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Original Research Article

Biostratigraphy, Thermal Maturity and Paleoenvironment of the Basal Part of Gombe Formation from Gongola Sub-Basin, Northern Benue Trough, North Eastern Nigeria

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ABSTRACT
The basal part of the Gombe Formation in the Gongola sub-basin (Northern Benue Trough) was investigated using integrated lithostratigraphic, palynological and foraminiferal analyses of (13) outcrop samples (GM-1 to GM-13) to establish age and paleoenvironment. The succession is characterized by recurrent coarsening-upward cycles, basal claystone/mudstone grading into interbedded siltstones and fine sandstones and locally capped by medium–coarse sandstones with bioturbated greenish–brown shales (Thalassinoides), localized ironstone development and ferrogenised sands. Palynological assemblages from most samples yield Maastrichtian marker taxa (e.g., *Tricolporopollenites* sp., *Cingulatisporites ornatus*, *Zlivisporites blanensis*, *Proteacidites dehaani*, *Distaverrusporites simplex*), while the microfossil record is dominated by arenaceous benthic foraminifera (e.g., *Haplophragmoides* spp., *Miliammina inflata*, *Trochammina* spp., *Ammobaculites coprolithiformis*, *Reophax guineana*). Integration of these data indicates a Late Campanian–Maastrichtian age with strong emphasis on the Maastrichtian and a depositional setting interpreted as marginal-marine to shallow inner-neritic influenced by deltaic–estuarine progradation. The abundance of terrestrially derived palynomorphs, freshwater indicators (e.g., *Botryococcus*) and charred plant fragments, together with the absence of calcareous/planktic foraminifera, point to strong terrestrial input, intermittent freshwater influence and dysoxic bottom conditions. Some samples (GM-2, GM-9, GM-12) show low fossil recovery.

INTRODUCTION

The Gongola Basin, a north–south trending arm of the Upper Benue Trough in northeastern Nigeria, forms part of the ~1000 km long Benue Trough. Its origin has been attributed to an unstable rift–rift–fault triple junction model leading to plate dilation and the opening of the Gulf of Guinea (Benkhelil, 1989; Fairhead & Binks, 1991). Alternative models propose rift- or wrench-related fault basin development, accompanied by widespread Mesozoic–Cenozoic magmatism (Coulon et al., 1996; Shemang et al., 2001).

While exploration in Nigeria has historically focused on the Niger Delta, the Gongola Basin has gained increasing attention due to its hydrocarbon potential. Within this basin, the Gombe Formation is of particular interest; however, its stratigraphic position, age, and depositional environment remain debated. The paucity of detailed biostratigraphic and paleoenvironmental studies has limited accurate correlation with other regional stratigraphic units.

This study integrates palynological and foraminiferal analyses to establish the relative age and depositional environments of the lower Gombe Formation. By analyzing fossil assemblages—pollen, spores, and benthic foraminifera—this work aims to resolve stratigraphic uncertainties, reconstruct paleoenvironments, and assess implications for hydrocarbon potential.

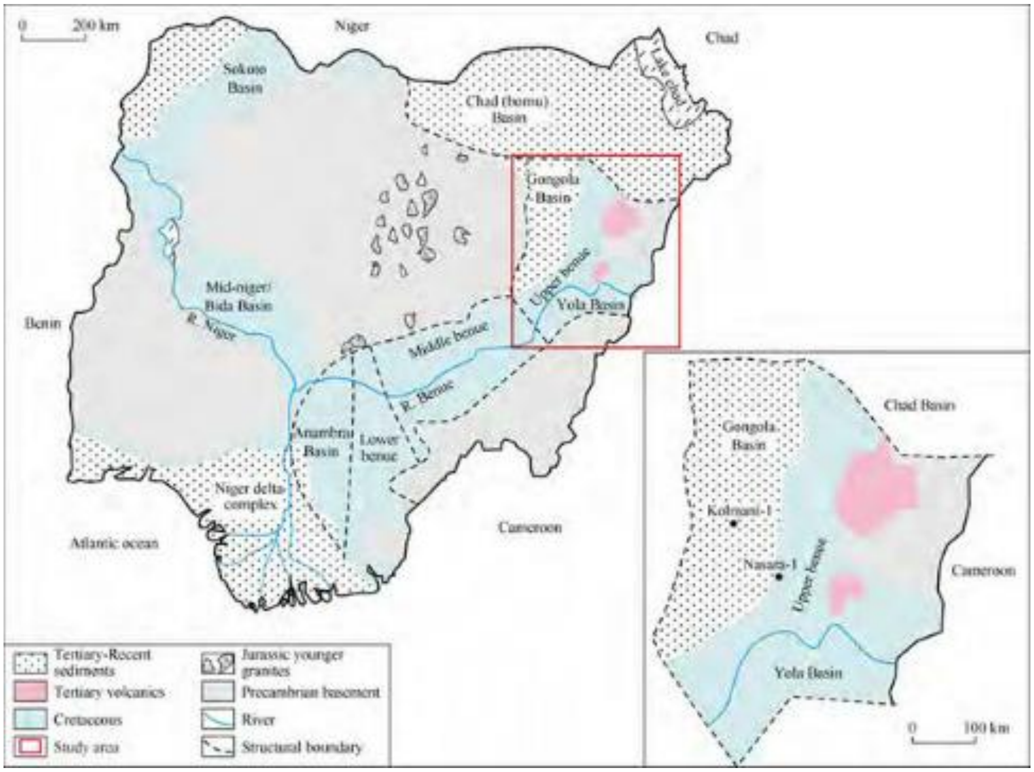

Figure 1: Geological Map of Nigeria Showing the Gongola sub-basin, Location of Northern Benue Trough (Obaje, 2009)

Geological setting

The Northern Benue Trough, located in northeastern Nigeria, is a NE–SW trending Cretaceous–Tertiary sedimentary basin formed during the Early Cretaceous rifting associated with the separation of the African and South American plates. Extending over 1000 km in length and about 150 km in width, it contains more than 6000 m of sediments (Abubakar, 2014; Sarki Yandoka et al., 2014). Two principal tectonic models have been proposed for its origin: a rift system model and a pull-apart basin model (Abubakar, 2014). The trough is subdivided into southern, central, and northern segments (Nwajide, 2013), with the northern segment comprising the Yola, Gongola, and Lau-Lamurde sub-basins (Guiraud, 1990). The Gongola Basin, trending N–S, is the focus of this study and is bounded by the Chad Basin to the north, the Adamawa Highlands to the east, and Nigerian Basement Complex rocks to the west. It is structurally influenced by NE-trending sinistral strike-slip faults such as the Gombe, Bima-Teli, Kaltungo, and Shani faults (Maurin et al., 1986).

