SEDIMENTOLOGY AND PALEOENVIRONMENT OF DEPOSITION OF YOLDE FORMATION OF THE GONGOLA BASIN (UPPER BENUE TROUGH, NIGERIA): DEDUCED FROM GRAIN SIZE DISTRIBUTION

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Abstract

The Yolde Formation is composed of sandstones, siltstones, mudstones, claystones, shales and minor limestones. These lithlogic units display a wide variety of colours ranging from brown, buff variegated colours indicating deposition in an oxidizing environment. Granulometric analysis showed that the sediments are dominantly moderately sorted and are mostly positively skewed. The bivariate plots of standard deviation vs. mean, standard deviation vs. skewness, standard deviation vs. first percentile, mean vs. first percentile and C-M pattern showed a dominance of fluvial environment. However, that of mean vs. first percentile indicated a prevalence of coastal environment. The probability curve plots show a dominance of two-sand population curves, indicating a prevalence of unidirectional currents. Paleocurrent analysis has shown that the Yolde Formation has a dominant source from the north-eastern direction, but with very minor contributions from the northwest.

Keywords: Yolde Formation, Sedimentology, Provenance

Introduction

This research focusses on the determination of the paleoenvironment of the Yolde Formation by using sedimentological parameters which include grain size, sorting, skewness, kurtosis and associated bivariate plots, and where possible ichnofossils are also used to support the interpretation of the sedimentological data.

Depositional environments control textural parameters such as size, sorting, packing, fabric, shape and roundness. Grain shape and roundness are controlled primarily by provenance and transport history respectively (Pettijohn et al, 1987). Packing is controlled by grain shape and locally by environmental factors such as energy dissipation and productivity for rapid loading. Particle size and sorting (including detrital clay content) are controlled by factors such as average energy levels, rate of dissipation of high energy, maximum energy level, fluctuation in energy level and level of biogenic activity and climatic conditions (Boggs, 2006). These textural elements of environmental significances were employed in establishing bivariate plots for environmental analysis.

Yolde Formation is a transitional marine unit that conformably overlies the Bima Sandstone in all the three arms of the Upper Benue Trough (Dike, 2002). It consists largely of alternation of coarse, medium and fine grained sandstones which are usually cross-bed, ripple marked or massive bedded. Mudstones, claystones, grey to greenish shales and thin limestone or calcareous sandstones are also assoiated (Carter *et al*., 1963; Allix, 1983; Zaborski *et al*., 1997; Shettima, 2005).

Geologic and stratigraphic setting

The Benue Trough is a major NE-SW trending rift basin of 50 – 150 km width. It extends for over 1000 km (Nwajide, 2013), 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 to Tertiary sediments associated with volcanic (Abubakar, 2006). It is geographically sub-divided into lower, middle and upper portions (Fig. 1). The trough was believed to have been formed from extensional process during Late Jurassic to Early Cretaceous break-up of the continents of Africa and South America (Grant, 1971), but Benkhelil (1989) suggested sinistral wrenching as the tectonic processes responsible for its evolution.

The Upper Benue Trough is Y shaped made of three arms, namely: the E – W trending Yola Arm, N – S trending Gongola Arm or Gongola Basin and the NE – SW trending main arm (Muri – Lau Basin) (Dike, 2002) (Fig. 2).

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 the upper Bima (B3). Its lithology and depositional environments have been discussed by (Carter *et al*., 1963; Allix, 1983; Guiraud, 1990) (Fig. 3).

The Yolde Formation lies conformably on the Bima Sandstone. This formation of Cenomanian age (Lawal and Maullade, 1986) represents the beginning of marine incursion into the Gongola Arm. The Yolde formation was deposited in a barrier-island and deltaic settings (Shettima, 2005; Abubakar *et al*., 2006).

The Turonian-Santonian Pindiga Formation conformably overlies the Yolde Formation (Popoff *et al*., 1986; Zaborski *et al*., 1997). Its lower part is laterally equivalent to the Gongila Formation whereas its upper part ties up with the Fika Shales and they represent a full marine incursion into the Gongola Arm. Shttima *et al*., 2018

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).

Methodology

Sampling was carried out from outcrops by digging a trench of about 2 ft so as to avoid weathered horizons. Thirty eight sandstone samples were collected from outcrop sections of the Yolde Formation for this studies as shown on (Fig.4). Granulometric analysis was carried out using the conventional method of Folk and Ward (1957) and about 200g of each sample was sieved for about 30 minutes in a Ro-Tap shaker. The graphical parameters such as graphic mean, standard deviation, skewness and kurtosis were determined using the formula of Folk and Ward (1957). The bivariate plots of Friedman (1961, 1967 and 1979), Moiola and Weiser (1968) and Passega and Bryramjee (1969) were used to interprete the paleoenvironments of all the analysed sandstone samples. The log probability curve of grain size distribution of the analysed samples based on Visher (1969) and Dike (1972) were also plotted.

Two hundred and eighty-eight (288) measurements were taken from both declination (azimuth) and inclination of foreset planes. The obtained data were corrected for tilt so as to restore the deformed strata to its original position. The data is then grouped into appropriate class intervals from which current rose diagrams are constructed for the paleocurrent direction of Yolde Formation.

Univariate Grain Size Parameters: Graphic Mean

The graphic mean grain size for the various samples (Table 1) range from (0.63 Φ – 3.85 Φ) i.e. (very fine to coarse grained sandstone) with an average of 2.04 Φ (fine grained sandstone), the values tends to frequently fluctuate reflecting change in the strength of the depositing medium.

Generally, the values of the graphic mean shows that samples from Ashaka stream section (Fig.5) range from very fine to fine grained sandstone, samples from Kwarin Gora stream section (Fig.6) range from very fine - medium grained sandstone, samples from Gabukka stream section (Fig.7), range from very fine – coarse grained sandstone while samples from Ruwan Kuka section, (Fig.8) and Doma stream section (Fig.9) have the same range with that of Gabukka stream section (i.e. fine – coarse grained sandstones).

The mean size of grains 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 values of standard deviation (Table 1) tend to show well sorted (0.42 Φ) to poorly sorted (1.61 Φ) with an average of (1.03 Φ) which implies that the whole formation is poorly sorted.

Generally, the well to poorly sorted nature of the sandstone tends to imply that the transportation agent responsible for the deposition must have been in different phases possibly prolonged, quick and rapid or can be suggestive of long or short distance of transportation and the nearness of the sediment source. Most of the samples studied are in harmony with the data.

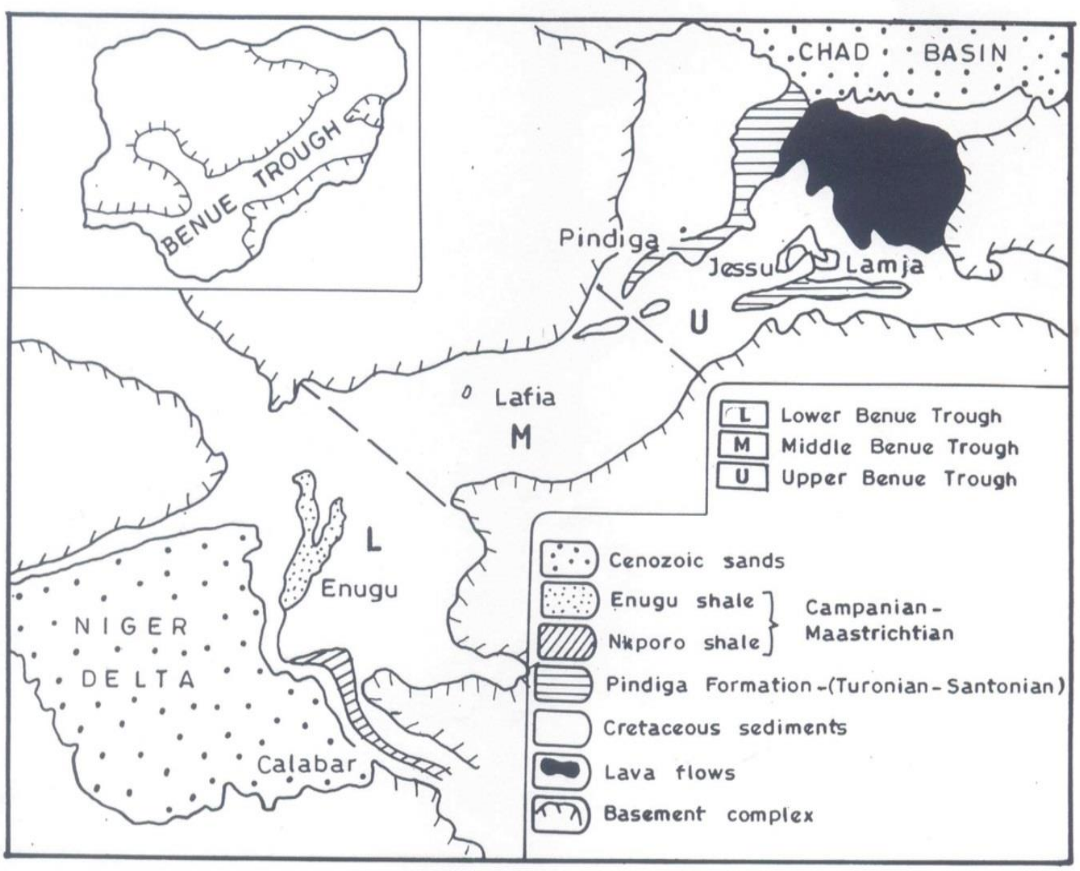


Fig. 1 Geographical subdivision of the Benue Trough (after Obaje and Lingoius, 1996)

