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Full Length Research Paper

Palynostratigraphy and palaeoenvironmental characterization and evidence of Oligocene in the terrestrial sedimentary basin, Bingerville area, Southern Côte d'Ivoire, Northern Gulf of Guinea

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A palynological investigation of two shallow boreholes in Anna, Bingerville area, at 13 km Northwest Abidjan, Southern Côte d'Ivoire, yielded rich and relatively well-preserved dinoflagellate cyst's assemblages that allowed recognition of Oligocene age. This recognition was based on global dinoflagellate cyst events, including mainly *Lejeunecysta* species represented by cf. *Lejeunecysta communis*, *L. lata*, *L. pulchra, Lejeunecysta* sp. cf. *L. granosa*, cf. *L. globosa, L. beninensis* and other *Pheolodinium magnificum, P. africanum, Selenopemphix nephroïdes* and *Cordosphaeridium inodes*. They are associated to terrestrial spores and pollen grains such as *Magnastriatites howardii*, *Spirosyncolpites spiralis*, *Perfotricolpites digitatus, Retitricoporites irregularis, Retimonocolpites irregularis, Pachydermites diederixii*, *Psilatricolporites operculatus* and *Punctodiporites harrisii*. The palynostratigraphic interpretations are based on a comparison with calibrated dinoflagellate cyst ranges from several reference sections, mainly in the peri-atlantic and incidentally peri-pacific basins. This study showed changes in the relative abundances of different species or groups of morphologically related species. These changes are palaeoenvironmentally controlled, indicating a deposition occurred between the continental nearshore and marginal marine areas under continental influence. The prevalence of peridinioid dinocysts assemblage suggests deposition in a subtropical province whereas terrestrial pollen grains and spores provided by plants of coastal vegetation dominated by pteridophyts and angiosperms evoke mangrove and swamp forests. These new palynological data, notably the presence of Oligocene especially in the Ivorian terrestrial basin north of the so called "faille des lagunes", specifies and modifies the previous local stratigraphic scale.

Key words: Palynostratigraphy, palaeoenvironment, Oligocene, sedimentary basin, Côte d'Ivoire.

INTRODUCTION

Many works based on Cretaceous-Tertiary sedimentation in Côte d'Ivoire basin (Figure 1) were summarized recently by Sombo (2002) and indicated Oligocene hiatus also recorded in some West African coastal basins. For these studies, this hiatus was probably due to a general uplift of continental shelves, followed by the West African coastal erosion by the end of Eocene. In recent years, the Laboratory of geology at the University of Cocody, Côte d'Ivoire, undertook sedimentological and biostratigraphic studies especially in the terrestrial part of the coastal basin (Charpy and Nahon, 1978; Bachiana et al., 1982; Digbehi et al., 1993; 1994) where Oligocene stage was never recorded.

In Bingerville area (Figure 2), are exposed various facies of the "continental terminal" series, a package of

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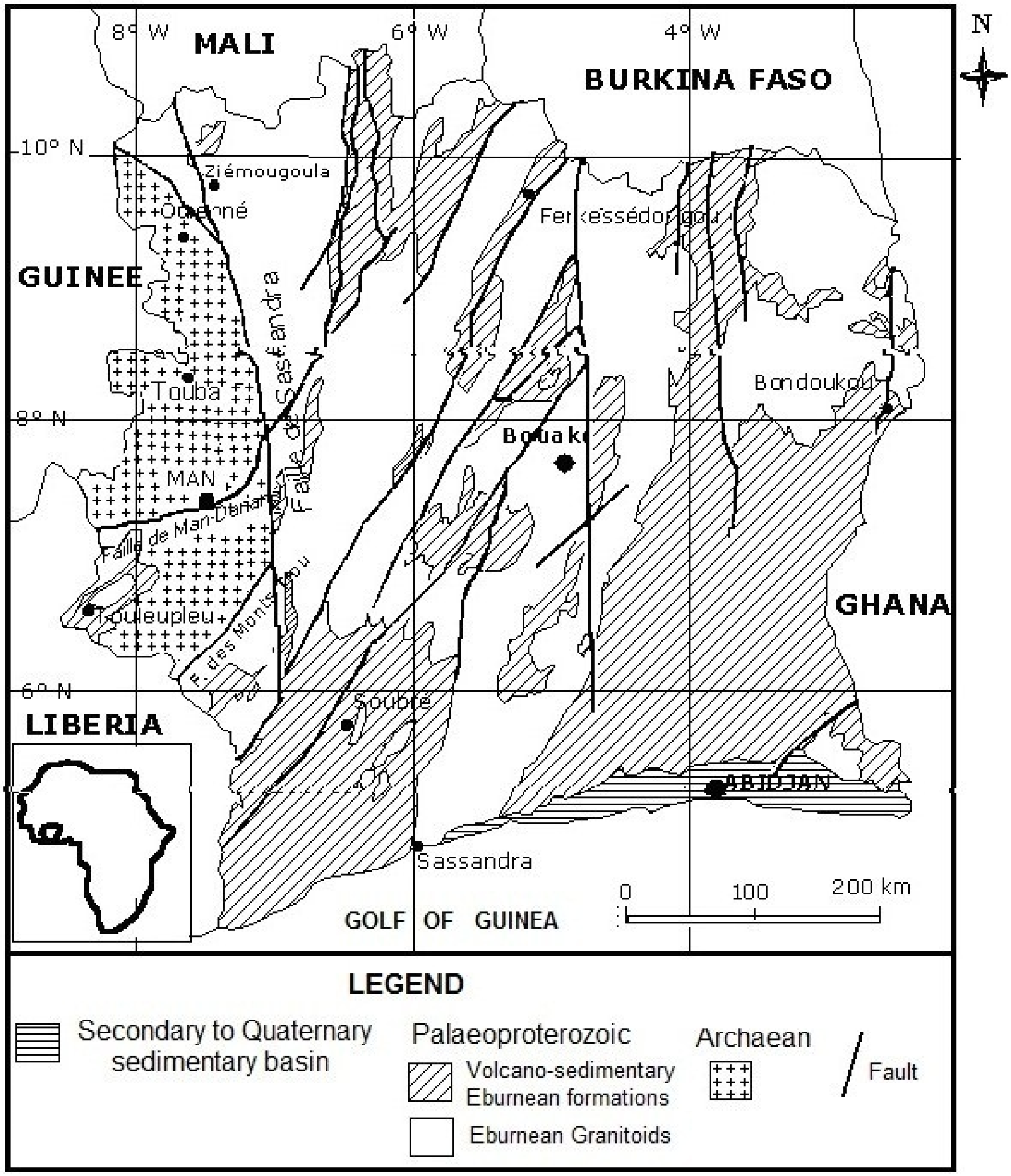

Figure 1. Geological setting and Cretaceous-tertiary sedimentary basin of Côte d'Ivoire.

Mio-Plio-Quaternary age as described in the synthesis of Digbehi et al*.* (2001). Few works in this area provided controversial results concerning the age of deposits that underlie this "continental terminal" series. Thus, Bacchiana et al. (1982) identified Miocene formations based on foraminifera assemblage and terrestrial spores and pollen species (*Verrutricolporites rotundiporus, Racemonocolporites hians, Psilatricolporites crassus, Retibrevitricolporites protrudens, Arecipites exilimuratus*).

In contrast, recent student's unpublished works around Bingerville, located North of the so called "faille des lagunes", and performed on gray clay underlying the "continental terminal" series, described a palynological assemblage characterizing Oligocene age. The present study was undertaken to establish a precise local palynostratigraphy in this area. It also aimed to propose a palaeogeagraphic reconstruction of the deposits crossed by the two shallow boreholes based on palyno-facies analysis.

