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Facies, Facies Association and Depositional Environments of the Deba-Fulani member of the Pindiga Formation in Gongola Basin of the Upper Benue Trough, North-East Nigeria

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Abstract

The depositional environment of the Deba – Fulani Member of the Pindiga Formation as investigated from facies and facies association indicated that the member was formed under a deltaic barrier island depositional environment. The moderate – well sorted samples observed from the delta front sands of the deltaic environment may suggest that the coast was probably under relatively moderate – high energy fluctuating conditions over time. The dominance of three – sand population curves which are usually associated with wave processes from these samples may further suggest that the delta may probably be a wave dominated delta.

Keywords: Facies, Depositional environment, Deba – Fulani Member, Pindiga Formation, Gongola Basin.

Introduction

In the major marine transgression phase that occurred in Gongola Basin of the Upper Benue Trough during the Turonian led to the deposition of the Pindiga Formation, there occurs a minor regressive phase which brought about the deposition of Dumbulwa, Deba – Fulani and Gulani Members in the middle part of the Pindiga Formation (Zaborski *et al.*, 1997).

Deba – Fulani Member is one of the recently recognised sedimentary units in Gongola Basin. It consists of glauconitic and feldsparthic calcareous sandstone, sandy limestone, shales with thin laminated sandstone and thick trough crossbedded fine grained sandstones at its base. Its upper part consists of well-bedded coarse – medium grained sandstone alternating with silty sand and silty shales (Zaborski *et al.*, 1997).

In this research, the concept of facies and facies sequences, in association with univariate grain size parameter were used in order to determine paleodepositional environment of the Deba – Fulani Member of Pindiga Formation.

Geologic 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 (Dike, 2002). The southern limit is the northern boundary of the Niger Delta, while the northern limit is the southern boundary of the Chad Basin (Fig.1). The Trough contains about 6000m of Cretaceous to Tertiary sediments, of which those predating the mid-Santonian have been compressionally deformed, faulted and uplifted in several places. The Benue Trough is geographically subdivided into Upper, Middle and Lower Benue Trough (Fig.1).

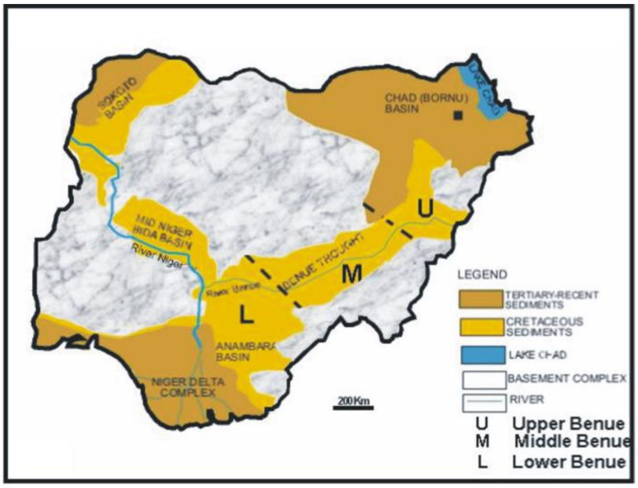

Figure 1: Geological Map of Nigeria showing the Benue Trough

The Upper 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 (Dike, 2002). The Gongola Arm (Fig. 2), which is separated from the Chad Basin to the north by the Dumbulwa-Bage High, is part of the West African Rift system that passes through Niger and Chad Republic (Zaborski *et al.*, 1997).

