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FACIES AND FACIES ARCHITECTURE AND DEPOSITIONAL ENVIRONMENTS OF THE CRETACEOUS YOLDE FORMATION IN THE GONGOLA BASIN OF THE UPPER BENUE TROUGH, NORTH-EASTERN NIGERIA

B. SHETTIMA, E.F.C. DIKE, M.B. ABUBAKAR, A.M. KYARI AND F.BUKAR

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ABSTRACT

Depositional environments of the Yolde Formation were studied based on the analysis of facies and facies architecture. Five sections within the Gongola Basin were studied and ten lithofocies were recognized based on lithology and sedimentary structures. The sandstone ranges from quartzarenite to subarkose and well to moderately sorted. They comprise of very fine, fine, medium and coarse-grained sandstones. Locally, there is occurrence of thin beds of limestone at the upper most part of the Yolde Formation. The facies architecture at the lower part of this formation is defined by fining upwards cycles interpreted as sequences of fluvial deposits formed from braided river system which consist of succession of massive beds of sandstones fining upwards to thin claystone. The facies architecture in the upper part is defined by:(i) fining upwards cycle of sandstones to claystone interpreted as delta plain distributary channel-overbank facies;(ii) coarsening upwards cycles of mudstones-sandstones interpreted as creavasse-splay deposits in an interdistributary bay fills and;(iii) coarsening upwards cycles of claystones-sandstones or interbedded sandstone and claystones-sandstones are interpreted as delta front sandstones on pro-delta claystones or delta front sandstones on delta slope sandstone and claystones respectively. The dominance of river sandstones over coastal sandstone from bivariate plot relationships and two-sand population plots for the Yolde Formation suggest the upper part of this formation may have formed in a fluvial-dominated delta.

KEY WORDS: Sedimentology, Facies architecture, Depositional environment.

INTRODUCTION

The Yolde Formation represents the onset of marine transgression in the Gongola, Yola and Muri-Lau Arm of the Upper Benue Trough and it conformably overlies the continental Bima Sandstone (Dike, 2002). It was deposited during the Late Albian to Late Cenomanian (Lawal, 1982; Allix, 1983; Lawal and Moullade, 1986).

It consists largely of interbedded coarse to fine grained crossbedded or ripple-parallel laminated and massive sandstone. They occur together with mudstones, claystones and grey to greenish shales. Thin beds of limestone occur, especially in its upper part where oyster beds are common (Carter *et al*., 1963; Shettima, 2005). The formation fines upwards, channel-filling coarse – grained sandstones with trough cross bedding occur in the lower part, while thinly – bedded, medium to fine-grained often bioturbated sandstones appear higher up (Zaborski *et al*.,1997).

Most of the earlier work done on the Yolde Formation were focused on the sedimentology with little emphasis on paleoenvironments. Prominent among these earlier works include Falconer (1911), Barber *et al*.(1954), Carter *et al*.(1963) and Zaborski *et al*.(1997). All these authors designated a transitional environment for the Yolde Formation.

This present research is aimed at establishing sub-depositional environment under the broader transitional environmental realms established by earlier workers for the Yolde Formation by applying the concept of facies and facies architecture coupled with textural parameters of grain size frequency data obtained from arenaceous units.

GEOLOGICAL AND STATIGRAPHIC SETTING

The Benue Trough is a major NE-SW trending rift basin of 50-150 km in width. It extends for over 1000 km, starting from the northern margin of the Niger Delta in the south to the southern margin of the Chad Basin in the north (Fig.1). The trough is a sedimentary basin containing up to 6000 m of Cretaceous-Tertiary sediments associated with volcanics. It is geographically sub-divided into lower, middle and upper portion (Fig.1). The trough is believed to have formed from extensional process during the Late Jurassic to the Early Cretaceous separation of the continents of Africa and South America (Grant, 1971; Olade, 1975), but Benkhelil (1989) suggested a sinistral wrenching as the tectonic process responsible for its evolution.

B. Shettima, Department of Geology, University of Maiduguri, Borno State.
E. F. C. Dike, National Centre for Petroleum Research and Development, A.T.B.U. Bauchi
M. B. Abubakar, National Centre for Petroleum Research and Development, A.T.B.U. Bauchi
A. M. Kyari, Department of Geology, University of Maiduguri, Borno State.
F. Bukar, Department of Geology, University of Maiduguri, Borno State.

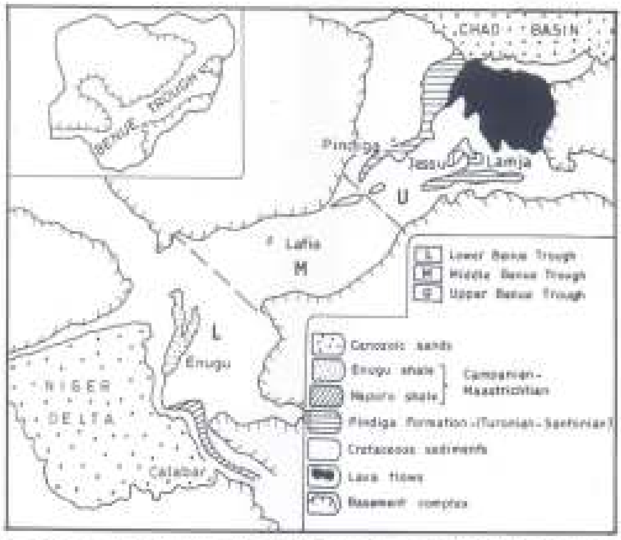

Fig. 1 Geographical subdivision of the Benue Trough (after Obaje and Ligouis, 1996)

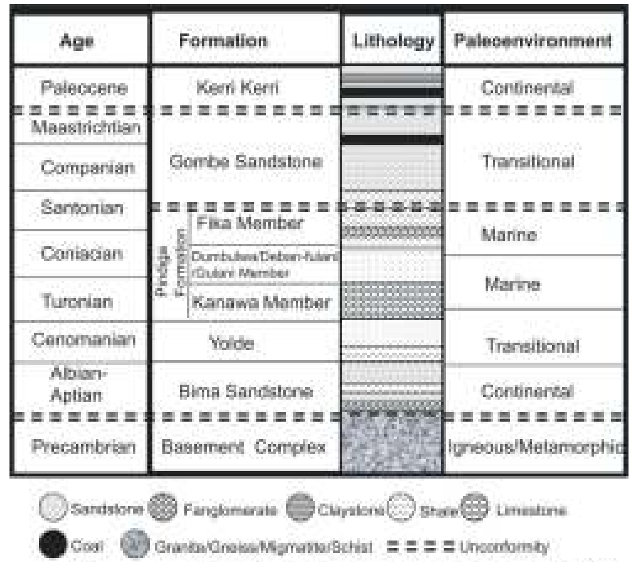

Fig.2 Stratigraphy of Gongola Basin (modified from Zaborski et al.,1997)

The Upper Benue Trough is Y-shaped made up of three arms namely: the E-W trending Yola Arm, N-S trending Gongola Arm and NE-SW trending main Arm (Muri-Lau Basin) (Dike, 2002) (Fig.1).

