



Palynology, Palynofacies and Foraminiferal Analyses of Lower Bima Member, Yola Sub-Basin, Northern Benue Trough, Nigeria: Implication for Age, Paleoenvironment and Thermal Maturity

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KEYWORDS

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Upper Benue Trough,
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Palynology,
Palynofacies,
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Cenomanian,
Paleoenvironment,
Hydrocarbon Potential.

ABSTRACT

The Lower Bima Member of the Yola Arm Northern Benue Trough, northeastern Nigeria exposed at Ture-Awak Section, was investigated through integrated lithostratigraphic, palynological, palynofacies, and foraminiferal analyses to establish its age, depositional environment, and thermal maturity. A ~45 m thick succession of sandstones, siltstones, mudstones, and shales at the Ture-Awak Road section was logged and interpreted as a prograding fluvial to lacustrine system with repeated fining- and coarsening-upward cycles. Palynological analysis of 21 outcrop samples (M1–M21) yielded a moderately diverse assemblage dominated by terrestrial pollen and spores, with additional occurrences of freshwater algae (*Botryococcus braunii*), fungal spores, and diatom frustules. The presence of diagnostic taxa, including *Cretacaeiporites*, *Monocolpites marginatus*, *Araucariacites*, *Proxaperites operculatus*, and *Triorites africaensis*, supports a Cenomanian age. Palynofacies assemblages are dominated by woody phytoclasts (PM-1, PM-4) with minor amorphous organic matter and algal remains, indicating predominantly gas-prone Type III kerogen with localized oil-prone intervals, while Thermal Alteration Index and spore colour index values suggest variable maturity from immature to peak oil window. Foraminiferal analysis reveals arenaceous benthic taxa (*Haplophragmoides*, *Trochammina*, *Ammobaculites*), which indicate marginal to restricted depositional conditions, and Foraminiferal Colour Index values (~2.0–3.5) correspond to paleotemperatures of 60–110 °C, consistent with early to peak oil generation. Therefore, palynological, palynofacies, and foraminiferal studies demonstrates that the samples were deposited in under humid/arid climate in fluvial-lacustrine depositional systems. The presence of source-prone shales and maturity parameters confirms that the samples are matured enough for hydrocarbon generation.

CITATION

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INTRODUCTION

The Yola Sub-basin, located in the Northern Benue Trough of Nigeria, is one of the country's important inland basins. It forms part of the larger West and Central African Rift

System (WCARS) (Fig. 1). For many years, oil exploration in Nigeria concentrated on the Niger Delta, especially after hydrocarbons were first discovered there in commercial quantities. Recently, however, attention has started to

shift toward the inland basins of the Benue Trough because of their promising geology and hydrocarbon potential (Abubakar, 2008). The Benue Trough stretches across northeastern Nigeria and is now widely recognized as a region with petroleum prospects, particularly within the Gongola and Yola sub-basins.

In the Yola Sub-basin, one of the most significant rock units is the Lower Bima Member. This formation is made up mainly of sandstones, with layers of siltstone and shale, showing that it was deposited in environments ranging from rivers to delta margins. Despite its importance, the Lower Bima Member is still not well understood. Studies have not fully explained its exact age, how it was deposited, or how important it may be for petroleum exploration. These uncertainties make it difficult to confidently link it with similar rock units elsewhere in the Benue Trough.

Earlier research has shown that the Benue Trough was strongly affected by mid-Santonian compression, which disturbed older rock layers and makes their interpretation more complex (Zaborski et al., 1998; Guiraud & Bosworth, 1997). Because of these challenges, there is a strong need to take a closer look at the Lower Bima Member. This study aims to do just that, by examining its stratigraphy, depositional environment, and petroleum potential. To achieve this, an integrated approach combining sedimentological and biostratigraphic methods is applied, with the goal of improving the geology and supporting petroleum exploration in the Northern Benue Trough. The results provide new insights into its age, depositional environment, and thermal maturity, within the Northern Benue Trough.

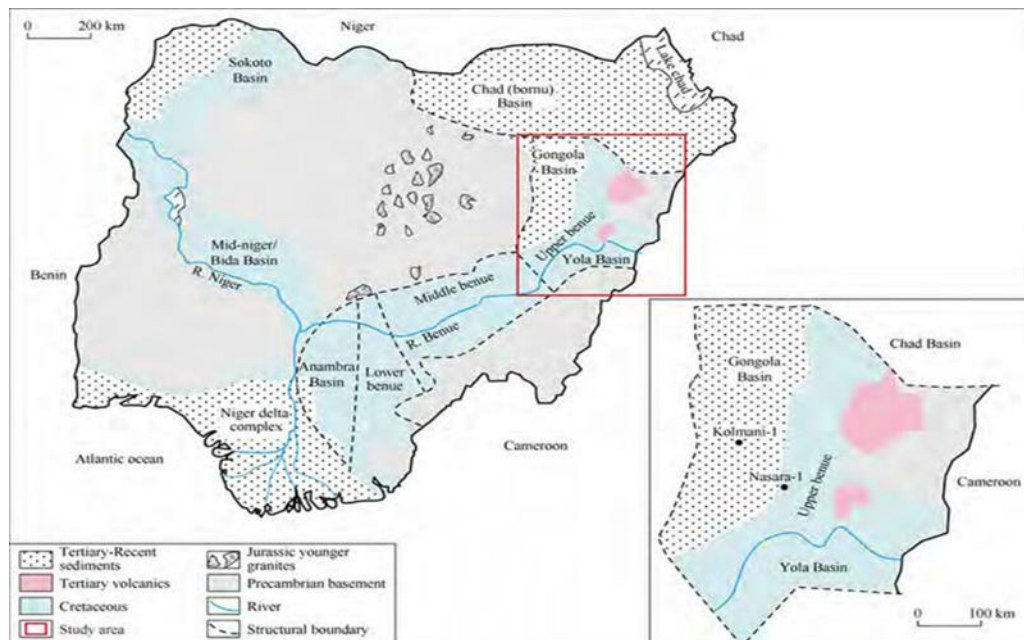


Figure 1: Generalised geological map of Nigeria showing the location of the Yola basin (after Abubakar, 2006)

Geological setting

The Benue Trough is a major northeast–southwest trending sedimentary basin in Nigeria, extending for more than 1,000 km and formed during the Early Cretaceous as a rift system related to the opening of the South Atlantic Ocean. It is divided into southern, central, and northern sectors, with the northern sector comprising the Gongola, Lau, and Yola sub-basins (figure 1). The Yola Sub-basin, situated in northeastern Nigeria around Yola town in Adamawa State, is structurally complex and strongly influenced by rift-related tectonics (Benkhelil, 1989). Its evolution is tied to the breakup of Gondwana, with Aptian–Albian extensional tectonics producing half-graben structures that were filled with continental sediments. Subsequent Cenomanian–Turonian thermal subsidence and marine transgression

deposited thick shallow-marine successions, while Santonian compression caused inversion, folding, and uplift that redefined basin architecture (Guiraud et al., 1992).