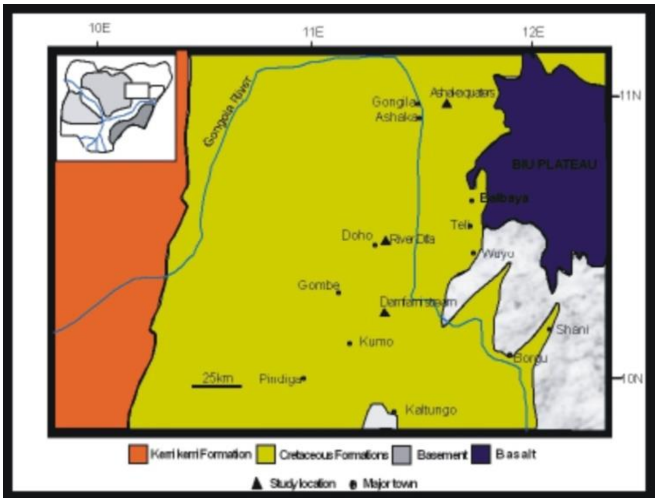

Figure 2: Geology and Sample locations (modified from Zaboski, 2003)

In the Gongola Arm the (Aptian-Albian) Bima Sandstone, a continental formation represents the basal part of the sedimentary succession. It unconformably overlies the Precambrian Basement Complex and consists of three siliciclastic members: the lower Bima (B1), middle Bima (B2) and upper Bima (B3). Its lithology and depositional environments have been discussed by (Carter *et al*., 1963; Allix, 1983; Guiraud, 1990) (Fig.3).

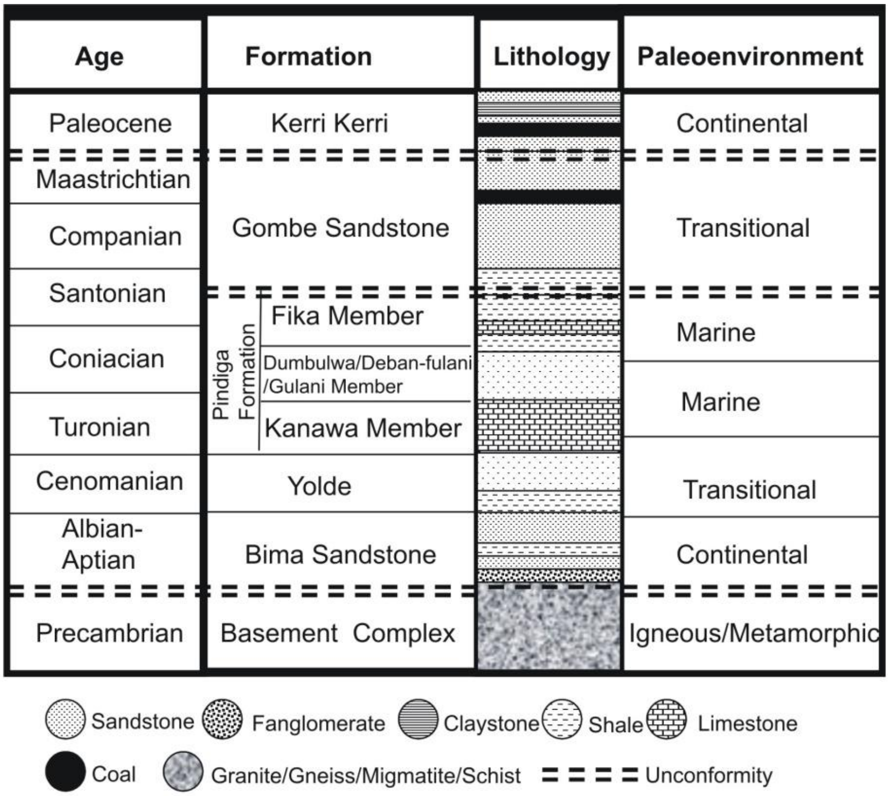

Figure 3: Stratigraphy of Gongola Basin (modied from Zaborski *et al.,* 1997)

The Yolde Formation lies conformably on the Bima Sandstone. This formation of Cretaceous age (Lawal and Moullade, 1986) represents the onset of marine incursion into the Gongola Arm.

