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Sedimentology and Depositional Environment of the Mid-Maastritchtian Ajali Sandstone inIdah and Environs, Northern Anambra Basin, Northcentral Nigeria

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Abstract: *Outcrops of Mid-Maastrichtian strata belonging to the Ajali Sandstone in the northern Anambra Basin, Northcentral Nigeria were mapped and logged. Samples were studied and used to determine textural and mineralogical characteristics, and paleoccurrent direction, provenance, palaeoenvironment and palaeogeography so as to develop a depositional history for the rocks in the study area. On the basis of the lithologic and sedimentary characteristics, the rocks have been grouped into two facies from bottom to top; cross-bedded sandstone facies and shale facies. On the basis of Grain size analysis, it reveals that the sandstones are white to red friable, coarse-grained, poorly sorted, leptokurtic, positively skewed flaser bedded, planar, and herringbone cross-bedded, but exhibit a fining-upwards sequence. The abundance of the very stable heavy-mineral species (zircon and tourmaline), their high degree of rounding, and overgrowths on tourmaline in the quartz arenites confirm their derivation from a pre-existing sedimentary rock source and, therefore, of a multicycle origin. The detrital rutile is derived from high grade metamorphic rocks. Paleocurrent framework, heavy-mineral and textural characteristics of the Ajali Sandstone of northcentral Nigeria revealed a provenace of the SantonianOkigwe-Abakaliki uplift was the major source area. Palaeocurrent analysis of the cross beds of the sandstones shows a unimodal high variability pattern indicating mainly NW-SE and as minor E-W directions of flow current as being responsible for their transportation. A continental (fluvio-deltaic) environment is proposed for the sandstones on the basis of grain size analysis, sedimentary structures, linear discriminate analysis, heavy mineral and palaeocurrent analysis. A depositional history proposed for the sandstone is that ancient sands were derived from both the pre-existing sedimentary, igneous and metamorphic rocks of the Nigerian Basement Complex by two ancient rivers flowing in both NW-SE and E-W directions.*
Keywords *-Ajali, Sandstone, Anambra Basin, Sedimentology, Environment*

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I. Introduction

Wright et al. (1985) defined the Anambra Basin as "the upper Senonian to Palaeocene depositional area located at the southern end of the Benue Trough, within which the Nkporo Group and younger sediments accumulated and which extended towards the southwest as the Niger Delta Basin". This definition lumps the lithofacies of three distinct basins into one continuous series simply on the basis of contiguity. Akande and Erdtmann (1998) and Obaje et al. (1999) consider the Anambra Basin a part and parcel of the Benue Trough on the premise that it is a consequence of the compressional history/stage of the trough. The genetic relationship notwithstanding, the basins are treated as separate entities. The perspective here is that the Anambra Basin is a distinct lithostratigraphic entity overlying the southern Benue Trough and is in turn overlain in its southern reaches by the Niger Delta Basin (Fig. 1).

The Anambra basin, it is generally characterized by sediments of Cretaceous and younger ages. Detrital rocks are formed by the sedimentation of minerals and rock fragments that were derived from mechanical breakdown of pre-existing rocks in the source area, and were transported to a depositional site (basin). These sediments could later form sedimentary rocks (shale, siltstones, sandstones, or conglomerates) after undergoing lithification, Often times, the rocks bear evidence of their depositional environment, transporting medium and original mineralogical composition. Such evidences can be reflected on the grain textures, sedimentary structures, and mineralogical composition. These indicators serve as tools for reconstructing ancient environments of deposition and provenance as well as establishing transportational, depositional and diagenetic histories of such rocks.

Due to paucity of documented interpretation and poor and limited knowledge on Sedimentology and depositional environments of the Maastrichtian Ajali Sandstone in the study area that perhaps may be attributed to lack of detail geological mapping, poor area accessibility, and few available surface sections.

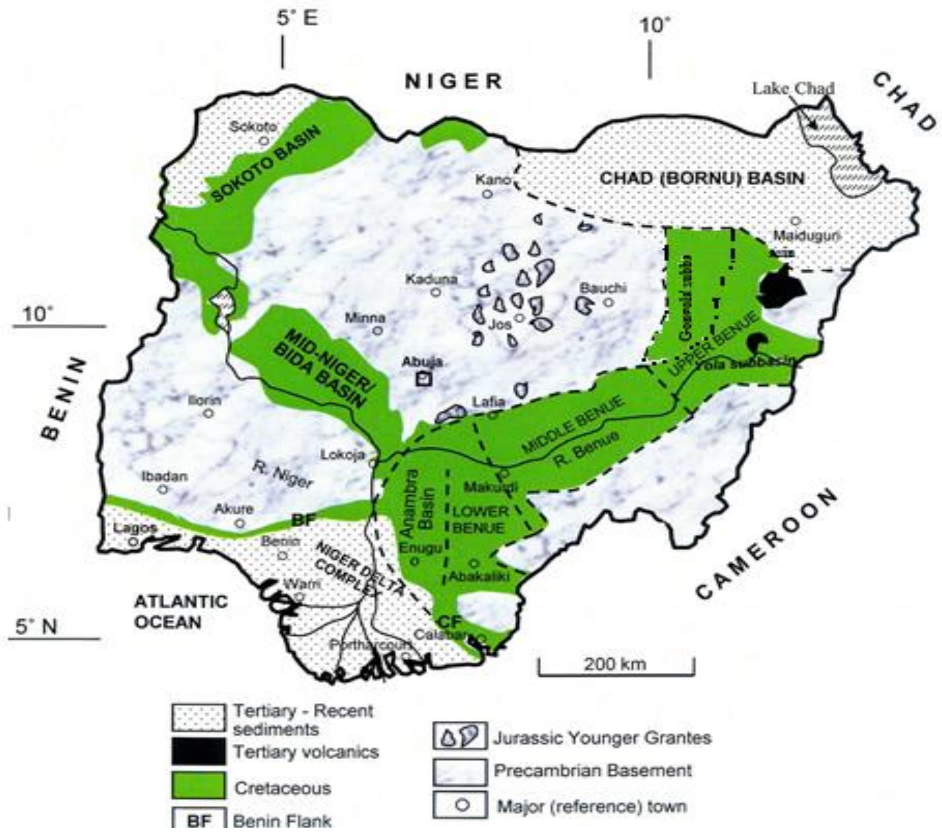

Fig. 1 Geological map of Nigeria showing the northern Anambra Basin (Modified after Obaje, 2009).

It was found that the study area consists of two major rock types namely shale and sandstone. These rocks are exposed at gullies, hills and road cuts with the sandstone underlying the shale. Common surface exposures are mainly sandstones, which occur in most parts of the study area and form the major objective of this study. Representative samples of these rocks were collected and were further subjected to various laboratory studies, which included grain size analysis and heavy mineral separation. The field study also involved careful study of primary sedimentary structures in order to establish palaeocurrent direction for the sandstones. Combination of both field observations and interpretation of results obtained from the laboratory studies were used to establish the sedimentological properties; provenance, palaeoenviroment and depositional histories as well as palaeogeography of the study area.

II Study Area

The study area is located in Kogi State, north central Nigeria and it lies within latitudes 7° 06' 00"N to 7° 21' 00" N and longitudes 6° 43' 00" E to 6° 58' 00"E.The area is a segment of the northern Anambra basin which basically consists of Manu Formation and Ajali Sandstone. Anambra basin itself comprises on almost triangular shaped embayment covering an area of about 30, 000 sqkm, it stretches from the area just south of the confluence of the river Niger and Benue across to area around Auchi, Okene, Agbo and Asaba west of the river and Anyigba, Idah (the study area), Nsukka, Onitah and Awka area, east of the river. The surface area of the basin is marked by the Udi, Idah and Kabba escarpments to the east, north and northwest respectively (Offodile 2002).

III Methodology

Traverses were taken, directional bearing were obtained with the aid of compass and Geographic Positioning System (GPS) along major roads and minor footpaths while sampling of representative rock units was carried out concurrently from exposures. Attention was devoted to locating stratigraphic outcrop sections which are mainly exposed along gullies and road cuts. Fresh samples were carefully collected from each section weathered layers which may give inaccurate results were avoided. Vital information like location, sample number, horizon description such as; lithologies, colours, sedimentary structures from each unit and date of the sampling were clearly indicated on the sample bags and all the relevant data were written in field.

