

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

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 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 dinocyst *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. [1] identified the main Cretaceous foraminifera and palynomorphs of the Ivorian sedimentary basin. [2] through a palynostratigraphic study identified in the Abidjan margin. The age of the main Cenozoic formations as well as their depositional environment.

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

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

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58 2. Geological and Structural Setting of the Study Area

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60 The Ivorian sedimentary basin represents the northern part of the basins of the Gulf of
61 Guinée. It has an emergent part (onshore basin) and a submerged part (offshore basin).

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

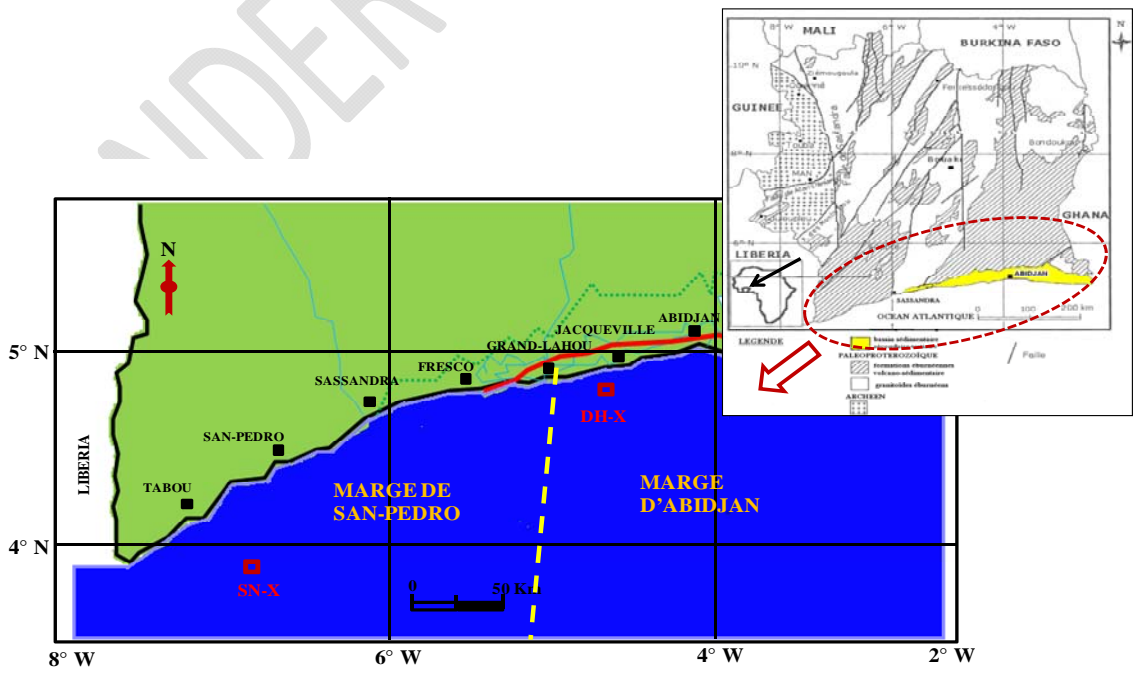
65 As for the offshore basin, it is dependent on two structural features (the Romanche fault and
66 the Saint-Paul fault), the nature and importance of the erosion and sedimentation mechanisms
67 since the opening of the Atlantic Ocean [10]. The relatively narrow continental shelf (20-30
68 km) occupies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

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

72 - the margin of Abidjan constitutes the eastern part of the offshore basin. Its base is about 6 to
73 8 km deep under thick sedimentary layers whose thickness increases towards the east. This
74 margin is cut south of Abidjan by a large underwater canyon called "bottomless hole" which
75 starts flush with the coast and reaches a depth of 1000 m at the embankment. It ends in the
76 abyssal plain at about 5000 m depth [8].

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

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83 **Fig. 1. Geological and Structural Map of the study area. Location of sounding (SN-X et DH-X)**
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85 86 **3. MATERIALS AND METHODS** 87

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

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

96
97 The taxonomic identification of foraminifera was done through specialized documentation.
98 The biostratigraphic division was based on the stratigraphic markers of the international scale,
99 [11]. Biozonation was specified from the bibliographic data of [12].

