Asian Journal of Geological Research

2(2): 1-15, 2019; Article no.AJOGER.50644

Palynological and Paleoecological Characterization of Upper Eocene-lower Miocene Deposits of the Southeastern Part of the Onshore Sedimentary Basin of Côte d'Ivoire (West Africa)

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Authors' contributions

This work was carried out in collaboration among all authors. Author GJMK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors BGR and DE managed the analyses of the study. Authors YNJP and DZB managed the literature searches. All authors read and approved the final manuscript.

Article Information

Editor(s):
(1) Dr. Mohamed M. El Nady, Exploration Department, Egyptian Petroleum Research Institute, Nasr City, Cairo, Egypt.
Reviewers:
(1) Luzia Antonioli, University of the State of Rio de Janeiro, Brazil.
(2) Jasenka Sremac, University of Zagreb, Croatia.
Complete Peer review History: http://www.sdiarticle3.com/review-history/50644

Original Research Article

Received 13 June 2019
Accepted 19 August 2019
Published 26 August 2019

ABSTRACT

Sedimentary rocks cuttings from two boreholes in Bingerville and Assinie (Côte d'Ivoire) were the subject of this study.
Sands and clays were collected from the Bingerville well and sands, green clays and limestones from the Assinie well.
The main objective of this work is to make an inventory of the plant species that existed at the time of the deposition of sediments on both sides of the lagoon fault based on palynomorph fossils.
Paleovegetation consisted of freshwater species such as (determined spores *Verrucatosporites usmensis, Laevigatosporites ovatus, Polypodiaceiosporites regularis,* and *Deltoidospora delicata*),

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which thrieved in a coastal wetland environment under a tropical climate with alternating warm and humid periods. Palynostratigraphic analyzses point to the age of the Upper Eocene and the Lower Miocene for the studied samples.

Keywords: Palynomorphs; paleovegetation; miocene; eocene; Bingerville: Assinie.

1. INTRODUCTION

The basin of Côte d'Ivoire in which this study is located, is part of a large set of coastal basins bordering the west Atlantic coast from southern Morocco to beyond Angola [1].

Cenozoic deposits, contain glauconites and remains of marine organisms, evidence of a transgressive sea, along with pollen grains and spores derived from the land.

Palynological studies on the ivorian sedimentary basin began in 1960 with the work of [2], devoted to the Cretaceous deposits.

Several other authors contributed to the palynolostratigraphical study of the ivorian basin, sometimes on Paleogene and Neogene deposits [3,4,5,6], sometimes Cretaceous [7,8].

Many unpublished dissertation studies (DEA) dissertations have also provided data on the biostratigraphy of Paleogene and Neogene age deposits [9,10,11] and upper Cretaceous age [12,13,14].

The present study was undertaken to date the formations of these two wells made in the Ivorian onshore basin on both sides of the Lagoons fault in order to contribute to the paleobotanic reconstruction of the region which remains enigmatic.

2. PRESENTATION OF THE STUDY AREA

The study area (Fig. 1) is located southeast of the Ivorian sedimentary basin on both sides of the lagoon fault. Two wells made at Bingerville (P1) and Assinie (P2), the geographical coordinates and depths of which are given in Table 1 are concerned to this study.

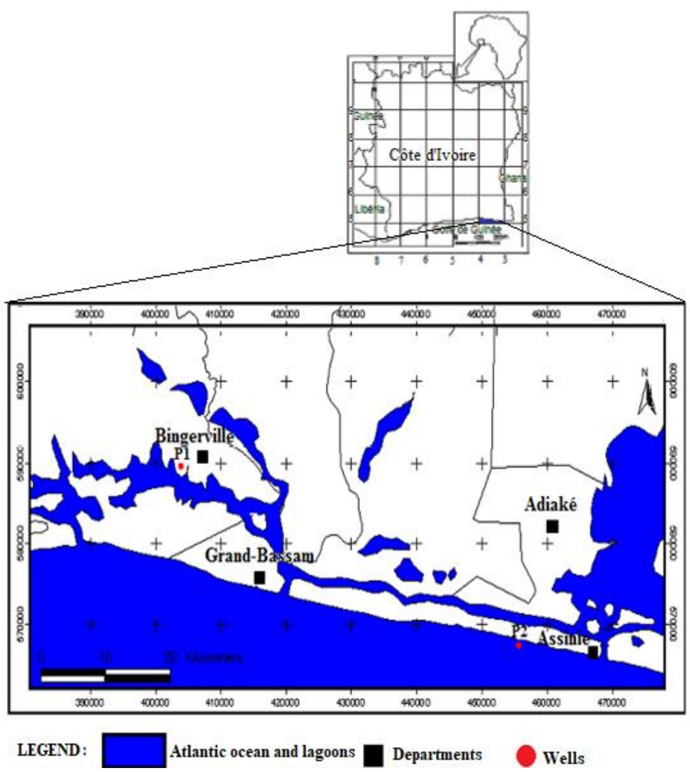

Fig. 1. Location of wells

Table 1. Coordinates of the wells

Site	Location	Longitude (w)	Latitude (N)	Depth in meter
Bingerville	P1	03° 52' 53,8''	05° 20' 06,8''	120
Assinie	P2	03° 24' 02,3''	05° 08' 54,8''	180

The geological history of the sedimentary basin of Côte d'Ivoire is linked to the opening of the South Atlantic, the consequence of which is the dislocation of Gondwana, which intimately united South America and Africa. This story recently recalled by [15] indicates that this basin is characterized by two distinct domains.

a) Continental domain or onshore basin area affected by a major "lagoon fault" along the coast from west to east. This accident has a vertical discharge of several thousand meters (4000 - 5000 m).
b) A marine domain or offshore basin known only through oil drilling. This offshore basin is subdivided into two margins including the margin of Abidjan and that of San-Pedro.

