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BIOSTRATIGRAPHY, PALEOENVIRONMENT AND HYDROCARBON POTENTIAL OF FIKA MEMBER OF PINDIGA FORMATION, GONGOLA SUB-BASIN, NORTHERN BENUE TROUGH, NE NIGERIA

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ABSTRACT

The Fika Member, a crucial stratigraphic unit within the Pindiga Formation, represents a significant geological entity with substantial implications for understanding the regional paleoenvironmental evolution and hydrocarbon prospectivity. This study integrates biostratigraphic analyses, sedimentological investigations, and hydrocarbon potential assessments to elucidate the depositional history, paleoenvironmental conditions, and source rock prospect of the Fika Member. Facies and their stratigraphical distribution analyses were conducted on the Fika Shale exposed mainly at Gabukka Stream 1 and 2. Twenty (20) samples collected were subjected for standard palynological and foraminifera analyses. A standard method of palynomorphs extraction that involves the use of Hydrofluoric and Hydrochloric acid was employed. For foraminifera analysis, washing and sieving method was used. It was discovered that agglutinated foraminifera are the dominance taxa in ten (10) out the twenty (20) samples studied. Based on the colours of the agglutinated foraminiferal and Foraminiferal Color Index (FCI) values suggest low thermal maturity for both oil and gas generation**.** The foraminiferal assemblages indicate marginal marine (fluvio marine) to shallow inner neritic environments. This is supported by the sedimentological data which indicates a shallow marine depositional environment. The biostratigraphic data suggest Santonian age for the Fika Member.

Keywords: Facies, Biostratigraphy, Paleoenvironment, Fika Member, Gongola Basin

INTRODUCTION

The Gongola Sub-basin of the Northern Benue Trough is one of the Nigerian frontier inland basins (Fig. 1) where an exploration activity is ongoing. It is also part of the West and Central African Rift System (WCARS). Over the past four decades, exploration efforts in Nigeria primarily centered around the Niger Delta following the initial discovery of hydrocarbons in commercial quantities. However, there has been a recent shift in focus towards the Benue Trough located in northern Nigeria (Abubakar, 2008). The Benue Trough has significant petroleum potential and based on the foregoing, exploration activities in the Benue Trough began in the 1970s. These efforts have revealed the presence of hydrocarbon-bearing formations particularly in the Gongola sub-basin of the Northern Benue Trough. The basin is a possible petroliferous region and therefore, there is a need for proper evaluation of its petroleum prospects.

Among the geological formations in the Gongola Sub-basin, the Fika Member of the Pindinga Formation has gained attention due to its sedimentary and stratigraphic significance. However, despite its importance, there is a lot of controversy relating to its stratigraphic position due to lack of comprehensive studies that investigate the age, depositional conditions, and hydrocarbon potential of this specific geological unit. The Pindiga Formation of the Gongola Sub-basin is considered to serve as source rock, reservoir rock and seal rock for the Lower and Upper Cretaceous petroleum systems. It is divided into members for easy identification. The Fika Shale or Fika Member is a sequence of shales intercalated with mudstone. The age of Fika Member is still controversial, for instant, Zaborski et al; (1998) suggested late Turonian to perhaps early Maastrichtian age. However, large part of Africa was affected by the mid-Santonian compression event (Guiraud and Bosworth, 1997). Therefore, it is believed that the Fika Member consists of two distinct parts: the lower portion, believed to have been deposited during the Late Turonian to Early Santonian in brief marine conditions, and the upper portion, dating from the Late Campanian to Early Maastrichtian.

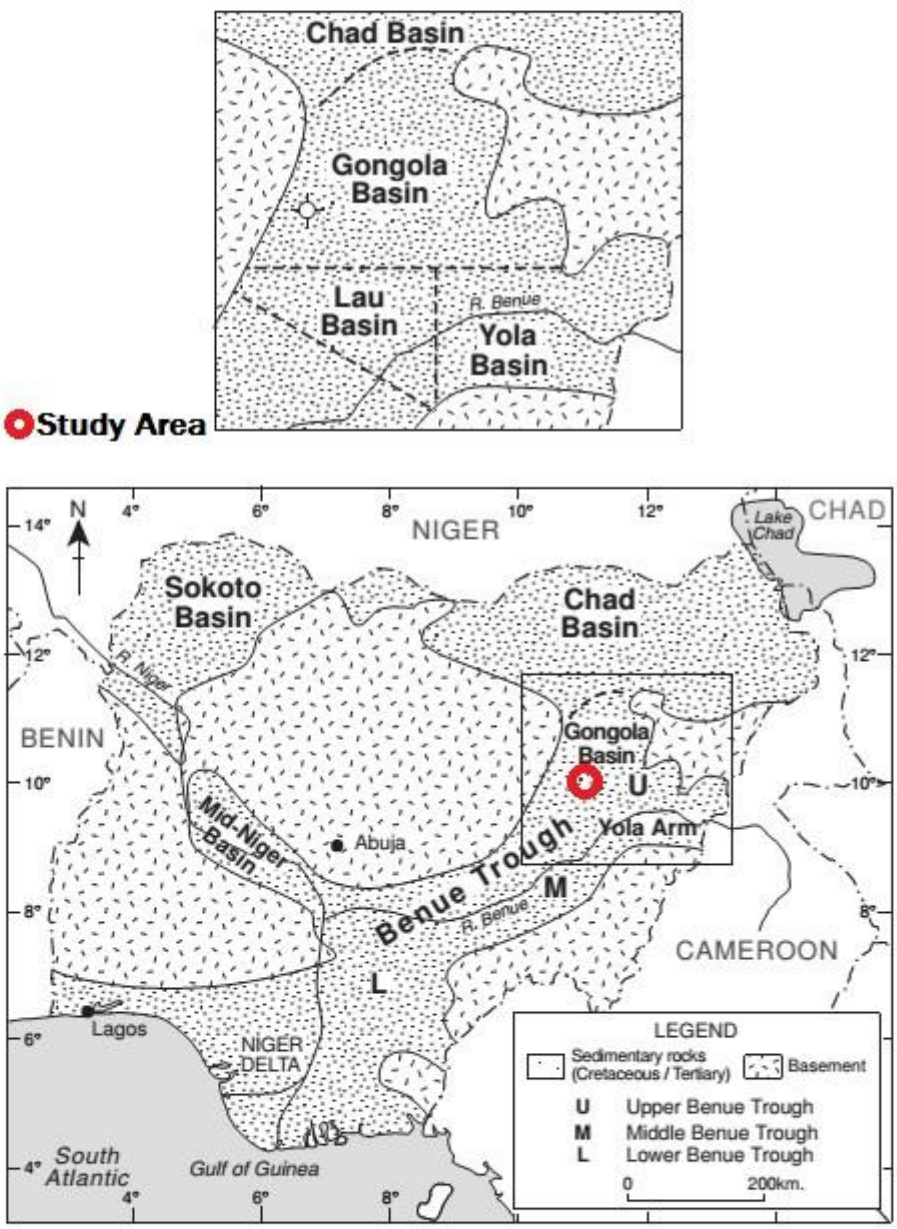


Figure 1: Generalised geological map of Nigeria showing the location of the Gongola Basin and the study area (after Abubakar, 2006)

This research will attempt to study the biostratigraphy, interpret paleoenvironments of deposition and determine hydrocarbon potential of the Fika Member of Pindiga Formation in the Gongola Sub-basin. The study will integrate outcrop sedimentological data and laboratory analyses and the outcomes of the study are expected to give new insight on hydrocarbon potential, depositional environment and stratigraphy of the Fika Member of Pindiga Formation of the Gongola Subbasin.