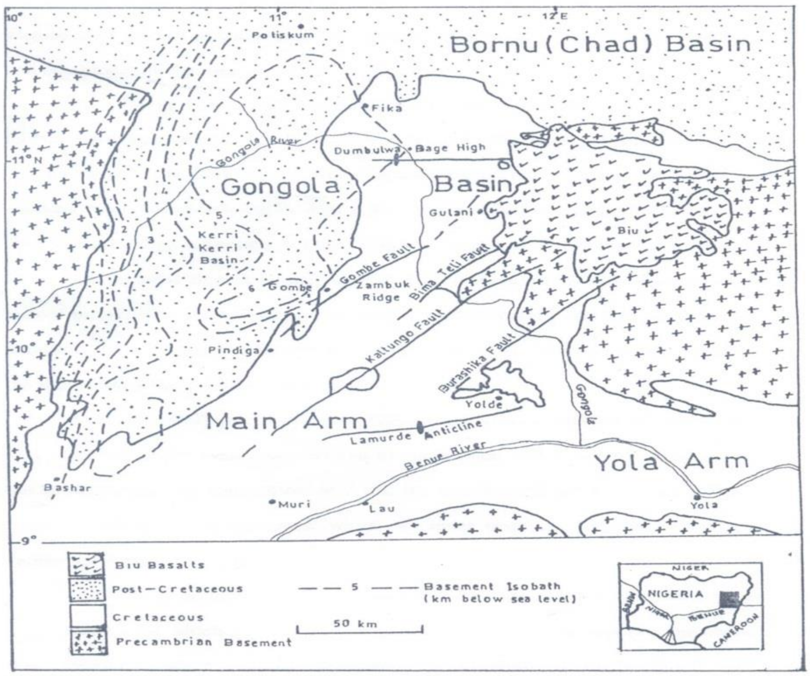


Fig. 2 Geological map of the Upper Benue Trough (after Zaborski, et al., 1997)

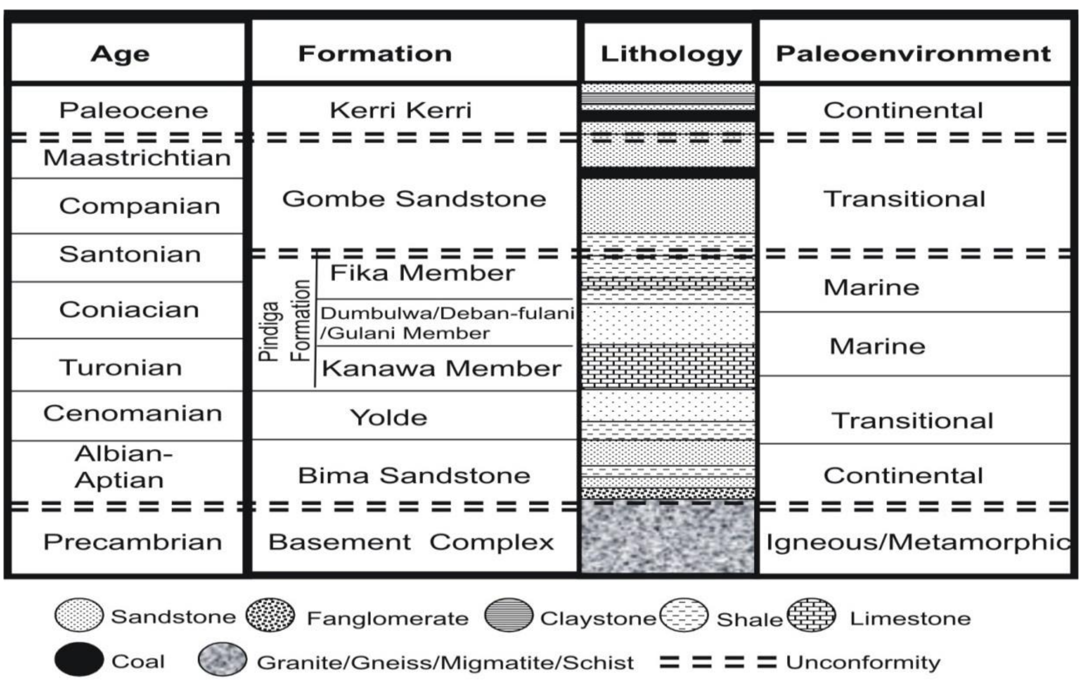


Fig.3 Stratigraphy of Gongola Basin (modified from Zaborski et al.,1997)

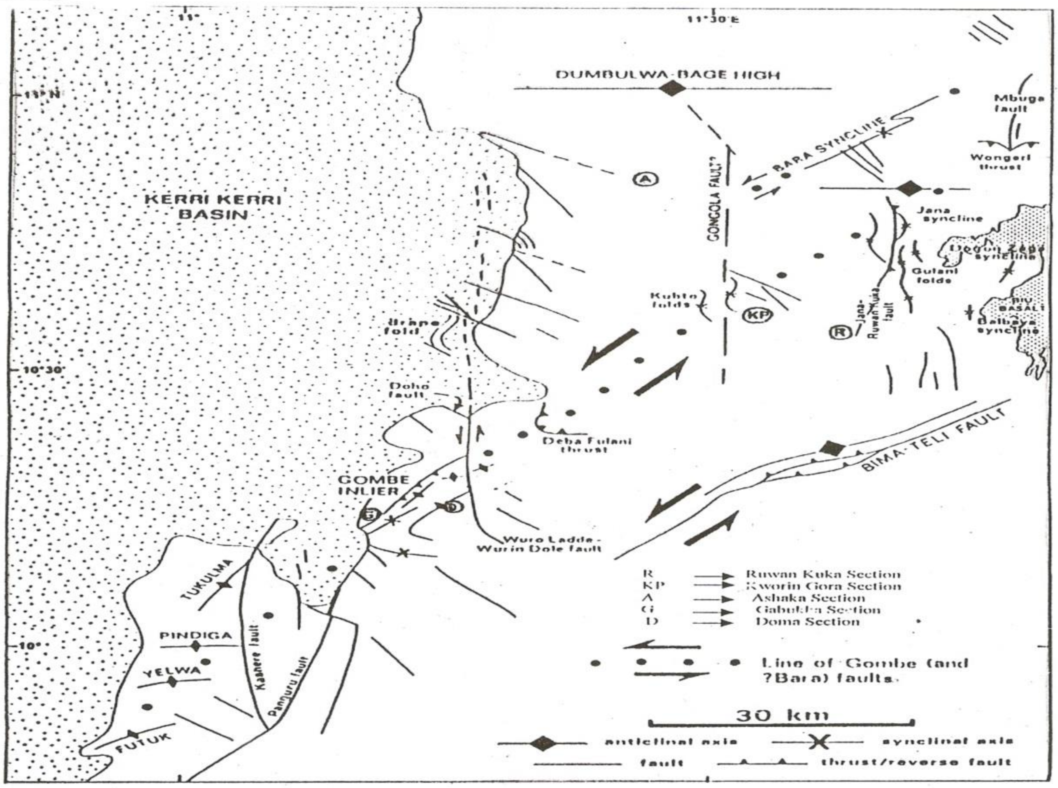


Fig.4 Map showing study locations and structural features of the Gongola Basin (modifeid from Zaborski et al.,1997)