COTE D'IVOIRE STRATIGRAPHIC OVERVIEW

Synthetic stratigraphic models proposed by many authors cited by Digbehi (1987), Chierici (1996) and Sombo (2002), summarized geological history of Côte d'Ivoire basin in four main steps: a) a rifting phase (Barremian-Albian) with margino-littoral sediments; b) a phase of

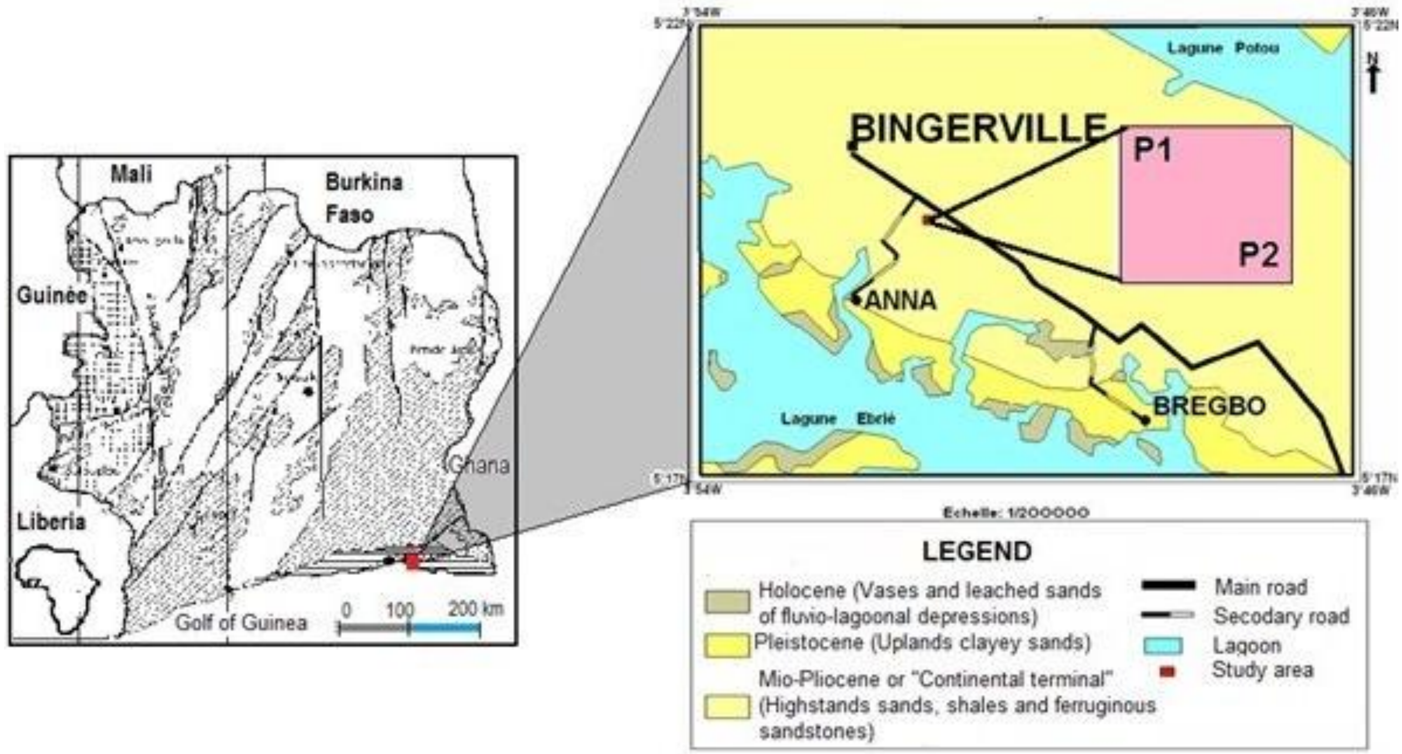

Figure 2. Surface geological settings and location of the shallow boreholes P1 and P2 in Bingerville area.

initial ocean expansion with first true marine transgressive deposits (Cenomanian-Lower Senonian) that allowed deposition of calcispherids limestones eroded during lower Senonian; c) a phase of active expansion and subsidence (Campanian-Maastrichtian) with transgressive marine clays overlying surfaces of erosion affecting in places cenomanian series; d) a phase of maximum expansion in tertiary during which occurred a major regressive phase ranging from late Eocene to Oligocene. During Cenozoic, marine sedimentation is mainly silico-clastic and occasionally carbonated. The Palaeocene series are generally clayey and occasionally glauconitic with limestone and sand observed in outcrops (Fresco) by Reyre and Tea (1981) based on dinoflagellate (*Apectodinium*) assemblage. In the eastern basin, palaeocene reaches 500 m thick (Digbehi et al., 1996; 1997). The Eocene (490 m) consists of sandy clays with small limestone beds (Ypresian-Lutetian) and shale's more or less sandy and glauconitic (Aka, 1991). The Lower Miocene is described in a small depression around Abidjan where it consists of dark shales of 600 m thick, rich in foraminifera (Klasz and Klasz, 1992). These marine shales are overlain or pass laterally into red shales, gray and white, kaolinitic facies.

MATERIALS AND ANALYTICAL METHODS

Fifty-three cutting samples recovered from indistinct tertiary succession in Bingerville area, (Figure 2) penetrated by two shallow boreholes P1 (20'21''N 03° 51'33''W, 29 samples) and P2 (05°20'18'' N and 03°51'34'' W, 24 samples), drilled in Southern Côte d'Ivoire terrestrial basin, are investigated for this study. These boreholes are separated by approximately 135 m, and are respectively 10.14 and 11.13 m of total depth.

Lithological analysis based on the field visual description of the 53 cuttings was complemented by observations of washing residue under a binocular microscope in. It resulted in synthetic lithological logs of two boreholes. Only 25 productive samples (the 28 others were barren and unproductive) were prepared according to standard palynological procedures (Oboh et al., 1996; Mahmoud and Shranck , 2007). Dilute hydrochloric (HCl 50%) and cold concentrated hydrofluoric (HF 70%) acids were used to remove carbonates and silicates respectively. The digested residues were then treated again with HCl (50%) to dissolve fluorides if any. Residues were screened through a 10 µm nylon polyamide sieve. For qualitative and quantitative study, at least two permanent slides per sample were prepared using Canada Basalm as mounting medium. The slides were examined using a Motic light microscope equipped with an integrated Motic digital camera. For quantitative palynology, a count of about 100 to 150 grains was made for each sample (when possible). Taxonomic determination of spores and pollen grains was based on morphographic classification of Potonie (1970) whereas identification of dinoflagellate cysts was done following Lentin and Williams (1985; 1987; 1989). The slides were stored at the Laboratory of Biostratigraphy, University of Cocody, Abidjan. The age determination of the drilled sediments was based solely on these palynological results. Palynostratigraphic interpretations were based on comparison with already identified dinoflagellate cysts ranging from several reference sections, mainly in the peri-Atlantic basins.

Their relative abundance was assessed in each well by adopting an arbitrary classification using the concepts of rare (0-5 taxa),

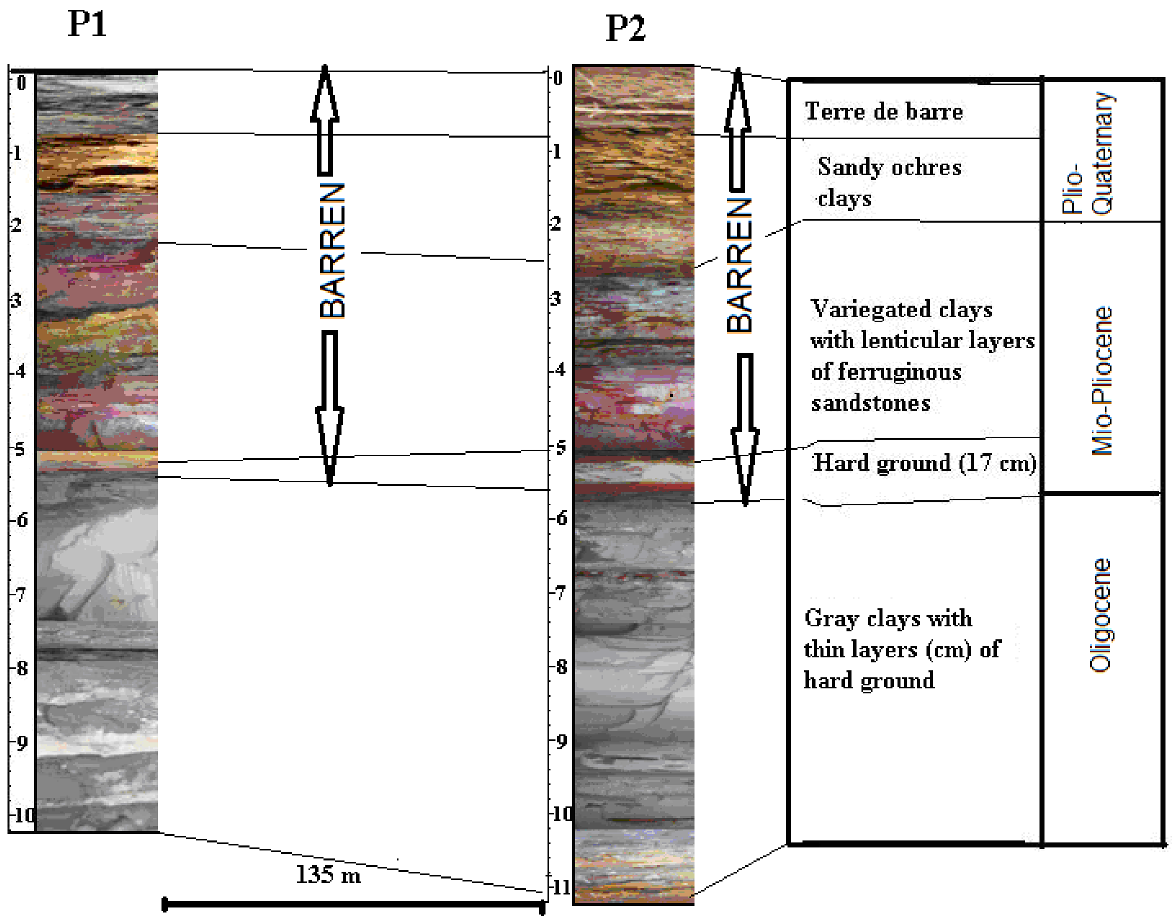

Figure 3. Lithostratigraphical correlation summary of the boreholes P1 and P2 in Bingerville area.

present (6 to 15), common (16 to 50) and abundant (>50). Depositional palaeoenvironment was approached by changes in the relative abundance of different species or groups of morphologically related species more specifically between terrestrial pollen and spores and marine dinoflagellate cysts, as adopted in many works (El-Beialy, 1990; Sluijs et al., 2005; Prebble et al., 2006).

