Paleoenvironmental Interpretation of Cenomanian-Coniacian Succession Within Yolo Town, Part of the Gongola Sub-Basin, Northeastern Nigeria

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ABSTRACT
Field mapping, granulometric and micropaleontological analyses were employed to examine the lithostratigraphy and re-construct the palaeo-depositional environments of the Cretaceous Pindiga and Yolde Formations within the Gongola sub-basin of the Northern Benue Trough. The Yolde Formation is characterized by fine-grained, tabular and cross stratified sandstones intercalated with silty-mudstone; with disharmonic, non-cylindrical folds which are consistent with soft sediment deformation that may be result of hydroplastic slumping of unlihified sandstone beds in energized depositional environment. Grain size analyses indicate a fluvial depositional environment with proximal sediment source. The Pindiga Formation is made up of mainly shales and fossiliferous limestone. Foraminiferal assemblages from the Pindiga Formation are mainly of agglutinated benthic taxa dominated by Haplophragmoides and Ammobaculites, which indicate brackish water, marsh to lagoon environment. However, their diversity as well as abundance is low compared to the Ostracods, of which Ovocytheridea symmetrica with smooth shells and lack of ornamentation suggest shallow marine depositional environment. The presence of both hypersaline (Cytherella sp.) and hyposaline (Brachycythere ekpo) species in the study area also indicate a brackish water depositional environment.

Keywords: Yolde Formation, Pindiga Formation, Paleoenvironmental, Microfossils, Granulometry, Northern Benue Trough

INTRODUCTION
The Northern Benue Trough (NBT) is one of the economically viable geologic basins in Nigeria. Over last two decades, the basin has witnessed increased interest and exploration-targeted researches. These are mostly geared towards the better understanding of the stratigraphy, tectonic setting, basin evolution and hydrocarbon potential (e.g. Zaborski et al., 1997; Ojo and Akande 2001; Obaje et al., 2004; Hamidu, 2012; Abubakar, 2014; Sarki-Yandoka et al., 2014; Abubakar et al., 2018). Different sections of the NBT are currently at different stages of exploration, with most being at the knowledge-building stage of exploration. This paper presents field and lithostratigraphic investigation of the Cenomanian-Coniacian succession of the Pindiga and Yolde Formations of the Gongola Sub-Basin of the NBT. Detailed field mapping integrated with sedimentological and micropaleontological analyses were employed to examine the lithostratigraphy and re-construct the palaeo-depositional environments of the Cretaceous Pindiga and Yolde Formations. The outcome of this research would update existing knowledge and advance our understanding of the stratigraphic setting and conditions of the depositional environment.

The study area is located about 5 km south of Yolo village within Alkaleri Local Government Area of Bauchi state. The area forms part of sheet 172, Futuk SE and lies between latitude 9°42’17” N to 9°39’31” N and longitude 10°49’2” E to 10°53’46” E.

Geologic Setting
The NBT is the northernmost portion of the Benue Trough; a major NE-SW trending intra-continental rift basin, that is about 850 Km long and on average 150 Km wide. This mega tectonic structure forms part of the West and Central African Rift System (WCARS) and extends from the Niger Delta in the south to the southern boundary of the Chad (Bornu) Basin in the north (Fig. 1). The Benue trough is arbitrarily subdivided into three sections; southern, central, and northern portions (Nwajide, 2013). The northern region further divides into a N-S trending Gongola arm (Gongola sub-basin) and E-W trending Yola arm (Yola sub-basin) (Fig. 1). The Benue Trough is filled with sediments related to continental and marine paleoenvironments, ranging in age from Cretaceous to Tertiary, with a maximum total thickness of about 6000 meters (Abubakar, 2014, Ayok et al., 2018). This thick succession of continental and marine sediments is associated with volcanics of Tertiary (Neogene) age in some places (Ayok et al., 2018). Pre-Santonian sediments within the trough were strongly affected by a mid-Santonian tectonic event, resulting in intense folding, faulting, and uplift of the various lithostratigraphic units in several places (Zaborski et al., 1997; Obaje, 2009; Abubakar et al., 2011; Ayok et al., 2018).
Fig. 1: Geological map of Nigeria with emphasis on the Southern (S), Central (C) and Northern (N) Benue Trough. The study area is indicated by black open square. (Modified from Gebhardt et al., 2019).

Local Geology
The study area forms part of the Gongola sub-basin of the NBTH, underlain by both Precambrian basement rocks and sedimentary rocks. Several workers such as Benkhelil (1989), Zaborski et al. (1997), Mamman et al. (2007), Zaborski (2003); Sarki-Yandoka et al. (2015), Abubakar et al. (2018) have reviewed and described in detail the geology and stratigraphy of the NBTH. In both arms, the Aptian-Albian continental Bima Group lies unconformably on the Precambrian Basement. Lithologically, this Group is dominated by sandstones intercalated with carbonaceous clays, shales, and mudstone. The Bima is conformably overlain by the Cenomanian, transitional/coastal marine Yolde Formation (sandstones, shales, clays, limestones, and claystones).

