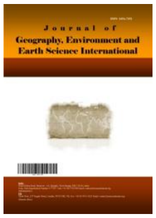

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Regressive Shoreface Depositional System of the Cretaceous Yolde Formation of the Gongola Sub-Basin Northern Benue trough N. E. Nigeria

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Authors' contributions

As Geology is field based course, all the authors participated in field work where data set used in developing this research article were generated. All authors read and approved the final manuscript.

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ABSTRACT

The characterization of lithofacies of the Yolde Formation at Briyel town in the Gongola Sub-basin of the Northern Benue Trough indicated coarsening upwards cycles composed transitional succession of six lithofacies that comprises of trough cross-beds, planar cross-beds, massive beds, ripple laminations, parallel laminations and mudstone. This coarsening and thickening upward symmetry is defined by a densely bioturbated mud dominated lower part transitionally grading into heterolithic interval composed thinly bedded sandstone and mudstones both of which developed below fair-weather wave base. This is capped by a succession of moderately bioturbated trough-planar crossbedded sandstone with poly-directional paleocurrent system. These assemblages reflect shoreface deposits and devoid of hummocky cross-stratification therein may account for a moderate wave oceanographic system. Evolution of this setting in the Gongola Sub-basin is indicative of a scenario of a broaden coastline in the coastal palaeogeography of the Yolde Formation typically suppressing due to frictional damping.

Keywords: Shoreface; Yolde formation; depositional system; Gongola Sub-basin.

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1. INTRODUCTION

The Gongola Sub-basin is the north-south trending portion of the Northern Benue Trough which accounts for the arbitrarily demarcated regions of the Benue Trough (Fig. 1). This evolved due to separation of the South American plate from the African plate during the late Jurassic to early Cretaceous times. Theories accounting for its origin and evolution are