The Turonian-Campanian Pindiga Formation conformably overlies the Yolde Formation (Popoff *et al*., 1986; Zaborski *et al*.,1997). Zaborski *et al.* (1997) subdivided the Pindiga Formation into five lithostratigraphic members: the Kanawa Member which is the basal member comprises of limestone and shale intercalations, the Gulani Member, the Deban-Fulani Member, the Dumbulwa Member and the Fika Member which is the top most Member consisting of shale and very few limestones. The Gulani, Deba-Fulani and the Dumbulwa members are lateral deposited during the middle Turonian regional regressive episode that occurred in the Benue Trough (Zaborski, *et al*., 1997).

The estuarine/deltaic Gombe Sandstone of Maastrichtian age (Carter *et al.*, 1963) overlies the Pindiga Formation and it represents the youngest Cretaceous sediment in the Gongola Arm.

The Paleocene Kerri Kerri Formation unconformably overlies the Gombe Sandstone and represents the only record of Tertiary sedimentation in the Gongola Arm (Adegoke *et al*., 1978; Dike 1993).

Materials and Methods

Three lithostratigraphic sections of the Deba – Fulani Member of the Pindiga Formation outcropping around Ashaka, Damfami and Sabon Gari (Figs. 4,5, and 6) in the Gongola Basin were considered to record data on lithologic variations, texture and biogenetic and physical sedimentary structures. Based on facies concept and supplement the environmental interpretation obtained from studies of the lithologic sections.

equivalents occurring in the middle part of the Pindiga Formation. They are application of Walters law in conjunction with facies relation provided by sedimentologic studies on ancient and modern environment, such as Visher (1965), Miall (1977) and Cant and Walker (1975), these data were utilized in designating lithofacies assemblages representing particular depositional environment.

Fifteen (15) samples were collected from the outcrop sections of the Deban - Fulani Member. These samples were subjected to granulometric analysis. 200gms of each sample was sieved for about 30 minutes in Ro-Tab sieve shaker. Statistical parameters; mean, standard deviation, skewness and kurtosis were determined using the formula of Folk and Ward (1957). Probability population curve was also plotted for the grain size distribution based on the methods of Visher (1969) and Dike (1972). The data obtained from granulometric analysis and probability curve plots were used to

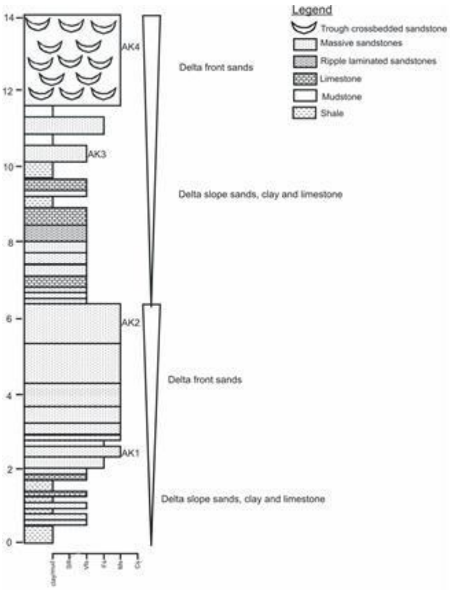

Fig 4. Ashaka quarry section (Deban-Fulani Member)

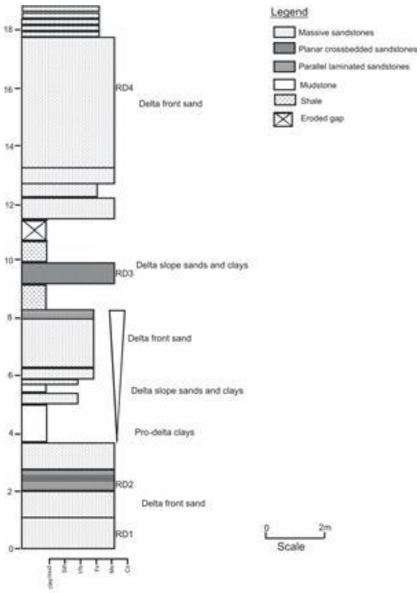

Fig. 5 Difa stream section (Deban-Fulani Member)

