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Barrier island complexes and incised valley fills of the Dumbulwa Member of the Pindiga Formation, Northern Benue Trough, NE Nigeria: A transgressive Turonian Coastline

B. Shettima,Y.B. Mohammed, M. Bukar
Department of Geology, University of Maiduguri, Borno State, Nigeria
Corresponding Author:B. Shettima

Abstract:*Facies analysis of the Dumbulwa Member of the Pindiga Formation indicated the occurrence of seven lithofacies that includes; trough crossbedded sandstone, hummocky cross-stratified sandstones, massive bedded sandstones, ripple laminated sandstones, parallel laminated sandstones, planar crossbedded sandstones and mudstones. These lithofacies forms three facies association that consists of delta front sands facies association (FadI), pro-delta facies associations (FadII) and estuarine channel facies association (FadIII).Stratigraphic disposition of these facies association indicated that the evolution of the lithostratigraphic architecture of the Dumbulwa Member commenced with the development of progradational deltaic packages (FadI) these were superposed by transgressive deposits of the fluvio-tidal channel sequences (FadIII).These sequencesgrade into transgressive deltaic succession (FadI)reflecting arelative progradational phase accompanying the net transgressive regime characterizing the mid-Cretaceous global sea level rise.*

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I. Introduction

Coastal settings are region typically characterized by interplay of waves, tides and fluvial processes, building out definite facies packages that are precursory to environmental synthesis. Shifting of these hydrodynamic processes landwards or basin–wards as a consequence of sealevel fluctuations generate transgressive or regressive sequences. In the Gongola Sub–basin of the Northern Benue Trough, falling sea level masking themid–Cretaceous transgressive phase, developed regressive sandstone units comprising of the Dumbulwa, Deba-Fulani and GulaniMembers directly overlying the transgressive shales and limestones sequences. The Dumbulwa Member evaluated in this research is generallyrestricted to the westernpart of the sub-basin, occurring at the baseof the foothill of the Kerri Kerri Plateau and around the core of the Dumbulwa–Bage High that marks the northern boundary of the Gongola Sub-basin. Zaborski et al. (1997) indicated that the formation generally contains sequences of coarse grained feldpathic tabular crossbedded sandstones, locally intercalated with thinly bedded fine grained sandstone. These build into channel filling successionof fluviatile origin with amalgamated thicknesses of over 200m, dating lower to middle Turonian (Zaborski et al., 1997).Most of the studies on this formation are commonly centered on sedimentology, lithoor biostratigraphy, therefore this current researchaims to evaluate the facies and facies association of the Dumbulwa Member of the PindigaFormation with an objective of establishing its paleodepositional environments.

II. Geological and Stratigraphic Setting

The Benue Trough is a major NE-SW trending rift basin of 50-150 km in width, and extends forover 1000 km, starting from the northern margin of the Niger Delta in the south to the southernmargin of the Chad Basin in the north (Fig.1). The trough contains up to 6000 m of Cretaceous-Tertiary sediments associated with volcanics prominently occurring at Biu and Longuda plateaus. It is geographically sub-divided into southern, central and northern portion (Fig.1) (Nwajide, 2013). The trough is believed to have formed from extensional process during the Late Jurassic to Early Cretaceous riftingapart of the African and South Americanplates (Grant, 1971; Olade, 1975), however,Benkhelil (1989) suggested a sinistral wrenching as the tectonic process responsible for its evolution.

The Northern Benue Trough is Y-shaped made up of three arms namely: The E-W trending Yola Sub–basin, N–S trending GongolaSub–basin and NE-SW trending main Arm (Muri-Lau Basin) (Dike, 2002) (Fig.1). In the GongolaSub–basin, the (Aptian-Albian) BimaFormation, a continental formation represents the basal part of the sedimentary succession, unconformably overlying the Precambrian Basement Complex. It consists of three siliciclastic members: the lower Bima (B1), middle Bima (B2) and upper Bima (B3) believed to have developed in fluvio-lacustrine environment (Carter et al., 1963; Allix, 1983; Guiraud, 1990; Shettima et al.,

2018) (Fig.2). The Cenomanian Yolde Formation conformably follows (Lawal and Moullade, 1986) and accounts for the beginning of marine incursion into the GongolaSub–basin. Full marine incursion occurred in the Turonian and lasted upto the Santonian with the deposition of the Pindiga Formation (Popoff et al., 1986; Zaborski et al., 1997, Abdulkarim et al., 2017). The estuarine/deltaic Gombe Sandstone (Dike and Onumara, 1999) of Maastrichtian age (Cater et al., 1963) represents the youngest Cretaceous sediments in the GongolaSub–basin. The Paleocene Kerri-Kerri Formation unconformably overlies the GombeFormation and represents the only record of Tertiary sedimentation in the GongolaSub–basin (Adegoke et al., 1978; Dike, 1993).

