LITHOSTRATIGRAPHY AND RESERVOIR QUALITY OF THE AJALI SANDSTONE AT UDI, ANAMBRA BASIN, SE NIGERIA.

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ABSTRACT

The studied area lies within the Anambra Basin and is bounded by latitude 6°21ˈ45˝and 6°28ˈ00˝ N and Longitude 7°23ˈ45˝and 7°28ˈ00˝E and it covers an area of about 73.70km^2. The area is characterized by two formations, the Mamu Formation and the Ajali Sandstones. The Ajali sandstone overlay the Mamu Formation. Both formations are of Maastrichtian age. The Mamu Formation is consists of shale with some occurrences of coal. Five lithologic units were observed in the Ajali Sandstone. These include the coarse – pebbly grained facies (basal); cross – stratified, medium – coarse grained facies; fine – medium grained facies; siltstone/shale facies; and coal/carbonaceous mud facies unit. Sedimentary structures observed include planar cross-beds, beddings and ravinement surfaces. In the paleoenvironmental reconstruction using pebble morphology and paleocurrent analysis, both indicated a high energy fluvial environment. From the sieve analysis, the four samples collected from the four locations are poorly to well sorted, symmetrical to very negatively skewed, fine to medium grained and its kurtosis ranges from mesokuritc to very leptokurtic. The Ajali Sandstone is the main aquiferous unit in the area. Geologic deposits of economic significance found in the area include ferruginized sandstone, cemented sandstone, and coal. The sandstone indicated excellent reservoir qualities with high porosity and permeability.

Keywords: Lithostratigraphy, paleocurrent, grain sizes, reservoir quality, Ajali Sandstone.

INTRODUCTION

The study area lies between latitude 6°21ˈ45˝and 6°28ˈ00˝N and Longitude 7°23ˈ45˝and 7°28 ˈ00˝E within the Southeastern part of Nigeria (Fig. 1). It covers Enugu-Ngwo, Obioma, Aboh and Nsude all in Udi Local Government Area of Enugu State. The area is about 73.70km^2 and could be accessed through the Onitsha-Awka-Enugu expressway. The vegetation is of the semi-tropical rainforest type and is influenced by topography and human activities.

Geologically, the area lies within the Anambra Basin which is situated within the eastern and western part of the lower Benue Trough of Nigeria. It is roughly triangular in shape and covers an area of about 40000sq km (Uma and Onuoha, 1988).

Two formational units characterize the study area and they include the Ajali Formation and the Mamu Formation. The Upper Maastrichtian Ajali Formation is classified as false-bedded and highly friable sandstone while the Mamu Formation (Lower Maastrichtian) which is known as the Lower Coal measure made up of shale with intercalations of sand and siltstone. Both formations have a dip amount of $\leq 10^0$. The Mamu Formation is noted to be the main coal-bearing unit in the area.

The geological survey of Nigeria started the mapping of the Southeastern Nigeria in 1922.

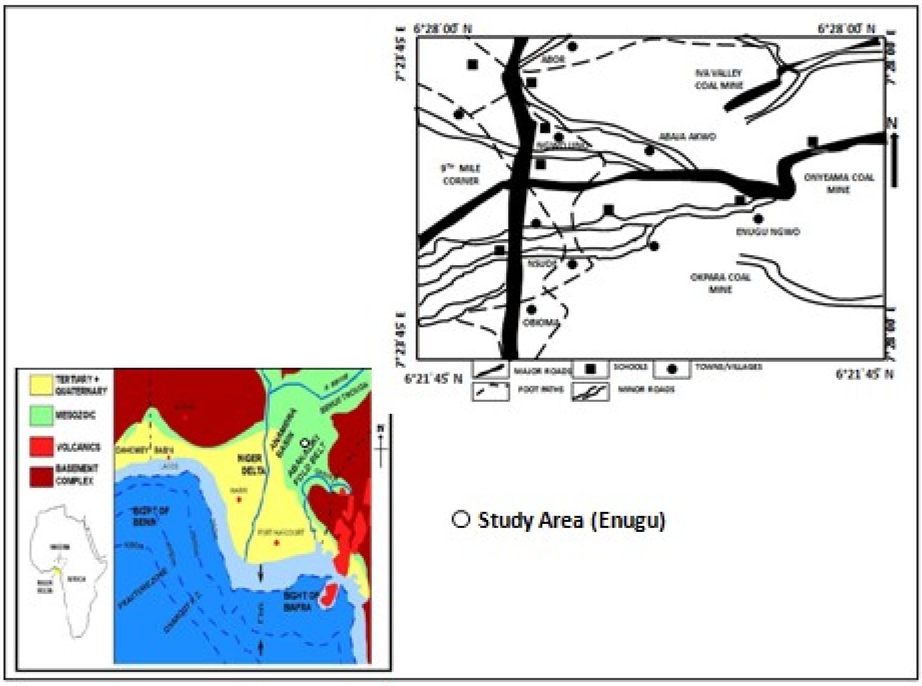

Fig. 1: Map of the study area showing sample locations (in set: map of Africa and Nigeria with location of Enugu.