Geologic Setting

The Benue Trough is a major rift basin within Nigeria. It was formed from the tension generated due to the separation of South American and African plates in Late Jurassic to Early Cretaceous (King 1950). It spans approximately 1000 kilometers in length and 150 kilometers in width. Several authors have proposed various tectonic models to explain the formation of the Benue Trough. For instance, King, (1950) suggested tensional forces leading to a rift structure, while Stonley, (1966) proposed a graben-like configuration. Grant, (1971) introduced the Rift-Rift-Failed (RRF) triple junction model, which suggests plate dilation and the consequent opening of the Gulf of Guinea. Additionally, Olade, (1975) regarded the Benue Trough as either the third failed arm or aulocogen of a three-armed rift system associated with hotspot activity. The Benue Trough is part of the mega-structure termed "West and Central African Rift System" (WCARS). It is filled with sediment up to 6000m depths of Cretaceous-Paleogene associated with some Tertiary volcanics (Carter et al; 1963, Abubakar, 2006). It is sub-divided geographically into Southern, (Lower) Central (Middle) and Northern (Upper) Benue portions (Nwajide, 2013; Abubakar, 2014).

The Northern Benue Trough comprises two primary sub-basins: the Gongola Sub-basin, which trends North-South, and the Yola Sub-basin, which trends East-West. The study area lies in North East Nigeria. Gongola Basin is part of the NNE-SSW trending rift basin containing about 6000m of thick Cretaceous-Tertiary sedimentary rocks. These strata include Bima, Yolde, Pindiga, Gombe and Kerri-Kerri formations. The Bima Formation was interpreted as continental (alluvial, braided river and lacustrine) and it is followed by the transitional coastal to shallow marine sediments of the Yolde Formation. Marine Cenomanian to Santonian sequences of Pindiga Formation were deposited conformably on Yolde Formation. The Fika Member of Pindiga Formation (Fig. 2) is exposed in several areas within the basin due to various tectonic events in the Upper Benue Trough of northeastern Nigeria.

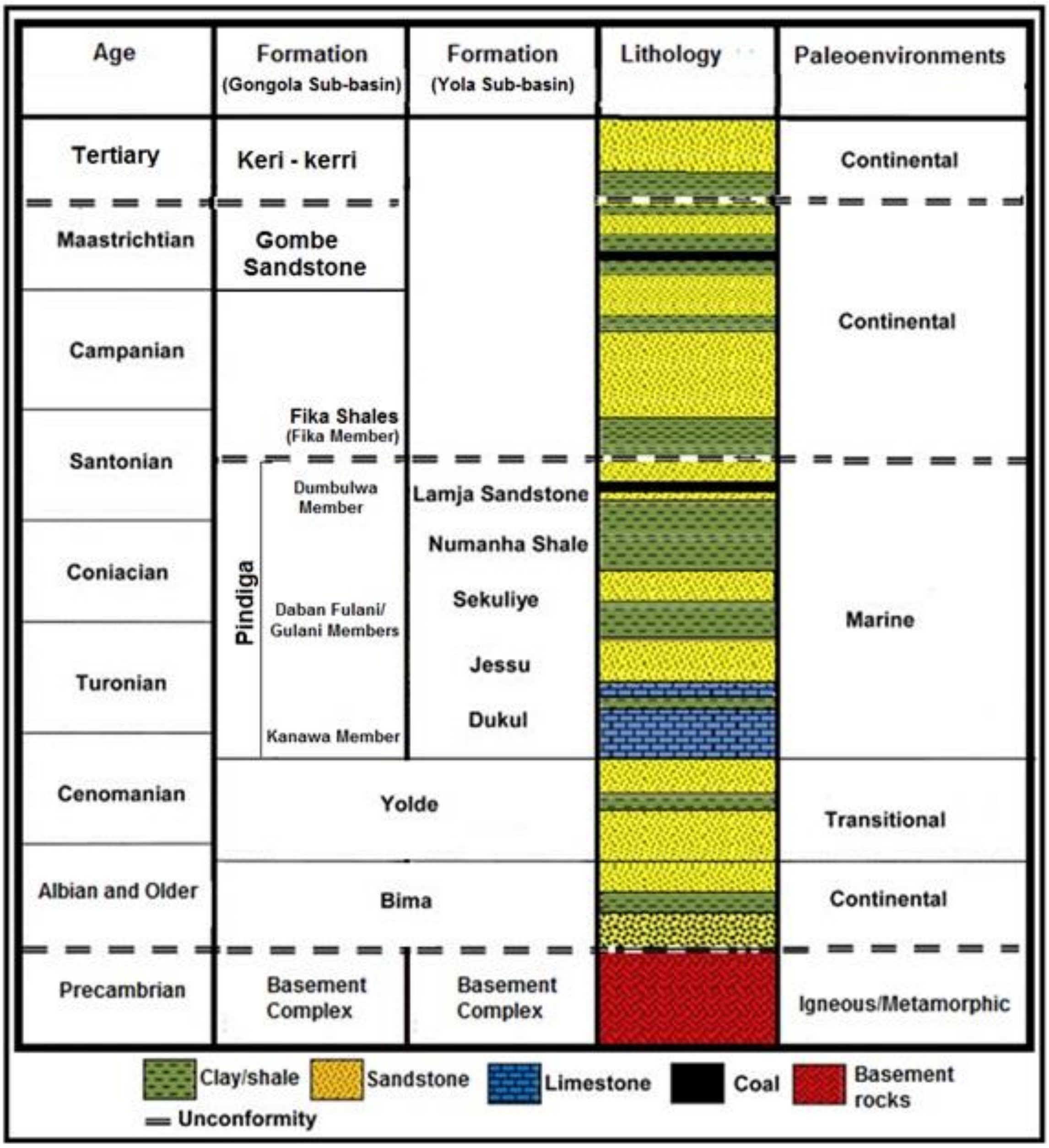


Figure 2: Stratigraphic succession of the Northern Benue Trough with special reference to the Gongola Basin (after Sarki Yandoka, 2015)

MATERIALS AND METHODS

Fieldwork was carried out in the Gongola Sub-basin and strata of Fika Member were logged. Sedimentological information such as grain size, fossil content, lithology type were recorded in field notebook. A total of twenty (20) outcrop samples of shales were collected for further laboratory studies. Ten (10) out the 20 samples collected were subjected to standard palynological and foraminifera analyses. For foraminifera analysis, approximately 20 grams of each sample were immersed in kerosene within a clean, dry aluminum bowl for 24 hours to facilitate disaggregation. Subsequently, they underwent washing through a 63 µm sieve to eliminate coagulated particles, followed by placing the fine residues on filter papers for drainage and subsequent oven drying at 40°C. The dried samples were then fractionated through 250 µm, 125 µm, and 63 µm sieves for convenient sorting. Using a size 00 brush under a binocular stereo microscope, the samples were meticulously sorted. All selected specimens were then affixed to micropalaeontological slides for quantitative analysis.

