

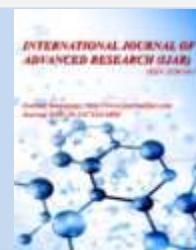


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RESEARCH ARTICLE

BIOSTRATIGRAPHIC CHARACTERIZATION OF THE CRETACEOUS DEPOSITS OF THE SAN-PEDRO MARGIN OF DRILL HOLES K1 AND K2 OF BLOCK KL: PALEOENVIRONMENT IMPLICATION

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Abstract

The KL block studies was carried out the eastern part of the San Pedro margin, it has an area of 2034 km² with a water depth varying from 500 to 2750 m with two probings (K1 and K2). The objective of this work is to carry out a biostratigraphic and paleoenvironmental study based on the associations of planktonic and palynomorph microfauna in the formations of the KL block boreholes. From a lithological point of view, the base of the boreholes generally comprises alternating limestone and argillite, very fine to fine grained quartz sandstone. Its upper part is overlain by claystone interbedded with limestone, silstone and siliceous cemented sandstone and alternating claystone, medium to coarse grained sand and siliceous cemented quartz sandstone. The Albian is determined by the presence of the species *Ticinellamadecassiana*. The Cenomanian is identified by the micropalaeontological assemblages composed of *Globigerinelloides* spp., *Guembelitria* spp., *Hedbergella* spp., *Hedbergelladelrioensis*, *Globigerinelloides bentonensis* and *Loeblichella* cf. *hessi*. The Turonian is based mainly on the species *Hedbergellaplanispira*, *Heterohelix moremani* and *Whiteinella archaeocretacea*. The Early Senonian is characterized by associations of species (*Hedbergellasp*, *Hedbergella* cf. *delrioensis*, *Buliminacrassa* and *Whiteinella baltica*) and palynomorphs (*Proteaciditestiabaensis*, *Odontochitinacostata*, *Odontochitinaporifera* and *Tricolpites* sp). The roof of the Campanian is known by the association of the palynomorph (*Trichodinium castanae*) and the microfossil (*Gaudryina cretacea*) The Maastrichtian is highlighted by the associations composed of species *Rzehakina epigona fissistomata*, *Rzehakina minima*, *Plectina lenis*, *Reophax duplex*, *Reophax pilulifera*, *Reophax globosus*, *Gaudryina pyramidata* and *Afrobolivina afra*) and palynomorphic species (*Andalusiella gabonensis*, *Cerodinium granulostratum* and *Palaeocystodinium australinum*). All the micropalaeontological data coupled with those of the microfaunas make it possible to envisage a depositional environment of the internal platform type with continental influence on an external platform.

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Introduction:-

In Ivory Coast, the first bitumen seeps in the area of Eboinda in 1950 marked the beginning of oil exploration. Thus, research conducted, by oil companies in close collaboration with university geologists led to encouraging results with the offshore discovery of the oil fields "Bélier" in 1974 and "Espoir" off Jacqueline in 1979, marking the starting point of oil exploration. (Koffi 2017).

The oil fields exploited in the Ivorian Offshore Basin have as reservoir rock, generally, sandstone banks of Cretaceous age (Bié, 2012, Koffi 2017). Therefore, the biostratigraphic characterization of the KL block will allow us to determine the ages of the geological formations east of the San-Pedro margin of the Côte d'Ivoire offshore basin, which are still poorly known.

These ages are determined on the basis of the first appearance of certain forms associated with the last appearance of other species in the direction of sedimentation.

Geological overview-

The Ivory Coast, with a surface of 322462 Km² belongs to the old platform of Zest Africa. It is formed by two geological units of unequal surface that are:

-the base of Côte d'Ivoire belonging to the West African craton and more precisely to the Man ridge. It includes the Archean domain in the West and the Paleo-Proterozoic domain in the East (Bessoles, 1977).

-The sedimentary basin occupying the southern part of the territory is composed of continental and marine deposits. It owes its origin to the opening of the South Atlantic in the Lower Cretaceous 106 Ma ago. This basin is crossed by two major faults of ENE-WSW direction. It represents more than 3/5 of the coastline and is divided into a crescent-shaped onshore area and an offshore area which is subdivided into two margins (Abidjan and San-Pedro) where oil exploration takes place (Aka, 1991; Monde, 1997).

Study area-

Ours study area is located in the eastern part of the San Pedro margin in the KL block (Figure 1). This block an area of 2034 Km² with a water depth varying from 500 to 2750 m with two(2) holes (K1 and K2):

1. Borehole K1 is located to the North - East of the KL block. It is a submerged hole with a final depth of 3592 m.
2. Hole K2 located to the South- West of the KL block. The final depth of this submerged hole is 4556m.