Ogbukagu (1982) studied the Southeastern Nigerian stratigraphic sequence under the geological survey of Nigeria. The study concentrated along the railways that link Port Harcourt and Enugu.

The Shell-B.P. (D' Archy Exploration Party) conducted geological and geophysical studies in Southeastern Nigeria between 1933 and 1946. The result of the exploration gave a clearer understanding of the geology and structure of the Southeastern Nigeria.

Tattam (1944) indicated that there is a relationship between coals bearing sediment occurring in the Southeastern Nigeria. He noted that coal occurs in two distinct formations (Upper and Lower Coal measures) Nsukka and Mamu Formations and are separated by a thick series of sandstone known as Ajali Sandstone. Reyment (1965) used the biostratigraphy of index fossils in dating various formations including the Ajali Sandstone.

Ladipo (1986) studied the influence of tides for depositional environment and assigned the Ajali Sandstone to be deposited on deep marine facies. The Ajali Sandstone has been studied by various authors. Early workers described it as bedded sandstone (Groove 1951; Simpson 1955), the top of the sandstone consists of red earth (Laterite) formed by weathering and ferruginization. The middle zone consists of friable white sandstone having medium to coarse grains. Thick cross-beds were also observed and must have been brought by the action of water during the upper Cretaceous with varying thickness and it dips in a South-West direction. The sand grains and larger fragments are angular with white clay as cements. Groove (1951) and Reyment (1965) suggested that the Ajali Sandstone was deposited in a continental environment from the sedimentological evidence of its moderately sorted and cross-bedded sandstone with dominantly single direction fining upward sequence.

However, below the Ajali Sandstone unit is the Mamu Formation (Lower Coal Measure). The underlain Mamu Formation is made up of two members namely: (1) Sandstone which is intercalated with shale and 2) the lower coal measures which consist of shale, sandy shale and coal. The Maastrichtian Mamu Formation conformably overlies the Enugu shale. The variation in lithology within small thickness suggests frequent face changes. These are common in energy environment (Reyment, 1965). The bedded sandstone sub-units of the Mamu Formation consist mainly of siltstone and sandstones.

Regional Geological Setting

The tectonism in Southern Nigeria probably started in Early Cretaceous, with the separation of Africa from South America due to the opening of the Atlantic. This resulted in the development of the Benue Trough which stretched in a NE-SW direction (Fig. 1), resting unconformably upon the Pre-Cambrian basement complex. It extends from the Gulf of Guinea to the Chad Basin and is thought to have been formed by the Y-shaped (RRR) triple junction ridge system that initiated the breaking up and dispersion of the Afro-Brazilian plates in Early Cretaceous (Kogbe, 1989).

After the evolution of the Benue Trough, sediments started depositing in the Trough. Stages of sedimentations in the trough were in three cycles; the Pre-Cenomanian deposit of Asu River Group followed by the Cenomanian-Santonian sedimentation. According to Hogue (1977) the inversion tectonics of the Abakaliki anticlinoria which led to the evolution of both Afikpo Syncline and Anambra basin, represented the third cycle of sedimentation which produced the incipient Nkporo shale, Enugu shale and Owelli sandstone. The Nkporo group is overlain conformably by the Coal Group consisting of the Mamu, Ajali and Nsukka Formations that form the terminal units of the Cretaceous series.

Stratigraphic Setting

The sandstones which is about 330 m thick is an extensive stratigraphic unit conformably overlying the Lower Coal Measure (Mamu Formation) and Nkporo Formations that are 400 and 200 m thick, respectively and underlying the Upper Coal Measure (Nsukka Formation) in the Maastrichtian (Reyment, 1965 and Nwajide, 1990) (Fig. 2). The Ajali Formation is typically characterized by white coloured sandstone (Reyment, 1965) while the Mamu Formation is essentially composed of sandy shale and some coal seams; the Nkporo Formation consists mainly of grey - blue mudstone and shale with lenses of sandstone (Obaje, 2009). According to Reyment (1965), the prevailing unit of Ajali Formation consists of thick, friable, poorly sorted sandstone. The Ajali sandstone at Udi and environs in Imo State of Anambra basin is the object of this study.

