian

Sandy-clay sedimentation with limestone, sandstone and abundant pyrite and carbonaceous debris suggest continental (lacustrine) environment and anoxic conditions.

This interval poor in foraminifera and containing scarce palynomorphs suggests a continental environment.

- Interval (2535 - 2580 m) of the Cenomanian

The lithology composed of calcareous clay containing frequent glauconites and carbonaceous debris indicates a shallow oceanic to suboxic marine environment fed by continental inputs. The predominance of pelagic species and the scarcity of benthic suggest a transition to the internal platform. The scarcity of dinocysts and the abundance of spores and pollen indicates a shallow marine environment.

- Interval (2498-2530 m) of the Turonian

The sedimentation is clayey with calcareous past and glauconite. The deposit environment is shallow marine, oxic to suboxic and continental influence.

The microfauna of Turonian in *Hedbergelles* and *Heterohelicidae* suggest an internal platform.

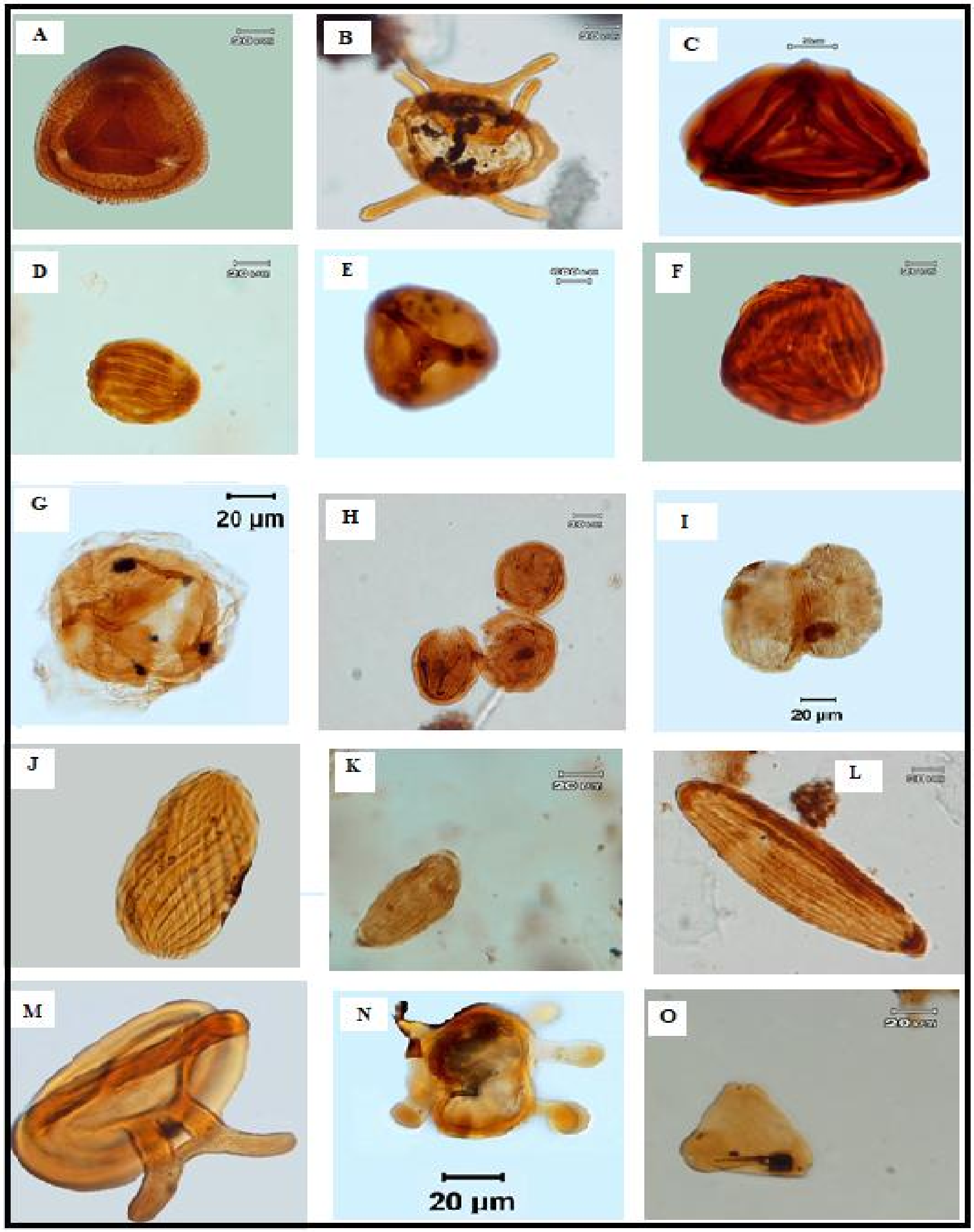

Fig. 8. Some spores and pollen from the SN-X and DH-X sounding