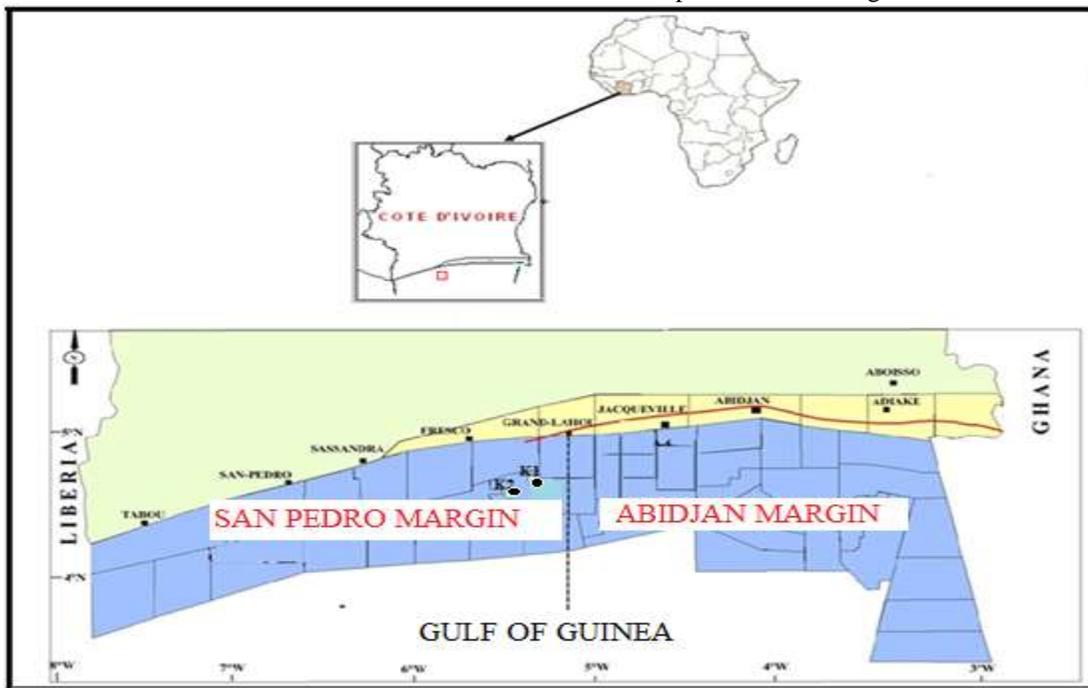


Figure 1:- Location of the KL oil block in the San Pedro margin.

Materials And Methods:-

The material used consists of 190 samples distributed as follows: 90 for the K1 survey and 100 for the K2 survey.

Micropalaeontological method-

A quantity of approximately 40g of sample to be studied is taken (and crushed if necessary in a mortar). This sample is then poured into a plastic beaker which is marked with the number of the sampled cuttings.

Each sample is then attacked with hydrogen peroxide, i.e. 10% hydrogen peroxide. The mixture (hydrogen peroxide + sediment) is stirred with a rod until the reaction is complete. The product is left to stand for an average of 12 hours.

There follows a series of preparations for the study which consists of washing, drying, bagging the samples and sorting the microfossils.

Palynological study methods-

Each sample of excavated material will undergo a palynological preparation which consists in destroying all the mineral phases to keep only the organic phase generally constituted of sporopollinic or palynomorphic material.

The technique used is the standard technique of palynology laboratories using strong acids (HCl and HF) to extract the palynomorphs. The laboratory preparation for palynological analysis begins with sampling, which consists of taking 20g of sample and putting it in a 2-liters beaker numbered according to a particular dimension, thus avoiding errors. Then comes the chemical treatment phase which aims to eliminate all the mineral matter contained in the sediments. Finally, palynological slides are made.

Dating by stratigraphic fossils-

It is based almost exclusively on the microfossils and palynomorphs contained in the formations. This is possible thanks to the use of the distribution scale of planktonic foraminifera (Figure 2, 3 and 4) of Caron (1985); as well as the work of palynology of Digbehi et al. (1997).

Biostratigraphic species and depositional environments-

The presence or absence of foraminifera can give information on:

- The position of the deposit in relation to the shoreline;
- The proximity of the shoreline, the depth;
- The physico-chemical conditions of the sea water (salinity, oxygenation and temperature).

The morphology of planktonic foraminifera can also provide information on the paleoenvironment (Caron, 1983).

Results and interpretations:-

Biostratigraphy of the Cretaceous formations-

Lower Cretaceous-

The Lower Cretaceous is marked by a single stage, the roof of the Albian in borehole K1 was identified at 3414 m by the last appearance of the species *Ticinella madecassiana*. The associations of microfaunal species (*Ticinellaprimula* and *Ticinellamadecassiana*), and palynological species (*Afropollisjardinus*, *Callialasporitesdampieri*, *Oligosphaeridium* Complex, *Classopollisbrasiliensis* and *Classopollisclassoides*, *Vitreisporitespustulosus*, *Elaterosporitesprotensus*) justify this age. The Albian is located in the interval 3595 to 3414 m (Figure 2).

As for borehole K2, its roof is determined from the last appearances of micropalaeontological species, notably *Ticinellamadecassiana*, *Hedbergellaplanispira*, *Hedbergelladelrioensis* and *Globigerinelloides ultramicra* at 4475 m. Furthermore, the associations of microfaunal species (*Hedbergellaamabilis* and *Ticinellaprimula*) and palynomorphs (*Classopollisbrasiliensis*, *Classopollis*spp, *Elaterosporitesverrucatus*, *Callialasporitesdampieri*, *Afropollisjardinus*, *Classopollispinosus* and *Elaterosporitesklaszi*) confirm the age of this interval 4556–4457 m (Figure 3).

Figure 2:- The Albian of the K1 borehole.