For the Palynological and palynofacies analysis, twenty (20) samples (F2-F21) were prepared using standard palynological analysis employed dilute Hydrochloric acid (HCl), concentrated Hydrofluoric acid (HF), and Nitric acid

(HNO3). These agents were utilized to eliminate carbonate minerals, silicate minerals, and concentrate the palynomorphs, respectively. Neutralization of the acidic reaction was achieved using Potassium hydroxide (KOH) and distilled water. Subsequently, the residue rich in palynomorphs was affixed to labeled glass slides using Norland adhesive mounting medium for microscopic examination.

For Palynofacies processing, Nitric acid (HNO_3) was omitted from the procedure, and the unoxidized residue was affixed to cover slips and mounted on glass slides using Norland adhesive. Particulate organic matter (palynofacies) has proven valuable in deducing depositional environments (Lukaye, 2008; Oyede, 1991). Palynomaceral types PM-1, PM-2, PM-3, PM-4, and Structureless Organic Matter (SOM) as classified by Oyede, (1991) were identified and subsequently correlated to the Herbaceous, Woody, Coaly and Amorphous particulate types of Staplin, (1969) using transmitted light microscope. The abundances and size variations of these components were analyzed to interpret the potential paleoenvironment of sample deposition, in conjunction with the retrieved sporomorphs. The colour variations of palynomacerals (e.g. kerogen) in the strewn slides are also useful in approximating the hydrocarbon generating potential of the source rocks (Staplin, 1969). This method is done in conjunction with the use of the standard Thermal Alteration Index (TAI).

RESULTS AND DISCUSSION

Lithostratigraphic Description

The Fika Member of Pindiga Formation is exposed at Kware/Gabukka stream sections. Two composite sections were logged in detail (Fig. 3). The sections consist of nodules and concretions intercalated with gypsum. The gypsum may be diagenetic whereas the shale is black to grey in color.

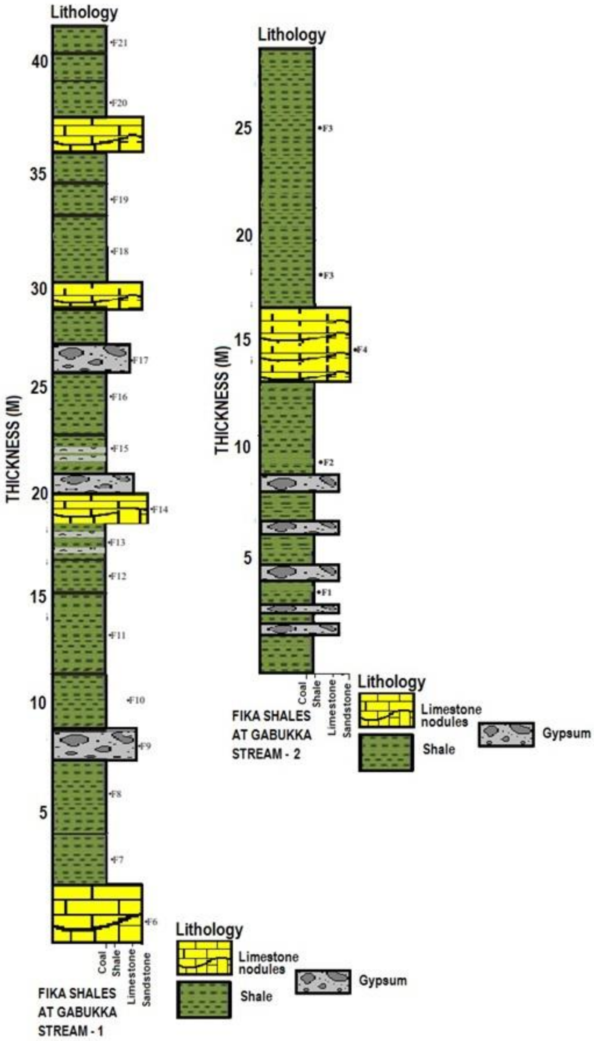


Figure 3: Lithologic logs of the Fika Shale outcropped at Gabukka Stream 1

Foraminiferal Analysis

The results of foraminiferal recoveries are generally good. Most of the samples were populated by arenaceous benthic species (Table 1). Calcareous species (planktic and benthic) were not recorded. This could be attributable to the depositional environments of the sediments. The benthic foraminifera recorded include *Miliammina pindigensis*, *Ammomarginulina emir*, *Ammobaculites bauchensis*, *Ammobaculites pindigensis*, *Ammobaculites gombensis*, *Haplophragmoides excavata*, *Haplophragmoides pindigensis*, *Haplophragmoides bauchensis* and *Reophax guineana*. The foraminiferal dating of these outcrop samples were guided by the works of Blows, (1969, 1979) and Petters, (1979, 1982). Though, planktic foraminiferal species are absent in the samples but the arenaceous benthic foraminiferal species whose stratigraphic distributions have been well established in the Nigerian Sedimentary basins were used to assign ages (Fig 4).

Table 1: Detail results of Foraminiferal Analyses of ten (10) samples

S/N	Foraminifera	Count	Type
1	*Ammobaculites bauchensis*	44	AB
2.	*Ammobaculites pindigensis*	49	AB
3.	*Haplophragmoides bauchensis*	161	AB
4.	*Haplophragmoides excavata.*	71	AB
5.	*Bathysiphon sp*	17	AB
6.	*Reophax guineana*	36	AB
7.	*Ammoastuta nigeriana*	63	AB
8.	*Haplophragmoides pindigensis.*	67	AB
9.	*Arenaceous indeterminate*	50	AB
10	*Trochammina sp.*	8	AB
11	*Textularia sp.*	47	AB
12	*Ammobaculites gombensis*	7	AB
13	*Ammobaculites benuensis*	4	AB
14	*Haplophragmoides narivaensis*	18	AB
15	*Arenaceous indeterminate*	31	AB
16	*Miliammina pindigenesis*	19	AB
17	*Ammomarginulina emir*	13	AB

