



Reconstruction of Paleoecology of Early Miocene Subsurface Deposits from Microflora in the Eboïnda Area (South-Eastern Côte d'Ivoire, West Africa)

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Authors' contributions

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

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ABSTRACT

The early Miocene palynoflora was recovered from well P1 located in the Aboisso area, about 175 km around of Abidjan (south-eastern Côte d'Ivoire, West Africa). Pteridophyta spores, angiosperm and gymnosperm pollen grains have been identified. The main objective of this work is to inventory all the palynomorphs encountered, to propose a local palynostratigraphy and to reconstitute the paleobotany of our study area during the Tertiary formations north of the lagoon fault. The samples were processed according to the classical procedure of extraction and concentration of palynomorphs. The lithology contains brown to black clays, coarse to fine sands, and reddish to

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motley clays. This study showed that the dominance of freshwater ferns such as *Verrucatosporites usmensis*, *Laevigatosporites ovatus*, *Polypodiaceosporites simplex*, *Cingulatisporites pseudocicatricosus* and *leiotriletes adriensis* which evokes a swampy environment. Also the development of *Bombacaceae* (*Bombacacidites annae*), and the abundance of Pteridophyte spores of the Polypodiaceae family (*Verrucatosporites usmensis*, *Laevigatosporites ovatus*, and *Polypodiaceosporites simplex*) indicate the climate was tropical with alternating dry and wet periods. Early Miocene sediments are placed in a continental type environment.

Keywords: Paleoecology; deposits; early miocene; microflora, Eboïnda area.

1. INTRODUCTION

Many studies have been carried out within the Eboïnda area (south-eastern Côte d'Ivoire, West Africa). According to an internal report by [1], Studies were carried out in the eastern part of the onshore basin from 1976 to 1983 by PETROCI to highlight the bituminous zones at Eboïnda. The studies of [2] and [3] in the sector aimed to specify the lithostratigraphic characteristics of the formations, their origin, the factors, and phenomena involved in the transport and deposition of sediments. At the bio stratigraphic level, little work in this sector has provided controversial results regarding the age of the deposits. The palynological works of [3] have allowed to distinguish a fictitious Maastrichtian (it is a mixture of palynomorphs from the Maastrichtian and the Danian), a Plio-Quaternary and Quaternary. He also noticed the absence of the Miocene. On the other hand, our recent work in the Eboïnda sector describes a palynological assemblage characterizing the Early Miocene age. The objective of this study is to inventory all the palynomorphs characterizing the early Miocene precisely in the area, to reconstruct the paleoecological deposits through using of diagnostic palynomorphs.

2. LOCATION AND THE GEOLOGICAL CONTEXT OF THE STUDY AREA

The Eboïnda region located in the onshore sedimentary basin, is in the east of Cote d'Ivoire in the region of Aboisso. It is about 175 km from Abidjan and closed to the border of Ghana. This zone lies between latitudes 5° 15' and 5° 30' North and longitudes 3° 00' and 3° 15' West (Fig. 1). The onshore part of the sedimentary basin of Côte d'Ivoire in crescent shape covers an area of 8.000 km² [4,5]. It is centered on Jacquville (50 km west of Abidjan) and extends from Fresco (in the west) to Axim in Ghana (in the east) over a length of 360 km, where it is called of the Tanoé

basin [6]. It is in this visible part that the Ebrié lagoon system develops. It is a vast expanse of water with an area of about 560 km² supplied by three watersheds and small coastal rivers. This very narrow basin is crossed from west to east by a fault known as the "lagoons fault" [3,7]. The rejection of this oscillates fault between 3,500 and 5,000 m. The action of this emerged basin allows to distinguish two zones:

- To the North of this fault, the sedimentary cover rarely reaches 300m in thickness.
- To the south of this fault, where the base sinks to 4,000m vertically from the coast, the basin is deep.

3. MATERIALS AND METHODS

Dating and inference of the paleoecology of the sediments was carried out on 12 samples from Well (P1). The well (P1) was drilled in the onshore part of the Ivorian sedimentary basin (Fig. 1). Sampling was carried out every 0.5 meters. The palynological preparation undertaken on twelve samples followed the standard procedure as generally adopted in recent work [8]. These consisted essentially of treating about 20 g of material with 30% hydrochloric acid and then 70% concentrated hydrofluoric acid for demineralization. Subsequently the addition of strong base (NaOH) allowed the palynological material to be clarified. The taxonomic determination of the spores and pollen grains and the dating of the sediments is based on the morphographic classifications of [9] and [10]. The determination of the paleoenvironment is based on the relative proportions of dinokysts (marine organisms) to spores and pollen grains (continental organisms) in the palynological assemblage [11]. The palaeobotanical analysis is based on the ecological importance and the different botanical affinities of the sporomorphs (Table 1).

