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Full Length Research Paper

Depositional Environment of the Exposures of Turonian Eze - Aku Formation at Uwakanda 1, Southeastern Nigeria

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ABSTRACT

The sediments of the outcrop sections at Uwakande 1, Obubra southeastern Nigeria were studied for their textural variation. The study employed the characterization of the litho-facies, granulometry and pebble morphometric analysis. The sand fractions of the sediments are coarse to very coarse. Statistical parameters resulting from granulometry show that they are poorly sorted, very positively skewed and platykurtic. Results from bivariate plots and pebble morphometric analysis indicated the predominance of high energy fluvial fractions. Minor high energy, probably beach sediment is indicated by some individual clasts with Oblate-Prolate Index and Maximum Projection Sphericity values of less than -1.5 and 0.66, respectively. Thin section analysis of the pebbles shows that the sediments consist mainly of quartz, and low amount of feldspar, which is an indication of granitic rock derivative. The pebbles of the Turonian Eze-Aku Formation outcrop sections at Uwakanda 1 may be a fan deposit of possible the Oban massif or the Cameroun highland.

Keywords: Eze-Aku, Platykurtic, bivariate, morphometric, oblate, prolate and clast.

INTRODUCTION

The characteristic properties of sedimentary rocks are generated through the combined action of various physical, chemical, and biological processes that make up the sedimentary cycle. Sedimentary processes and conditions that constitute the depositional environment play a primary role in determining the textures, structures, bedding features, and stratigraphic characteristics of sedimentary rocks. Environmental analysis thus involves identifying responsible elements or properties that have environmental significance (Boggs, 2006). Environment of deposition is the location in which sediment deposition occurs. It can be defined in terms of physical, chemical, biological or geomorphic variables (Reineck et al., 1980), and is characterized by a unique set of processes operating at a specified rate and intensity which impart sufficient imprints on the sediment, so that a characteristic deposit is produced. Environmental parameters can be divided into three groups: physical, biological, and chemical. The physical processes are the most important, as they provide the most basic information for depositional environment interpretation (Reineck et al., 1980).

In studying ancient sediments, it is important to record all the primary sedimentary structures, grain features and parameters, and bioturbation structures of individual units of a sedimentary sequence, and try to interpret the hydrodynamic conditions under which the unit was probably deposited. The lateral and vertical relationship of various units and the determination of their geometry were studied, and these can be compared with models of comparable environments based on information from the study of present day environment (Reineck et al., 1980).

This study presents stratigraphic interpretations for the Turonian Eze-Aku Formation. The study area is located at mile 6 (popularly called Tank) in Obubra, southeastern

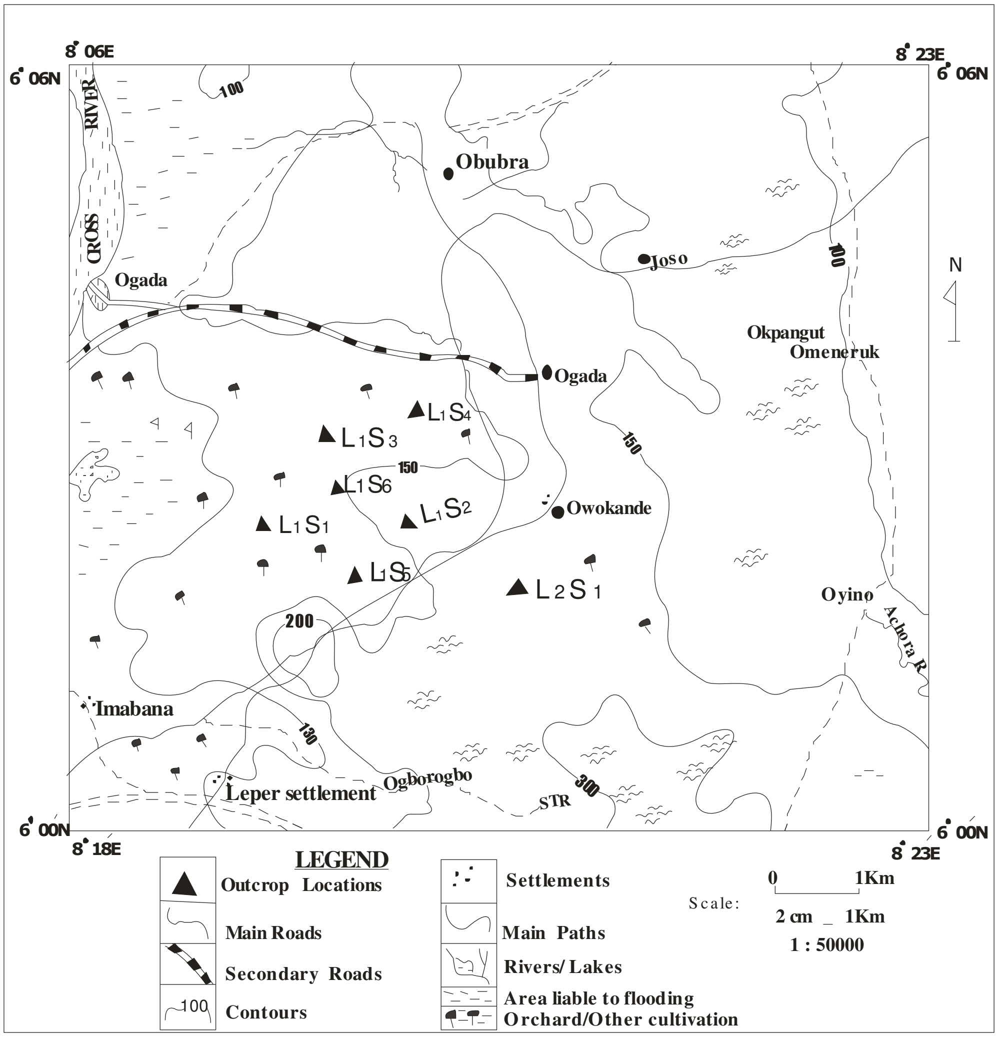

Fig1, Topographic map of Obubra and its Environs.