3. MATERIALS AND METHODS

The studied materials consisted of twenty-five (25) cuttings from two water wells located at Bingerville (10 samples) and Assinie (15 samples). Each sample was palynologically prepared as practiced in paleobotany laboratories [3].

Procedure consists of destroying all the mineral phases of the sediment with strong acids (30% HCl and 70% HF) and preserving the organic phase generally consisting of sporopollinic materials.

A final attack with nitric acid (HNO3) 68% cold in order to clear the palynological material and organic matter content. After this last attack, the residue is sieved on a 10 µm single-use cloth and then the sporopollenic residue obtained is mounted between the blade and the coverslip using a special resin.

Using a biological microscope, observations are made to identify the palynomorphs contained in the slides. These palynomorphs made it possible to date the formations studied and to characterize the paleoenvironment of the region. Paleobotanical analysis is based on the ecological importance and different botanical affinities of the determinated sporomorphs.

4. RESULTS

4.1 Lithological Analysis of the Wells

4.1.1 Lithology of the Bingerville well

The lithology of cuttings from the well (P1) located in Bingerville shows from the bottom tot he top: coarse white sand (120 – 97 m); sandy variegated clays (97 – 92 m); coarse sands (92 - 86 m); compact variegated clays and dark clays (86-44 m); reddish-brown sands (44 - 39 m) testifying to a strong presence of ferric oxide; very compacted dark clays (39 -25 m) and yellow-orange laterite clays (25-2 m) (Fig. 2).

4.1.2 Lithology of the Assinie well

The lithological analysis of the cuttings of the Assinie well (P2) shows from older to younger horizons: Glauconitic limestones of greenish-gray color with shell debris (180-164 m); intensively green clays, rich in glauconites (164 - 65 m), sandy clays (65-47 m); coarse orange-yellow sands, with rare shelly debris (47 - 23 m); medium to fine grained shellfish sands, of a light yellow color rich in bivalve debris (23 - 2 m) (Fig. 3).

4.2 Qualitative and Quantitative Analysis of Palynomorpha from the P1 and P2 Wells

The palynomorphs of the well P1 are composed mainly of spores and pollen grains (85%) and scarce dinocysts (15%). The state of conservation of these palynomorphs is excellent.

The palynological material of the well P2 is composed of spores and pollen grains (73%) as well as dinocysts (27%). This quantitative study has made it possible to observe many fossil palynomorphs, some of which are of stratigraphic interest.

4.3 Palynostratigraphy

Well P1

Palynological analysis of the Bingerville well (P1) revealed two stages, defined by associations composed mainly of spores and pollen grains and rare dinocysts (Fig. 4).

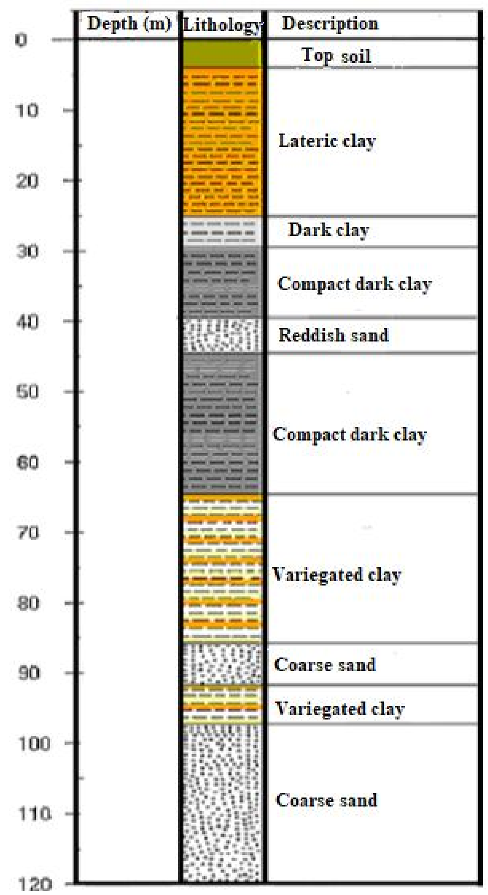

Fig. 2. Schematic lithological column of the P1 well (after [16])

The upper horizon ranges from 25 m to 51 m and is characterized by the following spores and pollen grains: *Cupressacites hiatipites, Laevigatosporites ovatus, Polyadopollenites microreticulatus, Psilatricolporites laevigatus, Striatopollis catatumbus, Retitricolporites irregularis, Verrucatosporites usmensis, Retitriporites* sp. and *Monocolpopollenites* sp.

The lower horizon ranges from 51 m to 120 m is marked by species of spores and pollen grains such as: *Psilatricolporites crassus, Verrustephanocolporites complanatus, Retitricolporites irregularis, Verrucatosporites usmensis, Retimonocolpites irregularis.* These spores and pollen grains are associated with the following dinocysts: *Selenopemphix quanta, Batiacasphaera* sp., *Spiniferites ramosus* and *Cleistosphaeridium flexuosum.*

Well P2

Palynological analysis of the P2 well also highlighted two stages as well (Fig. 5).