The Gongola Basin hosts a well-defined Cretaceous stratigraphy. The Aptian–Albian Bima Sandstone forms the basal unit, unconformably overlying the Precambrian basement and comprising three members (B1, B2, B3) deposited in continental settings (Tukur et al., 2015). It is overlain conformably by the Cenomanian Yolde Formation, representing the onset of marine influence in barrier island–deltaic environments (Lawal and Maullade, 1986; Shettima, 2005). Above this, the Turonian–Santonian Pindiga Formation, laterally equivalent to the Gongila Formation and Fika Shale, records a full marine transgression (Carter et al., 1963). The Maastrichtian Gombe Sandstone, of estuarine to deltaic origin, conformably overlies the Pindiga Formation and marks the youngest Cretaceous unit in the basin. The sequence is capped unconformably by the Paleocene Kerri Kerri Formation, the sole Tertiary deposit in the Gongola Basin (Dike, 1993).

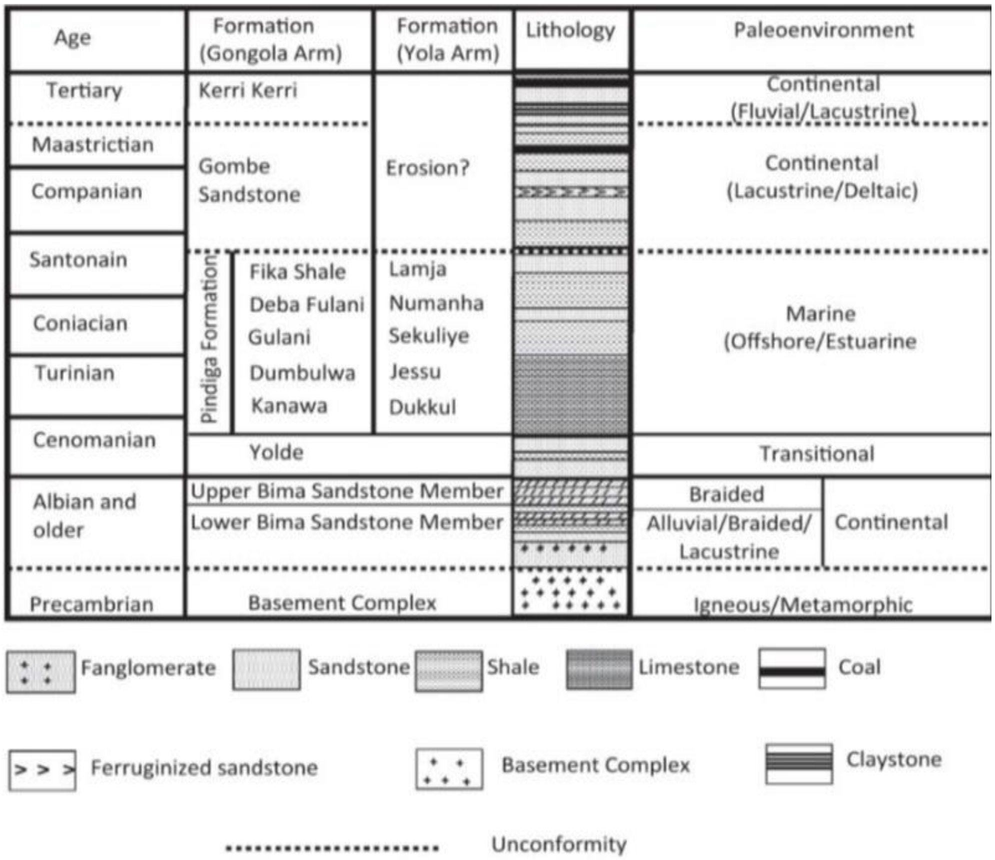

Figure 2: Stratigraphy succession of Benue Trough (Tukur et al. 2015)

MATERIALS AND METHODS

Fieldwork commenced with reconnaissance of the Gombe Formation to identify suitable outcrops and establish stratigraphic context. Outcrops were examined for lithology, texture, color, bedding structures, and weathering, following standard geological survey protocols (Compton, 1985; Tucker, 2011). Thirteen representative samples were systematically collected from fine-grained sedimentary units (shales, siltstones, and mudstones) for palynological and foraminiferal analyses. Fresh, unweathered material was extracted using a geological hammer and chisel, with each sample labeled, bagged, and documented with GPS coordinates, lithologic descriptions, and stratigraphic positions in accordance with micropaleontological sampling guidelines (Batten, 1999). Laboratory preparation for foraminifera involved drying, kerosene soaking, wet sieving (63 µm mesh), and separation into four size fractions for micropaleontological picking and identification. Palynological processing entailed acid digestion (HCl, HF), heavy liquid separation with zinc bromide (SG 2.2), oxidation (HNO_3), and KOH treatment to remove humic acids. Final organic residues were sieved, mounted on slides with PVA/resin, and labeled for microscopic examination of palynomorphs. All procedures adhered to industry-standard and published methodologies, ensuring stratigraphic precision and microfossil preservation.

RESULTS AND DISCUSSION

Presentation of Results

Lithostratigraphy

The Gombe Formation in the Gongola Sub-basin exhibits well-developed coarsening-upward cycles across all studied sections (Figure 3). Each cycle typically begins with thick claystone/mudstone (0.6–1.7 m) at the base, overlain by interbedded fine-grained sandstone and whitish to grey shale/claystone, and capped by thick light-brown fine- to medium-grained sandstone. Bioturbation is common in the greenish to brownish shale intervals, with *Thalassinoides* burrows being the most frequent trace fossil.

At the Gabukka stream section, the succession is overlain by vertically stacked, red to maroon massive sandstones (1.3–3.1 m thick), medium- to coarse-grained, and often ferruginized. Ironstone horizons occur sporadically, and many sandstones show ferruginization with occasional trace fossils. The bioturbated mudstone facies, grey to dark grey at the base and whitish at the middle to upper parts, reflects deposition under low-energy conditions, characteristic of offshore marine settings below storm wave base, but also possible in quiet lacustrine, lagoonal, tidal flat, or delta.

