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Tidal Flat Depositional System of the Cretaceous Yolde Formation of the Gongola Sub-basin Northern Benue trough N. E. Nigeria: Implication for Macro-Tidal Coastline

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Authors' contributions

All the authors participated in generating the data for this research. All authors read and approved the final manuscript.

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ABSTRACT

This research aims to evaluate the facies and facies association of the Yolde Formation at Kware stream in the Gongola Sub-basin of the Northern Benue Trough with objective of characterizing its paleodepositional environment. Six lithofacies consisting of trough crossbedded sandstone facies (St), massive bedded sandstone facies (Sm), planar crossbedded sandstone facies (Sp), ripple laminated sandstone facies (Sr), parallel sandstone facies (Sl) and mudstone facies (Fm) defining its stratal packages were skewed into distinctive assemblages of flaser, wavy and lenticular bedding. This present a fining upward signature with facies association typical of tidal flat system. This is evident of a coastal progradation with sequences reflecting migration of a supra-tidal mudflat over intertidal mixed-flat zone which progressively superposed subtidal sandflats. This is indicative of a coastal shoreline with a relatively progradational phase within the net transgressive regional framework of the Cretaceous Yolde Formation.

Keywords: Yolde formation; depositional environment; Gongola sub-basin; Benue trough; tidal flats.

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1. INTRODUCTION

The Gongola Sub-basin is the north-south trending arm of the Northern Benue Trough that represent the tip of Benue Trough (Fig. 1), forming as a consequence of separation of the South American plates. The opening of the basin occurred during the late Jurassic, but account of its evolution is highly controversial with two theories adjudged reflective of its development. The rift model theory was proposed at inception by earlier workers 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 proxy to rifting, therefore considered the trough as of strike-slip tectonic origin, as it falls in tune and orientation to the major transcurrent fault systems of the Romanche, Chain and Charcot suture zones [7,8,9]. The opening of the trough is accompanied by transgressive and regressive sequences in the Aptian-Albian times with the Northern Benue Trough characterized by continental depositional regimes. Transgressional activity reached this part of the trough in the Cenomanian, depositing transitional-marine sequences of the Yolde Formation. This researched is aims to evaluate the facies and facies association of this formation at Gabukka stream that represents one of its major outcrops in the Gongola Sub-basin in order to establish depositional model that characterizes its development.

1.1 Geological and Stratigraphic Setting

The Benue Trough of Nigeria is a rift basin in the Central West Africa that extends NNE-SSW for about 1000 km in length and 50-150 km in width [3,10]. The southern limit is the northern boundary of the Niger Delta, while the northern limit is at the Dumbulwa-Bage High, which marks the southern boundary of the Chad Basin (Fig. 1) [11]. The Benue Trough is geographically subdivided into Northern, Central and Southern Benue Trough (Fig. 1). The Northern Benue Trough is made up 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 is over 6000 m deep containing Cretaceous to Tertiary sediments 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 represents the oldest sedimentary units in the Gongola Sub-basin, conformably overlying the Basement Complex Rocks (Fig. 2) [13,11,14,15]. The deposition of syn-rift sequences thereof is largely controlled by the horst and graben systems and is represented by the alluvial fan-lacustrine deposits of the Bima I Formation, the lowermost in the group, which is unconformably superposed by the post-rift braided river sequences of the Bima II and III Formations [11,14,15]. The Yolde Formation conformably followed in the Cenomanian, marked by the transitional-marine deposits [16], representing the onset of the mid-Cretaceous global marine transgression in the basin [e.g. 17]. This reached its acme in the Turonian and deposited the shallow marine shale and limestone sequences of the Kanawa Member of the Pindiga Formation [11,18]. Regressive Sandy Members of the Dumbulwa, Deba-Fulani and Gulani sandstones conformably followed in the mid-Turonian with decelerating transgressive conditions (Fig. 2) [11,10]. Renewed rising relative sea levels in the late Turonian transcending into the Coniacian and early Santonian led to deposition of the deep marine blue-black shales of the Fika Member which represents the youngest units of the Pindiga Formation [11,19]. This marine transgression is accompanied by compressional tectonics in the mid-Santonian [20], which resulted from changing orientation of the displacement vectors between the African plate and European/Tethys plates [21]. This event led to thrusting of the pre-Maastrichtian sediments towards the west of the Gongola Sub-basin, creating an accommodation for the deposition of the Campano-Maastrichtian regressive deltaic sequences of the Gombe Formation [22,19]. The mid-Maastrichtian is characterized by another phase of compressional event and it is followed by the unconformably deposits of the Paleogene fluvio-lacustrine Kerri Kerri Formation [23,24] (Fig. 2). The Paleogene-Neogene is notable for volcanics, emplaced along the eastern margin of the Gongola Sub-basin [25].