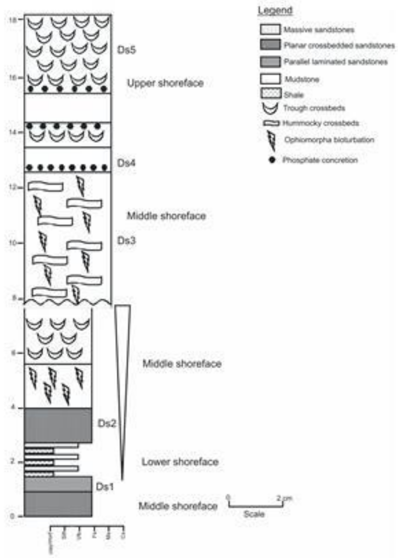

Fig. 6 Danfami stream section (Deban-Fulani Member)

Fig.7 mudstone facies

Fig.8 planar crossbedded`sandstone facies

Fig.9 trough crossbedded`sandstone facies

Fig.10 massive`sandstone facies

Fig.11 parallel laminated sandstone facies

Fig.12 ripple laminated sandstone facies

Fig.13 carbonate mud facies

Results

Facies Analysis

Seven facies were recognized based on lithology and sedimentary structures as follows:

Facies A: Mudstones/Claystones/Shales

These facies comprises of shales or mudstones units and it occurs in all the studied sections (Fig. 7). Deposition of this facies is by vertical accretion from suspension due to weak current (Miall, 1978).

Facies B: Planar Cross-Bedded Sandstone

This facies was only recorded at Ashaka and Sabon gari section (Figs. 4 and 5) and ranges from light brown-grey-buff with bed thickness 1.2 m – 1.8m. The sandstones are either fine or medium. This facies usually forms migrating cross-channel bars and sandwaves (Cant and Walker,1978; Miall, 1978; Rust, 1978).

Facies C: Trough Cross-Bedded Sandstone

The facies consists of brown and buff trough crossbedded medium-grained sandstones (Fig.9), and it occurs in Ashaka and Damfami sections (Figs. 4 and 6). The cross-bedded units range from 0.5m to 2m. The facies was probably formed by migrating sinuous crested dunes or mega-ripples. Miall (1977, 1978) has reported that trough cross-bedding in braided channels are formed by sinous crested dunes or mega-ripples.

Facies D: Massive Sandstone

The sandstones are usually light brown or brown, and occur anywhere in the succession and are found in all the sections studied. Lithologically, it varies from fine-grained to medium-coarse-grained sandstone (Fig. 10).The thickness varies from 1.4m to about 6m. Martin and Turner (1998) have reported the occurrence of massive type sandstones in fluviatile and estuarine environments, especially in braided rivers. Thus, this facies may be associated with channelised flood flows around bars.

Facies E: Parallel Laminated Sandstones

Lamination is produced by less severe or short-lived fluctuations in sedimentation conditions than those that generated the beds (Boggs, 1995) and this facies was only observed at Sabon gari and Damfami stream sections (Figs. 5 and 6).This facies occurs in fine-grained sandstones whose grain sizes ranged from 0.7m – 1.0m (Fig. 11). They result from changing depositional conditions which causes variation either in grain size, content of clay and organic material, mineral composition or microfossil content of sediments (Simons *et al.*, 1965).

Facies F: Ripple Laminated Sandstones

This facies was only observed at Ashaka quarry section (Fig.4) with a thickness varying from 0.6 – 1.0m (Fig.12). It forms either when the water surfaces show little disturbance, or waves are out of phase with bedforms and the hydrodynamic condition that generate this bedform is called the lower flow regime (Simons *et al.*, 1965).