Nigeria. It comprises of few other major villages such as Ogada 1 and 2, Imabana Iyamitet, and Uwakande 1, and lies between longitude 8^{o}19'E and 8^{o}23'E; and latitude 6^{o}2'N and 6^{o}7'N (Fig.1). It covers an area of 68.25 square kilometers, where good exposures are accessible through road cuts, stream channels, and local gravel mining sites.

Structural and Tectonics Overview

The Tectonic history of Southern Benue Trough, southeastern Nigeria dates back to the Albian. The Abakaliki-Benue Trough originated as a failed arm of the triple junction rift-ridge system that, led to the separation of Africa from South America during the Aptian/Albian, as suggested Burke et al. (1972) and Nwachukwu (1972). The opening of these arms started in Middle Aptian in the Southern Atlantic by crustal stretching and downwarping accompanied, by the development of coastal evaporite basins. It reaches the Gulf of Guinea by Late Albian and extends North East, to form the Benue-Abakaliki Trough. However the North East – South West trending Benue–Abakaliki Trough is thought to be the result of the Pre-Albian rifting of the African Shield, prior to the opening of the south Atlantic, Uzuakpunwa (1974). Murat (1970) identified three main tectonic phases in the Benue Trough which has controlled the sedimentary filling of the sedimentary basin. The first phase began during Albian and was characterized by movement along major NE-SW trending Benue–Abakaliki Trough. This led to two stable areas on either side of the Benue–Abakaliki Trough, called the Anambra platform on the west and Ikpe Platform on the East. On the Eastern flank, there was the NW-SE trending Ikang Trough and the Ituk High as well as the Eket Platform, all persisted into the Tertiary without Significant changes (Fig.2).

A second major tectonic event resulted from compressional movements along the established NE-SW trend that led to the folding of the sediments of the Benue–Abakaliki Trough. This resulted in a series of NE-

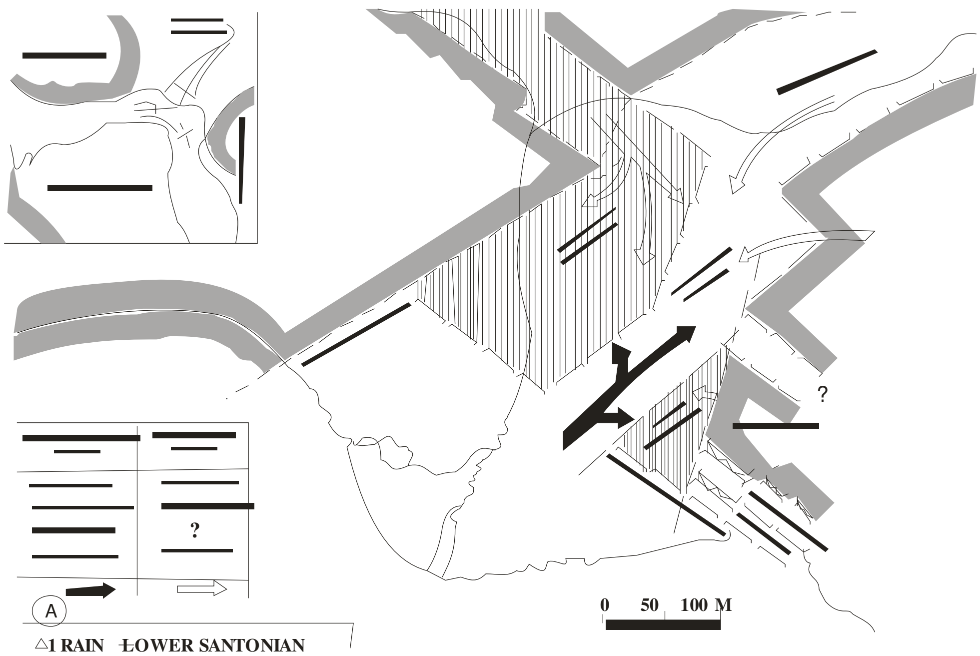

Fig2. The Tectonic Map of SE Nigeria during Albian-Tertiary (After Murat, 1970)

SW trending folds that formed the Abakaliki Anticlinorium, and the downwarping of the Anambra Platform, to form the wide Anambra basin and the narrow Afikpo Syncline on the west and east of the Abakaliki Anticlinorium respectively (Fig.3 Kogbe 1976). The onset of this folding phase in the Late Santonian was accompanied by pronounced igneous activities. These account for the occurrence of a large number of intermediate and basic intrusions in the study area. This second tectonic phase was interpreted as the closing of an embryo Benue Ocean (Burke et al., 1971). This was as a result of differential movement between two parts of the African plate as a consequence of differences in the rate of spreading and direction between the section of the Mid Atlantic Ridge opposite the bulge of Africa and south of the Gulf of Guinea.

The third phase of Murat (1970), which occurred towards the end of the Eocene, was not represented in the study area. But there are in its geological record, recent alluvial deposits along the bank of the Cross River.

Geologic Evolution

The study area falls between the south Eastern Benue Trough and Ikom-Mamfe Embayment. Its geologic evolution dates back to the Albian times, with the deposition of Mamfe Formation which is a member of the Asu River Group. This is predominantly a fluviatile clastic sequence. The type locality of the Mamfe Formation is on the bank of Cross River at Mamfe near Cameroun, where about 800m of massive arkosic sandstones with Marl, sandy limestone and shale intercalations are exposed (Reyment, 1965). The sequence on the Nigerian part of this basin comprises of conglomeratic immature arkosic cross-bedded coarse-medium sandstones and mudstones (Petters et al., 2004). The Asu River Group which lies uncomfortably on the basement represents the oldest stratigraphic unit exposed in the area. It is characterized by a thick sequence of marine shale with inter- bedded siltstones and minor bands of sandstone and limestone.

