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PALEOENVIRONMENTAL INTERPRETATION OF THE UPPER CRETACEOUS AND TERTIARY SEDIMENTARY DEPOSITS IN THE GONGOLA SUB-BASIN, UPPER BENUE TROUGH, NE-NIGERIA

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ABSTRACT

The Gongola Sub-Basin plays a significant role in understanding the geologic evolution of the Upper Benue Trough, it is equally important due to hydrocarbon exploration ongoing in the Sub-Basin. Palynological and lithological analyses were conducted on studied samples to interpret paleoenvironmental conditions of the sedimentary deposit. Palynological evidence including relative abundance and diversity of miospores, marine (dinocysts) and freshwater (*Pediastrum and Botryococcus)* indices coupled with lithological data recorded from twelve (12) boreholes, each drilled to the depth of 63 meters have been used to interpret the paleoenvironment of the Upper Cretaceous and Tertiary sedinentary deposits of the Kashere-Billiri-Futuk general area within the Gongola Sub-Basin, Upper Benue Trough in northeast Nigeria. The admixture of palynomorphs recovered from borehole sections D, F, I, N, O, R, S, T, V and X which include *Proxapertites cursus*, *Proxapertites operculatus* (brackish water palynomorphs), *Cingulatisporites ornatus, Gleicheniidites sp., Cyathidites australis, Longapertites marginatus, Echitriporites trianguliformis, Proxapertites operculatus, Distaverrusporites simplex* and Diatom frustules revealed a primarily terrestrial deposition environment characterized by lacustrine settings . Borehole sections B and P with characteristic palynoflora of *Cingulatisporites ornatus, Tricolporopollenites* sp., *Gleicheniidites senonicus, Ephedripites* sp. *Cyathidites* sp., *Longapertites* sp., *Echitriporites trianguliformis* and *Distaverrusporites simplex,* however, indicates a deposition of sediments with a predominantly fluvial-lacustrine influences.

Keywords: Paleoenvironment, Marker species, Palynomorphs, Pollen, Spore

INTRODUCTION

Recently, significant new hydrocarbon discoveries have been documented in the Upper Benue Trough via the drilling of Kolmani River 1, 2, 3, and 4 wells located in Bauchi and Gombe States of Nigeria. This is notably one of the pioneer major discoveries within the Nigerian frontier Basins. Prior to the hydrocarbon discoveries, various exploration activities were carried out within the Basin, this include gravity survey, magnetic and aeromagnetic survey, radiometric survey and studies, telluric surveys as well as 2D and 3D seismic data acquisition, processing and interpretation. Seismic refraction survey was also carried out as part of the exploration activities within the sedimentary Basin. Other earlier research carried out within the Basin include the determination of the paleoenvironment of deposition of the sedimentary successions e.g Carter *et al*., 1963, Zarbosky *et al*., 1997, and Mohammed *et al*., 2019, to mention but few. However, despite these earlier efforts, further investigation is required to have a more coherent understanding of the paleoenvironments of the deposits due to the criticality of its knowledge in hydrocarbon exploration and exploitation. It is therefore the goal of this research to reinvestigate the paleodepositional environments of the Upper Cretaceous and Tertiary sediment of the Gongola Sub-Basin, Upper Benue Trough in an area covering about 320sqkm with view of revealing a more accurate and reliable understanding of their depositional environments. In line with this, thirty-one (31) boreholes were drilled within the study area and twelve borehole sections were chosen for the analysis. Paleoenvironmental analysis was carried out for each of the twelve (12) borehole sections utilizing their palynoflora contents with the support of the lithologic units within the sections. The 196 samples analyzed via standard chemical treatment described by Brasier (1981), enable the identification of some marker palynomorphs which provide useful information regarding the depositional environments (Wall *et al*. 1977; Lister and Batten 1998; Harker and Sarjeant 1990; Tyson 1993, 1995; Batten 1984). The presence of some environmentally restricted marker species in the samples analyzed are potentially a strong proxy for paleoenvironmental interpretations (El Atfy *et. al*., 2013).

