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BIOSTRATIGRAPHY AND PALEOENVIRONMENTAL ANALYSIS OF THE YOLDE FORMATION, NORTHERN BENUE TROUGH, NIGERIA

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ABSTRACT

This research is an attempt to investigate the micropaleontology of the Yolde Formation with the view to determine the age and paleoenvironments of the formation. The Yolde Formation, a key stratigraphic unit within the Benue Trough, provides insights into the Cretaceous paleoenvironments of the region. A total of ten samples were examined using a light microscope. Samples two and six exhibited the greatest taxonomic diversity, each containing 13 different taxa, while the other samples showed a range of 1 to 11 taxa. The benthic taxa *Marssonella, Ammobaculites agulutinans, and Plectina* were found to be prevalent throughout the composite section. Certain taxa, such as *Marssonella Verneuilinoides Sp., Gyroidinoides sp., and Textularia subhauriiw,* each constituted approximately 30% of the benthic assemblage. Common benthic indicators identified in the Yolde Formation include *Marssonella, Verneuilinoides Sp., Ammobaculites agulutinans, Plectina cenomana Sp., Tritaxia tricarinata, Gyroidinoides Sp., Heterohelix Sp. etc.* The presence of *Bulbobaculite Sp. and Gavelinella Sp.* in the Yolde Formation indicates that this formation dates to the Cenomanian age. This dating is supported by the identification of other foraminifera such as *Marssonella, Verneuilinoides sp., Ammobaculites agulutinans, Plectina cenomana sp., Tritaxia tricarinata, Gyroidinoides sp., Heterohelix sp.,* etc. These benthic foraminifera are linked to low-oxygen paleoenvironments that reached the seabed. The presence of *Ammobaculites Spp., Tritaxia tricarinata, and Gyroidinoides Sp.* suggests anoxic conditions. Consequently, the paleoenvironments represented by the benthic foraminifera and the lithofacies reflects a paleoenvironments ranging from inner neritic to middle neritic zones within lower shoreface to upper shoreface.

Keywords: Biostratigraphy, Foraminifera, Age, Paleoenvironment, Shoreface

INTRODUCTION

The Benue Trough originated from the formation of the Atlantic Ocean, which was caused by rifting as Africa broke away from South America during the Mesozoic era (Genik, 1993). This sedimentary basin stretches approximately 800 kilometers into the African landmass and maintains a relatively uniform width of about 150 kilometers (Abubakar et al., 2011). It is composed of a variety of deposits ranging from continental to marine, including siliciclastic sandstone, mudstone, and some limestone. The thickness of these deposits can reach around 6000 meters at the basin's center (Benkhelil, 1989). The Benue Trough is sub-divided into three sectors: Upper, Lower, and Middle Benue Troughs based on their geographical positions (Carter, et al.,, 1963). The southern end, known as the Lower Benue Trough, is bordered by the Anambra Basin, while the northern end, referred to as the Upper Benue Trough, is adjacent to the Chad Basin (Fig.1). The Upper Benue Trough is subdivided into two smaller basins known as the Gongola and Yola sub-basins. The majority of the initial studies conducted on the Yolde Formation primarily concentrated on sedimentology, with minimal attention given to paleoenvironments and the significance of age as determined by microfossils, and this is due to the fact that majority of them worked on the lithofacies of the Yolde Formation. Notable contributions to this field include works by Falconer, (1912) ; Barber & Tait, (1954); Barber et al., (1954); Carter et al., (1963), and Zarboski et al., (1997). Each of these researchers identified a transitional environment associated with the Yolde Formation. According to Haq & Boersma, (1998) micropaleontology refers to the examination of microscopic fossils that traverse various classification categories. A microfossil is defined as a small fossil whose unique features are best analyzed using a microscope. These microfossils are characterized by their diminutive size and significant numerical prevalence, often found in relatively small sediment samples. Consequently, this field employs more stringent quantitative analytical methods. Marine microfossils, in particular foraminifera, can be located in sediments ranging from the Precambrian era to the present day, and within any section of the stratigraphic column, one or more groups can typically be identified as valuable for biostratigraphic purposes. microfossils occur in sediments of Precambrian to Recent ages, and in every part of the stratigraphic column one or more groups can always be found useful for Biostratigraphic, paleoenvironmental and palaeoecological interpretations. For example, the benthic foraminifera group is more suitable for reconstructing depositional environments in addition to Biostratigraphic indicators, as the occurrence is restricted to well-defined habitats Haq & Boersma, (1998). This work is aim at determining the age and paleoenvironments of the Yolde Formation in Yola Arm of the Northern Benue Trough.

The Benue Trough is a rift basin that is part of the West and Central African Rift System. It is divided into three sections: the Upper, Middle, and Lower Benue Trough (Carter, et al., 1963; Benkhelil and Robineau, 1989; Guiraud, 1990; Guiraud and Maurin, 1992). The Upper Benue Trough (Fig. 1) consists of two primary sub-basins: the Gongola Arm, which trends north-south, and the Yola Arm, which trends east-west (Zaborski, 2003; Abubakar, 2014; Shettima, 2016). This trough features sedimentary deposits that extend for approximately 1,000 km in length and vary in width from 50 to 150 km within Nigeria. The rift basin itself trends in a northeast-southwest direction and is characterized by a combination of continental and marine sedimentary deposits with an overall thickness reaching up to 6,500 m. The development of this basin has been linked to various proposed tectonic models concerning large-scale intracontinental structures. All three suggested models propose that the formation of the Benue Trough is associated with intraplate rifting.

i. (I) The initial model for the evolution of the Benue Trough related to rifting was proposed by King, (1950). This concept was supported by later researchers such as in (Grove et al., 1966; Cratchley et al., 1984). They suggested that the primary force driving the rifting process is tensional movement, a conclusion derived from gravity data.
ii. Grant, (1971), attributed the origin and development of the Benue Trough to the movement of a continental plate during the Late Jurassic to Early Cretaceous period, which led to the separation of two continents: Africa and South America.
iii. The third evolutionary theory regarding the Benue Trough is associated with left-lateral movement during the Early Cretaceous period (Popoff et al., 1983; Benkhelil and Robineau, 1989; Fairhead and Binks, 1991). This process is showed a trend in northeast-southwest transcurrent fault that originates from the ridge of the Atlantic Ocean.

The sedimentary basin consists of seven distinct formations: Bima Sandstone, Yolde Formation, Dukul Formation, Jessu Formation, Sekuliye Formation, Numanha Formation, and Lamja Formation. (Fig. 2).