RESULTS

Figure 3 shows lithostratigraphic correlation synthesis of the two boreholes. Four lithofacies are distinguished along each of them and they range upwards as follows: (i) gray clays which provided the whole microflora analyzed; they are overlain by (ii) variegated clays above a hard surface (or hard ground) consisting of ferruginized clay that seems to represent periods of stop in the cementation process, with the result this soft sediment units alternate one with the other layers; (iii) subjacent ochre's sandy clays include gravel; these sandy clays are topped by (iv) gray clayey sands called "terre de barre" with levels of stone line. Because of their sharp deterioration, the twenty-eight samples of superficial levels (0 to 5, 64 m in P1 and 0 to 5, 63 m in P2), were barren and provided no microfossil (foraminifera and palynomorphs).

Palynostratigraphical approach

The residual materials recovered after maceration of samples for palynological analysis are mainly composed of amorphous organic matter and fragments with colors ranging from brown to dark. The most abundant are wood remains (wood cuticles or stems). Microflora provided by these boreholes includes modest numbers of marine and terrestrial palynomorphs with an average abundance of 30 species (Index). These assemblages exceptionally limited in diversity but globally dominated by *Lejeunecysta* species (*Lejeunecysta* sp. cf. *L. communis*, *L. lata*, *L. pulchra,* cf. *L. granosa*, *L. globosa,* cf. *L. beninensis*) associated with other species *Pheolodinium magnificum, P. africanum, Tuberculodinium vancampoae, Selenopemphix nephroïdes, Batiacasphaera* spp dont *Batiascaphaera* sp. cf. *B. micropapillata* and *Cordosphaeridium inodes*. Terrestrial assemblage retrieved from this section was composed of

DEPTH (M)	10.14	9.84	9.66	9.24	8.94	8.54	8.14	7.84	7.54	7.24	6.94	6.64	6.34	6.04	5.64
Batiacasphaera spp	37	40	17	18	24	28	65	30	32	19	21	10	16	20	64
Exochoshaeridium bifidium	5	6	3	2	3	3	3	4	2		1	1	5	2	
Cometodinium spp	2	1	1		3			1					3		
Achosmophaera spp	21	12	5	6	15	6	12	5	10	2	6	3	2	1	4
Lejeunecysta spp	1	3	5	3	6	5	5	17	7	11	11	3	5	8	21
Inaperturopollenites spp	10	15	7	7	10	8	12	14	10	6	7	8	5	11	12
Monosulcites spp	8	18	6	9	4	27	16	8	10	20	16	18	17	19	21
Tricolpopollenites spp	24	22	7	49	7	17	26	4	11	164	42	25	19	45	48
Retitricolporites irregularis	3	11	3	2	3	7	3	5	2	7	5		3	2	4
Retitricolporites spp	5	18		5	3	14	19			9	12		3		7
Monocolpites spp	28	10	3	3	3	8	12			22	13	9	13		9
Retimonocolpites irregularis	2	3	2	3	3		4	6		12	6	7		4	5
Triorites spp	2	5	2	5	4	4	2		2	2	6				1
Tetrad spp	2	11	3	7	3	7	17	4	6		10	3		7	13
Verrucatosporites usmensus	8	32	12	4	11	14	11	10	14	17	12	8	8	6	5
Deltoidospora spp	2		1	1											
Hystrischopharidium sp	2													2	
cf. *Spinidium* spp	5														
Cordosphaeridium inodes		5	3	5	2	2	2	4	1	4				2	5
Tuberculodinium vancampoae		2	1	2		3	4		2	6				2	
Crototricolpites densus		4					5	3	5	4	4				1
Pachydermites diederixi		3	1	4	2		2	3	4						
Spirosyncolpites spiralis		2				6	5			6					12
Psilatricolporites operculatus		2				2					4		3		
Spore indet															
Glaphyrocysta spp				2											
Perfotricolpites digitatus				2					2		2				
Phelodinium spp					1			1	1						
Retibrevitricolpites triangularis						3				1					
Magnastriatites howardii							2		2			2		2	
Operculodinium spp										2					
Bombacacidites spp										2					
Tricolpites spp													2	3	
Acritarchs	32	3	5	2	6	25	12	4	11	4		5	6	5	3
Foraminiferal test inner linings	135	20	37	12	60	16	27	45	3	6	2	1		1	4

Figure 4. Relative frequency of main palynomorphs populations (spores, pollen grains and dinoflagellate cysts) recorded in the borehole P1 in Bingerville area.

Magnastriatites howardii, Spirosyncolpites spiralis, *Retimonocolpites irregularis, Retitricoporites irregularis, Pachydermites diederixii, Perfotricolpites digitatus* and *Psilatricolporites operculatus.* The taxa most representative of this assemblage are recorded in Figures 4 and 5 according to depth in each of two boreholes. The relative frequency of occurrence of these taxa in both borehols a P1 and P2 shows a broadly similar distribution (Figures 4 and 5):

1) *Batiacasphaera* spp including the species *Batiacasphaera* sp cf. *micropapillata* is the most abundant dinoflagellate cysts identified;
2) The whole species of *Lejeunecysta* spp. is present and relatively concentrated on the top wards; They are more frequent in P2.
3) *Cordosphaeridium inodes* is observable only in one sample at the base of P1 (sample 10.14 m);
4) *Retitricolporites irregularis* and *Retimonocolpites irregularis* broadly follow the same vertical pattern while *Psilatricolporites operculatus* is only visible in the upper two-thirds of the productive interval; They are very

DEPTH (M)	10.2	9.73	9.23	8.73	8.23	7.73	7.23	6.78	6.13	5.63
***Batiacasphaera* spp**	48	90	47	55	71	49	84	77	62	102
Exochoshaeridium bifidium	12	6	5	5	5	3	3	5	1	5
***Cometodinium* spp**	4		11	2	1			1		2
***Achosmophaera* spp**	9	14	15	7	9	6		4	9	4
Dino indet	6		7		1	2	2		1	5
Tuberculodinium vancampoae	14	15		6	2	3	4		2	5
Selenopemphix nephroides	3		11	2	3		2			
***Lejeunecysta* spp**	24	13	13	4	5	2	9	4	16	6
***Inaperturopollenites* spp**	6	11	6	12	15	7	10	12	16	19
***Monosulcites* spp**	20	10	5	10	15	15	17	35	14	12
***Monocolpites* spp**	4	6	2	1	3	2	3	5	2	2
***Tricolpopollenites* spp**	8	13	6	4	19	23	29	130	18	7
Retitricolporites irregularis	8	15	3	6	12	3	16	6	10	11
Retimonocolpites irregularis	10	3	4	2	5	3		11	4	3
Spirosyncolpites spiralis	8	12	4	3	5	5	2	2	8	3
***Triporites* spp**	3	5	4	2	9			8	3	2
Psilatricolporites operculatus	2	2	3	1	2	3	1	2		1
Tetrad	4	5	9	3	16		3	2		
Verrucatosporites usmensus	7	21	7	7	14	4	13	4	6	11
***Deltoidospora* spp**	12	34	11	17	24	9	16	12	7	22
***Polyadopollenites* spp**	1		2			2				
Spore indet	1	6	2							3
Perfotricolpites digitatus	3			2						
Retibretricolpites triangularis	1									
Magnastriatites howardii		5	3	5						
Pachydermites diederixi		7		5	3					
***Phelodinium* spp**			1	2				3		2
***Stephanocolporites* spp**				2			7	32	3	2
***Tricolpites* spp**								7		
Acritarchs	27	7	7	8	8	12	4	6	13	13
Foraminiferal test inner linings	174	24	187	71	138	22	77	117	52	164
STAGE	OLIGOCENE									

Figure 5. Relative frequency of main palynomorphs populations (spores, pollen grains and dinoflagellate cysts) identified in the borehole P2.

constant in both boreholes

5) The whole palynological assemblage is dominated by non-diagnostic taxa such as indeterminate forms *Inaperturopollenites* spp., *Monosulcites* spp., *Tricolpopollenites* and *Deltoidospora* spp. that are common to numerous throughout the interval.