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

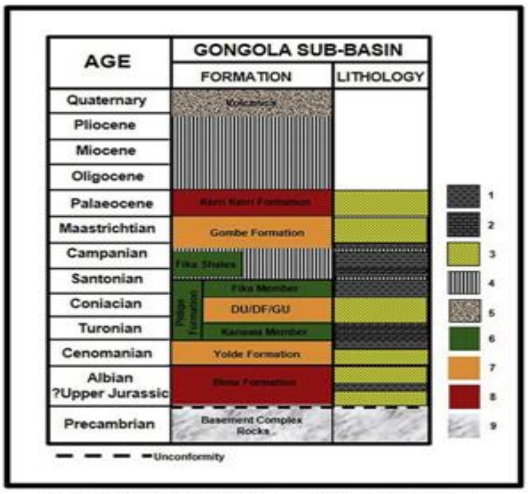

Fig. 2. Showing the stratigraphy of the Gongola Sub-basin (modified from Zaborski et al., 1997). 1-Mudstone, 2-Limestone, 3-Sandstone, 4-Hiatus, 5-Basalt, 6-Marine sediments, 7-Transitional-marine sediments, 8-Continental sediments, 9-Basement Complex (DU-Dumbulwa Member, DF-Deba Fulani Member, GU-Gulani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

III. Materials and Methods

Three lithostratigraphic sections of the Dumbulwa Member of the Pindiga Formation outcropping around Dumbulwa–Bage High (Fig.1) in the Gongola Sun-basin of the Northern Benue Trough where the outcrop provides continuous exposure of stratigraphic units around set of cliff lines.The sections were measured and described to detail stratigraphically, taking into account detailed records of thicknesses, grain sizes, sedimentary and biogenic structure and geometry from which facies assemblages and association were evaluated. Paleocurrentanalysis were also carried out on the abundant planar and trough crossbedded sandstones in order to determine the hydrodynamic systems operating. 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 10^0, tilt correction was also carried out value using the procedure adopted by Tucker (1994).

IV. Results

Lithostratigraphy

The Dumbulwa Member of the Pindiga Formation studied at the Jauro village (eastern fringes of Dumbulwa hill) (Fig.3a) and Badabdi village (Fig.3b) are lateral equivalent. The section at the Jauro village (Fig.3a) consists of 4m thick limestone at base passing upwards to interbedded ripple and parallel laminated sandstones and mudstone of about 14m. This is overlain by sets of fining upward cycles. The cycles at the base are 4 – 7m thick and consist of trough crossbedded sandstones that are mostly bioturbated, poorly sorted and coarse grained with erosional bases and pebble lag deposits which fines upward to bioturbated mudstones (80cm – 2m thick). The upper parts of the cycles are mostly defined by erosionally based (occasionally defined by rip – clasts) bioturbated, moderately sorted, medium – coarse grained hummocky cross – stratified sandstones (2.5 – 5m thick), capped by bioturbated mudstones (50cm – 1.5m thick). The hummocky cross – stratified sandstones are associated with ripple and parallel laminated sandstones. At the top of the section, the facies sequences changed to coarsening upward cycles defined by thick bioturbated mudstone (3 – 6m) at base, capped by moderately sorted, medium grained, swaley cross – stratified sandstones occasionally associated with ripple laminated sandstones.The section at the Badabdi village (Fig.3b) also displays same fining upward cycles which typically composed of *Thalassinoides*. The bioturbated, coarse grained, hummocky cross – stratified sandstones are 4.6 – 8.4m thick while the mudstones are 20cm – 9m thick.