The upper horizon range from 47 to 85 m is revealed by the palynological association composed of spores and pollen grains such as *Laevigatosporites ovatus, Leiotriletes adriennis, Polypodiaceoisporites regularis, Polypodiisporites speciosus, Cingulatisporites* sp.

The lower horizon extends from 85 to 180 m and is marked by spores and pollen grains such as *Pachydermites diederixii, Retitricolporites irregularis, Spinizonocolpites echinatus,, Cicatricosporites dorogensis, Margotricolporites rauvolfii, Verrucatosporites usmensis.* To these spores and grains of pollen are associated dinocysts such as *Cometodinium obscurum, Spiniferites ramosus, Operculodinium centrocarpum, Batiacasphaera* sp., *Cordosphaeridium inodes, Isabelidium* sp. and *Lingulodinium machaerophorum*.

4.4 Paleobotanical Characterization

The paleobotanical study of these two wells shows the presence of pollen grains from the

Arecaceae (*Retitricolporites irregularis, Monocolpopollenites* sp.), Fabaceae (*Striatopollis catatumbus*), Schizeaceae (*Inaperturopollenites* sp.), Pelliceria (*Psilatricolporites crassus),* Nypa (*Spinizonocolpites echinatus, Retimonocolpites irregularis*), Apocynaceae (*Margotricolporites rauvolfii, Brevitricolporites molinae*). These pollen grains are associated with spores of Polypodiaceae (*Laevigatosporites ovatus, Verrucatosporites usmensis, Polypodiaceiosporites regularis*), Schizeaceae (*Cicatricososporites dorogensis, Leiotriletes adriennis*), to Cyatheaceae (*Deltoidospora delicata*) and to Lygodium (*Crassoretitriletes vanraadshooveni*).

Palynoflora consists of angiosperm pollen grains typical for tropical rainforests and coastal swamps (*Pachidermites diederixii, Retitricolporites irregularis* and *Striatapollis catatumbus*), ancestors of the present-day palm trees of the genus Nypa (*Spinizonocolpites echinatus, Retimonocolpites irregularis*), fern spores basically hygrophilous freshwaters that develop in moist, swampy areas (*Laevigatosporites ovatus, Verrucatosporites usmensis, Polypodiaceiosporites regularis*).

This palynoflora indicates a tropical paleoclimate with alternating warm and humid periods. The association of coastal marine ecosystems (*Cordosphaeridium inodes, Spiniferites ramosus*) with this paleovegetation indicates a coastal marine ecosystem in this area.

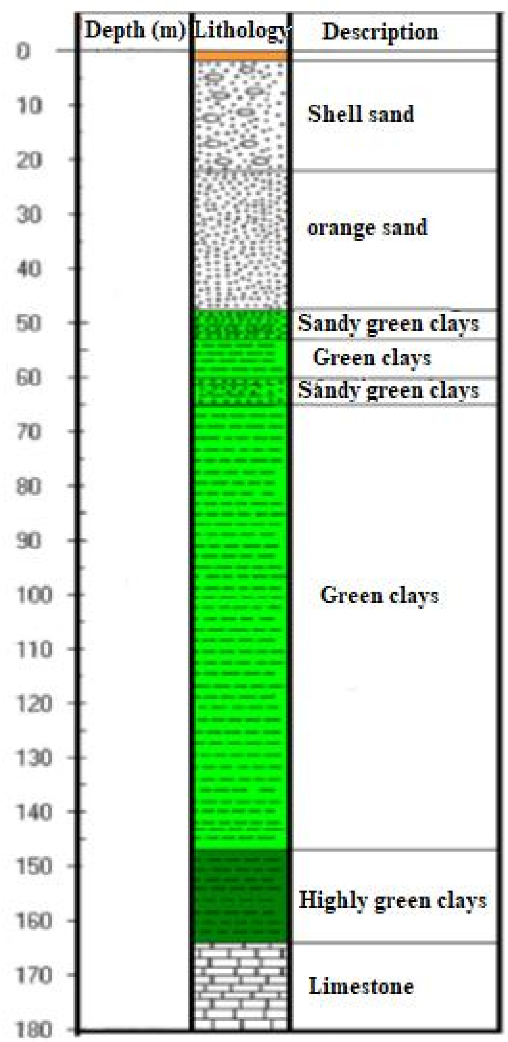

Fig. 3. Schematic lithological column of the P2 well (after [16])

Table 2. Palynomorph count sheet for the well P1

DEPTH IN METER	TOTAL DINOCYSTS	TOTAL SPORE AND POLLEN	DINOCYSTS					SPORE AND POLLEN GRAIN														
			Batiacasphaera sp.	*Lingulodinium machaerophorum*	*Selenopemphix quanta*	*Operculodinium centrocarpum*		*Cupressacites hiatipites*	*Verrucatosporites usmensis*	*Retitricolporites irregularis*	*Polyadopollenites microreticulatus*	*Striatopollis catatumbus*	*Retitriporites* sp.	*Psilatricolporites crassus*	*Verrustephanocolporites complanatus*	*Psilatricolporites laevigatus*	*Monocolpopollenites* sp.	*Inaperturopollenites* sp.	*Magnaperiporites spinosus*	*Monosulcites* sp.	*Retimonocolpites irregularis*	*Laevigatosporites ovatus*
30		15						2	6	1	1		1			2	1					1
34		12						1	3	2	2		1			1	1					1
42		23							13	1	2	1	2			1	1					2
47	1	17			1				5	1	1	3	3			1	2					1
53	2	20			2				6	2			2	2	1	3	2	1				1
59	1	16			1				3	2			1	1	2	1	2	1				3
64	4	16	2		2				4	3			1	1	1	1	1	1	1			2
70	6	20	5		1				2	3			3	2	1	1	2	2	2			2
75	7	18	3	1	3				3	1			1	2	1	2	1	2	1	1	1	2
94	11	23	6	1	2	2			4	1			4	1	3	2	1	1	2	1	1	2
TOTALS			16	2	12	2		3	49	17	6	4	19	9	9	15	14	8	6	2	2	17