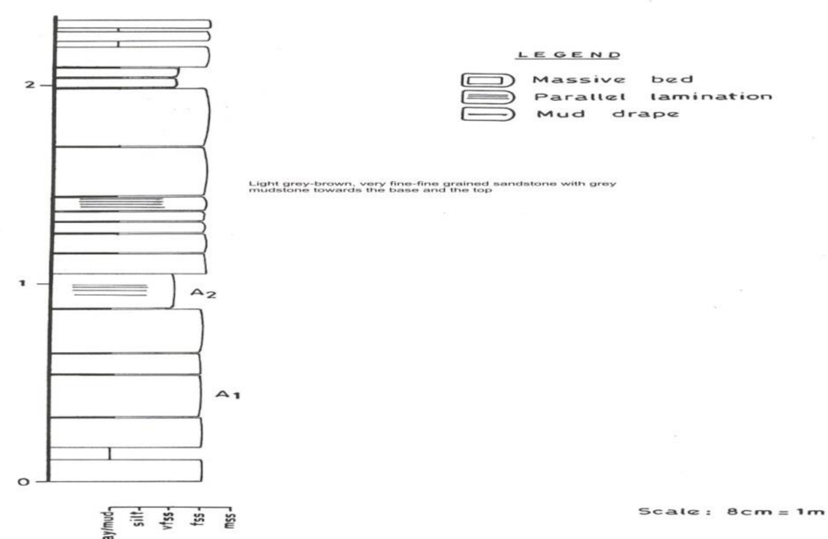


Fig.5 Section of Yolde Formation at Ashaka stream

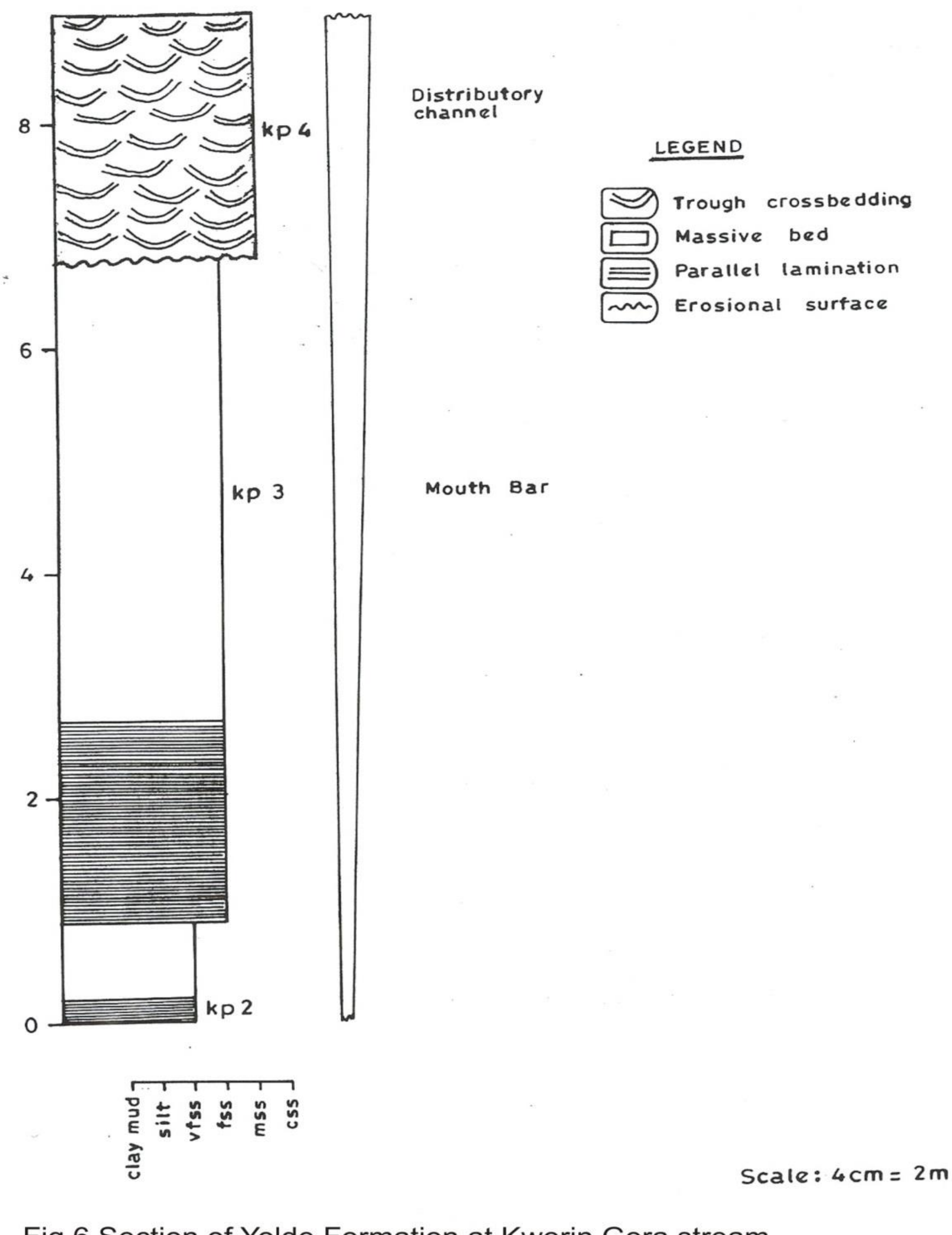


Fig.6 Section of Yolde Formation at Kworin Gora stream

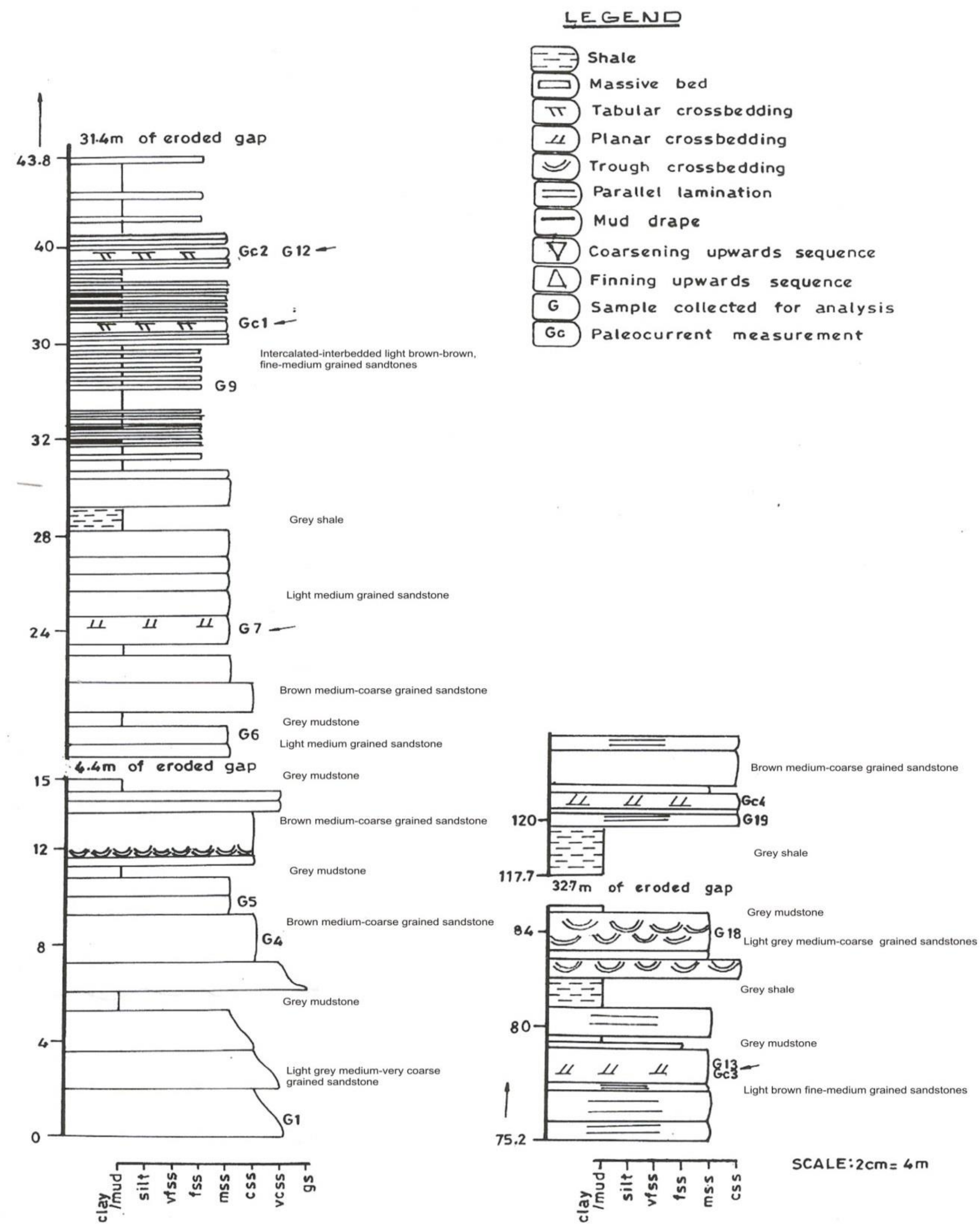


Fig.7 Section of Yolde Formation at Gabukka stream

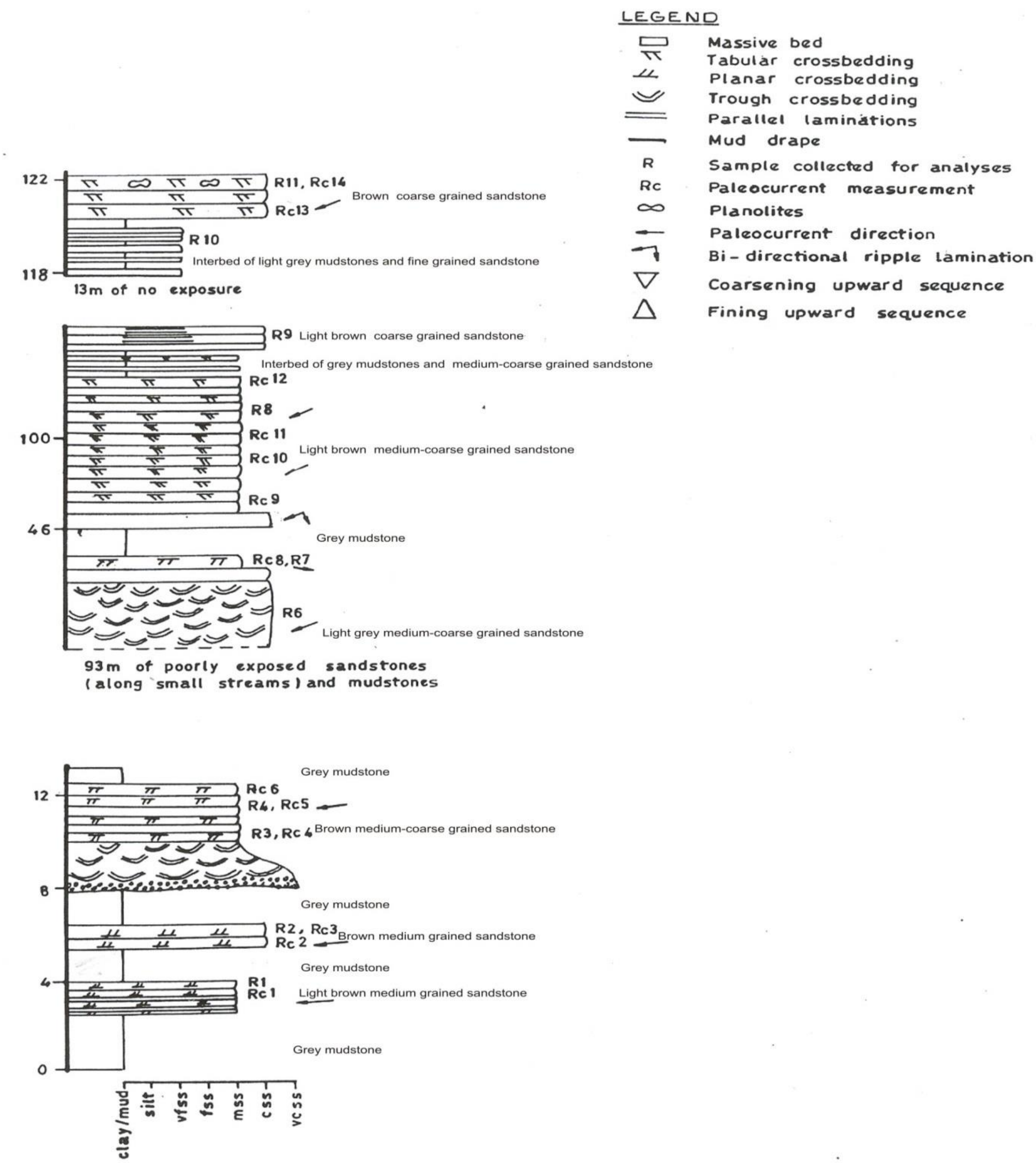


Fig.8 Section of Yolde Formation at Ruwan Kuka Village

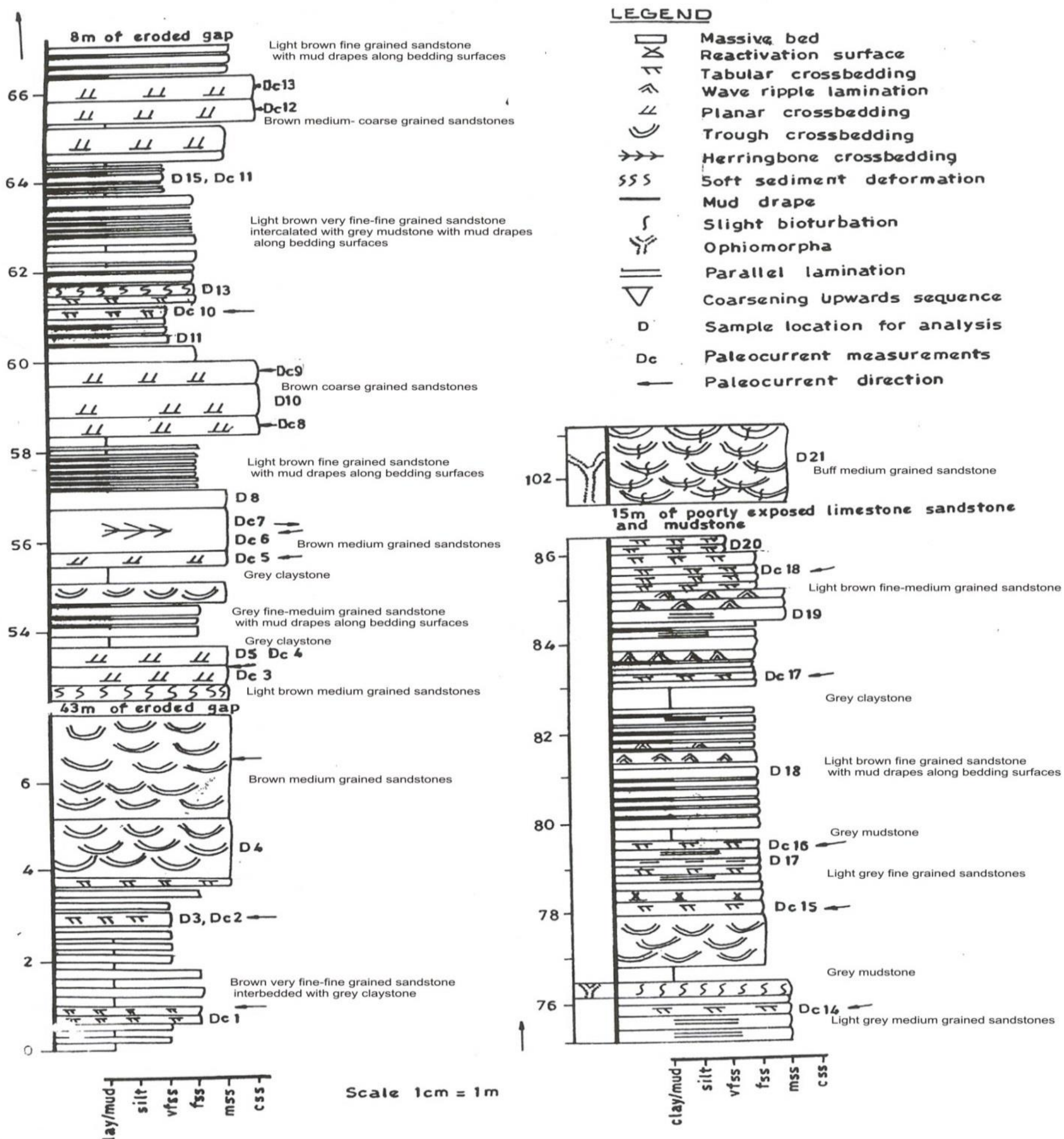


Fig.9 Section of Yolde Formation at Doma stream

obtained by Friedman (1967) and Abdul-Wahab (1988) for fluvial sands.

Inclusive Graphic Skewness (Ski)

The samples analysed have skewness values ranging from (-0.32 to 0.80Φ) 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 are not removed by current. Such reflects fluvial origin and this is in agreement with data of many workers (Friedman, 1961, 1967; Agumanu, 1993).

Inclusive Graphic Kurtosis (Kc)

The values of kurtosis (Table 1) for the various samples range from (0.56Φ – 2.55 Φ) indicating (very platykurtic to very leptokurtic), with an average of 1.32Φ (leptokurtic). Little geologic information can be derived from values of kurtosis (Pettijohn *et al*, 1987), but, the data agree largely with fluvial sand (Abdel-Wahab, 1988).

Bivariate Grain Size Parameters:

Mean Versus First Percentile

The standard plot of mean versus first percentile was based on the work of Friedman (1979) which was used in distinguishing lnland dune sand from river sand (Fig.10). The plots for the sample tends to show that 18.4% of the samples fell into the river sand environment, while 81.6% plotted into the inland dune sand environment.

Standard Deviation versus First Percentile