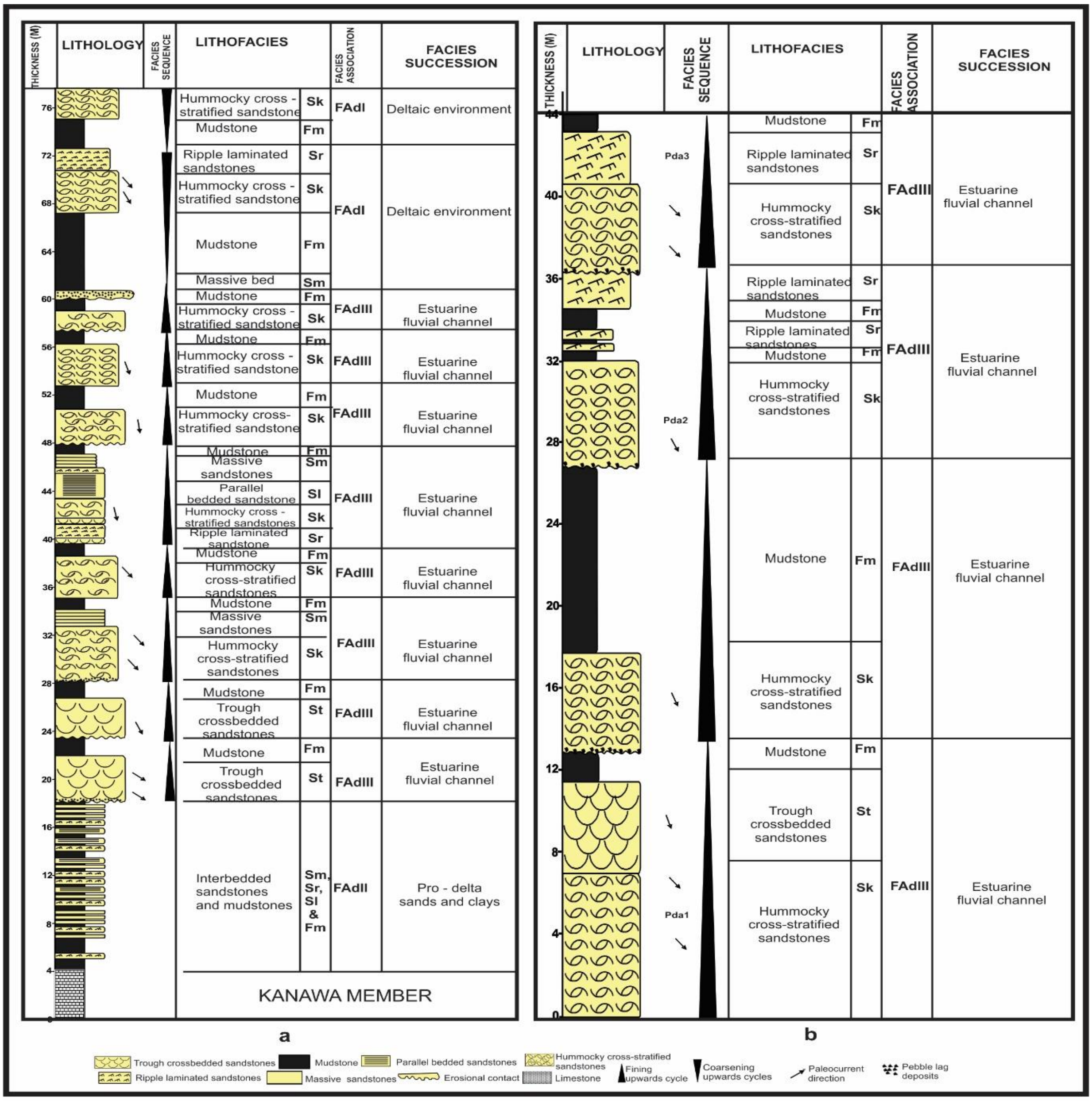

Fig.3 Lithologic section of the Dumbulwa Member: a) Jauro village and b) Badabdi village

Facies Analysis

FaciesSk: Hummocky cross-stratified sandstone facies

The Hummocky cross-stratified sandstone facies composes of units of several sets of irregular convex-up cross-beds, some 8-15 cm thick(Fig.4a). It is composed of well sorted fine - medium sandstone with rounded grains that are mostly bioturbated and thicknesses range from 60cm – 1.4m. It is commonly overlain by ripple laminated sandstone facies (Sr) and locally associated with trough crossbedded sandstone facies (St), mud partings are also common.This facies form from oscillatory and unidirectional current combined, and is typical of storm deposits of shoreface zones (Tucker, 2003).

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 – 2m. the commonly compose of erosional basal boundaries typically associated with mudclast and streaks. They are dominantly bioturbated with *thalassinoides* ichnogenera (Fig.4b). This lithofacies was interpreted to have formed from migrating sinuous 3-D dunes that stack up to generate bar forms in channel (Plint, 1983; Boggs 1995; Miall, 1978, 2010).