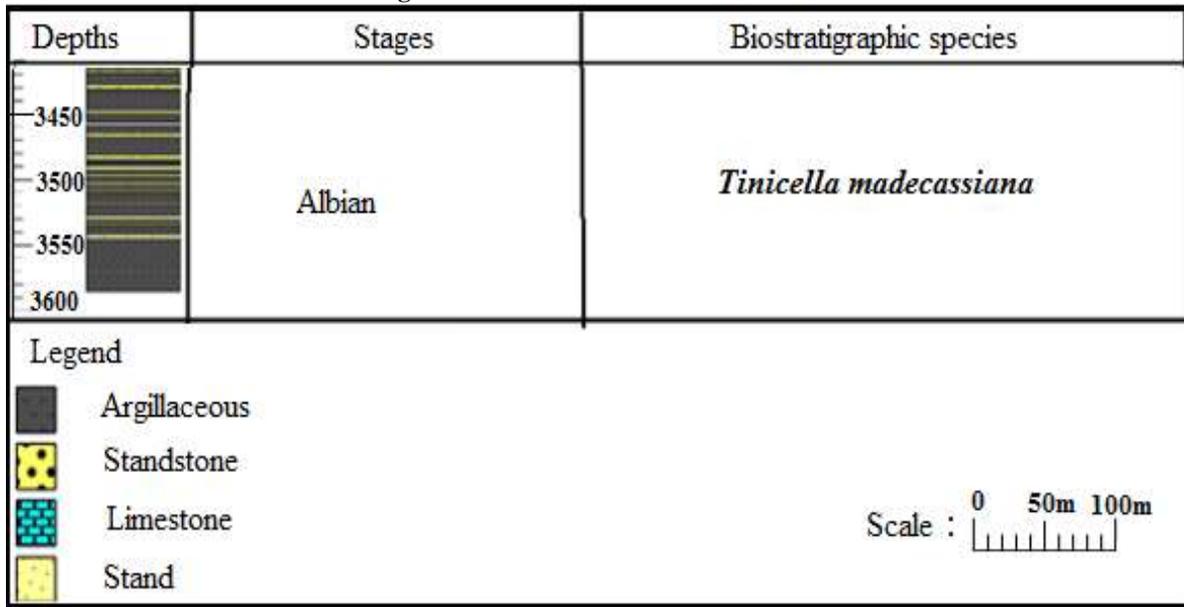
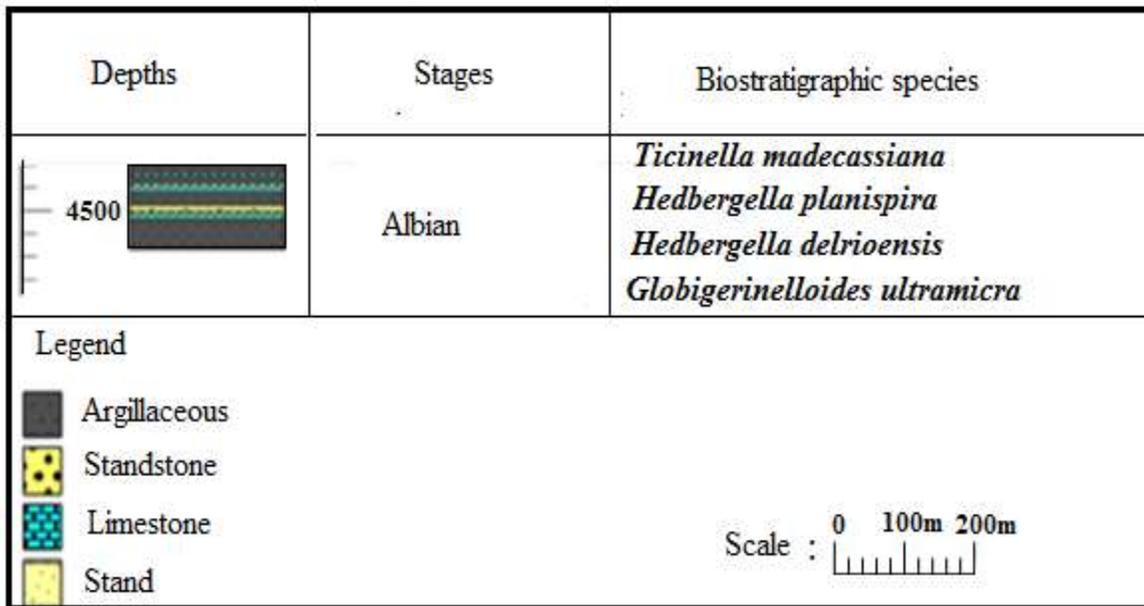


Figure 3:- Albian of the K2 borehole.



Late Cretaceous-

Late Cretaceous subsystem is composed of the Cenomanian, Turonian, Early Senonian, Campanian and Maastrichtian (Figure 4 and 5).

Cenomanian-

Cenomanian roof of borehole K1 was identified by the last appearance of the palynomorph *Classopollisclassoides* at elevation 3344m. The abundance of small planktonic foraminifera dominated by the genus *Hedbergella* and *Classopollis* spp. *Classopollis spinosus*, *Cretaceopollismulleri* and *Cupuliferoidaepollenites minutus* justify a Cenomanian age located between intervals 3414 and 3344 m.

The latest appearances of palynological species (*Classopollis major*, *Classopollisbrasiliensis* and *Classopollis* spp.,)

highlight Cenomanian roof at 4391 m in borehole K2. This age is confirmed in the 4457-4391 m interval by associations of microfaunas (Holocryptocanumbarbui, Cenospaera spp., Cryptamphorellaconara, Hedbergelladelrioensis, Patellulaverteroensis, Hedbergella spp., Hedbergella simplex and Hedbergellaplanispira) and palynomorphs (Classopolisbrasiliensis and Classopolis major).