The stratigraphy of the Yola Sub-basin reflects this tectono-sedimentary evolution. The Bima Formation represents the earliest syn-rift fill and is subdivided into Lower, Middle, and Upper members (Carter et al., 1963; Genik, 1993; Yandoka et al., 2014; Bello et al., 2021). The Lower Bima Member (Aptian–Albian) comprises medium- to coarse-grained sandstones interbedded with organic-rich shales deposited in fluvial, floodplain, and marginal lacustrine environments. Sedimentary structures such as cross-bedding, ripple lamination, and shale intercalations support this interpretation (Petters, 1982; Dike & Nwajide,

1990). Paleontological and geochemical evidence indicates deposition in a humid tropical setting prior to marine transgression, with organic-rich shale intervals showing petroleum source potential (Okosun, 1995; Ojo & Akande, 2003; Obaje et al., 2004; Ibrahim et al., 2022). The Middle and Upper Bima Members (Late Albian–Early Cenomanian) record a shift to deltaic and shallow-marine environments, represented by thick sandstones, conglomerates, and large-scale cross-stratification, reflecting high-energy coastal deposition (Guiraud & Maurin, 1992; Nwajide, 2013). Above the Bima Formation, the Yolde Formation records the first major Cenomanian marine incursion, with sandstones, siltstones, shales, and limestones deposited in deltaic to shallow-marine settings (Zaborski, 1998; Adekeye et al., 2020). Overlying units such as the Dukul,

Sekuliye, Numanha, and Lamja formations record alternating continental and marine phases through the Late Cretaceous. These successions collectively provide petroleum system elements: the Dukul and Numanha shales act as potential source rocks; the Sekuliye and Lamja sandstones serve as reservoirs; and interbedded shales form effective seals (Sarki Yandoka, 2015; Olade & Erdtmann, 2018; Bello et al., 2021; Ibrahim et al., 2022). Overall, the stratigraphic successions of the Yola Sub-basin illustrate the interplay of syn-rift tectonics, subsidence, sea-level change, and inversion in controlling its depositional evolution (figure 2). The Lower Bima Member, with its interbedded sandstones and organic-rich shales, is of particular geological importance as it combines potential source and reservoir facies that underpin the petroleum system framework of the basin.

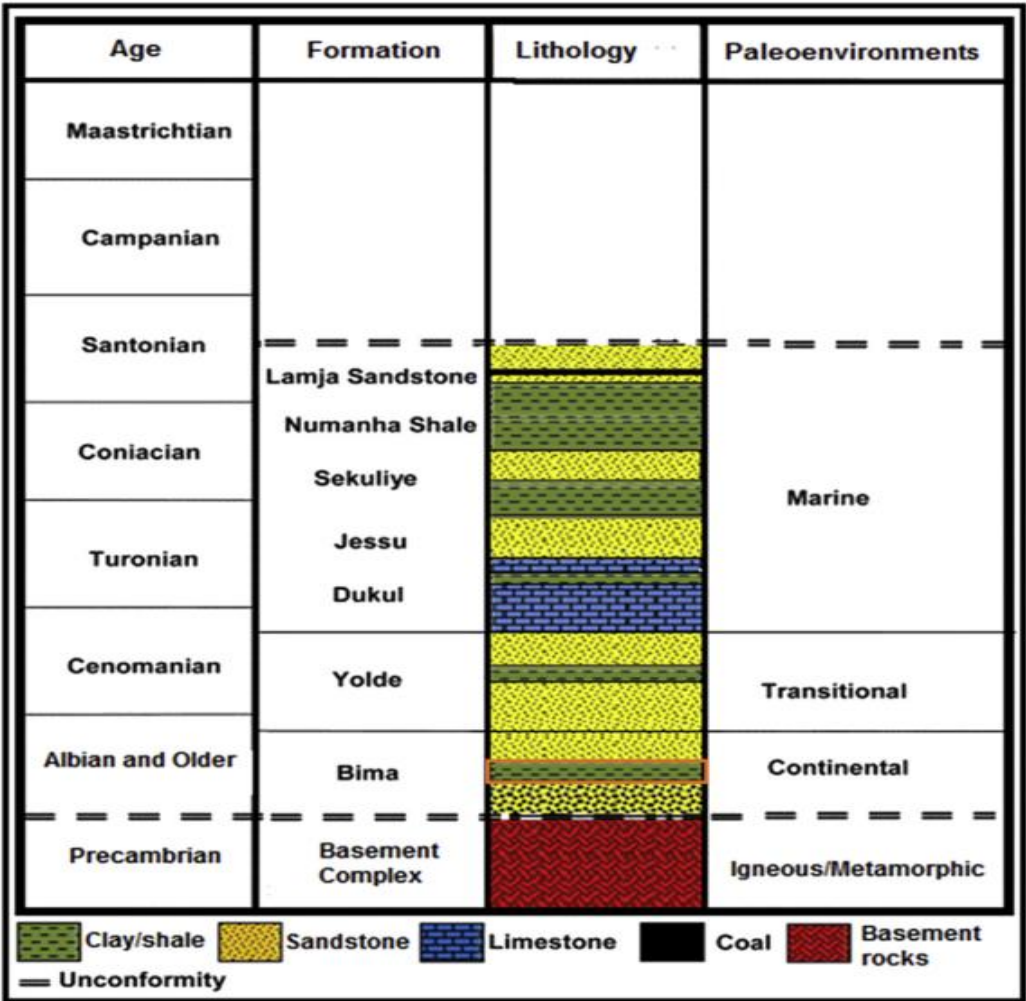


Figure 2: Stratigraphy of Yola Sub-basin Succesion (Modified after Sarki Yandoka, 2015)

MATERIALS AND METHODS

Fieldwork began with reconnaissance of the Lower Bima Member in the Yola Sub-basin at Ture-Awak Section to identify accessible exposures and establish stratigraphic context. Outcrops were examined for lithology, texture,

colour, sedimentary structures, and fossil content, following standard geological field protocols (Compton, 1985; Tucker, 2011). Twenty-one fresh shale samples were systematically collected from measured section. Samples were taken from fine-grained intervals using a geological

hammer and chisel, avoiding weathered surfaces. Each sample was labeled, bagged, and documented with GPS coordinates, lithologic descriptions, and stratigraphic positions in line with micropaleontological sampling guidelines (Batten, 1999).

Laboratory preparation for foraminifera involved drying, kerosene soaking, wet sieving through a 63 μm mesh, and separation into multiple size fractions for microscopic picking and identification. For palynological analysis, standard maceration procedures were applied, including acid digestion with HCl to remove carbonates, HF to dissolve silicates, and HNO_3 for controlled oxidation, followed by neutralization with KOH to eliminate humic acids. Heavy liquid separation using zinc bromide (SG 2.2) was carried out to concentrate palynomorphs, and the residues were sieved and mounted on slides using PVA/resin for examination under transmitted light microscopy. Palynofacies slides were prepared from unoxidized residues to preserve organic matter and mounted using Norland adhesive. Organic constituents were classified into amorphous, woody, coaly, and

herbaceous types, following the palynomaceral scheme of Staplin (1969).