A total of 9 samples from Ajali Sandstone were selected from different locations for sieve analysis while four samples were collected for heavy mineral analyses atSedimentology Laboratory, Department of

Geology Ahmadu Bello University Zaria and Sedimentology Laboratory, Department of Earth Sciences, Kogi State University, Anyigba. Granulometric analysis (sieve analysis) was carried out on the samples with primary aim of determining particles size distribution and other grain size parameters like sorting, skewness, mean and kurtosis. The statistical parameters of the grain size frequency distribution were obtained and computed using method used by Folk and Ward (1957).These were used as an independent function or combined in multivariate analysis such as the Linear Discriminate Function(LDF) and Coarse Median (CM) pattern to interpret the depositional environments and processes. For the CM pattern, parameter C (one percentile of the grain size distribution) and M (the median) were plotted with phi values of the C and M obtained from cumulative curves in phi and converted to microns using the standard formular µm= $2^{-\phi}$ x 1000.For heavy mineral analysis, the sandstones were sieved to obtain the very fine to fine sand fractions (4 phi preferred) which are commonly analyzed because it is the size fraction likely to contain the highest percentage of heavy minerals.The heavy minerals were finally identified with the help of a binocular microscope.

In addition, the azimuthal readings of the dip directions of all types of cross-stratification generated by the flow within the limits of preservation were measured in the field for paleocurrent studies. A total of 45 readings of cross-strata azimuthal dip directions were taken from beds of the Ajali Sandstone.Current roses were plotted and standard deviations computed from the measured data.

IV Results and Discussion

Lithostratigraphic sections

Outcrops of Ajali Sandstone were studied in the southern to western part of the study area towards Ikare from Ajaka main town (Figure 2). They occurred as lateratized shale with thin beds of very fine-grained sandstone and siltstone (Plate I). A section was studied at Ogbogba, west of Ajaka town and found to comprise a 8.0 m thick white, coarse grained, friable moderately sorted sandstone with a thin lens of clay, alternation of red and white friable moderately sorted sandstone, white coarse grained, poorly sorted sandstone with clasts ranging from angular to subangular, white coarse grained poorly sorted ferruginized sandstone and coarse grained friable dirty red sandstone, alternation of milky white, yellow, grey and brown parallel laminated sandstone (Plate I, II, III and Figure 3). Sedimentary structures in the Ajali Sandstone are flaser cross-bedding, tabular cross-bedding and reactivation surfaces occur (Plate I, II, III, Figure 2 and 3).Lithologic description of Ajali Sandstone exposed at Ikare Road, south of Ajaka town, comprises of a 8.0 m thick intercalation of dark yellow to grey lateratized fissile shale and dirty red very thin lens of very fine sandstone and siltstone (Plate I and Fig. 2).Predominance of argillaceous and fine grained strata indicate a low energy or quiet environment. The yellow to light grey colour suggests oxicpalaeo environmental conditions.

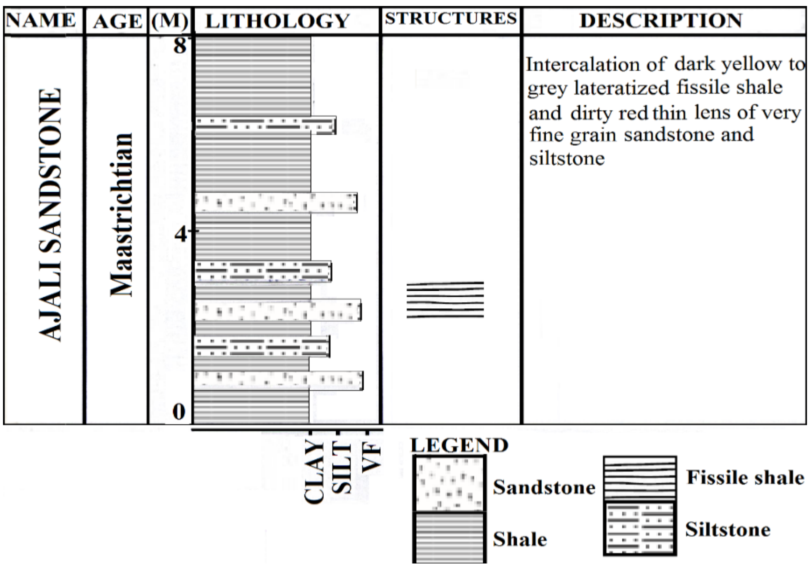

Fig. 2: Lithostratigraphic section of lateratizedshales of Ajali Sandstone exposed at Ikare Road, south of Ajaka town.

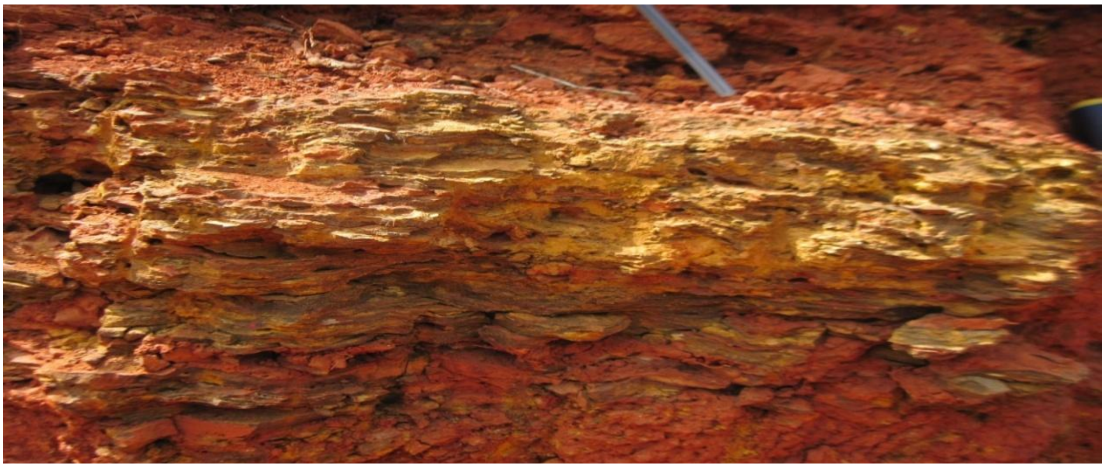

Plate I: Ajali Sandstone exposed at Ikare Road, south of Ajaka town.

Lithologic section of Ajali Sandstone exposed northwest of Ogbogba town comprises of (i) a 3 m thick of white coarse grained, friable, moderately sorted, tabular cross-bedded sandstone with clast ranging from angular to well rounded towards the base and reactivation surfaces overlain by (ii) a 0.7 m thick alternation of red and white, friable, poorly sorted, negatively skewed, mesokurtic, flaser cross – bedded coarse grained sandstone which passes upward into (iii) a bed of a 1.8 m thick poorly sorted, coarse to gravel grained, near symmetrical, mesokurtic, herringbone cross-bedded sandstone with wave ripples and clasts ranging from angular to subangular (plate II and III). The bed shows a change in clast,that is pebbly coarse grain highlighting the base of the bedset and lens of clay towards the top of the bed showing a fining upward sequence respectively and in turn overlain by (iv) a 0.7 m thick bed of white, coarse grained, poorly sorted, ferruginized, flaser cross-bedded sandstone. The ferruginied, flaser cross-bedded sandstone overlie a 1 m thick coarse grained, friable, moderately sorted, negatively skewed, platykurtic, dirty red sandstone which is overlain by (v) a 0.5 m thick medium grained, poorly sorted, near symmetrical, very platykurtic, tabular cross-bedded sandstone which transit into (vi) a 0.5 m thick, medium grained, poorly sorted, near symmetrical, very platykurtic, tabular cross-bedded sandstone underlying a (vii) 0.8 m thick bed of intercalation of dark yellow to grey, lateritized fissile shale and dirty red thin lens of very fine sandstone and siltstone terminating the section (Fig. 3).