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

105 Taxonomic identification was based on biozones determined by [1], from palynological
106 markers.

107 The determination of deposition environments results from the integrated study of several
108 parameters including microfauna, microflora, lithology and the production of organic matter.
109 Most taxa have specific living conditions and can serve as environmental indicators
110 (bathymetry, turbidity, salinity, brightness, etc.) [13]. The criteria for identifying
111 depositional environments are by biological, lithological, petrographic, geochemical [14].
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113 **4. RESULTS** 114

115 **4.1 Biostratigraphy of the SN-X sounding** 116

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

119 **- Interval (3010-3080 m)**

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

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123 **- Interval (2530-2590 m)** It contains sandstone intercalated with clay and past limestone.
124 This interval is dated by *Classopollis* palynoflores at 2530 m, which indicate the Cenomanian
125 roof. The species *Ephedripites ambiguus* (Fig. 8K), *Ephedripites* sp., *Galeacornea clavis*
126 (Fig. 8.M), *Pemphixipollenites inequixinius*, *Steevesipollenites cupuliformis* and *Triorites*
127 *africaensis* (Fig. 8O) present at 2535 m characterize the upper Cenomanian.
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129 **- Interval (2498-2530 m)**

130 It presents the same lithological composition as the previous interval. The association of
131 planktonic foraminifera with *Hedbergella planispira* (Fig.6-3), *Whiteinella baltica*,

132 *Whiteinella archaeocretacea*, *Hedbergella cf. simplex*, *Archaeoglobigerina cf. blowi*,
133 *Hedbergella delrioensis* (Fig. 6-4), *Hedbergella. globulosa* (Fig. 6-5), *Hedbergella. reussi*
134 and *Hedbergella. glabrans* date the Turonian. The appearance of *Classopollis brasiliensis*
135 (Fig. 8I) at 2530 m allows fixing the Cenomanian / Turonian limit.

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137 **- Interval (2460-2498 m)**

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

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143 **- Interval (2440 -2460 m)**

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

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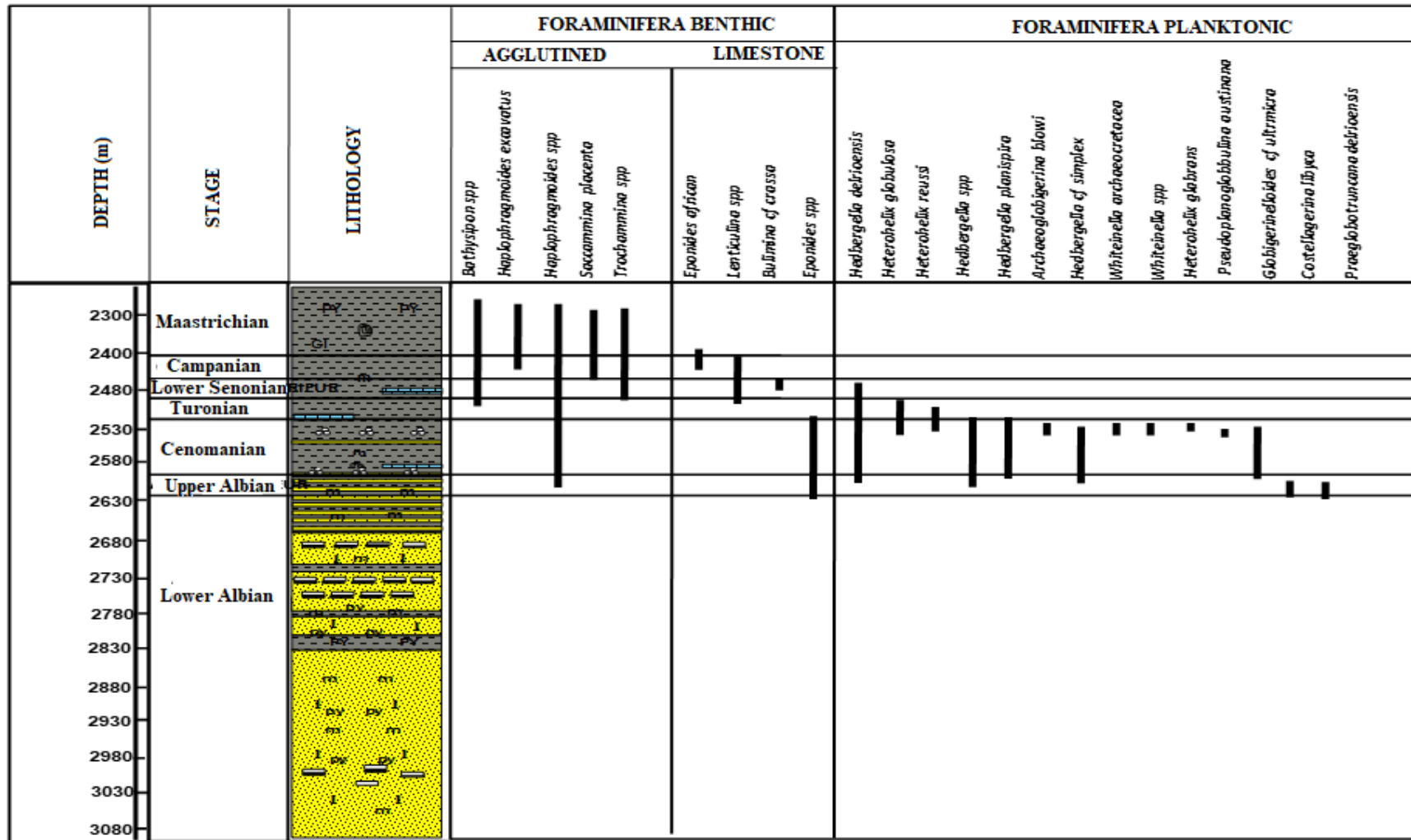