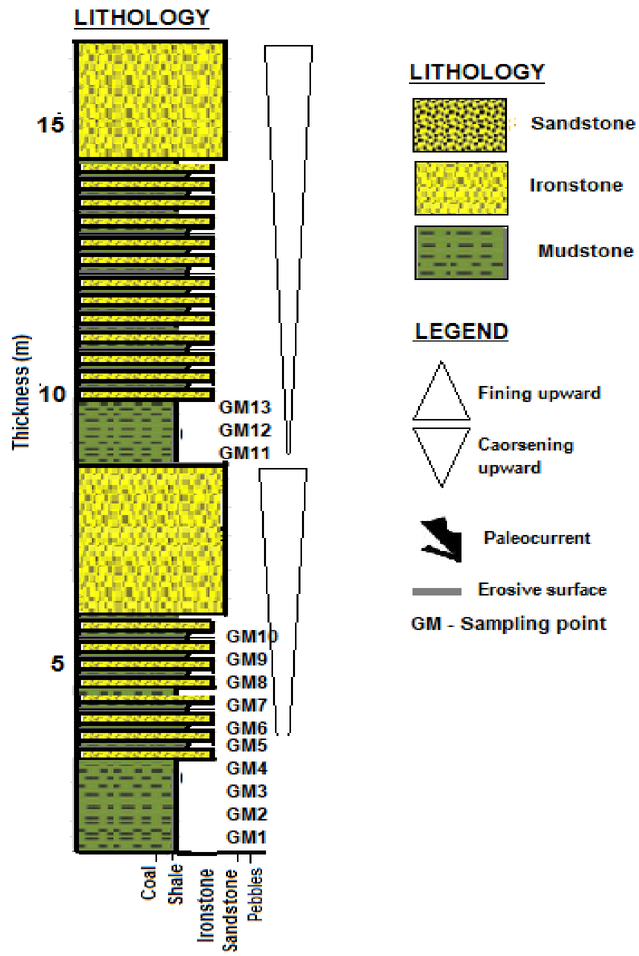

Figure 3: Lithostratigraphic section of the lower (basal) part of Gombe Formation at Gabukka stream(latitude 10°18’05’’ N, Longitude 11°12’14.6’’E)

Figure 4: Field photograph showing (i-iii) the sandstone interbedded with mudstone and trace fossils and (iv) mudstonefacies at gabukka stream, Gongola Basin(latitude 10°18’05’’ N, Longitude 11°12’14.6’’E)

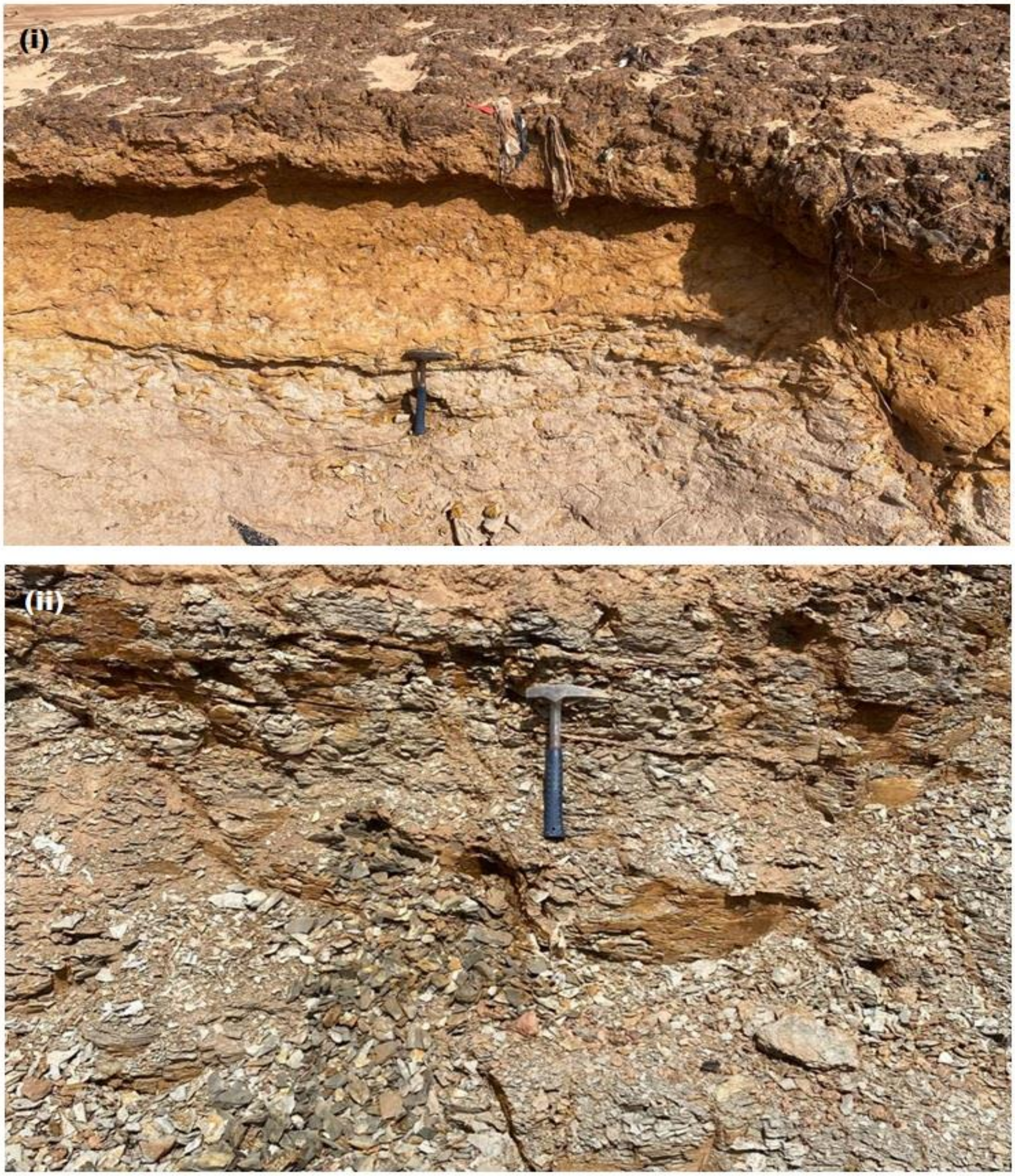

Figure 5: Field photograph showing (i) ironstone with ferrogenisation at top and mudstone at base and (ii) mudstone facies where samples were collected(latitude 10°18'05'' N, Longitude 11°12'14.6''E)

Palynological Analysis

Palynological analysis of the samples revealed a generally low abundance of palynomorphs (Table 1). The assemblage is dominated by terrestrially derived taxa, including *Tricolporopollenites* sp., *Ephedripites* sp., *Proteacidites dehaani*, *Cingulatisporites ornatus*, *Cyathidites minor*, *Gleicheniidites senonicus*, and *Distaverrusporites simplex*. Freshwater algal remains (*Botryococcus braunii*), fungal spores, charred grass (*Graminae*) cuticles, and diatom frustules were recorded in minor quantities. The overall scarcity of palynomorphs, combined with the presence of freshwater algae and diatoms, suggests deposition under marginal to non-marine conditions, possibly influenced by fluvial or lacustrine environments (Figure 4).