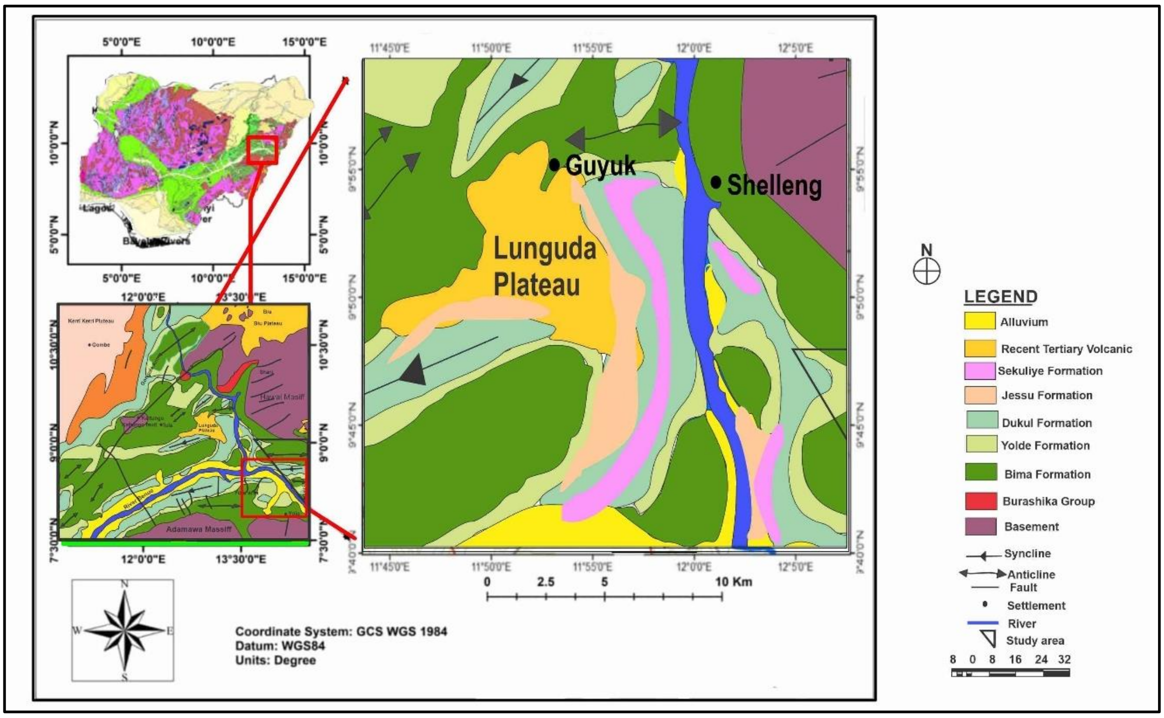

Figure 1: The Geologic map of the Yola Arm of the Northern Benue Trough

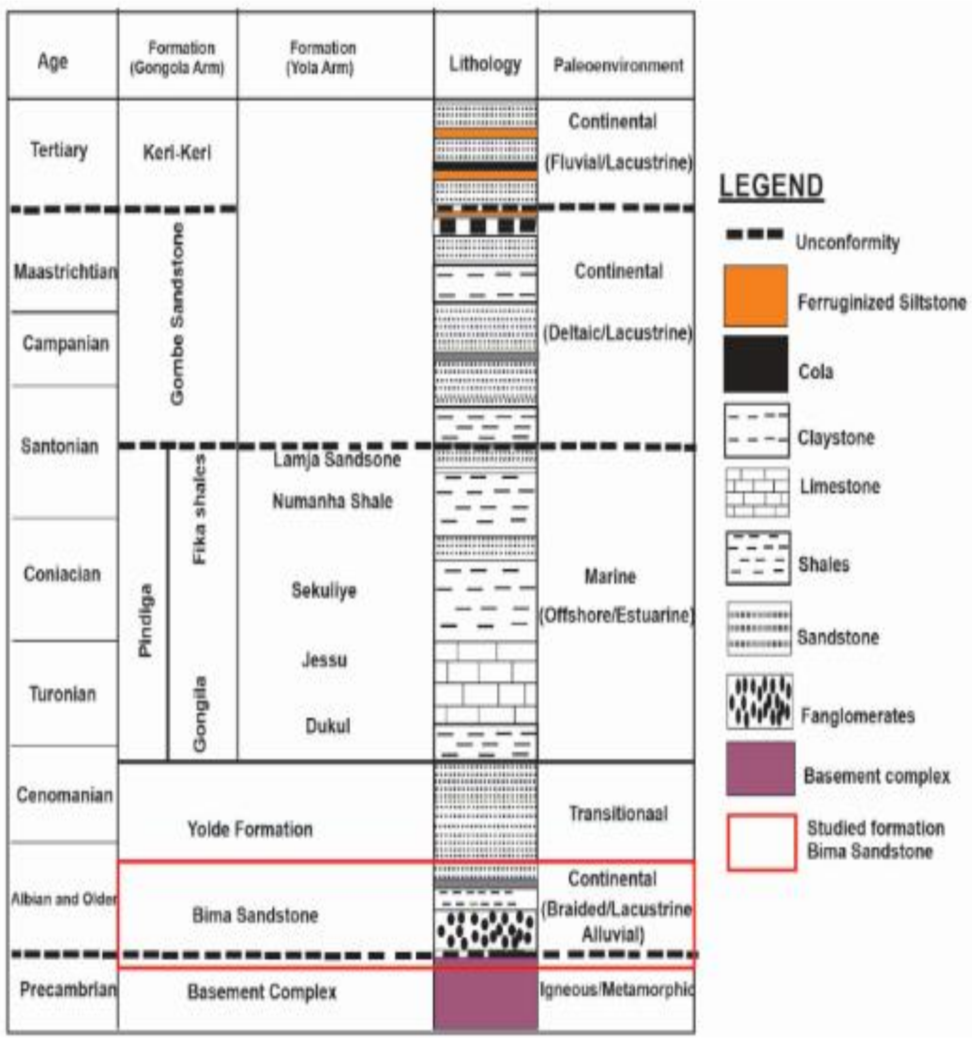

Figure 2: Stratigraphic succession of the Upper Benue Trough (modified by Finthan et al., 2023)

MATERIALS AND METHODS

Shale samples were collected and disintegrated into smaller fragments using a pestle and mortar. These fragments were then processed with a 15% hydrogen peroxide solution and sodium bicarbonate ($NaHCO_3$) to extract microfossils from the shale samples. The resulting mixture was boiled, filtered through a sieve with a mesh size of 63µm (0.63mm), and subsequently dried in an oven. From the remaining material, Foraminifera microfossils were carefully selected. The analysis of these microfossils have been studied using a light microscope, with their identification and classification based on the criteria established by (Gibson, 1989; Haq & Boersma, 1998; Papazzoni et al., 2023). The research utilized micropaleontology concepts for age determination and paleoenvironmental studies related to foraminifera according to Volkheimer & Melendi, (1976).