RESULTS AND DISCUSSION

Lithostratigraphy and Lithofacies

The Bima Shale at Ture–Awak Road is about 55 m thick and displays repeated fining-upward cycles (figure 3). Each cycle starts with siltstone and mudstone containing thin sand beds, passes into ripple-laminated or cross-bedded sandstone, and is capped by finer mudstone and siltstone with occasional coal seams. The section begins with siltstone–mudstone and thin sandstone (BS11–BS10), overlain by cross-bedded sandstones (BS9–BS7) that fine upward into ripple-marked sands and mudstone, while the upper beds (BS6–BS1) show thinner sandstones with siltstone and mudstone, including crevasse-splay deposits. The middle (BS17–BS16) is dominated by sandstones, while the upper beds (BS15–BS12) consist of mudstone and siltstone with thin sandstone interbeds. The facies in this section indicate deposition in a fluvial-lacustrine dominated setting (e.g. Sarki Yandoka, 2015).

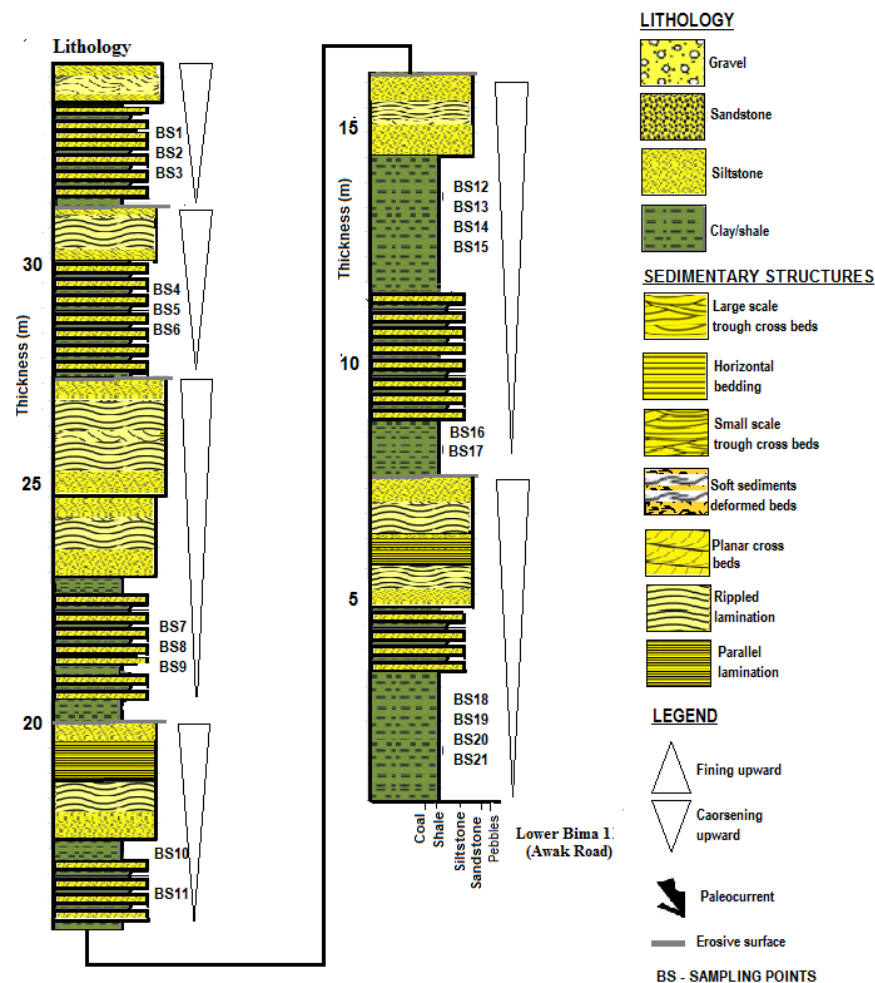


Figure 3: Lithostratigraphic section of Lower Bima outcropped at Ture-Awak Road (Yola Basin) in based on this study

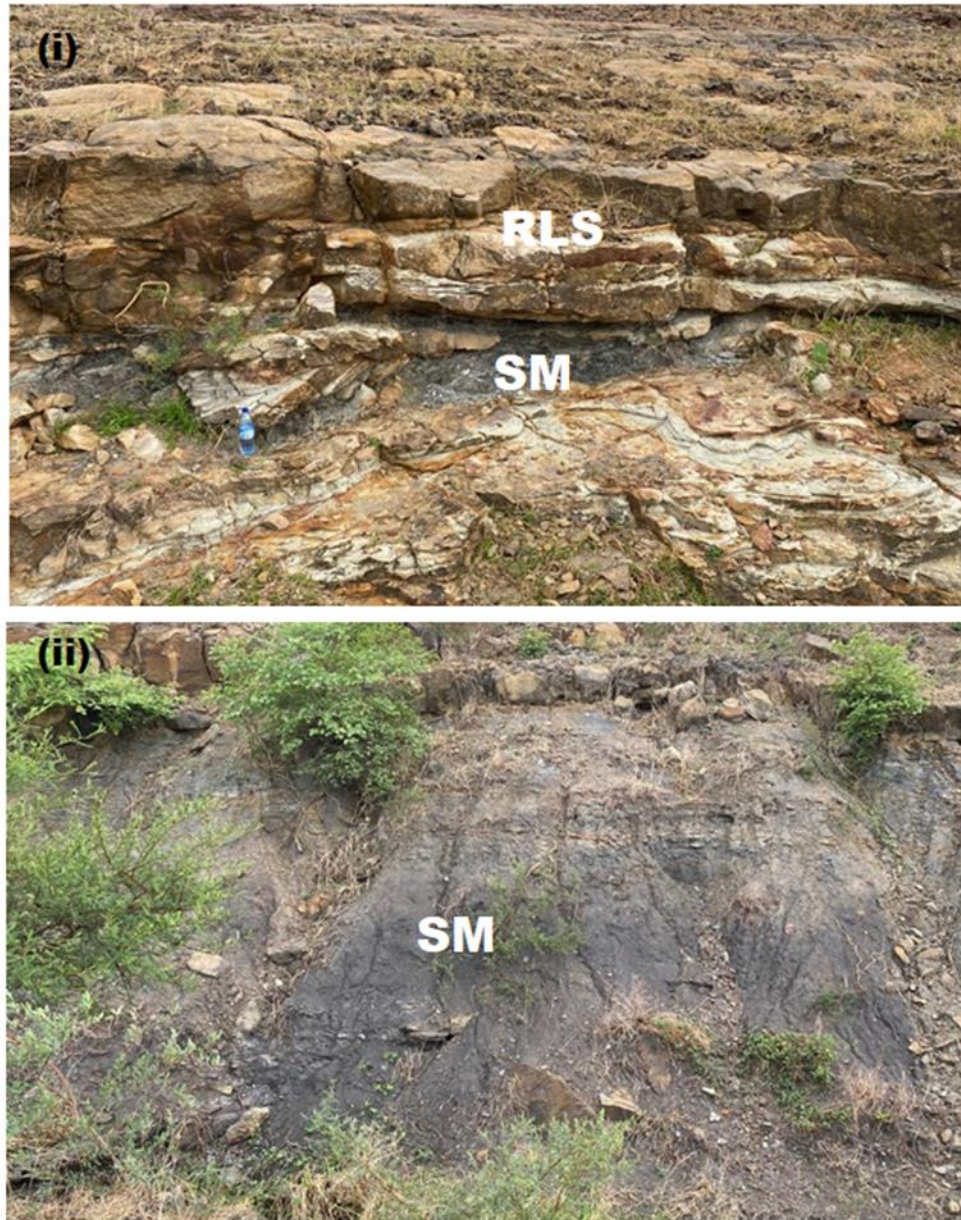


Figure 4: Field photograph of rippled laminated sandstone (RLS) and shale/mudstone (SM) facies