Table 1: Palynomorphs Records and Counts Base on this Study

S/N	Palynomorphs	Counts	Type
1	*Polypodiaceoisporites sp.*	1	S
2	*Cyathidites minor*	8	S
3	*Tricolporopollenites sp.*	11	P
4	*Cingulatisporites ornatus*	6	S
5	*Monosulcites sp.*	2	P
6	*Laevigatosporites sp.*	7	S
7	*Fungal spores*	28	FS
8	*Ephedripites sp.*	3	P
9	*Zlivisporites blanensis*	4	S
10	*Tricolpites sp.*	2	P
11	*Diatom frustules*	22	DF
12	*Graminidites sp.*	3	P
13	*Monocolpites marginatus*	2	P
14	*Proteacidites dehaani*	2	P
15	*Botryococcus braunii*	20	FWA
16	*Charred graminae cuticle*	7	CGA
17	*Distaverrusporites simplex*	3	S
18	*Proxapertites operculatus*	2	P
19	*Longapertites sp*	1	P

P=Pollen, S=Spore, FS= Fungal Spores, DF= Diatom Frustules, FWA=Fresh Water Algae CGC=Charred Graminae Cuticle

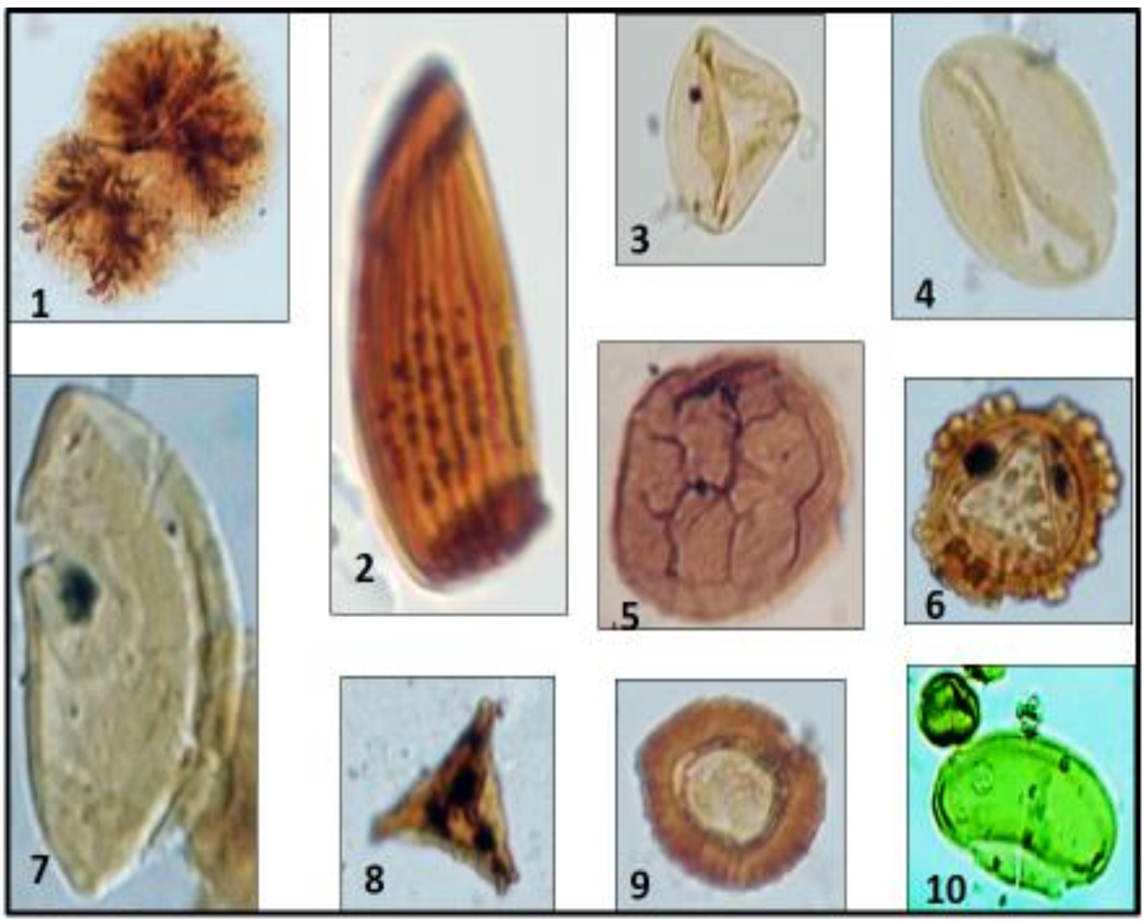

Figure 6: photomicrographs of palynomorphs facies showing (1) *Botryococcus braunii (2) Ephedripites sp. (3) Cyathidites minor (4) Monocolpites marginatus (5) Zlivisporites blanensis (6) Distaverrusporites simplex (7) Longapertites sp (8) Tricolporopollenites sp (9)Cingulatisporites ornatus (10) Laevigatosporites sp.*