Facies G: Hummocky crosbedded sandstone

This facies was only recorded at Damfami stream section (Fig.6) with thickness of up to 4m. This facies is formed by strong surge of varied directions that are generated by large storm waves (Harms *et al.,* 1982).

Facies H: Limestone (Carbonate mud)

Carbonate mud (micrite) is composed of very fine grained calcite crystals and they form from inorganic precipitation of aragonite which are later converted to calcite owing to surface water supersaturation with calcium biocarbonate (Boggs, 1995). The presence of carbonate mud in ancient limestone is commonly interpreted to indicate deposition under a quiet water conditions where little winnowing of fine mud took place (Boggs, 1995).

Univariate Grain Size Parameters

The graphic mean represents average grain size distribution. The average size is generally controlled by strength of the depositing current, the initial grain size and source of the material (Folk and Ward, 1957; Sahu, 1957; Pettijohn, *et al.,* 1987). The graphic mean size for the various samples (Table 1) range from (1.38ø – 3.17ø) i.e. (medium to very fine grained sandstone) with an average of 1.98ø (medium grained sandstone).

The mean size of a grain still has no definite trend to support any environmental interpretation. Furthermore, Friedman (1967) pointed out that the average mean size is not sensitive as an environmental indicator.

Inclusive Graphic Standard Deviation (Sorting)

The degree of sorting in sandstones generally depends on sediment source, grain size and depositional regime. It is indicative of hydrodynamic conditions (range of velocities and degree of turbidity) operating within the transporting medium and to some extent, it is suggestive of the distance of travel (Krumbein and Sloss, 1963; Reineck and Singh, 1973).

The values of standard deviation (Table 1) tend to show well sorted (0.45ø) to poorly sorted (1.08ø) with an average of (0.74ø) which implies that the whole formation is moderately sorted.

The dominance of well sorted and moderately sorted samples may suggest that the transportation responsible for the deposition was very turbulent where there is a lot of winnowing and waxing activities.

Inclusive Graphic Skewness (Ski)

Skewness is a measure of the symmetry of the distribution and it is a very useful descriptive term for the depositional processes of the sediments. The samples analysed have skewness values ranging from (-0.17ø to 0.70ø) i.e. from negatively skewed to very positively skewed respectively (Table 1). These values may suggest that the samples must have been formed in an environment with a highly fluctuating energy conditions.

Table 1. Grain size distribution and qualitative parameters for samples analysed

SAMPLE NO.	GRAPHIC MEAN (Mz)	GRAPHIC STANDARD DEVIATION (SORTING)	GRAPHIC SKEWNESS (Ski)	GRAPHIC KURTOSIS (Kc)
AK1	1.38 Medium grained	0.45 Well sorted	-0.17 Negatively skewed	3.57 Very leptokurtic
AK2	1.90 Medium grained	0.76 Moderately sorted	0.19 Nearly symmetrical	3.76 Very leptokurtic
AK3	3.15 Very fine grained	0.70 Moderately sorted	0.03 Nearly symmetrical	0.83 Platykurtic
AK4	1.38 Medium grained	0.98 Moderately sorted	0.26 Positively skewed	1.78 Leptokurtic
DS1	3.17 Very fine grained	0.77 Moderately sorted	0.41 Positively skewed	1.62 Leptokurtic
DS2	1.74 Medium grained	0.93 Moderately sorted	0.38 Positively skewed	1.56 Leptokurtic
DS3	1.51 Medium grained	1.08 Poorly sorted	0.46 Positively skewed	1.85 Leptokurtic
DS4	1.98 Medium grained	0.44 Well sorted	0.43 Positively skewed	11.90 Very leptokurtic
DS5	1.96 Medium grained	0.49 Well sorted	0.70 Very positive skewed	2.53 Very leptokurtic
RD1	1.52 Medium grained	0.98 Moderately sorted	0.43 Positively skewed	1.34 Leptokurtic
RD2	2.14 Fine grained	0.81 Moderately sorted	0.07 Nearly symmetrical	2.59 Very leptokurtic
RD3	2.37 Fine grained	0.77 Moderately sorted	0.13 Nearly symmetrical	1.97 Leptokurtic
RD4	1.50 Medium grained	0.46 Well sorted	0.06 Nearly symmetrical	1.28 Leptokurtic