Légende: A- Parasyncolpites sp.; B- Elaterosporites protensus C- Appendicisporites potomacensis; D-: Schizea certa; E- Matonisporites phlebopteroïdes; F- Cicatricosisporites baconicus; G - Crybelosporites pannuceus; H- Classopollis classoides; I - Classopollis brasiliensis; J - Ephedripites baghornii; K- Ephedripites ambigus; L- Steevesipollenites binodosus; M- Galeacornea clavis; N-Elaterocolpites castelaini; O- Triorites africaensis

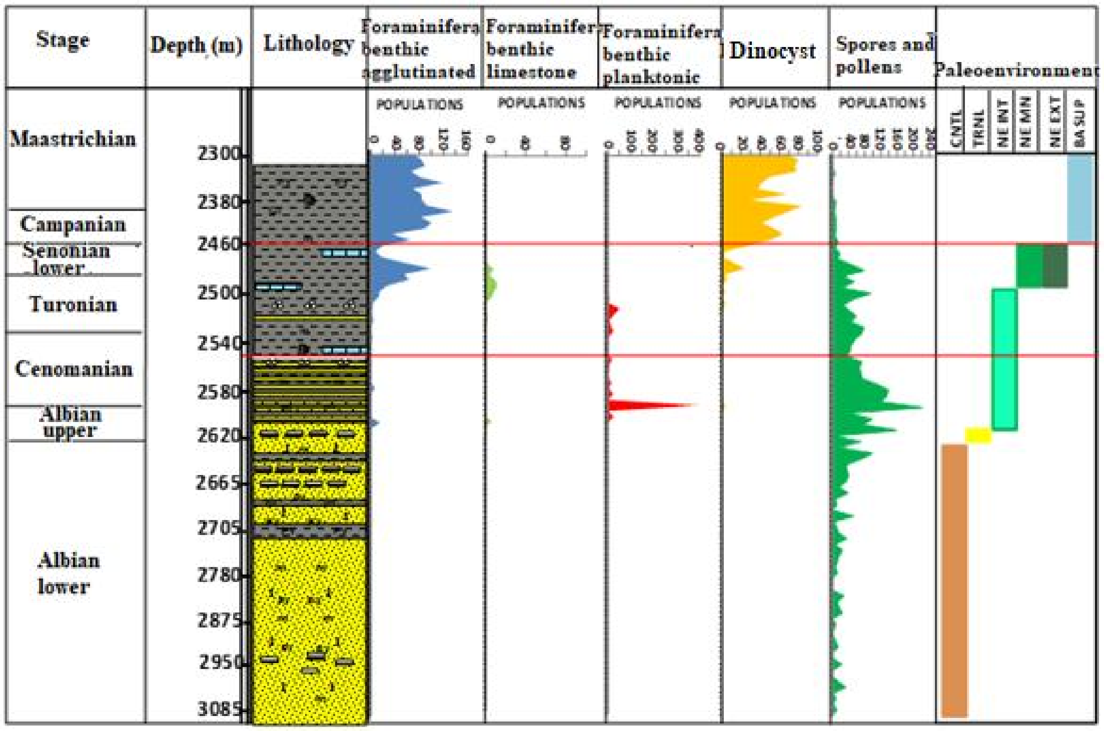

Fig. 9. Paleoenvironmental synthesis of the SN-X sounding

CNTL : Continental; TRNL : Transitional; NE INT: internal neritic; NE MN : medium neritic; NE EXT : external neritic; BA SUP : upper bathyal

- Interval (2460 - 2498 m): Lower Senonian

The past limestone clay sedimentation with abundant glauconites and carbonaceous debris suggests a shallow, oxic to suboxic marine deposition medium influenced by continental inputs. The diversity of planktonic foraminifera (*Hedbergella, Heterohelix*) associated with agglutinated (*Haplophragmoides*) and limestone benthic suggest a medium to the outer neritic domain. Spores and pollen and scarce and undiversified dinocysts characterize a shallow marine area with a low continental influence.