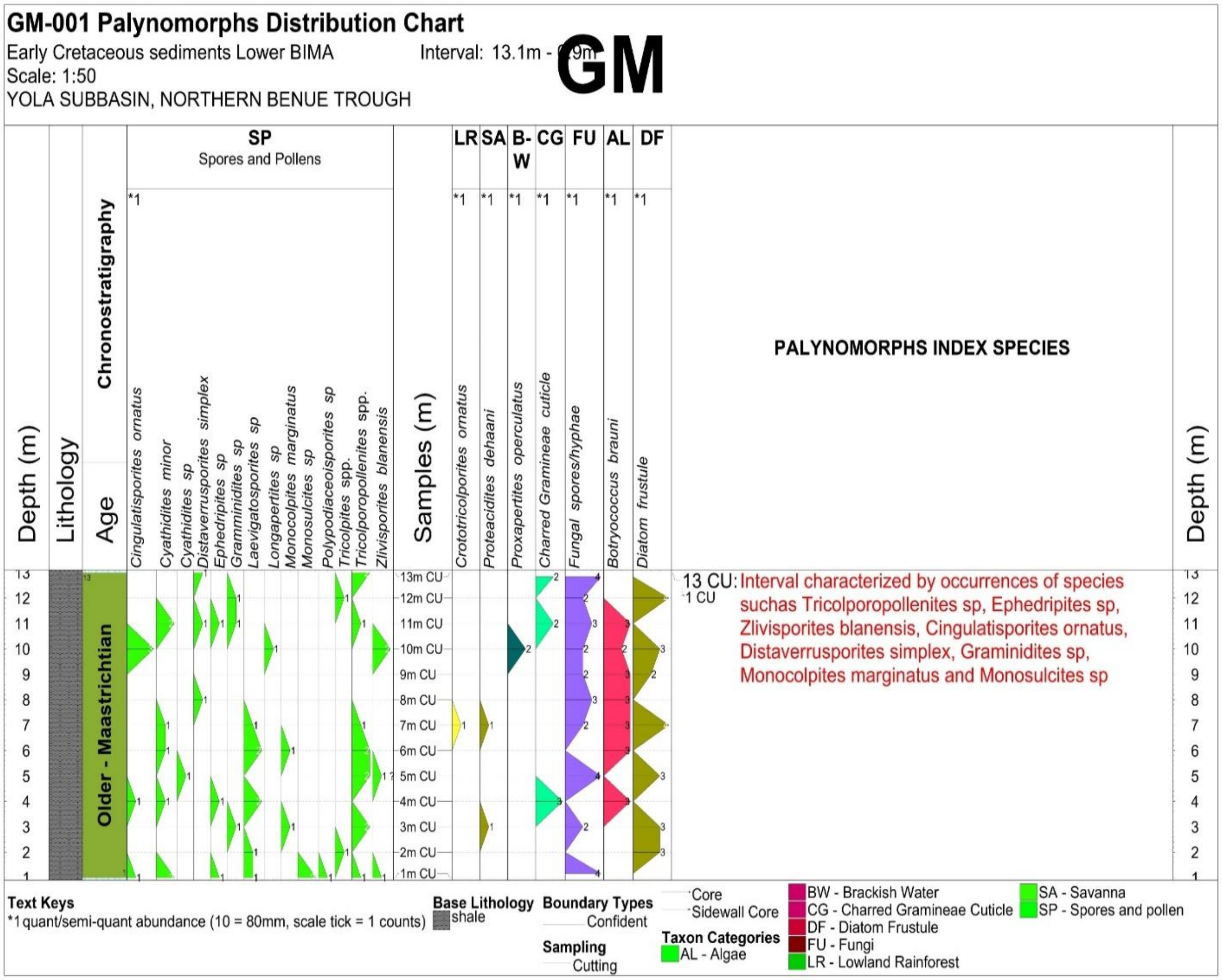

Figure 7: Palynomorphs Distribution Chart Base on this Study

Foraminiferal Biostratigraphy

Foraminiferal recovery are generally low to moderate, with assemblages dominated by arenaceous benthic taxa. No calcareous (planktic or benthic) species were recorded, a condition likely attributable to the depositional environment and the limitations of weathered outcrop material. Outcrop sampling, restricted to exposed strata, is prone to diagenetic alteration and mechanical weathering, which can result in poor preservation, low confidence data, and reduced biostratigraphic resolution.

Age determinations were guided by the stratigraphic frameworks of Blow (1969, 1979), Petters (1979, 1982, 1995), and Bassey (1991). Although planktic species were absent, the stratigraphically well-constrained arenaceous benthic foraminifera known from Nigerian sedimentary basins were used for age assignment. Key species recorded include *Miliammina inflata*, *Haplophragmoides bauchensis*, *H. hausa*, *H. excavata*, *H. talokaensis*, *Haplophragmoides* sp., *Trochammina texana*, *Trochammina* sp., *Reophax guineana*, and *Ammobaculites coprolithiformis*.(Figure 6)

Depositional environment interpretations were supported by comparison with established paleoenvironmental models (Adegoke et al., 1976; Petters, 1979, 1982, 1995; Murray, 1991).

Table 2: Detail Result of Foraminiferal Analysis Base on this Study

S/N	Foraminifera	Count	Type
1	*Ammobaculites coprolithiformis*	3	AB
2	*Haplophragmoides excavata.*	14	AB
3	*Haplophragmoides hausa*	22	AB
4	*Textularia sp.*	16	AB
5	*Arenaceous indeterminate*	9	AB
6	*Trochammina sp*	5	AB
7	*Haplophragmoides bauchensis*	6	AB

S/N	Foraminifera	Count	Type
8	*Haplophragmoides sp*	5	AB
9	*Miliammina inflate*	152	AB
10	*Bathysiphon sp.*	2	AB
11	*Haplophragmoides talokaensis.*	7	AB
12	*Trochammina texana*	5	AB
13	*Reophax guineana*	5	AB