AB= Arenaceous Benthic

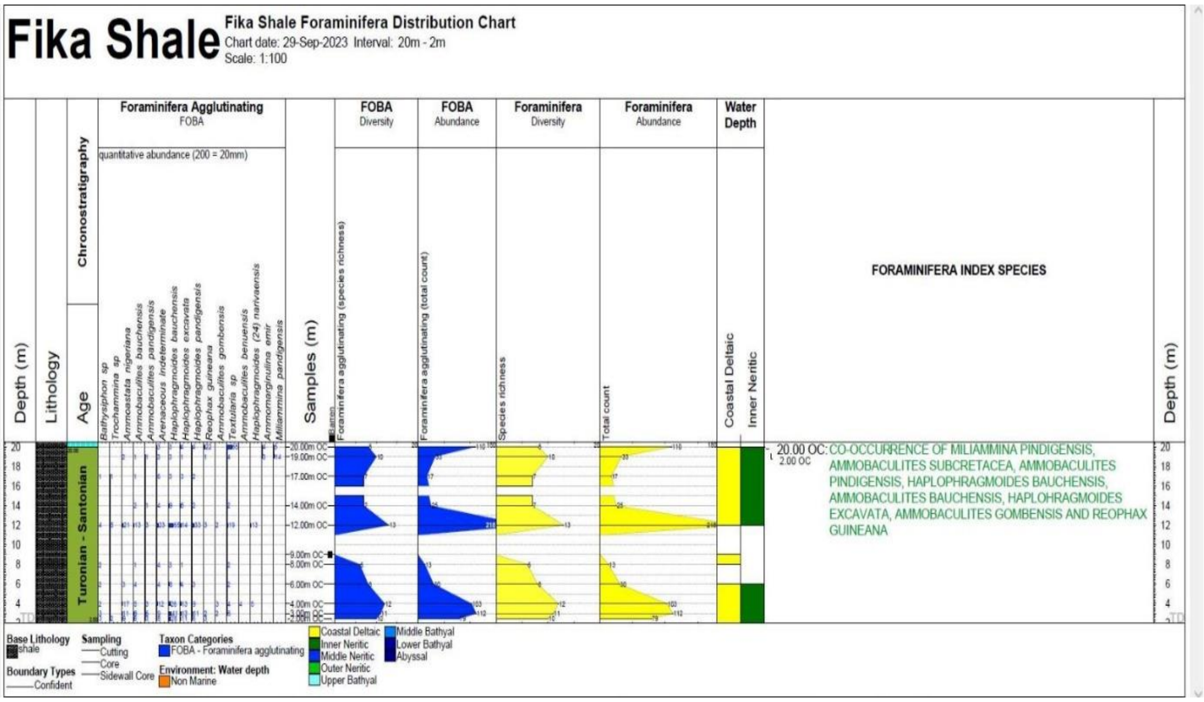


Figure 4: Fika Shale Foraminiferal Distribution Chart based on this study

Palynological Analysis

The twenty outcrop samples studied indicate poor palynomorphs recovery. Few frequency of land derived sporomorphs such as *Cyathidites minor*, *Tricolporopollenites* sp., *Cingulatisporites ornatus* and *Longapertites* sp. were recorded especially in samples F9, F10, F14, F16 and F19. Few occurrences of *Botryococcus braunii*, fungal spores and diatom frustules were also recognized. The studied samples (F2-F21) recorded low frequency of palynomorphs (Table 3; Figs. 6 and 7).

Table 2: Palynomorphs Records and Counts in the F2-F21 Samples

Samples	Palynomorphs	Counts	Type
F2	*Botryococcus braunii*	2	P
	Diatom frustules	3	P
	Monocolpites sp.	1	S
	Ephedripites sp.	1	P
	Cingulatisporites ornatus	2	S
F3	*Fungal spores*	2	S
	Charred Graminae Cuticle	1	CGC
F4	*Diatom frustules*	1	DF
	Fungal spores	2	S
	Cyathidites sp.	1	S
	Retimonocolpites sp.	1	P
F5	*Botryococcus braunii*	2	FWA
	Cyathidites sp.	1	S
	Laevigatosporites sp.		
F6	*Laevigatosporites sp.*	2	S
	Cyathidites minor	2	S
	Fungal spores	3	S
	Retimonocolpites sp	1	P
	Rugulatisporites caperatus	1	P
F7	*Cyathidites sp.*	1	S
	Tricolporopollenites sp.	1	P
	Fungal spore	2	S
F8	*Monocolpites sp.*	1	P
	Diatom frustules	2	DF
	Botryococcus braunii	2	FWA
F9	*Cingulatisporites ornatus*	2	S
	Laevigatosporites sp.	2	S
	Longapertites sp.	1	P
	(?) Gleicheniidites sp.	1	S
	Retimonocolpites sp.	2	P
	Fungal spores	1	S
F10	*Tricolporopollenites sp.*	2	P
	Cyathidites minor	2	S
	Polypodiaceoisporites sp.	1	S
	Monocolpites sp.	1	P
	Proteacidites sp.	1	P
	Zlivisporites blanensis	2	S
F11	*Inaperturopollenites sp.*	1	P
	Fungal spores	2	S
	Laevigatosporites sp.	1	S
F12	*Botryococcus braunii*	2	FWA
	Diatom frustules	2	DF
F13	Fungal spores	2	S
	Cyathidites sp.	1	S
F14	*Diatom frustules*	2	DF
	Charred Graminae Cuticle	2	CGC
	Cyathidites minor	2	S
	Inaperturopollenites sp.	1	P
F15	*Botryococcus braunii*	3	FWA
	Fungal spores	2	S
	Ephedripites sp.	1	P
	Cingulatisporites ornatus	1	P
F16	*Longapertites marginatus*	2	P
	Cyathidites minor	3	S
	Distaverrusporites simplex	1	S
	Diatom frustules	2	DF
	Tricolporopollenites sp.	1	P
	Cingulatisporites ornatus	1	S

	Fungal spore	2	S
	Droseridites cf. senonicus	1	P
F17	*Tricolporopollenites sp.*	1	P
	Fungal spores	2	S
	Botryococcus braunii	1	FWA
	Rugulatisporites caperatus	1	S
	Distaverrusporites simplex	1	S
F18	*Charred Graminae Cuticle*	2	CGC
	Diatom frustules	3	DF
	Retimonocolpites sp.	1	P
	Longapertites sp.	1	P
F19	*Cingulatisporites ornatus*	2	S
	Tricolporopollenites sp.	1	P
	Cyathidites minor	3	S
	Fungal spore	1	S
	Inaperturopollenites sp.	1	P
	Zlivisporites blanensis	1	S
F20	*Diatom frustules*	1	DF
	Botryococcus braunii	2	FWA
	Ephedripites sp.	1	P
F21	*Fungal spores*	1	S
	Charred graminae cuticle	1	CGC
	Cingulatisporites ornatus	2	S
	Tricolporopollenites sp.	2	P
	Droseridites sp	1	P