Table 3. Palynomorph Count Sheet for the well P2

DEPTH IN METER	TOTAL DINOCYSTS	TOTAL SPORE AND POLLEN	DINOCYSTS								SPORE AND POLLEN GRAIN																
			Batiacasphaera sp.	*Spiniferites ramosus*	*Cordosphaeridium inodes*	*Cometodinium obscurum*	*Operculodinium centrocarpum*	*Isbelidium* sp.	*Lingulodinium machaerophorum*		*Brevicolporites molinae*	*Laevigatosporites ovatus*	*Margocolporites rauwolfii*	*Deltoidospora delicata*	*Cingulatisporites* sp.	*Tricolpites* sp.	*Leiotriletes adriennis*	*Baculatisporites* sp.	*Retitriporites* sp.	*Verrucatosporites usmensis*	*Pachydermites diederixii*	*Retitricolporites irregularis*	*Spinizonocolpites echinatus*	*Cicatricosisporites dorogensis*	*Polypodiaceoisporites regularis*	*Momipites* sp.	*Retitricolporites* sp.
52		13									1		1		2		1	1	1	5					1		
60		12									1		2		1		1	1	2	1					3		
64		20									2	2	3		1		2	3	2	4					1		
71	2	22	2								2	3	2		1		1	3	1	8					1		
76	1	14	1								1	1	1		1		1	2	3	3					1		
82	1	13	1								1	2	1		1		1	2	1	2					2		
94	8	12	1	1	2	1	1	1	1			1	1			1		2		1	2	1	1	1	1		
103	9	17	2	1	1	1	2	1	1			1	2			1		1		4	1	2	2	1	2		
112	8	17	1	2	1	1	1	1	1			3	3			1		1		2	1	1	1	2	2		
121	10	20	1	1	2	2	1	2	1			1	2	2		3		1		3	1	2	2	1	1		1
130	12	25	2	3	1	2	2	1	1			2	1	1		1		1		11	1	1	2	1	1	1	1
139	11	18	1	1	1	3	3	1	1			1	1	1		1		2		5	1	1		1	2	1	1
144	11	16	1	1	1	2	2	2	2			2	3	2		1		1		1	1	1		1	1	1	1
152	12	17	2	3	2	2	1	1	1				1	2		2		2		2	1	1		1	2		3
165	7	15		2	1	1	1	1	1				4	1		2		1		2	1	2		1			1
TOTALS			15	15	12	15	14	11	10		8	19	26	9	7	13	10	24	10	54	10	12	8	10	21	3	8

5. DISCUSSION

5.1 Palynostratigraphy

Palynological analysis revealed lower Miocene and Upper Eocene age of the studied samples. Lower Miocene age has been identified through associations of *Cupressacites hiatipites, Laevigatosporites ovatus, Polyadopollenites microreticulatus, Psilatricolporites laevigatus, Striatopollis catatumbus, Retitricolporites irregularis, Verrucatosporites usmensis, Leiotriletes adriennis, Polypodiaceoisporites regularis, Retitriporites* sp.

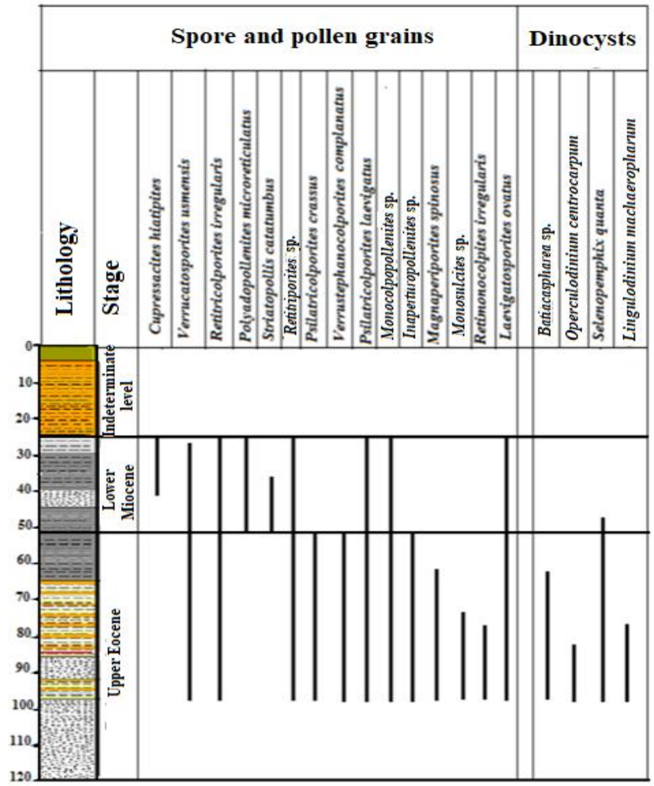

Fig. 4. Vertical distribution of the main Bingerville palynomorphs (P1)