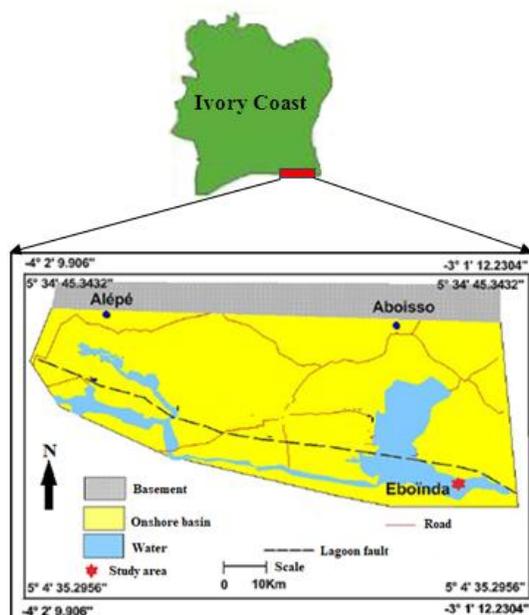


Fig. 1. Approximate geographical location of well P1

Table 1. The botanical affinities of selected pollen and spores recognized in this study

Fossil species	Botanic Affinity
	Pteridophyta
<i>Laevigatosporites ovatus</i> <i>Deltoidospora minor</i>	Filicopsida (Askin, 1990b); Hygrophytic (Wang <i>et al.</i> , 2005) Cyatheaceae; (Couper, 1958; Macphail, 1999); Marécages (Salard-Cheboldaeff, 1977); Hygrophytic-Mesophytic; (Wang <i>et al.</i> , 2005)
<i>Verrucatosporites usmensis</i>	Polypodiaceae (Jaramillo and Dilcher, 2001); comparable to <i>Stenochlaena palustris</i> (Blechnaceae) (Germeraad <i>et al.</i> , 1968)
<i>Cingulatisporites pseudocicatricosus</i> <i>Leiotriletes adriensis</i>	Pteridopsida (Thomson <i>et al.</i> , 1953) Cyatheaceae (Krutzsch and Vanhoorne , 1977)
<i>Polypodiaceoisporites simplex</i> <i>Baculatisporites sp</i>	Filicopsida Filicopsida; Osmundaceae (Burger 1994); Marécages (Germeraad <i>et al.</i> , 1968)
	Angiospermae
<i>Bombacacidites annae</i>	Bombacaceae (Germeraad <i>et al.</i> , 1968); Malvaceae s.l., alluvial (Jaramillo and Dilcher, 2001)
<i>Monocolpopollenites sp.</i> <i>Spinizonocolptes echinatus</i>	Palmae or Cycadales (Nichols <i>et al.</i> , 1973) Arecales; Muller 1968; Palmae, <i>Nypa</i> , recent mangrove of Indo-Malesian area (Germeraad <i>et al.</i> , 1968); coastal plain (Jaramillo and Dilcher, 2001)
<i>Monocolpites marginatus</i> <i>Retitricolporites irregularis</i>	Arecales; Rull 2001 Magnoliopsida; Archangelsky 1973
	Gymnospermae
<i>Monosulcites sp.</i> <i>Inaperturopollenites sp.</i>	Arecaceae; Couper, 1953 Cupressales, Pinidae; Digbehi <i>et al.</i> , 1996
	Algae
<i>Pteropermopsis danica</i>	Champignons d'eaux douce et saumâtre (Ola-Buraimo <i>et al.</i> , 2012); Hygrophytic Wang <i>et al.</i> , (2005)

4. RESULTS

4.1 Lithological Characterization

The lithostratigraphic column of well P1 shows four lithofacies in the direction of the drilling. But the interest was in the last three lithofacies; namely U2, U3 and U4 (Fig. 2).

Unit II (U2): In this Unit the clay of reddish to motley color, friable to soft is weakly micaceous. The sandy fraction has translucent to reddish, medium to fine grains. Carbonaceous debris is very scarce there. Glauconite and pyrite are rare.