Palynological Analysis

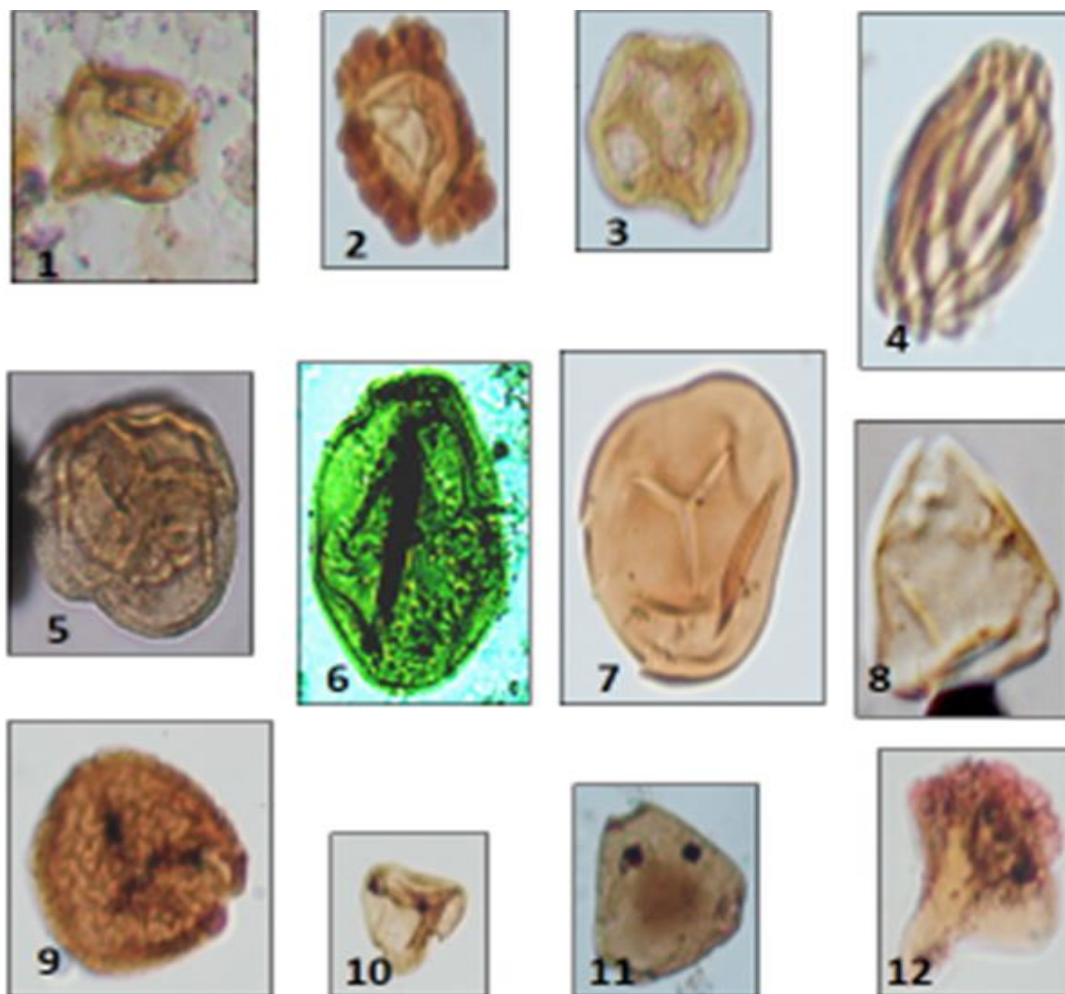
Palynological recovery from the 21 outcrop samples is low-moderate overall (Table 1). The assemblage is dominated by terrestrially derived pollen and spores, notably *Triorites* cf. *africaensis*, *Tricolporopollenites* sp., *Cretacaeiporites* sp., *Araucariacites* sp., *Steevesipollenites* sp., and *Galeacornea* sp., together with fern spores (*Cyathidites* sp., *Cyathidites australis*, *Distaverrusporites simplex*, *Laevigatosporites* sp.).

Freshwater indicators—*Botryococcus braunii*, diatom frustules, and charred grass cuticles—occur alongside abundant fungal spores, reinforcing a non-marine to marginal setting. The co-occurrence of *Triorites* cf. *africaensis* and *Galeacornea* sp. suggests a Cenomanian or slightly older age. Palynofacies spectra dominated by PM-1 (opaque phytoclasts) and PM-4 (cuticular/structured OM), with lesser PM-2 and rare PM-3/SOM, indicate strong terrestrial influx with limited marine influence (figure 4).

Table 1: Palynomorphs Records and Counts Base on this Study

SN	Palynomorphs	Count	Type
1	<i>funga spores</i>	32	FS
2	<i>graminidites sp</i>	9	P
3	<i>diatom frustules</i>	26	DF
4	<i>Monocolpites</i>	1	P
5	<i>botryococcus braunii</i>	34	FWA
6	<i>Triorites</i>	7	P
7	<i>cretacaeiporites sp</i>	8	P
8	<i>cyathidites sp</i>	5	S
9	<i>galeocornea sp</i>	5	P
10	<i>charred gramineae cuticle</i>	5	P
11	<i>araucariacites sp</i>	13	P
12	<i>milfordia sp</i>	1	P
13	<i>tricolporopollenites sp</i>	14	P
14	<i>triorites africaensis</i>	2	P
15	<i>cyathidites australis</i>	7	S
16	<i>distaverrusporites simplex</i>	5	S
17	<i>steevesipollenites sp</i>	2	P
18	<i>laevigatosporites sp</i>	1	S
19	<i>monocolpites marginatus</i>	2	P
21	<i>cingulatisporites ornatus</i>	5	S
22	<i>rugulatisporites caperatus</i>	1	S
23	<i>tricolipites sp</i>	2	P
24	<i>triotites cf africaensis</i>	3	P
25	<i>monosculcites sp</i>	1	P
26	<i>proxaperites operculatus</i>	1	P

P= Pollen, S=Spore, FWA=*Botryococcus braunii*, FS= *Funga spores* Age: Cenomanian



Figures 5: Photomicrographs of Selected Palynomorphs showing of Lower Bima at Ture-Awak: (1) *Milfordia* sp bm-5 (2) *Distavernusporites simplex* Bm-17 (3) *Cretacaeiporites* sp BM-2 (4) *Steevesipollenites* sp BM-8 (5) *Tricolporopollenites* sp BM-5 (6) *Araucariacites* sp BM-11 (7) *Cyathidites australis* BM-7 (8) *Triorites africaensis* BM-7 (9) *Rugulatisporites caperatus* BM- (10) *Cyathidites* sp BM-20 (11) *Triorites* sp BM-15 (12) *Botryococcus braunii* BM-11