Friedman (1979) likewise developed this bivariate plot to distinguish river sands from inland dune sand (Fig.11). The plots indicate that 53% of the samples plotted within the river field sand while 47% of the samples plotted within the inland dune sand field.

Standard Deviation versus Skewness

The bivariate plots of standard deviation versus skewness are based on the work of Friedman (1961, 1967, 1979) and Moiola and Weiser (1968). The plot of Friedman (1961) tends to show the distribution of samples between the field of beach and fluvial environment. 83.9% fell into the river field while 16.1% fell into beach field (Fig.12). Friedman (1967, 1979) likewise show distribution of sand between river and beach environment. For Friedman (1967), 76% of the sample fell into the river field environment while 24% belong to the beach environment (Fig.13). The plots based on Friedman (1979) shows that 88.3% of the samples plotted within the river field environment while 11.7% plotted within the beach environment (Fig. 14). The plots of Moiola and Weiser (1968) also helps to separate river sand from beach sands and it tends to show that 88.9% of the studied samples plotted within the river field environment while 11.14% fell into the inland dune sands environment (Fig. 15).

Standard Deviation Versus Mean Size

The Moiola and Weiser (1968) plots of standard deviation versus mean size is used in delineating dune sand from river sand and all of the studied sample plotted within the river field environment (Fig.16).

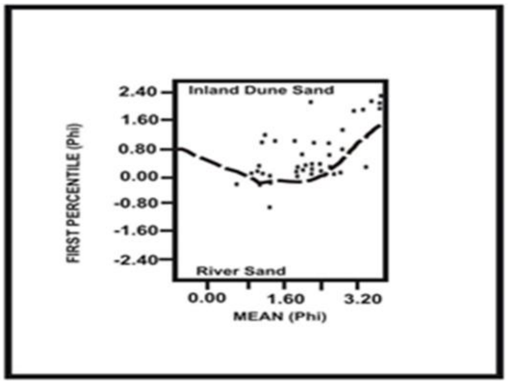


Fig.10 Bivariate plot of First percentile vs. Mean (after Friedman,1979)

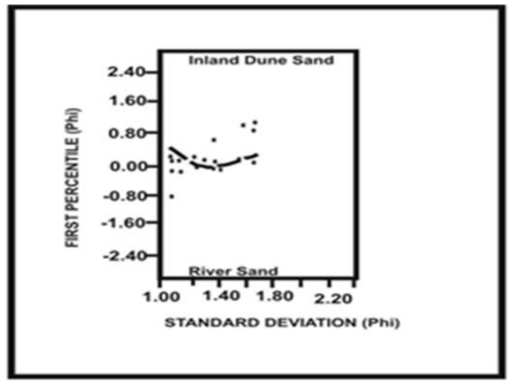


Fig.11 Bivariate plot of First percentile vs.Skewness (after Friedman,1979)

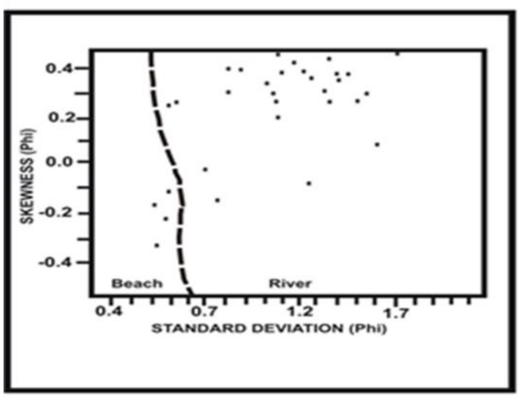


Fig.12 Bivariate plot of Skewness vs. Standard deviation (after Friedman,1961)