The Turonian period marked the beginning of another marine transgression. During this period the Eze-Aku Formation was deposited (Olade, 1975). The Turonian consists of fossiliferous marine series outcropping throughout the Benue Trough. This formation comprises of the Amasiri sandstone and the Ezillo Formation members (Table1). They consist of hard grey and black calcareous shale, limestone and siltstone. Locally the shale grades into sandstone (Kogbe, 1976). The sandstone outcrops extend from Afikpo through Ugep, and then to Apiampu.

METHODS OF STUDY

Four composites sections of the Turonian succession outcropping in Uwakanda 1 area, Obubura, southeastern Nigeria (Fig. 1) were studied to gather data on the stratigraphic succession, textural and lithologic variations and sedimentary structures. These data were used to infere the possible depositional environment and the hydrodynamics of the transporting medium. The collected samples were separated into sands for grain size analysis, and pebbles and cobbles, for pebble morphometric analysis.

Table1. Lithostrstigrahic correlation between Calabar Flank, Abakaliki Trough, Anambra Basin and the Middle Benue Trough (Petters et al., 2004).

AGE	CALABAR FLANK (Fatters et,al, in; rod)	ABAKALIKI TROUGH (Ojoh , ISSO)	ANAMBRA BASIN (Murat, 1972)	MIDDLE BENUE TROUGH (Murat, 1972; Offodila, 1976)
MAASTRICH-TIAN	Nkporo Shale FM	Mpo Hilic Fm.	Nsukka Fm; Ajali Sst.; Mamu; Enugu	Lafia Fm
CAMPANIAN		Akpoha - Ekori Sst.	Owelli; Nkporo; Afikpo	
SANTONIAN	? ? ?			
CONIANCIAN	New Netim Mari Fm.	Nkalagu Fm.	Agwu Shale	Wadatta Limestone; Agwu Shale
TURONIAN	Ekenkpon Shale Fm.	Ezo - AsuGoup: Agu - Ojo Sst.; Nora Shales	Eze - Aku Shale Group	Makurdi Sst.; Eze-Aku Shale Group
CENOMANIAN		Ezillo	Asu River Group	Asu River Group: Keana Fm
ALBIAN	Mfamosing Limestone Fm	Asu River Group: Ibli / Aglla Sst.; Ngbo; Ekebeligwe; Mfafe Fm		Awo Fm; Gboko Lst.; Arufu Lst.; Uomba Fm
EARLY CRETACEOUS	Awi Fm.	(Not Exposed)	Basal Grite and Sandstones (Not Exposed)	Basal Sandstone
G and Older	Basement Complex			

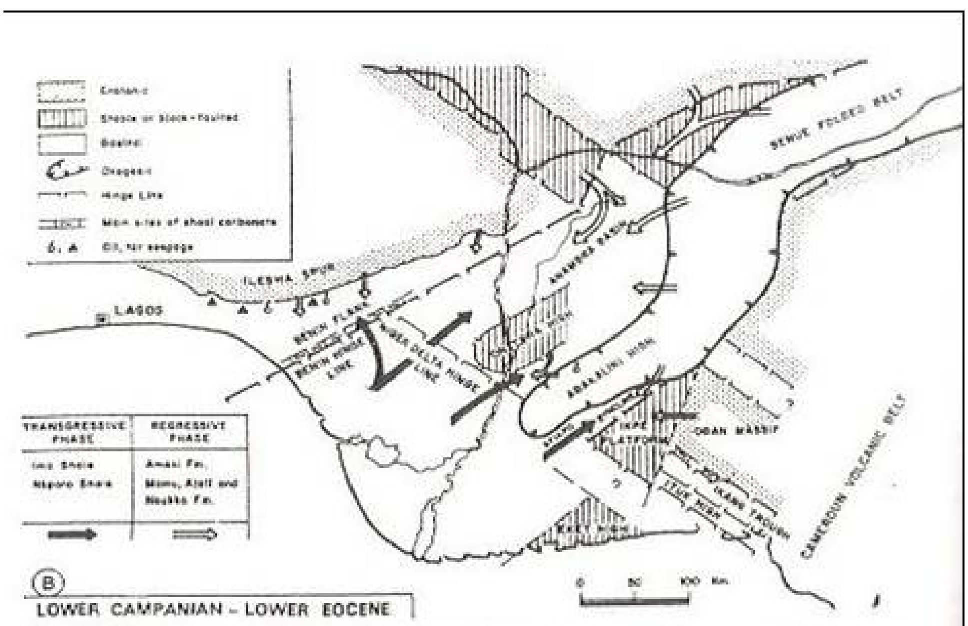

Fig3, The Tectonic map of SE Nigeria during the Campanian-Eocene (adapted from Murat, 1970).