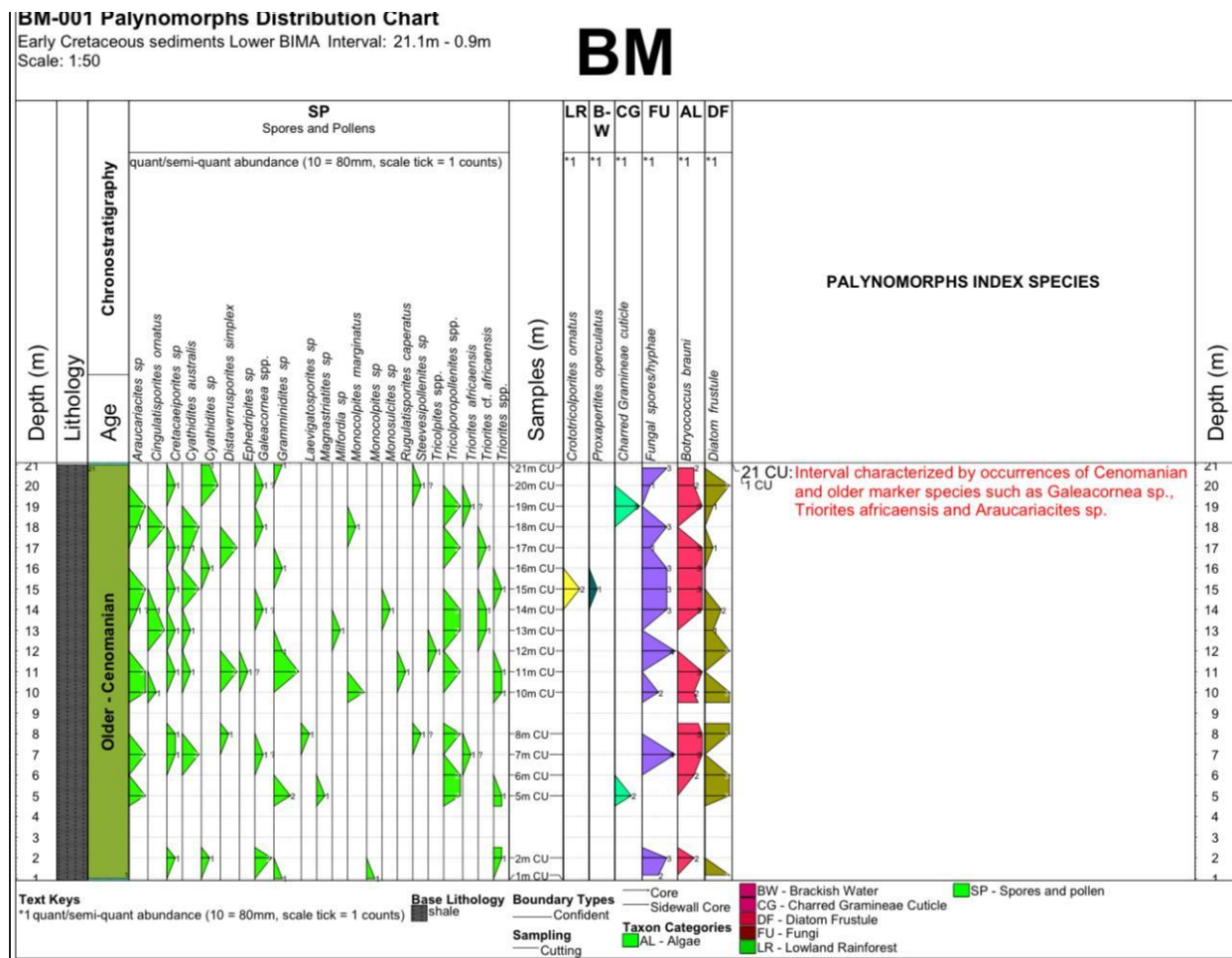


Figure 6: Palynomorph Distribution Chart of the Lower Bima outcropped at Ture-Awak, Yola Basin (M1–M21, based on this study)

Foraminiferal Analysis

Foraminiferal recovery from the twenty-one (21) ditch-cutting and outcrop samples of the Lower Bima Member (Yola Sub-basin) is generally good, and the assemblage is dominated by arenaceous benthic forms (AB) (Table 2). Calcareous species (planktic and benthic) were not recorded, a pattern attributable to the depositional conditions of these siliciclastic sediments. The arenaceous benthics include *Haplophragmoides*

bauchensis, *Trochammina taylorana*, *T. exigua*, *T. wickedeni*, *T. subconica*, *Ammobaculites subcretacea*, and *A. coprolithiformis*; a few samples were barren or yielded only indeterminate arenaceous fragments. Age assignment was guided by Blows (1969, 1979) and Petters (1979, 1982); despite the absence of planktic forms, the established stratigraphic ranges of these AB taxa in the Nigerian sedimentary basins support a mid-Cretaceous (Albian–Cenomanian) interval (figure 5).

Table 2: Detail Results of Foraminifera Analyses of Ten (21) Samples

S/N	Foraminifera	Count	Type
1	<i>haplophragmoides bauchensis</i>	18	AB
2.	<i>trochammina taylorana</i>	12	AB
3.	<i>arenaceous indertiminates</i>	22	AB
4.	<i>trochammina sp</i>	32	AB
5.	<i>trochammina exigua</i>	67	AB
6.	<i>textularia subconica</i>	4	AB
7.	<i>ammobaculites coprolithiforms</i>	2	AB
8.	<i>haplophragmoides sp</i>	18	AB
9.	<i>trochammina wickedeni</i>	3	AB
10	<i>ammobaculites sp</i>	2	AB
11	<i>Barren</i>	3	AB

S/N	Foraminifera	Count	Type
12	<i>miliammina</i> sp	2	AB
13	<i>bathysiphon</i> sp	2	AB
14	<i>haplophragmoids</i> sp	14	AB
15	<i>ammobaculites subcareetacea</i>	5	AB