In the Gongola sub-basin, the Pindiga Formation directly overlies the Yolde Formation. This Formation is entirely marine, and consists of carbonaceous shales and limestones, intercalating with pale coloured limestones, shales and thin sandstones. Post-Santonian stratigraphic succession in the Gongola sub-basin is characterized by the Campano-Maastrichtian Tukulma Group, comprising of the Upper Fika Formation (marine shale), transitional Arowa Formation and continental Duguri Formation (Hamidu et al., 2013). The Kerri-Kerri Formation (claystones, sandstones and siltstones) of Tertiary age caps the stratigraphic succession in the Gongola sub-basin.

In the Yola Arm, the basal Bima and Yolde Formations are succeeded by the Dukul, Jessu and Sekuliye Formations, the Numah Shale, and the Lamja Sandstone. These form the Turonian–Santonian equivalents of the Gongila and Pindiga Formations, except the Lamja sandstone which is mostly a marine sandstone sequence.

METHODOLOGY
Detailed field mapping on a scale of 1:25,000 was undertaken in the study area, utilizing traverse method and also mapping along stream channels. Sedimentary successions with regards to their lithology, structures and fossilization, were studied. Rock samples were collected for laboratory analyses (petrography, granulometry, and micropaleontology). Laboratory analyses were carried out at the Department of Geology, Ahmadu Bello University, Zaria, Nigeria.

Petrographic Analysis:
Thin sections of limestone were prepared according to the method described by Reed and Mergner (1953) and studied under a polarizing microscope.

Granulometric analysis:
This was carried out using samples from Yolde Formation to determine the grain size distribution. Subsequently, calculations, deductions and interpretations were made based on Folk and Ward (1957).

Paleontological analysis:
Fresh samples from the Pindiga Formation were obtained for micropaleontology. About 200g of each sample was prepared according to the method described by Armstrong and Brasier (2005). The extracted micro fauna was studied under a binocular microscope.

RESULTS AND DISCUSSION
Geology of the study area
The area of study is characterized by the Yolde Formation in the western part, while the undifferentiated Pindiga Formation covers about 60%, including the entire northern and eastern parts. Alkali basalts occur in the central and south western parts as hills (Fig. 2).
Paleoenvironmental Interpretation...

Fig. 2: Geological map of the study area

**Yolde Formation:** The Yolde Formation is poorly exposed and was only seen along stream channels, consisting of bedded sandstone with thinly bedded (10 cm average) irregular mudstones covered by sparse vegetation and subdued topography. The exposed sections consist of whitish brown, medium to fine-grained quartz arenite that is occasionally intercalated with thin beds of milky-white, massive silty-mudstones at the bottom. The sandstone averages about 3.7 m thick, ranging between 1.8 m to 5.5 m, with ferruginization increasing rather rapidly upward leading to the exposure having thick ferruginized capping (Fig. 3a). The exposures are mostly heavily fractured within which amorphous silica has crystallized as void filling with authigenic mineral likely to be hematite iron oxide (Fig. 3b).

Through cross bedded sections were observed toward the top that are sheet-like, with the sets dipping at angles from 6-31° to the horizontal while the fore-sets have similar thickness, with an average thickness of 30 cm (Fig. 3d&e). Ripple marks and traces of *Thalassinoidea* were also observed. The dominant ripples identified are one directional and asymmetrical with sinuous to lobe-like (linguoid) crests (Fig. 3c). They consist of alternating sub-parallel, small-scale ridges and hollows. These ripple marks could have been produced by a unidirectional flow, with observed paleocurrent direction indicating a southwest-moving current.

Localized, small-scale, irregular folds were observed where the beds (individual layers) are folded in non-cylindrical manner and disharmonic (Fig. 4). The fold type is quite difficult to establish due to the extreme variability and complex geometry, as well as the top of the fold being covered by thick overburden and lateral discontinuity of the beds. However, the folds observed are consistent with soft sediment deformational structures (SSDS). Their occurrence in sand deposits can be explained by slumping; where the SSDS are triggered by cyclic shaking of the un lithified beds by nearby tectonics, forcing the mudstone beds to give way causing the hydroplastic sandstone layers to slump and consequently fold (Guiraud and Plaziat, 1992). Another possible cause of these SSDS is transpressional stresses that affected the region at the time the sediments were un lithified favored by sand hydroplasticity, liquefaction and fluidization causing the deformation. This is further supported by the fact that unconsolidated grain sediments deformation depends on two correlated conditions: (i) susceptibility of the sediments to deformation which depends on the granulometry and grain arrangement of the sediment (ii) driving stress (Guiraud and Plaziat, 1992).