P= Pollen, S=Spore, FWA=Fresh Water Algae, DF= Diatom Frustules, CGC=Charred Graminae Cuticle
Age: Late Cretaceous (Maastrichtian - Turonian)

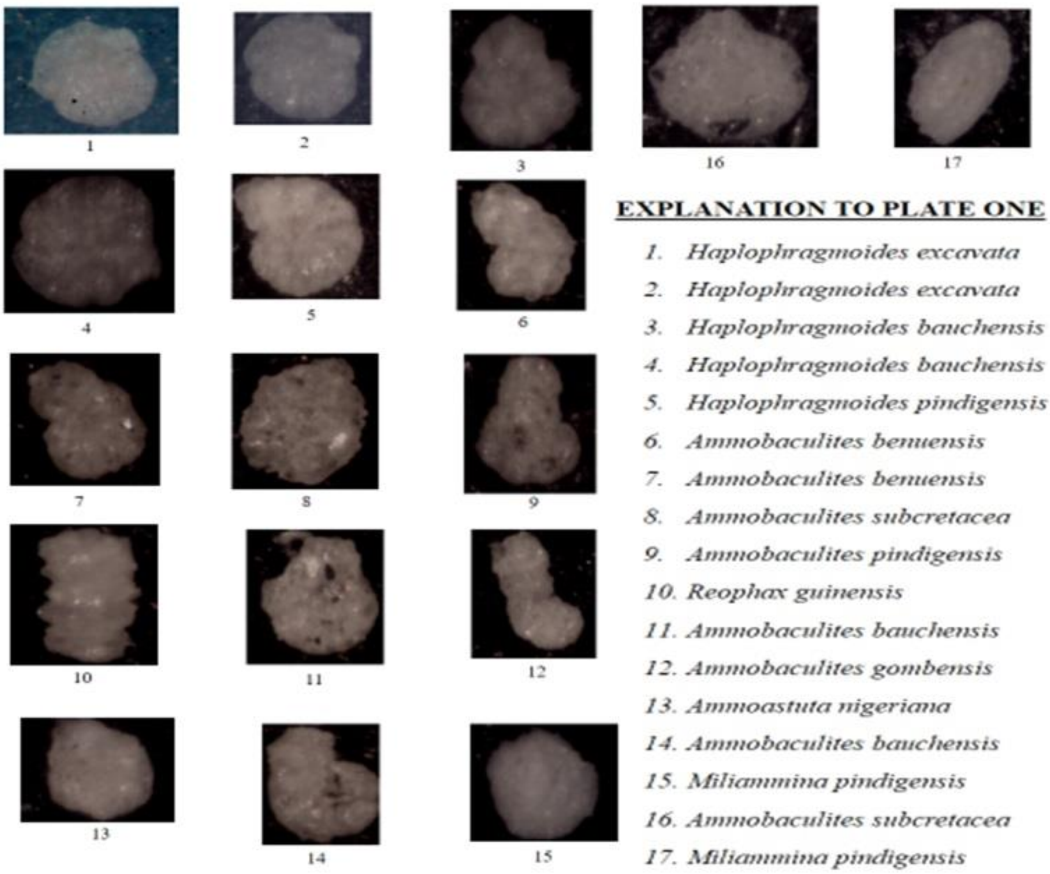


Figure 5: Photomicrograph of foraminiferal species showing *(1) Haplophragmoides pindigensis, (2) Ammobaculites gombensis, (3) Trochammina sp (4) Haplophragmoides pindigensis (5) Haplophragmoides excavata (6) Ammobaculites gombensis (7) Ammobaculites bemienses, (8) Ammoastuta nigeriana, (9) Haplophragmoides bauchensis, (10) Milliammina Pindigensis, (11) Haplophragmoides bauchensis, (12) Ammobaculites bemienses, (13) Haplophragmoides bauchensis, (14) Reophax guineana, (15) Milliammina Pindigensis, (16) Ammobaculites gombensis*

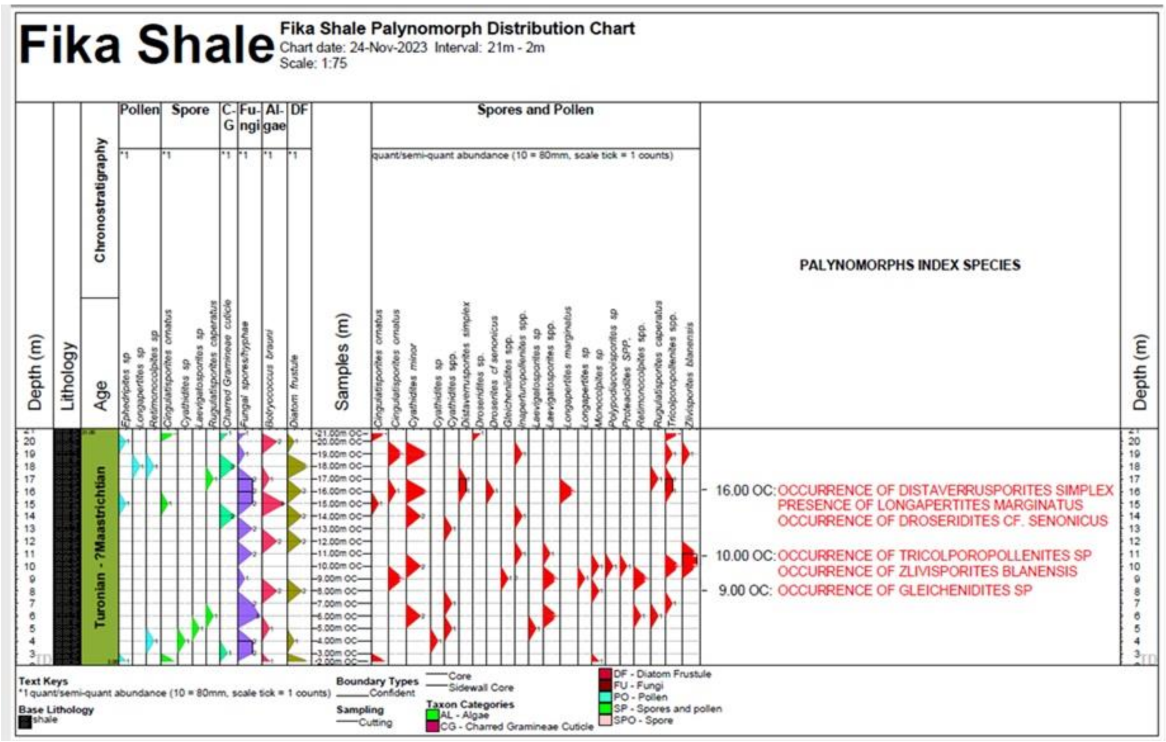
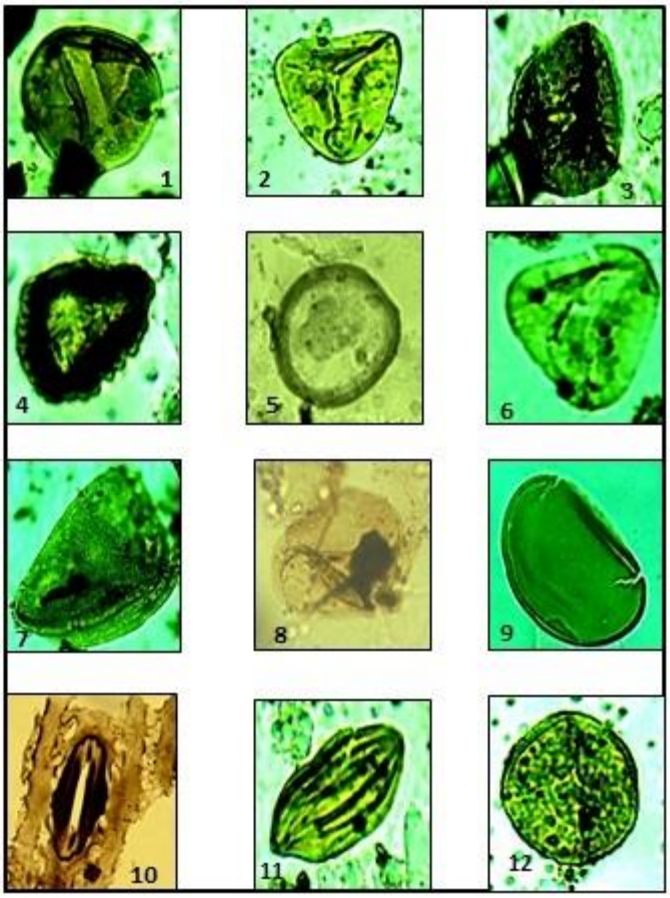