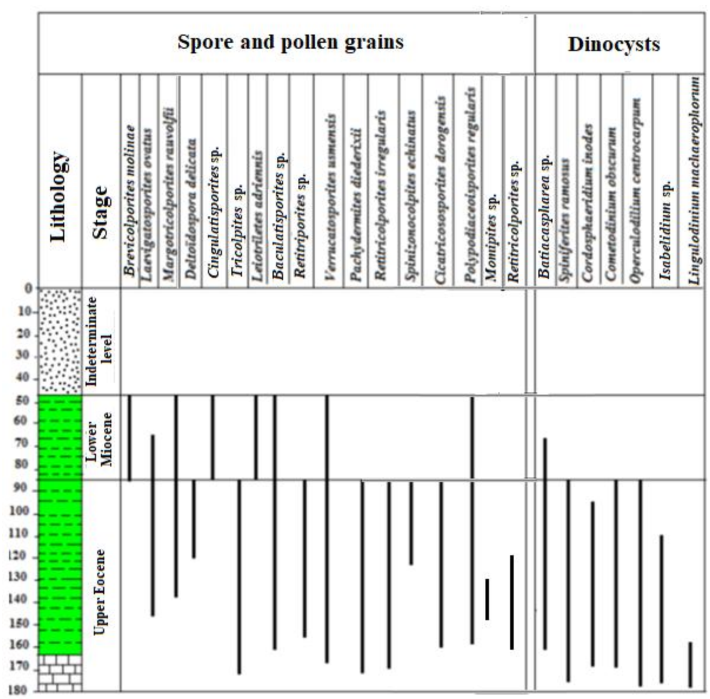

Fig. 5. Vertical distribution of the main Assinie palynomorphs (P2)

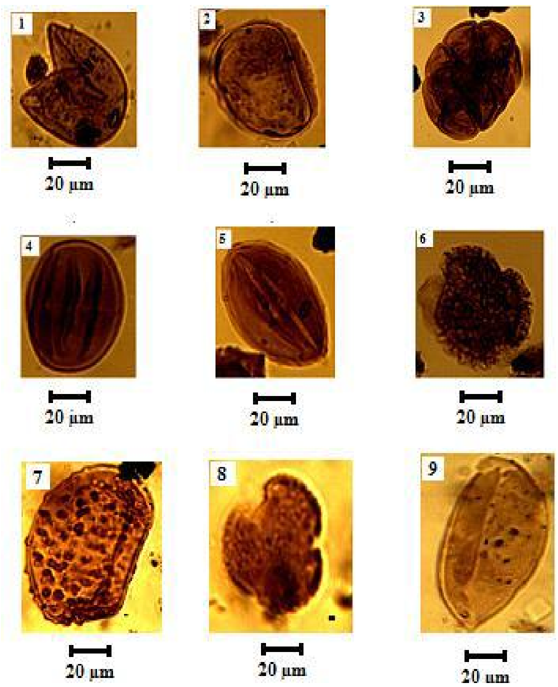

Fig. 6. Spores and pollen grains from the Lower Miocene of Bingerville (from [4])

1. Cupressacites hiatipites; 2. Laevigatosporites ovatus; 3. Polyadopollenites microreticulatus; 4. Psilatricolporites laevigatus; 5. Striatopollis catatumbus; 6. Retitricolporites irregularis; 7. Verrucatosporites usmensis; 8. Retitriporites sp.; 9. Monocolpolleniites sp.

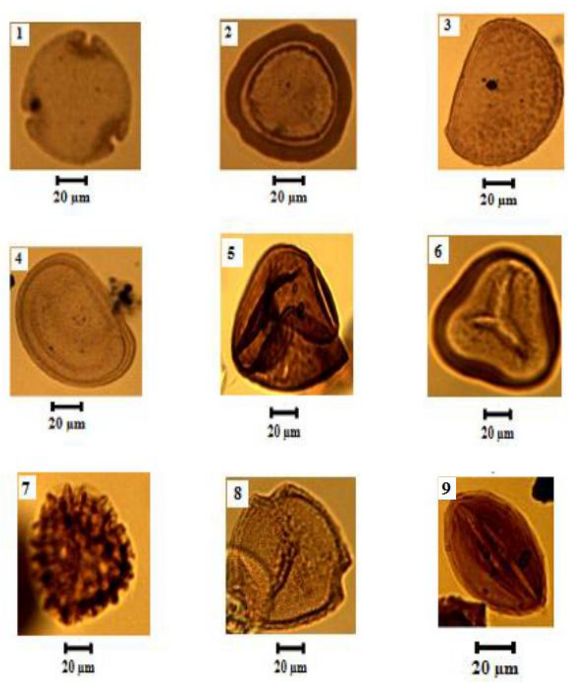

Fig. 7. Spores and pollen grains from the Lower Miocene of Assinie (from [4])

1. Brevicolporites molinae; 2. Cingulatisporites sp.; 3. Verrucatosporites usmensis; 4. Laevigatosporites ovatus; 5. Leiotriletes adriennis; 6. Polypodiaceoisporites regularis; 7. Baculatisporites sp.; 8. Margotricolporites rauvolfii; 9. Striatopollis catatumbus