The variation in clast, that is from pebbly coarse highlighting the base of the bed set indicating a repetitive fining upward sequence suggest a change in energy flow from high energy to low energy. The presence of reactivation surface (Plate III) within Ajali Sandstone suggests fluvial action (Reading, 1996; Tucker, 1996) suggests that the presences of flaser bedding are linked to tidal influence. Flaser bedding is where cross-laminated sandstone contains mud streaks, usually in the ripple troughs. It is common in tidal-flat and delta front sediments, where there are fluctuations in sediment supply or level of current (or wave) activities (Tucker, 1996). These features suggest a tidally influenced fluvial – and fluvial channels and deltaic depositional environment.

Plate II: Ajali Sandstone exposed at Ogbogba Hill northwest Ogbogba town.

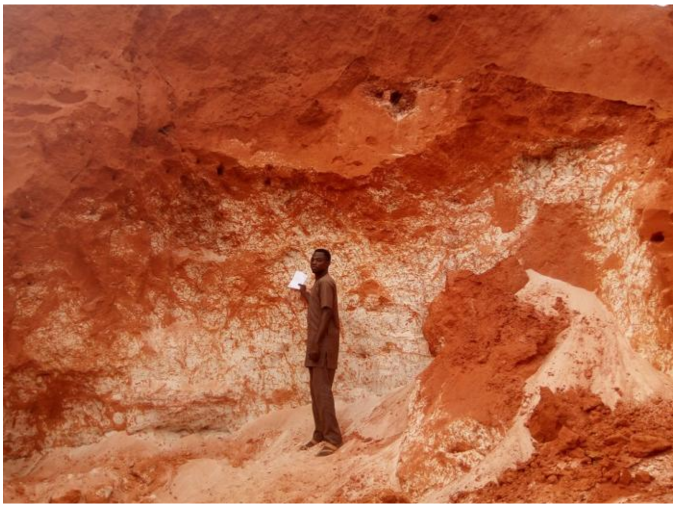

Plate III: Ajali Sandstone exposed at Ogbogba Hill northwest Ogbogba town.

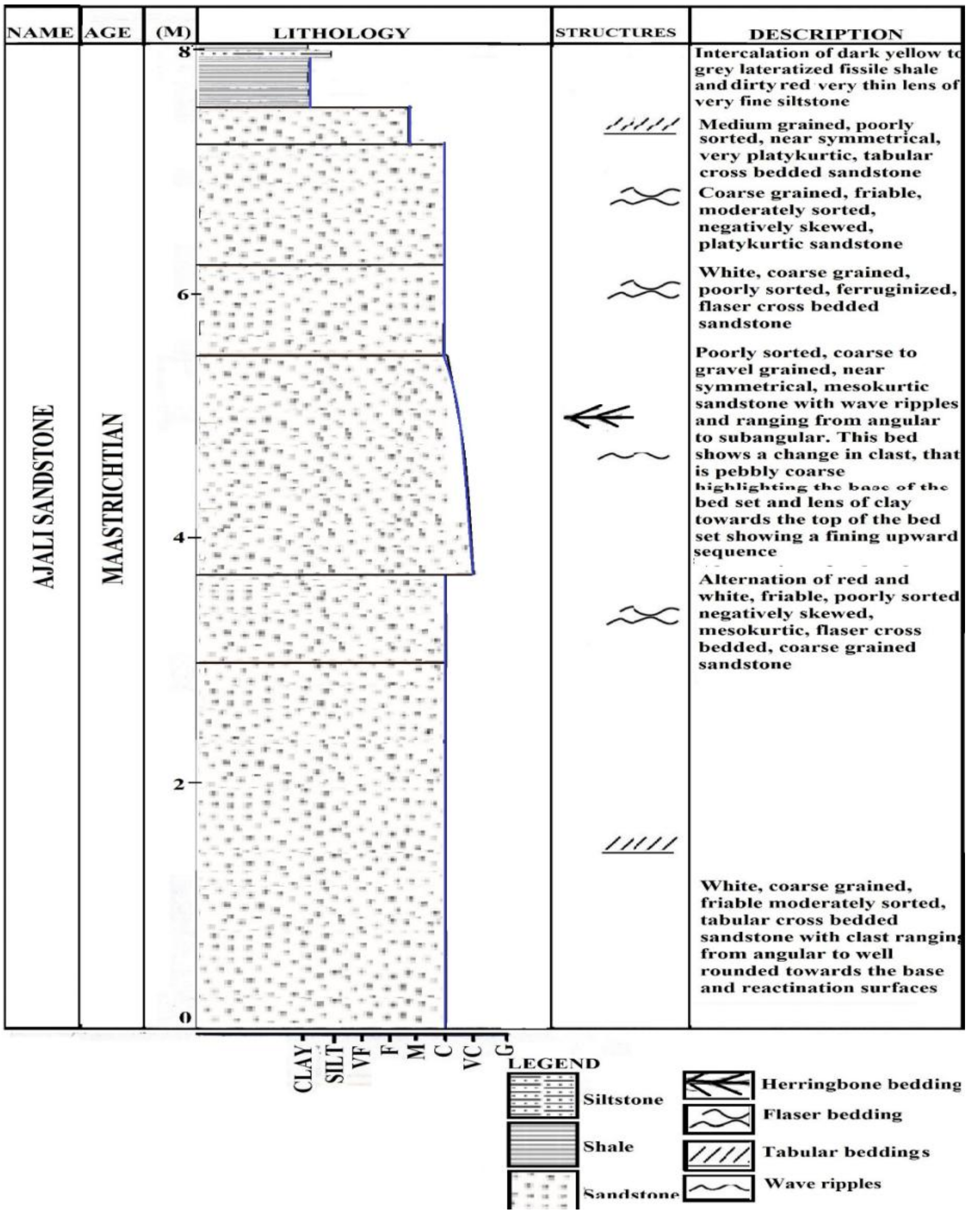

Fig. 3: Lithostratigraphic section of Ajali Sandstone exposed at Ogbogba Hill northwest Ogbogba town.

Granulometric Studies

The mean grain size in a deposit is generally a function of the energy of the processes controlling transport and deposition, that is, particles are segregated according to their hydrodynamic behaviour which depends on the size, specific gravity and shape. In contrast, the degree of sorting of grains in a deposit is a function of the persistence and stability of the energy condition except by availability of grains that can be deposited in the environment.Nine samples were sieved and statistical parameters of each of the sandstone samples were determined as presented in Table 1and Fig. 4.

The histogram plots of the cumulative weight percentage against phi scale show that the sandstone facies of Ajali Sandstone in the study area are unimodal (Fig. 5).The scatter plot between mean size and standard deviation (Fig. 6) shows that 44.40% of the samples fall in the river process field while 55.60%of the samples falls in the inner shelf. It indicates fluvial signature in the sediments and therefore the depositional environment is dominantly a fluvial system. These indicate samples support mixing of populations as indicated by kurtosis values (Table 1).

Table 1: Grain size distribution and quantitative parameters of samples of the sandstone facies of Ajali Sandstone in the study area.

Sample ID	Mean (mm)	Sorting (ϕ)	Skewness (ϕ)	Kurtosis
AJ1	0.920 Coarse sand	1.370 Poorly sorted	-0.230 Negatively skewed	0.920 Mesokurtic
AJ2	0.800 Coarse sand	0.990 Moderately sorted	-1.900 Negatively skewed	0.770 Platykurtic
AJ3	0.980 Coarse sand	1.110 Poorly sorted	-0.230 Negatively skewed	1.040 Mesokurtic
AJ4	-0.020 Gravel	1.020 Poorly sorted	0.040 Near symmetrical	1.000 Mesokurtic
AJ5	0.850 Coarse sand	1.000 Moderately sorted	-0.140 Negatively skewed	0.820 Platykurtic
AJ6	0.200 Coarse sand	1.520 Poorly sorted	-0.095 Negatively skewed	1.430 Leptokurtic
AJ7	0.800 Coarse sand	1.970 Poorly sorted	-0.100 Negatively skewed	0.730 Platykurtic
AJ8	1.200 Medium sand	0.220 Poorly sorted	0.070 Near symmetrical	0.640 V.platykurtic
AJ9	0.850 Coarse sand	1.000 Moderately sorted	-0.140 Negatively skewed	0.820 Platykurtic