Turonian-

It is not highlighted in hole K1 due to the lack of biostratigraphic markers.

Turonian roof in hole K2 is highlighted by the presence of the palynomorph Foveotricolpitesgiganteusat 4370m. Also the presence of the planktonic foraminifer Hedbergellaplanispira justifies the existence of Turonian age between 4391 and 4370m.

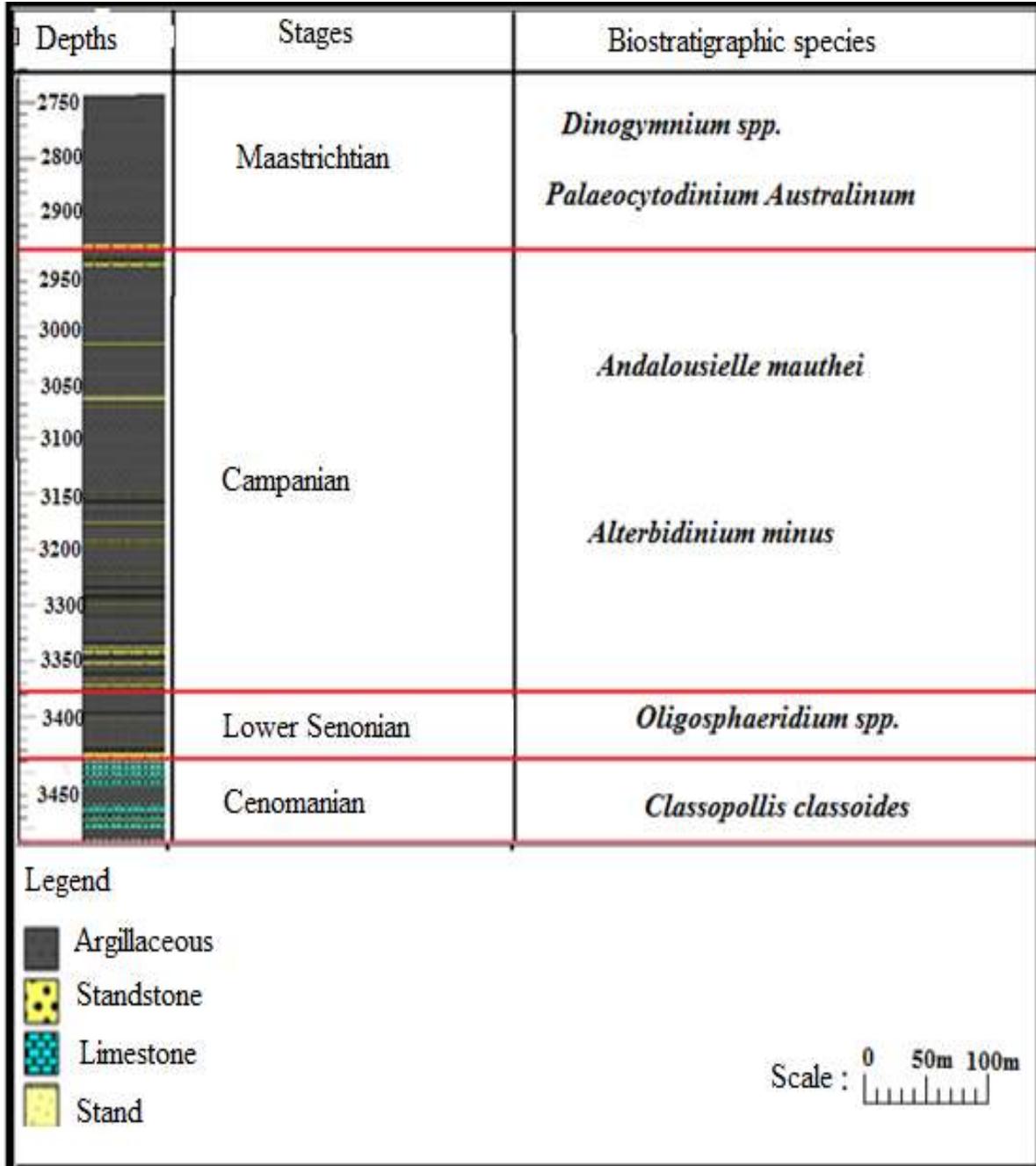


Figure 4:- Late Cretaceous of the K1 borehole.

Early Senonian-

The identification of the Early Senonian in Hole K1 is essentially based on palynomorphs. The top of this age is highlighted by the last appearance of the species *Oligosphaeridium* complex at 3271 m. Palynological associations such as *Odontochitina* costata, *Oligosphaeridium* spp., *Ariadnaesporites verrucatus* attest to a Early Senonian age between 3344 and 3271m.

The roof of Early Senonian is determined by the disappearance of the palynomorph *Oligosphaeridium* sp. at 4316 m in borehole K2. Palynological (*Cretacaeorites muelleri*, *Oligosphaeridium* complex, *Hexaporotricolpites melianovii*) and micropalaeontological (*Neobulimina subregularis*) associations attest to a Early Senonian age of the 4370 to 4316m interval.