**Paleo-environmental studies of Yolde Formation using Grain Size Analysis**

Grain size analysis was carried on rock samples from the Yolde Formation to determine its grain size distribution (summarized in Table 1). From hand specimen observation, the sandstone of Yolde formation consist of more than 95% quartz grains making it a quartz arenite. The sub-angular to rounded grain shape together with the mean grain size distribution (Table 1) indicate proximal sources for the sediments. The beds fine upward indicating the slowing of the sediments-laden current that deposits them.
Fig. 3: Selected field photographs of the Yolde Formation occurrence. A) Ferruginized capping of the reddish-brown tabular cross bedded sandstone atop weathered thinly bedded mudstone. B) Quartz veins with streaks of geothite. C) Asymmetrical ripple marks on a bedding plane of the formation. D) Tabular cross stratification in exposed beds that have been affected by tectonic seismic movement. E) Trough cross bedding with iron capping.

Fig. 4: Folded sandstone beds observed on Yolde Formation. A) Gentle normalization of folded bedded from complex folded core. B) Evidence of hydroplastic sagging of the sandstone beds. C) Front view of the deformed beds.
Table 1: Summary of grain size analysis result

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Mean</th>
<th>Median</th>
<th>Sorting</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td>0.77</td>
<td>1.6</td>
<td>1.77</td>
<td>-0.10</td>
<td>0.91</td>
</tr>
<tr>
<td>Sample 2</td>
<td>2.12</td>
<td>2.3</td>
<td>1.47</td>
<td>-0.11</td>
<td>0.81</td>
</tr>
<tr>
<td>Sample 3</td>
<td>2.11</td>
<td>2.2</td>
<td>1.41</td>
<td>-0.11</td>
<td>0.79</td>
</tr>
<tr>
<td>Sample 4</td>
<td>2.15</td>
<td>2.4</td>
<td>1.38</td>
<td>-0.13</td>
<td>0.83</td>
</tr>
<tr>
<td>Sample 5</td>
<td>0.79</td>
<td>1.6</td>
<td>1.80</td>
<td>-0.10</td>
<td>0.93</td>
</tr>
<tr>
<td>Sample 6</td>
<td>2.00</td>
<td>2.1</td>
<td>1.31</td>
<td>-0.12</td>
<td>0.78</td>
</tr>
<tr>
<td>Sample 7</td>
<td>0.81</td>
<td>1.9</td>
<td>1.82</td>
<td>-0.14</td>
<td>0.92</td>
</tr>
</tbody>
</table>

The sandstones in the Yolde Formation are of high to moderate energy environment, evident from the variations in mean distribution of the grains (fine grained to coarse grained). The sediments are also poorly sorted which is an indication of rapid deposition when energy levels suddenly drop as typical in fluvial systems, making the sediments texturally immature. Despite the poor sorting of the sediments, they are generally coarse skewed which suggests that the sediment is dominated by fine grains. The Kurtosis is mesokurtic to platykurtic which is expected, considering the poor sorting of the sediments. This is also an indication of the poor maturity of the sediment and a possible fluvial transportation system. The bivariate analysis of skewness against sorting (Fig. 5) suggests that the samples must have been deposited by a fluvial system (Friedman, 1967). Thus, the Yolde Formation represents a transitional sequence between the continental Bima Group that lies beneath and the marine deposits of the Pindiga Formation.

Pindiga Formation: This is characterized by weathered, grey to brownish-yellow shales, scattered regolith and beds of fossiliferous limestone of the Kanawa Formation (Ayok et al., 2014) and grey shale of the Fika Formation (Hamidu et al., 2013). The brownish-yellow shale is featureless and interbedded with 5-15cm thick, yellowish-brown limestone (Fig. 6). Desiccated mud cracks were observed on the shale unit that extends downwards. However, at the foot of Jada basaltic hill in the southeastern part of the study area, the shale is dark grey, flaky and hardens down the exposure. The flaky nature of the shale is a direct result of the heat that accompanied the volcanic emplacement. Thin irregular, lenses of discontinuous gypsum were found within the shales.