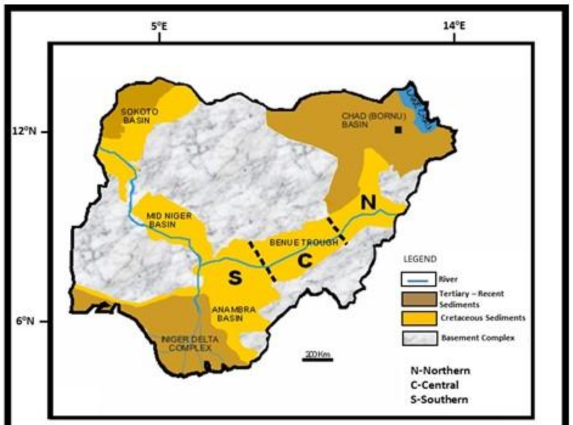

Fig.1a Geological Map of Nigeria showing the Benue Trough

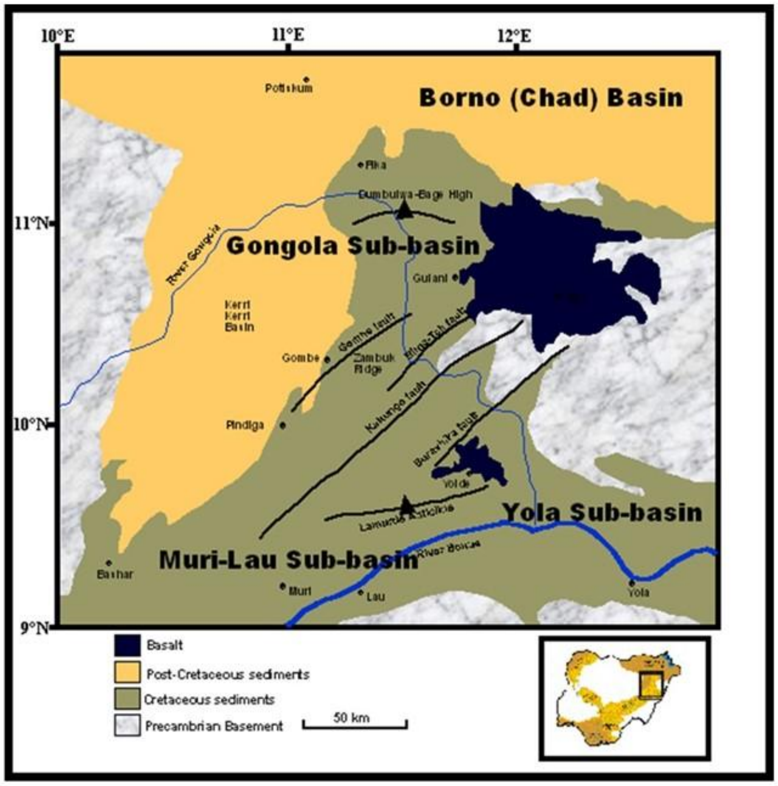

Fig.1b Geological map of the Northern Benue Trough (modified from Zaborski *et al*., 1997)

categorized into two major theories consisting of the rift and pull-apart. The rift model theory was proposed earlier and supported to date [1,2,3,4] indicating initiation through tensional regimes induced by mantle plume convection activities [5,6]. This is opposed to the pull-apart model because of the absences of boundary fault that are the index to rifting, therefore considered strike-slip tectonic origin as a precursor, as it aligns in orientation to the major transcurrent fault systems of the Romanche, Chain and Charcot suture zones [7,8,9,10a,10b,10c]. The opening of the trough is followed by transgressive and regressive sequences in the Aptian-Albian times where the Northern Benue Trough characterized by continental depositional regimes. This region of the trough recorded transgressional and in the Cenomanian, depositing transitional-marine sequences of the Yolde Formation. This research aims to evaluate the facies and facies association of this formation at Briyel village that represents one of the major outcrops in the Gongola Sub-basin to establish a depositional model that characterizes its development.

1.1 Geological and Stratigraphic Setting

The Benue Trough located in Nigeria is a rift basin in Central West Africa that stretches in a NNE-SSW for about 1000 km in length and 50-150 km in width [3,11] and it is geographically subdivided into Northern, Central and Southern Benue Trough (Fig. 1). The Benue Trough