Figure 6: Fika Shale Palynomorphs Distribution Chart based on this study



X400 Magnification

1. *Monocolpites* sp.
2. *Gleicheniidites* sp.
3. *Zlivisporites blanensis*.
4. *Distaverrusporites simplex*.
5. *Cingulatisporites ornatus*.
6. *Cyathidites minor*.
7. *Longapertites marginatus*.
8. *Inaperturopollenites* sp.
9. *Laevigatosporites* sp.
10. Charred Graminae Cuticle.
11. *Ephedripites* sp.
12. *Rugulatisporites caperatus*.

Figure 7: Photomicrograph of palynofacies assemblages showing *Monocolpites sp., Gleicheniidites sp., Zlivisporites blanensis, Distaverrusporites simplex, Cingulatisporites ornatus, Cyathidites minor, Longapertites marginatus, Inaperturopollenites sp., Laevigatosporites sp., Charred Graminae Cuticle, Ephedripites sp., Rugulatisporites caperatus*

Late Cretaceous

The foraminiferal assemblage that characterized these samples are mostly arenaceous species and this includes*: Miliammina pindigensis, Ammomarginulina emir, Ammobaculites bauchensis, Ammobaculites pindigensis, Ammobaculites gombensis, Haplophragmoides excavata, Haplophragmoides pindigensis, Haplophragmoides bauchensis* and *Reophax guineana.* (Fig. 4). This assemblage had been reported in some of the sedimentary basins in Nigeria. *Haplophragmoides excavata* has been reported in the Coniacian part of Nkalagu Formation and Nkporo Shale (Petters, 1982; Bassey, 1991). Originally described from the American Gulf Coast, this species has been reported from the Coniacian to Maastrichtian of North America (Silver, 1968). The species has also been reported in the Paleocene sediment of the Niger Delta where it has its extinction level (Last stratigraphic appearance). *Haplophragmoides bauchensis* was reported in the Turonian to Coniacian sediments of Nkalagu Formation (Petters, 1979) and in the Turonian – Santonian outcrop section of the Pindiga Formation that was tentatively assigned to Turonian – Santonian age (Petters, 1979). *Haplophragmoides pindigensis, Haplophragmoides bauchensis Ammobaculites bauchensis, Ammobaculites pindigensis, Ammoastuta nigeriana, Miliammina pindigensis, Ammomarginulina emir* and *Reophax guineana* (Fig. 5) were also reported in the outcrop section of the Pindiga Formation that was tentatively assigned to Turonian – Santonian in the valley near Pindiga village (Petters, 1979). On the basis of the above Foraminiferal associations, the studied interval of the Fika Member is assigned Late Cretaceous, not younger than Maastrichtian age.

For the palynomorphs, the recovered palynoflora is dominated by Late Cretaceous species such as *Tricolporopollenites* sp., *Distaverrusporites simplex, Gleicheniidites* sp., *Inaperturopollenites* sp., *Cingulatisporites ornatus* in association with few records of *Rugulatisporites caperatus* (Maastrichtian-Santonian), and *Zlivisporites blanensis* (Maastrichtian-Turonian). This assemblage suggests an age not younger than late Cretaceous (Maastrichtian-Turonian) for the studied samples. *Longapertites* sp. in association with *Cingulatisporites ornatus*, *Zlivisporites blanensis*, and *Botryococcus braunii* has been reported from Campanian to early Maastrichtian strata of the Gongola Sub-basin. The taxa assemblage in this study falls within *longapertites* sp zone of Lawal and Moullade (1986). Based on the records of palynomorphs the Fika Member was deposited during Campanian-Maastrichtian age.

The foraminifera assemblage of the Upper Benue Trough are not age diagnostic, hence, the aforementioned foraminifera were tentatively assigned to Turonian – Santonian (Petters, 1979). However, palynological analysis seems to provide a better stratigraphic interpretation of the Upper Benue Trough (Lawa and Moullade, 1986; Abubakar, 2011 and Usman et al; 2020). Concerning this, the Fika Member of Pindiga Formation palynomorphs assemblages were correlated with Longapertites sp zone of Lawal and Moullade (1986) which was dated Campanian – early Maastrichtian age , analysis of the Fika Member.

Palynofacies Analysis

The palynofacies types, percentage abundance and hydrocarbon generating potentials of the samples are shown in Table 4. The details of the palynofacies (kerogen) analysis based on Visual Kerogen Typing (VKT) which is indicative of the paleoenvironment and the Spore Colouration Index (SCI) and Thermal Alteration Index (TAI) that help in identification of hydrocarbon generating potential of the sediments.

Based on Oyede, (1991) and Staplin, (1969) the major classes of palynomaceral identified in the samples include; Palynomaceral 1 (PM-1) / Coaly (Plant materials that are predominantly dense black, dark brown, or orange-brown, often exhibiting irregular shapes), Palynomaceral 2 (PM-2)/Woody (Plant materials with a structured color ranging from brown to orange), Palynomaceral 3 (PM-3)/Woody (Light-colored, structured material occasionally containing stomata), Palynomaceral 4 (PM-4) / Coaly (black equi-dimensional, blade or needle shaped material) and Structureless Organic Matter (SOM) that composed of bacterially reworked biomass preserved in anoxia.