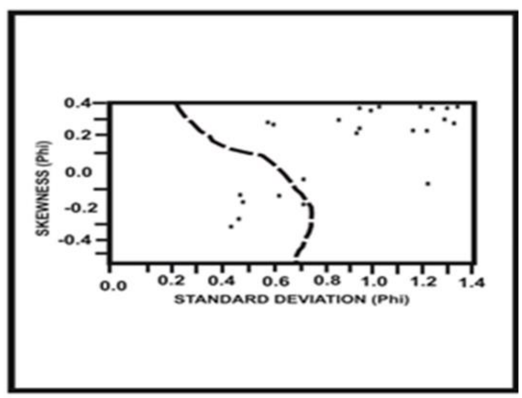


Fig.13 Bivariate plot of Skewness vs. Standard deviation (after Friedman,1967)

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

SAMPLE NO.	GRAPHIC MEAN (Mz) Φ	GRAPHIC STANDARD DEVIATION (SORTING)	GRAPHIC SKEWNESS (Ski) Φ	GRAPHIC KURTOSIS (Kc)Φ
A1	2.99 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	0.88 Platykurtic
KP3	2.98 Fine grained	0.86 Moderately sorted	0.46 Positively skewed	1.41 Leptokuritic
KP4	1.42 Medium grained	1.59 Poorly sorted	0.31 Positively skewed	0.95 Mesokuritic
G1	0.63 Coarse grained	1.09 Poorly sorted	0.50 Very Positively skewed	2.04 Very leptokuritic
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	1.82 Medium grained	1.26 Poorly sorted	0.30 Positively skewed	0.80 Platykurtic
G7	1.82 Medium grained	1.59 Poorly sorted	0.10 Positively skewed	0.91 Mesokurtic
G9	3.71 Very fine grained	0.67 Moderately sorted	0.26 Positively skewed	0.98 Mesokurtic
G12	2.95 Fine grained	0.61 Moderately sorted	- 0.15 Coarsely skewed	0.58 Very platykurtic
G13	1.74 Medium grained	0.95 Moderately sorted	0.28 Positively skewed	0.62 Very platykurtic
G18	1.88 Medium grained	1.31 Poorly sorted	0.28 Positively skewed	1.69 Very leptokurtic
G19	0.89 Coarse grained	1.18 Poorly sorted	0.57 Very positively skewed	1.92 Very leptokurtic
R1	1.88 Medium grained	1.18 Poorly sorted	0.39 Positively skewed	1.60 Very leptokutic
R3	0.77 Coarse grained	1.39 Poorly sorted	0.39 Positively skewed	1.03 Mesokurtic
R3	1.87 Medium grained	1.64 Poorly sorted	0.49 Positively skewed	0.86 Platykurtic
R4	1.88 Medium grained	1.15 Poorly sorted	0.39 Positively skewed	1.56 Very leptokurtic
R6	1.03 Medium grained	0.98 Moderately sorted	0.80 Positively skewed	1.33 Leptokurtic
R7	1.05 Medium grained	0.97 Moderately sorted	0.72 Positively skewed	2.55 Very leptokurtic
R8	1.74 Medium grained	0.93 Moderately sorted	0.38 Positively skewed	1.56 Very leptokurtic
R9	3.24 Very fine grained	0.49 Well sorted	-0.12 Negatively skewed	2.40 Very leptokurtic
R10	0.99 Coarse grained	0.97 Moderately sorted	0.35 Positively skewed	1.02 Mesokurtic
R11	0.99 Coarse grained	0.84 Moderately sorted	0.32 Positively skewed	2.39 Very leptokurtic
D3	3.17 Very fine grained	0.77 Moderately sorted	0.41 Positively skewed	1.62 Very leptokurtic
D4	1.98 Medium grained	1.49 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
D8	1.78 Medium grained	1.25 Poorly sorted	0.43 Positively skewed	1.50 Very leptokurtic
D10	0.67 Coarse grained	0.99 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	3.26 Very fine grained	0.91 Moderately sorted	0.41 Positively skewed	1.02 Mesotokurtic
D17	2.98 Fine grained	1.21 Poorly sorted	0.24 Positively skewed	0.76 Platykurtic
D18	1.23 Medium grained	0.79 Moderately sorted	-0.07 Negatively skewed	12.14 Very leptokurtic
D19	1.38 Medium grained	0.98 Moderately sorted	0.26 Positively skewed	1.78 Very leptokurtic
D20	3.33 Very fine grained	0.46 Well sorted	-0.17 Positively skewed	0.56 Platykurtic
D21	1.98 Medium grained	1.22 Poorly sorted	0.35 Positively skewed	1.03 Mesokurtic

Note. A- Ashaka stream; KP- Kworin Gora stream; G –Gabukka stream; R –Ruwan Kuka stream; D –Doma stream

The plot of standard deviation versus mean size based on Friedman (1979) tends to show that 28.9% of the sands fell into the river sand field, while 71.1% fell into the inland dune sand (Fig.17).

The C-M Pattern

The C-M pattern was introduced by Passega (1957) in an attempt to establish the relationship between texture of sediments and processes of deposition. The C represents one percentile (Φ_1) diameter (in microns), and M is the fifty percentile (Φ_{50}) and it is also (in microns). The values of C and M was determined from the cumulative curve of individual samples in table 1 (in phi scale), and the values are converted to microns using the Wentworth (1922) grade scale. Logarithmic scale is normally used for the construction of C – M pattern (Fig.18).

Passega and Byramyee (1969) divided the basic C-M pattern into nine classes each reflecting a certain mode of transportation (rolling, sliding, graded suspension or saltation and uniform suspension). The samples plotted on the C-M diagram tend to occupy classes I, II IV, V, and VI. The first class suggests transportation by sliding, while the rest represents transportation by graded suspension or saltation and uniform suspension.

Passega (1957, 1964) has shown that the C-M diagram can be subdivided by points (N, O, P, Q. R and S) into segments that correspond to a particular sedimentation mechanism. The NO segment represents a deposit formed mostly by rolling, OP segment represents a mixture in variable proportion of rolling grains and suspension, where the values of C are generally higher than 800µm. Segment PQ corresponds to suspended sediment, segment QR represents deposit formed by graded suspension (saltation) and RS represents deposit formed by uniform suspension. All the investigated samples tend to occupy all the segments.

The scattered distribution pattern displayed by the investigated samples on the C-M diagram within the various fields of rolling, saltation (graded suspension) and uniform suspension tends to largely resemble that proposed pattern for flood plain and channel deposits.

Probability Plots:

The different sand populations in a probability curve plot are of environmental significance (Moss, 1965; Visher, 1969; Dike, 1972b; Reineck and Singh, 1980). Such sand population members are characteristic of fluvial, beach, wave zone. According to Visher (1969), characterization of two sand populations are characteristic of fluvial setting; three sand populations are characteristic of wave zone bars; four sand populations are characteristic of beach setting.

Cumulative probability distribution curves (Fig.18, 19 and 20) of analysed samples tend to show two to three straight line segments.

Samples displaying three segments probability curve 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^o – 42^o that forms 0.2% - 10% of the distribution.

The samples characterized by two segments probability curve 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^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.

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

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

The probability population curves shows a dominance of two population curve and this may suggest fluvial setting owing to the fact that there are no marine indicators in the investigated samples. Dike (1972b) suggested that three sand population curves are associated with wave zone/tide form sands bars e.g. tidal delta, sub tidal delta, nearshores sands bars and shoals associated with tidal embayment, hence, the three sand population plots is associated with marine environment.

Paleocurrent Analysis:

Studies on paleocurrent direction usually allow for the reconstruction of the current direction through which the basin received its sediments. In this research, measurements of azimuth of cross-beddings were used in the construction of the paleocurrent direction. The beds range in thickness from 20cm to 80cm and striking at an angle 336^o to 028^o. The beds usually dip between 15^o to 28^o and the cross-beddings dip at an angle of 13^o to 27^o. The azimuths of crossbeds were subjected to tilt correction because the tectonic dip exceeded (10^o).

Generally, the current rose diagram gives an overall idea of the paleocurrent direction, while the vector mean is used to measure the average flow direction. The vector mean is determined by computing the summation of the sine and cosine for each direction of the azimuth orientation (Fig.21) and the mean is the arc tan of the resulting tangent.

In analyzing the azimuth directional data, the dispersion of the data is given by the vector magnitude, and it is also known as the consistency ratio (Lindholm, 1987). High value usually indicate high dispersion and in this analysis the vector mean for the Yolde Formation is 65.48, while the vector magnitude stands at 90.45 (Fig. 22).