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.2).

The Yolde Formation lies conformably on the Bima Sandstone. This formation of Cretaceous age (Lawal and Moullade, 1986) represents the beginning of marine incursion into the Gongola Arm. The Turonian-Santonian Pindiga Formation conformably overlies the Yolde Formation (Popoff *et al*., 1986; Zaborski *et al*., 1997). It is laterally equivalent to the Gongila Formation and the Fika Shales, all of which represents a full marine incursion into the Gongola Arm.

The estuarine/deltaic Gombe Sandstone (Dike and Onumara, 1999) of Maastrichtian age (Cater *et al*., 1963) overlies the Pindiga Formation and it represents the youngest Cretaceous sediments 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

Five stratigraphic sections of the Yolde Formation outcropping in the Gongola Basin (Fig.3) were studied and measured to record data on the lithological variations, texture, fossils, sedimentary structure and paleocurrent. These data were used to establish lithofacies assemblages representing particular depositional environment. Thirty-six samples were also collected from outcrop sections of the Yolde Formation during field study by digging a trench of about 2ft so as to avoid weathered horizons. Both petrographic and granulometric analysis was carried out for these samples. Granulometric analysis was carried out by the conventional method and about 200g of each sample was sieved for about 30 minutes in a Ro-Tap shaker. The log probability curve of grain size distribution of the analysed samples based on Visher (1969; 1972) and Dike (1972b) were also applied to aid in interpreting the paleodepositional environments.

RESULTS

Facies Analysis:

Five good outcropping sections of the Yolde Formation have been studied. They were logged at different localities in the Gongola Arm of the Upper Benue Trough (Fig.3) and they include: Ruwan kuka village, Kworin Gora stream, Ashaka stream, Gabukka stream and Doma stream (Figs. 4, 5, 6, 7 and 8) respectively.

Nine facies were recognized based on lithology and sedimentary structures and they are as fallows:

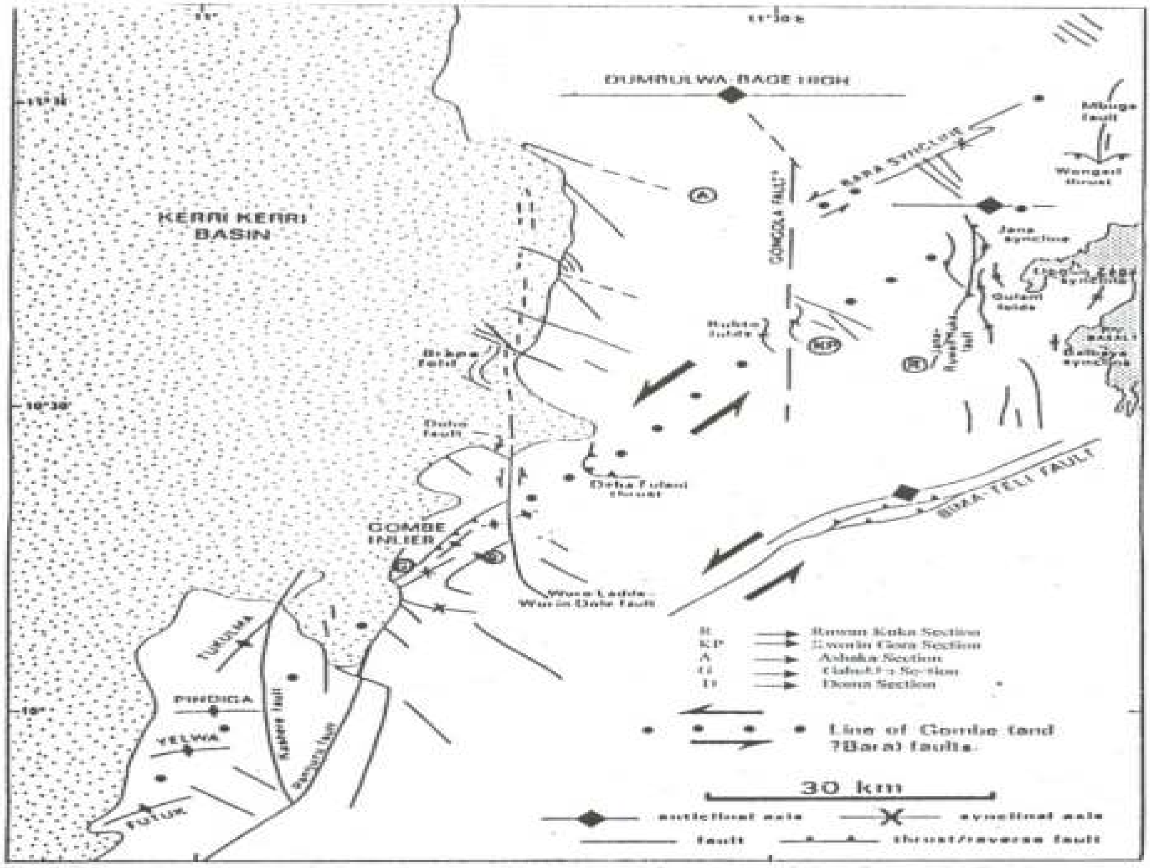

Fig.3 Map showing study locations and structural features of the Gongola Basin (modified from Zaborski et al.,1997)

Facies A: Mudstones/Claystones/Shales

These facies comprises of massive shales or mudstones units with thickness of up to about 4m measured at the base of the Ruwan kuka section (Fig. 4). It also occurs as thinner units 0.4-1m at Gabukka, Doma and Ashaka Stream section (Figs. 7, 8 and 6). Deposition of this facies is by vertical accretion from suspension due to weak current.

Facies B: Planar Cross-Bedded Sandstone

This facies was recorded in Gabukka, Doma and Ruwan Kuka sections (Figs. 7, 8 and 4) and ranges from light brown-grey-buff with bed thickness of 30 to 100cm. The sandstones are medium to coarse-grained with planar cross-bedding indicating flow at oblique to right angles to direction shown by the trough-cross-bedded sandstone facies. The facies therefore may have been formed by migrating cross-channel bars and sandwaves. Miall (1978), Cant and Walker (1978) and Rust (1978) have noted similar facies in braid bars of fluvial deposits (Fig.9).