Table 3: Palynofacies Records and Hydrocarbon Generating Potential (F2-F21 samples)

Sample	Oyede (1991)					Staplin (1969)			
	Type	Cts.	%	Particle type		TM	Col.	TAI	Ro
F2	PM1	85	42.5	Coaly	Inertinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM4	30	15						
	PM3	15	7.5	woody	Vitrinite				
	PM2	60	30						
	SOM	10	5	Amorph.	Amorph.				
F3	PM1	90	45	Coaly	Inertinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM4	15	7.5						
	PM3	25	12.5	woody	Vitrinite				
	PM2	50	25						
	SOM	20	10	Amorph.	Amorph.				
F4	PM1	75	37.5	Coaly	Inertinite	Dry Gas/ Barren	black	4- to 5	1.50->2.00
	PM4	35	17.5						
	PM3	25	12.5	woody	Vitrinite				
	PM2	55	27.5						
	SOM	10	5	Amorph.	Amorph.				
F5	PM1	65	32.5	Coaly	Inertinite	Dry Gas/ Barren	Dark brown	3+ to 5	1.20->2.00
	PM4	30	15						
	PM3	20	10	woody	Vitrinite				

	PM2	75	37.5				-		
	SOM	10	5	Amorph.	Amorph.		black		
F6	PM1	80	40	Coaly	Inertinite				
	PM4	30	15						
	PM3	12	6	woody	Vitrinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM2	60	30						
	SOM	18	9	Amorph.	Amorph.				
F7	PM1	76	38	Coaly	Inertinite				
	PM4	24	12						
	PM3	15	7.5	woody	Vitrinite	Dry Gas/ Barren	black	4- to 5	1.50->2.00
	PM2	65	32.5						
	SOM	20	10	Amorph.	Amorph.				
F8	PM1	80	40	Coaly	Inertinite				
	PM4	35	17.5						
	PM3	15	7.5	woody	Vitrinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM2	50	25						
	SOM	20	10	Amorph.	Amorph.				
F9	PM1	75	37.5	Coaly	Inertinite				
	PM4	25	12.5						
	PM3	15	7.5	woody	Vitrinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM2	65	32.5						
	SOM	20	10	Amorph.	Amorph.				
F10	PM1	80	40	Coaly	Inertinite				
	PM4	30	15						
	PM3	15	7.5	Woody	Vitrinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM2	60	30						
	SOM	15	7.5	Amorph.	Amorph.				
F11	PM1	70	35	Coaly	Inertinite				
	PM4	25	12.5						
	PM3	20	10	Woody	Vitrinite	Dry Gas/ Barren	black	4- to 5	1.50->2.00
	PM2	65	32.5						
	SOM	20	10	Amorph.	Amorph.				
F12	PM1	72	36	Coaly	Inertinite				
	PM4	22	11						
	PM3	24	12	Woody	Vitrinite	Dry Gas/ Barren	black	4- to 5	1.50->2.00
	PM2	64	32						
	SOM	18	9	Amorph.	Amorph.				
F13	PM1	68	34	Coaly	Inertinite				
	PM4	25	12.5						
	PM3	20	10	Woody	Vitrinite	Dry Gas/ Barren	Black	4- to 5	1.50->2.00
	PM2	65	32.5						
	SOM	22	11	Amorph.	Amorph.				
F14	PM1	65	32.5	Coaly	Inertinite				
	PM4	30	15						
	PM3	15	7.5	Woody	Vitrinite	Dry Gas/ Barren	Black	4- to 5	1.50->2.00
	PM2	70	35						
	SOM	20	10	Amorph.	Amorph.				
F15	PM1	80	40	Coaly	Inertinite				
	PM4	25	12.5						
	PM3	15	7.5	Woody	Vitrinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM2	65	32.5						
	SOM	20	10	Amorph.	Amorph.				
F16	PM1	85	42.5	Coaly	Inertinite				
	PM4	30	15						
	PM3	15	7.5	Woody	Vitrinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM2	60	30						
	SOM	10	5	Amorph.	Amorph.				

F17	PM1	75	37.5	Coaly	Inertinite				
	PM4	20	10						
	PM3	20	10	Woody	Vitrinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM2	65	32.5						
	SOM	20	10	Amorph.	Amorph.				
F18	PM1	73	36.5	Coaly	Inertinite				
	PM4	24	12						
	PM3	21	10.5	Woody	Vitrinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM2	68	34						
	SOM	14	7	Amorph.	Amorph.				
F19	PM1	78	39	Coaly	Inertinite				
	PM4	25	12.5						
	PM3	20	10	Woody	Vitrinite	Dry Gas/ Barren	Black	4- to 5	1.50->2.00
	PM2	62	31						
	SOM	15	7.5	Amorph.	Amorph.				
F20	PM1	73	36.5	Coaly	Inertinite				
	PM4	30	15						
	PM3	15	7.5	Woody	Vitrinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM2	65	32.5						
	SOM	17	8.5	Amorph.	Amorph.				
F21	PM1	85	42.5	Coaly	Inertinite				
	PM4	30	15						
	PM3	15	7.5	Woody	Vitrinite	Dry Gas/ Barren	Dark brown - black	3+ to 5	1.20->2.00
	PM2	60	30						
	SOM	10	5	Amorph.	Amorph.				

TM=Thermal Maturity. Col.=Colour. TAI=Thermal Alteration Index. Ro=Vitrinite reflectance index, PM = Palynomaceral, SOM = Structureless Organic Matter

Visual Kerogen Typing (VKT)

The samples (Table 3) are generally characterized by abundant occurrence of small to medium sized PM-1 (brackish water environment) and small sized PM-4 (commonly found in brackish water to fluvio-marine environment) and PM-2 kerogen types, with relatively common records of SOM, and PM-3 (Fig. 8). This admixture suggests a predominantly fluvio-marine paleoenvironment of deposition. This interpretation is further corroborated by the occurrence of occurrence of Tricolporopollenites sp., pteridophytic spores such as *Cyathidites minor, Cingulatisporites ornatus and palmae species such as Longapertites marginatus and Longapertites sp.*

Table 4: Summary of Biostratigraphic and Paleoenvironmental Analyses

Foraminiferal Biostratigraphic summary of Fika shales (Important Foraminiferal Index species)				
Depth (m)	**Epoch/Period**	**Age Ma)**	**Benthic Zones**	**Signifiant Index Species**
F2 – F20	Late Cretaceous (Santonian - Turonian)	84.0 - 92.0	*Haplophragmoides bauchensis – Ammobaculites pindigensis* (Campanian – Early Maastrichtian)	Interval characterized by occurrences of *Miliammina pindigensis, Haplophragmoides bauchensis, Ammomarginulina emir, Haplophragmoides excavata, Haplophragmoides pindigensis, Ammobaculites bauchensis, Ammobaculites pindigensis, and Reophax guineana.*