2. MATERIALS AND METHODS

Topographic, structural and geological maps of Gombe town and environs that are located within the Gongola Sub-basin were employed in the fieldwork of this research to identify potential areas where the Yolde Formation are well exposed. Along these well exposed outcrops identified, lithostratigraphic sections of this Formation outcropping around kware stream (Fig. 4) were systematically logged to record data on lithologic variations, texture, bed geometry, paleocurrents, sedimentary structures and fossil content. Based on facies concept and application of Walters law in conjunction with facies relation provided by sedimentologic studies on ancient and modern environment, these data were utilized in designating lithofacies assemblages representing 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 [e.g. 26]. The dip and strike as well as the azimuth of the crossbeds were measured using compass clinometers in this analysis, and considering that the regional dip of the beds are generally greater than 10°, tilt correction was also carried out on the values using the procedure adopted by [26].

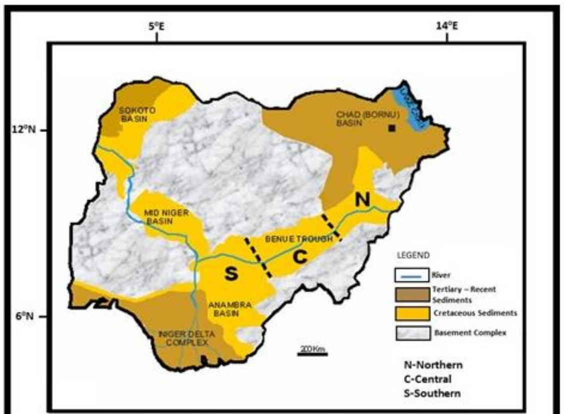

Fig.1a Geological Map of Nigeria showing the Benue Trough

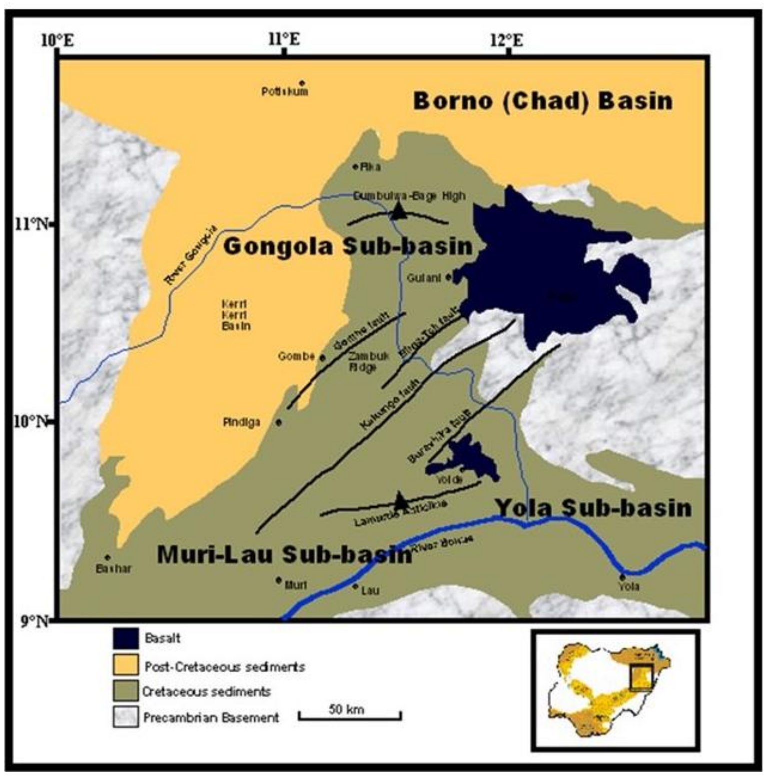

Fig. 1b. Geological map of the Northern Benue Trough (modified from Zaborski et al. 1997)

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 1–12 m. They commonly compose of erosional basal boundaries typically associated with mudclast and streaks and 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 [27,28,29a,b,c].