Fig4. General outcrop of the Paraconglomeratic sections at location 1 Uwakanda 1

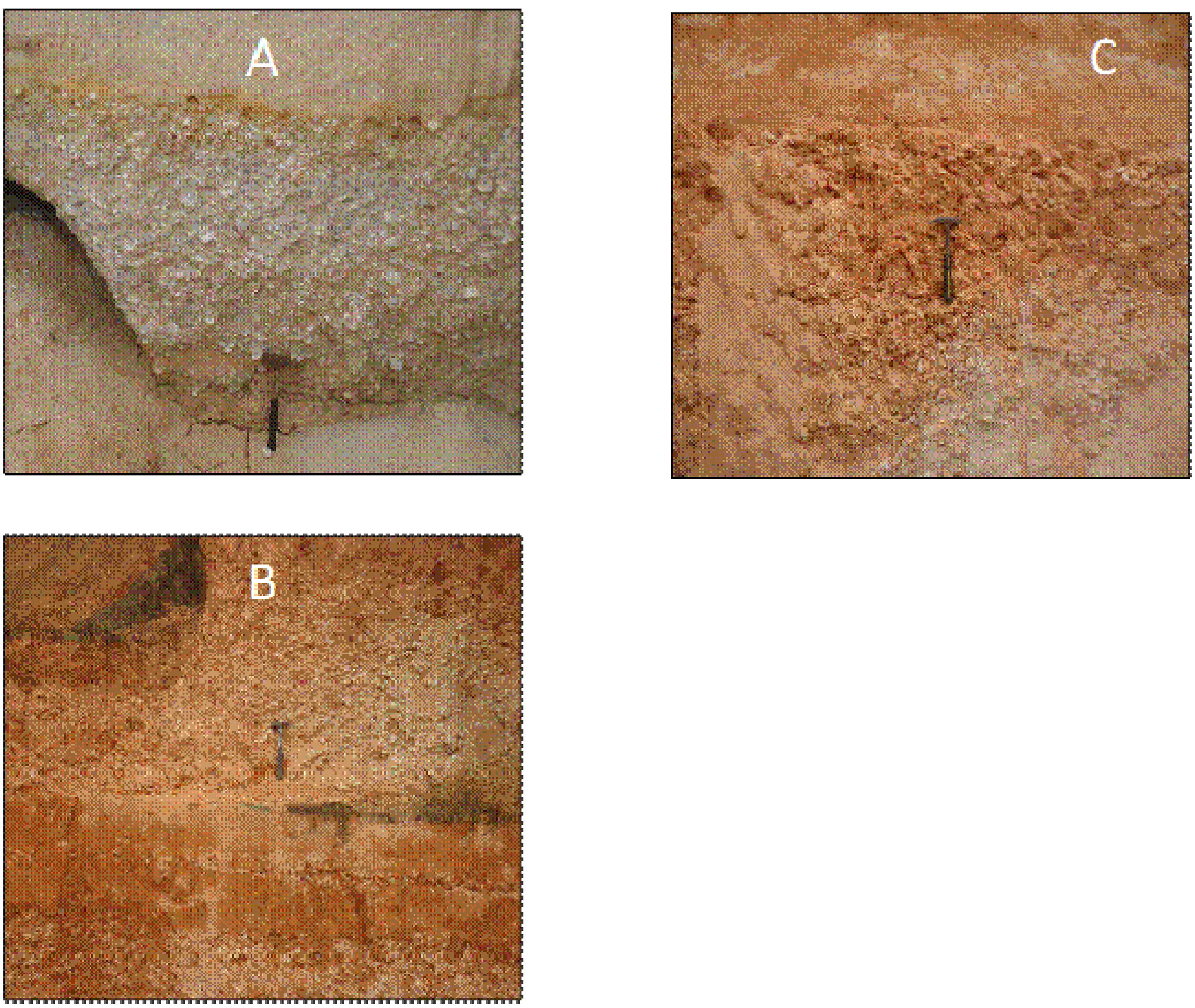

Fig5. A, B and C showing Paraconglomeritic facies.

Table2. Summary of percentile values of analysed samples.

Location	ϕ_5	ϕ_{16}	ϕ_{25}	ϕ_{50}	ϕ_{75}	ϕ_{84}	ϕ_{95}
$L_1S_1U_1$	-1.25	-1.15	-1.05	-0.20	0.90	1.45	2.45
$L_1S_1U_2$	-1.25	-1.11	-1.09	-0.90	-0.50	0.20	1.15
$L_1S_2U_1$	-1.35	-1.25	-1.22	-1.00	0.55	1.70	3.78
$L_1S_2U_2$	-1.40	-1.24	-1.15	-1.00	0.05	1.00	2.88
$L_1S_2U_3$	-1.36	-0.90	-0.75	-0.30	0.45	1.20	2.80
$L_1S_3U_1$	-1.37	-1.20	-1.10	-0.25	1.05	1.65	3.30
$L_1S_3U_2$	-1.42	-1.26	-1.19	-1.01	0.65	1.40	3.35
$L_2S_1U_2$	-1.25	-1.05	-0.75	0.25	1.18	1.80	4.05
MEAN	-1.33	-1.15	-1.03	-0.55	0.54	1.30	2.97

Table3. Summary of statistical parameters

SAMPLE NUMBER	MEDIAN DIAMETER (MD)	GRAPHIC MEAN (GDϕ)	GRAPHIC STANDARD DEVIATION (GDϕ)	GRAPHIC SKEWNESS (GSϕ)	GRAPHIC KURTOSIS (GKϕ)
$L_1S_1B_1$	-0.20	0.03	1.21	+0.35	0.75
$L_1S_1B_2$	-0.90	-0.003	0.69	+0.69	1.05
$L_1S_2B_1$	-1.00	-0.18	1.52	+0.85	1.19
$L_1S_2B_2$	-1.00	0.25	1.21	+0.80	1.46
$L_1S_2B_3$	-0.30	0.00	1.16	+0.71	1.46
$L_1S_3B_1$	-0.25	0.20	1.42	+0.43	0.89
$L_1S_2B_2$	-1.01	-0.29	1.39	+0.82	1.06
$L_2S_1B_2$	0.25	0.33	1.52	+0.26	1.13
MEAN	-0.55	0.04	1.27	+0.61	1.13

In undertaking pebble morphometric analysis, ten pebble or cobble size grains were selected at random from each bed, for measurement. These measurements were carried out on the orthogonal axes of the pebbles which include the long axis, *L*; the intermidiate axis, *I ;* and the short axis *S.* The dimension of the pebbles was measured with veneer caliper, ruler or micrometer screw. The values were used for computing the statistical parameters such as Zingg (1935), Wentworth (1922), Dobkins and Folks (1970).

RESULT AND DISCUSSION

The outcrop section at Uwakanda 1 is white, brownish-white, 15-18m thick paraconglomeritic sequence, comprising pebble clasts of various sizes sandwiched in medium- coarse sand matrix interbedded with massive sandstone facies. The paraconglomeritic facies lack imbriecation and are very poorly sorted. The general outcrop of the study area in Uwakanda 1 is shown in Fig.4

The paraconglomeratic facies of interest are shown in Fig. 5 A, B, and C.