Fig. 2. Foraminifera distribution of sounding SN-X

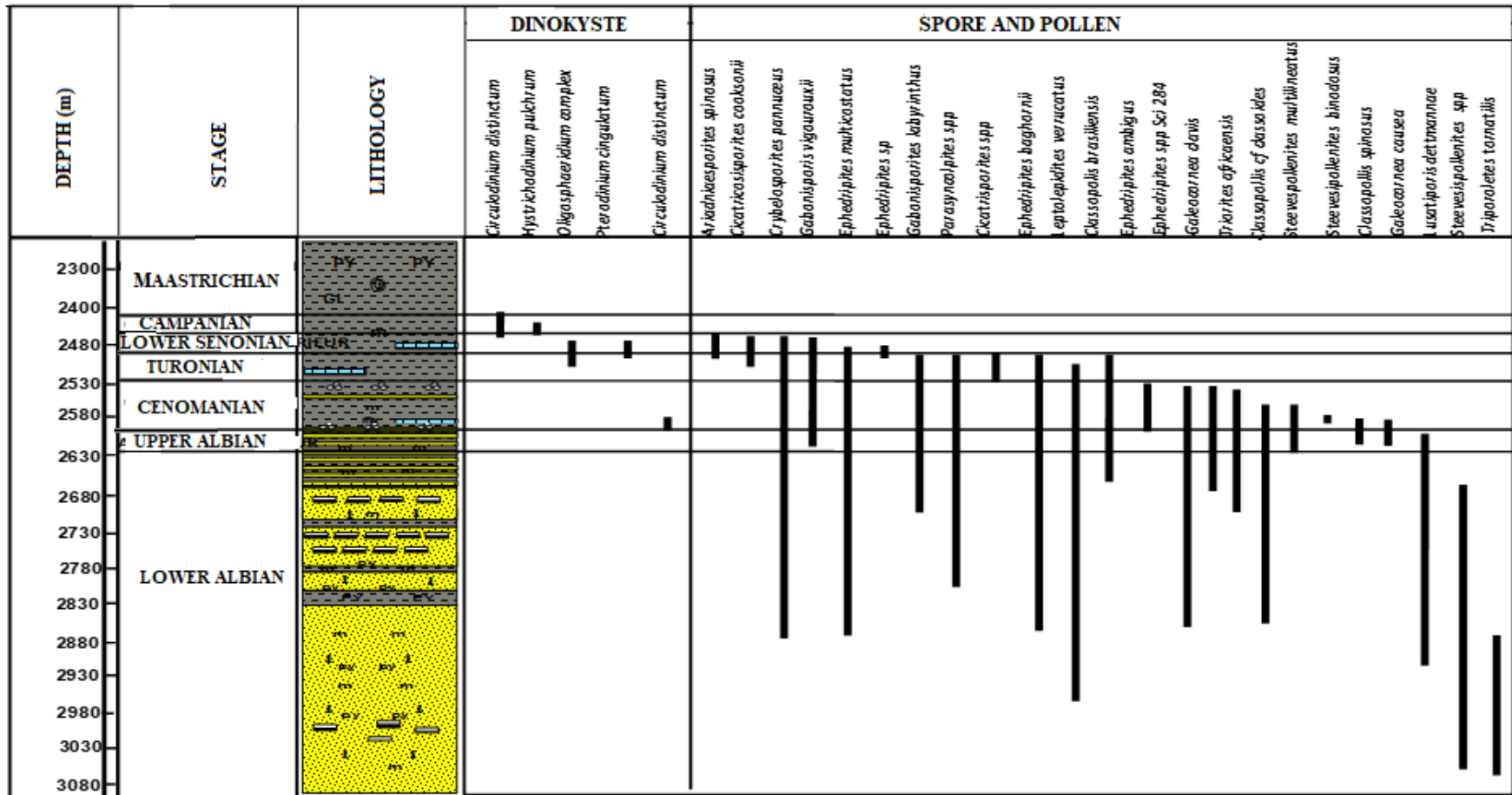


Fig. 3. Palynomorph distribution of sounding SN-X

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* (Fig. 6-1), *Globigerinelloides caseyi*, *Hedbergella angolae*, *Hedbergella gorbachikae* (Fig. 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.