Unit III (U3): These coarse to fine sands are rounded to sub-angular, translucent, red-orange and milky in some places. The clay fraction is reddish-brown, friable. Pyrite is rare there, unlike mica flakes which are numerous.

Unit IV (U4): It is a brown to black clay and sometimes oxidized, soft and moderately firm, friable to plastic. The sandy fraction contains fine, translucent, rounded to sub-angular grains as well as the presence of laterite and numerous pebbles, sub-rounded to sub-angular.

4.2 Palynological Characterization

4.2.1. Quantitative analysis

The main palynological data are provided in the Table 2. The palynological assemblage is dominated by spores and pollen grains. This assemblage, limited in diversity, counts 1094 individuals of spores (867) and pollen grains (214) grouped in 14 species. Also, we note 13 algae. No dinoflagellates were found in the study interval. The assemblage includes spores of Pteridophyta (79, 25%), angiosperm pollen grains (6, 03%) gymnosperm pollen grains (13, 53%), and algal forms (1, 19%) (Fig. 3).

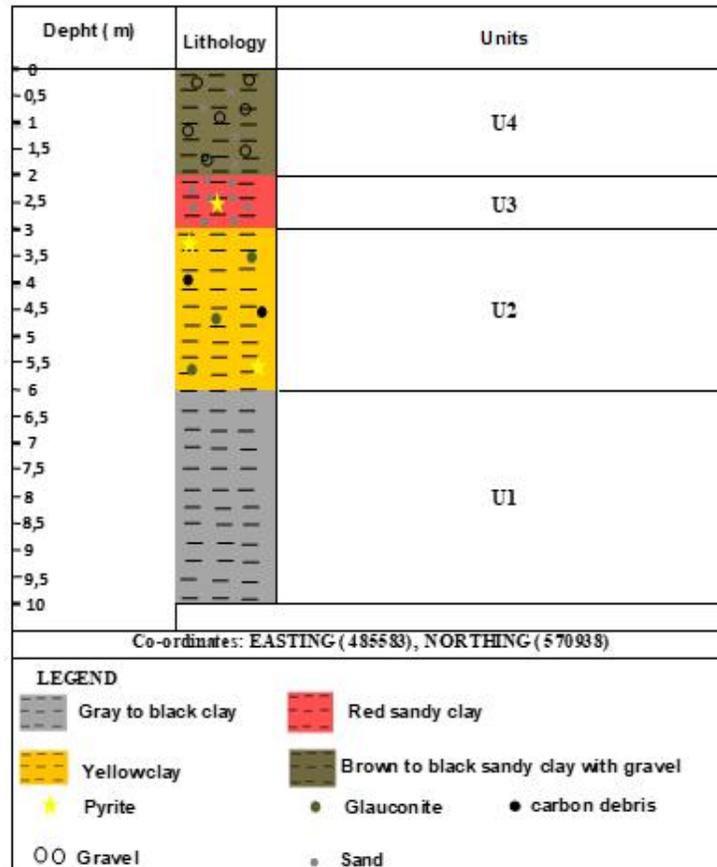


Fig. 2. Litho-stratigraphy of well P1

Table 2. Spores and pollen grains count sheet in Well P1

Depth	Spores								pollen grains						
	Pteridophytes				Angiosperms				Gymnosperms	Algae					
0m-0,5m	9	1	12	55	7	19	1	2	3	2	1	5	12	1	112
0,5m-1m	3	5	15	20		8						5	5		51
1m-1,5m	10		3	2	7	1				1		3	17	1	24
1,5m-2m	1		5	59	3	3	3					2	13	1	74
2m-2,5m	2	9	11	58		4			2	8	1	8	8		94
2,5m-3m	2		5	56	5	4			4	4	2	4	8	1	95
3m-3,5m	7	5	6	25		1		6		1		3	4		51
3,5m-4m	2	7	1	53	4	3			4	4	2	2	2	1	74
4m-4,5m	8	4	6	18	1	1	1		8	1	2	2	2	1	52
4,5m-5m	9	7	8	7		2						5	8		33
5m-5,5m	26	2	50	60	11	38		2		8	2	10	8	4	199
5,5m-6m	13	6	22	10	8	15	2		5	2	4	6	13	3	87