The best preserved taxa of spores, pollen grains and dinoflagellate cysts are illustrated in Plates 1, 2 and 3. This assemblage of both boreholes, thought to be Oligocene age, contains also microforaminiferal inner test linings (planispiral and trochospiral shaped) and rare acritarchs.

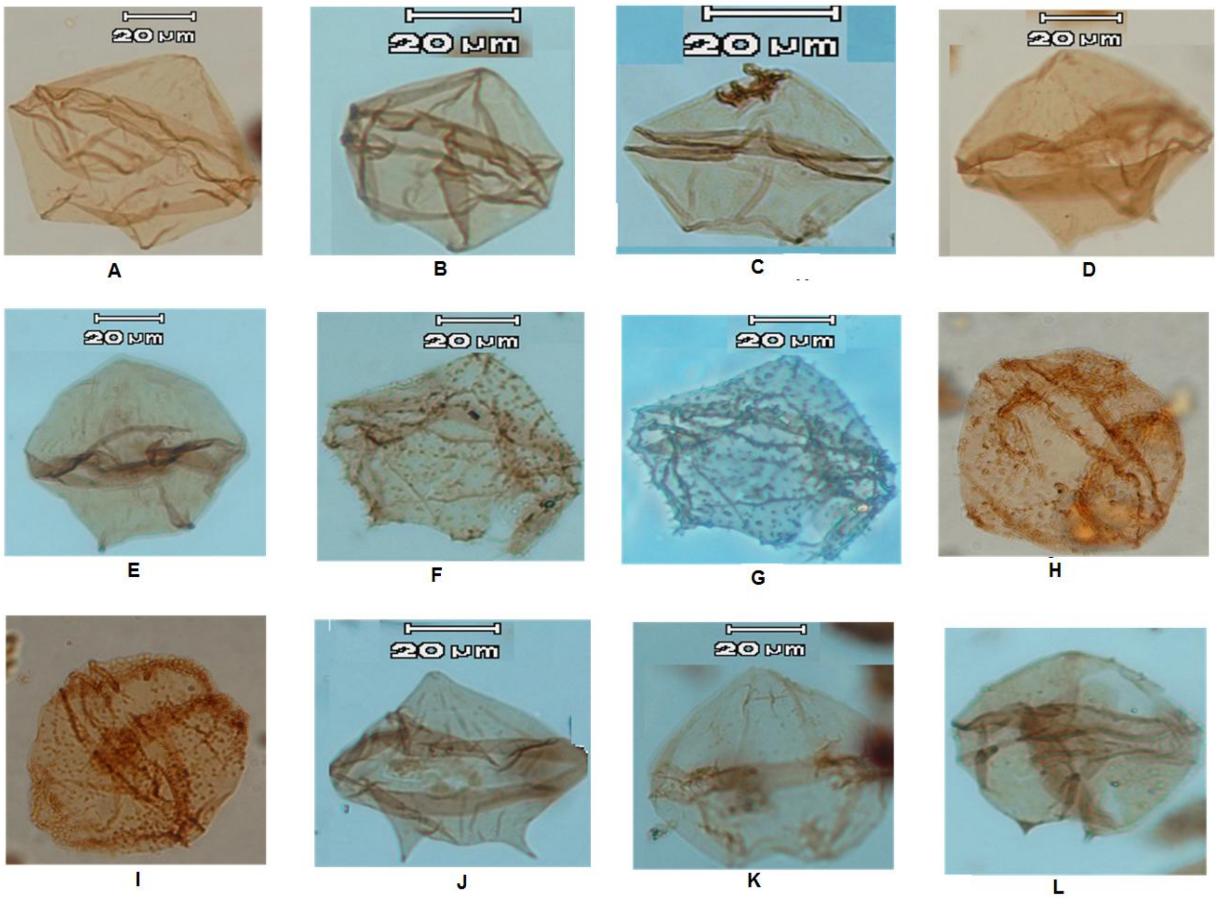

Plate 1. Assemblage of main dinoflagellate cysts described in the two shallow boreholes in Bingerville area. All dinocysts are ×1000. A. *Lejeunecysta lata*, M40/2; P2 (9.73 m). B. *Lejeunecysta lata*, D39/3; P1 (7.24 m). C. *Lejeunecysta lata*, S 34/4; P1 (7.24 m). D. *Lejeunecysta* sp.cf. *L. beninensis*. V 31/2, P2 (9.23 m). E. *Lejeunecysta* sp.cf. *L beninensis,* K 24/3, P2 (6.13 m). F. *Lejeunecysta* sp.cf. *L granosa*, R 44/4, P1 (7.24 m). G. *Lejeunecysta sp.*cf. *L granosa*, phase contraste, R 44/4, P1 (7.24 m). H. *Lejeunecysta* sp.cf. *L granosa*, O 37/1, P1 (10.14 m). I. *Lejeunecysta* sp.cf. *L granosa*, L 25/1, P1 (10.14 m). J. *Lejeunecysta pulchra*, V 44, P2 (6.13 m). K. *Lejeunecysta* sp.cf. *L globosa*, K 47/1, P1 (6.94 m). L. *Lejeunecysta sp.*cf. *L communis* × 1000, S 28/4, P2 (10.23 m).

Palynofacies and depositional environments

Quantitatively, 6498 palynomorphs were counted in the two boreholes P1 (3035) and P2 (3463). In P1 (Figure 6A), 1760 spores and pollen grains represent 58% and 1275 dinocysts, acritarchs and microforaminiferal inner test linings, 42%. Marine microplanktons varied in proportion with inner walls (29.3%), dinocysts (61%) and acritarchs (9.7%). In contrast, P2 (Figure 6B) shows spores and pollen grains representing 36%, whereas marine microorganisms (64%) are mainly represented by microforaminifers (48.8%), dinocysts (46%) and acritarchs (around 5.2%). Among the dinoflagellate cysts in productive intervals (Figure 7) the vertical distribution shows populations of proximates relatively well represented in regards to chlorates types even if they appear "sawtooth" shaped in P1 than in P2.

In both boreholes, the relatively high values of Proximate populations (*Batiacasphaera* spp, *Lejeunecysta* spp.) to the detriment of Chorate dinocyst (*Achomosphaeridium* sp., *Cometodinium* sp.) suggest shallow marine setting that could be attributed to estuarine-marginal marine environment. In the two boreholes two palynological sub-facies reflecting two distinct environments are distinguished (Figure 8).

In the sub-facies 1 (10.14 to 8.54 m) in P1, (10.23 to 8.73 m) in P2, fluctuation curves are "sawtooth" shaped reflecting more frequent neashore influence in marine marginal setting. - In sub-facies 2 (8.54 to 5.64 m) in P1 and (8.73 to 5.63 m) in P2, spores and pollen grains are dominant compared to marine microplankton in P1. This high percentage of terrestrial spores and pollen grains indicate a continental nearshore influence, also supported by the abundance of woody debris and epidermal tissues. In contrast, in P2, marine microplankton and terrerstrial populations are equivalent, suggesting marginal setting. Therefore, these two sub-facies suggest sedimentation operated in estuarine area