AB = Arenaceous Benthic Proposed age : Albian - Cenomanian

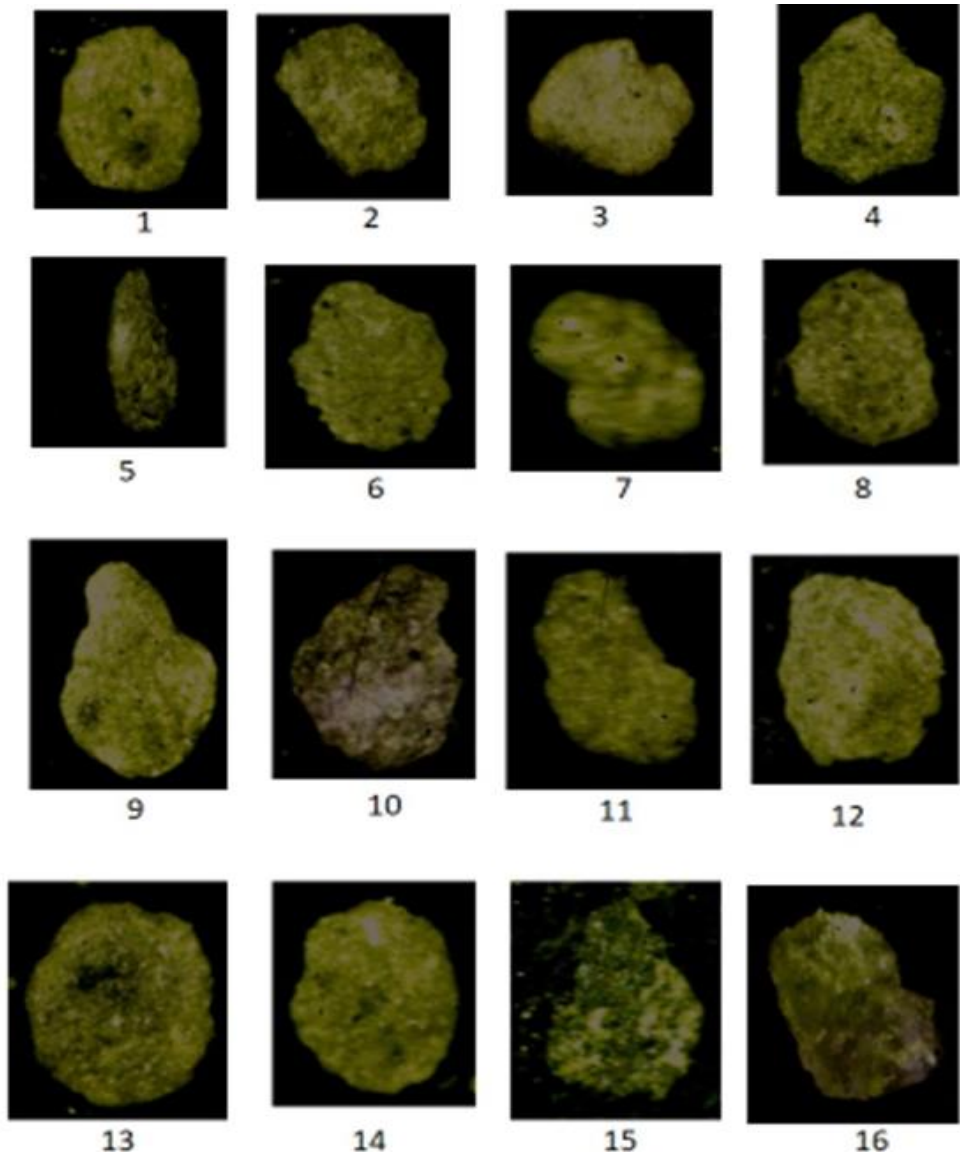


Figure 7: Photomicrograph of Selected Foraminifera from Lower Bima at Ture-Awak: *Trochammina taylorana* (BS6), *Trochammina* sp. (BS8), *Haplophragmoides* sp. (BS5), *Ammobaculites coprolithiformis* (BS3), *Trochammina exigua* (BS8), *Ammobaculites subcretacea* (BS8, BS10), *Miliammina* sp. (BS13), *Trochammina wickedeni* (BS5), *Arenaceous indeterminate* (BS9)

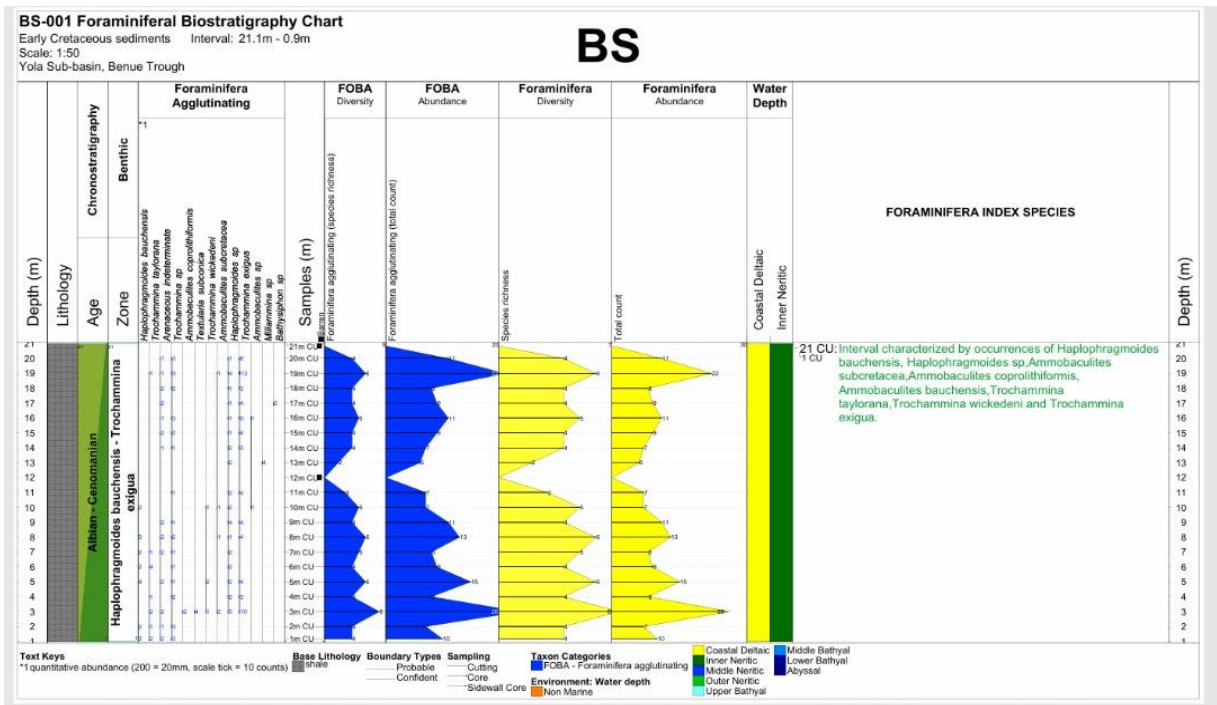


Figure 8: Foraminifera Distribution Chart of the Lower Bima outcropped at Ture-Awak, Yola Basin (M1–M21, based on this study)

Foraminiferal Colour Index

The Foraminiferal Colour Index (FCI) is a thermal maturity indicator based on the progressive darkening of foraminiferal tests with increasing burial temperature. 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. Initially light yellow to greenish in immature stages, the tests darken to brown at the onset of

hydrocarbon generation and eventually to grey-black at peak maturity. With further burial and heating, they become opaque black, corresponding to overmature conditions (>200 °C), where hydrocarbons are exhausted and only dry gas may remain.

These colour transitions are calibrated with the Munsell colour system (Munsell, 1975) and standardized FCI values (Staplin, 1969; Pearson, 1984). Low values (FCI 2.0–2.5) represent immature to early oil onset, values of 2.5–3.0 fall within the early oil window, while 3.0–3.5 indicates the peak oil stage.