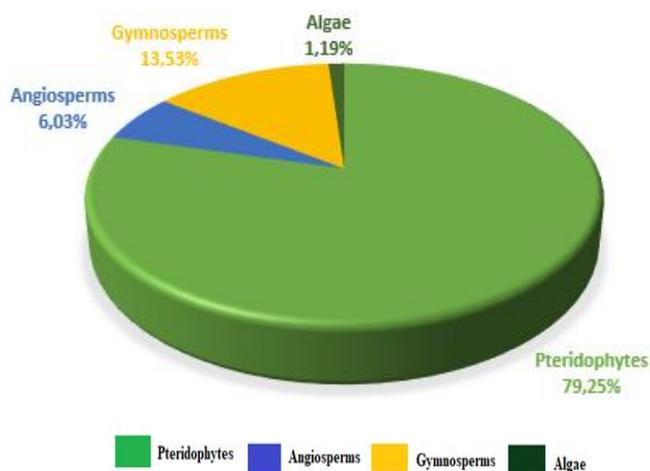


Fig. 3. Diagram representing the percentages of the different taxonomic groups identified

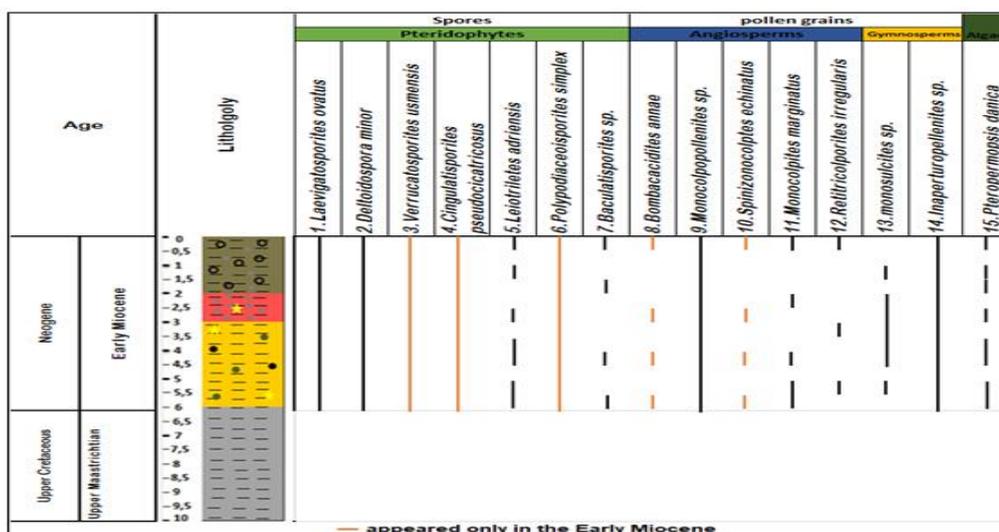


Fig. 4. Vertical distribution and palynostratigraphy of palynomorphs from well P1