- 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.

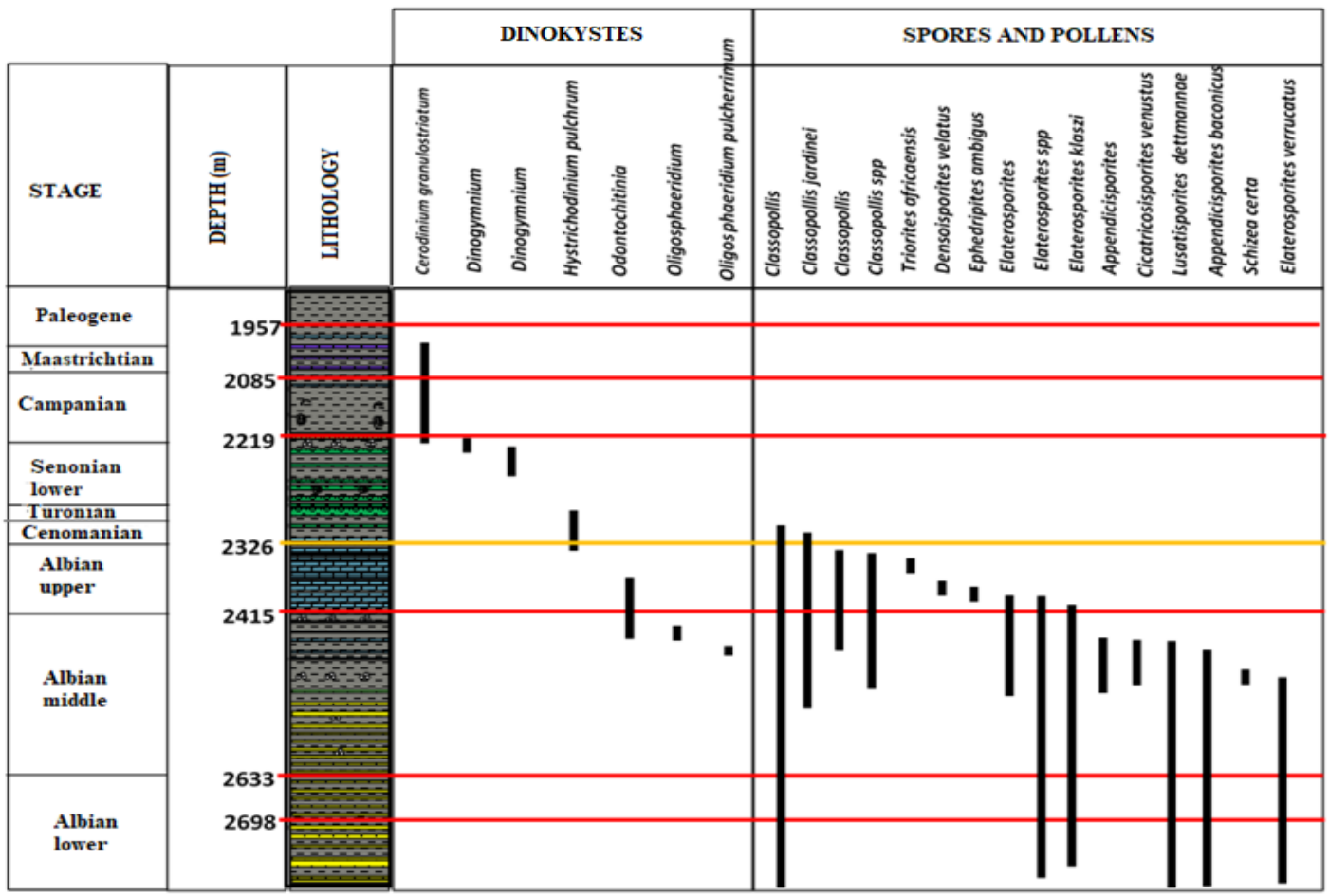


Fig. 5. Distribution of palynomorphs of the sounding DH-X

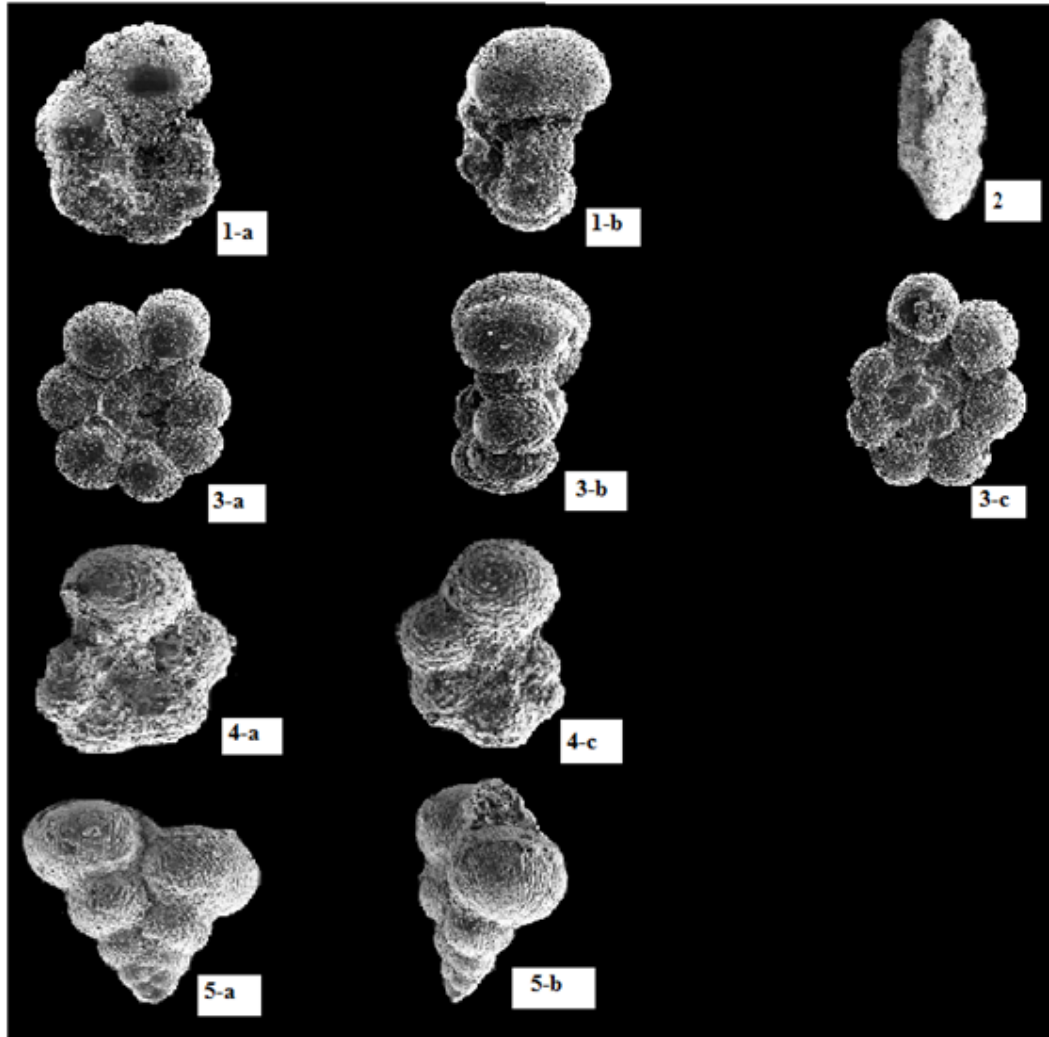


Fig. 6. Some planktonic foraminifera and benthic foraminifera agglutinated from the DH-X and SN-X sounding

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)