Table 3: Foraminiferal Colour Index (FCI) and Thermal Maturity

Plate Nos	Foraminiferal colour index (Munsell colour observed)	FCI value	Estimated temperature (°C)	Interpretation of maturity / potential
	Yellow-green to olive	2.0–2.5	~60–85 °C	Immature to early oil onset; hydrocarbons just beginning to form
	Light olive brown	2.5–3.0	~80–95 °C	Early oil window; active hydrocarbon generation.
	Brown to greyish brown	3.0–3.5	~95–110 °C	Peak oil window; maximum hydrocarbon generation potential.

Palynofacies Analysis

Palynofacies examination of the outcrop samples shows five main organic matter types (PM-1 to PM-4 and SOM) as described by Oyede (1991) and Staplin (1969). The assemblages are dominated by opaque phytoclasts (PM-1) and cuticular fragments (PM-4), with smaller amounts of woody particles (PM-2), some structureless organic matter (SOM), and rare transparent tissues (PM-3). This

dominance of PM-1 and PM-4, together with the presence of minor woody and amorphous material, suggests a strong terrestrial input and preservation under fluctuating oxygen and energy conditions. Overall, the composition indicates deposition in a brackish to fluvio-marine transitional environment, where organic matter was variably preserved depending on redox conditions.

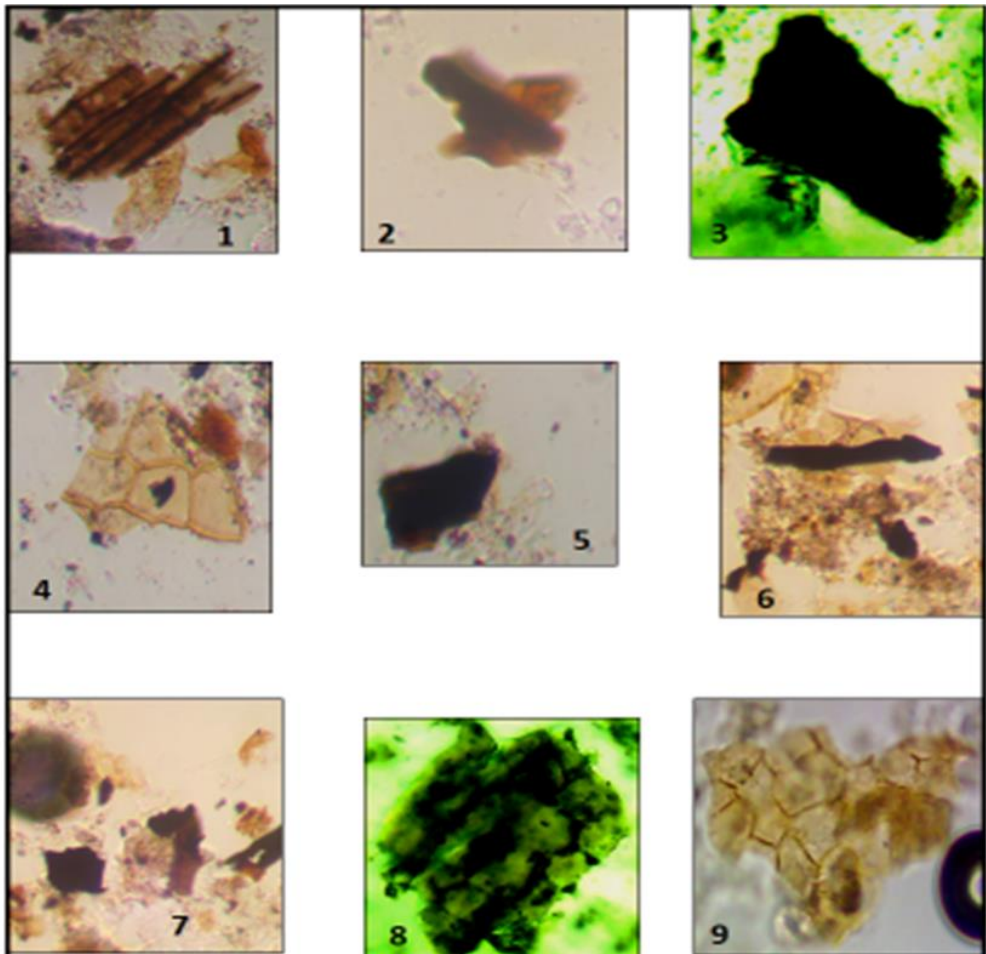


Figure 9: Photomicrographs of the palynofacies in selected BM samples

Table 4: Size Distribution of Palynomacerals (PM-1 to PM-4) Identified in the Study Samples”

S/N	DESCRIPTION	SIZE
1	Palyno Macerals PM-3	Medium
2	Palyno Macerals PM-1	Large
3	Palyno Macerals PM-2	Small
4	Palyno Macerals PM-3	Medium
5	Palyno Macerals PM-1	Small
6	Palyno Macerals PM-4	Small
7	Palyno Macerals PM-1	Small
8	Palyno Macerals PM-2	Medium
9	Palyno Macerals PM-3	Large

Spore Colour Index

Spore Colouration Index (SCI) was determined by comparing the colours of spores and pollen under the microscope with standard reference charts and calibrating them against the Thermal Alteration Index (TAI) and %Ro values. The results show a wide maturity range, with SCI values between about 2 and 10. Samples dominated by amorphous organic matter (AOM) and thin woody cuticles (Plates 3, 4, and 8) display green–yellow to pale yellow

colours (SCI 2–3), pointing to an immature to very early oil stage. In contrast, woody-rich assemblages (Plates 1, 2, 6, 7, and 9) yield yellow-brown to brown hues (SCI 5–7), reflecting early to peak oil generation. The inertinite-rich interval (Plate 8) is dark brown to black (SCI 9–10), indicating overmaturity and a shift into the condensate to gas generation stage. Overall, the SCI data highlight variable maturity across the section, ranging from immature through peak oil to gas-prone intervals.

Table 5: Palynofacies Characteristics, TAI, and Petroleum Potential

Sample ID	Main organic material (palynomacerals)	Color	TAI	%Ro eq.	Maturity stage
1	Woody particles	Light–mid brown	2.3–2.6	0.60–0.90	Early lower peak oil
2	Woody + waxy/lipid fragments	Yellow-brown to brown	2.2–2.5	0.55–0.85	Early oil window
3	AOM + minor woody	Bright green/yellow (AOM)	1.8–2.2	0.45–0.70	Immature very early oil
4	Thin woody cuticles	Thin woody cuticles	1.7–2.1	0.40–0.65	Immature very early oil
5	Opaque inertinite	Black	3.0–3.2†	>1.10	Late oil condensate/gas
6	Woody > opaque	Dark yellow-brown	2.5–2.8	0.75–1.05	Upper early peak oil
7	Woody + opaque + some AOM	Brown with black pieces	2.3–2.7	0.65–1.00	Early peak oil
8	AOM >> woody/opaque	Strong green/yellow (AOM)	1.8–2.2	0.45–0.70	Immature very early oil
9	Woody	Yellow-brown	~2.0–2.3	0.50–0.75	Early oil onset

Biostratigraphy and Age Determination

The age of the studied succession was established by integrating palynological and foraminiferal evidence. Although palynomorph recovery was generally moderate, several key taxa were identified. These include *Triorites cf. africaensis*, *Cretacaeiporites* sp., *Galeacornea* sp., *Steevesipollenites* sp., *Tricolporopollenites* sp., and *Araucariacites* sp., alongside a variety of fern spores such as *Cyathidites* spp. and *Distaverrusporites simplex*. Of particular importance is *Triorites africaensis*, which has long been recognised as a reliable Cenomanian index fossil in West African palynostratigraphy (Jan du Chêne et al., 1978; Salard-Chebouldaef, 1979). The associated presence of *Cretacaeiporites* and *Galeacornea*, whose stratigraphic ranges are generally confined to the Late Albian–Cenomanian, further supports this interpretation. Together, these associations indicate that the studied interval is best placed within the Cenomanian. Other recovered palynomorphs, such as *Botryococcus braunii* and diatom frustules, provide valuable environmental information but are not considered biostratigraphically diagnostic.