RESULTS AND DISCUSSION

Foraminifera Micropaleontology

The benthic foraminiferal density fluctuates between the recovered specimens per gram of dry sediment (YF/g) with one exception. The ten samples investigated from the Yolde Formation (Table 1 and Fig. 3) show an unevenly distributed of taxa richness. Sample two and six (2 & 6) yields the highest taxon diversity with 13 taxa each, while the remaining 8 samples record between 1-11 taxa each. The benthic taxa *Marssonella*, *Ammobaculites agulutinans*, *Plectina* are abundant throughout the composite section (Fig. 3). Some of the taxa e.g . *Marssonella Verneuilinoides Sp., Gyroidinoides sp, and Textularia subhaurii* (Figure 4 a, b, c and d) represent ~30% of the benthic assemblage each. The lowermost samples contain taxa (i.e., *Bulbobaculite sp.*) (Fig. 5 and Table 1). The abundance of the *Ammobaculites agulutinans and Heterohelix sp* (Figs. 3, 4 c and 5 a) at 1.8 m and 5.6 m of the stratigraphic intervals in the Yolde Formation suggest that the community was adapted to sufficient organic matter input and abundant food sources in the Yolde Formation (Jorissen et al., 2007). Increased paleo-productivity can also result to the abundance of the species at this levels (Alegret et al., 2003; Wang et al., 2020; Wang et al., 2021).

Table 1: Distribution of foraminifera in the investigated samples. Each column contains the percentage and the number of individuals picked (in brackets)

	S/No	1	2	3	4	5	6	7	8	9	10
	Species										
1	*Marssonella*		25(1)								
2	*Verneuilinoides sp*	12.5(1)	15(2)			20 (2)	2 (1)	12(1)			
3	*Ammobaculites agulutinans*	12.5(1)	12.5(1)								
4	*Plectina cenomana sp*	10(1)					9(2)	20(1)	14.3(1)	12.5(1)	
5	*Tritaxia tricarinata*	8(1)	17.5(2)	40(2)			21(1)	8(4)	14.3(1)	25(2)	
6	*Gyroidinoides sp*	25(1)									
7	*Heterohelix sp*	13(2)	16(2)	27(2)	20(1)	20 (2)		10(2)	14.3(1)	25(2)	
8	*Bulbobaculite sp*	15(1)	10(2)	10(1)	18(2)	22(2)	27(2)	9(2)	14.3(1)	25(2)	
9	*Gavelinella sp*	4(2)	9(2)	13(2)	12(3)	28(1)	11(2)	41(2)	14.3(1)	25(2)	
10	*Tritaxia sp*	25(2)	20 (1)	10 (3)	50 (3)	10 (3)	30 (3)				
	∑	100(11)	100(13)	100(10)	100(9)	100(10)	101(13)	101(7)	100(5)	100(9)	

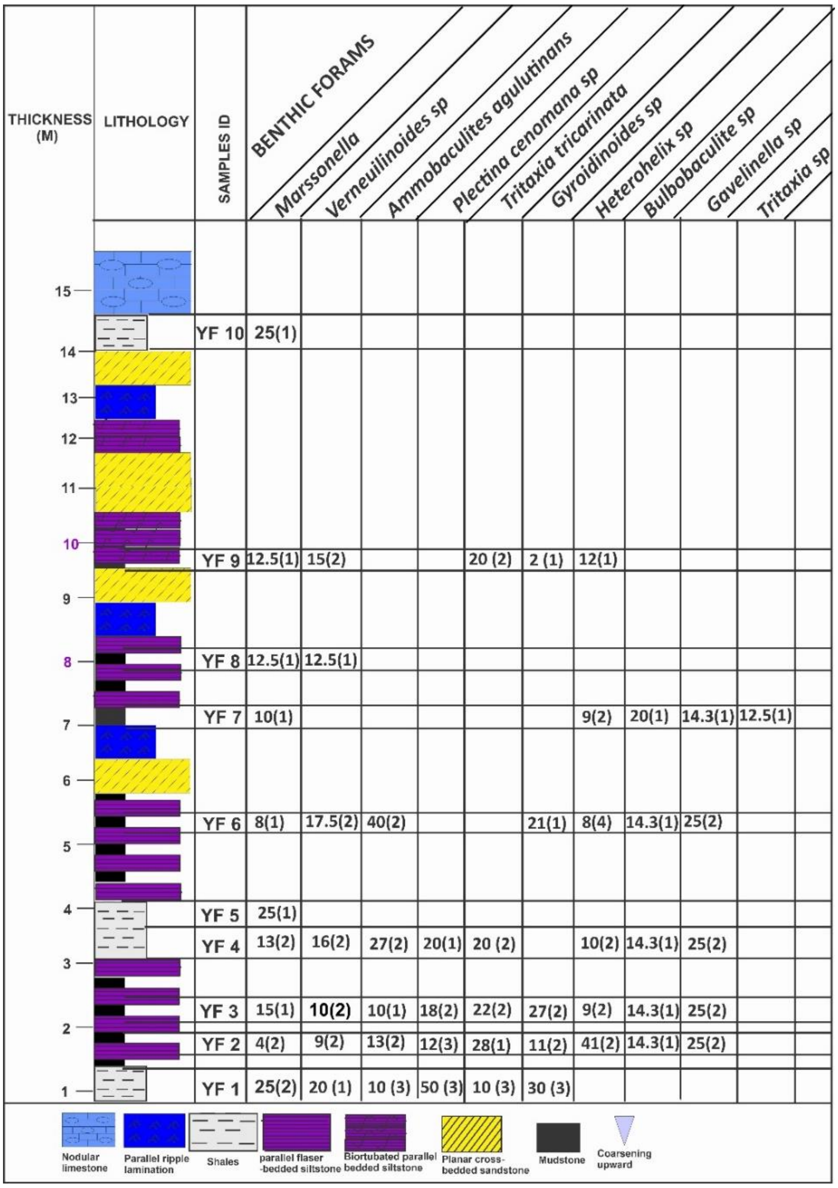

Figure 3: Biostratigraphic section of the Yolde Formation showing foraminifera distribution in abundance, and stratigraphic order