Campanian-

Campanian in borehole K1 is essentially based on the association of the palynomorphs and a few microfauna. Indeed, the last appearances of palynomorphs identified at elevation 2868m such as *Subtilisphaera* spp. and *Alterbidinium* minus allowed the identification of the roof of this zone. This interval consists of an association of palynomorphs such as *Trichodinium castanae*, *Xenascusceratioides*, *Achomosphaeraramuliferagabonense*, *Spinidinium densispinatum* and benthic calcareous and agglutinated foraminifera *Afrobolivina afra*, *Buliminella quadrilobata*, *Plectina lenis*, *Siroplectammina navarroana*, and *Reophax globosus*. A Campanian age is assigned to the interval 3271 to 2868 m.

The disappearance of the palynomorph *Pseudopolykrikos africaensis* at elevation 3690 m identified Campanian roof in borehole K2. This interval is composed of associations of palynomorphs (*Ariadnaesporites spinosus*, *Rugulatisporites caperatus*, *Xenascusceratioides*, *Trichodinium castanea*, *Hystrichodinium pulchrum*, *Andalusiella mauthei*, *Nematosphaeropsis "africaensis"*, and *Unipontidinium grande*) and microfaunas (*Haplophragmoides walteri*, *Karrerella conversa*, *Rzehakina epigona*, *R. minima*, *Plectina lenis*, *Praebulimina fang*, *P. prolixa*, *P. reussi*, *P. exigua robusta*, *Gabonitadistorta*, *G. distorta irregularis*, *Gabonellabasispinata*, *Neobulimina subregularis*, *Gabonellabasispinata*, *Neobulimina canadensis*, *Bulimina exigua*, *Bulimina brevispira*, *Buliminella gabonica altispira*, *B. quadrilobata*, *B. gabonica longicamerata*, and *robusta* confirm a Campanian age that places it in the interval 4316 to 3690m.

Maastrichtian-

The last appearance of the palynomorph *Dinogymnium* spp affected the Maastrichtian roof at elevation 2750 m. Palynological association consisting of *Proteacidites sigali*, *Palaeocystodinium gabonense*, *Palaeocystodinium australinum*, *Andalusiella mauthei*, *Senegalinium cerodinium*, *Senegalinium* spp. *Echitriporites trianguliformis* and *Dinogymnium acuminatum* support this age. Maastrichtian ranges from 2868 to 2750 m in borehole K1. Maastrichtian is 180 m high in borehole K2 and shows no micropalaeontological markers. The palynological species have allowed us to highlight the roof of this stage. Indeed, at elevation 3510 m, the last appearances of the palynomorphs *Senegalinium bicavatum*, *Palaeocystodinium australinum* and *P. gabonense* indicate the Maastrichtian roof. In addition, an association of the palynological species *Palaeocystodinium* species, *Palaeocystodinium golzowense*, *P. lidiae*, *Gabonisporis vigourouxii* and *Alterbidinium minus* characterizes this age. Maastrichtian is located in the interval 3690 to 3510m.