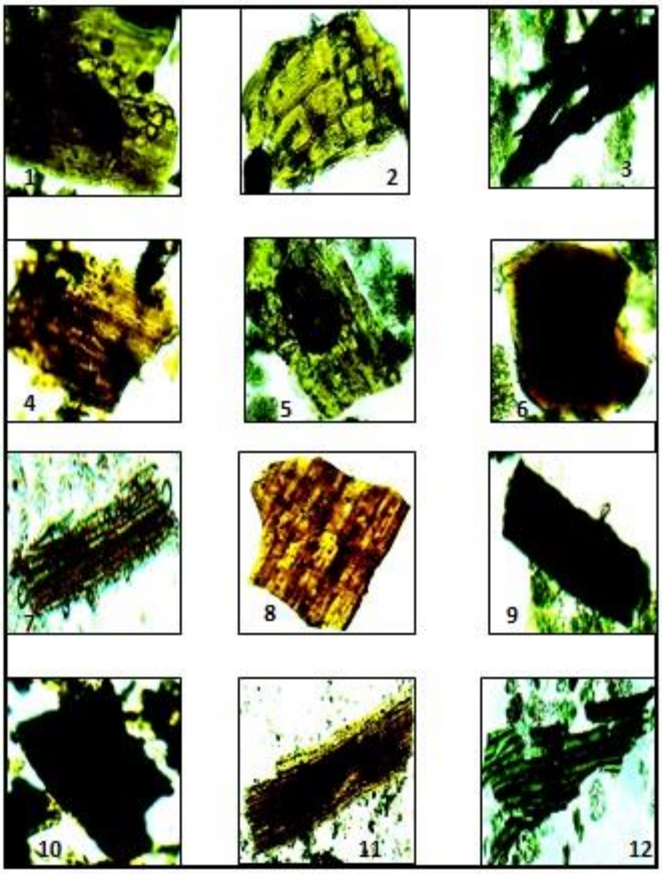


Figure 8: Photomicroraph of palynofacies assemblages showing phytoclast, woody fragments and amorphous organic matter and brownish to black color indicating thermal maturity

Spore Colouration Index (SCI) / Thermal Alteration Index (TAI)

The samples show colour variation from dark brown to black which is approximately 8.5-10 on the SCI scale of Pearson, (1984). This correlates with the TAI value of 3+ to 5 and estimated Ro value of 1.2->2.00 of Staplin, (1969) and Pearson, (1984). This suggests the samples fall within a super mature horizon in the basin making it predominantly gas prone.

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 to shallow Inner Neritic settings based on the recorded foraminiferal assemblage dominated by arenaceous benthic species such as *Haplophragmoides excavata, Haplophragmoides bauchensis, Haplophragmoides pindigenis, Ammobaculites bauchensis, Ammobaculites pindigensis, Ammobaculites benuensis, Ammobaculites gombensis, Ammomarginulina emir, Ammoastuta nigeriana* and R*eophax guineana.* The above foraminiferal association indicates marginal marine (fluvio marine) to shallow Inner Neritic environments (Adegoke et al, 1976; Petters, 1979, 1982). 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. Similarly, Petters, (1980) has used the dominance of arenaceous species of *Haplophragmoides, Ammobaculites, Reophax* and *Miliammina* which he used in concluding that the paleoenvironment of Pindiga Formation of the Gongola Sub-basin depict a paralic to a very shallow neritic environment. The dominance of agglutinated foraminiferal species also suggests restricted, low oxygen bottom water conditions. On the basis of the arenaceous foraminiferal assemblage recorded in the studied interval of the Fika Member indicates marginal marine to proximal Inner Neritic settings. This is supported by dominance of PM-1(brackish water environment) and small sized PM-4 (commonly found in brackish water to fluvio-marine environment) and PM-2 kerogen types, with relatively common records of SOM, and PM-3 that generally suggest fluvio-marine paleoenvironment.

Biostratigraphy and Age

The sample is characterized by co-occurrences of *Haplophragmoides excavata, Haplophragmoides bauchensis, Haplophragmoides pindigensis, Ammobaculites bauchensis* and *Ammoastuta nigeriana* suggesting a Turonian – Santonian age.

Thermal Maturation and Hydrocarbon Potential

The samples from Fika Member (Table 5) exhibit a complete spectrum of Foraminiferal Color Index (FCI) values, ranging from light grey to light brownish-grey. When assessing maturity level, the fossil color's darkness, determined using the Munsell Colour Chart, is the most crucial parameter among the three. To practically evaluate this darkness, specimens are juxtaposed with standard Munsell color chips for direct comparison. Subsequently, the darkness value is directly converted into an FCI number as outlined in the table 5.

Agglutinated foraminifera dominated the assemblage of the samples studied. These agglutinated foraminiferal colours ranged from light grey to light brownish grey to grey with corresponding FCI values of 2 to 3, these correspond to temperature range (TAI values) of 60 to 75 indicating low thermal maturity for both oil and gas generation. The samples generally show colour variation from dark brown to black which is approximately 8.5-10 on the SCI scale correlating with TAI value of 3+ to 5 and estimated Ro value of 1.2->2.00 (Staplin, 1969) suggesting a mature horizon in the basin making it predominantly gas prone.

Table 5: Foraminiferal Colour and Interpretation Potential

S/No	Sample No	Foraminiferal colour Index (From Munsell colour system)	FCI value	Estimated Temperature	Interpretation potential
1	F2	Light Grey	2	60	Low Thermal Maturity
2	F3	Light Grey	2	60	Low Thermal Maturity
3	F4	Light Brownish Grey to Grey	3	75	Low Thermal Maturity
4	F6	Light Grey	2	60	Low Thermal Maturity
5	F8	Light Brownish Grey to Grey	3	75	Low Thermal Maturity
6	F12	Light Grey	2	60	Low Thermal Maturity
7	F14	Light Brownish Grey to Grey	3	75	Low Thermal Maturity
8	F17	Light Brownish Grey to Grey	3	75	Low Thermal Maturity
9	F19	Light Grey	2	60	Low Thermal Maturity
10	F20	Light Grey	2	60	Low Thermal Maturity

CONCLUSION

The Fika Member of the Pindiga Formation contains fossils indicative of Campenian–early Maastrichtian age. The paleoenvironmental analysis suggests that 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. The organic matter within the Fika Member possesses characteristic of agglutinated foraminiferal colours ranged from light grey to light brownish grey to grey with corresponding Foraminiferal Colour index (FCI) values of 2 to 3, these correspond to temperature range (TAI values) of 60 to 75 indicating low thermal maturity for both oil and gas generation. Integration of biostratigraphic and paleoenvironmental data with geochemical analyses provides a comprehensive assessment of the Fika Member's prospectivity for oil and gas exploration and its age constrain.

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