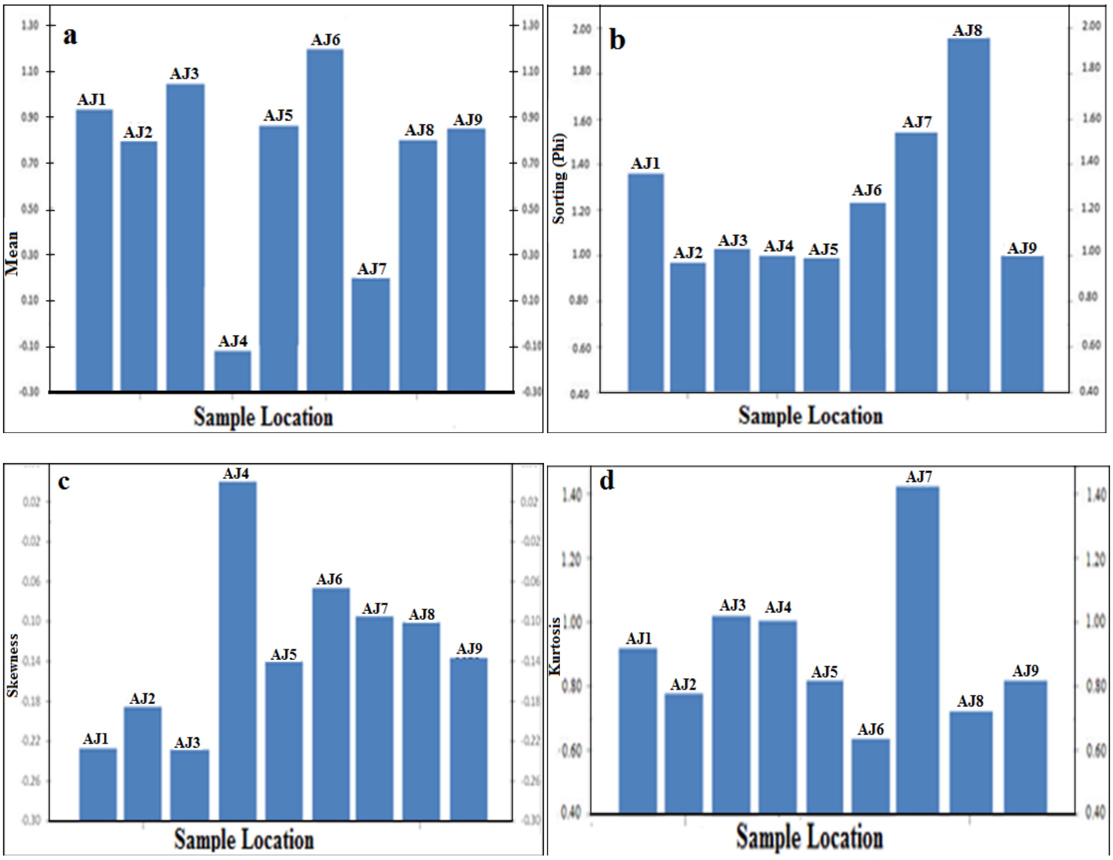

Fig. 4: Average values of grain size statistical parameters of the study area: (a) mean; (b) sorting; (c) skewness and (d) kurtosis

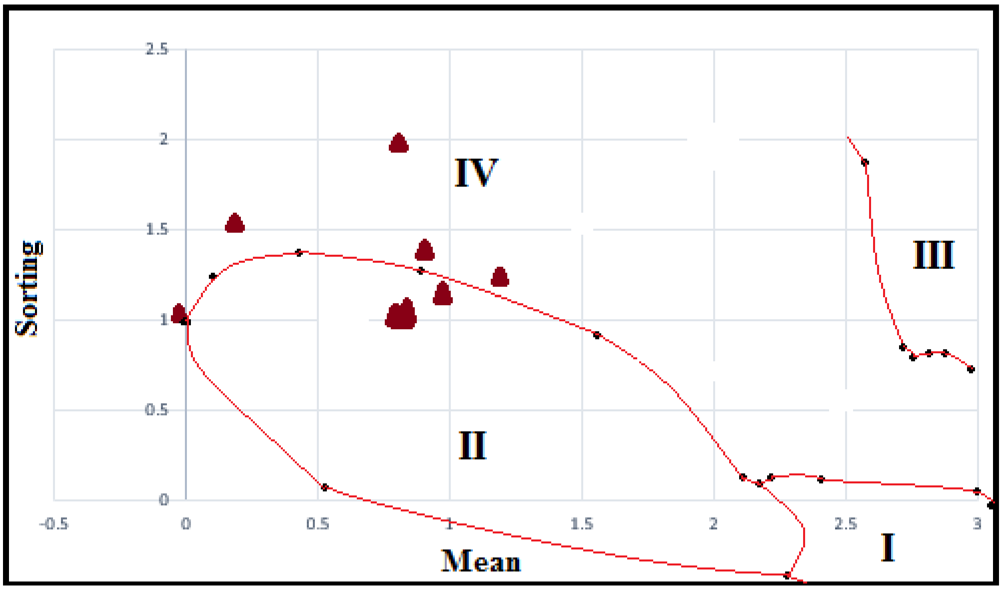

Fig. 5: Energy Process diagram (after Stewart, 1958) I Beach Process; II River Process; III Quiet water; IV Inner shelf.

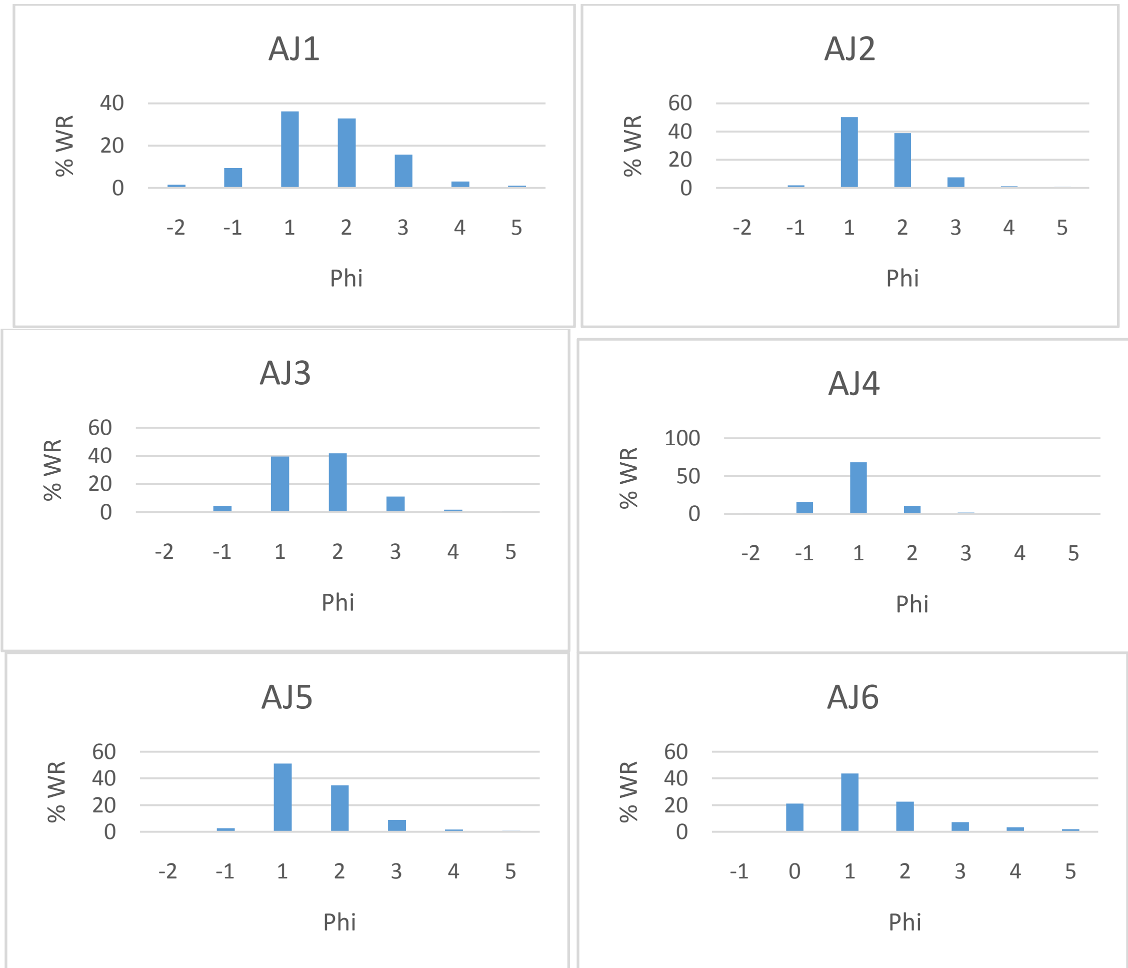

Fig. 6: Histogram plots of the Ajali Sandstone that underlie the study area.