From the data obtained, the mechanical sieve analysis cumulative curves were plotted. These were valuable in estimating statistical parameters such as graphic mean, standard deviation, skewness, kurtosis, proposed by Folk and Ward (1957). Quantitative graphical values for the various percentile and quartiles were obtained from the cumulative curves from various samples Tables 2 and 3. The percentage data were analyzed using the bivariate Figs. 6 and 7 and multivariate environment discriminant techniques after Moiola and Weiser (1968); Friedman (1961); Dobkins and Folk (1970); Sahu (1964) and Stratten (1973).

From the interpretation of graphic mean, it can be deduced that the sediment is made up predominantly of coarse and a small amount of very coarse sand (values ranges from -0.003 to 0.33) which lies between coarse sands and granules on the Wentworth scale. This indicates high energy depositional environment suggested by Pettijohn (1957). It also indicates that the sediments were deposited at the stream channels when the energy and competency of the transporting medium has decreased, thus coarser sediments are being deposited. The graphic standard deviation values ranges from 0.69 to 1.52, indicating poor sorting of sediments and few moderately well sorted samples ($L_1S_1B_2$). On the average, the sediment is poorly sorted, indicating a fluctuating current strength. Sample $L_2S_1B_2$.

($GS_K\phi$ = +0.26) is positively skewed while the rest are very positively skewed. The average skewness of (+0.61) corresponds to very positively skewed, indicating that coarse particles exceeds the fines.

The kurtosis values range from platykurtic (0.78 and 0.89), through mesokurtic (1.05 and 1.06), to leptokurtic (1.13, 1.19 and 1.46). Meanwhile the average value of kurtosis is 1.13, (leptokurtic). The variation in the range of value of kurtosis indicates that the sediments were deposited at different regimes of stream power.

Poor sorting and positive skewness are consistent with river sands. The average value of sorting and skewness are 1.27 and +0.61 respectively. However, the

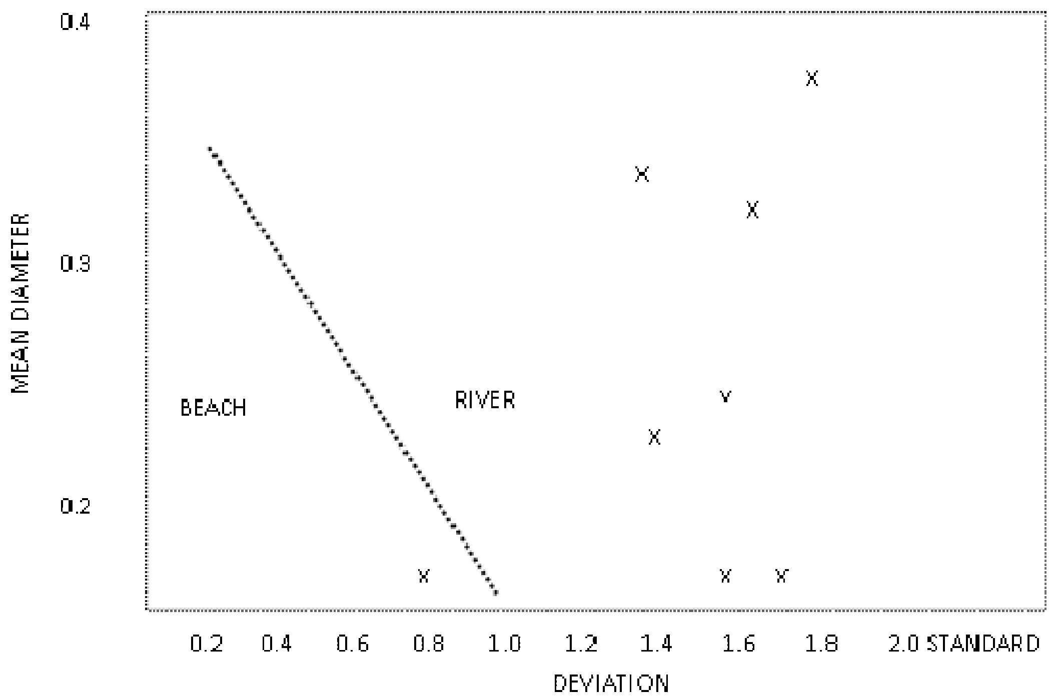

Fig6. Plot of Mean size against Standard Deviation (after Moiola and Weiser, 1968)