2.1.2 Facies Sm: Massive sandstone facies

The massive sandstone facies are moderately sorted with fine – medium grained sandstone that are commonly bioturbated. It ranges between 50– 60 m in thickness and commonly buildup to form thicker units usually overlain by trough crossbedded sandstone (St) or 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 [29a,c].

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 above trough crossbedded sandstone facies with thicknesses in the range of 20 cm – 1 m, individual foresets ranged from 1 cm – 3 cm. they are commonly bioturbated with mud-drapes and parting occurring along corset and forest planes (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 [26,29c].

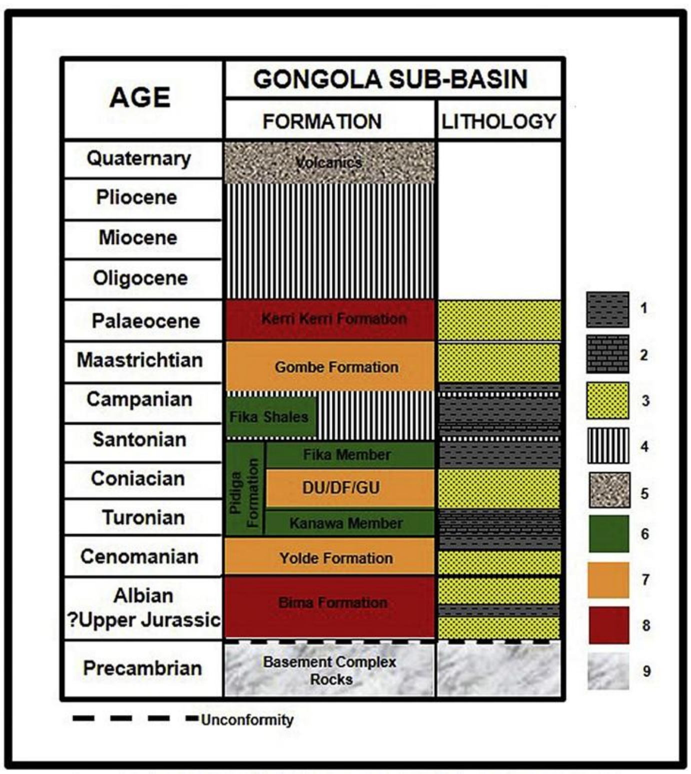

Fig. 2. Showing the stratigraphy of the Gongola sub-basin (modified from Zaborski et al., 1997), 1-Mudstone, 2-Limestone, 3-Sandstone, 4-Hiatus, 5-Basalt, 6-Marine Sediments, 7-Transitional-Marine Sediments, 8-Continental Sediments, 9-Basement Complex (DU-Dumbulwa, DF- Deba Fulani Member, GU-Gulani Member)

2.1.4 Facies Sl: Parallel laminated sandstone facies

This lithofacies is generally fine grained with thicknesses ranging between 25 – 40 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 or mineral composition (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].

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 10–20 cm and it is mostly associated with parallel lamination (Sl) and siltstone (Fml) (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 [29b,c].

2.1.6 Facies Fm: Mudstone facies

This lithofacies is dominantly grey coloured and commonly bioturbated with thicknesses ranging from 60 cm – 7 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 [26,30].