Linear Discriminate Function

According to Sahu (1964), the statistical method of analysis of the sediments to interpret the variations in the energy and fluidity factors seems to have excellent correlation with the different processes and the environment of deposition. Linear discriminate function (LDF) analysis of the sediment samples was carried out using the following equations shown.

(i). For the discrimination between Aeolian process and Littoral (intertidal zone) environment, the following equation was used:

$Y_{1(A:B)} = -3.5688\ M + 3.7016\sigma I^2 - 2.0766\ SK + 3.1135\ KG$

If Y is >−2.7411, Beach is suggestedbut if Y is <−2.7411, Aeolian deposition is indicated.

(ii). For the discrimination between Beach (back shore) and Shallow agitated marine environment (sub – tidal environment), the following equation was used:

$Y_{2(B:SM)} = 15.6534\ M + 65.7091\ \sigma I^2 + 18.1071\ SK + 18.5043\ KG$

If Y is <63.3650, the environment is ‘Beach (backshore)’ but if Y is >63.3650, the environment is ‘Shallow agitated marine’ (sub – tidal environment).

(iii). For the discrimination between Shallow agitated marine environment (sub – tidal environment) and the fluvial deltaic environment, the following equation was used:

$Y_{3(SM:F)} = 0.2852\ M - 8.7604\sigma I^2 - 4.8932SK + 0.0482KG$

If Y is >−7.4190, the environment is ‘Shallow marine’ (sub – tidal)but if Y is <−7.4190, the environment is ‘Fluvial deltaic’.

Where M is the mean grain size, ***σ***I is the inclusive graphic standard deviation (sorting), SK is the skewness and KG is the graphic kurtosis.

The three discriminate functions (Y1, Y2 and Y3) were plotted as bivariate scatter plots and used to improve the success rate and refinement of the discrimination of the depositional environment. Fig. 7shows the scatter plot of Y1 and Y2. Based on the classification of depositional environments using Y2 Vs Y1 graph, 97.83% of the analysed sandstone samples in this study were plotted within the field of beach/shallow marine environment while 2.17% were plotted within the field of Aeolian shallow agitated. These graphs were divided into three fields (1) the eolian processes/beach environment, (2) beach and littoral environment and (3) beach environment/shallow marine agitated deposition (Sahu, 1964). A similar plot of Y3 Vs Y2 to distinguished fluvial deltaic and beach deposits shows that 91.30% of the samples were plotted in the fluvial deltaic field while 8.70% were plotted within turbidity field (Table 2 and Fig. 8).

Table 2: Linear discriminate function of sandstone facies of Ajali Sandstone(After Sahu, 1964).

Sample ID	Y1	Remark	Y2	Remark	Y3	Remark
AJ1	7.01	Beach	150.59	Shallow Agitated marine (subtidal)	-15.01	Fluvial deltaic
AJ2	3.57	Beach	87.73	Shallow Agitated marine (subtidal)	-7.39	Sha. marine
AJ3	4.78	Beach	111.38	Shallow Agitated marine (subtidal)	-9.34	Fluvial deltaic
AJ4	6.95	Beach	87.28	Shallow Agitated marine (subtidal)	-9.27	Fluvial deltaic
AJ5	3.51	Beach	91.65	Shallow Agitated marine (subtidal)	-7.79	Fluvial deltaic
AJ6	13.98	Beach	180.06	Shallow Agitated marine (subtidal)	-19.65	Fluvial deltaic
AJ7	21.78	Beach	261.12	Shallow Agitated marine (subtidal)	-28.35	Fluvial deltaic
AJ8	3.37	Beach	127.16	Shallow Agitated marine (subtidal)	-12.32	Fluvial deltaic
AJ9	5.59	Beach	73.55	Shallow Agitated marine (subtidal)	-2.90	Fluvial deltaic
		100%		100%		Fd=84.60% Sm=15.40%

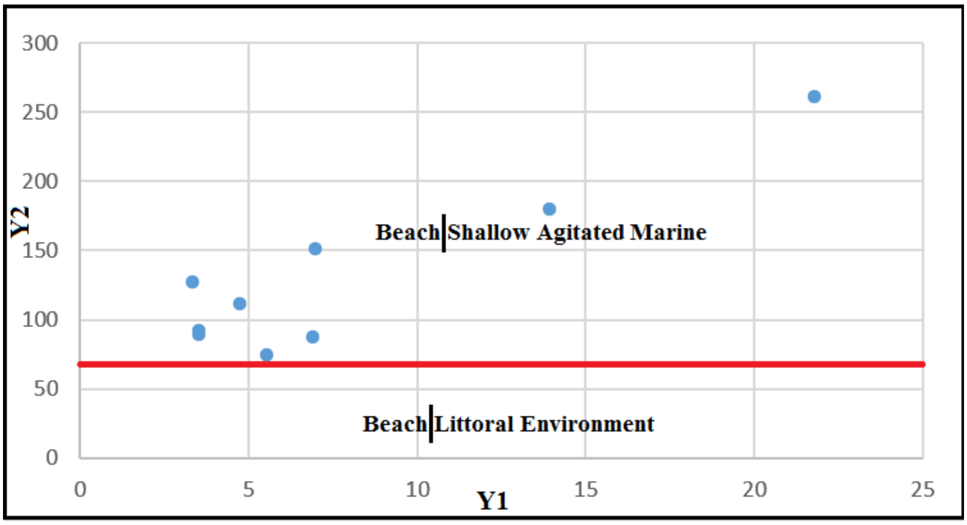

Fig. 7: Linear Discriminate Function (LDF) Y1 Vs Y2 scatter plot for the sandstone facies of Ajali Sandstone in the study area.

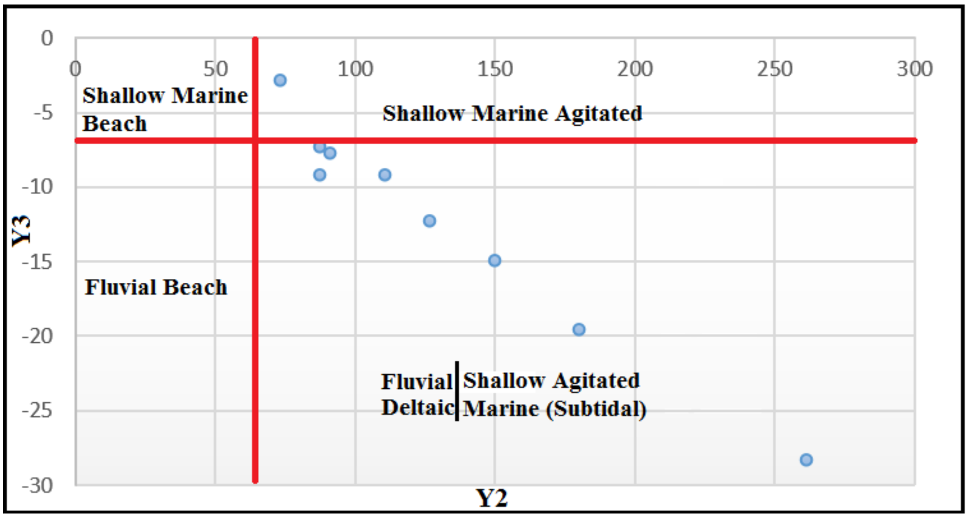

Fig. 8: Linear Discriminate Function (LDF) Y2 Vs Y3 scatter plot for the sandstone facies of Ajali Sandstone in the study area.