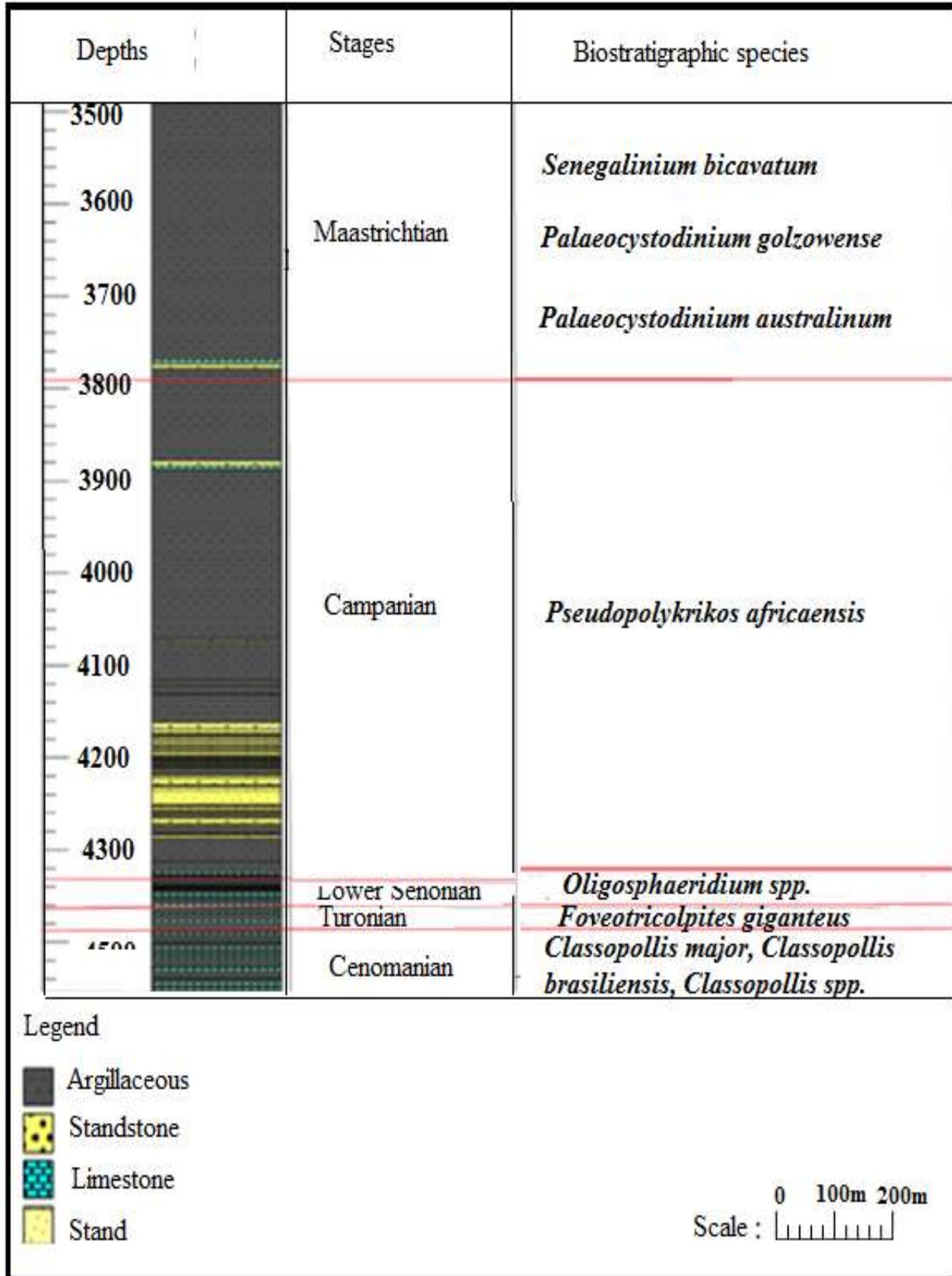


Figure 5:- Upper Cretaceous of the K2 borehole.

Correlative analysis of Cretaceous drill holes-

Boreholes K1 and K2 are located within an anticline system in the KL block of the San- Pedro margin (Figure 6). They are located to the northeast and southwest, respectively. More specifically, K1 is located on the hinge and K2 is located on the western flank of the anticline. However, a correlative lithostratigraphic West-East analysis can be performed.

- Albian of holes K1 and K2 has a similar style of deposition. It is marked by alternating argillite, sand, and minor proportions of limestone with sandstone interlayers (K2). The accessory minerals present are carbonaceous debris and pyrites. All its lithological characteristics are typical of shallow and reducing environments with variable energy. From west to east, terrigenous contents are low on the western flank (hole K2) and high on the hinge (hole K1). The thickness of the Albian is variable (93-181m). It is thick in the North-East with a thickness of 181m and narrows in the South-West (99m).

- Cenomanian, its thickness increases from West to East with relatively equivalent thicknesses for K1 and K2 (about 70m). It is characterized by an alternation of sandstone, claystone and limestone in all the boreholes.

- Turonian is absent in borehole K1 and is present in a flake in borehole K2 where it is composed of mudstones with limestone layers. As Turonian is poorly represented in the entire Ivorian basin, its absence in borehole K1 could be explained by Turonian regression which strongly eroded the deposits of the Ivorian margin and could accentuate the erosion or non-deposition phenomena thus creating an unconformity.

-Early Senonian, its thickness increases from west to east. It is composed of alternating limestones and argillites. In addition to these two formations, sandstones and sands are encountered in the K1 boreholes. The presence of clay-sandstone deposits (K1) and the local enrichment of limestone (K2) are possibly related to the regression (fall in sea level) that took place during the post-rift phase of the Ivorian sedimentary basin. This drop caused a strong erosion of Early Senonian deposits.

-Campanian, has a lithology consisting of alternating sandstone, sand and mudstone. Its thickness decreases from west to east.

-Maastrichtian, is essentially clayey with sandstone and limestone in all the drill holes. Accessory minerals such as pyrite and glauconite are present in this stage. It is characterized by a rise in sea level due to eustatic variations, attested to by the abundance of mudstones in this zone. Moreover, the presence of glauconite confirms this hypothesis, because it develops in open marine environment and far from active sedimentation zones, preferably during long periods of non-deposition due to relative sea level rise. Table I highlights the synthesis of these stages.

Table I:- Summary of stratigraphic stages of the KL block boreholes.

STAGES	K1	K2
MAASTRICHTIAN	2750m - 2868m	3510m – 3690m
CAMPANIAN	2868m – 3271m	3690m – 4316m
LOWER SENONIAN	3271m - 3344m	4316m – 4370m
TURONIAN	ABSENT	4370m – 4391m
CENOMANIAN	3344m – 3414m	4391m – 4457m
ALBIAN	3414m - 3595m	4457m - 4556m