FaciesSl: Parallel laminated sandstone facies

This lithofacies is generally fine grained with thicknesses ranging between 30 – 80cm.It is commonly associated with trough crossbedded sandstone facies (St), ripple laminated sandstone facies (Sr) and mudstone facies (Fm). Bioturbations and mica flakes are commonassociated attributes and boundaries are generally sharp. Laminations mostly show variation in grain size or mineral composition (Fig.4c). 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 (Tucker, 2003).

FaciesSr: Ripple laminated sandstone facies

Theripple laminated sandstone faciescomposes of fine – very fine grained sandstone that are well sorted with rounded grains. Thicknesses ranges from 50cm – 1m and it is mostly associated with parallel lamination (Sl) and siltstone (FmI) (Fig.4d). 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 (Miall, 1996; 2010).

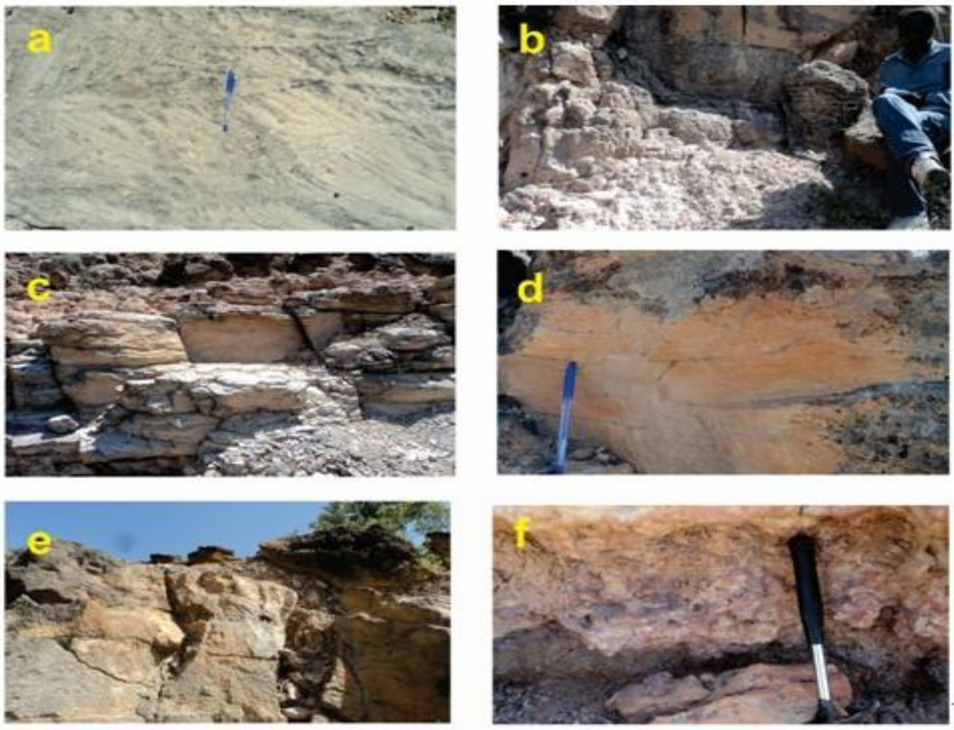

Fig.4 showing photomicrographs of the Dumbulwa Member: (a) Hummocky cross-stratification (b) Trough crossbedded sandstone (St); (c) Parallel laminated sandstone (Sl); (d) Ripple laminated sandstone(Sr); (e) Massive bedded sandstone (Sm); (f) Mudstones (Fm)

Facies Sm: Massive sandstone facies

The massive sandstone facies is moderately sorted with fine – medium grained sandstone that are commonly bioturbated. It ranges between 70cm – 1m in thickness and commonly buildup to form thicker units usually overlain by trough crossbedded sandstone (St) or parallel laminated sandstone facies (Sr) (Fig.4e). 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 channelised flood flows around bars (Miall, 1978, 2010).

FaciesFm: Mudstone facies

This lithofacies is dominantly grey coloured and commonly bioturbatedwith thicknesses ranging from 60cm – 4.5m. 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..4f). 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 (Tucker, 2003; Boggs, 2006).