CM Pattern

Grain size parameters and the plots of CM patterns help to distinguish between the sediments of different environments of fluvial and deltaic deposits (Passega, 1964; Visher, 1969). In the present study, an attempt has been made to identify the modes of deposition of sediments of the area northeast of Idah by CM pattern. Parameter C (one percentile of the grain size distribution) and M (the median) were plotted with phi values of the C and M obtained from cumulative curves in microns (Fig. 9). The relation between C and M is the effect of sorting by bottom turbulence. CM pattern is subdivided into three segments namely, NO (rolling), OPQ (bottom suspension and rolling), QR (graded suspension no rolling), RS (uniform suspension), S (pelagic suspension). The plotted results of northeast of Idah sediments shows that 65.2% of the samples fall in rolling while 35.8% fall in bottom suspension and rolling condition (Fig. 9).

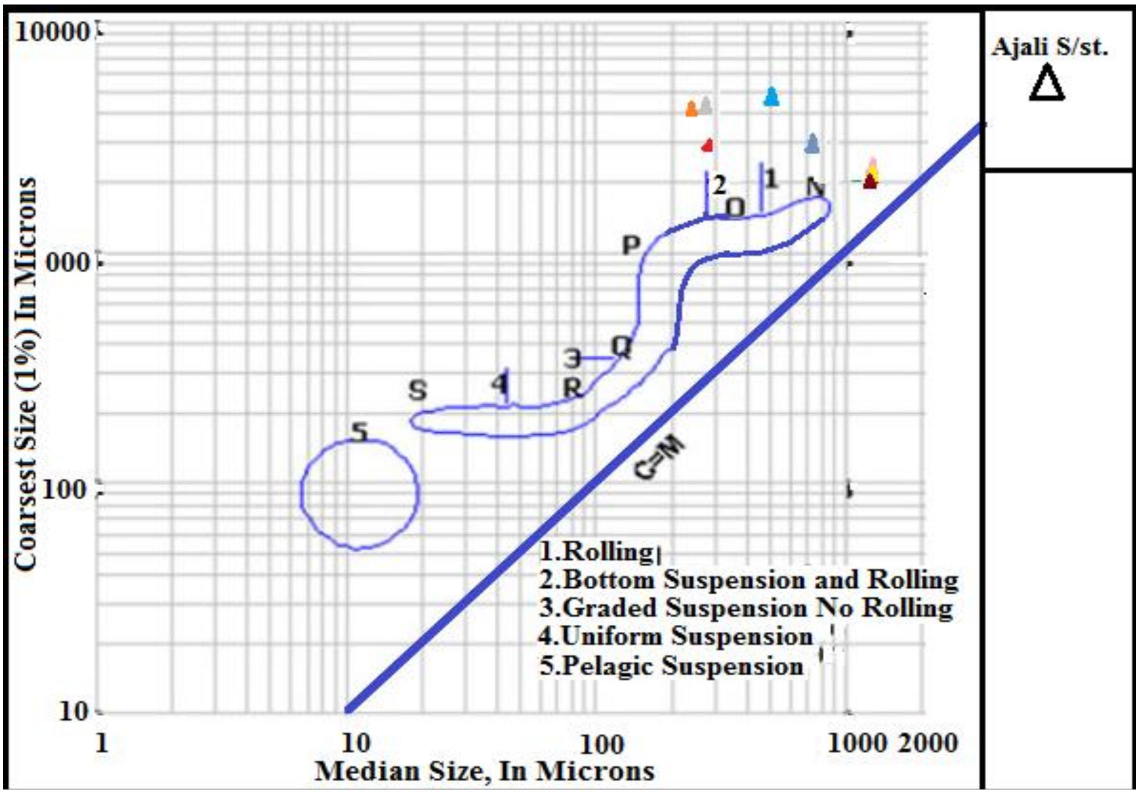

Fig. 9: CM diagram for sandstone facies samples in the study area showing sedimentary processes in the Ajali Sandstone to include rolling, bottom suspension and rolling(Passega1957, 1964).

Paleocurrent Studies

Cross-stratification is ubiquitous in the sandstone facies of the Ajali Sandstone in the study area. The cross-beds range from large-scale tabular, wedge-shaped and trough to small-scale ripple and herringbone cross-strata (Hoque, 1976, 1977; Banerjee, 1979; Ladipo, 1985; Amajor, 1986). The average length of a cross-stratum is about 90 cm. Foreset contacts vary from scoured through curved to sharp parallel plane surfaces. In some beds the cross-strata are graded, with coarse sand at the base and fine sand at top. In others, suspension deposits drape foreset strata whereas others show a pronounced alternation of coarse and fine cross-strata (Tables 3 and Fig. 10 and 11).

Table 3: Azimuthal readings and statistical values for the sandstone facies of Ajali Sandstone in the study area.

S/N	Azimuthal Reading (X)	F	$F(X)$	$X-\bar{X}$	$(X-\bar{X})^2$	$F(X-\bar{X})^2$	%	Foreset dip
1	30	1	30	-230	53268.64	53268.64	2.2	21
2	47	1	47	-213.8	45710.44	45710.44	2.2	24
3	249	1	249	-11.8	139.24	139.24	2.2	18
4	254	3	762	-6.8	46.24	138.72	6.7	22
5	255	1	255	-5.8	33.64	33.64	2.2	22
6	257	1	257	-3.8	14.44	14.44	2.2	23
7	259	2	518	-1.8	3.24	6.48	4.4	21
8	260	2	520	-0.8	0.64	1.28	4.4	23
9	261	1	261	0.2	0.04	0.04	2.2	21
10	262	1	262	1.2	1.44	1.44	2.2	20
11	265	4	1060	4.2	17.64	70.56	8.9	18
12	270	6	1620	9.2	84.64	507.84	13.3	22
13	271	1	271	10.2	104.04	104.04	2.2	22
14	274	2	548	13.2	174.24	348.48	4.4	25
15	275	5	1375	14.2	201.64	1008.2	11.1	19
16	276	1	276	15.2	231.04	231.04	2.2	18
17	280	3	840	19.2	368.64	1105.92	6.7	24
18	281	2	562	20.2	408.04	816.08	4.4	21
19	286	3	858	25.2	635.04	1905.12	6.7	25

20	288	1	288	27.2	739.84	739.84	2.2	21
21	291	2	582	30.2	912.04	1824.08	4.4	23
22	297	1	297	36.2	1310.44	1310.44	2.2	22
		$\sum F$ =45	$\sum F(X)$=11738			$\sum F(X-\bar{X})2$=109286		

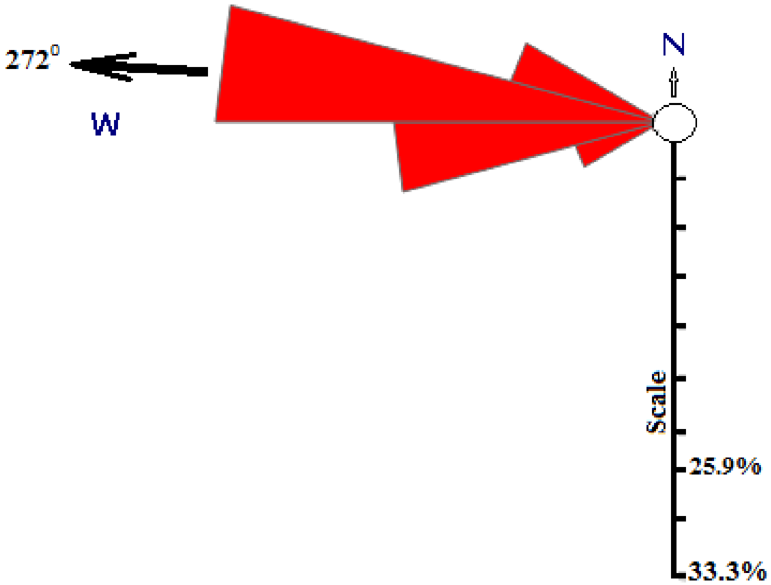

Fig. 10: Paleocurrent pattern from cross bed azimuths in the Ajali Sandstone showing a unimodal high variability pattern in the NWW direction in fluvial environment.