Geology of the Area

The Upper Benue Trough forms the northern stretch of the giant Benue Trough, which extends to northeast from the Bright of Benin to Lake Chad with about 800km in length and 150 km in width (Obaje, 2009). The Upper Benue Trough is said to be over 6000m thick and made up of two arms, the Gongola Arm and the Yola Arm, and the stratigraphic succession is such that the oldest Formation which is the Albian Bima Sandstone lies unconformably on the Precambrian Basement complex. This Formation was deposited under continental conditions (fluvial, deltaic, lacustrine) and is made up of coarse to medium grained sandstones, intercalated with carbonaceous clays, shales, and mudstones (Obaje, 2009).The Yolde Formation lies conformably on the Bima Sandstone. This Formation represents the beginning of marine incursion into this part of the Benue Trough. The Yolde Formation was deposited under a transitional/coastal marine environment and is made up of sandstone, limestone, shale, clay and claystone (Zaborski et al., 1997). Pindiga Formations lie conformably on the Yolde Formation. These formations represent full marine incursion into the Upper Benue. Lithologically, this formation is

characterized by the dark/black carbonaceous shales and limestones, intercalating with pale colored limestones, shales and minor sandstones (Zaborski et al., 1997). The Gombe Sandstone is stratigraphically deposited on Pindiga Formation and is dated Maastriachian in age (Lawal and Moullade, 1986). Lithologically, it consist of sandstones and siltstones and minor shales with ferruginized capping and occasional mudstone parting and occasional coal seams which are mainly localized. Laying on top of the Gombe Sandstone is the Paleogene Kerri - kerri Formation, it is the youngest Formation within the Gongola Sub-Basin and is essentially flat-lying and unfolded Formation (Adegoke *et al.* 1986 and Dike 1993). This formation overlies the basement complex in the western part of the Gongola sub–basin and progressively overstepped the Cretaceous sediments to the east, with the sediments mostly made up of clayey grit, coarse-grained sandstone, siltstone, with claystones dominating the lithology in most places, typical sections, which are exposed in Gombe Aba, Dukku and Alkaleri (Adegoke et al. 1986).

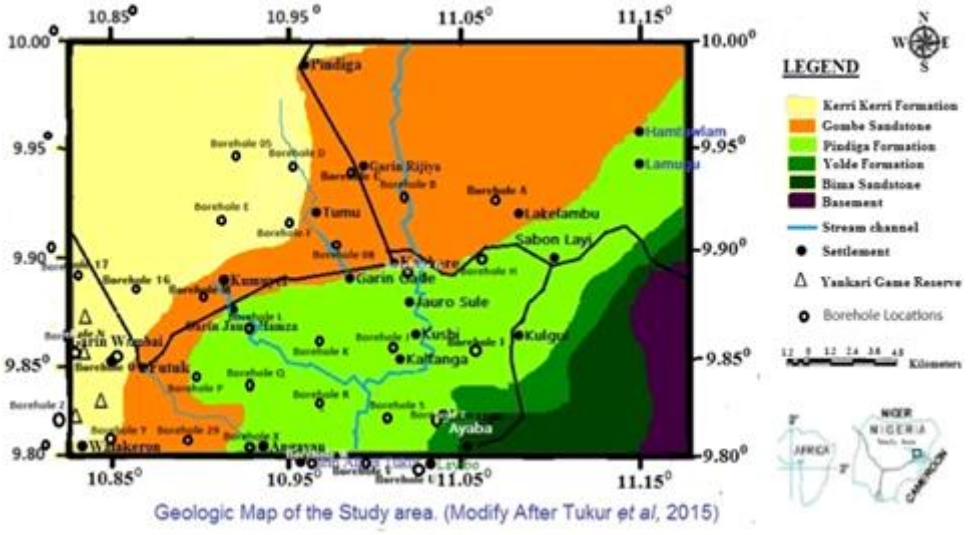


Figure 1: Geologic Map of the study area showing the borehole location

Basically, the study area is consisting of the Gombe Sandstone Formation towards Tumu, Pindiga and part of Kashere around the middle and part of the northeastern segment of the prospect and Kerri-kerri Formation towards the southern and the northwestern segment of the prospect area (*Abdulkarim et al., 2024*).

Location, Extent and Accessibility

The study area is located within Akko, Billiri and Alkaleri LGs of Gombe and Bauchi States, Northeastern Nigeria. The Area falls between latitude 9°48′ to 10°00′ N and longitude 10°51′ to 11°09′ E which span an area of about 320Sqkm. It can be access via Alkaleri-Billiri-Yola, Kashere-Pindiga-Gombe Major roads and other Inter and intra village roads.