FaciesAssociations

Three facies association were identified in the Dumbulwa Member of the Pindiga Formation which includes: Delta frontfacies association (FAdI), Pro-deltafacies association (FAdII) and Estuarine Channelfacies association (FAdIII) (Figs.3).Thedelta front facies association (FAdI) is composed of coarsening upward cycle defined by 2 – 5m thick bioturbated, medium – coarse grained, moderately sorted, swaley cross – stratified sandstone facies (SkI) commonly associated with ripple laminated sandstone facies (Sr) and underlain by bioturbated mudstone facies (Fm). The pro-delta fans facies association (FAdII) consist of very fine grained sandstone and mudstone facies (Fm) and ranges in thickness from 2 – 11m. The sandstone is defined by trough crossbedded sandstone facies (St), ripple laminated sandstone facies (Sr) and parallel laminated sandstone facies (Sl) with thicknesses varying from 15 – 40cm, while the mudstones range in thickness from 10 – 30cm and are generally bioturbated and contain *Paleophycus* and *Thalassinoides*ichnofacies. The incised valley fill facies association (FAdIII) iscomposed of fining upward cycles defined by thick sandstone facies in the range of 1.5 – 6m overlain by mudstone facies (Fm) of 80cm – 4m thick. The sandstone facies consist of *Thalassinoides*bioturbated, massive sandstone facies (Sm) and hummocky cross – stratified sandstone facies (Sk) with typically erosional bases associated with pebble lag and mudclast deposits. These facies are generally coarse grained and dominantly moderately sorted. Mud–drapes are common along foresets and bedding planes. Trough crossbedded sandstone facies (St) is also present in this association and is composed of very coarse grained sandstones with sub–angular pebbles of quartz and feldspars. Locally, parallel bedded sandstone facies (Sl) and ripple laminated sandstone facies (Sr) are also present. The overlying mudstone facies (Fm) are generally grey coloured and dominantly bioturbated.

V. Discussion

Coastal depositional settings are largely governed by shoreline morphology and imposing the transgressive and regressive dynamics from eustatic sea level changes. When such conditions are stationed to reflect high fluvial discharge with high sediment flux exceeding the rate of creation of accommodation space, hence a deltaic evolution (Coleman and Wright 1993; Bhattacharya, 2006). The FadIIfacies association composed of bioturbatedinterbeds succession of ripple laminated sandstones facies, parallel laminated sandstone facies and massive bedded sandstone facies intercalated with mudstone facies may suggest that the lower part of the Dumbulwa Member of the Pindiga Formation at Jauro village (Fig.3a) is formed of deltaic depositional environment. The facies association in this regards are indicative of pro-delta sequences, with an overlying transgressive erosional surface accounting for obliteration of the subaqueos and the upper delta plain sequences as a consequence of wave and tide ravinement activities (Dalrymple et al., 1992). Continuous transgressive inundation of this deltaic system changes the coastal trajectory patterns in which the feeding fluvial systems becomes submerged and flooded, shifting the depositional dynamics landwards, forming incised valley fills (Dalrymple and Choi, 2007). The manifestation of the scenario is depicted by the fluvio-tidal activity of the facies associations (FadIII) with bioturbated trough crossbedded sandstone facies and mudstone facies giving fining upward cycles.The changing channel morphology of the fluvio-tidal channel succession from fluvial dominated, tide influenced and tide dominated, may account for shoreline trend perpendicularly dissected by channels indicating gradual seawards increase in tidal energy and inversely seaward decrease in fluvial activities. This amalgamated fluvio-tidal succession is reflective of high rate of transgression associated with high rate of fluvial discharge, which is in consonance and consistence with incised valley fill estuary model (Dalrymple and Choi, 2007). These transgressive successions are followed by renewed progradationalregime atthe Jauro village section (Bhattacharya, 2010),probably as a consequence climate driven sedimentation leading to the development of deltaic sequences with pronounced delta front sands influenced by hummocky cross-stratifications and pro-delta sands and clays. Though, a likely scenario may evolve under transgressive setting where fluvial discharge and sediment flux are anomalously high locally directing the depositional locus seawards forming a delta with advancing transgressive phase.

VI. Conclusion

Lithostratigraphic architecture of the Dumbulwa Member of the Pindiga Formation is characterized by progradational deltaic sequences developed during the initial retard phase of the mid-Cretaceous global transgressive event. Superseding transgressive regimes followed with development of fluvio-tidal channel sequences with varying channel architecture displaying fluvial dominated signatures, tide influenced and tide dominated channel types. These are succeeded by storm dominated transgressive delta reflecting impulse of high sediment flux probably induced by climate, building progradational packages in the net surging transgressive phase of the late shoreline of the Dumbulwa Member.

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