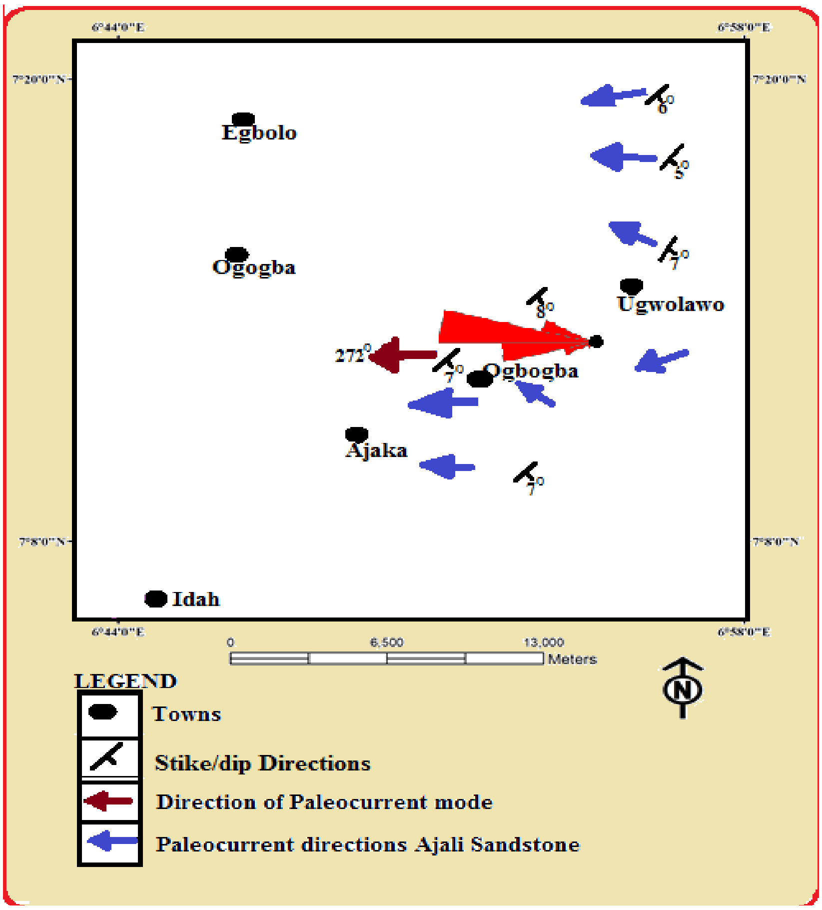

Fig. 11: Paleocurrent map of the Maastrichtian Ajali Sandstone in the study area

The paleocurrent of the sandstone facies of Ajali Sandstone was determined using paleocurrent analysis. Current rose diagrams plotted was used and studied to identify the paleocurrent directions (Fig. 10 to 11).The paleocurrent analysis result shows that the variance value is 2,429. This value indicates that Ajali Sandstone was deposited in fluvial-deltaic environment (Tanner, 1955; Pryor, 1960 and Selley, 1966). The value of the mean vector azimuth indicates 272^o (Table 3). This value and the rose diagram (Fig. 10) suggest that the direction of paleocurrent as at the time of deposition, acted in northwest direction and the provenance was southeast. The rose diagram reflects unimodal high variability paleocurrent pattern for the Ajali Sandstone (Fig. 10). These paleocurrent patterns (unimodal) suggest sediments deposited in an environment where fluvial currents was prevalent with net long – shore marine transport (Selley, 1966). The direction of provenance indicated that the sediments of the Ajali Sandstone in the study area were sourced from the Basement Complex of Nigeria probably the Cameroun Mountains in southeastern part of the country and or the adjacent northeast trending Okigwe-Abakaliki anticlinorium of Santonian age. This conforms to the measurements made by Hoque and Ezepu (1977), Amajor (1987), Obi (2000) and Nwajide (2014).

The radiating paleocurrent pattern is regionally significant because the trends are oriented towards the paleo-strandline and parallel to the regional structural dip (Fig. 10). This suggests that the original depositional basin in which the Ajali sands accumulated had a similar shape and orientation and that the paleocurrent system, paleoslope and, perhaps, the sediment dispersal pattern in the basin were all nearly parallel to one another.These paleocurrent data suggest that the Santonian uplift shed Ajali clastics into the Anambra and western sector of the Afikpo Basin. The implication for the paleoslope is that it was generally to the west and southwest. This would place the sediment dispersal centre, i.e. the geographical location of the provenance area, to the east and northeast, which is largely the Abakaliki fold belt.

Heavy Minerals

Four samples collected for heavy minerals analysis from Ajali Sandstone in the study area were denoted as UGB1, EM1, OGB1 and OJU1.Heavy mineral suite consists of both opaque and non-opaque forms, and showed moderate diversity. The identified heavy minerals include zircon, apatite, rutile, tourmaline, garnet, staurolite, hematite and magnetite. The latter two were grouped together as opaque minerals. The opaque minerals constitute 11.37%, on the average while the non-opaque has the following composition: tourmaline (30.81%), rutile (4.74%), staurolite (5.68%), zircon (42.18%), apatite (4.74%) and garnet (0.47%) as presented in Table 4. The average ZTR% index is 87.73% with Rutile as the least abundant of ultra-stable mineral. This value indicates sub-mature to immature mineralogy of the sandstone.

Table 4: Relative abundances of heavy mineral assemblages in the study area

Sample location	Zircon	Tourmaline	Rutile	Apatite	Staurolite	Garnet	Total	ZRT	ZRT Index (%)	Opaque
Ugb1	25	21	3	1	5		55	49	89.09	8
Emachi	21	14	2	2	1	1	41	37	90.24	5
Ugogba	20	16	3	5	3		47	39	82.98	6
Oju1	23	14	2	2	3		44	39	88.64	5
Total	89	65	10	10	12	1			350.95	24
Percent composition	42.18	30.81	4.74	4.74	5.68	0.47				

The abundance of the very stable heavy-mineral species (zircon and tourmaline), their high degree of rounding, and overgrowths on tourmaline in the quartz arenites confirm their derivation from a pre-existing sedimentary rock source and, therefore, of a multicycle origin (Potter and Pettijohn, 1977). Force (1980) has shown that most detrital rutile is derived from high grade metamorphic rocks. On integration with the paleocurrent pattern, the Oban massif is the likely source. Based on the paleocurrent framework and heavy-mineral and textural characteristics of the Ajali Sandstone of northcentral Nigeria, the SantonianOkigwe-Abakaliki uplift was the major source area. The Oban basement complex is minor. The clastic contributions from these sources are geographically distinct. The Cameroon basement rock complex did not contribute much to the sediments, either because of its distance from the depositional basin and/or the shielding effect of the Santonian uplift.

Palaeogeography

Palaeogeographic history of the study area is established on the basis of grain size distribution pattern, field relation of the sediments, heavy mineral and palaeocurrent analysis.The depositional processes suggested by the assemblage of sedimentary structures present in the lithofacies association of the Ajali Sandstone are regressive (fluvial) processes. The sandstone facies association characterized by herringbone cross bedding, flaser bedding, planar cross bedding, reactivation surfaces, and clay drapes in the study area provide evidence of tidal currents and deposition by oscillatory flow conditions in tide and wave dominated shoreline environments (DeCelles, 1987; DeCelles and Cavazza, 1992; Colguhoun, 1995).The study has shown that the Ajali Formation is a product of fluvial transport and tidal current energy. The heavy mineral suits and paleocurrent analysis suggests that the sediments were sourced from the Abakaliki Anticlinorium and Cameroun highlands and transported by rivers to the coastline where they are shaped by tidal current energy. During the Maastrichtian times, the Anambra shelf was funnel shaped and has an extremely wide, low gradient slope. Elliot (1978) and Schopt (1980) have suggested the width and slope of paleo-shelves as critical paleogeographic factors influencing tidal effects. During the regressive phases, the input from the proto-rivers dominates, leading to a gradual closing and smoothing out of the funnel shaped estuary.The offshore to landward transition in the study area is indicated by the presence of fluvial facies associations, such as the fluvial channel sandstones in the study area. On the basis of the detailed facies analysis, I confirm the influence of fluvial processes in the sedimentation of parts of the Ajali Sandstone in the study area.