The foraminiferal assemblage also contributes significantly to the age interpretation. The assemblage is dominated entirely by arenaceous benthic species, including *Trochammina taylorana*, *T. exigua*, *T. wickedeni*, *T. subconica*, *Ammobaculites subcretacea*, *A. coprolithiformis*, and *Haplophragmoides bauchensis*. Similar faunas have been documented from Albian–Cenomanian successions in the Benue Trough and other Nigerian basins, particularly in the works of Petters (1979, 1982) and Blows (1969, 1979). The absence of planktonic and calcareous benthic foraminifera, although limiting for precise zonal correlation, is typical of marginal marine siliciclastic facies and does not conflict with a mid-Cretaceous age assignment. When combined with the

palynological evidence, the arenaceous foraminiferal ranges reinforce the conclusion that the Bima Shale at Ture–Awak Road belongs to the Cenomanian Stage of the Late Cretaceous, consistent with regional biostratigraphic frameworks for the Gongola and Yola sub-basins.

Paleoenvironment

The interpretation of the paleoenvironment of the studied interval is derived from the integration of lithofacies, palynological, palynofacies, and foraminiferal data. The arenaceous foraminiferal assemblage is dominated by *Trochammina taylorana*, *Trochammina exigua*, *Trochammina wickedeni*, *Trochammina subconica*, *Ammobaculites subcretacea*, *Ammobaculites coprolithiformis*, and *Haplophragmoides bauchensis*. The absence of calcareous benthic and planktonic taxa, coupled with the overwhelming dominance of agglutinated foraminifera, suggests deposition in restricted marginal-marine to shallow inner neritic environments, characterized by fluctuating salinity and periodic marine incursions (Petters, 1979, 1982). The palynological assemblage, dominated by terrestrially derived pollen and spores such as *Triorites cf. africaensis*, *Cretacaeiporites* sp., *Tricolporopollenites* sp., *Araucariacites* sp., *Steevesipollenites* sp., and diverse fern spores, supports strong continental input. The frequent recovery of freshwater indicators, including *Botryococcus braunii*, diatom frustules, and fungal spores, points to the influence of fluvial, swamp, and floodplain conditions, consistent with a river-dominated delta plain setting.

Palynofacies composition further corroborates this interpretation. The dominance of PM-1 (opaque phytoclasts) and PM-4 (cuticular/structured organic matter), along with minor PM-2, rare PM-3, and some structureless organic matter, reflects brackish to fluvio-marine transitional conditions, where organic matter was

variably preserved under alternating oxic and dysoxic states (Tyson, 1995; Batten, 1996; Sarki Yandoka, 2015, 2016). In addition, coal seams and carbonaceous shales observed in the lithostratigraphy indicate localized swamp development, while bioturbation in fine-grained intervals (notably *Thalassinoides* burrows) reflects episodes of marine incursion into otherwise fluvial-dominated environments. Taken together, the evidence suggests that the Bima Formation at Ture–Awak Road was deposited in a marginal marine to shallow neritic setting, controlled by fluvial input, swamp development, and periodic brackish to marine incursions, a conclusion that aligns with earlier regional studies in the Gongola and Yola sub-basins (Petters, 1979, 1982; Sarki Yandoka, 2015, 2016, 2022).

Thermal maturity

The ability of the Lower Bima Member in the Yola Sub-basin to generate hydrocarbons depends on two main factors: how mature the organic matter is and the type of organic matter preserved. Evidence from the Foraminiferal Colour Index (FCI) shows that the formation records conditions ranging from immature to early oil generation. Samples with FCI values of 2.0–2.5 (about 60–85 °C, equivalent to 0.55–0.70% Ro) represent rocks that are only beginning to mature and have not yet fully entered the oil window. In contrast, samples with FCI values of 2.5–3.5 (about 80–110 °C, equivalent to 0.70–1.00% Ro) indicate that parts of the succession fall within the early to peak oil window, where petroleum generation has already started (Staplin, 1969; Pearson, 1984; Munsell, 1975).

Palynological and palynofacies evidence adds more detail. Layers rich in amorphous organic matter (AOM) are linked with Type II kerogen, which is more oil-prone and usually formed under oxygen-poor conditions. On the other hand, layers dominated by woody and opaque particles are tied to Type III kerogen, which is more gas-prone and reflects stronger input from land plants and/or oxidized organic matter (Tyson, 1995; Bustin, 1988). This means that the Lower Bima Member contains a mixture of Type II and Type III kerogen, showing that it has the capacity to generate both oil and gas depending on maturity. Overall, this mix explains why some intervals in the unit remain immature while others are already capable of generating hydrocarbons. The combined results of stratigraphy, palynofacies, and maturity analysis show that the Lower Bima Member holds significant petroleum potential and could make a meaningful contribution to the hydrocarbon resources of the Benue Trough (Obaje, 2009; Zaborski et al., 1998).

CONCLUSION

This study integrated palynological, palynofacies, and foraminiferal analyses of twenty-one samples (M1–M21) from the Lower Bima Member in the Yola Sub-basin, Upper Benue Trough, to reconstruct its age, paleoenvironment,

and hydrocarbon potential. The recovered palynomorph assemblages include abundant pollen, spores, freshwater algae (*Botryococcus braunii*), fungal spores, and diatom frustules, together with rare arenaceous benthic foraminifera. Diagnostic taxa such as *Cretacaeiporites* sp., *Monocolpites marginatus*, *Araucariacites* sp., and *Proxaperites operculatus* constrain the succession to the Cenomanian age, in agreement with regional stratigraphic records. Paleoenvironmental reconstruction indicates a dominantly continental to fluvio-lacustrine depositional system under warm, humid tropical conditions, with minor brackish incursions evidenced by rare arenaceous foraminifera. Palynofacies analysis reveals organic matter dominated by woody phytoclasts and amorphous organic matter, consistent with shallow freshwater deposition under alternating oxic–dysoxic conditions. Hydrocarbon evaluation suggests that *Botryococcus braunii* and other oil-prone algal remains provide Type I/II kerogen input, while inertinite and oxidized cuticles contribute limited gas-prone material. Although thermal maturity is generally low, the assemblages indicate fair to moderate hydrocarbon potential, highlighting the significance of the Lower Bima Member in the petroleum system framework of the Yola Sub-basin.

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