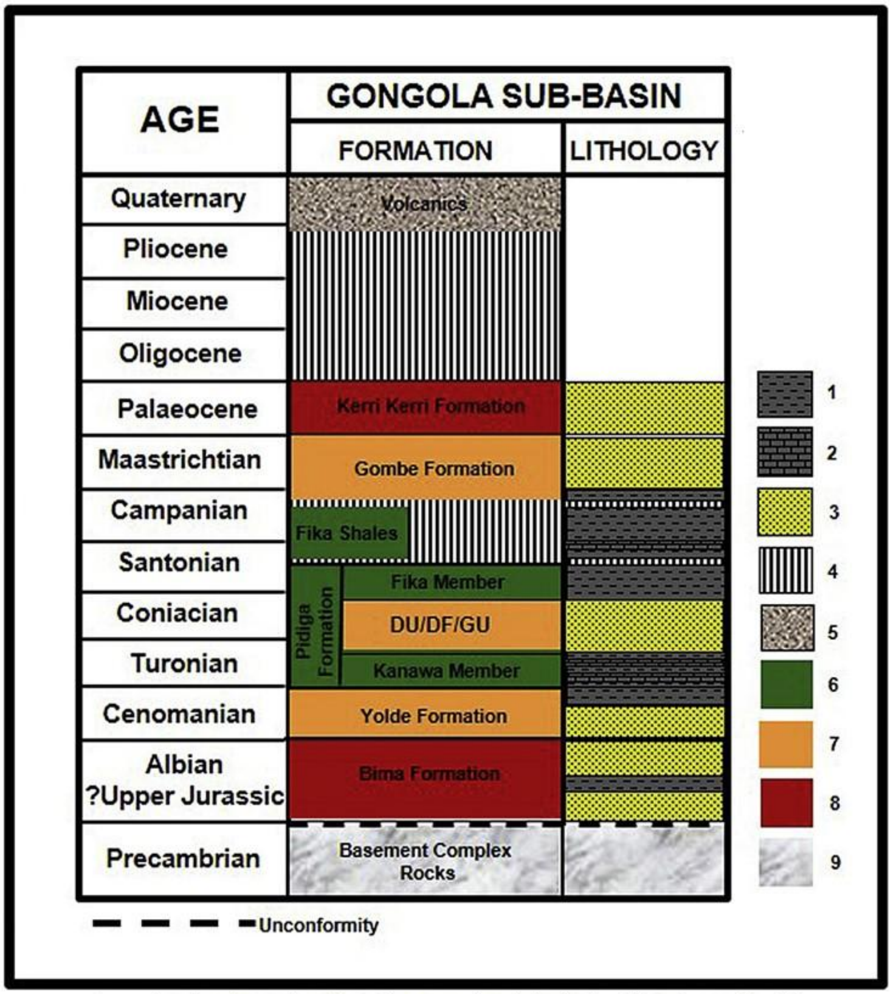

Fig. 2 Showing the stratigraphy of the Gongola Sub-basin (modified from Zaborski et al., 1997). 1-Mudstone, 2-Limestone, 3-Sandstone, 4-Hiatus, 5-Basalt, 6-Marine sediments, 7-Transitional-marine sediments, 8-Continental sediments, 9-Basement Complex (DU-Dumbulwa Member, DF-Deba Fulani Member, GU-Gulani Member).

constitutes of three arms: The N-S striking Gongola Arm, E-W striking Yola Arm and the NE-SW striking Muri-Lau Arm [12] (Fig. 2). The Trough host over 6000 m of sediments that consists of Cretaceous to Tertiary deposits of which those predating the mid-Santonian have been tectonically deformed, to form major faults and fold systems across the basin. The Bima Group of the Aptian-Albian is the oldest sedimentary units in the Gongola Sub-basin, conformably overlying the Basement Complex Rocks (Fig. 2) [13,14,15,10a]. The deposition of syn-rift sequences of the group is largely controlled by the horst and graben networks and is represented by the alluvial fan-lacustrine deposits of the Bima I Formation, representing the lowermost unit in the group. This is unconformably superposed by the post-rift braided river sequences of the Bima II and III Formations [14,15,10a]. Following conformably is the Yolde Formation in the Cenomanian, marked by transitional-marine deposits [16]. This representing the onset of the mid-Cretaceous global marine transgression in the basin [17] that reached its acme in the Turonian, thus depositing the shallow marine shale and limestone sequences of the Kanawa Member of the Pindiga Formation [14,18]. Regressive Sandy Members of the Dumbulwa, Deba-Fulani and Gulani sandstones conformably followed in the mid-Turonian because of decelerating transgressive conditions (Fig. 2) [14,11]. The surging relative sea levels in the late Turonian continued into the Coniacian and early Santonian setting in the deposition of the deep marine blue-black shales of the Fika Member that represents the youngest units of the Pindiga Formation [14,19]. This marine transgression is followed by compressional tectonics in the mid-Santonian [20], resulting as a consequence of changing the orientation of the displacement vectors between the African plate and European/Tethys plates [21]. This event led to the thrusting of the pre-Maastrichtian sediments towards the western part of the Gongola Sub-basin, creating accommodation for the deposition of the Campano-Maastrichtian regressive deltaic sequences of the Gombe Formation [22,19]. The mid-Maastrichtian recorded another phase of the compressional event and thereafter followed by the unconformable deposits of the Paleogene fluvio-lacustrine Kerri Kerri Formation [23,24] (Fig. 2). The Paleogene-Neogene is characterized by volcanic, which are oriented in a northeastern trend along the eastern margin of the Gongola Sub-basin [25].