V Conclusion

The Ajali Sandstone of the study areahas been subdivided into (2) units or facies on the basis of lithological and sedimentary characteristics observed at outcrop sections sampled. Stratigraphically, the units include; (i) Cross-bedded Sandstone Facies- Base(ii) Shale Facies –Top.The basal cross-bedded facies consists of white to red, fine, medium, coarse to very coarse grained, friable, poorly to moderately sorted sandstone overlain by the topintercalations of yellow to light grey fissile shales with thin very fine-grained sandstone and siltstone. Sedimentary structures such as flaser bedding, planar/tabular cross-bedding, herringbone cross-beddings and reactivation surfaces with wave ripples indicate a tidal flat and delta front environments. The variation in clast; that is from pebbly coarse grained highlighting the base of the bed set indicates a repetitive fining upward sequence, suggesting a change in energy flow from high energy to low energy. The paleocurrent studies indicate northwest direction of flow of water depositing the sediment. The rose diagram reflects unimodal high variability paleocurrent pattern suggesting a fluvial-deltaic environment for Ajali Sandstone in the study area. Mineralogically, the sandstones are made up of the opaque minerals which constitute 11.37%, on the average while the non-opaque has the following composition: tourmaline (30.81%), rutile (4.74%), staurolite (5.68%), zircon (42.18%), apatite (4.74%) and garnet (0.47%) (Table 4). The average ZTR% index is 87.73% with Rutile as the least abundant of ultra-stable mineral. This value indicates sub-mature to immature mineralogy of the sandstone.Based on the paleocurrent framework and heavy-mineral and textural characteristics of the Ajali Sandstone of northcentral Nigeria, the SantonianOkigwe-Abakaliki uplift was the major source area. The Oban basement complex is minor.

The Linear Discriminate plots and Tractive current diagram of the sandstone facies of the Ajali Sandstone in the study area suggests shallow marine environment, most likely a tidal/sub-tidal shore line environment.Comparing the results of the Linear Discriminate Function with the overall results from the sedimentary structures, sieve analysis, CM pattern and paleocurrent analysis shows that the variations in the energy and fluidity factors have excellent correlation with the different processes and the environment of deposition. Therefore, this method of discrimination should be considered as a supporting technique to enhance good paleoenvironmental studies.

References

[1]. S.O.Akande, and Erdtmann, B.D. Burial Metamorphism (Thermal Maturation) in Cretaceous Sediments of the Southern Benue Trough and Anambra Basin, Nigeria.American Association of Petroleum Geologists Bulletin,**82**,1998 P.1191-1206.

[2]. L.C.Amajor.Sedimentary facies analysis of the Campano-Maestrichtian Ajali Sandstone, southeastern Nigeria.Bulletin Nigeria Mining and GeosciencesSociety, **21**, 1986, P. 21.

[3]. L.C.Amajor.Paleocurrent, petrography and provenance analyses of the Ajalli Sandstone (Upper Cretaceous), Southeastern Benue Trough, Nigeria. Sedimentary Geology, **54**, 1987, P. 47-60.

[4]. Banerjee. Analysis of cross bedded sequences: An example from the Maastrichtian Ajali Sandstone of Nigeria. Quart.Journ.of Geol., Min. and Met. Soc., India 51,1979, 69- 81.

[5]. G.P. Colguhoun.Siliciclastic sedimentation on a storm and tide- influenced shelf and shoreline: the Early Devonian Roxbourgh formation, NE Lacthan fold belt; Southeastern Australia. Sedimentary Geolology, **97**, 1995, P. 69–98.

[6]. P.G. DeCelles. Variable preservation of middle Tertiary coarse-grained, nearshore to outershelf storm deposits in southern California.Journal of SedimentaryPetrology, **57**, 1987, P. 250–264.

[7]. P.G.DeCellesand W. Cavazza. Constraints on the formation of Pliocene hummocky cross-stratification in Calabria (southern Italy) from consideration of hydraulic and dispersive, equivalence, grain-flow theory and suspended-load fallout rate.Geological Society of America Bulletin, **93**, 1992, P. 663–680.

[8]. D.H. Elliot. Gondwana basins of Antartica.In Campbell, K.S.W. (Editor) – Gondwana geology. Papers presented at the 3rd Gondwana Symposium, Canberra, Australia, 1983.

[9]. Australian National University Press, Canberra, Australia, 1975, 493-536.

[10]. R.L. Folk and W.C. Ward. Brazos River bar: a study in the significance of grain size parameters. Journal of Sedimentary Petrology **27**,1957, P. 3–26.

[11]. E.R. Force. The provenance of rutile.Journal of Sedimentary Petrology**50**, P. 485–488.

[12]. Hoque M. (1976): Significance of textural and petrographic attributes of sandstones, southern Nigeria [J]. Journal Geological Society of India, **17**, 1980, 514–521.

[13]. M. Hoque. Petrographic differentiation of tectonically controlled Cretaceous sedimentary cycles, southeastern Nigeria. Sedimentary Geology, **17**, 1977, P. 235-245.
[14]. M. Hoqueand C.M. Ezepue.Petrology and paleogeography of the Ajali Sandstone.Journal of Nigeria Mining and Geosciences Society,**14**, 1977, P. 16-22.
[15]. K.O.Ladipo. Paleogeography of the Anambra Basin.13th Colloquium of African Geology, Abstr.,Vol. 371, 1985, CIFEG (Int. Centre for Training and Exchange in theGeosciences).
[16]. O.K..Ladipo.Tidal shelf depositional model for the Ajali Sandstone, Anambra Basin, southern Nigeria.Journal of African Earth Sciences **5(2)**, 1986, P. 177–185.
[17]. C.S. Nwajide.Geology of Nigeria's Sedimentary Basin, CSS Bookshops Limtd, Lagos, 2014, P. 277 – 346.
[18]. N.G.Obaje. Geology and Mineral Resources of Nigeria.Lecture notes in Earth Science, Springer – Verlag Berlin Heidelberg. 2009, P. 58 – 62.
[19]. N.G. Obaje, O.K. Uluand S.W.Petters..Biostratigraphic and geochemical controls of hydrocarbon prospects in the Benue Trough and the Anambra Basin, Nigeria.Nigeria Association of Petroleum Exploration Bulletin, V.**14**, 1999, P. 18-54.
[20]. G.C.Obi.Depositional Model for the Companian–Maastrichtian Anambra Basin, Southern Nigeria.Ph.D. Thesis, University of Nigeria, Nsukka, Nigeria, 2000, P. 291.
[21]. R. Passega. Grain size representation by CM patterns as a geological tool. Journal of Sedimentary Petrology, 34(**4**), 1964, P. 830–847.
[22]. P.E.Potter and F.J.Pettijohn.Paleocurrents and Basin Analysis.Springer, New York, .Y., 2nd ed., 1977, P. 425.
[23]. W. A. Pryor.Cretaceous sedimentation in Upper Mississippi Embayment.American Association of Petroleum Geologists Bulletin. 44, 1960, P. 1473-1504.
[24]. H.G. Reading.Sedimentary Environment Processes, Facies and Stratigraphy.Blackwell Scientific Publications, Oxford.1996, P. 671.
[25]. B.K..Sahu.Depositional mechanisms from the size analysis of clastic sediments.Journal ofSedimentary Petrology, **34**(1), 1964, P. 73- 83.
[26]. T.J.M.Schopt.Paleoceanography.Harvard University press, Cambridge, Massachusetts, P. 341.
[27]. Selley, R.C. (1966): Paleocurent and sediment Transport in near Shore Sediment of Sincte Basin. Libya Journal of Geology. Vol. 75, No. **2**,1980, P. 215-222.
[28]. H.B.Stewart.Sedimentary reflections of depositional environment in San Miguel Lagoon, Baja California, Mexico.American Association of PetroleumGeologists, Mexico, 1958.
[29]. W.F.Tanner.Paleogeographic reconstructions from cross-bedding studies.American Association of Petroleum Geologists Bulletin.**39**, 1955, P. 247-248.
[30]. M.E.Tucker.Sedimentary Rocks in the Field.John Weley and Sons, Chichester, New York, P. 150.
[31]. Visher, G. S. (1969): Grain size distribution and depositional processes. Journal of Sedimentary Petrology, **39**, 1996, P. 1074–1106.
[32]. J.B. Wright, D.A.Hastings, and H.R. Williams.Geology and Mineral Resources of West Africa.George Allen and Unwin, London, 1985, P. 187.

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