AB= Arenaceous Benthic

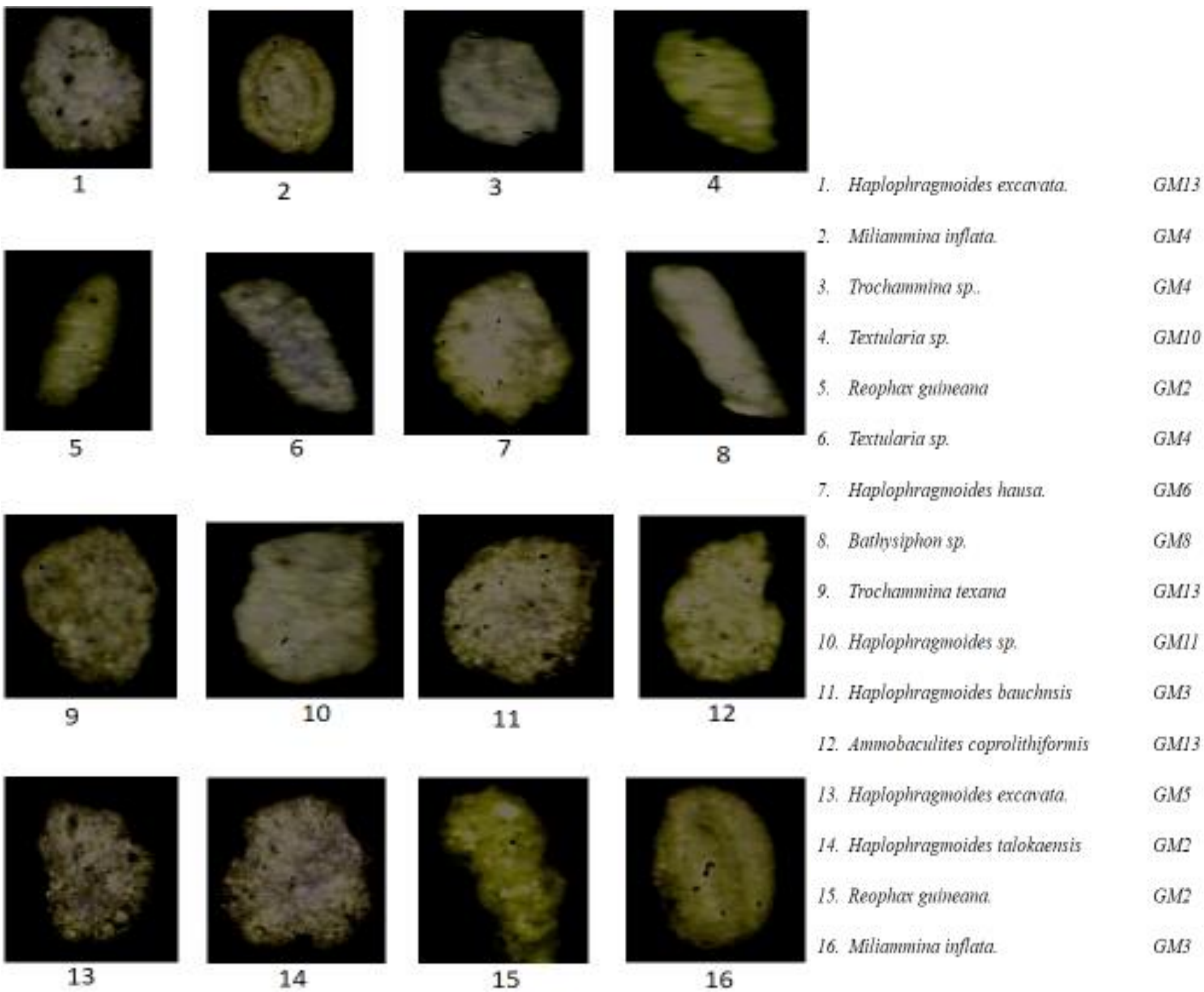

Figure 8: Photomicrograph of foraminifera spacies showing (1) *Haplophragmoides excavata. (2) Miliammina inflate (3) Trochammina sp (4) Textularia sp.(5) Reophax guineana (6) Textularia sp(7) Haplophragmoides hausa (8) Bathysiphon sp.(9) Trochammina texana (10) Haplophragmoides sp (11) Haplophragmoides bauchensis (12) Ammobaculites coprolithiformis (13) Haplophragmoides excavata. (14) Haplophragmoides talokaensis. (15) Reophax guineana (16) Miliammina inflate*