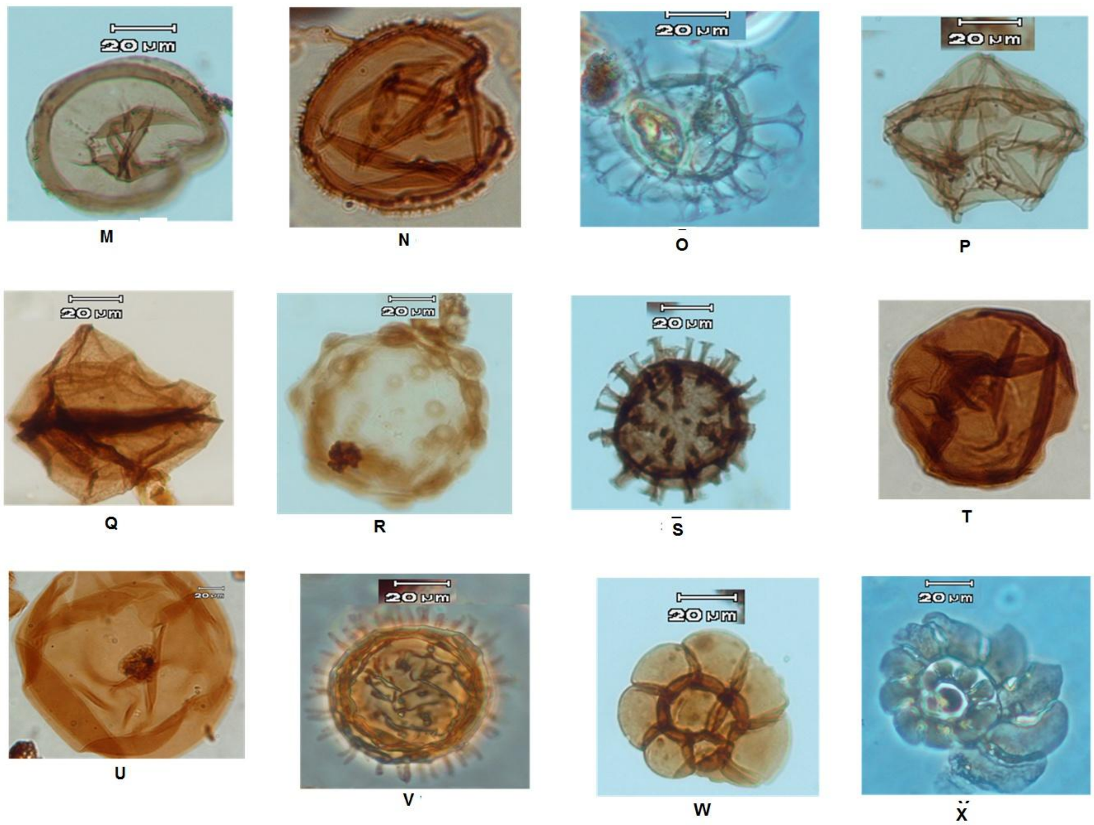

Plate 2. Assemblage of main dinoflagellate cysts described in the two shallow boreholes in Bingerville area (continued). All dinocysts are ×1000. M. *Selenopemphix nephroides*, E 44, P1 (8.14 m). N. *Selenopemphix* sp.cf. *S. coronata*, J 44/3, P2 (9.23 m). O. *Achomosphaera sp.* cf. *A. gabonensis*, J 32, P1 (10.14 m). P. *Pheolodinium africanum*, V 29/1, P2 (5.63 m). Q. *Phelodinium magnificum*, E 48/2, P1 (10.14 m). R. *Tuberculodinium vancampoae*, G 38/2, P2 (9.73 m). S. *Cordosphaeridium inodes*, V 46/1, P1 (10.14 m). T. *Batiacasphaera* sp. cf. *B. micropapillata*, E 33/4, P1 (8.54 m). U. *Batiacasphaera* sp. cf. *B. micropapillata*, K 38/4, P2 (6.78 m). V. *Exochosphaeridium bifidum*, J 26/1, P1 (10.14 m).W. Trochospiral microforaminiferal inner test linings, Natural light × 400, G 23/1, P1 (8.54 m). ×. Planispiral microforaminiferal inner test linings, Phase contraste ×400, N 33/3, P1 (8.14 m).

under a marine influence.

Attempt to botanical and paleoecological reconstruction

Some taxa identified in this work led to grouping of them according to several botanical affinities (Figures 9 and 10):

1) Thallophytes fairly represented (1%) by Hytrichosphaeridaceae *(Hystrichosphaeridium* sp., *Cordosphaeridium* sp.) are common in tropical forests near the coast (Selkirk, 1974) and increased humidity associated with high temperature;
2) Pteridophyts are abundant (56% in P1 and 67.75% in P2) with various botanical affinities as Parkeriaceae (*Magnastriatites howardii*), Cyatheaceae (*Deltoïdospora* spp.) and Polypodiaceae (*Verrucatosporites usmensis*). According to Salard, (1977), this association suggests a wet and marshy area whereas the palaeoclimate is considered to have been warm temperate and humid in accordance to works of Mai (1998).
3) Spermaphyts (43% in P1 and 32.25% in P2) associating monocotyledon Palms (*Retimonocolpites irregularis*), and dicotyledon Guttiferous (*Pachydermites diederixii*, *Psilastephanocolporites* sp.) as well as Leguminosae (*Spirosyncolpites spiralis*) indicate moist evergreen forests and swamp. In conclusion, many microorganisms of terrestrial origin in Bingerville area, are provided by coastal vegetation plants (mangrove and swamp forests) dominated by Cyathaaceae, Polypodiaceae and Palms; vegetation developed under tropical climates usually hot and humid.

DISCUSSION

Many works (Dybkjær, 2004; Hannah, 2006; Pross et al., 2009) use dinocyst data as an important tool for pointing

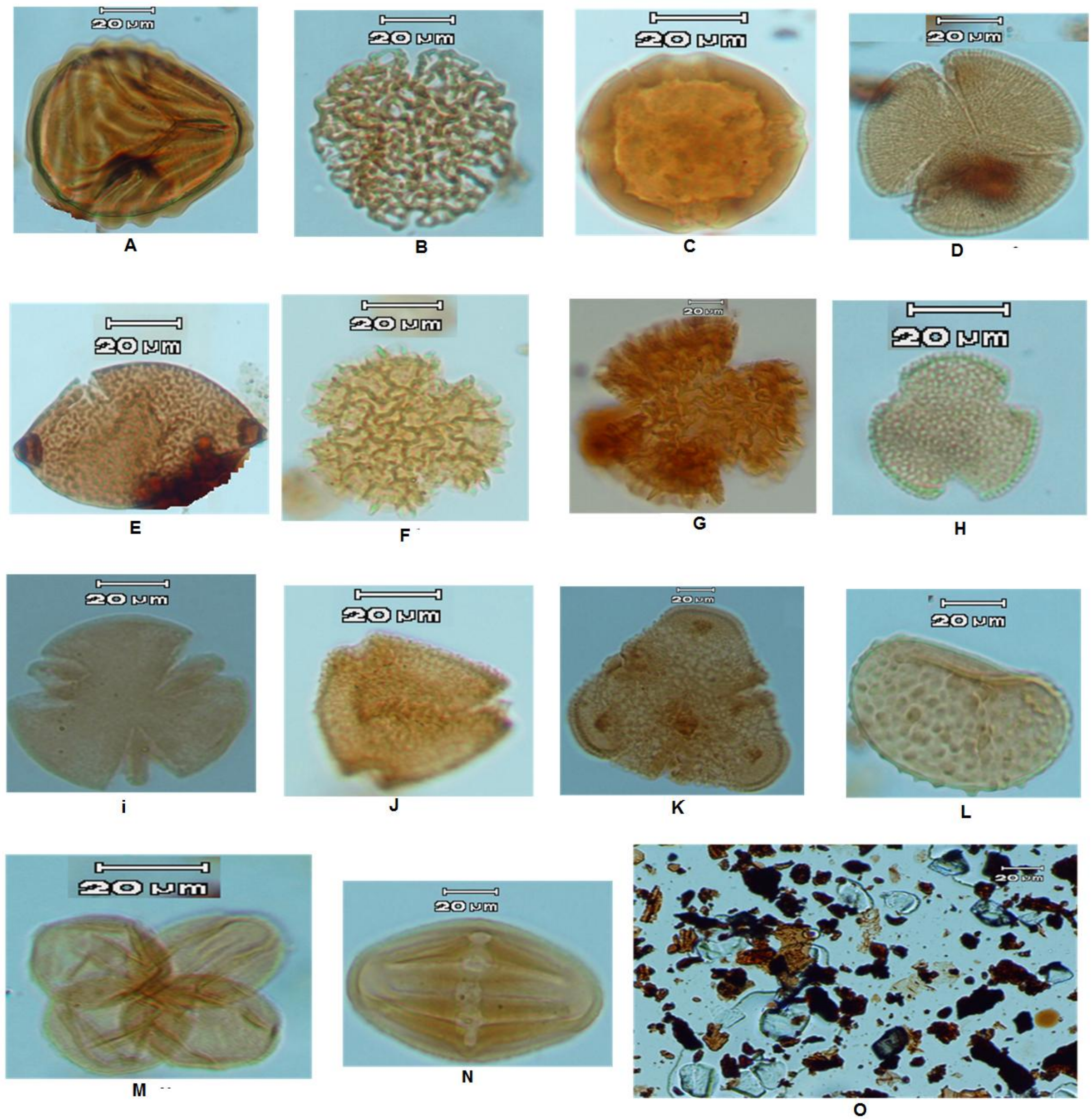

Plate 3. Main terrestrial spores and pollen grains recorded in the two shallow borehones in Bingerville area. All taxa are ×1000. A. *Magnastriatites howardii*, E33/3, P2 (9.73 m) .B. *Spirosyncolpites spiralis*, D 39/1, P1 (9.66 m). C. *Pachydermites diederixii,* W 18/3, P2 (9.73 m) . D. *Perfotricolpites digitatus* x1000, L 29/3, P1 (9.84 m). E. *Punctodiporites harrisii*, N 19/3 P1 (5.64 m). F. *Retitricolporites irregularis*, F 20/4, P1 (6.94 m). G. *Retitricolporites irregularis*, F 20/4, P1(6.94 m) H. *Crototricolpites densus*, T 46, P1 (7.24 m). I. *Psilatricolporites operculatus*, Q 47/4, P1 (8.14 m). J. *Retimonocolpites irregularis,* T 41, P1 (7.24 m). K. *Bombacacidites* sp. ×1000, F 24/1, P2 (7.73 m). L. *Verrucatosporites usmensis* , U 46/1, P1 (7.24 m). M. *Inaperturopollenites* in tetrad, U 33/4, P2 (9.73 m). N. *Polyadopollenites* sp., F 19/1, P1 (6.94 m). O. Palynological facies (organic matters) ×100. V 42/3, P1(9.24 m).