AK- Ashaka section: DS- Dampami stream section: RD- Difa stream section

Inclusive Graphic Kurtosis (Kc)

Kurtosis is a measure of the peak of distribution and values of kurtosis (Table 1) for the various samples range from (0.83ø – 11.90ø) indicating (platykurtic to very leptokurtic), with an average of 2.81ø (leptokurtic). Little geologic information can be derived from values of kurtosis (Pettijohn *et al*, 1987), but, with the dominance of leptokurtic, it may be suggested that the samples were affected by similar depositional conditions.

Probability Plots

The different sand populations in a probability curve plot are of environmental significance. Such sand population members are characteristic of fluvial, beach, wave zone, e.t.c. According to Visher (1969) characterization: two sand populations are characteristics of fluvial setting; three sand populations are characteristics of wave zone bars; four sand populations are characteristics of beach setting.

Cumulative probability distribution curves (Figs.14 and 15) of analyzed samples tend to show two to three straight line segments.

Sample displaying three segments probability curve are: AK1, AK2, AK3, DS1, DS4, DS5, RD2, RD3 and RD4. They are characterized by:

i) A suspension segment with a slope of 15^o – 57^o that forms 4% - 27% of the distribution.

ii) A well sorted saltation population with a slope of 67% - 79% that forms 43% - 81% of the distribution.

iii) A poorly sorted traction population with a slope of 23^o – 42^o that forms 0.2% - 10% of the distribution.

The samples characterized by two segments probability curve are: AK4, DS2, DS3 and RD1. They are characterized by:

i) Poorly sorted suspension population with a slope of 7^o – 43^o that forms 3% - 48% of the distribution.

ii) A well sorted saltation with a slope of 53^o – 84^o that forms 42% - 89% of the distribution.