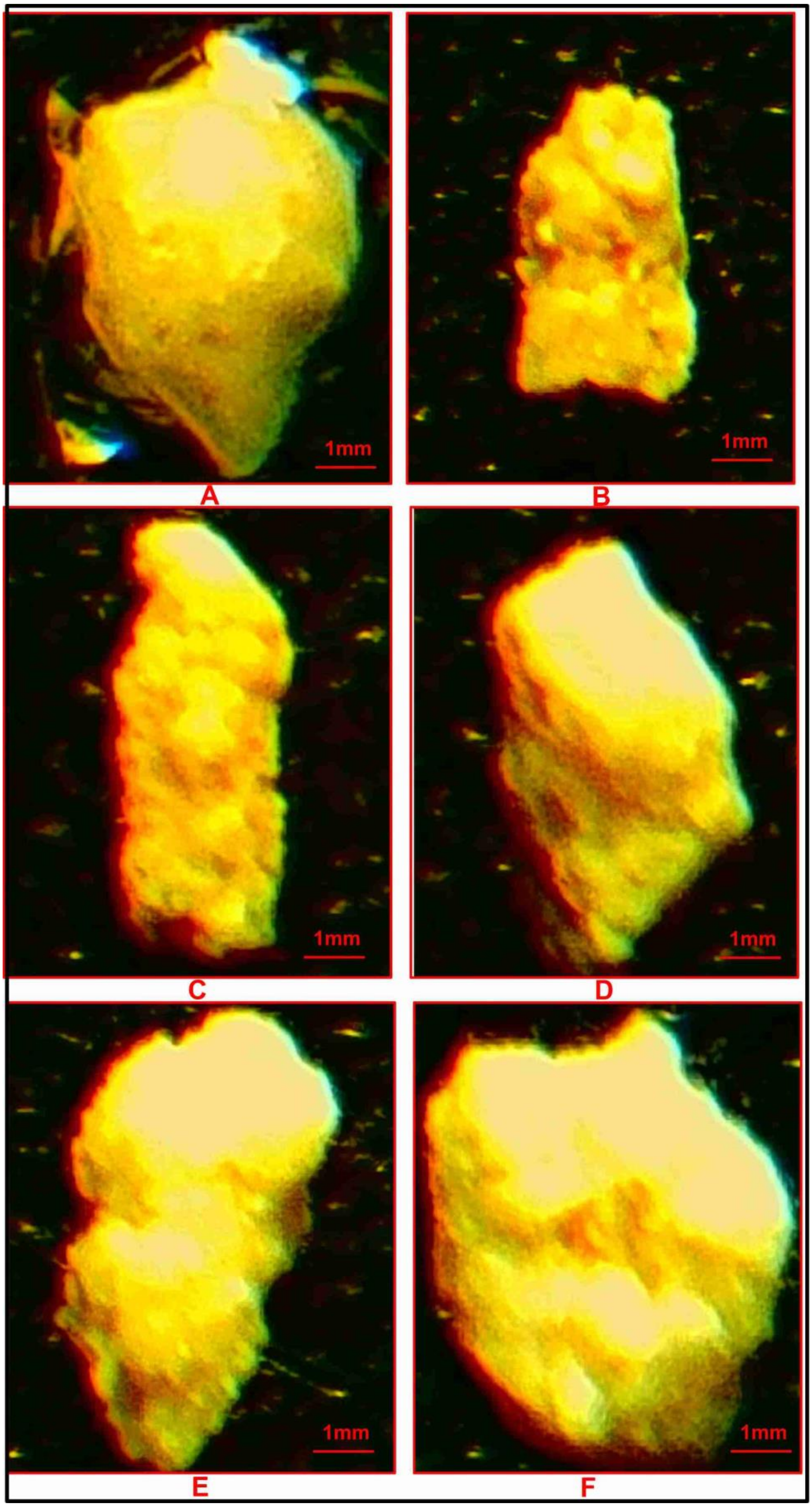

Figure 4: Images of selected benthic foraminifera from Yolde Formation: A. Marssonella, B. Verneuilinoides sp, C. Ammobaculites agulutinans, D. Textularia subhaurii E. Tritaxia tricarinata, F. Gyroidinoides sp.

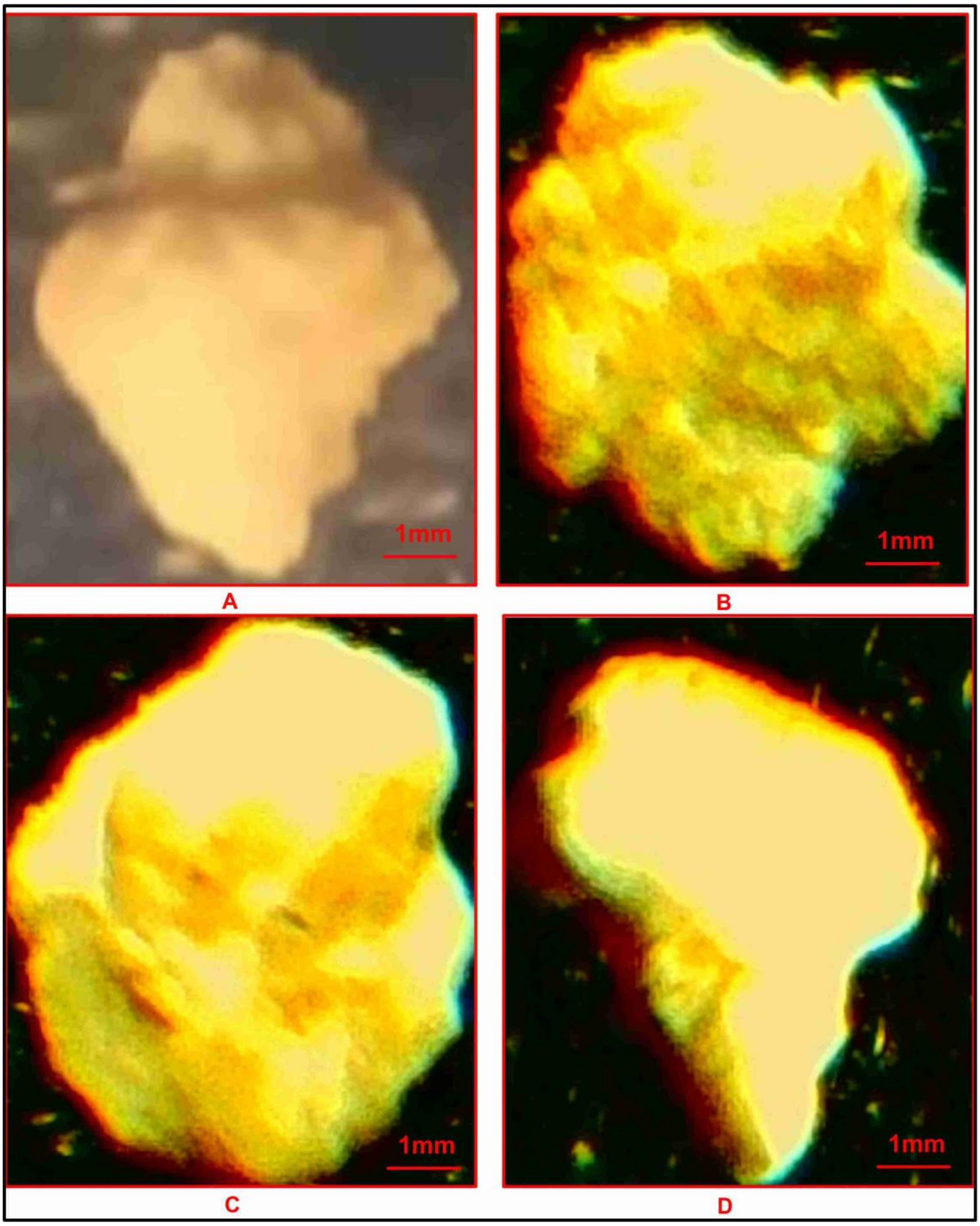

Figure 5: Images of selected benthic foraminifera from Yolde Formation: A. Heterohelix sp, B. Bulbobaculite sp, C. Gavelinella sp, D. Tritaxia sp.