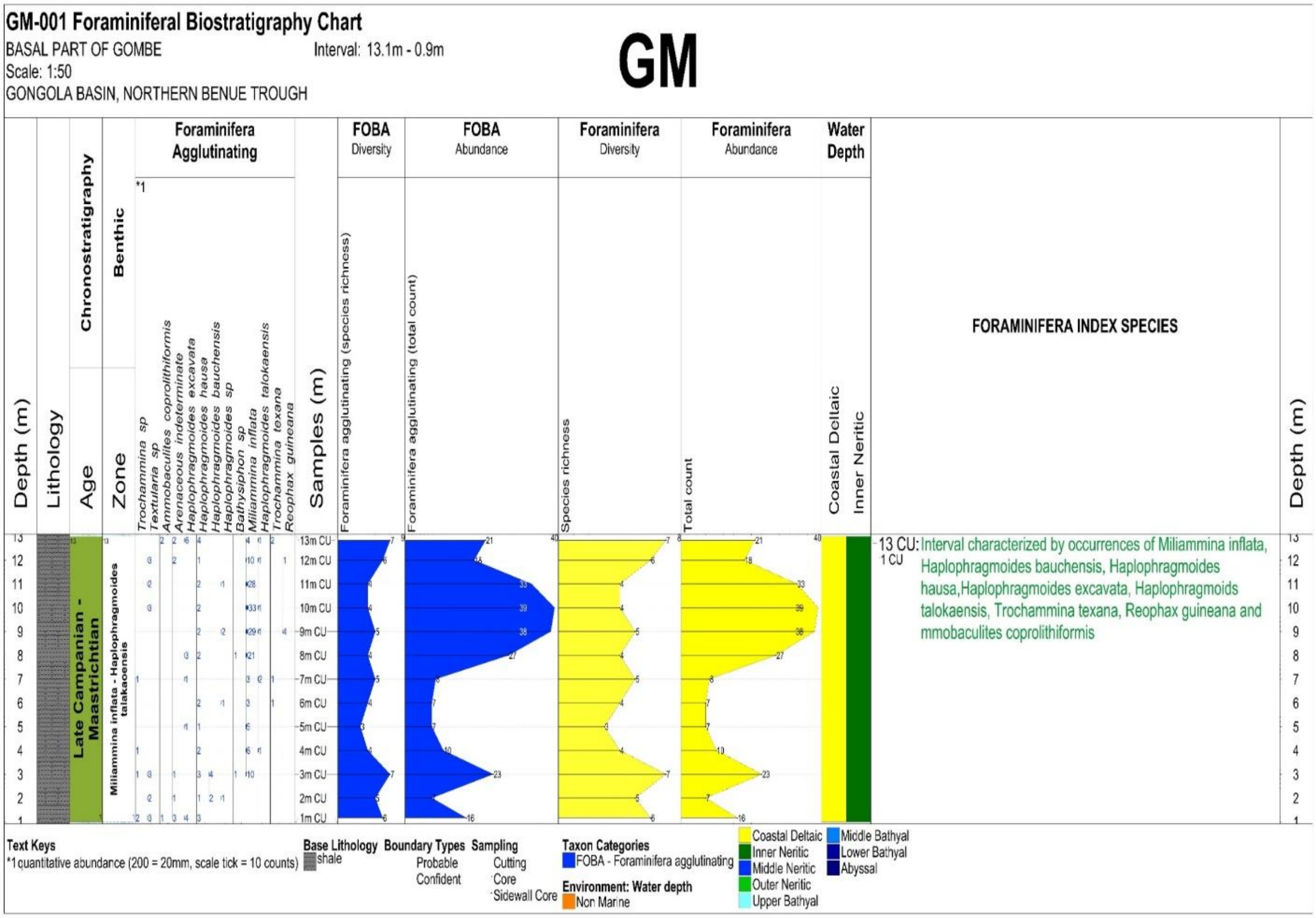

Figure 9: Foraminiferal Biostratigraphy Chart Base on this Study

Foraminiferal Colour Index

The Foraminiferal Color Index (FCI) is a thermal maturity indicator based on the progressive darkening of foraminiferal tests in response to increasing burial temperatures. Foraminifera are calcareous microfossils that are initially white to translucent when deposited. As sedimentary successions are buried, organic matter within or coating their tests undergoes thermal alteration, causing a gradual change in test coloration from pale yellow to brown and eventually to black.

This systematic color transformation is calibrated into a semi-quantitative scale, ranging from FCI 1 (white to pale yellow; <50 °C, thermally immature) through FCI 4–6 (brown to dark brown; 80–140 °C, oil window) to FCI 10 (opaque black; >200 °C, overmature/dry gas zone). Thus, FCI provides direct evidence of maximum paleotemperature conditions experienced by sediments.

The method is particularly valuable in carbonate-rich successions where vitrinite reflectance data are scarce or absent. It is widely applied in hydrocarbon exploration to determine whether strata have entered the oil or gas windows, and it complements other maturity indicators such as vitrinite reflectance, Conodont Alteration Index (CAI), and Palynomorph Thermal Alteration Index (TAI).

Despite its usefulness, FCI is semi-empirical and subject to observer bias in color assessment, and its reliability can be affected by diagenetic overprints such as recrystallization or oxidation. Nevertheless, when integrated with other thermal maturity parameters, FCI provides an effective and inexpensive tool for basin modeling, petroleum system evaluation, and thermal history reconstruction

Table 3: Foraminifera Colour and Interpretation Potential

S/N	Sample No	Foraminiferal colour index (from munsell colour system	FCI value	Estimated Temperature (C)	Interpretation Potential
1	GM2	White to vary pale yellow	2	45	Immature(pre-oil window)
2	GM3	White to vary pale yellow	2	40	Immature(pre-oil window0
3	GM4	Pale yellow	4	55	Onset of hydrocarbon generation
4	GM6	White to vary pale yellow	2	45	Immature(pre-oil window)
5	GM8	White to vary pale yellow	2	40	Immature (pre-oil window)
7	GM10	Pale yellow	5	60	Onset of hydrocarbon generation
8	GM11	White to vary pale yellow	2	45	Immature (pre-oil window)
9	GM13	White to vary pale yellow	2	50	Immature (pre-oil window)

Biostratigraphy

The foraminiferal assemblage that characterized these samples are mostly arenaceous species and this includes*:* *Miliammina inflata*, *Haplophragmoides bauchensis, Haplophragmoides hausa, Haplophragmoides excavata, Haplophragmoids talokaensis, Trochammina texana, Reophax guineana* and *Ammobaculites coprolithiformis*. This assemblage had been reported in some of the sedimentary basins in Nigeria.

Haplophragmoides hausa has been reported in the Maastrichtian part of Nkporo shale in the Calabar Flank (Bassey, 1991), Abundant occurrence of this species was first reported from the Dukamaje Formation in the Sokoto Basin (Petters; 1979a)

Haplophragmoides excavata has been reported in the Coniacian part of Nkalagu Formation and Maastrichtian Nkporo Shale (Petters 1982, Bassey 1991). Originally described from the American Gulf Coast, this species has been reported from Coniacian to Maastrichtian of North America. (Sliter 1972). The species has also been reported in the Paleocene sediment of the Niger Delta where it has its extinction level (Last stratigraphic appearance).

Ammobaculites coprolithiformis has been reported from the Upper Cretaceous of North America and in the Jurassic – Early Cretaceous of Europe (Gordon, 1965). In Nigeria, this species occurs in abundance in Pindiga Shale and Fika Shale of the Benue Trough as well as in Dukamaje Formation of the Sokoto Sandstone of Nupe Basin (Petters, 1982). This species was also reported in the Maastrichtian part of Nkopro shale in the Calabar Flank (Bassey, 1991).

Trochammina texana has been reported by Silter (1972) from the Campanian - Maastrichtian of North America. This species was also reported from the Maastrichtian part of Nkporo shale (Bassey, 1991)

On the basis of above foraminiferal associations, the studied samples from the Gombe Formation is assign Late Campanian to Maastrichtian age

Table 4: Foraminiferal Biostratigraphic Summary showing the Important Foraminiferal INDEX SPECIES

Depth (m)	Epoch/Period	Age (Ma)	Benthic Zones	Significant Index Species
GM1 – GM13	Late Campanian - Maastrichtian	66.0 - 75.0	*Haplophragmoides talakaoensis – Miliammina inflate*	Interval characterized by occurrences of *Miliammina inflata*, *Haplophragmoides bauchensis, Haplophragmoides hausa, Haplophragmoides excavata, Haplophragmoids talokaensis, Trochammina texana, Reophax guineana* and *Ammobaculites coprolithiformis.*

Paleoenvironment

The interpretation of the paleoenvironment of the outcrop samples were inferred mainly from foraminiferal assemblage. The depositional environment of the samples are predominantly marginal marine (fluvio marine) to shallow Inner Neritic settings based on the recorded foraminiferal assemblage dominated by arenaceous benthic species such as *Miliammina inflata*, *Haplophragmoides bauchensis, Haplophragmoides hausa, Haplophragmoides excavata, Haplophragmoids talokaensis, Trochammina texana* and *Ammobaculites coprolithiformis*.

The above foraminiferal association inditates marginal marine (fluvio marine) to shallow Inner Neritic environments (Adegoke *et. al* 1976, Petters 1979, 1982).