- Interval (2445 - 2460m): Campanian

Clay deposits from fine calcareous containing abundant glauconites and carbonaceous debris characterize a low-energy shallow marine environment and oxic to suboxic conditions with a continental influence. The absence of planktonic foraminifera suggests a deep sea near the upper bathyal range.

4.3.2 Paleoenvironment of the sounding DH-X

Fig. 10 presents the log of synthesis made on the basis of the results of statistical studies of the main groups of microfossils (foraminiferas and calcispheres) and palynomorphs of the DH-X sounding.

- Interval (2377 -2703 m): Upper Albian

Marly limestones surmounted by clays characterize a shallow marine environment of low energy. The scarcity of glauconite and the absence of pyrite indicate an oxidizing environment [6]. The planktonic species present *Ticinella madecassiana, Ticinella primula, Ticinella raynaudi, Globigerinelloides bentonensis, Globigerinelloides caseyi, Hedbergella angolae, Praeglobotruncana delrioensis, Costellagerina libyca, Hedbergella gorbachikae* and the spores and pollens found characterize an internal neritic domain.

- Interval (2335 - 2371 m): Cenomanian

Marly limestone with calcispheres containing scarce glauconites indicates a low-energy oxidizing marine environment [6]. Abundant and diverse *Hedbergella* and *Globigerinelloides* suggest an internal neritic domain with strong continental influence as evidenced by the frequency of spores and pollen.