2. MATERIALS AND METHODS

Topographic maps of Gombe town and environs that are located within the Gongola Sub-basin were employed in the fieldwork of this research to identify outcropping areas where the Yolde Formation are well exposed. Along these well-exposed outcrops identified, lithostratigraphic sections of this Formation outcropping around Briyel town (Fig. 4) were systematically logged to record data on lithologic variations, texture, bed geometry, paleocurrents, sedimentary structures and fossil content. Based on the facies concept and application of Walters law in conjunction with facies relation provided by sedimentologic studies on the ancient and modern environment, these data were utilized in designating lithofacies assemblages representing the particular depositional environment. Paleocurrent measurements were also carried out on the abundant planar and trough crossbedded sandstones and the various orientations determined were used to evaluate provenance and hydrodynamic processes [26]. The dip and strike, as well as the azimuth of the cross-beds, were measured using compass clinometers in this analysis, and considering that the regional dips of the beds are generally greater than 10°, tilt correction was also carried out on the values using the procedure adopted by [26].

2.1 Facies Analysis

2.1.1 Facies St: Trough crossbedded sandstone facies

This lithofacies composes of medium – very coarse-grained sandstone, dominantly poorly sorted with sub – angular to sub – rounded grains, ranging in thickness from 1–1.4 m. They commonly compose of erosional or straight basal boundaries and are dominantly bioturbated (Fig. 3a). This lithofacies was interpreted to have formed from migrating sinuous 3-D dunes that stack up to generate bar forms in channel [27,28,29,30,31].

2.1.2 Facies Sm: Massive sandstone facies

The massive sandstone facies are well sorted with fine – medium grained sandstone that are commonly bioturbated. It ranges between .07– 1 m in thickness and commonly as thin units overlain by trough crossbedded sandstone (St) or interbedded with parallel laminated sandstone facies (Sr) (Fig. 3b). This facies is generally deposited as plane beds in lower flow regime and/or rapid sedimentation due to high deposition rates with no preservation of sedimentary structures. It is commonly deposited on bars by stream floods and mostly associated with channelized flood flows around bars [29,31].

2.1.3 Facies Sp: Planar crossbedded sandstone facies

This lithofacies composed of fine – medium grained sandstone with sub – rounded to well-rounded grains and typically occurs below trough crossbedded sandstone facies with thicknesses in the range of 20 – 70 cm, individual foresets ranged from 1 – 2 cm and they are commonly moderately bioturbated (Fig. 3c). This lithofacies was interpreted to have been produced from migration of 2-D dunes or sheet loading and/or interpreted as transverse bars formed under lower flow regime [26,31].

2.1.4 Facies Sl: Parallel laminated sandstone facies

This lithofacies is generally fine grained with thicknesses ranging between 15 – 30 cm. It is commonly associated with trough crossbedded sandstone facies (St), ripple laminated sandstone facies (Sr) and mudstone facies (Fm). Bioturbations and mica flakes are common associated attributes and boundaries are generally sharp. Laminations mostly show variation in grain size (Fig. 3d). This facies is produced by less severe or short-lived fluctuations in sedimentation conditions than those that generate beds. They result from changing depositional conditions that causes variation either in grain size, content of clay and organic material, mineral composition or microfossil content of sediments [26].