out stratigraphic sequences in boreholes, showing distinct changes at the sequence boundaries and increased relative abundance and diversity of dinocysts at marine flooding surfaces. These dinocysts are herein used for correlating between the two studied boreholes, for dating deposits, for interpreting changes in the depositional environment because eustatic sea-level changes are considered to be the main factor in sequence formation and changes in the depositional environment (Larson et al., 2010). Other works (Bruch and Mosbrugger, 2002; Hably et al., 2007; Akkiraz et al., 2011) document that stratigraphic intervals were also analyzed to reconstruct climate and vegetation based on independent or combined quantitative approaches when

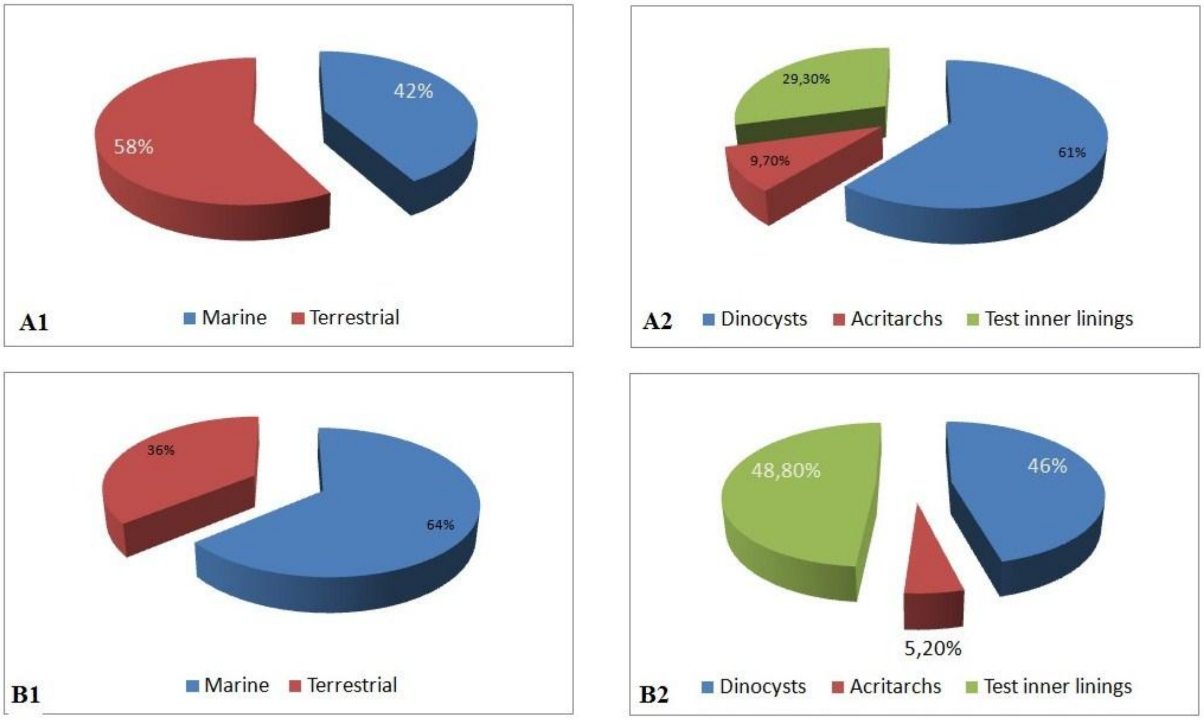

Figure 6. Sectorial distribution of palynomorphs in P1(A) and P2 (B) in Bingerville area.

applied on detailed palynological data. In ancient depositional environments (Oboh et al., 1998; Beraldi et al., 2006; Vincens et al., 2006), the diversity and abundance of palynomorphs being transported into, and preserved in the basin of deposition, are dependent on number of fundamental factors (climate, vegetation and sediment supply) as well as burial conditions. In this way, successive shifts in the composition of the dinoflagellate cyst assemblages are often interpreted in terms of sea-level and sea-surface temperature (SST) fluctuations (Brinkhuis, 1994).

It is true that all these general considerations are not applicable to this study performed in Bingerville area. But based on available data from this work, it is conceivable to discuss two fundamental aspects: (i) the validity of the local palynostratigraphic scale proposed and (ii) the paleobotanical and paleoecologic context of sedimentation in this part of the Ivorian terrestrial basin during Oligocene.

Validity of the local palynostratigraphical scale proposed

In general, almost species of *Lejeunecysta* (Lentin and Williams, 1985) including *Lejeunecysta. lata, L. pulchra, L. fallax, L.* cf. *granosa*, characterize Oligocene age, and most of these species were encountered in the present palynological residues. In other works (Salard, 1977; Duenas, 1980; Biffi and Grignani, 1983; Prebble et al., 2006) they are associated to terrestrial or other marine Oligocene indicator species (*Cicatricosisporites dorogensis, Verrutricolporites rotundiporus, Selenopemphix nephroïdes, Magnastriatites howardii*, *Cicatricosisporites dorogensis Punctodiporites harrisii* (although scarce in our study) , *Perfotricolpites digitatus*). In contrast, Salard-Cheboldaeff (1979) estimated that species *Pachydermites diederixii, Retitricolporites irregularis* and *Bombacacidites* sp. are Miocene age in Senegal, while *Verrutricolporites rotundiporis* marks this stage in kwa-kwa formations in Cameroon. This species is absent in residues studied, indicative therefore of a probable absence of Lower Miocene in Bingeville area. Moreover, according to works citez by Mao et al. (2004), *Cordosphaeridium inodes*, uncommon in Bingerville area (only five specimen are recorded in borehole P1, 10.14 m deep) is Oligocene age in Australia, Oligocene-middle Miocene or Eocene age in Germany. The absence of Fossil mimosoid pollen recorded in the Lower Oligocene of the Ebro Basin, northern Spain (Cavagnetto and Guinet, 1994) is indicative of the correlatively absence of Lower Oligocene in Bingerville area. Number of other works (Mao et al., 2004; Versteegh et al., 2007) mentions key species of Oligocene (*Enneadocysta pectiniformis; Cordosphaeridium gracile, Homotryblium tenuispinosum Thalassiphora pelagic*) that are unfortunately absent in the present works. According to Bujak (2009), *Tuberculodinium vancampoae* is mainly Miocene- top of Pleistocene age, *Lejeunecysta golobosa* of upper-middle Miocene age, *Selenopemphix nephroides* is base of