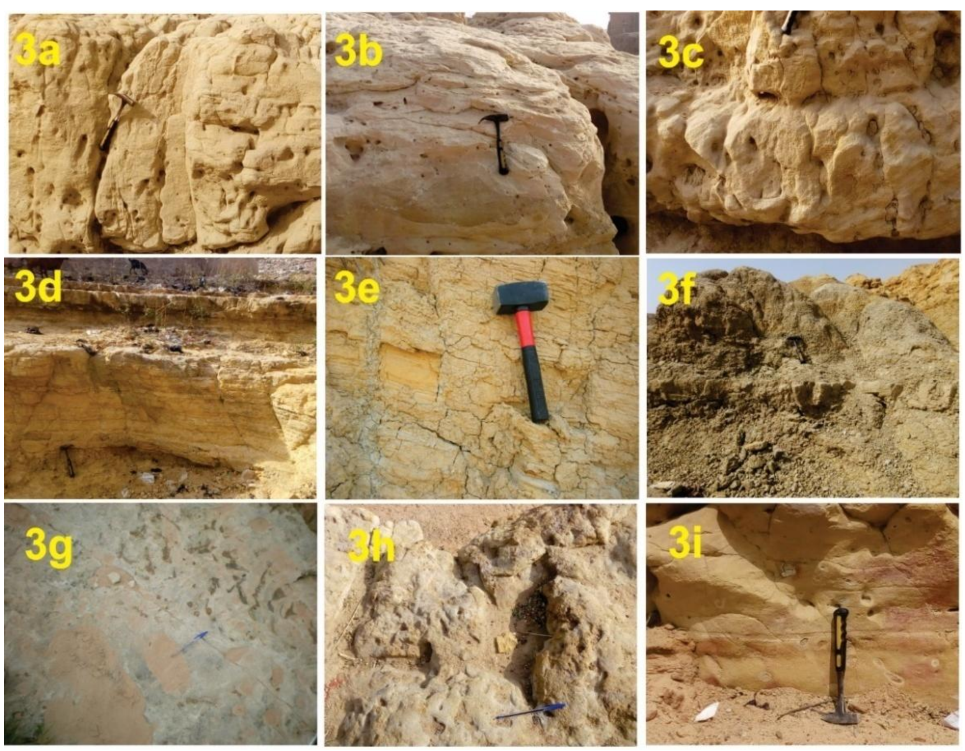

Fig. 3. a) Troughcrossbedded sandstone, b) massive bedded sandstone, c) planer crossdedded sandstone, d) ripple laminayed sandstone, e) parallel laminated sandstone, f) mudstone, g) skolithos ichnogenera, h) thalassinoides ichnogenera and i) diplocraterion ichnogenera

2.2 Sedimentary Facies Associations

This facies association composes of fining upwards heterolithic packages of 2-7 m thick amalgamating to form multistory succession (Fig. 4). This assemblage is commonly restricted to the upper stratigraphic horizon of the Yolde Formation, mostly preceding tide influenced fluvial channel facies. Architectural elements consist of a basal flaser bedding with medium grained, well sorted sandstone hosting dominantly successive planar crossbedded cosets depicting unidirectional current system (Fig. 4b-c). Occasionally, coarse grained trough crossbedded sandstone facies (St) with sharp boundaries underlain these units, but rarely, scouring is also common. Mud-drape are abundant along bedding planes but scanty on foreset surface and bioturbation are scarce showing ophiomorpha and planolites, while mica flakes are pervasively disseminated within these cosets units that successively thins upwards. This progressively grades into wavy bedded units constituting of thin interfluve of lensiod sandstones units composed of planar cross-strata and ripple cross-laminated sandstone facies (Sp and Sr) (20-40 cm thick) within mudstone matrix. Mud-streak are mostly common between foreset laminations and bioturbation are dense, particular within the mudstone matrix, which with increasing thickness and corresponding starved arenaceous input generates lenticular bedding that consists of thin ripple cross-laminated and massive bedded sandstone facies (Sr and Sm) (5-10 cm thick) (Fig. 4). These are superimposed by mudstone facies (Fm) of 6-13 m thick, having glauconite and dense bioturbation with indexes of (BI:3-5). These units are rarely encountered in the successive individual fining upward cycles, which may likely be due to poor preservation or erosion. Trace fossil content includes skolithos, thalassinoides and diplocraterion. Paleocurrent evaluation indicated a bidirectional current regime with dominant south-western trend and a subordinate field in the north-western direction (Fig. 4).