Lithostratigraphic section of Yolde Formation

Facies descriptions and interpretations

According to Anderton (1985), sedimentary facies is a specific volume of rock that is distinguished from other rock units by a variety of features, including grain size, geometry, and structure. The studied section of the Yolde Formation from the study area is located in Gwana village. They are primarily made of sandstones, siltstones, and shales (Fig. 7 a-h). Most of the sandstones are buff or light brown, with occasional white ones. The shales, however, exhibit a light-gray to dark-gray coloration. Based on sedimentary structures, lithology, bioturbation, and trace fossils, these rock units were classified into eight (8) facies, which were then interpreted using previous research by Harms et al., (1975), Bhattacharya & Giosan, (2003); Catuneanu et al., (2010), Harms et al., (1975), Bhattacharya, (2006), (Deltas, 2010), Plint, (2010), Souza et al., (2012), Bressan et al., (2013), to mention a few. The Yolde Formation's sub-paleodepositional settings and depositional processes were revealed by the recognized facies and facies association, this is to substantiate the deduced paleoenvironment based on the recovered benthic foraminiferas (Fig. 6 and 7).

Eight (8) distinct lithofacies were identified from Yolde Formation (Fig. 7 a-h). These are:

(i) Inter-bedded sandstone and clay/shale (flaser-beddeds), (ii) Ripple cross-laminated sandstone (Sr),(iii) Horizontal laminated sandstone (Sh), (iv) Planar cross-bedded sandstone (Sp), (v)Trough Cross-bedded Sandstone (St), (vi)

Hummocky cross-bedded sandstone (Hsc) (vii) Clay/Shale (Fl).

These lithofacies provide valuable insights into the depositional environment and sedimentary processes that have shaped the Yolde Formation in the Yola Sub-basin.

Clay/Shales Facie (Fl)

Description: This facies consists of clay/shale units with a thickness of up to approximately 2.9 meters, measured at the base of the Cham and Dukul sections. The facies exhibit sharp to gradational contact with both the lower and overlying beds. The color of the facies ranges from gray to dark and is capped by nodular sandstone at the Dukul outcrop (Fig. 7 a).

Interpretation

This facies is interpreted as deposition below and immediately above the storm wave base in an offshore-to-offshore transition environment (Nichols & Thompson, 2005; Aliyu et al., 2017; Sarki Yandoka et al., 2015, 2019). Similar facies were interpreted as suspension deposit in a low-energy environment (Coleman, 1969).