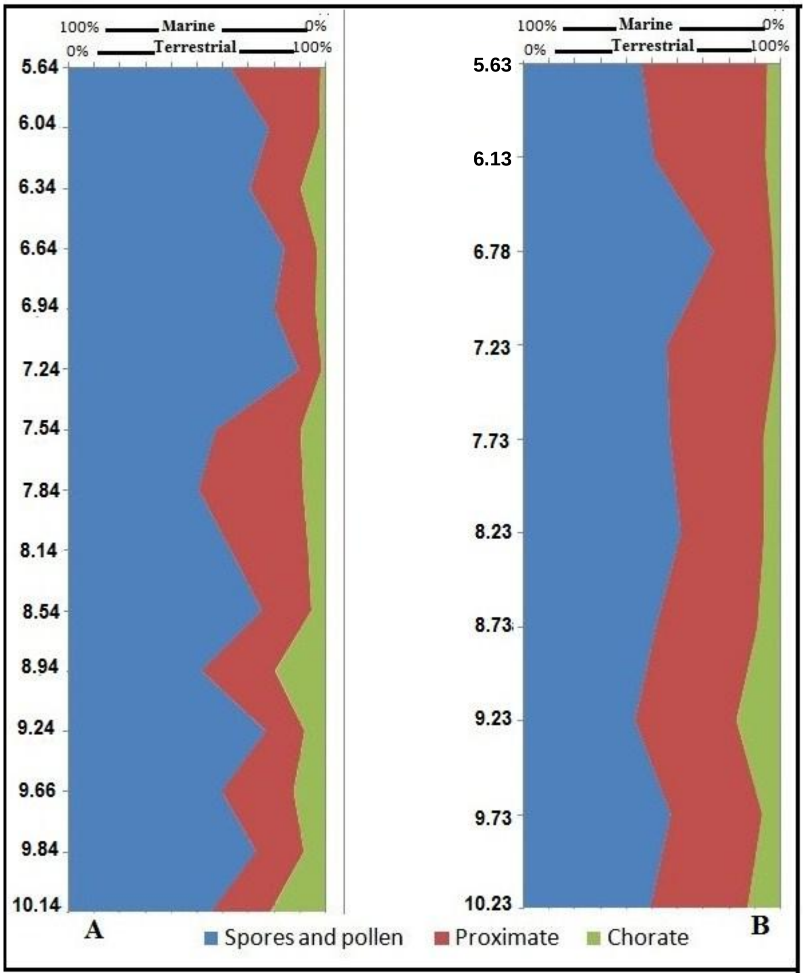

Figure 7. Vertical distribution of Proximate and Chorate Dinoflagellate cysts in the two boreholes P1 (A) and P2 (B) compared to terrestrial populations in Bingerville area.

Oligocene top of Pliocene age, *Lejeunecysta granosa* is Rupelian age and *Cordosphaeridium inodes* is assigned to Paleocene to Priabonian age. Some species of Oligcène assembage age defined in this work have a vertical extent varying according to latitude and basins. Thus, according Slimani et al. (2010), *Lejeunecysta globosa*, *Lejeunecysta communis* and *Cordosphaeridium inodes* as well as many of indeterminate forms *Glaphyrocysta* spp. are known in the top of the Maastrichtian at Ouled Haddou, southeastern Rif, Morocco. Similarly, species *Exocosphaeridium bifidum*, and *Phelodinium africanum* and *P. magnificum* are known from the base of the Danian. Moreover, many forms of indeterminated *Lejeunecysta* are recorded in the Miocene deposits on the continental margin of New Jersey, USA (Verteuil, 1996). For other palynomorphs, the FAD and LAD were established in the Llanos and Llanos basins in footshills Colombia (Jaramillo et al., 2005). Thus, *Selenopemphix nephroides* is between the FAD (17.83 Ma) and LAD (6.89 Ma), *Tuberculodinium vancampoae* (18.03 to 3.46 Ma), *Verrucatosporites usmensis* (36.57 to 0, 08 Ma), *Perfotricopites digitatus* (49.62 to 1.26 Ma), *Spirosyncolpites spiralis* (42.69 to 2.22 Ma) and *Retibrevitricolpites triangulatus* (51.28 to 32, 14 Ma). In shallow marine deposits of Kalmthout wells North of Belgium, Louwye and Laga (1998) showed a palynflora which most species were encountered in this study but dated of undifferentiated Neogene age. These species are *Tubeculodinium vancampoae, Selenopemphix nephroides, Selenopemphix coronata, Cordosphaeridium inodes*,, *Cordosphaeridium gracile*, *Batiacasphaera micropapillata, Adnasphaeridium multispinosum* and *Apectodinium homomorphum*.

In Deutschland, the compiled distribution of dinoflagellate cysts established by Kothe and Piesker (2007) indicates that *Selenopemphix nephroides* is comprised between Paleocene (D4na) and Eocene (DN2B), *Batiacasphaera micropapillata* and *Tuberculodnium vancampoae* were recorded in the interval late middle Eocene (D11), late middle Miocene

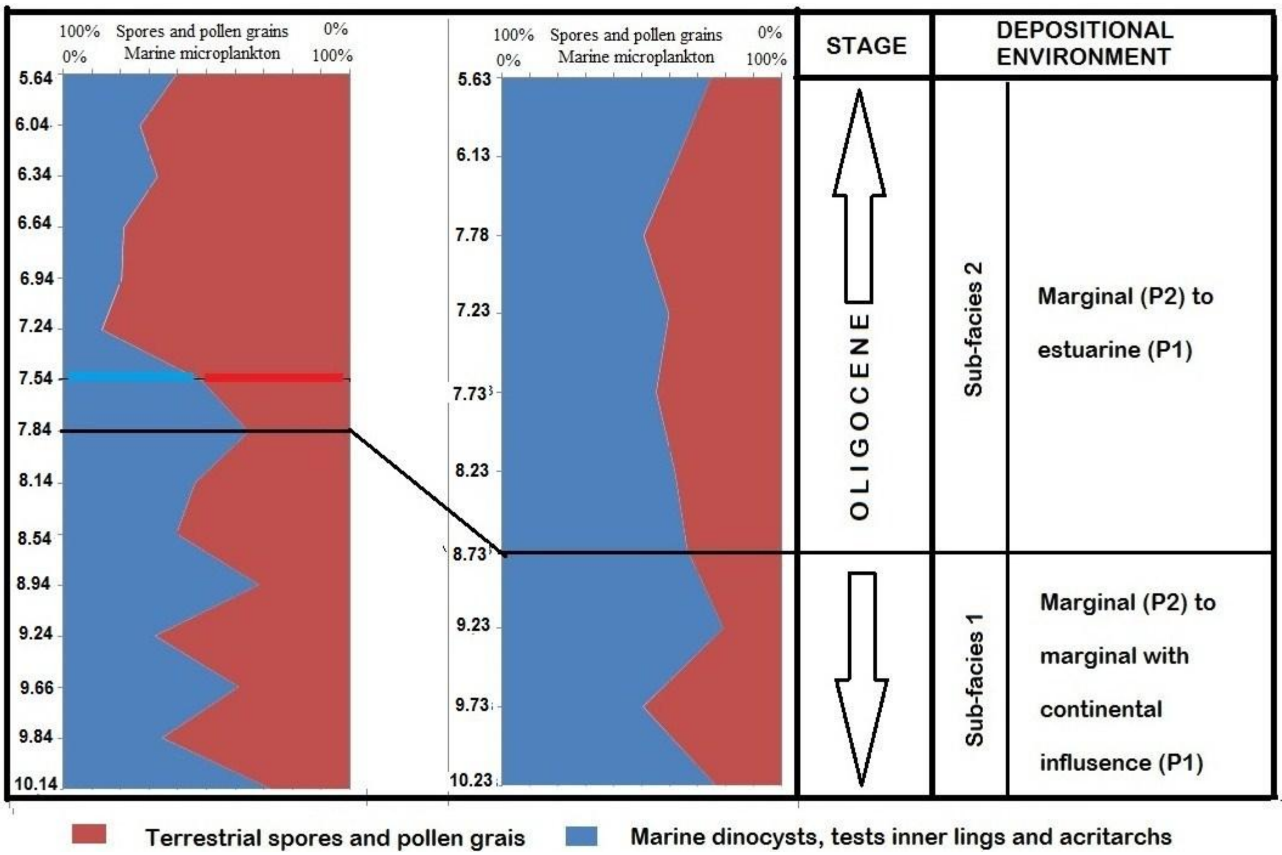

Figure 8. Vertical distributions of palynomorphs and depositional interpretation in the boreholes P1(A) and P2 (B) in Bingerville area.

(D19), *Cordosphaeridium inodes* observed in the indistinct Paleogene (D3na-D15) and *Phelodinium magnificum* (D3nb-D6). Pramparo and Papu (2006) have identified in Upper Maastrichtian age formations of Cerro Butalo, south of the province of Mendoza in Argentina, species such as *Lejeunecysta granosa* and *Phelodinium magnificum*. In addition, Costa and Downie (1979) described in the Rockall Plateau, the species *Cordosphaeridium inodes* and have dated Paleocene - top middle Eocene.

Despite some differences in palynological assemblages composition between west-central Africa coastal basins and the study area (Northern Gulf of Guinea), main stratigraphical species indicators of Oligocene occur in both regions. Therefore, the stratigraphic distribution of species identified in this work clearly confirms Oligocene age (Figures 4 and 5). The present palynological analysis substantially improves the understanding of the depositional history and processes within the Northern so-called “faille des lagunes” in Bingerville area.