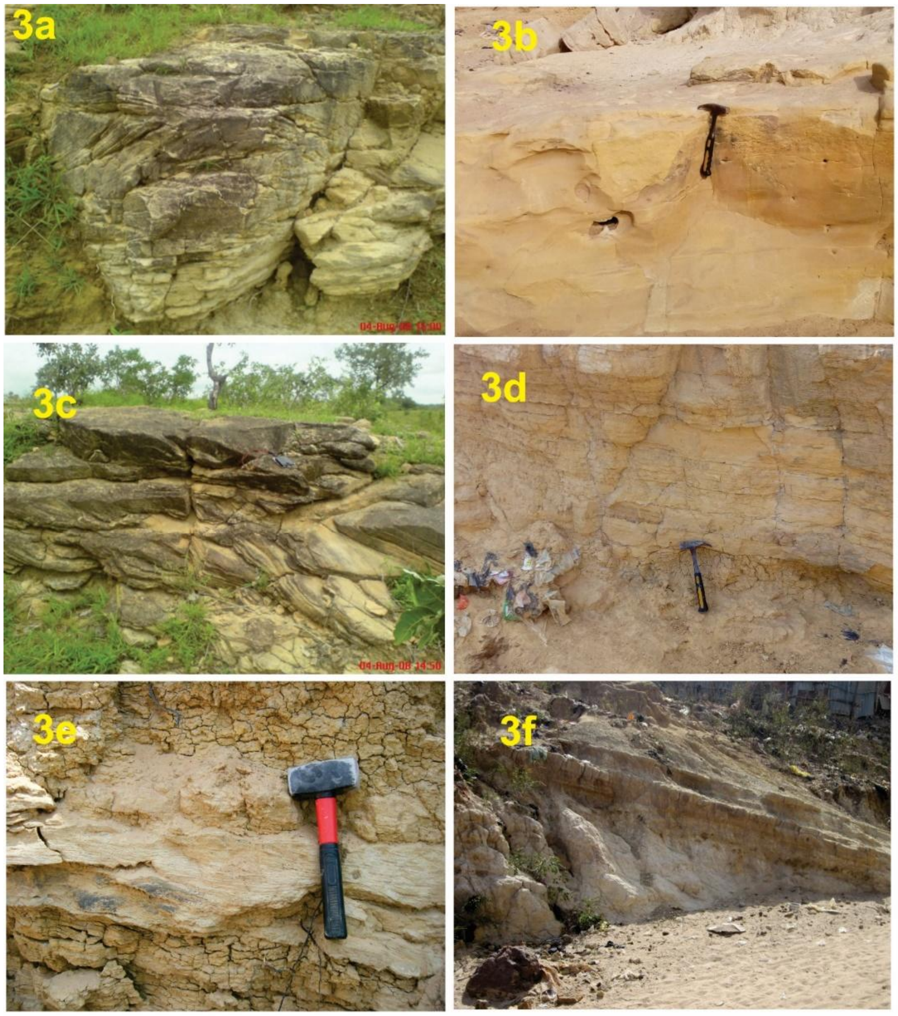

Fig.3a trough crossbedded sandstone, b) massive bedded sandstone, c) planar crossbedded sandstone, d) parallel laminated sandstone, e) ripple laminated sandstone, f) mudstone,