Facies C: Trough Cross-Bedded Sandstone

The facies consist of brown and buff trough crossbedded coarse-grained sandstones, though at times conglomeratic. It occurs in the lower part of the Ruwan Kuka section (Fig. 4) where it forms the base of a fining-upward sequence and are fine-grained. At Gabukka, Doma (Fig.7 and 8), it occurs at several levels in medium-coarse grained sandstone. The cross-bedded units are 10cm to 2m thick. 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 sinus crested dunes or mega-ripples (Fig.10).

Facies D: Tabular Cross-Bedded Sandstones

This facies tends to consist of light brown to grey sandstone. It occurs at several levels in Ruwan Kuka, and Doma (Figs. 7 and 8) ranging in thickness 30cm to 1m. The facies was probably formed process of bar migration (Miall, 1977) (Fig.11).

Facies E: Massive Sandstone

The sandstones are usually brown and buff 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 with the coarse type restricted to the Gabukka

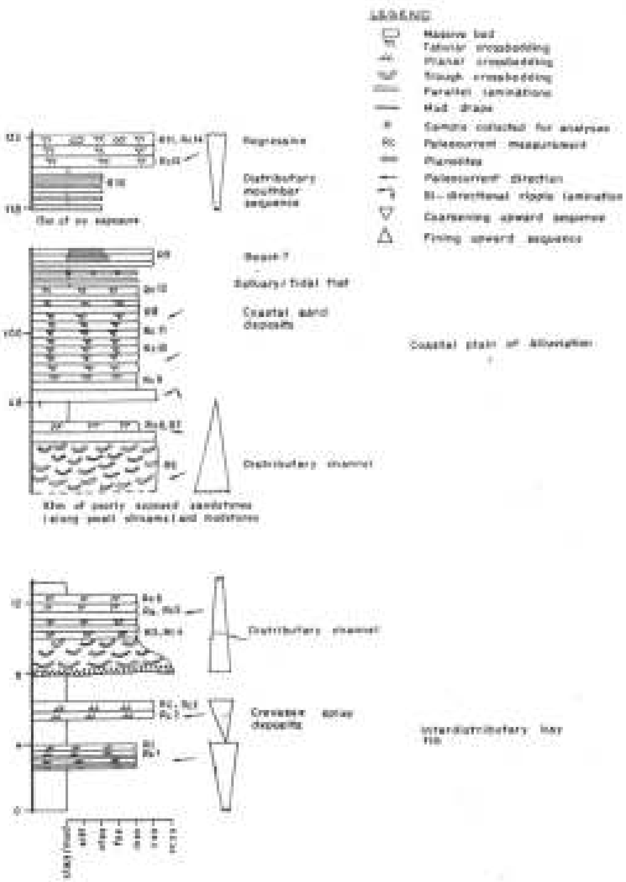

Fig.4 Section of Yolde Formation at Doma stream

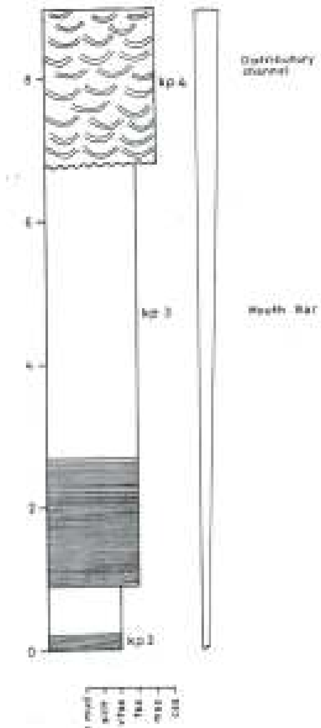

Fig.5 Section of Yolde Formation at Kwaron Gora Stream

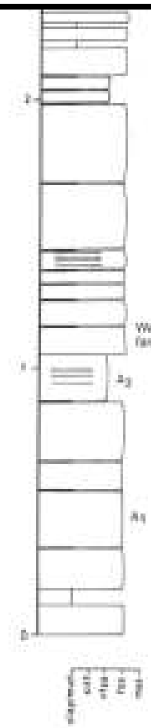

Fig. 6 Section of Yolde Formation at Ashaka Stream

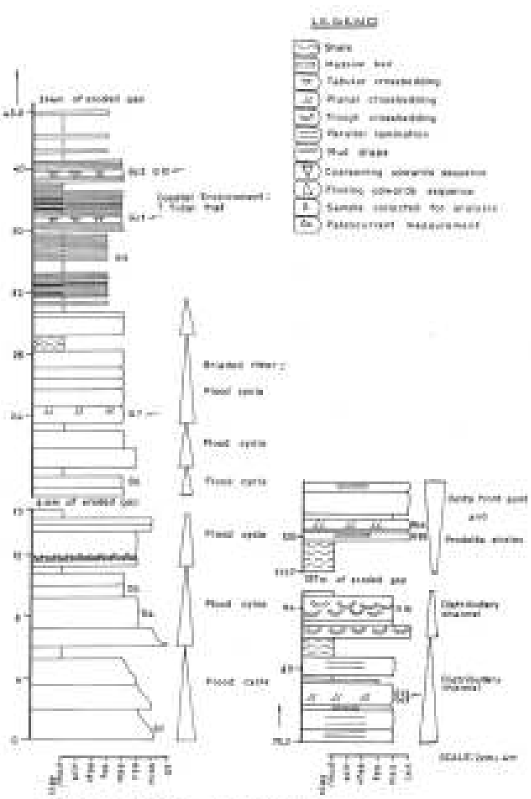

Fig.7 Section of Yolde Formation at Gabukka stream

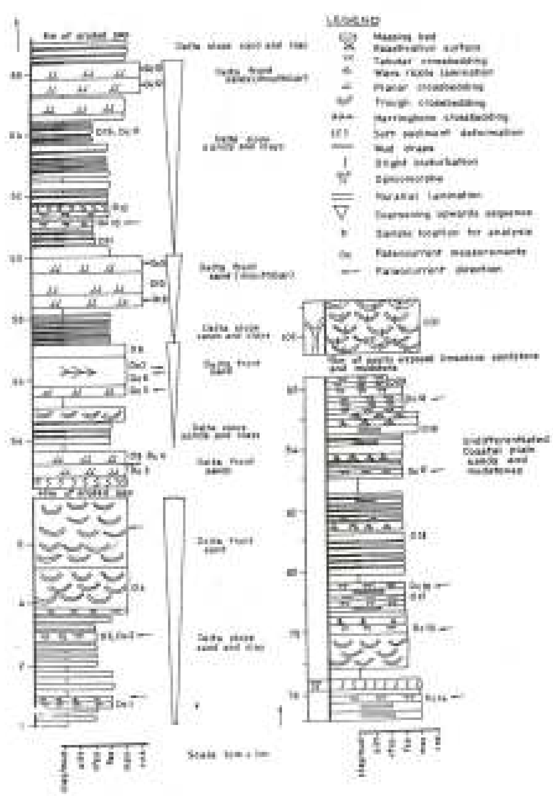

Fig.8 Section of Yolde Formation at Doma stream

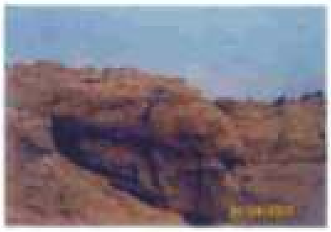
Fig.9 Planar crossbedded sandstone


Fig.10 Trough crossbedded sandstone


Fig.15a Ripple laminated sandstones


Fig.15b Ripple laminated sandstones


Fig.11 Tabular crossbedded sandstone


Fig.12 Massive bedded sandstones


Fig.16 Ophiomorpha burrowed sandstones


Fig.13 Parallel laminated sandstone

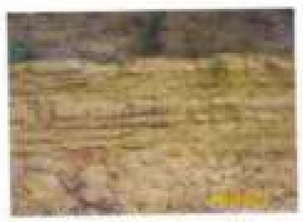
Fig.14 Interbedded sandstones and mudstone

Fig.17 Poorly sorted coarse grained sandstone (q-quartz, cm-cement, pl-crosspolar).

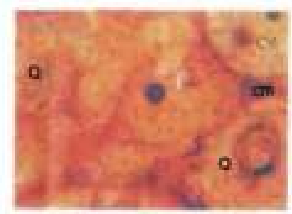

Fig.18 Well sorted medium grained sandstone (Q-quartz, f-feldspar, cm-cement, Cx-crosspolar).

The facies was probably deposited on bars by stream floods. Martin and Turner (1998) have reported that occurrence of massive type sandstones in fluviatile and

Facies F: Parallel Laminated Sandstones

Lamination is produced by less severe or short-lived fluctuations in sedimentation conditions than those that generate beds and this facies is common in all the composition or microfossil content of sediments. But laminations produced by alternating layers of finer and coarser grained sediments are probably the most common kind (Boggs, 1995) (Fig.13).

Facies G: Interbedded Flat-Bedded Sandstone and Mudstones