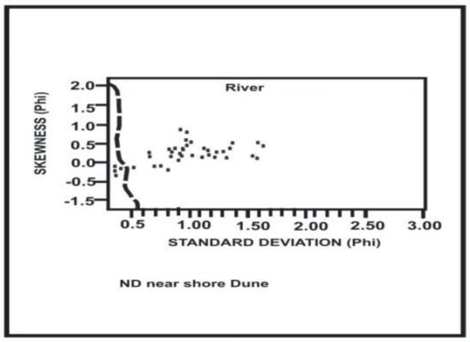


Fig.14 Bivariate plot of Skewness vs. Standard deviation (after Friedman,1979)

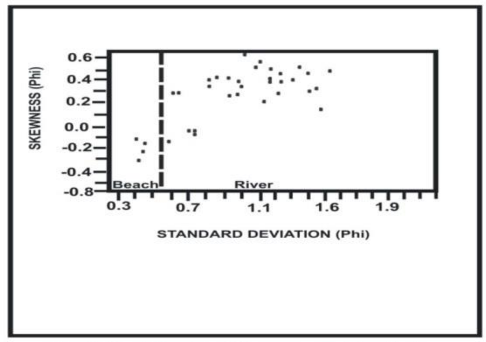


Fig.15 Bivariate plot of Skewness vs. Standard deviation (after Moiola and Weiser,1968)

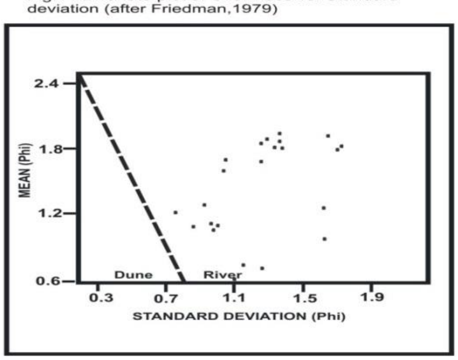


Fig.16 Bivariate plot of Mean vs. Standard deviation (after Moiola and Weiser,1968)

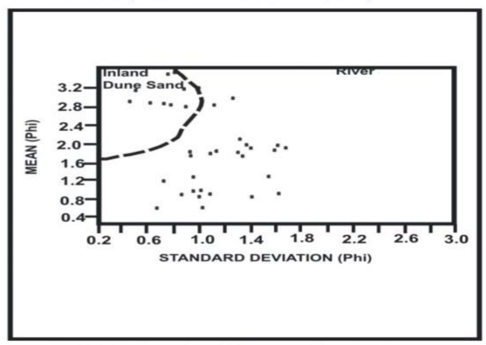


Fig.17 Bivariate plot of Mean vs. Standard deviation (after Friedman,1979)

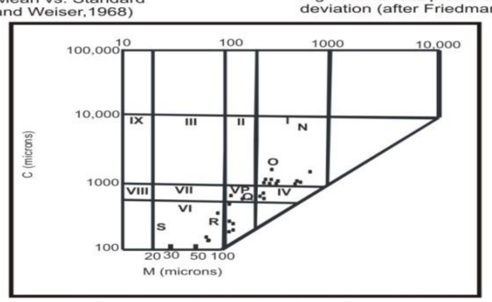


Fig.18 C-M diagram of Yolde Formation (after Passega,1957; Passega and Byramjee,1969)