3. DISCUSSION

Tidal flats typically occur in an open coast of low-relief environments mostly flanking the coastline of broad shelf with conspicuous tidal rhythms. They are hydrodynamically indexed to macrotidal coastal ranges, but are also common to mesotidal to microtidal coasts, nonetheless the former favors the development of more extensive tidal flats, [31]. Unlike wave processes that quickly dissipated on the shore, tides can propagate progressively increasing in magnitude into lagoons, estuaries and deltaic distributaries for tens to hundreds of kilometers landward from the shore due to confining of cross-sectional area of the funnel-shape attribute of the environments [32], thus, the evolution of tidal flats. The concept of sand flat, mixed flat and mud flat was introduced to characterize the physiography of tidal flats to respectively subdivide the lower, middle and upper part of the area between low and high tide of an intertidal flat [33]. Thus, textures in intertidal flats in different settings may contain different properties depending on both the materials available to form the flat and the energy regime [e.g. 34]. The facies association composed of fining upward cycle defined by bioturbated St – Sp facies with mud-drapes along bedding planes at base, displaying flaser bedding, passing upwards to Sm facies, Sp facies interbedded with Fm facies showing wavy bedding and topped by Sr to Sm facies intercalated with thick Fm facies in which the sandstone facies usually pinch-out, indicative of lenticular bedding are representative of this setting.

The flaser bedded zone in this facies association are reflective of sand-flats which typically occupy the lower portion of most tidal flats and commonly contain dune crossbedding and ripple cross-laminations depending on current speed and form under sub-tidal conditions [35,36]. The region is usually of very gentle slope with a fining-seaward trend of surface sediment because of the availability of coarse sediment and decreasing total hydrodynamic energy seaward due to increasing water depth. This level is typically characterized by regressive phases consisting of two parts, with the lower half coarsening upward from lower to upper subtidal flats, and the upper half fining upward from lower to upper intertidal flats [37,38]. An account of the later architectural symmetry is completely absent in the stratal packages, which reflects solely gradation into wavy bedding, consisting of interbeds of sandstone and mudstone facies indicative of mix–flats that contain mud layer that form by slack – water settling and lenticular bedding, composed of pinchout sandstones facies intercalated with mudstone facies representative of mud–flats which lay further landward into the supra-tidal regions [39,40]. Intertidal flats generally grade landward into saltmarshes or mangroves with mostly less physiographic differentiations between sheltered and exposed tidal flats. The availability landward of coarse sediment supply corroborated with landward decreasing total hydrodynamic energy, fining upward signature evolve because surface sediment spatially fines landward from the lower intertidal flat to the supratidal flat with a vivid manifestation in the study herein. Temporally, a prograding intertidal flat will build up an upward-fining succession with conspicuously developed flaser bedding at the base, wavy bedding at the middle, and lenticular bedding at the top, overlapped by saltmarsh deposits as clearly reflected (Fig. 4). Sheltered tidal flats usually contain more channel-filed deposits and thick sand-flat deposits as opposed to exposed tidal flats which are characterized by abundance of combined-flow and wave-induced structures, masking and predominating tidal deposition in the vertical sequence in terms of layer thickness, especially for sandy open coast tidal flats [41,32], thus the architectural signatures of the tidal flats established herein are reflective of a sheltered tidal flats.

On the overall context of the stratigraphy of the Gongola Sub–basin, the Cenomanian inundation of the trough set the template for the evolution of the tidal flat sequences as a consequence of marine transgression and hydrodynamics staged therein interacting with pre-existing fluvial systems and defining new coastal morpho-dynamics thereby setting in the necessary conditions for the development of this environment.