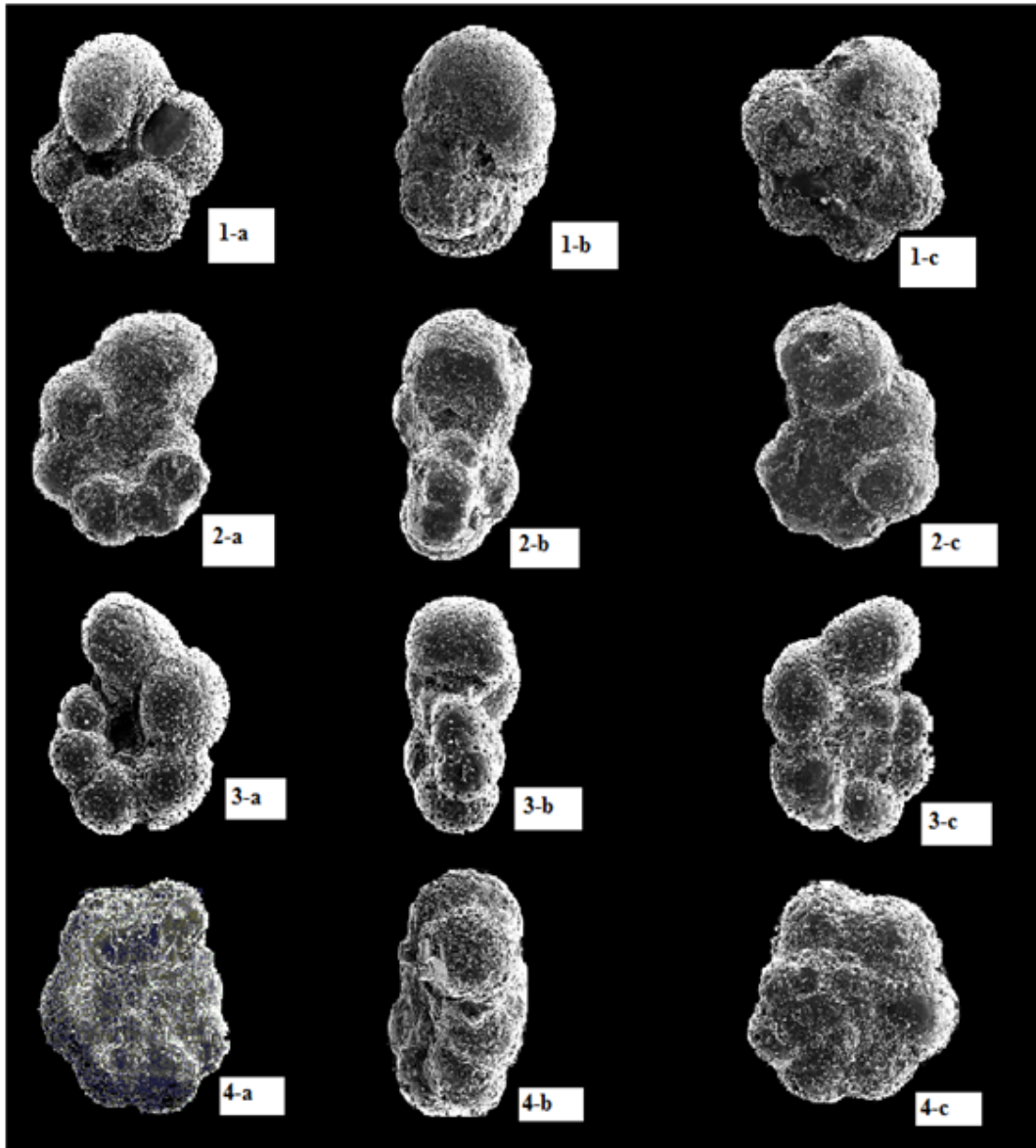


Fig. 7. Some planktonic foraminifera characteristic of Albian SN-X and DH-X sounding

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)