Palaeocological and palaeobotanical contexts

Detailed investigations of biological affinities of some pollen grains revealed a number of plant fossils. Therefore, we conclude that the floral diversity and ecological characteristics of the pollen taxa identified indicated that Oligocene vegetation in Bingerville area was characterized by a complex mangrove swamp reflecting warm climatic conditions in accordance to works of Cavagnetto and Anadón (1996). Furthermore, in many regions, evidences of temperature increase were established at the end of the Oligocene or at the beginning of the Miocene, more precisely during the Aquitanian (Sittler, 1967). According to Germeraad et al. (1968), one of the most important aspects of nearly twenty years of intensive study of the pollen-and-spore content of tertiary sediments in some parts of tropical South America, Africa and Asia, is their statistically achieved uniformity. This is demonstrated by a larger number of marker species which occurred notably in both the South American and west African regions, tropical today (transatlantic distribution). More later, this uniformity continued to be observed. Indeed, works of Servant et al. (1993) showed that late Quaternary pollen assemblages from three lacustrine cores (West Cameroon, southeastern Amazonia and central Brazil) are correlated, by the radiocarbon chronology, with other palaeoenvironmental records in Africa and South

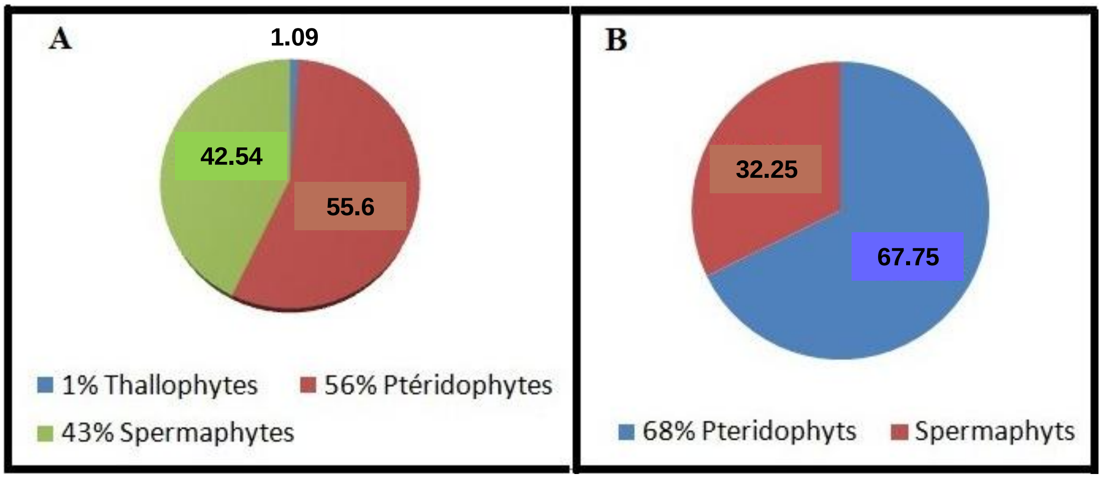

Figure 9. Sectorial distributions of various botanical affinities identified within the boreholes P1 and P2 in Bingerville area.

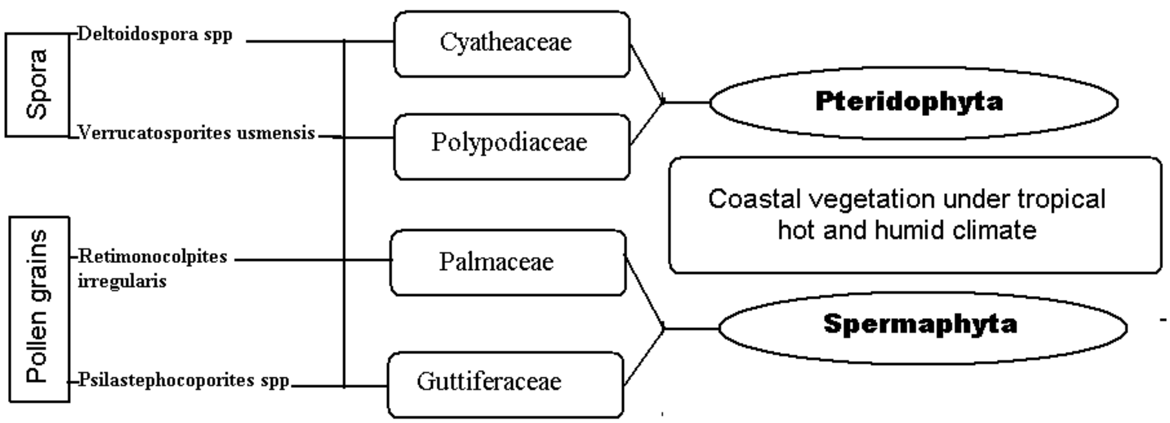

Figure 10. Botanical affinities of palynomorphs deducted form the palynological studies of boreholes P1 and P2 in Bingerville area.

America, with a well-developed dense forest observed in both continents at this time.

Conclusions

The following conclusions may be drawn from the results of the present study:

1) The palynological analysis of gray clays that underlies the barren Mio-Pliocene variegated clays in Bingerville area, reveals a palynoflora relatively rich, well preserved. Marine Dinoflagellate cysts assemblage recorded is dominated by species *Lejeunecysta pulchra L. lata, L. fallax, L.* cf. *granosa* associated to *Selenopemphix nephroïdes, Tuberculodinium vancampoae, Batiacasphaera sp.* cf. *Batiacasphaera micropapillata* and *Cordosphaeridium inodes*. Terrestrial spores and pollen are associated to this assemblage namely *Magnastriatites howardii, Spirosyncolpites spiralis Perfotricolpites digitatus, Pachydermites Diederixii, Bombacacidites* sp., *Punctodiporites harrisii, Retitricolporites irregularis, Retimonocolpites irregularis etc*.. This assemblage is particularly very similar to that described in Nigeria, which characterizes Oligocene age;

2) Detailed facies within the sections show a sedimentation realized on marginal marine areas with frequent continental influence.

3) Terrestrial spores and pollen imply botanical affinities as plants of a coastal vegetation (mangrove and swamp forests). This vegetation with dominant Cyatheacea, Polypodiaceae and Palms, generally develops under hot and humid tropical climate conditions.

4) These new results complement the previous local palynostratigraphic scale and confirm the presence of Oligocene in north of the so-called “Faille des lagunes” within the terrestrial sedimentary basin of Côte d'Ivoire.

List of the main recorded taxa

Dinoflagellate cysts

Achomosphaera sp.cf. *A*. *ramulifera gabonensis*. (Boltenhagen, 1977) Lentin and Williams, 1981
Batiacasphaera sp. cf. *B. micropapillata* (Stover, 1977)
Cometodinium sp.
Cordosphaeridium inodes (Klumpp, 1953) Eisenack, 1963, emend. Sarjeant, 1981.
Dino indet.
Exochosphaeridium bifidum (Clarke and Verdier, 1967) Clarke et al., 1968).
Glaphyrocysta spp.
Hystrichosphaeridium spp.
Lejeunecysta sp. cf. *L. beninensis* (Biffi and Grignani, 1983)
Lejeunecysta sp. cf. *L.communis* (Biffi and Grignani, 1983)
*Lejeunecysta globosa (*Biffi and Grignani, 1983)
Lejeunecysta sp. *cf. L. granosa* (Biffi and Grignani, 1983).
Lejeunecysta lata (Biffi & Grignani, 1983).
Lejeunecysta sp. cf. *L. pulchra* (Biffi and Grignani, 1983).
Lejeunecysta spp.
Operculodinium sp.
Phelodinium sp. cf. *L. africanum* (Biffi and Grignani, 1983).
Phelodinium magnificum (Stanley, 1965) Stover and Evitt 1978
Selenopemphix nephroides (Benedek, 1972) Bujak et al., 1980.
*Selenopemphix coronata (*Bujak in Bujak et al. 1980)
Spinidinium spp.
Tuberculodinium vancampoae (Rossignol, 1962) Wall, 1967.

Spores and pollen grains

Bombacacidites spp.
Crototricolpites densus (Salard-Cheboldaeff, 1978).
Deltoïdospora spp.
Monocolpites spp
Inaperturupollenites sp.
Magnastriatites howardii (Germeraad et al., 1968).
Monosulcites sp.
Pachydermites diederixi (Germeraad et al., 1968).
Perfotricolpites digitatus (Gonzalez, 1967)
Polyadopollenites spp.
Psilatricolporites operculatus, (Van der Hammen and Wijmstra, 1964).
Psilatricolporites sp.
Punctodiporites harrisii (C.P. Varma and Rawat, 1963).
Retibrevitricolpites triangulatus (Van Hoeken-Klinkenberg, 1966)
Retimonocolpites irregularis (Salard-Cheboldaeff, 1978).
Retitricoporites irregularis (Van der Hammen and Wijmstra, 1964).
Spirosyncolpites spiralis (Gonzalez, 1967)
Spore indet
Stephanocolpites spp.
Tetrad indet
Tricolpites spp.
Tricolporopollenites spp.
Triorites spp.
Verrucatosporites usmensis (Van der Hammen) Germeraad et al., 1968.

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