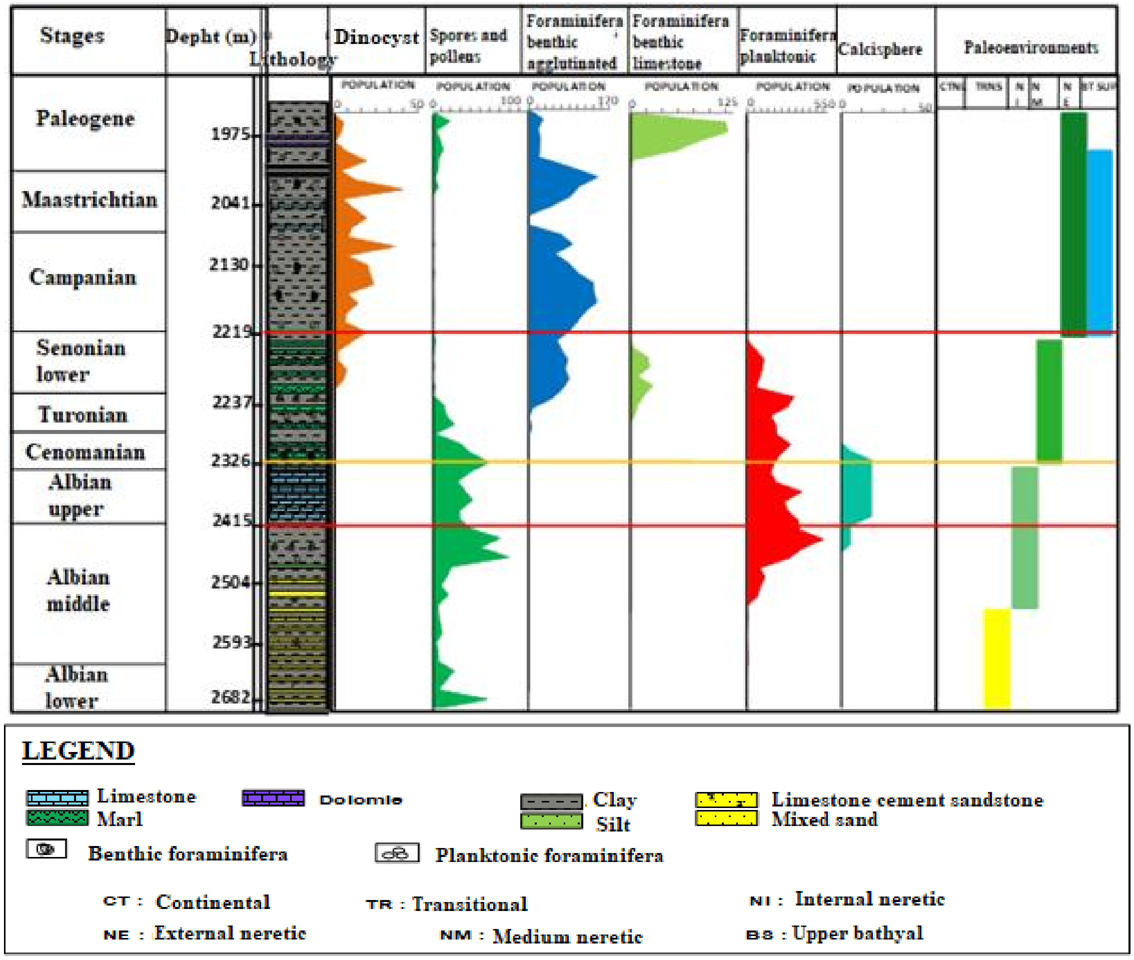

Fig. 10. Paleo-environmental synthesis of the sounding DH-X

- Interval (2319 - 2335 m): Turonian

Limestone and marly sediments containing scarce glauconites in some places suggest a low energy oxidizing marine environment [6]. Agglutinated foraminifera associated with calcareous benthic forms and large *Hedbergellas* characterizes a medium neritic domain with external neritic influences.

- Interval (2223-2301 m): Lower Senonian

The moderate presence of glauconite and the absence of pyrite in marly sediments indicate oxidative conditions [6]. The scarcity of carbonaceous debris evokes a deep marine environment. The predominance of the genre *Marginotruncana, Dicarinella, Archaeoglobigerina, Hedbergella, Heterohelix* associated with calcareous and agglutinated benthic foraminifera characterizes the external continental shelf.

5. DISCUSSION

Based on the microfauna and microflora studied, planktonic foraminifera (*Hedbergella, Oligisteginidae, Ticinella and Globigerinelloides*) characterize epicontinental sea associations. For **[**15], they characterize an open continental shelf and therefore the medium to the external neritic zone. This corroborates the paleoenvironmental interpretations deduced from this work.

The determination of Paleobioprovinces from the planktonic foraminifera of Cretaceous [16] doesn't take into account the specific composition of associations. It establishes paleoenvironment by taking into account general morphotypic criteria, the numerical predominance of globular foraminifera and the carenacé foraminifera.

The great similarity of the species identified in the West African peri-Atlantic basins (Sénégal, Ghana-Côte d'Ivoire, Benoué ditch) reflects the effective opening of the central Atlantic in the Gulf of Guinée to upper Cretaceous [17]. This period is characterized by a phase of fine deposits of limestone, marls, clays and limestone clays in a shallow environment with a transgressive tendency. The presence of calcispheres is often accompanied by the scarcity of dinocysts. This observation was also made by Ulrich and Timothy [18] who indicates that the calcispheres show unstable surface conditions.

6. CONCLUSION

The analysis of the faunistic and floristic associations of foraminifera, spores and pollen, dinocysts and *Calcisphaerulidae* made it possible to determine palaeo-provinces (inner to outer neritic).

The associations are characterized by planktonic foraminifera with globular (*Hedbergella and Globigerinelloides*) or keeled foraminifera (*Marginotruncana, Dicarinella, Archaeoglobigerina*), associated with agglutinated benthic genre (*Haplophragmoid, Spiroplectammina, Reophax, Bathysiphon*) and limestones (*Lenticulina, Nodosaria* and *Gyroidina*). Foraminifera is often associated with a microflora of dinocysts (*Oligosphaeridium, Circulodinium, Hystrichodinium*), spores and pollen (*Triorites, Classopollis, Steevesipollenites, Gnetaceaepollenites, Pemphixipollenites*).

These associations specified the palaeoenvironments in the neritic internal, medium or external domains. Massive limestones were established between the upper Albian and the lower Senonian, the matrix being generally present in the lower and medium Albian. The carbonate sediments of the Ivorian Cretaceous are essentially marine due to the scarcity of pollen and pollen grains and abundant planktonic foraminifers. The carbonated sedimentation was established between the medium Albian and the lower Senonian, with its peak in the upper Albian.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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