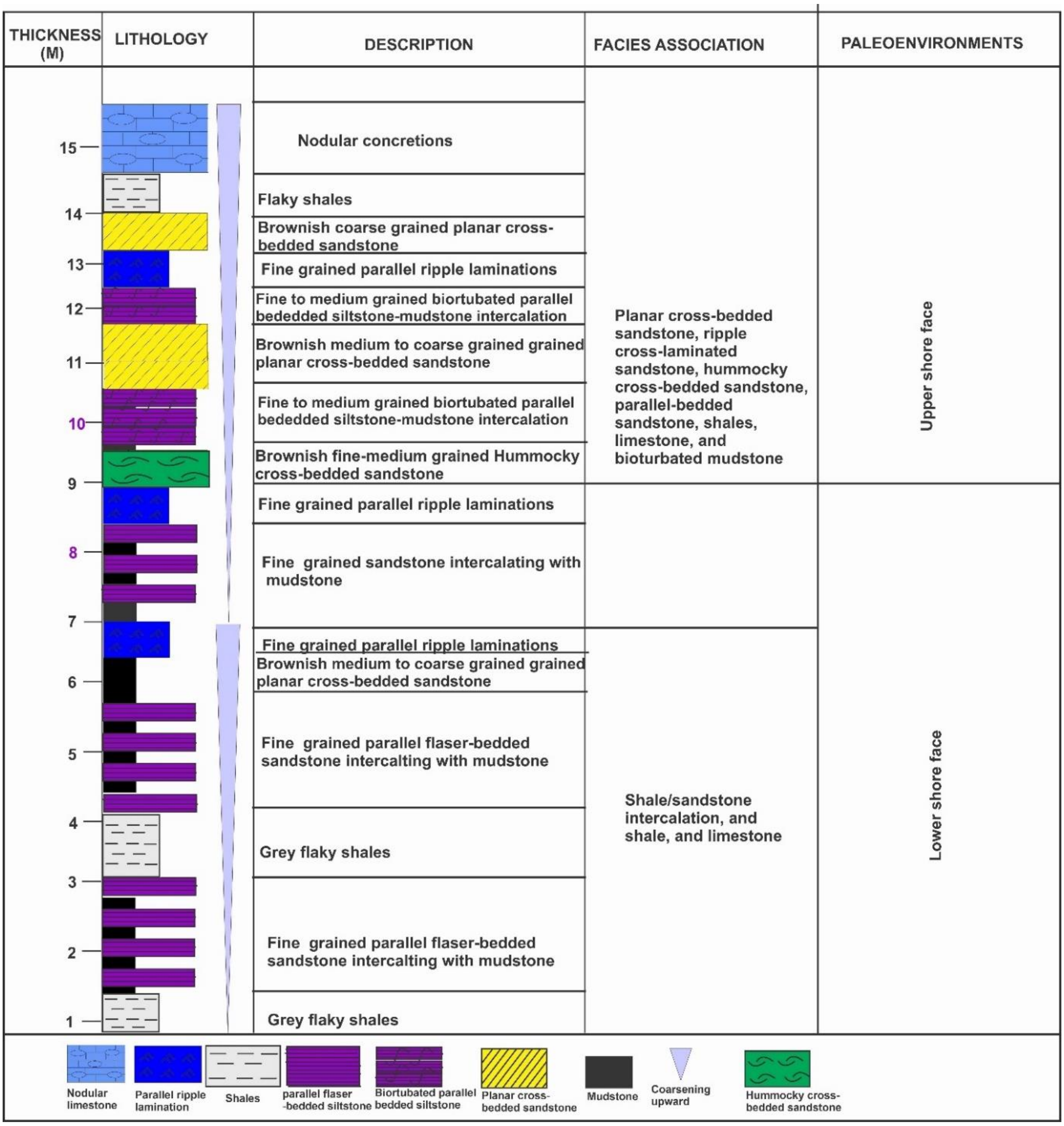

Figure 6: Lithostratigraphic Section of the Yolde Formation at Gwana Stream one

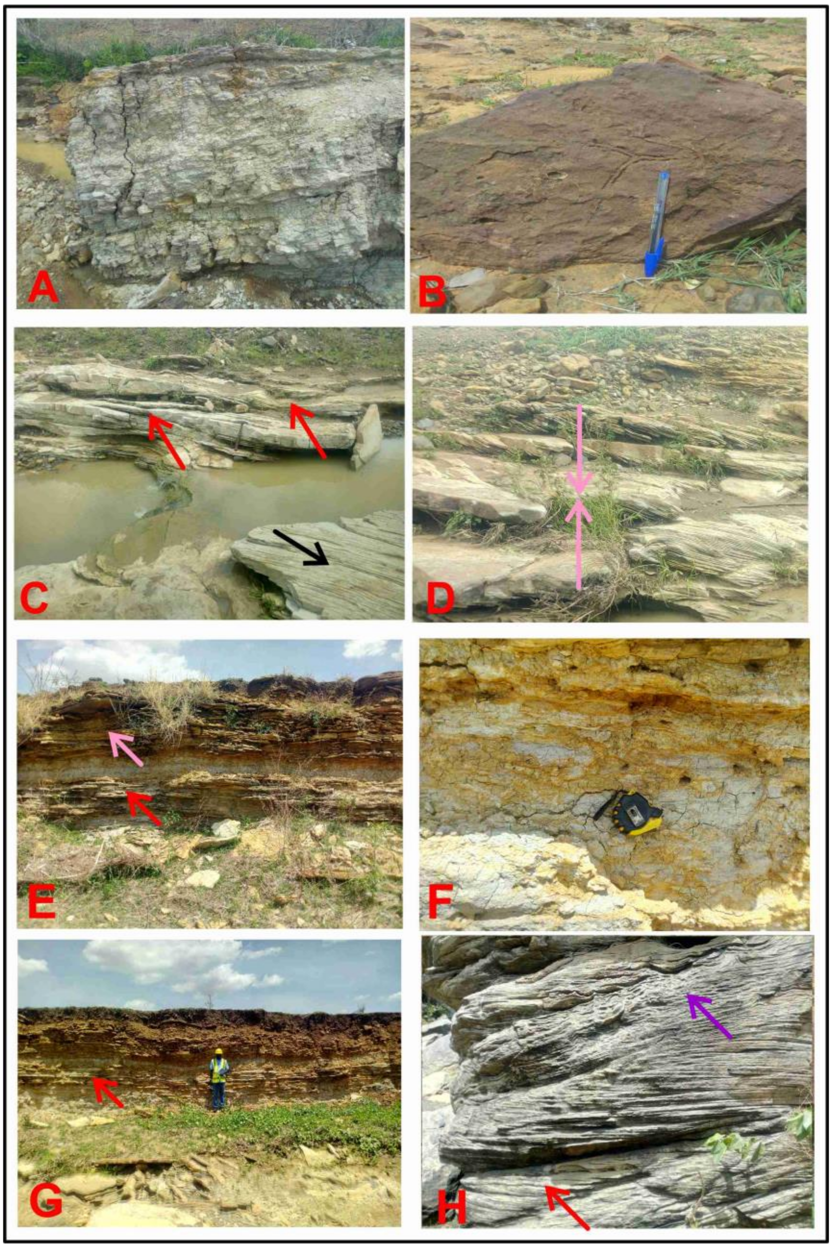

Figure 7: (A) Thick light grey shale (B) Bioturbated siltstone facies (Thalassinoides, see white arrow), (C) Hummocky cross-bedded sandstone facies (see 2 red arrow) and ripple cross-laminated sandstone facies (see black arrows), (D) Parallel bedded sandstone and thin bed of shales intercalations. (E) Flaser-bedded sandstone (see red arrow) and deformed parallel-laminated sandstone (see pink arrow), (F) Thick grey shales (G). Parallel and flaser bedded sandstone and shale intercalated facies (see red arrow), (H). Planar cross-bedded sandstone (see pink colour) and ripple cross-laminated sandstone

Interbedded Mudstone/Sandstone (Flaser-bedding)

This lithofacies is characterized by the presence of interbedded sandstone and clay or shale. This lithofacies primarily consists of sandstone with thin layers of clay in between. The sandstones exhibit features such as ripples and parallel lamination, with a sharp or erosional base. The thickness of individual sandstone beds ranges from 4 to 10 cm, and they are interspersed with thin clay lenses (Fig. 7 g). This lithofacies is deposited as a result of sediment supply fluctuations or wave current activity. Similar lithofacies have been associated with deposits formed by fluctuating currents (Tovmasjana, 2013).

Interpretation

The lithofacies CL is composed of alternating layers of sandstone and clay or shale. It primarily consists of sandstone with thin layers of clay in between. When examining the sandstones within this lithofacies, one can observe features such as ripples and parallel lamination, which indicate the movement and deposition of sediment over time. The base of these sandstone beds can be sharp or erosional, suggesting changes in the depositional environment. In terms of thickness, the individual sandstone beds within this lithofacies range from 6 to 10 cm. These beds are not continuous but rather separated by thin lenses of clay. This indicates that the sedimentation process was not uniform, and there were periods where clay or shale deposition occurred instead of sandstone. The interpretation of this lithofacies suggests that it is a result of fluctuations in sediment supply or wave current activity. Sediment supply fluctuations can occur due to various factors such as changes in river discharge or sea level fluctuations (Coleman 1991).

Facies Sr: ripple cross laminated sandstone Description:
This facies occurs in very fine to fine grained sandstone. It is observed within the gradational boundary of the coarsening upward unit, which indicates increase in energy of the depositional medium. The dominant ripple identified is wave ripples. The sandstones are moderately well sorted to well sorted. The beds thickness ranges from 3 to 21 cm (Fig. 7 h). This facies is mostly overlain by cross-bedded sandstone.

Interpretation

These facies were interpreted to represent deposition below and immediately above the storm wave base in offshore and offshore transition zone within shallow marine environment (Bressan and Palma, 2009; Bressan et al., 2013; Nichols, 2009). Similar facies were interpreted as wave ripple cross-laminated sandstone that formed due to relatively low velocity currents or moderate wave action in a nearshore environment (Romos et al., 2006).

Facies Sh: Sandstone with Horizontal Lamination

This type of facies is distinguished by the presence of thin layers of sandstone (Fig. 7d). It can be found as a substantial layer of sandstone or as separate units within clay or shale. It exhibits a distinct sharp base and is characterized by fine to medium-grained sandstone. The thickness typically ranges from 3 cm to 1m.

Interpretation

The association of this facies with clay/shale suggests that it was deposited in a low-energy environment, indicating a shallow marine setting (Souza et al., 2012; Sedimentology, 2013; Sarki Yandoka, Abdullah, et al., 2015).

Facies Sp: sandstone with planar cross-bedding

The facies Sp is characterized by the presence of medium to coarse-grained sandstones with planar cross-beds, which have a thickness ranging from 15 to 25 cm (Figs. 7 h and h). This type of sandstone exhibits high angle inclination and straight crested dunes, and it is bounded by sharp or erosional surfaces at the base. The sandstone in these facies is moderately sorted. It is interpreted to have been formed by the migration of cross-channel bars. Similar facies have been associated with the migration of dunes under unidirectional flow due to wave swash processes in the upper shoreface or the migration of ridge and runnels in the foreshore zone (Sarki Yandoka, Abdullah, et al., 2015; Aliyu et al., 2017; Finthan & Mamman, 2020; Seli & Finthan, 2022).

Interpretation and Description

The sandstones in these facies are medium to coarse-grained and exhibit planar cross-bedding with a thickness ranging from 10 to 20 cm. The high angle inclination and straight crested dunes, along with the sharp or erosional surface at the base, characterize these facies. The sandstone is moderately sorted, and it is interpreted to have formed through the migration of cross-channel bars. Similar facies have been linked to the migration of dunes under unidirectional flow due to wave swash processes in the upper shoreface or the migration of ridge and runnels in the foreshore zone (Sarki Yandoka, Abdullah, et al., 2015; Aliyu et al., 2017; Finthan & Mamman, 2020; Seli & Finthan, 2022).