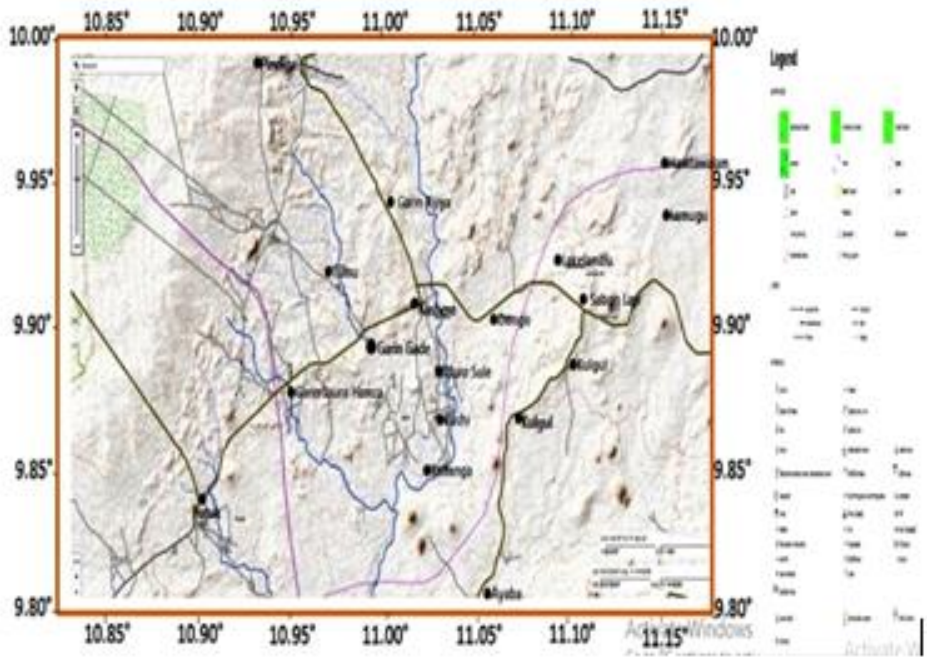


Figure 2: Topographic map of the study area showing access across the area

MATERIAL AND METHODS

Reconnaissance survey was carried out for one (1) week to identify the drilling location as planned from simulation and to ascertain whether the location could be drilled as it is planned, or some borehole location would require offset due to different reasons. The boreholes were planned to be drilled in 4km-by-4km matrix within the 320sqm area. Offset of the borehole drilling point may be necessitated when the original drilling point is on a main road, inside river, inside houses, on shrine or burial ground among others, as well as the accessibility of the locations. From the plan, the maximum offset made was 20meters as most of the planned drilling locations were found to be accessible without much challenge. Where there is accessibility challenges, a bulldozer was deployed to clear the path for seamless movement of drilling rig.

The Reconnaissance was followed by nine (9) weeks of proper field work where thirty-one (31) boreholes were drilled to 63m depth in 4km-by-4km matrix using mud circulation rotary drilling rig and water tanker. Measurement of the location and elevation of each drill points were carried out using hand-held GPS with accuracy of about 99.88%. 500g of dich samples (drill cuttings) were collected from 196 levels in 12 boreholes drilled for the purpose of palynology analysis. The samples were stored in airtight polythene sample bags to avoid contamination, thereafter, the samples were transported to the laboratory in an airtight cooler. 25 grams of samples were used for the palynological analysis. The samples were subjected to standard chemical treatment described by Brasier (1981). The process is as follows;

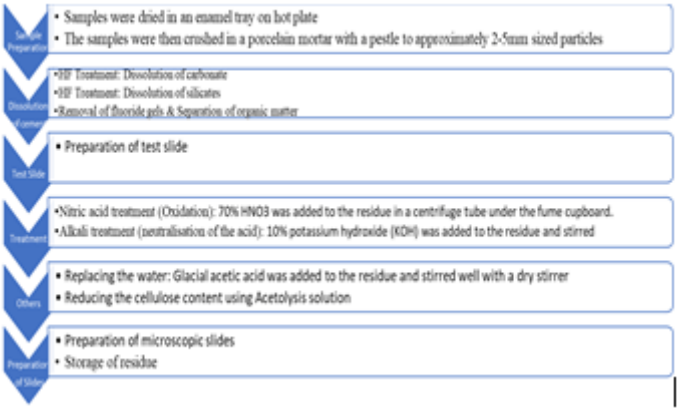


Figure 3: Palynological Sample analysis process.