The sandstones form medium to thick flat beds of 20 to 80 and occur in units of up to 2 to 10m. There grain size range from fine to medium-grain. They form the middle sand unit of the coarsening upward sequence at the base of the Doma stream section (Fig. 8) and it consists of very fine to fine-grained sandstones. At Gabukka stream section (Fig. 7) it occurs in medium to fine grained facies in the upper part of the section at several levels (Fig. 7). They may be produced from differential slow single episodes of sedimentation of fine-grained sediments from suspension (Fig.14).

Univariate grain size parameters

The graphic mean size (Mz) of the samples range from (0.63ø – 3.85ø) i.e. coarse to very fine-

estuarine environments, especially in braided rivers. Thus, this facies may be associated with channelised flood flows around bars (Fig.12).

sections and are usually observed in fine-grained sandstones. They result from changing depositional conditions that causes variation either in grain size, content of clay and organic material, mineral

Facies H: Ripple Laminated Sandstones

This facies forms either when the water surface show little disturbance, or water waves are out of phase with bedforms. The hydrodynamic condition that generate this bedform is called the lower flow regime (Simons *et al.*, 1965). Ripple laminated sandstones were observed only at Ruwan Kuka and Doma stream section (Figs. 4 and 8) and they usually form from fine grained sandstones. The one at Ruwan Kuka section tends to exhibit bidirectional current orientation (Figs.15a and b).

Facies I: Herringbone Cross-Bedded Sandstones

This facies is usually associated with high energy setting define by more than one current trend. This facies occurs only at Doma stream section (Fig. 8) and it consists of medium-grained sandstones. It is most at times associated with delta front sands, estuarine and barrier island settings.

grained sands, with an average of 2.04 ø (fine-grained sands) (Table 1). The value tends to fluctuate, reflecting change in the strength of the deposition medium. 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.

The standard deviation (sorting) (Table 1) tends to show well sorted (0.42ø) poorly to sorted (1.61ø) with an average of (1.03ø) which is in consonances with Friedman (1967) data for fluvial sands.

Skewness values range from (-0.32ø to 0.80ø) i.e. from negatively skewed to very positively skewed respectively. However, positively skewed values predominate (Table 1), and this may be due to the fact that much of the silt and clay was not removed by current, though the clay may be secondary. Furthermore, the skewness data is comparable to the results of Friedman (1961, 1967) on fluvial sands.

The kurtosis values (Table 1) for the samples range from (0.56ø to 2.55ø) (very platykurtic to very leptokurtic), with an average of 1.32ø (leptokurtic). Little geologic information can be derived from values of kurtosis (Pettijohn *et al.*, 1973), but, the data agree largely with fluvial sand (Abdel-Wahab, 1988).