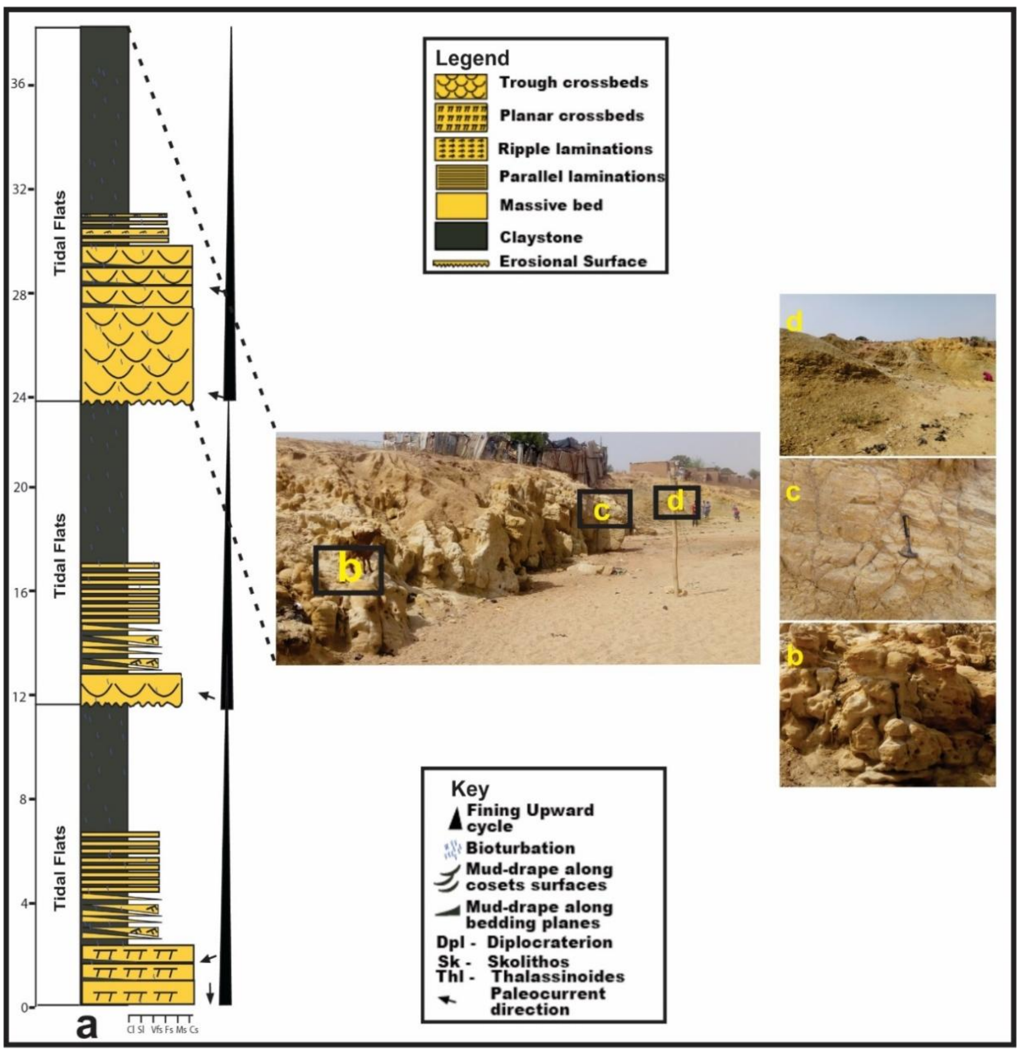

Fig. 4. a) Lithostrtaigraphic section of the Yolde Formation, b) Flaser bedded sandstone, c) Wavy bedded sandstone, and d) lenticular bedded unit

4. CONCLUSION

Lithofacies assemblage in the Cenomanian Yolde Formation at Kware stream of the Gongola Sub-basin indicated the occurrence of trough crossbedded sandstone facies (St), massive bedded sandstone facies (Sm), planar crossbedded sandstone facies (Sp), ripple laminated sandstone facies (Sr), parallel sandstone facies (Sl) and mudstone facies (Fm). Their relative association generated flaser, wavy and lenticular beddings temporally with increasing mudstone content. The fining upward symmetry from this facies succession is indicative of a tidal flat depositional system. Stacked succession of this cycles presents a coastal progradation within the net transgressive template of the Cretaceous Yolde Formation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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