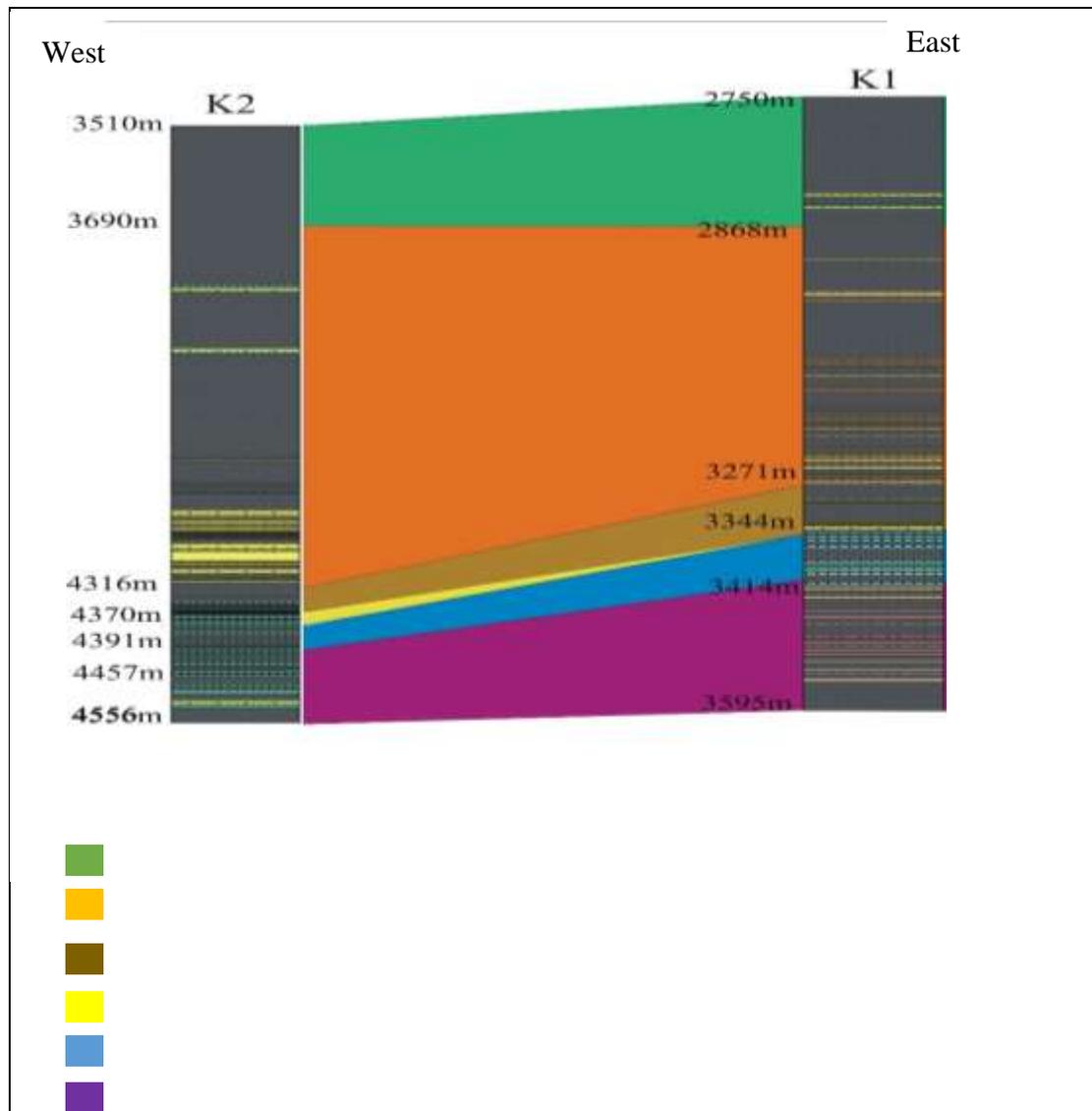


Figure 6:- Lithostratigraphic correlation of the Cretaceous formations.

Paleoenvironment of cretaceous deposits-

Paleoenvironment of Albian deposits-

Boreholes K1 and K2 have the same characteristics from the lithological and biostratigraphic point of view. The lithology is composed by an alternation of clay, sandstone, sand and limestone. The accessory minerals present are carbonaceous debris and pyrites.

The microfauna is essentially made up of planktonic foraminifera with little diversity marked by the presence of *Ticinella*, which characterizes shallow waters (Djéya et al., 2010). The effective absence of benthic foraminifera indicates that the conditions of life on the bottom were unsuitable for life, thus anoxic. This absence would be due to the anoxic bottom conditions that prevailed during the separation of Africa and South America in the Cretaceous (Bamba et al., 2008). The presence of dinokysts attests to a marine environment. Also, the simultaneous presence of carbonaceous debris and pyrites in low proportion characterizes a depositional environment close to the continent and a reducing environment. The high water energy is marked by the presence of sandstone and sand. In sum, the depositional environment is situated from the coast to the internal platform.

Paleoenvironment of Cenomanian deposits-

The dominance planktonic foraminifera would indicate a marine environment with a thick slice of water (open sea). The absence of benthic foraminifera indicates unfavorable conditions for life on the bottom. This microfauna, which is not very diversified, is made up of Hedbergella, which are organisms that develop and invade the inner to middle shelf where they can withstand variations in salinity and temperature (Leckie, 1987). The presence of limestone topped by alternating thick mudstone and thin sandstone beds would show that the energy of the environment is variable. The presence of glauconite and pyrite confirms that the depositional environment is marine and reductive. All these characteristics concern holes K1 and K2. The depositional environment during Cenomanian would vary from internal platform to medium and reductive.

Paleoenvironment of Turonian deposits-

It is essentially clayey with a limestone background with the presence of glauconite and carbonaceous debris, which would reflect a low-energy marine environment with continental influence. The microfauna and palynoflora are in poor condition. The depositional environment would be of the internal platform type with a condition influence for hole K2.

Paleoenvironment of Early Senonian deposits-

The presence of pyrite, glauconite and limestone would indicate a deep and reductive marine environment (boreholes K1 and K2) with conditions less favorable to the proliferation of microfauna, hence the near absence of both benthic and planktonic species in this stage. This interval is represented by a low thickness; this could be due to erosion. This erosion of Early Senonian probably occurred during the early oceanic expansion phase with the first frank marine transgression (Cenomanian – Early Senonian) (Chierici, 1996). The depositional environment would be between the internal and external platform.

Senonian suggest results based on palynoflora, consisting of species such as Oligosphaeridium complex and Oligosphaeridium spp. For Digbehi et al, (1997) palynomorphs such as Oligosphaeridium complex, Dinogymnium acuminatum, Dinogymnium sp., Xenascus sp., Oligosphaeridium pulcherrimum and Circulodinium distinctum characterize early Senonian of Côte d'Ivoire offshore.