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

SAMPLE NO.	GRAPHIC MEAN (Mz) ø	GRAPHIC STANDARD DEVIATION (SORTING)	GRAPHIC SKEWNESS (Ski) ø	GRAPHIC KURTOSIS (Kg) ø
A1	2.89 Fine grained	0.42 Well sorted	-0.32 Positively skewed	0.76 Platykurtic
A2	3.13 Very fine grained	0.48 Well sorted	-0.21 Positively skewed	0.62 Very platykurtic
KP2	3.00 Fine grained	0.77 Moderately sorted	-0.01 Positively skewed	0.68 Platykurtic
KP3	2.96 Fine grained	0.80 Moderately sorted	0.46 Positively skewed	1.41 Leptokurtic
KP4	1.42 Medium grained	1.53 Poorly sorted	0.51 Positively skewed	0.95 Mesokurtic
G1	0.83 Coarse grained	1.59 Poorly sorted	0.50 Very Positively skewed	2.08 Very leptokurtic
G4	0.97 Coarse grained	1.61 Poorly sorted	0.68 Very positively skewed	1.72 Very leptokurtic
G5	1.86 Medium grained	1.32 Poorly sorted	0.36 Positively skewed	0.61 Very platykurtic
G6	1.62 Medium grained	1.30 Poorly sorted	0.30 Positively skewed	0.88 Platykurtic
G7	1.82 Medium grained	1.59 Poorly sorted	0.13 Positively skewed	0.91 Mesokurtic
G8	3.71 Very fine grained	0.67 Moderately sorted	0.28 Positively skewed	0.98 Mesokurtic
G12	2.95 Fine grained	0.81 Moderately sorted	-0.15 Coarsely skewed	0.56 Very platykurtic
G13	1.74 Medium grained	0.95 Moderately sorted	0.28 Positively skewed	0.62 Very platykurtic
G16	1.86 Medium grained	1.31 Poorly sorted	0.28 Positively skewed	1.68 Very leptokurtic
G19	0.89 Coarse grained	1.18 Poorly sorted	0.57 Very positively skewed	1.92 Very leptokurtic
R1	1.65 Medium grained	1.18 Poorly sorted	0.38 Positively skewed	1.68 Very leptokurtic
R3	0.77 Coarse grained	1.39 Poorly sorted	0.39 Positively skewed	1.03 Mesokurtic
R3	1.87 Medium grained	1.84 Poorly sorted	0.49 Positively skewed	0.66 Platykurtic
R4	1.68 Medium grained	1.15 Poorly sorted	0.39 Positively skewed	1.58 Very leptokurtic
R6	1.03 Medium grained	0.98 Moderately sorted	0.66 Positively skewed	1.33 Leptokurtic
R7	1.95 Medium grained	0.97 Moderately sorted	0.72 Positively skewed	2.55 Very leptokurtic
R8	1.74 Medium grained	0.93 Moderately sorted	0.36 Positively skewed	1.98 Very leptokurtic
R9	3.24 Very fine grained	0.48 Well sorted	-0.12 Negatively skewed	2.40 Very leptokurtic
R10	0.99 Coarse grained	0.67 Moderately sorted	0.35 Positively skewed	1.02 Mesokurtic
R11	0.99 Coarse grained	0.64 Moderately sorted	0.32 Positively skewed	2.39 Very leptokurtic
D3	3.17 Very fine grained	0.77 Moderately sorted	0.41 Positively skewed	1.92 Very leptokurtic
D4	1.95 Medium grained	1.48 Poorly sorted	0.55 Very positively skewed	0.73 Platykurtic
D5	2.79 Fine grained	1.15 Poorly sorted	0.17 Positively skewed	1.01 Mesokurtic
D6	1.78 Medium grained	1.29 Poorly sorted	0.43 Positively skewed	1.50 Very leptokurtic
D10	0.87 Coarse grained	0.98 Moderately sorted	0.65 Very positively skewed	1.57 Very leptokurtic
D11	3.85 Very fine grained	0.73 Moderately sorted	-0.09 Nearly symmetrical	0.86 Platykurtic
D13	2.81 Fine grained	0.67 Moderately sorted	0.27 Positively skewed	1.59 Very leptokurtic
D15	3.30 Very fine grained	0.61 Moderately sorted	0.41 Positively skewed	1.02 Mesokurtic
D17	2.95 Fine grained	1.21 Poorly sorted	0.24 Positively skewed	0.76 Platykurtic
D18	1.23 Medium grained	0.78 Moderately sorted	-0.07 Negatively skewed	12.14 Very leptokurtic
D19	1.39 Medium grained	0.98 Moderately sorted	0.28 Positively skewed	1.76 Very leptokurtic
D20	3.33 Very fine grained	0.48 Well sorted	-0.17 Positively skewed	0.56 Platykurtic
D21	1.99 Medium grained	1.22 Poorly sorted	0.30 Positively skewed	1.03 Mesokurtic

Probability plots

The different sand populations in a probability curve plot are of environmental significance. Such sand population members are characteristic of either fluvial, beach and wave zone. According to Visher's (1969) characterization: two sand populations are characteristic of fluvial settings; three sand populations are characteristic of wave zone bars; and four sand populations are characteristic of beach settings.

Cumulative probability distribution curves (Figs. 19, 20 and 21) of analysed samples tend to show two to three straight-line segments.

Sample displaying three-segment probability curves are: A1, A2, KP2, G9, G13, D3, D5, D13, D15 and D20. 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° – 42° that forms 0.2% - 10% of the distribution.

The samples characterized by two-segment probability curves are: KP3, KP4, G1, G5, G6, G7, G18, R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, D4, D5, D10, D17, D18, D19 and D20. They are characterized by:

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

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

A single segment curve is characteristic of G12 and it displays:

i) A well sorted suspension population with a slope of 63-68° that forms 75-77% of the distribution.

The probability population curve shows dominances of two sand population curves and this may suggest fluvial owing to the fact that there are no marine indicators in the investigated samples. According to Dike (1972) suggests that the three sand population curves are associated with the wave zone tide formed sand bars e. g. tidal delta, sub-tidal delta, near-shore and sand bars and shoals associated with tidal embayment, hence the three sand population plots is associated with marine environment.