Facies Hcs: Hummocky Cross-Bedded Sandstone

The HCS facies is identifiable by its gently undulating low-angle cross lamination, featuring both concave upward and concave downward parts (Fig. 7c). These particular facies have been observed in both the Cham and Guyuk stream sections and is typically found within brownish fine to medium-grained sandstones. The individual thickness of this facies ranges between 30 and 50 cm.

Interpretation of Hcs Facies

The interpretation of this facies points towards storm and wave influence deposition at the outer shoreface and transitional zone. Various studies (Bhattacharya & Deltas, 1992; Walker & Cook, 1992; Catuneanu et al., 2010; Tucker, 2012) have associated similar facies with deposition above the fair-weather wave base (Aliyu et al., 2017; Duke et al., 1991; Sakai et al., 2006; Sarki Yandoka et al., 2019).

Facies associations

Facies associations: According to Anderton, (1985) and Barrier-island, (1981), a facies association is a collection of facies that together define a specific sedimentary environment. Four facies associations were identified based on the description and interpretation of the facies above: FA-1 (Upper shoreface), FA-2 (offshore transition to lower shoreface),

Facies association FA-1: Upper shoreface

The wave-rippled sandstone facies (RC) and the primarily hummocky cross-stratified sandstone facies (facies HC), Planar cross-bedded sandstone, bioturbated parallel-bedded sandstone, shale and limestone are the facies association FA-2 (Figs. 6 & 7 b-e). Compared to the facies association FA-1 (lower shoreface), the sediments in this association are generally coarser-grained (fine to medium) and moderately bioturbated. Furthermore, the Clay/Shale facies (facies Fl) are not included in this association, in contrast to the FA-1 facies association. According to one interpretation of the FA-1 facies association, the middle shoreface is where wave action occurs in the upper shoaling region close to the wave-breaking zone. This is because storm waves rework the bottom sediments with great energy and intensity (Alván & Von Eynatten, 2014; Plint, 2010; Sarki Yandoka, Abdullah, et al., 2015; Walker & Cook, 1992)

Facies association FA-2: Lower shoreface

This facies association consists of three facies: bioturbated Thalassinoides ichnofacies (Fig 7 b), wave-rippled sandstone facies, and clay/shale (Fig. g). In this association, the clay/shale facies (Fl) bears resemblance to the offshore marine facies association FA-1, with the exception that it occurs as relatively thin interbeds and is less bioturbated, indicating a potential increase in depositional energy. Given the genetic relationship between the aforementioned facies and their interpretations, this facies association could be interpreted as an offshore transition to lower shoreface, and also the association's stratigraphic occurrence alongside other associations that have been found (Fig. 7 b) in a broad shallow marine succession (offshore to shoreface) affected by storms and waves (McCubbin, 1981; Sedimentology, 2013). In an environment dominated by storms and waves, the offshore transition to lower shoreface facies association (FA-2) indicates suspension deposits laid down below and immediately above the fair-weather wave base (Catuneanu et al., 2010; Cullis et al., 2011; Storms, 2003; Walker & Cook, 1992).

Biostratigraphy of the Yolde Formation

Comparing the biostratigraphic data of the Yolde Formation to that of Atlantic and Tethyan records. The benthic foraminiferal record of the Yolde Formation shows similarities with Site 1138 (Holbourn & Kuhnt, 2002), and with industry wells from the north-western Australian margin i.e., Edaggee 1, Boologooro 1 in the Southern Carnarvon basin, (Haig et al., 2004). Common benthic markers recorded in the Yolde Formation include *Marssonella, Verneuilinoides Sp, Ammobaculites aggulutinans, Plectina cenomana Sp,* *Tritaxia tricarinata, Gyroidinoides Sp, Heterohelix Sp, Bulbobaculite Sp, Gavelinella Sp, Tritaxia sp,* and these are similar to those recovered at Site U1516 and Site 1138 in the rocks of Kerguelen Plateau e.g. agglutinated taxa *Bulbobaculites Sp, and Spiroplectinata annectens* (Holbourn & Kuhnt, 2002). Amongst other benthic foraminiferal markers similar to Yolde Formation from the Kerguelen Plateau represent Cenomanian sediments e.g. *Gavelinella intermedia*. The highest occurrence of *Bulbobaculite Sp, and Gavelinella Sp* in the Yolde Formation is tentatively used to mark the Cenomanian age as in (Haig et al., 2004). It is possible that the Agglutinated foraminifera were thriving under low-oxygen conditions in the Yolde Formation, but were with reference to the taphonomic bias, rarely documented by previous research in the Cretaceous basins in Nigeria e.g. (Reyment, 1965). The benthic foraminifera in the Yolde Formation show barren intervals, especially in the silty-sandy intervals during the latest Cenomanian (Fig. 3). The assemblage of *Bulbobaculite Sp, Gavelinella Sp* at the basal part of the composite section within the Yolde Formation perhaps should be consider as changes in the abundance of taxa that might be related to environmental change rather than to extinctions. Biostratigraphic observation for the Yolde Formation reflects Cenomanian benthic foraminiferal assemblages similar to the epeiric Western Interior Seaway (WIS) in the Rock Canyon section in the Cretaceous southern high latitude benthic foraminiferal assemblages during OAE 2 at IODP Site U1516, Mentelle Basin, Indian Ocean. During the OAE 2, most localities in the WIS record rare agglutinated taxa and document the reduced abundance of benthic foraminifera (Lowery et al., 2014; Lowery & Leckie, 2017).

The tropical Atlantic record from Demerara Rise (ODP Leg 207, Friedrich and Erbacher, 2006) demonstrates more biostratigraphic affinities at species level to the high southern latitudes assemblages than to those recorded in the Yolde Formation e.g. (Obuobie, 2008) documented the occurrence of *Praebulimina elata, Gavelinella cenomanica* and other cosmopolitan benthic foraminifera that are also recorded at Site U1516. The OAE 2 in the northwest European record of Eastbourne (UK) presents a cosmopolitan deep water assemblage Paul Weim, (1993), which is composed of agglutinated Spiroplectammina, Tritaxia, cosmopolitan calcareous taxa like *Gavelinella cenomanica (Osangularia sp. A, G. baltica, G. reussi, G. berthelini).* The absence of benthic foraminifera in the upper interval of the Yolde Formation may represent deteriorated paleoenvironmental conditions in the Cretaceous basin, particularly the Nigeria sedimentary basins, especially in the Yola Arm of the Northern Benue Trough.

Age of the Yolde Formation

The Cenomanian age of the Yolde Formation is supported by the occurrence of *Marssonella, Verneuilinoides sp, Ammobaculites agulutinans, Plectina cenomana sp, Tritaxia tricarinata, Gyroidinoides sp, Heterohelix sp, Bulbobaculite sp, Gavelinella sp, Tritaxia Sp.* these species have been documented from the Tethyan settings in Central, Eastern and Western Europe and Asia particularly at Betic Cordillera, Spain, (Niebuhr et al., 1999; Walaszczyk et al., 2004). Another evidence that the Yolde Formation is Cenomanian in age is due to the fact that, similar record from Eastbourne UK, higher numbers of benthic foraminifera that might correspond to the Plenus Cold Event as reported by Wolfgring et al., (2021). Wolfgring et al., (2021) correlated the d13C curve of Site U1516 to the carbon isotope record at Eastbourne (UK) which aided in the age identification of the studied formation as Cenomanian.