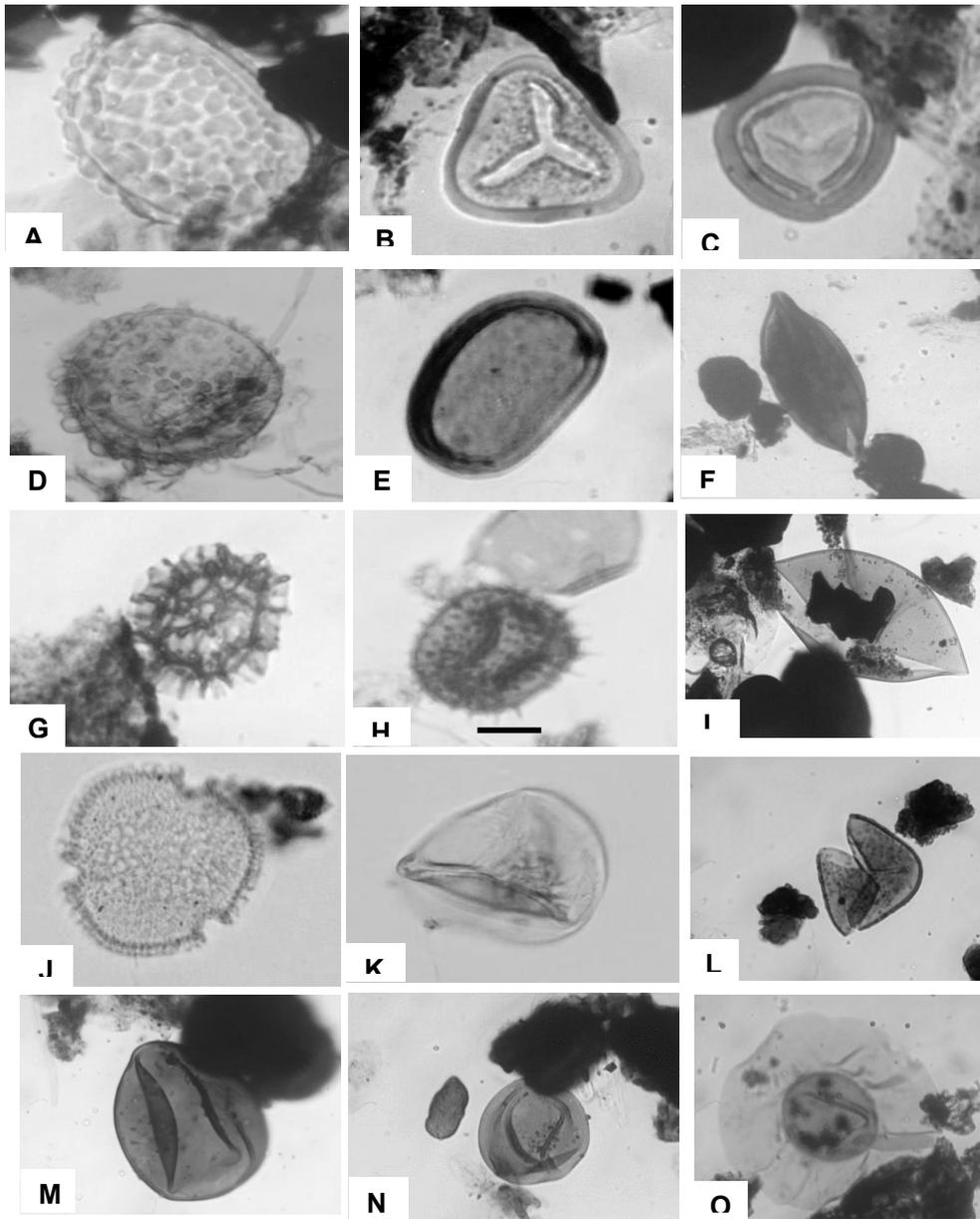


Fig. 5. Identified species comprising of pollen and spores in Well P1

4.2.2. Palynostratigraphy

The palynological association that allowed the dating of these formations includes sporomorphs such as *Verrucatosporites usmensis*, *Retitricolporites irregularis*, *Laevigatosporites ovatus*, *Leiotriletes adriennis*, *Bombacacidites annae*, *Polypodiaceoisporites regularis*, *Monocolpopollenites sp.*, *Deltoidospora minor*, *Monocolpites sp.* These associations allowed to suggest an Early Miocene age than the

sedimentary formations of the Eboinda area. The vertical distribution of the main palynomorphs according to their appearance is shown in Fig. 4. The different characteristic palynomorphs of this stage are illustrated on Fig. 5.

The scale bar in Figure H represents 20µm and applies to all specimens: A- *Verrucatosporites usmensis*; B- *Polypodiaceoisporites regularis*; C- *Cingulatisporites pseudocicatricosus*; D- *Baculatisporites sp.*; E-*Laevigatosporites*

ovatus; F-*Monosulcites* sp.; G-*Retitricolporites irregularis*; H-*Spinizonocolpites baculatus*; I-*Monocolpopollenites* sp.; J- *Bombacacidites annae*; K- *Leiotriletes adriennis*; L- *Deltoidospora minor*; M- *Monocolpites marginatus*; N- *Inaperturopollenites* sp.; O- *Pterpermopsis danica*.

4.2.3. Paleobotany

The palynological assemblages in the stratigraphic interval are entirely dominated by spores and pollen grains. Within this microflora, freshwater forms appear in varying proportions: *Verrucatosporites usmensis*, *Laevigatosporites ovatus*, *Polypodiaceosporites simplex*, *leiotriletes adriensis*, *Cingulatisporites pseudocicatricosus*. To these, are added the monocots (*Spinocolpites*) vegetation in this zone. Pteridophytes represented by the *Polypodiaceae* family (*Verrucatosporites usmensis*, *Laevigatosporites ovatus*, *Polypodiaceosporites simplex*, *Cingulatisporites pseudocicatricosus* and *leiotriletes adriensis*). These freshwater fern spores are inherently hydrophilic, indicating a swampy environment. The strong presence of *Cingulatisporites pseudocicatricosus* species is indicative of increased humidity. In the Early Miocene, Paleobotany would be represented by a dense humid mangrove forest covering the area.