Paleoenvironmental Studies of Pindiga Formation using Microfossil Analysis

Fresh rock samples from the Pindiga Formation were obtained for microfossil analysis. Two types of microfossils were found in the rock samples; Foraminifera and Ostracods. The Forams consist of the following species: *Ammobaculite pindigensis* (Hamza, 1995); *Haplophragmoides bauchensis* (Petters, 1979b); *Miliammina pindigensis* (Petters, 1979); *Reophax duplex* and *Reophax globosus* (Petters, 1979). While Ostracods species included: *Ovocytheridea symmetrica* (Reymet, 1960); *Ovocytheridea nuda* (Reymet, 1960); *Ovocytheridea reniformis* (Reymet, 1960); *Paracypris nigeriensis*; *Cytherella* sp. (Okosun, 1987); *Brachycythere ekpo* (Reymet, 1960); *Leguminocythereis reymeti* (Reymet, 1960); *Ovocytheridea sakaensis* (Okosun, 1987); and *Clithrocytheridea senegali* (Reymet, 1960). Their ages range from Turonian to Cenomanian.
The surfaces of the limestone beds contain fragmented shells and traces of *Thallasinoides* burrows while embodied by bivalves, ammonites and gastropods. These beds tend to form more resistant layers with irregular surfaces completely fossiliferous. In the lower parts of the exposure, condensed horizons of glauconites were seen which are less than 3 cm thick. The petrographic analysis of the limestone revealed that the allochems present consist of peloids (10%) and bioclasts (50%) with 40% reddish iron oxide rich micrites in the matrix (Fig. 7). Using Folks’ classification scheme for limestone, the rock could be pel-biomicrite while for Dunham it is packstone.

**Fig. 6:** An exposed brown limestone bed interbedded with yellowish brown shale. N09° 41' 32.5", E10° 51' 44.6".

**Fig. 7:** Photomicrograph of thin sections of limestone under plane polarized light (PPL) and cross polarized light (XPL). Magnification 40 X.

The Foraminiferal assemblage is mainly of agglutinated benthic taxa dominantly of *Haplophragmoides* and *Ammobaculites* but their diversity as well as abundance are low compared to the Ostracods. The relative abundance of the *Haplophragmoides* and *Ammobaculites* indicate brackish water, marsh to lagoon environment (Murray, 1973). The planktonic foraminifera present in the study area are non-keeled and relatively small-sized, indicating shallow water depositional environment (Petters, 1980; Leary *et al.*, 1989). In this study, some species were observed to be very small in size, which is indicative of dwarfism and/or juvenile assemblages. It is likely that the dwarfism represents a faster growth rate; i.e. individuals attained the reproductive stage earlier, resulting in a smaller overall size (Lipps, 1979). Another reason for the small size of the Foraminifera may be due to paedomorphism – a strategy for rapid reproduction used by populations living in environment when ideal conditions occur occasionally and short-lived. Petters (1979a, 1979b; 1982) reported the assemblages within the Pindiga Formation, probably reflects anoxic bottom water condition which will enhance the survival of the small sized foraminifers because of their low oxygen consumption.

Ostracods are one of the most abundant of fossil and there are about 33,000 living and fossil species (Cohen *et al.*, 1998). Ostracods are generally small, bivalve Crustacea, with two chitinous or calcareous valves that hinge above the dorsal region of the body form their carapace (Armstrong and Brasier, 2005). Eight different Ostracod species were identified in the study area. Ostracods are originally marine but they were said to have expanded into transitional environments during the Silurian (Bassett and Lawson,
Generally, the presence of Ostracods indicates marine to marginal marine depositional environment although the presence of *Ovocytheridea symmetraca* with smooth shells and lack of ornamentation suggests the depositional environment of the Pindiga Formation to be shallow marine. The well-preserved nature of most of the recovered Ostracods as evident by the high valve to whole-carapace ratio is an indication of rapid sedimentation in a high energy environment. Ostracods are very essential in the understanding of palaeo-salinity and their fluctuations in marginal marine successions (DeDeckker et al., 2001). The presence of both hypersaline (*Cytherella* sp.) and hypersaline (*Brachycysthera ekpo*) species in the study area indicates a brackish water depositional environment. Ostracods are also very useful in correlation, for instance the *Ovocytheridea symmetraca* specie, encountered in the study area, have been reported to mark a period of regression in the Yola arm of the Upper Benue Through (Opeloye and Obaje, 2005).

**CONCLUSION**

The Yolde Formation consist of sandstone-mudstone portion, interpreted to be of fluvial origin while the upper part with more thinly regular bedded bioturbated sandstone is of shallow marine origin with Late Albian to Late Cenomanian age. The Pindiga Formation is made up of featureless and fissiliferous shale, and fissiliferous limestone. The Foraminifers in the rocks of the Pindiga Formation are diagnostic of the Turonian to Maastrichtian age. Identified Ostracods species indicate a shallow marine depositional environment and are consistent with the Turonian to Maastrichtian age. Thus, the Pindiga Formation was deposited in a shallow water marine environment with high energy conditions believed to have been deposited during the Late Cenomanian to Early Turonian transgression which affected the entire Benue Trough.

**REFERENCES**