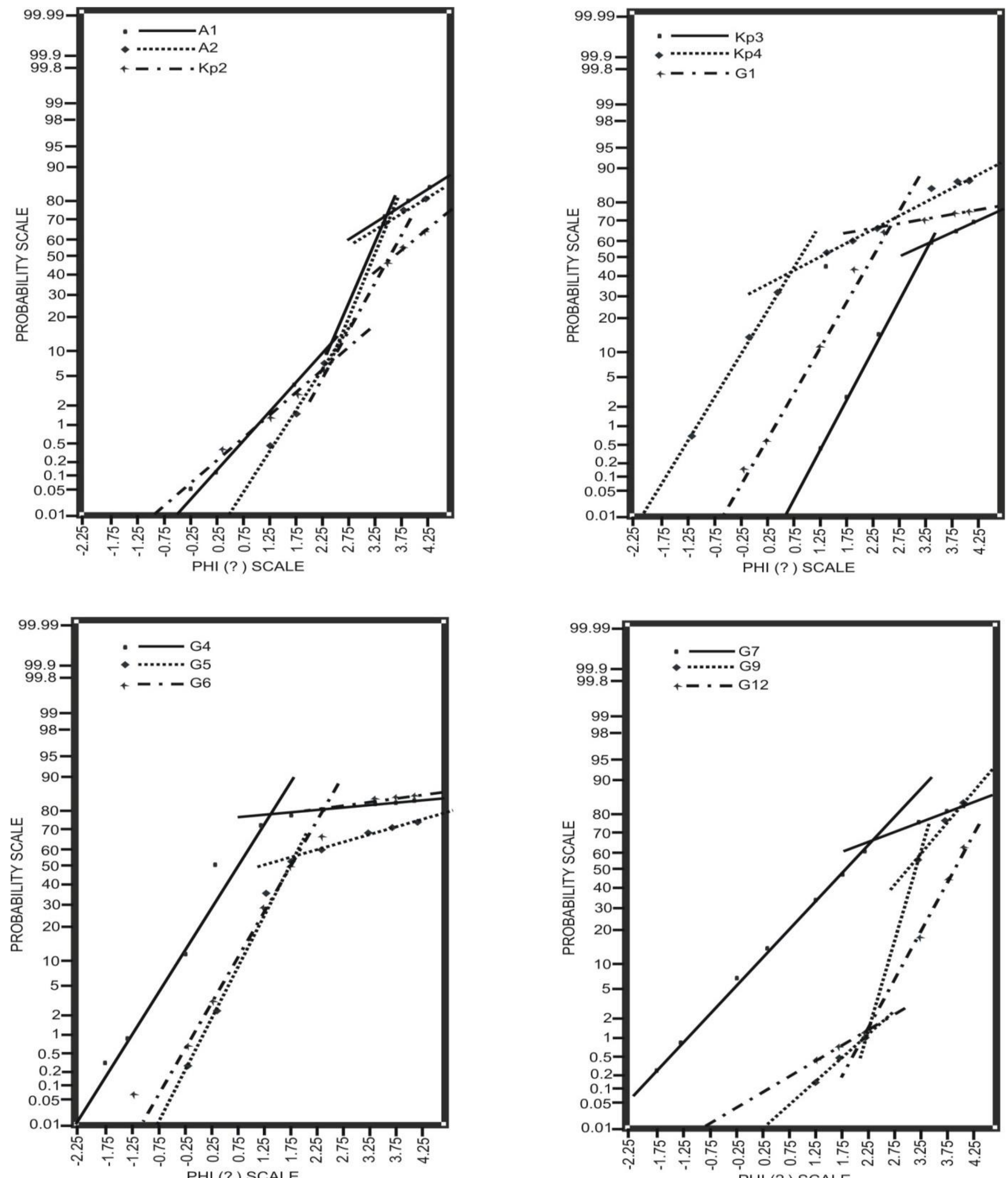


Fig.19 Probability curve plots for samples of Yolde Formation

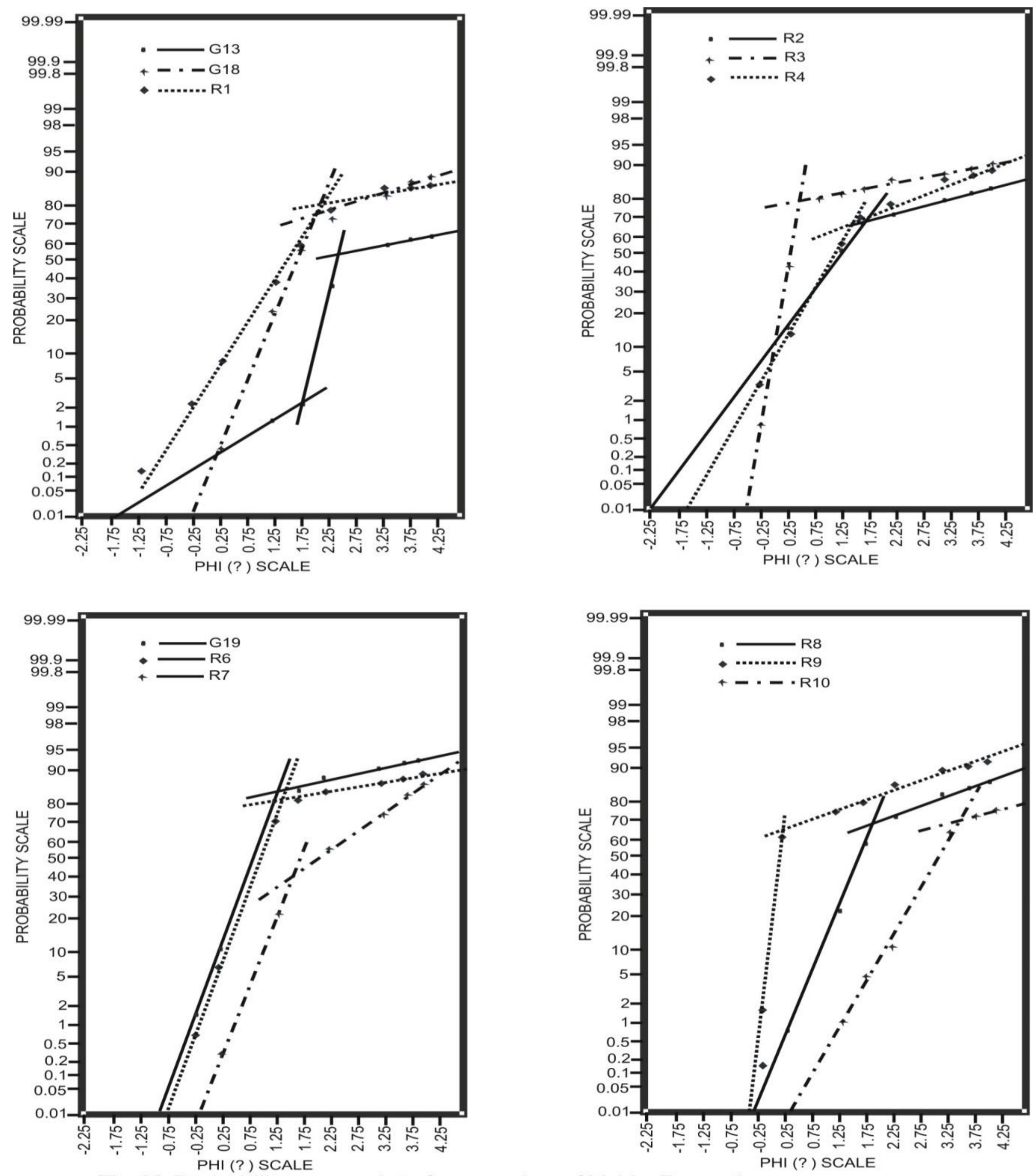


Fig.20 Probability curve plots for samples of Yolde Formation

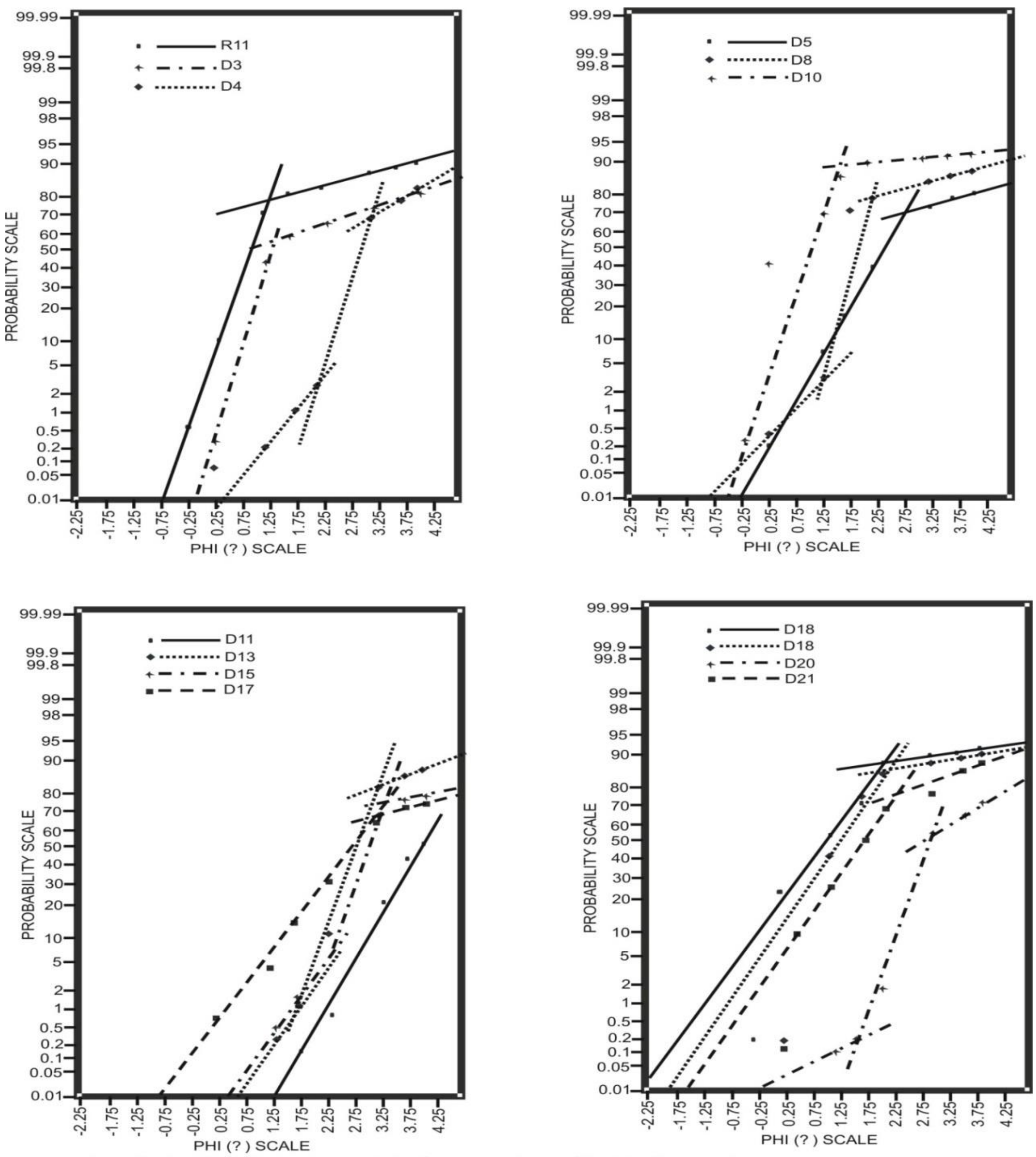
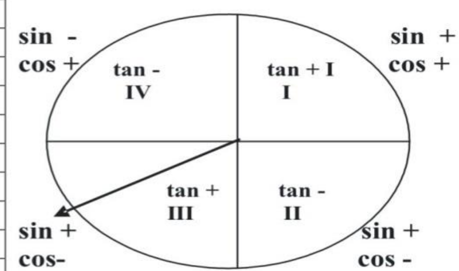


Fig.21 Probability curve plots for samples of Yolde Formation

AZIMUTH	SIN X	COS X
*114(1)	0.4136	-0.4067
116(5)	4.4939	-2.1919
117(2)	1.7820	-0.9079
121(2)	1.7143	-1.0301
122(4)	3.3922	-2.1197
123(2)	1.6773	-1.0893
241(5)	-4.3731	-2.4241
242(17)	-15.0101	-7.9810
243(18)	-16.0381	-8.1718
244(16)	-14.3807	-7.0139
245(21)	-19.0325	-8.8749
246(36)	-32.8876	-14.6425
247(25)	-23.0126	-9.7683
248(7)	-6.4903	-2.6223
249(13)	-12.1366	-4.6588
250(29)	-27.2511	-9.7683
251(21)	-22.6925	-7.8136
252(16)	-15.2169	-4.9443
253(15)	-14.3446	-4.3856
254(9)	-8.6514	-2.4857
255(4)	-3.8637	-1.0353
256(8)	-7.7624	-1.9354
257(3)	-2.9231	-0.6749
258(3)	-2.9344	-0.6237
259(2)	-1.9633	-0.3816
	-236.9917	-108.0968

- $Tan\,x = \frac{\Sigma n\,Sin\,x}{\Sigma n\,Cos\,x} = \frac{-236.9917}{-108.0968}$
- Arch tan = $\tan^{-1}(2.1924)$ = 65.48
- Vector Mean = 65.48
- $R = (\Sigma nSinx)^2 + (\Sigma nCosx)^{1/2}$ = 260.48
- $Vector\ \ Magnitude = \frac{R\,x100}{288}$

= 90.45



YOLDE FORMATION

***No. of reading** (After Lindholm, 1987)

Fig.22 Paleocurrent data azimuth of crossbeds)

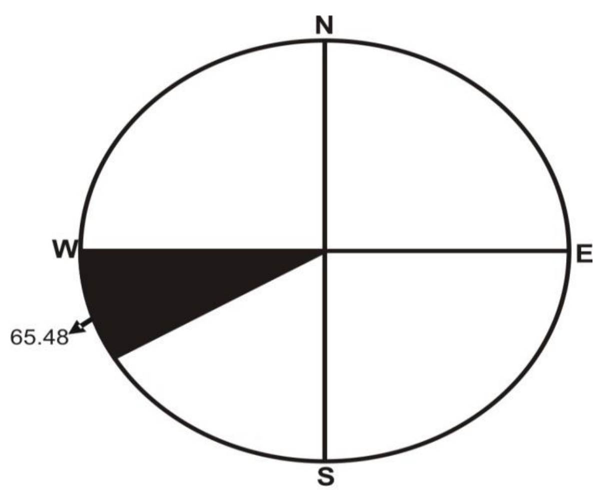


Fig.23 Composite paleocurrent direction of Yolde Formation

The vector mean indicated that the flow direction was in the southwestern direction.

The general paleocurrent direction based rose diagram for the Yolde Formation yielded a dominant flow in the southwest direction with minor mode in the southeastern direction (Fig.23).

Discussion

Yolde Formation is characterized by numerous lithofacies. They vary from mudstone-claystone-shale to very coarse grained sandstones with pebbles scattered within them. The coarse, medium and fine grained sandstones are either massive planar, tabular or trough cross-bedded or parallel laminated. These sandstones are either variegated buff or brown in colour indicating deposition in an oxidizing environment. Furthermore, the lack of marine fauna, trace fossil, glauconite and phosphate concretion in the study locations of Ashaka stream, Kworin Gora stream, and Gabukka stream may probably suggest deposition in a non-marine environment. However, the presences of *Planolites* and bi-directional ripple lamination at Ruwan Kuka section, and *Ophiomorpha* and herringbone crossbedding at Doma stream section may suggest marine setting for some part of the Yolde Formation.

Ophiomorpha and *Planolites* are classified under *Skolithos* and *Cruziana* ichnofacies respectively, and they generally indicate shallow marine environment (Frey and Pemberton, 1984). *Ophiomorpha* is an indicator of marine environment from shoreline to 30m water depth (Dike, 1972a).

The univariate grain size parameters cannot conclusively suggest a depositional environment, but, it can give a clue to some significant processes occurring within an environment of deposition. Abdel-Wahab *et al*. (1992) indicated sorting depends on sediment source, grain size and depositional regime. Standard deviation for the Yolde Formation ranges from well sorted – poorly sorted (0.42–1.13 Φ), and they might suggest deposition under relatively high – low energy regime. Agumanu (1993) suggested that fluctuation in skewness may probably reflect changes in depositional energy levels attributable to waning and waxing current. Both positive and negative skewness are obtained from the samples analysed, but they are predominantly positively skewed. This might indicate predominance of finer grain materials in the samples framework and river sands are generally positively skewed, and the skewness are in consonances with Friedman (1961,1967) data for fluvial sand.