Plate1: Some Palynological laboratory Equipment

RESULTS AND DISCUSSION

The paleoenvironmental analysis of the Cretaceous and Tertiary successions was achieved through the study and analysis of the recovered palynomorphs from twelve borehole sections as described below.

Borehole B

The palynological characteristics of the Borehole B section indicate freshwater to brackish water conditions. In most of the samples, the palynomorphs assemblage is exclusively terrestrial (Ojo *et. al.*, 2020), and occurrence of freshwater algae, *Botryococcus braunii (*Erdtman 1952) and charred graminae cuticles in the borehole section was recorded. This is a typical freshwater alga indicative of a freshwater swamp. However, marine dinocysts were recovered towards the middle part of the section and this interval is interpreted to mark the maximum flooding surface. Other Palynomorphs recovered in the borehole section include *Cingulatisporites ornatus, Tricolporopollenites* sp., *Gleicheniidites senonicus, Ephedripites* sp. *Cyathidites* sp., *Longapertites* sp., *Echitriporites trianguliformis* and *Distaverrusporites simplex*.

This palynoflora suggest deposition of sediments in a predominantly terrestrial (Lacustrine - (?)fluvial) environment.

Borehole D

The palynological characteristics of the Borehole D section (0-63m) indicate freshwater to brackish water conditions. In most of the samples, the palynomorphs assemblage is exclusively terrestrial (Ojo *et al.,* 2020), and occurrence of freshwater algae, *Botryococcus braunii (*Erdtman 1952) in the borehole section was recorded. This is a typical freshwater alga indicative of a freshwater swamp. However, marine dinocysts were recovered especially around 18-19m depth within the section which is indicative of maximum flooding surface. Other Palynomorphs recovered in the borehole section include *Proxapertites cursus, Proxapertites operculatus* (brackish water palynomorphs), *Cingulatisporites ornatus, Gleicheniidites sp., Cyathidites australis, Longapertites marginatus, Echitriporites trianguliformis, Proxapertites operculatus* and *Distaverrusporites simplex.* Diatom frustules were also identified. This palynoflora suggest deposition of sediments in a mainly terrestrial paleoenvironment.