As for Campanian, it contains palynomorphs such as Trichodinium castanea, Xenascus ceratoides. These results are in agreement with those of Digbehi et al, (2011) on the characterization of depositional environments in the Côte d'Ivoire offshore basin.

Maastrichtian is composed of the palynological genera that are: Senegalium and Palaeocystodinium typical of this age. It appears from the work of Bie (2012) that some authors such as Oloto (1989) and Jain and Millepie (1975) have shown that the species Palaeocystodinium australinum is a characteristic species of Maastrichtian in Senegal and Nigeria. In addition, Helene and Cabrera (2003) stated that the species Senegalium bicavatum, Palaeocystodinium australinum and Palaeocystodinium golzowense are good markers of the Late Maastrichtian.

Conclusions:-

The biostratigraphic characterization of the San-Pedro margin has highlighted the Lower and Upper Cretaceous stages. These stages range from Albian to the Maastrichtian. All stages are present with the exception of the Turonian in borehole K1.

Lithological correlations based on facies show that the KL block of the San Pedro margin is composed of five (5) main lithological facies, namely: a clay facies, a sandy facies, a sandy facies and a limestone facies. Clay, sand and sandstone dominate the lithologies described. They occur in the form of alternating layers and the terrigenous formations (sandstone and sand) encountered date from Albian to Campanian for holes K1 and K2.

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ANNEXE:-

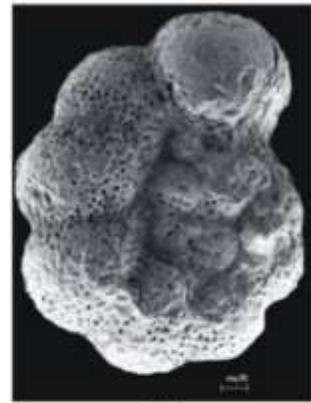
PLATE 1

- 1- *Ticinella primula* (Luterbacher, 1963) Albian
 - 1a- ombilcal view
 - 1b- spiral view
- 2- *Whiteinella archaeocretacea* (Pessagno 1967) Cenomanian
 - 2-a- spiral view
 - 2-b- Ombilcal view
 - 2-c- Profil view
- 3- *Whiteinella baltica* (Douglas and Rankin 1969) Turonian
 - 3-a- spiral view
 - 3-b- Ombilcal view
 - 3-c- Profil view
- 4- *Hedbergella delroensis* Early Senonian
 - 4-a- spiral view
 - 4-b- Ombilcal view
 - 4-c- Profil view

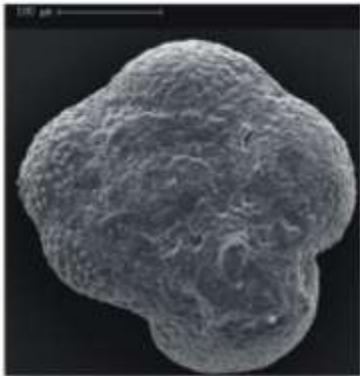
PLATE 1



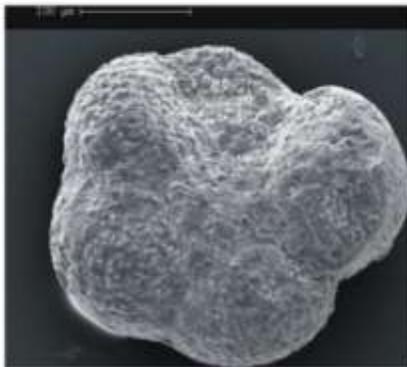
1a



1b



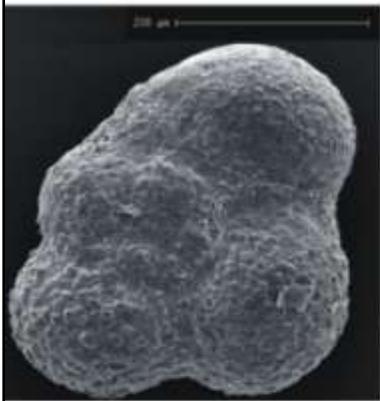
2a



2b



2c



3a



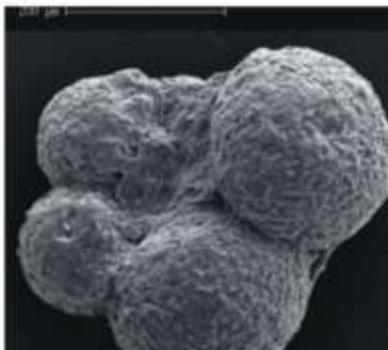
3b



3c



4a



4b



4c

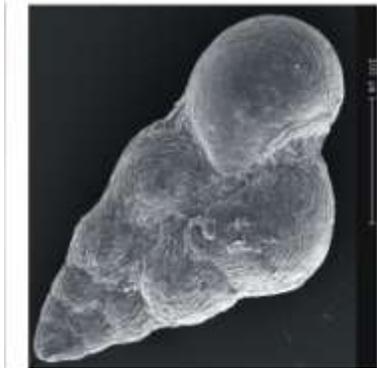
PLATE 2

1- *Heterohelixglobulosa* (Ehrenberg) **Maastrichian**

1-a- b-Ombilical view

1-c- Detail

PLATE 2



1a



1b

1c