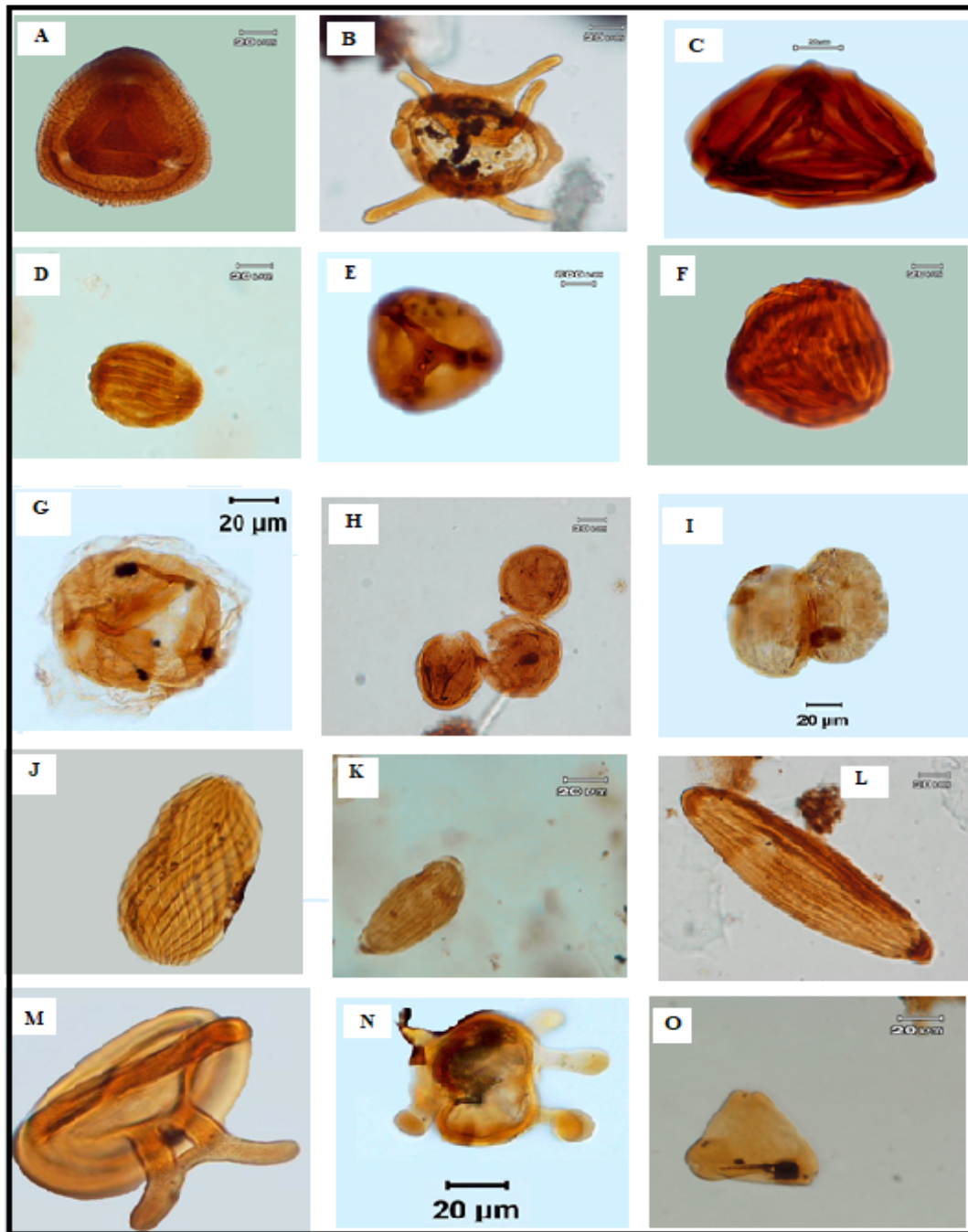


Fig. 8. Some spores and pollen from the SN-X and DH-X sounding

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 ambiguus* ; L- *Steevesipollenites binodosus* ; M- *Galeacornea clavis* ; N-*Elaterocolpites castelaini* ; O- *Triorites africaensis*

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.