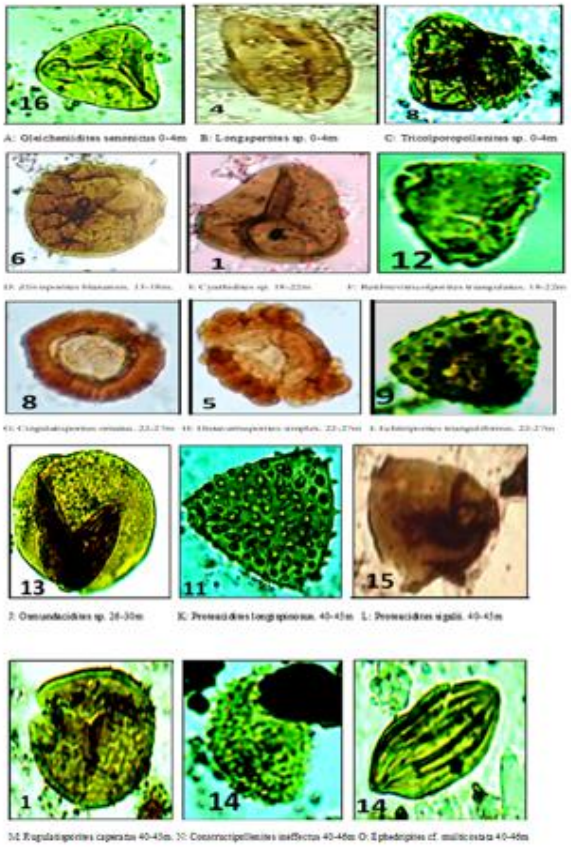


Plate 2: Some Palynomorphs recovered from Borehole B

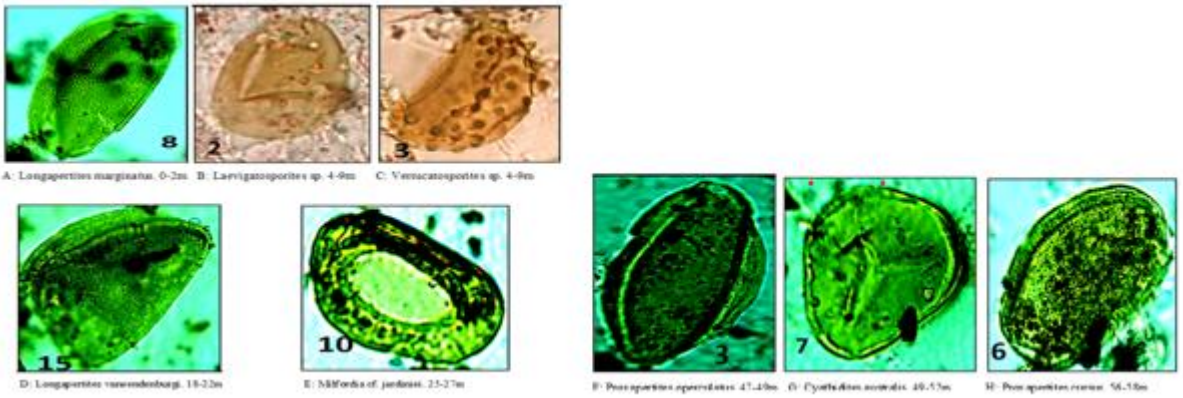


Plate 3: Some Palynomorphs recovered from Borehole D

Borehole F

The palynological characteristics of the Borehole F section (0-63m) indicate freshwater to brackish water conditions. In most of the samples, the palynomorph assemblage is terrestrial (Ojo *et al.,* 2020), and occurrence of freshwater algae, *Botryococcus braunii (*Erdtman 1952) in the borehole section was recorded. This is a typical freshwater alga indicative of a freshwater swamp. Other Palynomorphs

recovered in the borehole section include *Psilatricolporites crassus, Ctenolophonidites costatus, Retibrevitricolporites obodoensis* and *Pachydermites diederixi*. Diatom frustules and fungal spores were also identified. This admixture suggest deposition of sediments in a predominantly terrestrial (Lacustrine) environment.

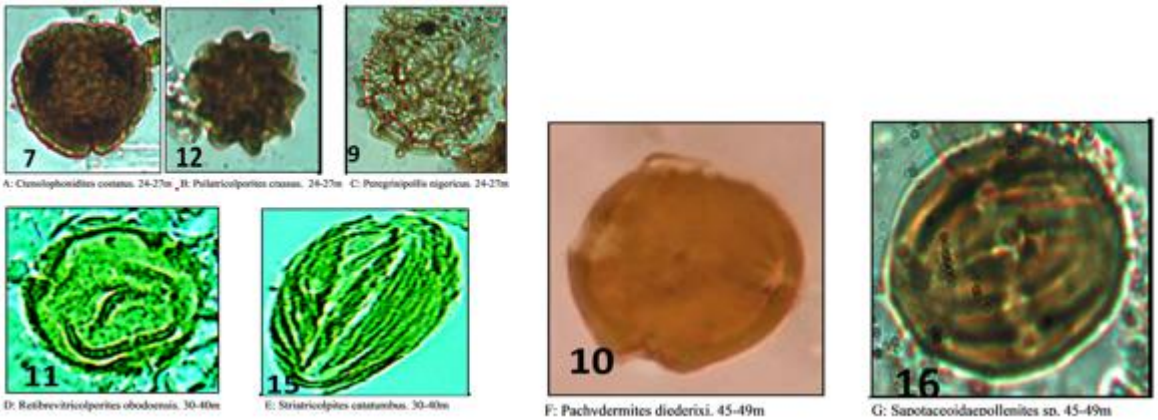


Plate 4: Some Palynomorphs recovered from Borehole F

Borehole I

The palynological characteristics of the Borehole I section (0-60m) indicate freshwater to brackish water conditions. In most of the samples, the palynomorphs assemblage is exclusively terrestrial (Ojo *et. al* 2020), and occurrence of Freshwater algae, *Botryococcus braunii (*Erdtman 1952) in the borehole section was recorded. This is a typical freshwater alga indicative of a freshwater swamp. Other Palynomorphs recovered in the borehole section include *Verrucatosporites* sp., *Laevigatosporites* sp., *Cingulatisporites ornatus and Tricolporopollenites* sp. *with* fungal spores among others. This suggests a predominantly terrestrial environment of deposition of sediments in the studied borehole interval.