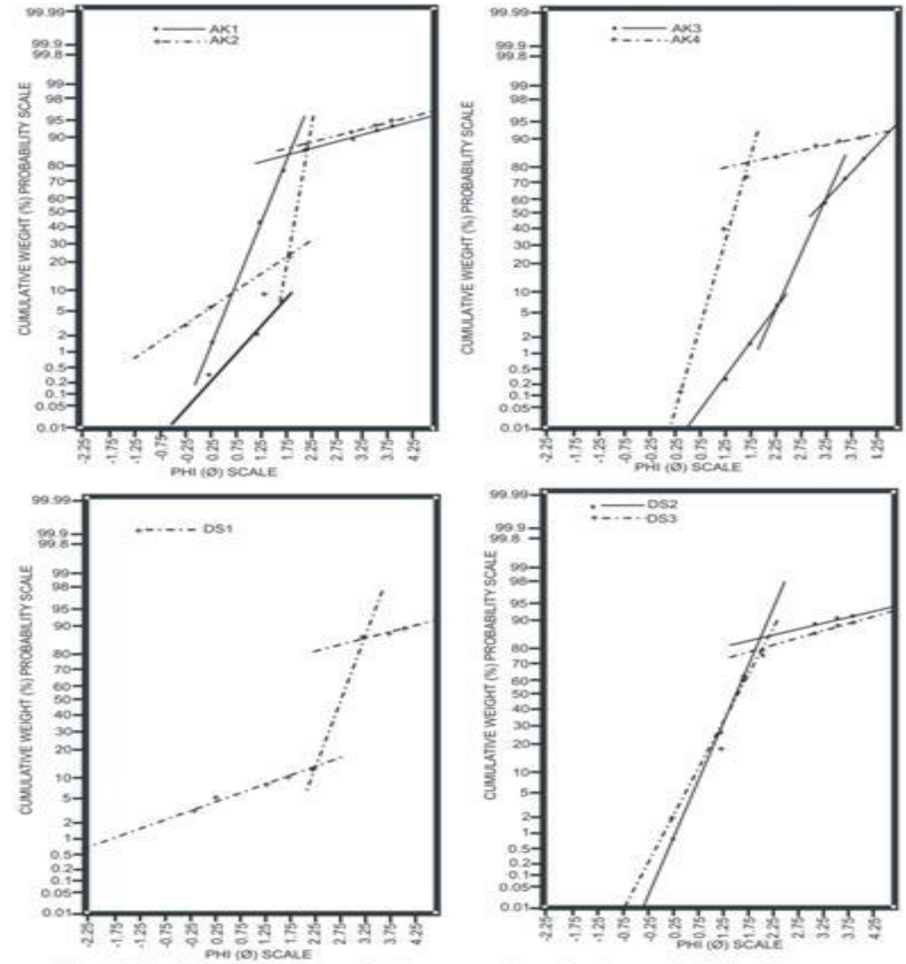

Fig. 14 Sand distribution population curves based on log probability plots

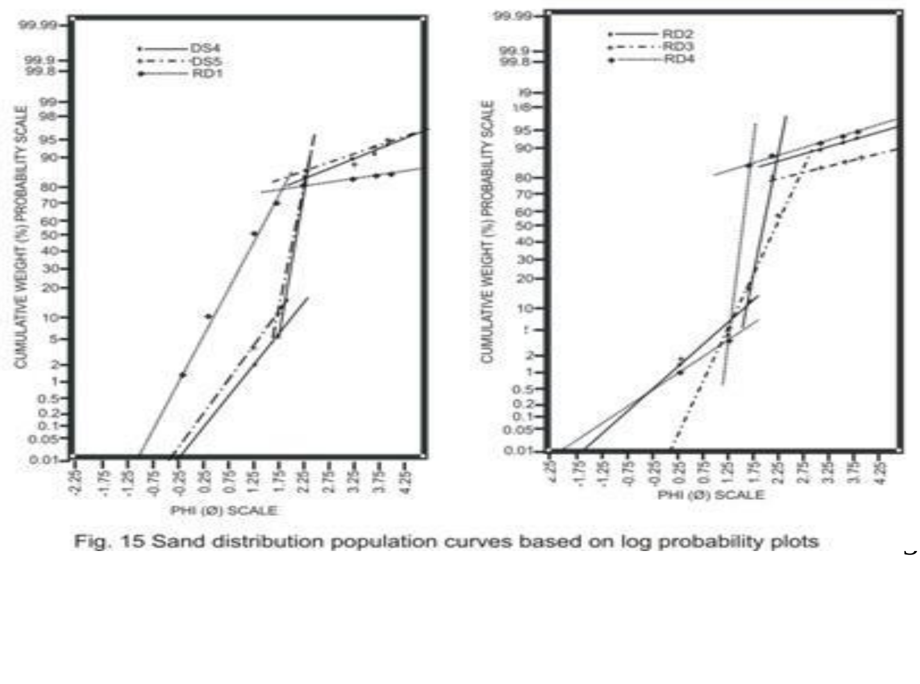

Fig. 15 Sand distribution population curves based on log probability plots

Discussion

The Ashaka Quarry Section (Fig.4) is composed of two coarsening upwards cycles. These cycles may represent delta slope facies consisting of intercalation of limestone, mudstone and thin sandstones passing upwards to delta front sands composed of either trough crossbedded or massive beds. The granulometric analysis of the sandstone samples of the delta slope sub-environment indicated well sorted sands (Table1) and their probability curve plots showed three-sand population curves (Fig.14) which are indicative wave processes (Visher, 1969; Dike, 1972), hence, the sand may have been deposited by wave currents. The delta front sands are composed of moderately sorted sand as observe from granulometric analysis (Table 1). Furthermore, the probability curve plots for their sample tend to indicates two-sand population curve (Fig.14) which are associated with unidirectional current (Dike, 1972). And owing to the fact that the sand lack marine indicators like glauconite, phosphate nodules or marine fossils, the unidirectional current may be that associated with fluvial current, hence, the delta front sand may probably represent a mouth bar deposit.