The family Lituolidae represented by the genera *Haplophragmoides, Ammobaculites* and *Trochammina* was recorded in this sample. Murray (1991) noted that high percentages of these genera indicate brackish water. Low diversities in foraminiferal assemblages (as recorded in the sample) are also characteristic of modern lagoons and estuaries (Murray, 1991). Whightman, (1990) noted that the foraminifera of the Cretaceous sediments of the Lusitanian Basin, Portugal which consist dominantly of *Ammobaculites, Haplophragmoides* and *Trochammina* indicates estuarine and marsh depositional environments. The occurrence of *Ammobaculites* in certain Cretaceous sediments shows its tolerance to low oxygen levels (Koutsoukos *et al.* 1990). The absence of planktic foraminiferal species in these samples confirms a transitional, brackish water, marsh – lagoonal environment for the lower Bima shales. The genus *Haplophragmoides* is commonly found in muddy to sandy substrates in environments ranging from marsh hyposaline lagoons and estuaries to bathyal (Murray, 1991).

The complete absence of calcareous benthics in the entire samples is indicative of anoxia as oxygen is required in the reaction leading to formation of the calcium carbonate tests. The dominance of arenaceous foraminiferal species in shallow water limestone and micaceous shales in the Benue Trough have been used by Petters (1980) to suggest shallow water habitat for the Nkalagu limestone exposed at the quarry site. The dominance of agglutinated foraminiferal species also suggest restricted, low oxygen bottom water conditions.

Adegoke *et al* (1976) have inferred near shore turbulent environment in the modern Niger Delta on the basis of arenaceous foraminiferal species of *Ammobaculites, Haplophragmoides* and *Trochammina* to be associated with near shore lagoonal environment of the Niger Delta. On the basis of the arenaceous foraminiferal assemblage recorded in the outcrop samples analyzed indicates marginal marine to proximal Inner Neritic settings.

Gremer (1974) also presented evidence that availability of calcium carbonate (CaCO3) controls the distribution of shell types. Agglutinated foraminifera which have least demand for carbonate for their shell construction are most abundant in hyposaline conditions (typical of marginal marine environment) and below calcite compensation depthg (CCD); miliolids are largely confined to hypersaline conditions (tropical, shallow water) and hyaline forms are found everywhere. Majority of foraminifera are adapted to normal marine salinities and it is in such conditions that assemblages with highest diversity are found. The triangular plots of the relative proportions of *Textularina, Miliolina* and *Rotalina* of the samples analyzed (Figure) indicate hyposaline conditions of depositional environment. The foraminiferal assemblages in the samples analyzed were dominantly arenaceous species. The dominance of arenaceous foraminifera are known to thrive well in moderate salinity and high temperature conditions.

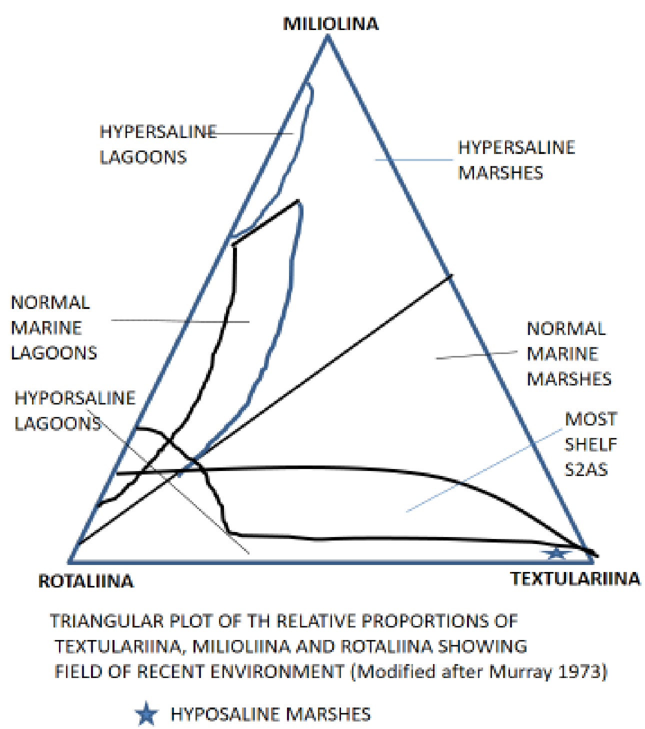

Figure 10: The triangular plots of the relative proportions of Textularina, Miliolina and Rotalina of the samples analyzed indicating hyposaline depositional condition

Thermal maturity

Palynofacies analysis of the GM samples indicates that the organic matter is dominated by terrestrially derived palynomorphs (e.g., *Tricolporopollenites*, *Cyathidites minor*, *Zlivisporites blanensis*, fungal spores, and charred cuticles), consistent with Type III kerogen that is gas-prone and associated with fluvio-deltaic to marginal marine settings (Tyson, 1995; Peters & Cassa, 1994). Minor contributions of the freshwater alga *Botryococcus braunii* suggest localized input of oil-prone Type I/II kerogen (Peters et al., 2005), though subordinate to the terrestrial signal. The assemblage, together with abundant woody debris and fungal spores, implies deposition under oxygen-restricted, low-energy conditions favorable for organic matter preservation. The absence of amorphous organic matter and the preservation state of palynomorphs indicate immature to early mature thermal stages (Bustin, 1988). Overall, the GM interval is gas-prone with limited oil potential, though deeper or more mature parts of the basin may yield greater oil potential.

CONCLUSION

This study integrates lithostratigraphic, palynological, and foraminiferal data from thirteen outcrop samples (GM-1 to GM-13) of the Gombe Formation, Gongola Sub-basin, to establish the age and palaeoenvironment of the succession. The section comprises repeated coarsening-upward cycles from basal claystone/mudstone to interbedded siltstone and fine sandstone, locally capped by medium–coarse sandstone. Bioturbated greenish–brown shales with *Thalassinoides*, ironstone horizons, and sporadic ferruginous sandstones indicate fluctuating depositional energy within a prograding nearshore system. Palynomorph assemblages, including Maastrichtian markers (*Tricolporopollenites* sp., *Cingulatisporites ornatus*, *Zlivisporites blanensis*, *Proteacidites dehaani*, *Distaverrusporites simplex*), and arenaceous benthic foraminifera (*Haplophragmoides* spp., *Miliammina inflata*, *Trochammina* spp., *Ammobaculites coprolithiformis*, *Reophax guineana*) indicate a Late Campanian–Maastrichtian age, with stronger evidence for the Maastrichtian. Facies and microfossil data suggest deposition in a marginal-marine to shallow inner-neritic setting influenced by deltaic/estuarine progradation, high terrestrial input, intermittent freshwater influx, and dysoxic bottom conditions. Limitations include uneven fossil recovery in some samples, absence of calcareous foraminifera, and outcrop weathering, which reduce stratigraphic resolution.

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