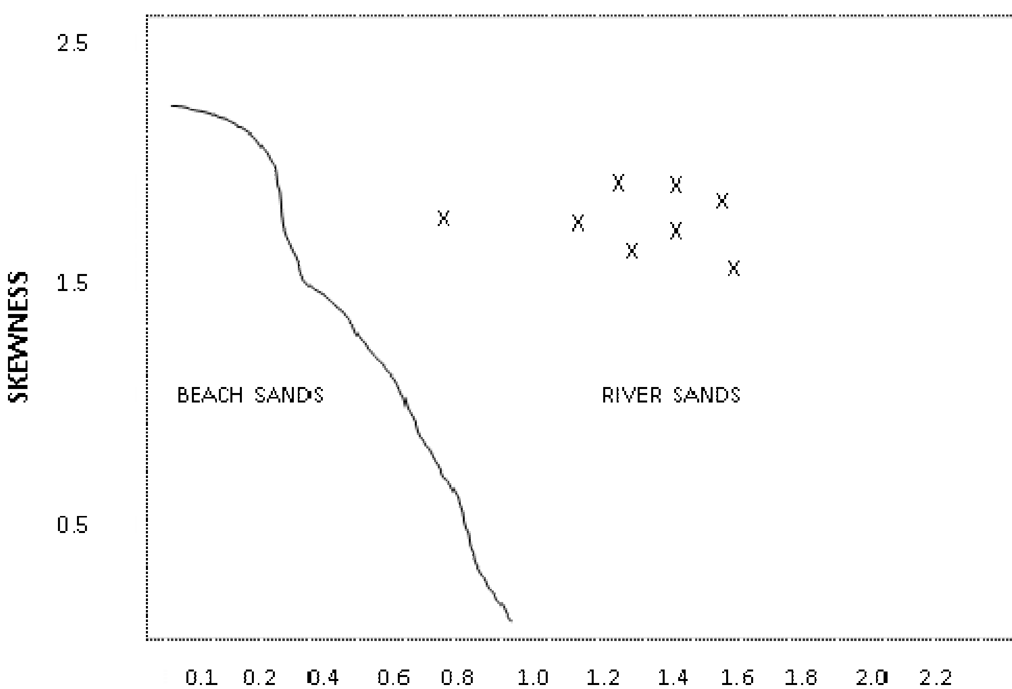

Fig7. Plot of Skewness against Standard Deviation (after Friedman, 1961)

sediments are poorly sorted and positively skewed, suggesting a high energy fluvial environment. It could be inferred that the sediment source area is close to the environment where they were deposited, (Reineck and Singh, 1980).This view is supported by the clear absence of fines in the sediments.

Multivariate discriminant plots (Sahu, 1964) was used to discriminate between the various environments and processes of sand deposition from grain size distribution. The Linear Multivariate Function *(LMF)* is represented as, Ÿu: Shallow marine: Fluvial = 0.2852(GMΦ)–8.7604(GDΦ)–4.8932(GSKΦ) +0.0482(GKΦ). If Ÿ is less

Table4. Summaries of Pebble Morphometric Analysis Results

S/N	I/L (cm)	S/L (cm)	S/L X100	$\frac{L-I}{L-S}$	$3\sqrt{\frac{S^2}{LI}}$	10(L-I/L-S– 0.5)S/L	FORM
$L_lS_1B_1$	0.657	0.414	41.40	0.714	0.899	1.043	C
$L_1S_2B_1$	0.681	0.418	41.80	0.581	0.688	0.862	B
$L_1S_2B_2$	0.710	0.397	39.70	0.517	0.605	-0.798	B
$L_1S_3B_1$	0.716	0.484	48.40	0.565	0.695	1.044	B
$L_1S_4B_1$	0.741	0.401	40.10	0.428	0.618	-1.738	B
$L_1S_5B_1$	0.784	0.514	51.37	0.456	0.688	-1.503	CB
$L_1S_6B_1$	0.711	0.508	50.79	0.584	0.737	1.594	CB
$L_2S_1B_2$	0.758	0.491	49.18	0.487	0.677	-0.415	CB
MEAN	0.720	0.453	45.30	0.542	0.701	0.011	B

Table5. Results of Roundness of 10 Pebble Suites

S/N	L (cm)	I (cm)	S (cm)	S/L (cm)	S^2	LI	$\frac{L-I}{L-S}$	$\frac{S^2}{LI}$	$3\sqrt{\frac{S^2}{LI}}$	10(L-I/L-S– 0.5)S/L	D_K	D_i	D_K/D_i
1	7.00	5.50	3.00	0.546	9.00	38.50	0.375	0.234	0.616	-2.292	3.00	5.30	0.566
2	5.20	3.30	2.30	0.442	5.29	17.16	0.655	0.308	0.676	3.510	1.30	3.30	0.394
3	4.50	3.30	2.80	0.622	7.84	14.85	0.706	0.528	0.808	3.309	1.10	3.00	0.367
4	6.40	5.50	3.00	0.469	9.00	35.20	0.265	0.256	0.635	-5.019	2.40	4.80	0.500
5	6.30	4.20	2.80	0.444	7.84	26.46	0.600	0.296	0.667	2.250	2.00	3.80	0.526
6	3.90	2.30	1.80	0.462	3.24	8.97	0.762	0.361	0.712	5.675	1.20	2.20	0.546
7	4.50	3.00	2.10	0.467	4.41	13.50	0.625	0.327	0.689	2.678	1.80	3.00	0.600
8	3.80	1.80	1.60	0.421	2.56	6.84	0.909	0.374	0.721	9.715	1.30	1.80	0.722
9	4.40	3.10	2.20	0.500	4.84	13.64	0.591	0.355	0.708	1.818	1.30	3.20	0.406
10	3.10	1.80	1.20	0.387	1.44	5.58	0.684	0.258	0.637	4.759	1.00	1.6	0.625
MEAN									0.617	-0.084			0.537