the three-sand population curve (Fig.15) depicted by its samples which are usually indicative of wave process (Visher, 1969; Dike, 1972), and this is usually akin to wave dominated delta (Abdul-wahab *et al.*,1992).

In the section at Danfami stream (Fig.6), the facies succession of planar crossbedded to parallel laminated fine grained sandstone at the base of the section which are

The facies succession at River Difa Section (Fig.5) is composed of massive to parallel laminated medium grained sandstone at base and this may represent delta front sands. This was suggested based on the fact that the sand tend to consists of moderately sorted grains (table 1) and are characterized by three-sand population curve (Fig.15) which is usually indicative of wave process (Visher, 1969; Dike, 1972). The overlying coarsening upwards cycle consisting of succession of claystone to interbedded claystone and massive to parallel laminated fine grained sandstone may suggest pro-delta clays passing upwards to delta slope clays and sands then delta front sands respectively. The succeeding shales interbedded with planar crossbedded sandstone may probably represent delta slope sand and clays, and this facies association may further indicate the resurgence of the sea leading to transgression, thereby setting another cycle for progradational sequences. Based on the well sorted grains observed in the overlying succession of light brown fine–medium massive grained sandstone (Table 1), the succession may suggest delta front sands. This may be further confirmed by

moderately sorted as observed from granulometric studies (Table 1) may suggest a middle shoreface environment. This is supported by the three-sand population curve plots observed from probability curve plots (Figs.14 and 15) considering the fact that three-sands population curves are usually associated with wave processes (Visher, 1969; Dike, 1972). In the overlying coarsening upwards cycle, the basal part is defined by interbeds of shales and very fine grained sandstones and this facies association may represent lower shoreface environment. This passes upwards to a succession of planar crossbedded, massive bedded and trough crossbedded fine grained sandstone in which the massive bed is bioturbated and the trough crossbed is truncated by erosion. These facies association may represent a middle shore-face environment and the two-sand population curve (Fig.14 and 15) observed in these facies may reflect period of tidal activity (Visher, 1969; Dike, 1972) and the overlying bioturbated sandstone unit may indicate quiet water regime. The overlying hummocky cross-stratified medium grained sandstone may represent a middle shoreface environment. The poor sorting observed for its samples may support this interpretation because storm deposit are generally poorly sorted, owing to lack of waning activities (Reineck and Singh, 1973), and the two-sand population curves (Figs.14 and 15) obtained from probability curve plots may further support this interpretation, because hummocky cross-stratification are produced by storm waves which are usually unidirectional (Visher,1969; Dike, 1972). The overlying succession of interbeds of massive and trough crossbedded medium grained sandstones associated with phosphate nodules may have been deposited in an upper shoreface environment. This interpretation may be further supported by the well sorted sand observed from granulometric analysis (Table 1) because upper shoreface sands are usually well sorted owing to high energy conditions in that setting (Reineck and Singh, 1973). In addition to this, the three-sand population plots (Fig.14 and 15) observed may also support this interpretation (Visher, 1969; Dike, 1972).

Conclusion

This research carried out on the bases facies and facies association and granulometric analysis indicated that the Deba-Fulani Members of the Pindiga Formation was probably deposited under a deltaic and barrier island depositional environment. The dominance of negatively skewed, well sorted sample and three–sand population curve observed from the deltaic environment may suggest that the delta was probably a wave dominated delta.

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