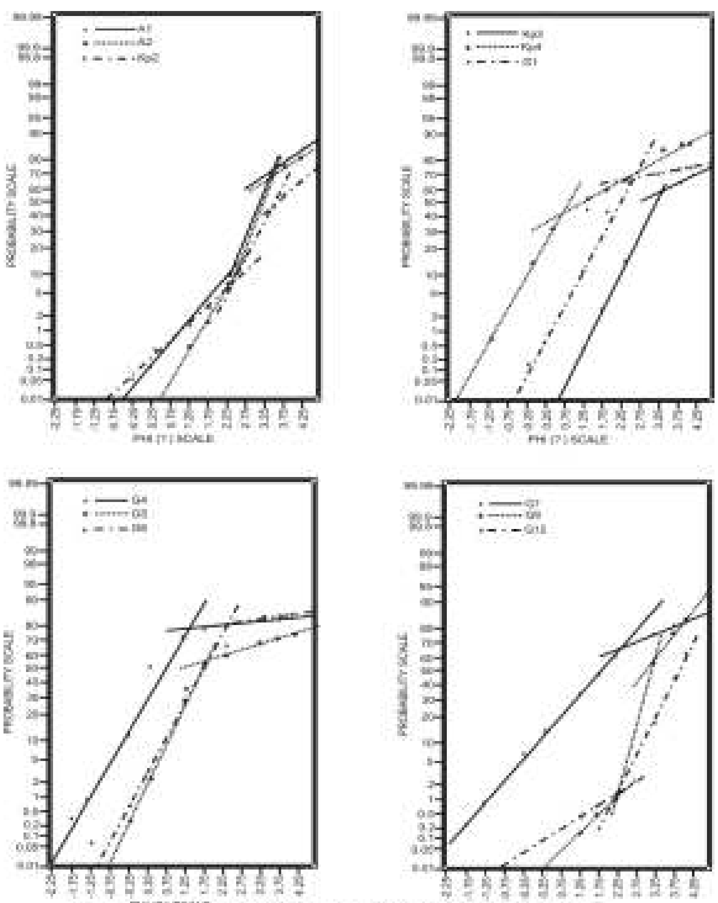

Fig.19 Probability curve plots for samples of Yolde Formation

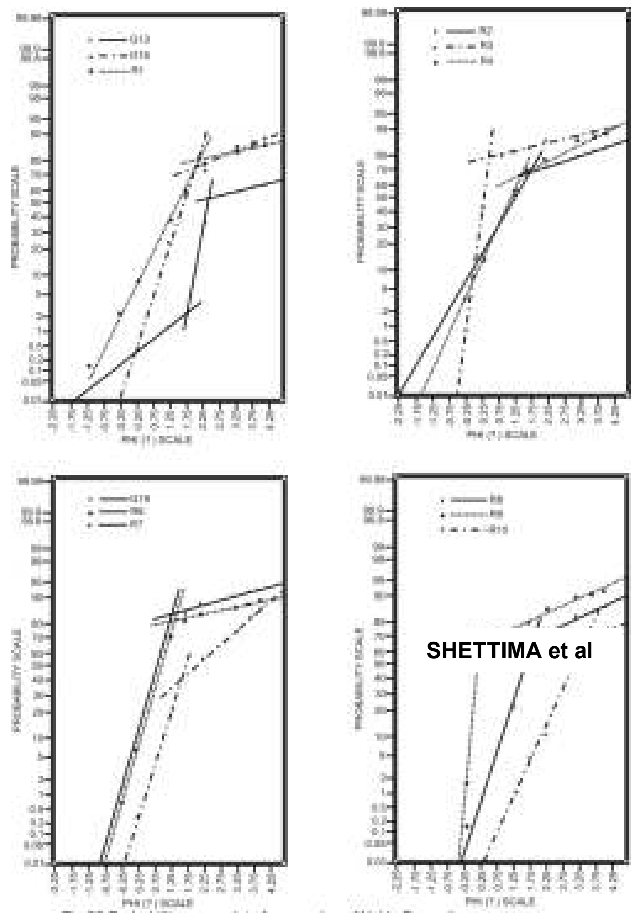

Fig.20 Probability curve plots for samples of Yolde Formation

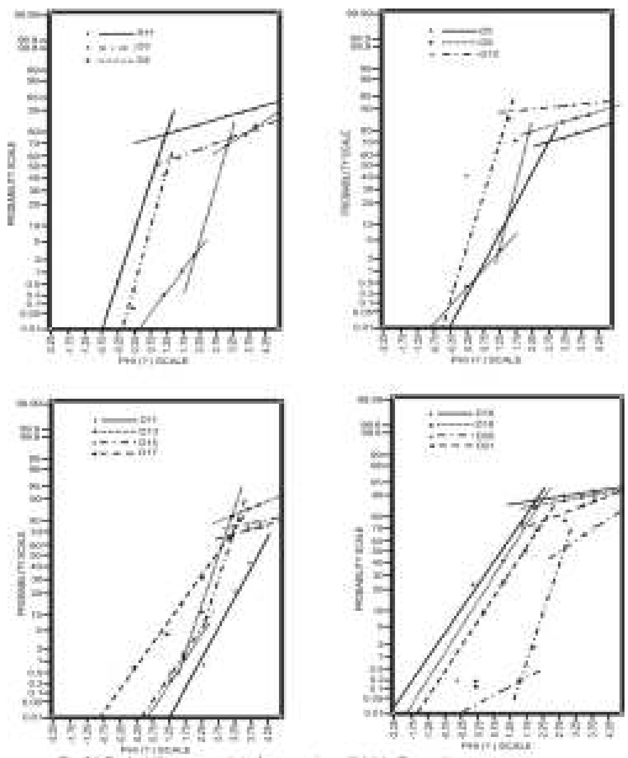

Fig.21 Probability curve plots for samples of Yolde Formation

Petrographic study

Twenty samples ranging from coarse to fine-grained sandstone were thin sectioned and subjected to petrographic studies. The sandstones consist mainly of quartz, feldspars and mica as framework elements with clay matrix and cements.

The framework composition of these sandstones is varied and is presented in (Table 2). The texture of these sandstones tends to show that sorting ranges from poorly to well sorted (1.0 – 0.4) but moderate sorting predominates (Table 2). The grain shape ranges from subangular to well rounded (0.2 – 0.5) with sub-angular dominating, and the sphericity varies from low-high (0.3 – 0.9) (Fig.17).

Quartz comprises an average of 73% of the framework grain of the sandstones. Some of the quartz grains exhibit straight extinction, while others show undulose extinction. Monocrystalline quartz is dominant, while polycrystalline quartz occurs in very few samples. The monocrystalline quartz grains range from fine to coarse-grains. Most of the quartz grains are characterized by various features such as dust lines, and quartz overgrowth (Fig.18).