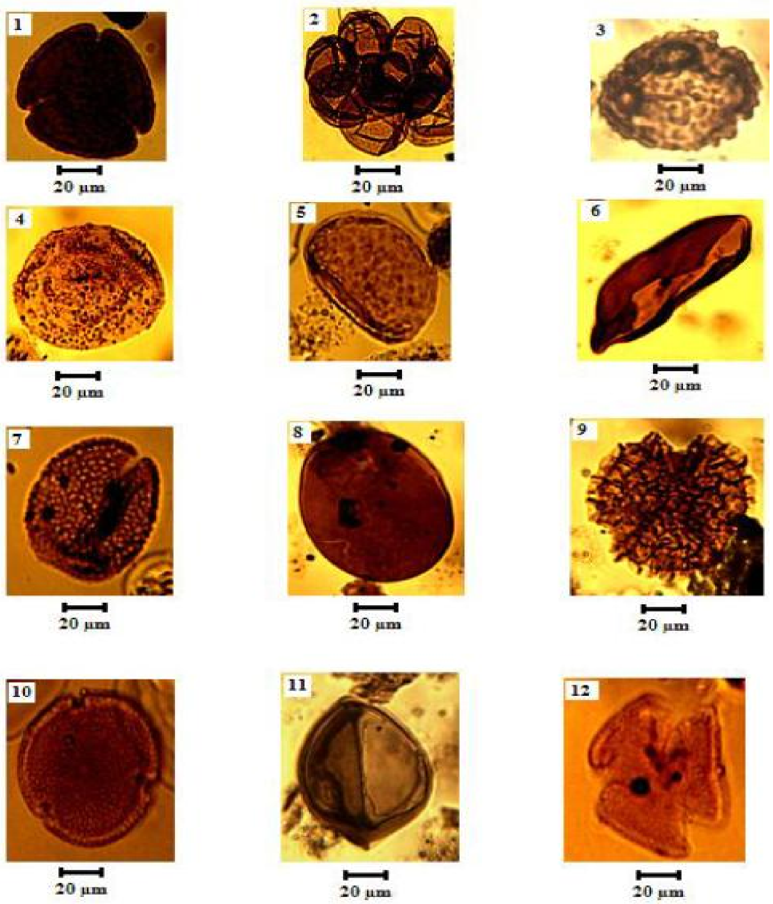

Fig. 8. Spores and pollen grains from the Upper Eocene of Bingerville (from [4])
1. Psilatricolporites crassus; 2. Inaperturopollenites sp.; 3. Verrustephanocolporites complanatus; 4. Magnaperiporites spinosus; 5. Verrucatosporites usmensis; 6. Monosulcites; 7. Retimonocolpites irregularis; 8. Laevigatosporites ovatus; 9. Retitricolporites irregularis; 10. Retitriporites sp.; 11. Monocolpopollenites; 12. Retitricolpites sp.

Our results are consistent with those of [17,18,19], who used some of these sporomorphs respectively in Soudan and Côte d'Ivoire to determine the Lower Miocene age of palynomorph assemblage.

The species *Crassoretitriletes vanraadshooveni* extends from Miocene to Pliocene in Nigeria [20] and from the Middle Miocene to the Pleistocene in Venezuela [21]. As for *Verrucatosporites usmensis*, it characterizes the Eocene to Pleistocene interval in Nigeria and Borneo [20,22].

Laevigatosporites ovatus is known from the Neogene in Burundi [23] and Paleogene in Nigeria [24].

Striatopollis catatumbus characterizes the Paleocene-Pleistocene interval in Nigeria [20] and the Pleistocene-Eocene range in Venezuela [21].

Brevicolporites molinae marks the Oligocene and the Lower Miocene in Cameroon [22] and the Miocene in Soudan [17].

The species *Retitriporites* sp. is a good marker of the Upper Oligocene and the Lower Miocene in Soudan [17]. However, the absence of *Lejeunecysta* (good marker of the Oligocene in Côte d'Ivoire) [7] in this interval restricts this age to the lower Miocene.

The Upper Eocene age was determined due to the associations of *Psilatricolporites crassus*, *Verrustephanocolporites complanatus*, *Retitricolporites irregularis*, *Verrucatosporites usmensis*, *Retimonocolpites irregularis, Pachydermites diederixii, Spinizonocolpites* *echinatus, Cicatricosporites dorogensis, Margotricolporites rauvolfii.*

Results can be compared [25,26,27,28] who described such palynomorph assemblage from the Upper Eocene in the Cameroun Basin. To these spores and pollen grains are associated dinocysts such as *Cometodinium obscurum, Spiniferites ramosus, Operculodinium centrocarpum, Batiacasphaera* sp, *Cordosphaeridium inodes*. [29], considers the species *Cordosphaeridium inodes* as an indicator of the Eocene in Germany, while [30] attributes it to the Middle Oligocene in Australia.

The species *Spinizonocolpites echinatus* last appears in the Upper Eocene as stated in many works [20,27,31,32,33] in Nigeria, Cameroun, Soudan and Ghana.

Psilatricolporites crassus characterizes the Upper Paleocene and Lower Eocene. In Cameroun, [27] identified it in the Lower Eocene and Middle Eocene. In Nigeria this species has been used by [20] to characterize the late Pliocene-Pleistocene interval. In South America, this species characterizes the Lower to Middle Eocene [31,34].