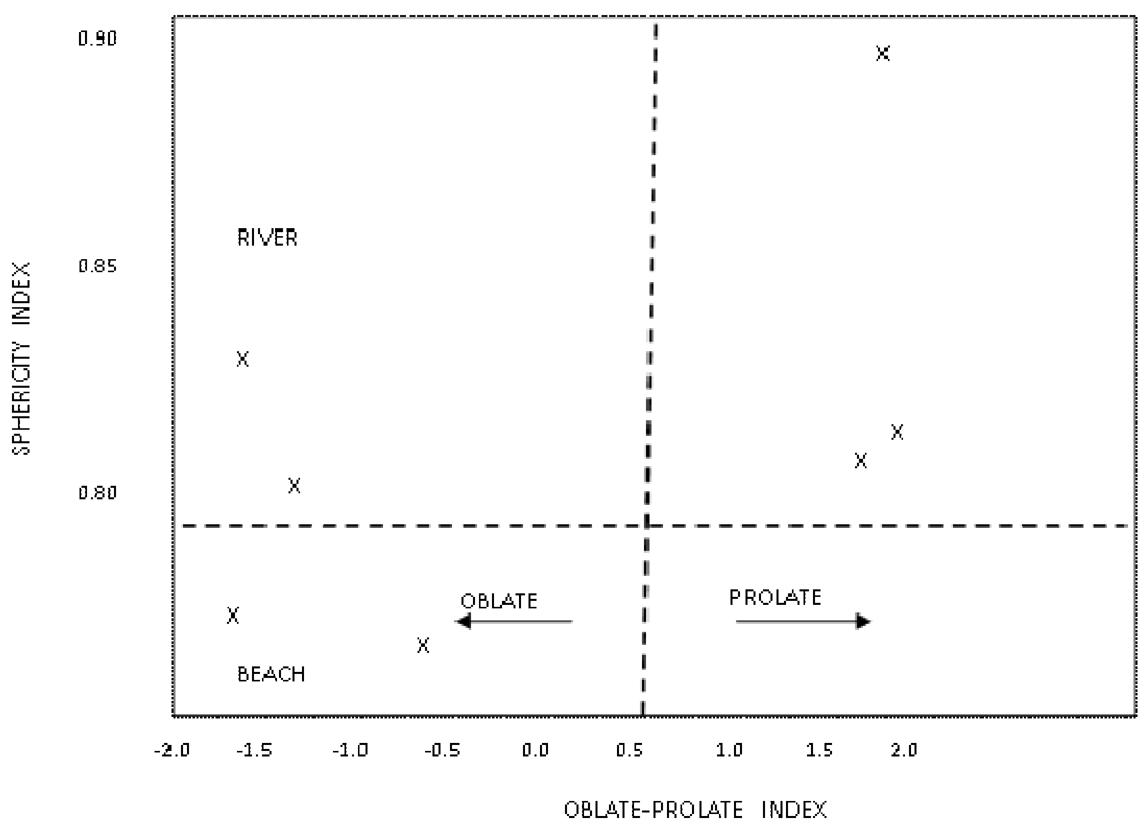

Fig8. Bivariate plot of Sphericity against OP (after Dobkins and Folk, 1970).

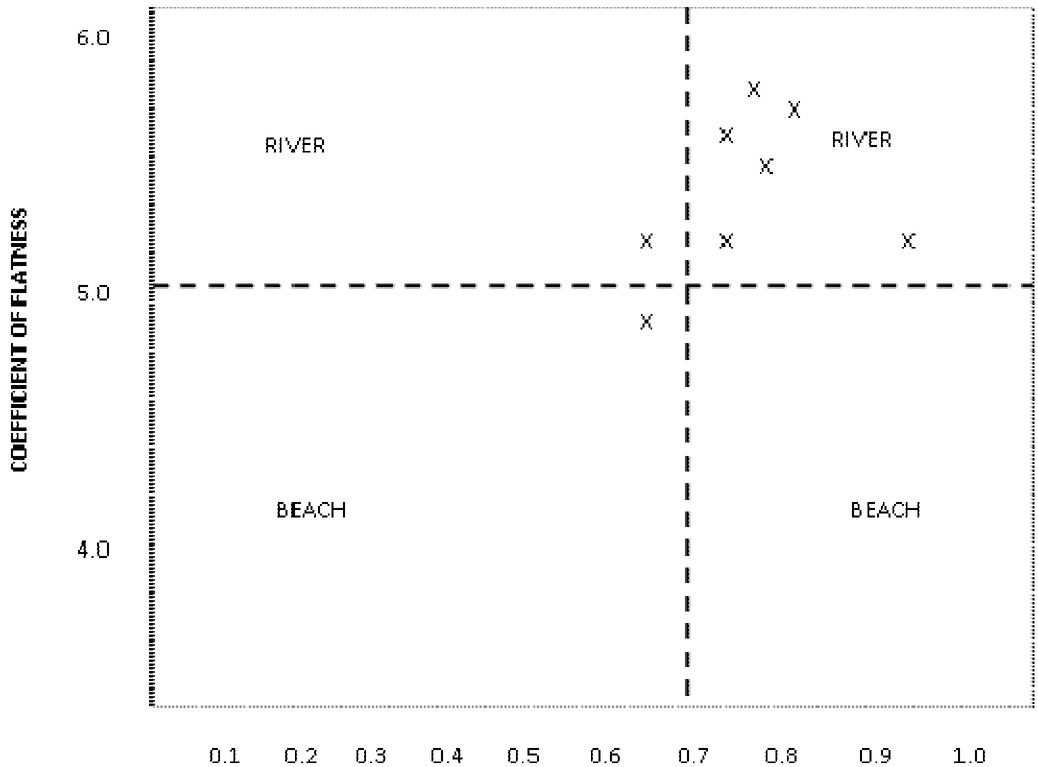

Fig9. Plot of Coefficient of Flatness against Sphericity (after Stratten, 1973)

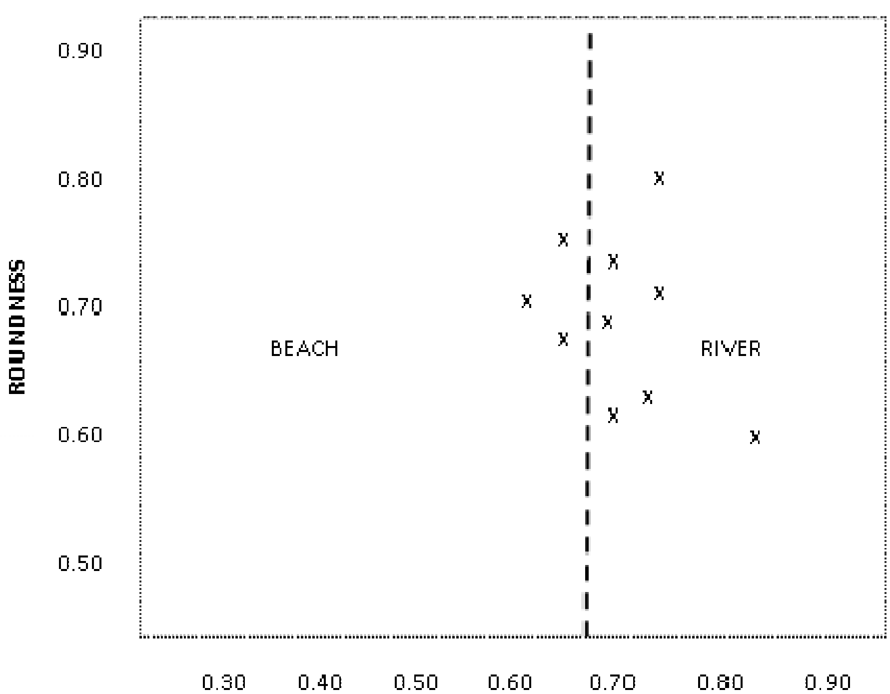

Fig10. Plot of Roundness against Sphericity (after Dobkins and Folk, 1970)

than -7.4190, it indicates a fluvial deposit if Ÿ is greater than -7.4190, it indicates a shallow marine deposit. In this study all the values are less than -7.4190, which indicate sediment deposition in a fluvial environment.