Table 2. Summary of result from petrography analysis/studies

S/N	SAMPLE NO.	SORTING 1	ROUNDNESS 2	SPHERICITY 2	GRAIN FABRIC 3	FRAME WORK COMPONENT 4				
						Quartz (%)	Feldspar (%)	Mica (%)	Opaque (%)	Cement Matrix (%)
1	A1	Well sorted (0.4)	Subrounded (0.4)	0.9 (high)	Grain Supported	72	8	1	1	4
2	KP2	Moderately sorted (0.5)	Subangular (0.3)	0.4 (Low)	Grain Supported	70	10	1	1	3
3	KP3	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	68	10	1	1	5
4	KP4	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	65	12	1	2	4
5	G2	Poorly sorted (1.0)	Subangular (0.3)	0.3 (low)	Grain Supported	65	13	1	2	2
6	G4	Poorly sorted (1.0)	Subangular (0.3)	0.3 (low)	Grain Supported	67	10	-	1	4
7	G6	Poorly sorted (1.0)	Subangular (0.3)	0.2 (low)	Grain Supported	68	12	1	1	5
8	G7	Poorly sorted (0.3)	Subangular (0.3)	0.8 (high)	Grain Supported	65	15	-	2	5
9	G12	Well sorted (0.4)	Subrounded (0.4)	0.3 (low)	Grain Supported	70	8	-	1	4
10	G13	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	68	11	1	1	4
11	G19	Poorly sorted (1.0)	Subangular (0.3)	0.3 (low)	Grain Supported	65	15	-	2	3
12	R1	Poorly sorted (1.0)	Subangular (0.3)	0.3 (Low)	Grain Supported	70	8	-	1	4
13	R3	Poorly sorted (1.0)	Subangular (0.3)	0.6 (high)	Grain Supported	68	13	1	1	3
14	R6	Moderately sorted (0.5)	Subrounded (0.4)	0.9 (high)	Grain Supported	72	8	-	1	4
15	R7	Moderately sorted (0.5)	Subrounded (0.4)	0.9 (high)	Grain Supported	70	10	1	2	4
16	R8	Well sorted (0.4)	Well rounded (0.6)	0.9 (high)	Grain Supported	95	2	-	1	3
17	R9	Well sorted (0.4)	Rounded (0.5)	0.9 (high)	Grain Supported	95	3	-	1	2
18	R11	Well sorted (0.4)	Well rounded (0.6)	0.9 (high)	Grain Supported	96	2	-	1	2
19	D5	Moderately sorted (0.5)	Subrounded (0.4)	0.9 (high)	Grain Supported	70	8	1	1	4
20	D9	Moderately sorted (0.5)	Subangular (0.3)	0.7 (high)	Grain Supported	70	12	1	2	5
21	D10	Poorly sorted (1.0)	Subangular (0.3)	0.8 (high)	Grain Supported	72	10	1	1	3
22	D11	Moderately sorted (0.5)	Subangular (0.3)	0.7 (high)	Grain Supported	69	15	-	1	4
23	D13	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	73	10	-	2	3
24	D17	Well sorted (0.4)	Rounded (0.5)	0.9 (high)	Grain Supported	80	8	1	2	4
25	D20	Moderately sorted (0.5)	Subangular (0.3)	0.3 (low)	Grain Supported	62	15	1	2	5

1 – Estimates based on Folk (1972), 2 – Estimates based on Powers (1953), 3 – Estimates based on Swanson (1985), 4 – Estimates based on Terry and Chillinger (1955)

The next most abundant grains are feldspars (4% - 15%). The feldspars are generally quite distinct from the quartz grains because of their relatively low relief, cleavages and fractures. Seriticization of the feldspar is quite a common feature in most of the studied samples. Potassium feldspars dominate, followed by plagioclase feldspar.

Muscovite makes up to (1%) of the grains. The pore space fillers are generally cement and matrix. The matrix consist of ironoxides, brown stained sericite, very fine-grained silt size quartz, feldspars and mica.

Opaque minerals range between (1 – 2%) in the samples analysed and they are referred as detrital iron oxide, possibly magnetite.

Using Folk's (1954) sandstone classification, the Yolde sandstone range from subarkose to quartzarenite, and their textural maturity [based on Folk (1974)] ranges from submature to mature.

DISCUSSIONS

The lower interval

The lower interval of the Yolde Formation was only recorded at Gabukka stream section (Fig. 7) and it is composed of fining upwards cycles. These cycles are genetic facies succession characterized by massive sandstone facies fining upwards to claystones facies. The facies association of this basal section is similar to those described by Maill (1977) for his Bijou Creek-Type model of braided river system, hence these cycles may represent channel-overbank deposit of a braided river system. The probability plot for the samples of these fining upwards cycles shows two-sand population plot (Fig.20). Visher (1969) indicated that two-sand population curves are usually associated with fluvial processes, however, Dike (1972) suggested that it is usually associated with unidirectional currents, hence such plots can also be generated by tidal currents flowing dominantly in one direction. Since there are no any marine indicators observed in these cycles, the two-sand population curve may be due to fluvial currents further supporting the earlier braided river interpretation. In addition to this, petrographic studies indicated that the samples of this cycles are poorly sorted and are generally composed of subangular grains (Table 2), and granulometric analysis also yielded a poorly sorted and positive skewness for these samples (Table 1) and these data are usually associated with fluvial sands (Abdel-Wahab *et al.*,1992; Friedman, 1961, 1979).

The upper interval

The fining upwards cycles in the upper interval are only observed at Ruwan Kuka village section (Fig.4) and Gabukka stream section (Fig.7). The fining upwards cycles at Ruwan Kuka village section are composed of crossbeddded sandstone facies fining upwards to mudstones facies, and this may suggest distributary channel-overbank deposits. Owing to the occurrences of tabular crossbedded sandstones in these cycles which are usually associated with bar migration (Miall, 1977), the distributary channels may be that of a braided river system. The probability plot for the samples of these cycles display two-sand population curve (Fig.19) and this coupled with lack of marine indicators may suggest fluvial setting (Visher, 1969; Dike, 1972), hence, supporting the earlier interpretation. The results of petrographic and granulometric analysis are also confirming the earlier interpretation (braided river), because the sorting of the samples ranges from poor-moderate, generally positively skewed (Table 1) and the texture is generally subangular (Table 2), and these data are in consonances with (Friedman, 1961, 1979) data for fluvial sands. The facies of the upper fining upwards cycles at Gabukka stream section (Fig.7) are slightly different compared to those of Ruwan Kuka section because they are composed of parallel laminated sandstone facies fining upwards to shales and trough crossbeded sandstones to claystone facies. These were likewise interpreted as distributary channel-overbank deposits and are further supported by the poor-moderate sorting and positive skewness of their samples (Tables 1 and 2) and the two-sand population curve from their probability plots which are indicative of fluvial environment (Visher, 1969; Dike, 1972) (Fig.20).

The two basal coarsening upwards cycles observed at Ruwan Kuka village are quite distinct from those of the other sections owing to their thicker mudstone and thinner crossbedded sandstones facies. Considering the lithofacies associations and their relative position with respect to the overlying interpreted fining upwards cycles (distributary channel-overbank deposits), these cycles may represent crevasse-splay deposits. Crevasse-splay deposits are usually associated with unidirectional currents because they form in a fluvial dominated environments and the probability plot for the samples of the coarsening upwards cycles are usually in consonances with it, because it yielded two-sand population curve which is associated with fluvial currents (Visher, 1969; Dike, 1972) (Fig.19). These interpretations may be further confirmed by the poor sorting and subangular grains observed from petrographic analysis (Table 2) and poor sorting and positive skewness from granulometric analysis for their samples, because these results with the lack of marine indicators are signatures to fluvial setting (Friedman, 1961, 1979).