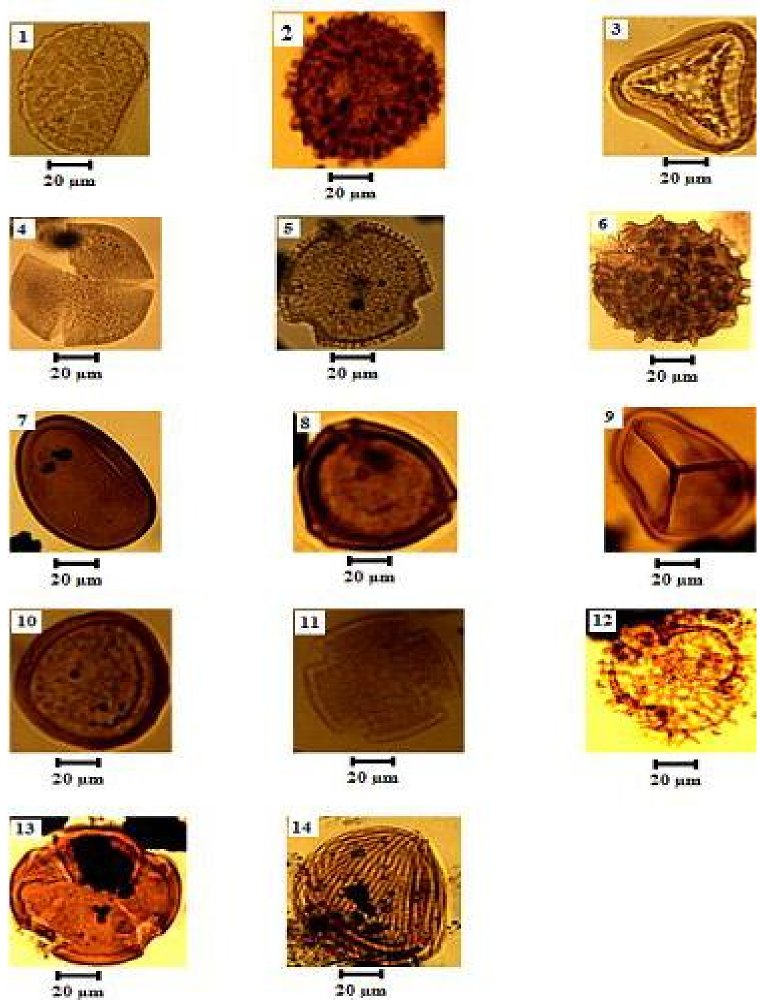

Fig. 9. Spores and pollen grains of the Upper Eocene of Assinie (from [4])

1. Verrucatosporites usmensis; 2. Baculatisporites sp.*; 3. Polypodiaceoisporites regularis; 4. Tricolpites; 5. Retitriporites* sp.*; 6. Spinizonocolpites echitanus; 7. Laevigatosporites ovatus; 8. Momipites* sp.*; 9. Deltoidospora delicata; 10. Cingulatisporites* sp.*; 11-13. Pachydermites diederixii; 12. Retitricolporites irregularis; 14. Cicatricososporites dorogensis*

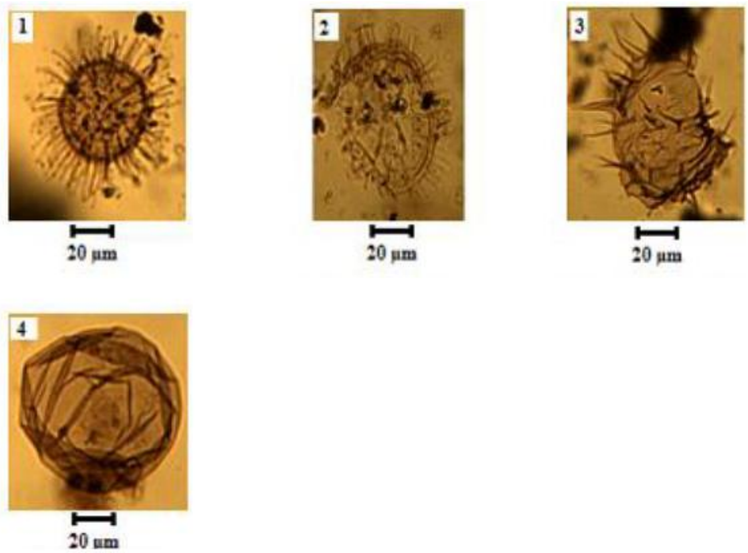

Fig. 10. Dinocysts of the Upper Eocene of Bingerville (from [4])
1. Lingulodinium machaerophorum; 2. Operculodinium centrocarpum; 3. Selenopemphix quanta; 4 Batiacasphaera sp.*;*

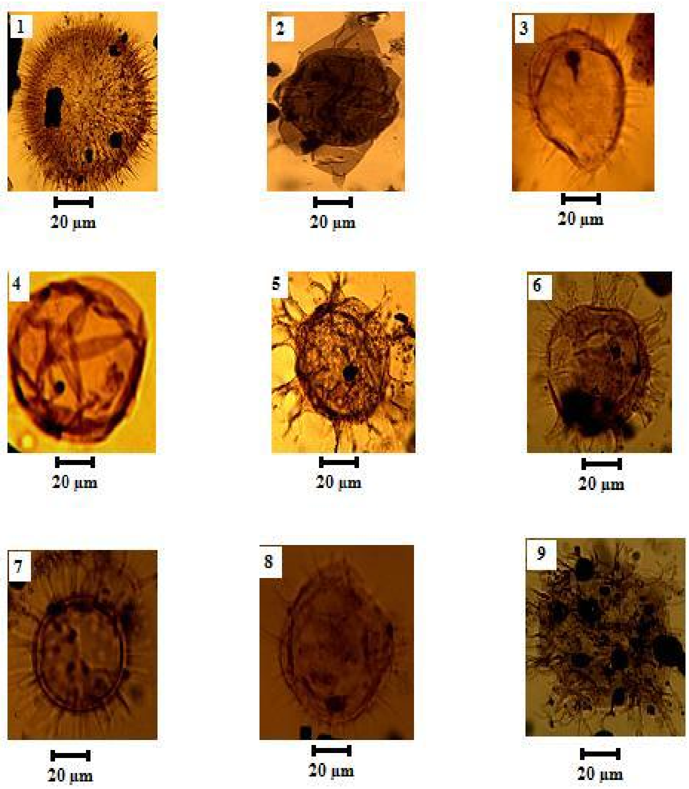

Fig. 11. Dinocysts of the upper Eocene of Assinie (from [4])
1. Comotodinium obscurum; 2. Isabelidinium sp.*; 3-8. Operculodilium centrocarpum; 4. Batiacasphaera* sp.*; 5-9. Spiniferites ramosus; 6. Cordosphaeridium inodes; 7. Lingulodinium machaerophorum*