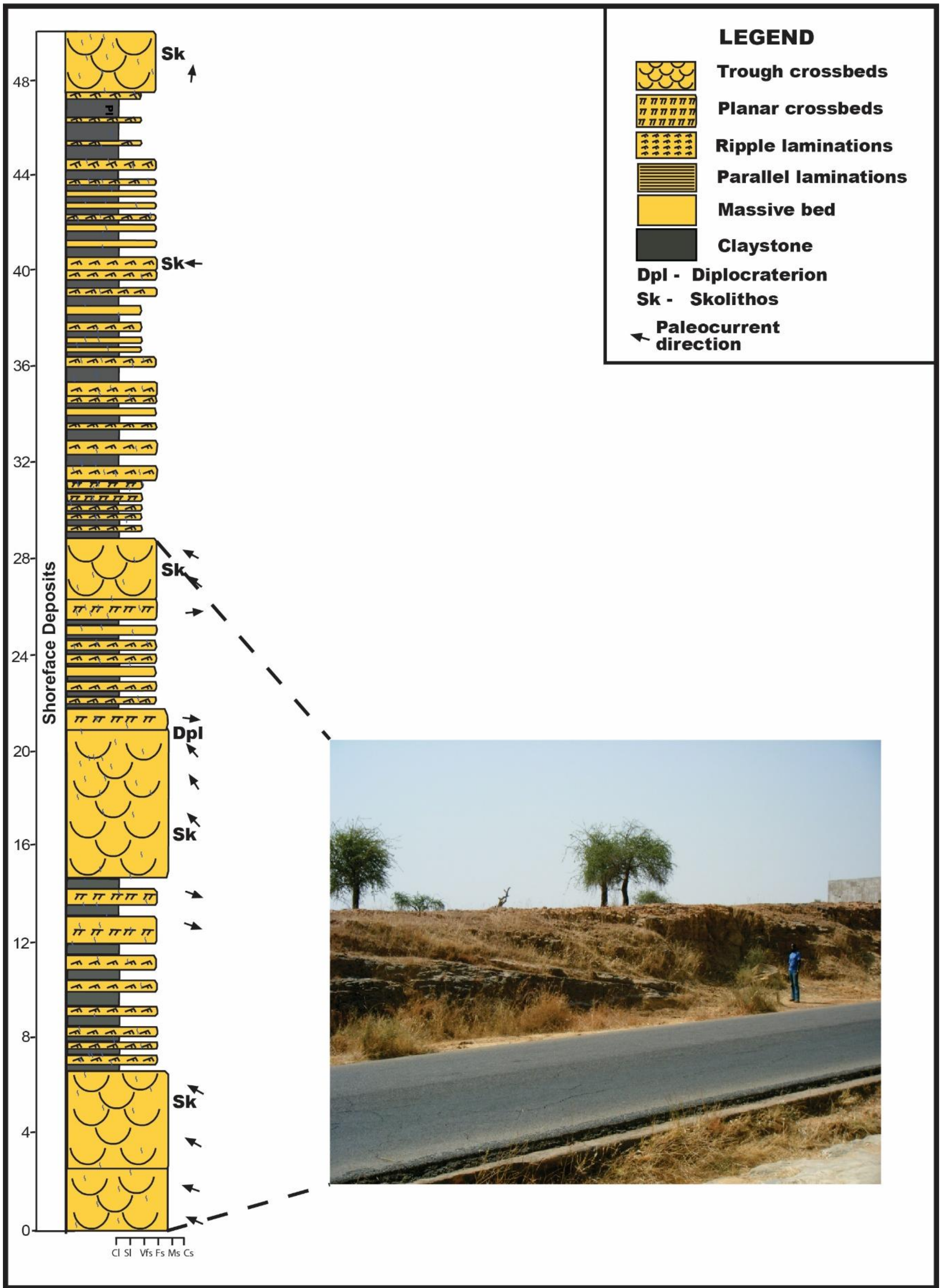

Fig.4 Showing lithostratigraphic section of the Yolde Formation at Briyel town

2.1.5 Facies Sr: Ripple laminated sandstone facies

The ripple laminated sandstone facies compose of fine–very fine grained sandstone that are well sorted with rounded grains. Thicknesses ranges from 10–30 cm and it is mostly associated with parallel lamination (Sl) and mudstone (Fm) (Fig. 3e). Asymmetrical forms are the commonly dominate and they are mostly bioturbated. This facies forms either when the water surface show little disturbance, or when water waves are out of phase with bedforms during lower flow regime, or forms through migrating current ripples, under lower flow regime [30,31].

2.1.6 Facies Fm: Mudstone facies

This lithofacies is dominantly grey coloured and commonly bioturbated with thicknesses ranging from 60 cm – 4 m. It is usually interbedded with ripple laminated sandstone facies (Sr) and massive sandstone facies (Sm) or define the base of trough crossbedded sandstone facies (Fig. 3f). This facies forms under environmental conditions where sediments are abundant and water energy is sufficiently low to allow settling of suspended fine silt and clay. They are characteristic of marine environment where seafloor lies below the storm base, but can form in lakes and quite part of rivers, lagoons, tidal flat and deltaic environment [26,32].

2.2 Lithofacies Association

This facies association is made of three distinctive intervals of lithofacies assemblages forming coarsening and shoaling up symmetry of 2-7 m thick (Fig. 3). The lowermost interval is mudstone facies (Fm) dominated but gradually buildup sandstone input toward its upper horizons, gradually increasing in thickness and grain size from siltstone – very fine sandstone) (Fig. 3a and 3f). Bioturbations appear dense, but displaying temporal degrading intensities and trace fossil diversity are low across the stratigraphic horizons with prominence in sandstone layers, typically showing skolithos, planolite and thalassinoides ichnofacies.