The coarsening upwards cycle observe at top most part of Ruwan kuka section and those of Kworin Gora, Gabukka and Doma streams sections (Figs. 4, 5, 7 and 8) respectively, are quite typical of deltaic setting. At Ruwan kuka (Fig.4) the coarsening upwards cycle is defined by interbedded fine grained sandstones and mudstones facies at the base to tabular crossbedded sandstones facies with *Planolites* and this may suggest delta slope sandstone and mudstones passing upwards to delta front sands. This suggestion is supported by the moderately sorted and sub-rounded texture of its samples (Table 2). The probability curve plot indicated a two sand population curve and this coupled with the texture may suggest a tidal influence. At Kworin gora (Fig.5), the succession in the coarsening upwards cycle may suggest case where a delta front sand having a massive and parallel laminated sandstone with well sorted sands displaying three sands population curve indicating wave influences (Visher,1969; Dike, 1972) is being prograded by a distributary channel deposit typified by the poorly sorted positively skewed trough crossbedded sandstone (Table 1) facies having an erossional base and it is characterized by two sand population curve (Fig.19) indicating fluvial influence (Visher, 1969; Dike, 1972). At Gabukka stream (Fig.7), the coarsening upwards cycle is defined by a shale at its base passing upwards to a succession of parallel laminated, planar crossbedded and massive sandstones facies and this may suggest a prodelta shales passing upwards to delta front sands. The setting under which this deltaic environment was formed may largely be fluvial as indicated by two sand population curve obtained from the probability distribution plots (Fig.20). Though, one sample indicated three sand population curve which is associated with wave processes (Visher,1969; Dike,1972), but, since the sample have generally indicated moderate sorting, subangular and positive skewed grains (Tables 1 and 2), these sediments may have been deposited by fluvial currents (Friedman, 1961,1979). At Doma stream (Fig.8), the first coarsening-upwards cycle may suggests a delta slope sands and clays passing upwards to delta front sands. The probability plot for samples of this cycle indicates both two and three sand population curves which are consistent with wave and fluvial or tidal processes (Fig.19). The three sand population curve is restricted to the delta slope part of the cycle and the two population curve is associated with the trough cross-bedded sandstone facies of the delta front sand which has a sharp erosional base. This coarsening-upwards cycle may represent a case where a distributary channel is cutting across a delta front sand and owing to this, the two sand population curve associated to fluvial currents because there are no marine indicators associated with it. Both petrographic and granulometric studies for samples of this cycle indicated moderately sorted sands (Tables 1 and 2) and they are generally positive skewed. Positively skewed sand are associated with fluvial setting (Friedman, 1979), hence, sediments forming this cycle where dominantly source from fluvial environment. The second, third and forth coarsening-upwards cycles may also represent transitions from delta slope sand and clay to delta front sands. The probability curve plots of these cycles display both two and three sand population curves with the latter dominating especially in the delta slope sands and the former in the delta front sands. The samples of the delta slope areas are well sorted and associated with three sand population curve indicating influence of wave activities, while that of the delta front sands consists of moderate sorting and two sand population curve which are indicative of fluvial setting (Visher, 1969; Dike, 1972), hence, this delta is prone to wave and fluvial dynamic processes.

Some of the facies associations have not given rise to fining or coarsening upwards cycles, however, they are quite definitive enough for environmental interpretation. At Ashaka stream section (Fig.6), the succession of massive sandstone and parallel laminated sandstone facies having mudrapes along bedding surfaces associated with thin mudstones facies may possibly be a washover fans and lagoonal mud. The well sorted sands that are negatively skewed (Tables 1 and 2) coupled with wave influenced three sand population curve (Fig.19) may support this interpretation because washover fans are formed from orthoquarztose sands of the beach foreshore and backshore which are well sorted owing to wave activities. The upper part of the Gabukka stream section (Fig.7) dominated by thick interbeds of fine grained sandstones and mudstones facies was interpreted as generally coastal but, it may probably represent tidal flat setting, while the upper part of the Ruwan Kuka section (Fig.4) consisting of planar crossbedded sandstones and massive sandstones facies which are moderately to well sorted with rounded grains (Tables 1and 2) associated with two sand population curve (Fig.20) were interpreted as coastal sands. Though, there are no marine indicators, but the negative skewness of the samples may suggest that the winnowing of the sandstone may be due to tidal currents. The sandstones and claystones facies of the upper part of the Doma stream section likewise does not fit into any known facies model, however, considering the presences of marine indicators like reactivation surfaces, limestone, *Ophiomorpha* trace fossils (Fig.16), ripple lamination moving into wavy laminations as well as three sand and two sand population curve indicative of wave and fluvial activities respectively (Visher, 1969; Dike, 1972) (Fig.21), coupled with well sorted and well rounded grains which are mostly negatively skewed in them, a broader coastal environment was suggested for them (Fig.8).

CONCLUSION

From this present study, the facies and facies architecture of five major sections of the Yolde Formation in the Gongola Basin of the Upper Benue Trough have been analysed. The dominant lithologic types are an association of very fine-fine-medium-coarse grained sandstones which are dominantly sub-arkose with few quartzarenite, interbedded fine grained sandstones and mudstones, shales and few limestones occurring towards the upper part.

The facies and facies architecture of the lower part of the Yolde Formation is defined by fining upwards cycles consisting of succession of massive beds of sandstone fining upwards to thin claystone and it is interpreted as sequences of a fluvial deposit formed from braided river system as indicated by (Miall, 1977) from his Bijou-Creek-Type model of braided river system.

The facies and facies architecture of the upper part of this formation is defined by (i) fining upwards cycle of sandstone to claystone interpreted as delta plain distributary channel-overbank deposits : (ii) coarsening upwards cycle of mudstones to sandstones and are interpreted as crevasse-splay deposits in an interdistributary bay fill and (iii) coarsening upwards cycle of claystone-sandstone or interbedded sandstones and mudstones-sandstone which were interpreted as delta front sandstones on pro-delta claystone or delta front sandstones on pro-delta claystones.

Though some facies associations have not given rise to fining or coarsening upwards cycles, but they are quite definitive enough for interpretation. The upper part of the Gabukka section dominated by thick interbeds of fine grained sandstones and mudstones was interpreted as generally coastal but, it may probably represent tidal flat setting, the upper part of the Ruwan Kuka section was interpreted as coastal sands and while the upper part of Doma stream section consisting of marine indicators like reactivation surfaces, limestone and *Ophiomorpha* trace fossils, a broader coastal environment was suggested for them.

Hence, the Yolde Formation is interpreted to have been deposited in fluvial (braided river) to transitional (deltaic, barrier island, tidal flat and coastal plain of alluviation) environments.

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