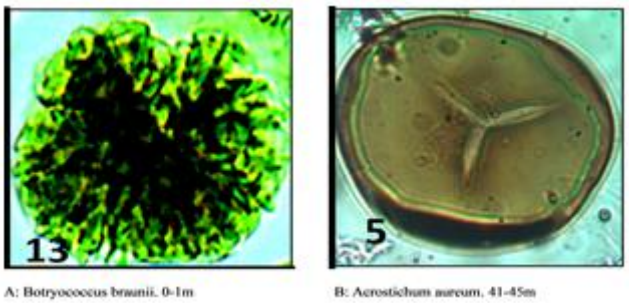


Plate 5: Some Palynomorphs recovered from Borehole I

Borehole N

The palynological characteristics of the Borehole N section (0-63m) indicate freshwater to brackish water conditions. In most of the samples, the palynomorphs assemblage is exclusively terrestrial (Ojo *et al.*, 2020), also Freshwater algae, *Botryococcus braunii (*Erdtman 1952) and *Tasmanites sp*. were recorded in the borehole section. This is a typical freshwater alga indicative of a freshwater swamp. Other Palynomorphs recovered in the borehole section include *Tricolporopollenites* sp., *Laevigatosporites* sp., *Verrucatosporites* sp., *Cyathidites* sp., *Echitriporites trianguliformis*, and *Polypodiaceoisporites* sp., with fungal spores and charred graminae cuticles. This admixture suggest deposition of sediment in a predominantly terrestrial environment.

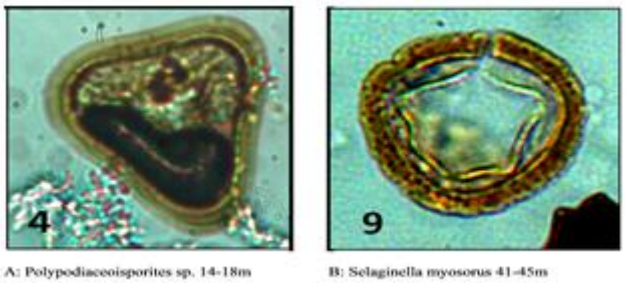


Plate 6: Some Palynomorphs recovered from Borehole N

Borehole O

The palynological characteristics of the Borehole O section (0-63m) indicate freshwater to brackish water conditions. In most of the samples, the palynomorphs assemblage is exclusively terrestrial (Ojo *et al.,* 2020), also Freshwater algae, *Botryococcus braunii (*Erdtman 1952), *Pediastrum sp.* and *Tasmanites sp*. were recorded in the borehole section. This is a typical freshwater alga indicative of a freshwater swamp. Other Palynomorphs recovered in the borehole section include *Cingulatisporites ornatus, Cyathidites minor, Longapertites sp., Monocolpites marginatus, Proxapertites cursus, Verrucatosporites sp. and Laevigatosporites sp.* with fungal spores and diatom frustules. This suggests a predominantly terrestrial environment of deposition for the studied borehole interval.

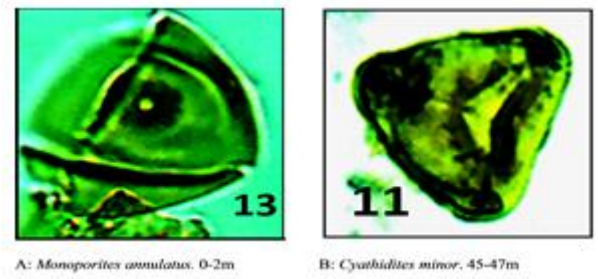


Plate 7: Some Palynomorphs recovered from Borehole O

Borehole P

The palynological characteristics of the Borehole P section (0-63m) indicate freshwater to brackish water conditions. In most of the samples, the palynomorphs assemblage is exclusively terrestrial (Ojo *et al.,* 2020), also Freshwater algae, *Botryococcus braunii (*Erdtman 1952), was recorded in the borehole section. This is a typical freshwater alga indicative of a freshwater swamp. Other Palynomorphs recovered in the borehole section include *Retimonocolpites sp., Zlivisporites blanensis, Verrucatosporites sp., Ephedripites sp., Polypodiaceoisporites sp., Spirosyncolpites bruni* and *Ephedripites sp.* with *Botryococcus braunii* and foraminifera wall linings. This suggests a predominantly terrestrial (lacustrine-fluvial) environment of deposition for the studied borehole interval.