This association grades into overlying interval of heterolithic assemblage with higher sandstone to mudstone ratio. The sandstone layers are between 5- 25 cm thick and occurs with sharp basal contacts. They are dominantly ripple and parallel laminated units (Sr and Sl) with few massive bedded facies (Sm) and bidirectional planer crossbedded facies (Sp), occurs towards the upper stratigraphic horizons (Fig. 3f). The mudstone interbeds range from mm – cm scale, with bioturbation ranging from moderate-dense. The bioturbation concentration in this interval are dominant in the mudstone facies (Fm) and trace fossil assemblage with common occurrences of skolithos, Arenocolites, planolites and diplocraterion. This interval gradationally moves into sandstone dominated upper interval having sharp basal boundaries. The sandstones are generally fine grained and are mostly amalgamated. Mudstone lamina are commonly absent in these units, but mud-drapes are infrequently present, occurring along truncation surface (Fig. 3c). Bioturbations are scarce, while trace fossil assemblage are characteristically of ophiomorpha, diplocraterion and skolithos ichnogenera. Paleocurrent directions display poly-directional pattern with orientation showcasing southwestern to northeastern trend, particular in the sandstone dominated intervals, whereas unimodal sets predominate in the heterolithic units with paleo-trajectory trending in the west to southwest direction.

3. DISCUSSION

The lowermost mudstone interval in this facies association having severe bioturbation are typical representation of quite water origin, developing under full marine condition, mostly evolving below fair weather wave base. Severe bioturbations signify prolong biogenic activity, indicating a relatively extensive fair weather conditions, promoting development of the mudstone, through slow and continuous accumulation of suspended sediments. Heterolithic units following these mudstone units are products of building marine dynamics. Progressively rising thickness and abundance of these intercalated sandstone units indicates gradual shoaling of the lower shoreface from open shelf realm occasioned with dense bioturbation as consequence of coastal progradation. Falling mudstone content in these interval with corresponding increase in grain size, indicate buildup of hydrodynamic energy, depositional rates and periodicity. Bioturbation are mostly scares reflecting rapid mud accumulation which commonly impedes biogenic activity [33]. Couplet packages of horizontally planer to low angle laminated horizons occurring infrequently throughout this interval are records of episodic waxing and waning currents developing from geotropic flow [34], in combination with tidal modulations [35].

Superposed scarcely bioturbated successions of bi-directional trough crossbedded represents a highly attenuated energy regime, characteristically defining complex and turbulent hydrodynamic of the upper shoreface settings [36]. Absence hummocky cross-stratification reflect scenarios of relatively low level aggradation, promoted by low deposition to transport ratio during storm [37]. Intercalated levels of planar crossbedded sandstone interphase within this package are suggestive of 2D dune migration levels.

4. CONCLUSION

The evaluation of stratigraphic packages of the Cretaceous Yolde Formation at Briyel town in the Gongola Sub-basin displayed coarsening upwards cycles formed of six lithofacies that comprises of trough crossbedded sandstones, planar crossbedded sandstone, ripple laminated sandstones, parallel laminated sandstones massive bedded sandstones and mudstones. This coarsening upwards cycles showcases differentiation of energy regime, where the lower mud dominated to middle interval depicted low energy conditions, evolving through fair weather wave base and followed by the upper sand dominated zone generated under turbulent regime indicted by the poly-directional paleocurrent system. This architectures are products of a shoreface deposit indicative of moderate wave energy because of the absences of hummocky cross-stratifications of storm origin. Manifestation of this environment in the paleogeography of the Yolde Formation accounts for a moderate energy coastline amidst damped tidal regimes due to friction dissipation associated with broaden coastline.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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