The bivariate plot of Friedman (1961, 1967, 1979) for skewness versus standard deviation and Moiola and Weiser (1968) for skewness versus standard deviation suggested both fluvial and coastal setting for the Yolde Formation but with the fluvial setting dominating (Figs.11, 12, 13 and 14). Friedman (1979) plots for mean versus first percentile and standard deviation versus first percentile likewise, suggested both fluvial and coastal environment for the Yolde

Formation (Figs. 9 and 10), however, plots based on mean versus standard of Friedman (1979) suggest a complete fluvial environment for the Yolde Formation (Figs.15 and 16). The C-M Pattern of Passega and Byramjee (1969) also suggested a fluvial setting for the Yolde Formation (Fig.17). Probability curve plots based on Visher (1969, 1972) and Dike (1972b) indicates that most of the samples have two sand populations (saltation and suspension). These probability curve types generally indicates unidirectional depositional current (Visher, 1969; Dike, 1972b) (Figs.18, 19 and 20).`Owing to the fact that about 76% of the two sand population plots lack marine to support marine setting, the predominance of fluvial setting is quite plausible.

The paleocurrrent direction of the Yolde Formation yielded a dominant unimodal trend in the southwestern direction indicating that the formation derived its source from the northeastern direction (Fig.22). This further confirmed by the paleocurrent analysis based on Lindholm (1987) which also indicated that the direction of sediment supply is in the southwestern direction (Fig.21).

Conclussion

The present studies based on grain size distribution have indicated that the Yolde Formation was deposited dominantly in a fluvial environment even though that some of the samples suggested a marine setting. This may further confirm that the deltaic environment established for some part of the Yolde Formation (Shettima, 2005; Abubakar *et al*., 2006) is a fluvial dominated delta. The paloecurrent analysis has also confirmed that the Yolde Formation derived its source from the northeastern part of the Gongola Basin.

References

Abubakar, M.B., Dike, E.F.C., Bukar, S. and Tukur, A. (2006), Lithostratigraphy and paleoenvironment of deposition of the Yolde Formation of the Gongola Arm, Upper Benue Trough, Nigeria. Nigerian Mining and Geosciences Society Abst. Vol., 42nd Conf., pp.48.

Abdel-Wahab, A, (1988), Lithofacies and diagenesis of the Nubia Formation at Central eastern desert, Egypt (abst.) **9th EGP. Exploration Conference, Cairo, 20-23 Nov. IIA,** 9.

Abdel-Wahab, A, Kholief M, and Salem, A. (1992), Sedimentological and Palaeoenvironmental studies on the clastic sequence of Gebel El-Zeit area, Gulf of Suez, Egypt. *Journal of African Earth Sciences*, **14, 1.** Pp. 121-12.

Adegoke, O.S., Jan du Chew, R.E., Agumanu, A.E. and Ajayi, P.O. (1978), Palynology and age of the Kerri-Kerri Formation, Nigeria, Revista Espanola Micropalaco-tologia **10,** 2-283.

Agumanu, A.E. (1993). Sedimentology of

Owelli Sandstone (Campano-Maastrichtian) Southern Benue Trough Nigeria. *Journal of Mining Geology*, 29, 2: 21-35.

Allix, P.(1983), Environments mesozoiques de la paritc nord-orientale du fosse de la Benue (Nigeira), stratigraphic sedimentologic, evolution goodynmique.*Traraux Laboratoire Sciences terre St.* Jerome Marselle (B) **21,** 1 – 200.

Benkhelil, J. (1989), The origin and evolution of the Cretaceous Benue Trough (Nigeria) *Journal African earth Sciences* ,**8,** 251-282.

Boggs, S. Jr. (2006). Principles of Sedimentology and Stratigraphy (4th eds.). Prentice Hall, Upper Saddle River, New Jersey, 1 – 139p.

Carter, J. D., Barber, W., Tait E.A and Jones, G.P. (1963), The geology of parts of Adamawa, Bauchi and Borno provinces in north-eastern Nigeria. *Bulletin Geological Survey Nigeria.* **30,** 1-99.

Dike, E.F.C. (1972a), *Ophiomorpla (Nodosa)* Lundgren environmental implications in Lower Greensand of the Isle of Wight. Proceedings of Geologists Association, **85**,165-177.

Dike, E.F.C.(1972b), Sedimentology of the Lower Greensand of the Isle of Wight, England. Unpub. D. Phil. Thesis, University of Oxford, England, 204.

Dike, E.F.C. (1993), The Statigraphy and structure of the Kerri-Kerri Basin Northeastern Nigeria. *Journal of Mining and Geololgy*.**29**, 2, 77-93.

Dike, E.F.C. (2002), Sedimentation and tectonic evolution of the Upper Benue Trough and Bornu Basin, Northeastern Nigeria. Nigerian Mining Geosciences Society 38th Annual and International Conference, Port Harcourt 2002 (NMGS/ELF award wining paper) Abstr. Vol.

Dike, E.F.C. and Onumara. I.S. (1999), Facies and facies architecture, and depositional environments of the Gombe Sandstone, Gombe and Environs, NE Nigeria Science Association of Nigeria Annual Conference. Bauchi, Abst. Vol.

Folk, R.L., and Ward, W.C. (1957), Brazos River bar, a study in the significance of grain-size parameters. *Journal of Sedimentary Petrology*, **30**, 514-529.

Friedman, G.M., (1961), Distinction between dune, beach and river sands from their textural characteristics. *Journal of Sedimentary Petrology*, **30**, 514-529.

Friedman, G.M. (1967), Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. *Journal of Sedimentary Petrology*, **37,** 327-354.

Friedman, G.M. (1979), Differences in size distribution of populations of particles among sands of various origins. *Sedimentology*, **26**, 3-32.

Frey, R.W., and Pemberton S.G. (1984), Trace fossil facies modes In: Walker, R.G. (ed)., **Facies Models** (2nd ed). Geoscience Canada, Reprint Series **1,** 189-207. Shettima *et al*., 2018

Grant, N.K. (1971), The south Atlantic Benue Trough and Gulf of Guinea Cretaceous Tripple. *Geological Survey of American Bulletin.* **82,** 2295-2298.

Guiraud. M. (1990), Tectono-sedimenatry framework of the Early Cretaceous continental Bima Formation (Upper Benue Trough N.E. Nigeria). *Journal of African Earth Sciences*, **10**,341-353.

Lawal, O.and Moullade, M. (1986), Palynological biostratigraphy of Cretaceous sediments in the Upper Benue Basin N.E. Nigeria. *Revenue Micropaleotologie*, **29**, 61-83.

Lindholm, R.C. (1987), A practical approach to sedimentology. Allen and Unwin, Boston, Sydney, Wellington (1st Ed), 276.

Moiola, R.J. and Weiser, D., 1968. Textural parameters: An evaluation. *Journal Sedimentary Petrology*, **38,** 45-53.

Moss, A.J., 1963. The Physical nature of common sandy and pebbly deposit part 2. *American Journal of Science*, **261,** 297-343.

Nwajide, C.S. (2013). Geology of Nigeria's sedimentary basins. CCSBookshop Ltd, Lagos, 86p.

Olade, M.A. (1975), Evolution of Nigerian's Benue Trough (aulacogen): a tectonic model. *Geological Magazine* **112,** 575-583.

Passega, R. (1957), Texture as characteristics of clastic deposition *American Association of Petroleum Geologists Bulletin*, **41**,1952 – 1984.

Passega, R. (1964), Grain size characteristics by C-M pattern as a tool. *Journal Sedimentary Petrology*, **34**,233-847.

Passega, R. and Byramjee. R. (1969), Grain size image Shettima, B. (2005), Sedimentology and reconstruction of the depositional environments of the Yolde Formation in the Gongola Arm of the Upper Benue Trough (N.E. Nigeria) MSc. Thesis (unpublished), ATBU Bauchi, pp.84.

Visher., G.S. (1965), Fluvial processes as interpreted from Ancient and recent fluvial deposits. In: Middleton, G.V., ed., Primary sedimentary structures and their hydrodynamic interpretation. Society of Sedimentary Petrologists Special Publication, **12**, 116-132.

Visher., G.S. (1969), Grain-size distribution and depositional processes. *Journal of sedimentary Petrology*, **39**, 1074-1106.

Visher., G.S. (1972), Physical characteristics of fluvial deposits. Society of Sedimentary Petrologists Special Publication,**16**, 84-97.

Wentworth, C.K., (1922), A scale of grade and class terms for clastic sediments. *Journal of Geology*, **30,** 377-392.

Zaborski, P., Ugodulunwa, F., Idornigie, A., Nnabo, P. and Ibe, K. (1997), Stratigraphy, Structure of the Cretaceous Gongola Basin, Northeastern Nigeria. *Bulletin Centre Research Production Elf Aquitatine*, **22,** 153- 185.

of clastic deposits. *Sedimentology,***13**, 233-252.

Pettijohn, F. J., Potter, P.E. and Siever, R. (1973), **Sand and Sandstones** 2nd Ed) Springer- Verlag, 407p.

Popoff. M., Wiedmann, J. and De Klazz, I. (1986), The Upper Cretaceous Gongila and Pindiga Formations, Northeastern Nigeria. Subdivisions, age stratigraphic correlations and paleogeographic implications. *Ecologea Geol. Helv.,***79**, 343-363.

Reineck, H.E and Singh, I.B. (1980), Depositional Sedimentary Environment, with References to Terrigenous Clastics. Springer-Verlag, Berlin, 439p.