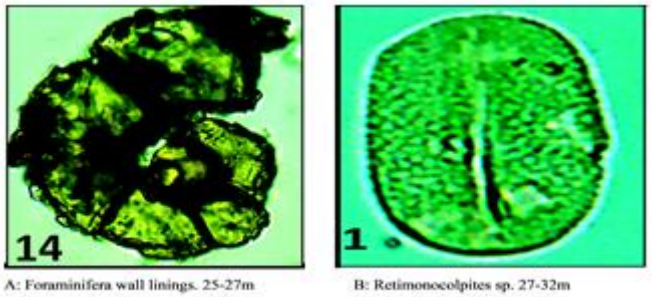


Plate 8: Some Palynomorphs recovered from Borehole P

Borehole R

The palynological characteristics of the Borehole R section (0-63m) indicate freshwater to brackish water conditions with the palynomorphs assemblage is exclusively terrestrial (Ojo *et al.,* 2020), and occurrence of Freshwater algae, *Botryococcus braunii (*Erdtman 1952) in the borehole section was recorded. This is a typical freshwater alga indicative of a freshwater swamp. However, marine dinocysts, *Leiosphaerides sp.* was recovered especially within the section which is indicative of marine incursion. Other Palynomorphs recovered in the borehole section include *Cyathidites minor, Proteacidites sigalii, Zlivisporites blanensis, Longapertites marginatus, Tubistephanocolporites cylindricus, Ephedripites ambiguus, Proxapertites operculatus, Retidiporites magdalenensis* and *Echitriporites trianguliformis* with Fungal spore/Hyphae suggest deposition of sediments in a predominantly terrestrial (lacustrine) environment for the studied borehole section.

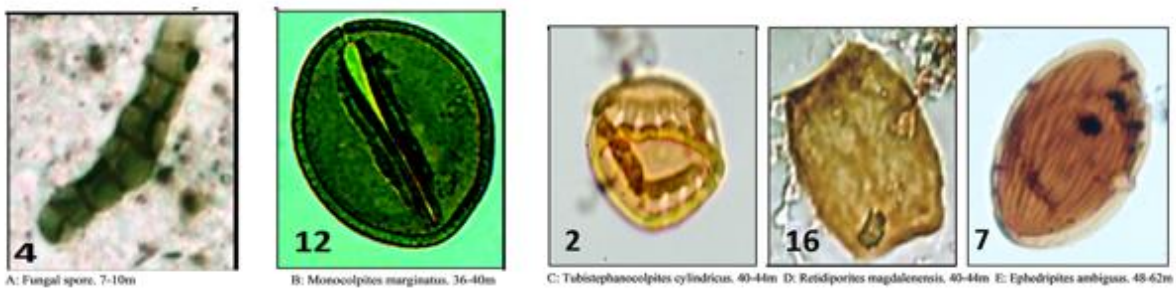
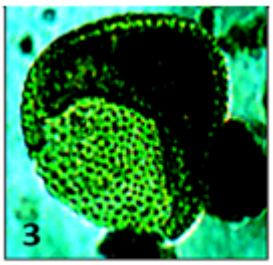


Plate 9: Some Palynomorphs recovered from Borehole R

Borehole S

The palynological characteristics of the Borehole S section (0-63m) indicate freshwater to brackish water conditions with the palynomorphs assemblage is exclusively terrestrial (Ojo *et al.,* 2020), and occurrence of Freshwater algae, *Botryococcus braunii (*Erdtman 1952) in the borehole section was recorded. This is a typical freshwater alga indicative of a freshwater swamp. Other Palynomorphs recovered in the borehole section include *Foveotriletes margaritae*, *Rugulatisporites* sp., *Cyathidites minor*, *Ephedripites multicostatus*, *Longapertites* sp. *Constructipollenites ineffectus*, *Tricolporopollenites* sp., *Laevigatosporites* sp., *Retimonocolpites* sp. and *Psilamonocolpites* sp. with diatom frustules were also identified. This suggests deposition of sediments in a predominantly terrestrial (lacustrine) environment for the borehole section.