4.2.4. Evolution of paleoclimates

In the Early Miocene, the development of the Bombacaceae (*Bombacacidites annae*), species characteristic of the flora of hot and dry regions, therefore, testify to a hot and dry climate. Within this microflora, there is an abundance of Pteridophyte spores of the *Polypodiaceae* family (*Verrucatosporites usmensis*, *Laevigatosporites ovatus*, and *Polypodiaceosporites simplex*) which generally colonize tropical and humid areas. This result shows that in the Early Miocene, the paleoclimate was tropical with alternating dry and wet periods.

4.2.5. Deposit environments

In this interval, the palynomorphs are largely dominated by spores and pollen grains (Fig. 3) in view of an absence of dinocysts in the well (P1). Absence of dinocysts could be due to unsuitable fossilization conditions. It follows from these observations that the depositional environment is continental.

5. DISCUSSION

5.1. Palynostratigraphy

The Early Miocene is identified by an association comparable to that described in aquifers from sub-surface formations of the Côte d'Ivoire lagoon region [12]. In particular, *Laevigatosporites ovatus*, *Retitricolporites irregularis*, *Verrucatosporites usmensis*, *Retitriporites* sp., *Monocolpopollenites* sp., *Leiotriletes adriennis*, *Polypodiaceosporites regularis*, *Cingulatisporites pseudocicatricosus*. Our results agree with those of [13,14,15,16] who used some of these sporomorphs respectively in Côte d'Ivoire to characterize the early Miocene. [10] and [8] recognized these species in the late Eocene of Cameroon, but which in the Senegal basin indicate the early Miocene.

5.2. Paleobotany

The species (*Verrucatosporites usmensis*, *Laevigatosporites ovatus*, *Polypodiaceosporites simplex*, *leiotriletes adriensis*, *Deltoidospora minor*,) described here are typical of a swampy area [17,18,19,20, 21,22]. Furthermore, the results of [13,14,15] in line with ours reveal that the spores of ferns such as *Laevigatosporites ovatus*, *Leiotriletes adriennis*, and *Verrucatosporites usmensis*, are derived from mangrove vegetation. All this is corroborated by the presence in our work of fresh and brackish water fungi (*Pterpermopsis danica*) according to [23]. The author [14] indicates like our work that *Polypodiaceae* (*Polypodiaceosporites regularis* and *Verrucatosporites usmensis*,) are derived from tree ferns which indicate the presence of a tropical forest.

5.3. Paleoclimate

The *Polypodiaceae* family represented in the analyzed sediments suggest a tropical and humid climate in the tropical and humid climate in the early Miocene. This is supported by many authors such as [24,25,26,13,14,27,28,29,15,30,19,20,31,32,33,22]. The appearance of *Polypodiaceosporites simplex* species in the early Miocene suggests a sub-tropical climate [34,35]. In addition, dry climatic conditions are also to be reported in the present work by the appearance of *Bombacacidites annae* in the early Miocene [3

6. CONCLUSION

The palaeoecological study of the sedimentary deposits in the Eboinda area near the Ghana border revealed certain geological characteristics. The lithology indicates the presence of sand and clay. The palynological analysis of these sediments revealed a strong presence of spores and pollen grains. This palynoflora allowed to assign it an early Miocene age. This vegetation, dominated by freshwater ferns, generally develops under tropical climatic conditions with alternating hot and humid periods. The dominance of terrestrial palynomorphs suggests a continental-type depositional environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Pteridophytes

Verrucatosporites usmensis, (Van der Hammen, 1956) Germeraad & Muller, 1968.

Baculatisporites sp.

Retitricolporites irregularis, Van der Hammen & Wijmstra, 1964.

Leiotriletes adriennis, (Krutzschn, 1959).

Polypodiaceoisporites regularis, Zhang; 1981.

Laevigatosporites ovatus, Wilson & Webster, 1946.

Deltoidospora minor (Couper, 1953) Pocock, 1970.

Angiosperms

Monosulcites sp.

Spinizonocolpites baculatus, Muller, 1968.

Bombacacidites annae. (Van der Hammen 1954) Germeraad *et al.* 1968.

Monocolpites marginatus Van Der Hammen, 1954.

Gymnosperms

Monocolpopollenites sp.

Inaperturopollenites sp.

Algae

Pteropermopsis danica.

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