Paleoenvironments

The shallow inner neritic environment is often recognized by its characteristic low species diversity and abundance, predominated by agglutinated foraminifera (Haq & Boersma, 1998). These intervals are characterized by fine to medium coarse-grained sand and thin shale beds signifying deposition in a slightly high to low energy environment (near shore setting). The presence of benthic foraminifera has been associated with low-oxygen zone that reaches the seabed. Fruch & Eicher, (1975) proposed that the reduced oxygen levels at the ocean floor during the Cretaceous period could be attributed to a diminished global thermal gradient. The oceanic circulation was proposed to have been more moderate with a low concentration of oxygen during the early to mid-Cretaceous period compared to the present era. Studies suggest that during the late-Cretaceous period, there was a low concentration of oxygen in the oceans compared to present day. This reduced oxygen level may have been influenced by factors such as decreased in primary productivity due to low nutrients in the oceans, altered photosynthetic activity by marine organisms, and potentially different atmospheric conditions that minimized oxygen retention in seawater Fruch & Eicher, (1975). Stratigraphically the Yolde Formation preserved important agglutinated benthonic foraminifera encountered which include *Ammobaculites Spp., Tritaxia tricarinata, and Gyroidinoides Sp.* The presence of these forams is indicative of brackish water to inner neritic environment. The recovery of these benthic forms from dark shale, dark silty to dark sandy shale facies is indicative of anoxic water conditions that correlate with minimum oxygen concentration Fruch & Eicher, (1975).

1) Inner Neritic This environment is delineated based on the presence of diagnostic inner neritic benthic foraminifera. This benthic foraminifera species include: *Marssonella, Verneuilinoides Sp, Ammobaculites agulutinans, Plectina cenomana Sp, Tritaxia tricarinata , Gyroidinoides Sp, Heterohelix Sp, Bulbobaculite Sp, Gavelinella Sp, Tritaxia Sp.* (Petters, 1981; Petters, 1982b; Zwaan et al., 1999) interpreted an assemblage of benthic foraminifera consisting of *Marssonella, Verneuilinoides Sp, Ammobaculites agulutinans, Plectina cenomana Sp, Tritaxia tricarinata, Gyroidinoides Sp, Heterohelix Sp, Bulbobaculite Sp, Gavelinella Sp, Tritaxia Sp* as indicators of fluvio marine to middle neritic environment. The occurrences of *Gyroidinoides Sp* was used to interpret inner neritic environment (Petters, 1982b). The lithology of the section in Yolde Formation interpreted as inner neritic environment is made up of shale to silty-shale. This environment probably lies within 0 – 30m on the continental shelf (Allen, 1965).

2) Middle Neritic This environment was inferred based on the co-occurrence of indicator benthic foraminiferal assemblages such as *Ammobaculites agglutinans Tritaxia tricarinata* (Petters, 1995). This marine environment lies between 30 – 100m of the continental shelf zone (Allen, 1965).

3) The identified lithofacies associated with Yolde Formation include; horizontally bedded sandstone (Sh) and clay/shale (FS) facies (Fig. 7). wave-rippled sandstone facies (RC), hummocky cross-stratified sandstone facies (facies HC), Planar cross-bedded sandstone (facies Sp), bioturbated parallel-bedded sandstone (Bs), shale (facies Fl) and limestone are the facies association with FA-1 (Figs. 6 & 7 b-e). The characteristics of this facies, including their

glauconitic composition, varying levels of bioturbation, and other trace fossil groups into facies association (FA-1), suggest they were deposited below the storm wave base in a low-energy offshore (shallow) marine setting (Buatois et al., 2002; McCubbin, 1981; Yandoka Sarki et al., 2015, 2019). It is believed that the nodular characteristics of the BS facies and the isolated occurrence of the HP facies reflect occasional storm influences (e.g., McCubbin, 1981; Alván & Von Eynatten, 2014). The genetic relationship between the aforementioned facies linked to facies association (FA-2) and their interpretations suggests that this facies association reflects transition from offshore to lower shoreface. Further, its stratigraphic presence alongside other identified associations (Fig. 7 b) within a wide shallow marine sequence (from offshore to shoreface) influenced by storms and waves is noted by McCubbin, (1981). In a storm- and wave-dominated setting, the offshore to lower shoreface facies association (FA-2) signifies suspension deposits formed just below and above the fair-weather wave base for the facies association (FA-2) (Catuneanu et al., 2010; Cullis et al., 2011; Storms, 2003; Walker & Cook, 1992). Therefore, the Yolde Formation is deposited in a paleoenvironmental setting that spand from transitional/lower shoreface to upper shoreface based on lithofacies.

CONCLUSION

The ten samples investigated from the Yolde Formation showed an unevenly distributed of taxa richness. Sample two and six (2 & 6) yields the highest taxon diversity with 13 taxa each, while the remaining 8 samples record between 1-11 taxa each. The benthic taxa *Marssonella, Ammobaculites agulutinans, Plectina* are abundant throughout the composite section. Some of the taxa e.g. *Marssonella Verneuilinoides Sp., Gyroidinoides sp, and Textularia subhaurii*w represent ~30% of the benthic assemblage each. (i.e., *Bulbobaculite sp.* Common benthic markers recorded in the Yolde Formation include *Marssonella, Verneuilinoides Sp, Ammobaculites agulutinans, Plectina cenomana Sp, Tritaxia tricarinata, Gyroidinoides Sp, Heterohelix Sp, Bulbobaculite Sp, Gavelinella Sp, Tritaxia Sp.* The highest occurrence of *Bulbobaculite Sp, and Gavelinella Sp* in the Yolde Formation marks the Cenomanian age. The absence of benthic foraminifera in the upper interval of the Yolde Formation may represent deteriorated paleoenvironmental conditions in the Cretaceous basin, particularly the Nigeria sedimentary basins, especially in the Yola Arm of the Northern Benue Trough. The Cenomanian age of the Yolde Formation is supported by the occurrence of *Marssonella, Verneuilinoides sp, Ammobaculites agulutinans, Plectina cenomana sp, Tritaxia tricarinata, Gyroidinoides sp, Heterohelix sp, Bulbobaculite sp, Gavelinella sp, Tritaxia Sp.* The presence of the benthic foraminifera is associated with low-oxygen zone that reaches the seabed during the early to mid-Cretaceous period. The recovery of *Ammobaculites Spp., Tritaxia tricarinata, and Gyroidinoides Sp.* is indicative of anoxic water conditions. From the sedimentary facies analysis, eight facies and two facies association were identified for the Yolde Formation, and this indicate a depositional setting that ranges from lower to upper shoreface paleoenvironments. Therefore, the paleoenvironments of the Yolde Formation base on the recovered benthic foraminifera and lithofacies reflects paleoenvironments that spans from inner neritic to middle neritic continental shelf zone within lower to upper shoreface during Cenomanian.

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