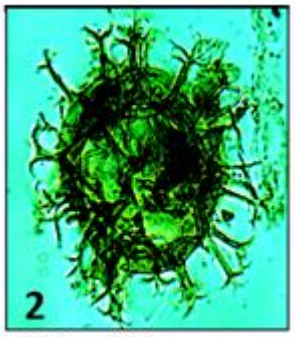


Foveotriletes margaritae. 14-23m

Plate 10: Some Palynomorphs recovered from Borehole S

Borehole T

The palynological characteristics of the Borehole T section (0-63m) include assemblage that is exclusively terrestrial (Ojo *et al.,* 2020), However, marine dinocysts, *Leiosphaerides sp.* was recovered especially around 16-19m depth within the section which is indicative of maximum flooding surface. Other Palynomorphs recovered in the borehole section include *Verrucatosporites* sp., *Monocolpites marginatus*, *Echitriporites trianguliformis*, *Zlivisporites blanensis*, *Cyathidites minor*, *Laevigatosporites* sp., *Verrucatosporites* sp., *Cingulatisporites ornatus*, *Monoporites annulatus*, *Retidiporites* sp. and *Longapertites* sp. with diatom frustules and fungal spore. This admixture suggest deposition of sediments in a predominantly terrestrial (Lacustrine) environment.



Spiniferites sp. 34-36m

Plate 11: Some Palynomorphs recovered from Borehole T

Well V

The palynological characteristics of the Borehole V section (0-61m) indicate freshwater to brackish water conditions with the palynomorphs assemblage is exclusively terrestrial (Ojo *et al.,* 2020), and occurrence of Freshwater algae, *Botryococcus braunii (*Erdtman 1952) in the borehole section was recorded. This is a typical freshwater alga indicative of a freshwater swamp. However, marine dinocysts, *Leiosphaerides sp.* was recovered especially within the section which is indicative of marine incursion. Other Palynomorphs recovered in the borehole section include *Verrucatosporites* sp., *Proxapertites cursus*, *Spiniferites* sp., *Echitriporites trianguliformis*, *Zlivisporites blanensis*, *Cyathidites minor*, *Laevigatosporites* sp., *Verrucatosporites* sp., *Cingulatisporites ornatus* and *Longapertites* sp. with diatom frustules and fungal spore. The admixture suggest deposition of sediments in a predominantly terrestrial (lacustrine) with rare episode of fluvio-marine condition.

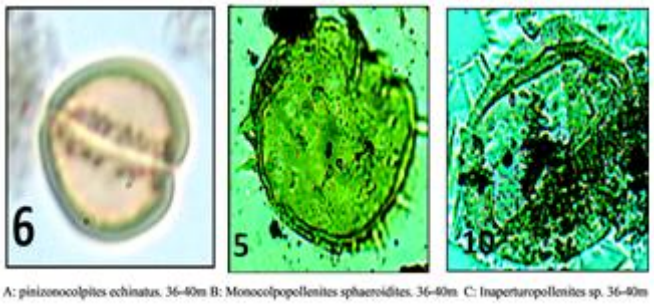


Plate 12: Some Palynomorphs recovered from Borehole X

Well X

The palynological characteristics of the Borehole X section (0-63m) indicate freshwater to brackish water conditions with the palynomorphs assemblage is exclusively terrestrial (Ojo *et al.,* 2020), and occurrence of Freshwater algae, *Botryococcus braunii (*Erdtman 1952) in the borehole section was recorded. This is a typical freshwater alga indicative of a freshwater swamp. Other Palynomorphs recovered in the borehole section include *Tricolporopollenites* sp., *Echitriporites trianguliformis, Distaverrusporites simplex, Laevigatosporites* sp., *Cyathidites minor, Monocolpites* sp., *Polypodiaceoisporites* sp. and *Inaperturopollenites* sp. with fungal spores, diatom frustules and charred graminae cuticle. This admixture suggest deposition of sediments in a predominantly terrestrial (? Lacustrine) environment.

CONCLUSIONS

Analysis of the palynomorphs that were recovered from the 196 samples across 12 boreholes drilled around the Kashere-Billiri-Futuk general area in Gombe and Bauchi states enable the paleoenvironmental interpretation of the depositional successions within the area. Palynologically, the presence of some environmentally restricted marker species in the samples analyzed is potentially a strong proxy for paleoenvironmental interpretations. From the foregoing, it can be concluded that the environment of deposition of the sedimentary succession within the study area is predominantly terrestrial lacustrine environments as observed in boreholes D, F, I, N, O, R, S, T, V and X. Boreholes B and P are indicative of fluvial – lacustrine environments. The presence of marine dynocysts in some part of the borehole sections is attributed to the episodic marine transgressions into the area, indicating maximum flooding surfaces.

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