The species *Pachydermites diederixi* present in this stage characterizes the Eocene and Miocene in Cameroon [27], Oligocene and Miocene in Soudan [17].

However, the presence in this stage of *Lingulodinium machaerophorum*, an Eocene marker in Egypt [35] and *Cordosphaeridium inodes* known from the Maastrichtian to Upper Eocene [7,24,32,36,37] restricts this age to the Upper Eocene.

5.2 Paleoecology

Paleobotanically, our work is in agreement with results of [19], considering the assemblage composed of *Verrucatosporites usmensis, Retitricolporites irregularis, Laevigatosporites ovatus, Leiotriletes adriennis, Pachydermites diederixii, Polypodiaceoisporites regularis* as a characteristic of tropical hot and humid climate.

The presence of the pollen grain *Brevitricolporites molinae* (Apocynaceae) typical of tropical forests [22] is confirmed in our work.

In addition, the results of [38] in conformity with ours reveal that fern spores such as *Laevigatosporites ovatus, Leiotriletes adriennis*, and *Verrucatosporites usmensis* indicate a humid tropical climate. This author also states that the species *Psilatricolporites crassus* is a pollen grain from mangrove vegetation which has been verified by our work.

The results of [39] reported by [40] indicate, as in our work, that Polypodiaceae (*Polypodiaceoisporites regularis*) are derived from tree ferns that indicate a thick and closed tropical forest.

For [40,41], the genus *Striatopollis catatumbus* encountered in our formations is a species of freshwater and coastal swamps. These results are verified by our work. These authors also claim that they can be found in the coastal plains as well as in tree savannas.

Similarly, our work is verified by results [42]. They claim that dinocysts such as *Operculodinium centrocarpum, Spiniferites ramosus, Cordosphaeridium inodes* and *Batiacasphaera* sp. indicate a marine depositional environment near the coast.

6. CONCLUSION

The palynostratigraphic and paleoecological study the plant fossil from the two wells of Bingerville and Assinie reveal the age and the depositional environment of the studied sample.

Dark, variegated sand and clays occur in the Bingerville well, while bioclastic sand, glauconite green clay and limestone in the assinie well.

Green clays contain remains of marine organisms, evidence of a transgressive sea at this time.The palynostratigraphic analyzes revealed a palynoflora characterizing the Upper Eocene and the Lower Miocene. Paleovegetation reveals the presence of species that develop in a mangrove environment with moist, lowland, partly marshy forest in a tidal estuarine coastal environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Spore and pollen grains

Baculatisporites sp. (Jaramillo & Dilcher, 2001)
Brevicolporites molinae (Schuler & Doubinger 1970) Salard-Cheboldaeff 1978
Cicatricosisporites dorogensis (Potonié&Gelletich, 1933)
Cingulatisporites sp.
Cupressacites hiatipites (Wodehouse, 1933) Krutzsch, 1971
Deltoidospora delicata (Sah, 1967)
Inaperturopollenites sp.
Laevigatosporites ovatus (Wilson & Webster, 1947)
Leiotriletes adriennis (Krutzsch, 1959)
Magnaperiporites spinosus (Gonzalez, 1967)
Margotricolporites rauvolfii (Salard-Cheboldaeff, 1978)
Monocolpollenites sp.
Monosulcites sp.
Pachydermites diederixii (Germeraad, & Muller, 1968)
Polyadopollenites microreticulatus (Salard, 1974)
Polypodiaceoisporites regularis (Zhang, 1981)
Psilatriporites sp.
Psilatricolporites crassus (Van der Hammen & Wijmstra 1964)
Psilatricolporites laevigatus (Van der Hammen and Wijmstra, 1964)
Retimonocolpites irregularis (Van der hammen & Wijmstra 1964)
Retitricolpites sp.
Retitricolporites irregularis (Van de Hammen & Wijmstra, 1964)
Retitriporites sp.
Spinizonocolpites echinatus (Muller, 1968)
Striatopollis catatumbus (Gonzàlez Guzmàn, 1967) Ward, 1986
Tricolpites sp.
Verrucatosporites usmensis (Van der Hammen, 1956) Germeraad et al. 1968
Verrustephanocolporites complanatus (Salard-Cheboldaeff, 1978)

Dinocyst

Batiacasphaera sp. (Jaramillo & Dilcher, 2001)
Cometodinium obscurum (Deflandre & Courteville, 1959) Monteil, 1991
Cordosphaeridium inodes (Klumpp, 1953) Eisenack, 1963
Isabelidinium sp.
Lingulodinium machaeropharum (Deflandre and Cookson, 1955) Wall, 1967
Operculodinium centrocarpum (Deflandre & Cookson, 1955) Wall, 1967
Selenopemphix quanta (Bradford, 1975) Harland, 1981
Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle3.com/review-history/50644