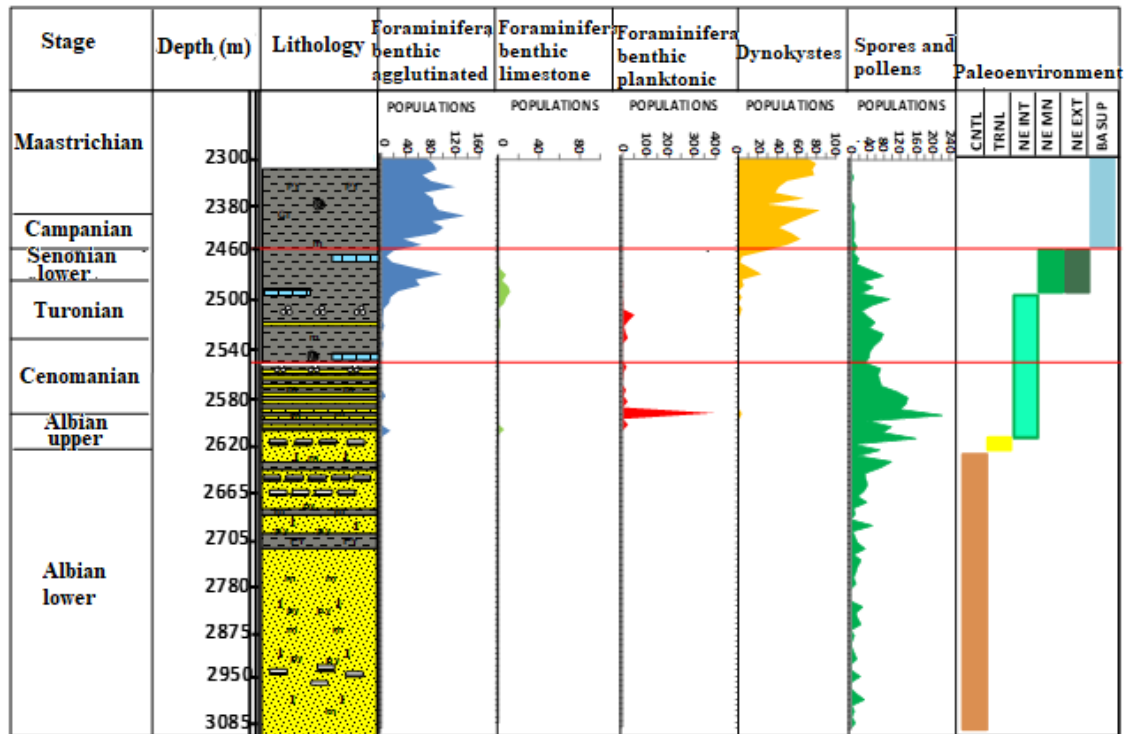


Fig. 9. Paleoenvironmental synthesis of the SN-X sounding

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

- Interval (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.

- 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.

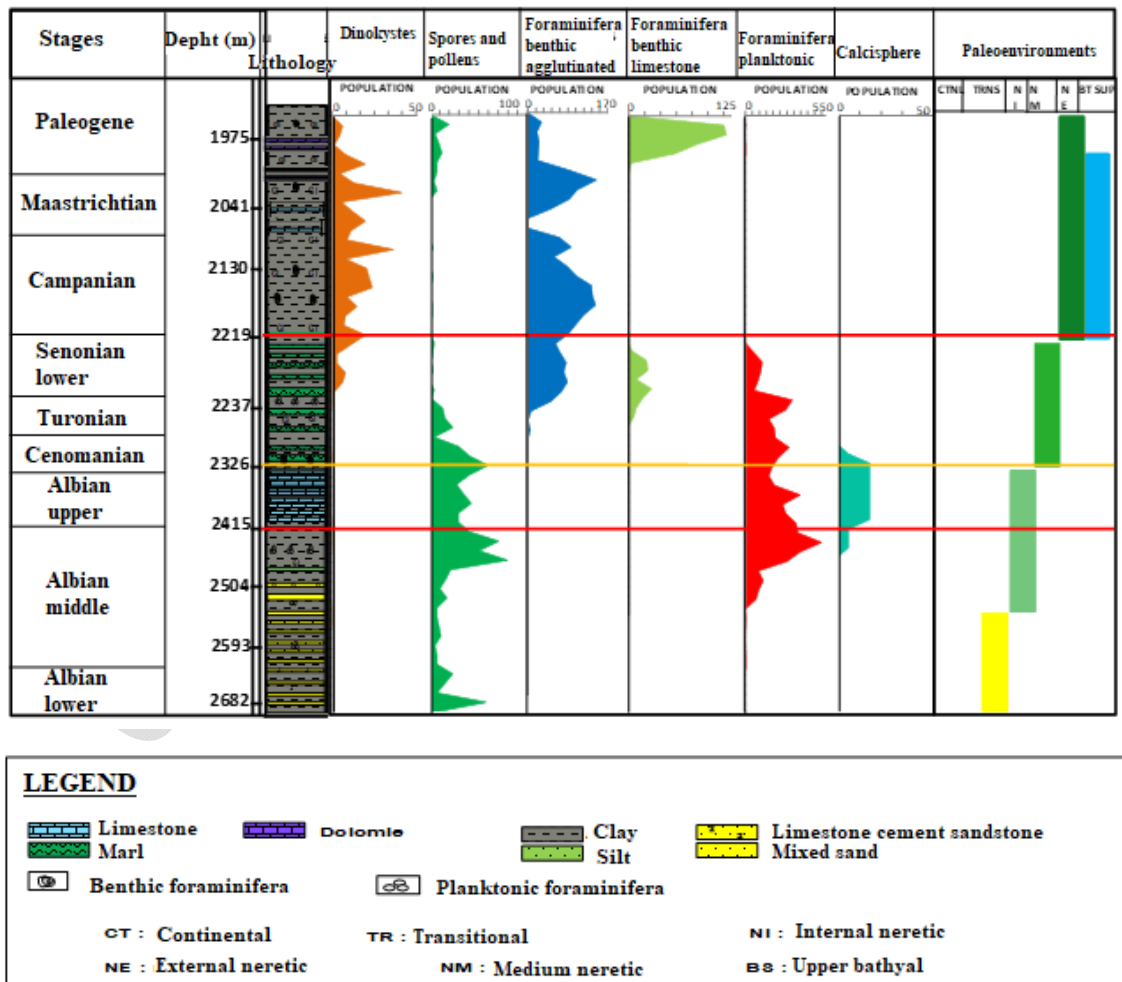


Fig. 10. Paleo-environmental synthesis of the sounding DH-X

- 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.

- 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 carenace 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 [18] who indicates that the calcispheres show unstable surface conditions.

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.

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