Morphometric Analysis Results and Interpretation

In pebble morphometric interpretation, the dominant forms (shapes) of the samples were obtained from the available data. The mean value of 10 pebbles were taken from the result obtained, the mean values of elongation ratio, flatness ratio, maximum projection sphericity index and oblate – prolate index range from 0.657 to 0.741, 0.397 to 0.484, 0.605 to 0.899 and -1.738 to 1.044 respectively. According to Hubert (1968), the elongation ratio values for fluvial environment ranges from 0.6 to 0.9 (Table 2). All the values of elongation ratio gotten from the morphometric data fall within this range, Maximum projection sphericity of pebbles is generally higher for fluvial environment (river) than for beaches (Dobkins and Folk,1970); Hubert, 1968). An imaginary magic line exist which distinguish pebble shape produced by surf processes from that which occur during fluvial transport (Fig. 8). The range of value for this “magic line” is from 0.65 to 0.66 (Dobkins and Folk, 1970). Pebbles whose value fall within 0.65 and above connote river environment. Values ranging from 0.64 to 0.72 could also go for river environment. Pebbles whose values fall below 0.65 denote beach environment (Inyang, 2001; Inyang and Enang, 2002).

From the result of maximum projection sphericity, all the values fall above 0.65; this is an excellent indication of fluvial action. The elongation ratio as well as the maximum projection sphericity result also reflects a fluvial setting.

The difference in oblate–prolate index between the river and beach are not as marked as much as sphericity difference. Thus, if the oblate – prolate index for a suite of ten pebbles falls below -2, it is about 87% certain that they are of beach environment, and if the values falls between -1 and +5, it is 69% certain that they are of fluvial environment. From this study the results of the value range between -1.783 and 1.594 which implies that the pebbles were all of fluvial origin.

Sphericity decreases with beach abrasion, but remains constant or increases slightly with fluvial transport, Sneed and Folk (1958). According to Dobkins and Folk (1970), Folk (1974), and Hubert (1968), large pebbles are most discoidal in size for beach gravel. River pebbles have the lowest roundness, highest sphericity and neutral oblate–prolate index.

Using the various bivariate plots of maximum projection sphericity against oblate–prolate index (Fig.9); and coefficient of flatness against sphericity (Fig.10), and roundness against maximum projection sphericity (Fig. 9), there is a clear indication that the pebbles were deposited in fluvial environment as the samples plotted within the fields of river environment.

SUMMARY AND CONCLUSION

Lithofacies interpretation was used as the primary tool for identifying the depositional conditions under which the Turonian sediments of the Eze-Aku Formation were deposited and preserved. The lithofacies consists mainly of orthoconglomeratic sandstone, paraconglomeratic sandstone, pebbly sandstone and shale (barely exposed in outcrop sections).

Detailed Sedimentological analyses show the hydrodynamic conditions prevalent at the time of deposition of the strata encountered at Uwakande 1 Obubra, southeastern Nigeria. The mean phi grain size (which is 0.04), as well as average value of skewness (+0.61), indicates that the coarse particles exceed fines. This also indicates that the transporting medium was high energy, and the mode of transport restricted to traction and saltation. The average of the coefficient of sorting (1.27) indicates poor sorting. The angularity of the detritus and general poor sorting indicates the first cycle deposition with a short transportation history. Also the very coarse grains and poor sorting implies that the sediments were deposited in a conglomeratic, coarse-grained braided river, developed probably when the discharge fluctuates widely, the volume of bed load is high, or the slope over which the river flows is relatively steep. These factors combine to cause a dumping of the sediments after a short distance of transportation. Kurtosis values vary from Platykurtic (0.78 and 0.89), Mesokurtic (1.05 and 1.06) and Leptokurtic (1.13, 1.19, and 1.46). This variation indicates that the sediments were deposited at different stream powers.

The sub-rounded to rounded nature of the pebbles as obtained from pebble morphometric analysis, show that they have been moved by a high energy medium within a short period of transport. This suggests that the sediment source area is close to the environment of deposition. The sediments could probably have originated from the highlands of Cameroon Mountain or from the igneous rocks of Obudu area, southeastern Nigeria.

From the pebble morphometric analysis results, all the values of elongation ratio fall within the limit for a fluvial environment ranging from 0.6 – 0.9 (see Hubert,1968). The high values (greater than 0.66) of maximum projection sphericity also indicates a fluvial setting. However, the various bivariate plots and the multivariate plot suggested by Sahu (1964) also indicate a fluvial setting. This is obtained when Ÿ is less than -7.4190. All the values of the multivariate plots are less than -7.4190.

From field observations, it was apparent that the level of compaction and lithification have not been so intense.

This may be attributed to the shallow depth at the outcrop locations, hence the use of the term gravels is preferred to conglomerates in describing the pebble sub-facies. There is no imbrication or preferred orientation shown by the pebbles.

Based on field observations of the outcrop samples, textural characteristics of the sand grains and laboratory grain size analysis and morphometric properties of the pebbles, the Turonian Eze-Aku strata at Uwakande 1, Obubra, southeastern Nigeria is suggested by this study to have been deposited in a fluvial (braided River) environment.

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