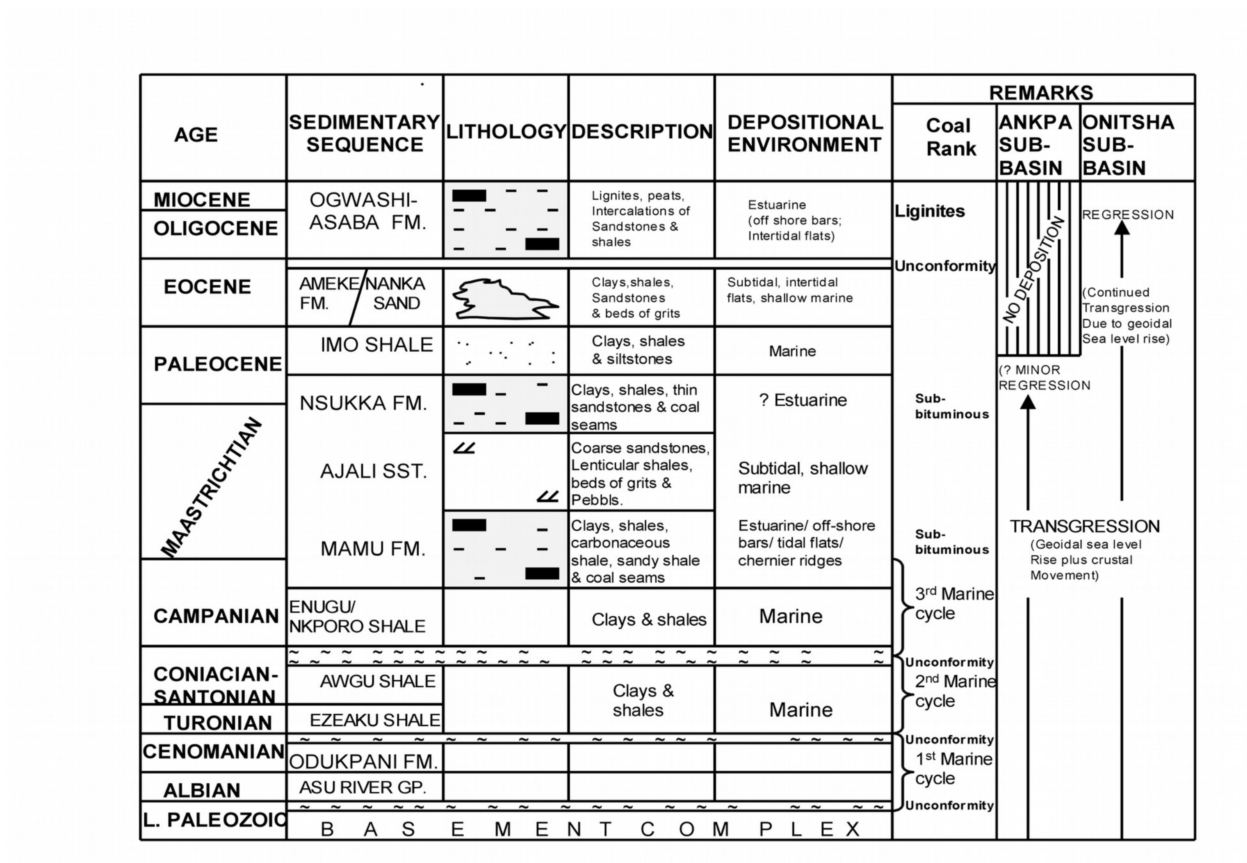

Fig. 2: The stratigraphy and environment of deposition of sediments in the Anambra Basin southeastern Nigeria (after Uzoegbu et al., 2014).

MATERIAL AND MERHODS

Intensive field study covered a total of four localities from where samples were taken. Eleven representative sandstone samples were retrieved from the field survey along road cut at Udi.

In the laboratory, the samples were later disaggregated and dried for at least 24 hours in an oven at 60^0 C to remove the moisture before analysis. Afterwards, sieve analysis was carried out for each of the samples. Lumped samples were disintegrated so that the sieve analysis result can be authentic. Sieving technique is applied to separating the grains of various size-classes, as proposed by (Ingram, 1971). British Standards were employed with a sieve set in the order of mesh sizes: 2 mm, 1mm, 500 µm, 250 µm, 150 µm and 75 µm respectively. The sieves were arranged in such a way that the one with the highest opening was placed at the top while the one with the smallest opening was placed at the bottom with the base pan at the base. The dried samples were placed at the top sieve, covered up and placed on a mechanical shaker. The amplifier was used to operate the shaker at a medium frequency. The sieve analysis was carried for about five minutes while checking at intervals. After the sieve analyses have been completed, the sediment in each sieve was weighed and recorded. These procedures were carried out for each of the eleven samples.

The remaining samples were subjected to Pebble Morphological and Paleocurrent analyses. For Pebble Morphological analysis, a term used to describe the form, roundness and surface texture of pebbles through the calculation of oblate, equiaxial or cubed, bladed and prolate. A total of twelve samples from Abor locality were used. The Paleocurrent analysis was obtained from measuring planar and trough cross-beds in the field at Abor by applying the following procedures of azimuth and dip. Mean Vector Azimuth (M.V.A) gives the mean direction of the depositional agent.

RESULTS AND DISCUSSION

The results from the sieve analysis, pebble morphometry and paleocurrent analysis where interpreted accordingly. It is basically used to determine the environment of deposition.

Lithostratigraphy

Some of these structures are seen in outcrops within the study area (Abor, Obioma, Nsude, Enugu Ngwo) and they include cross-beds lamination, reactivation surface, ravinement surface.

These are bedding structures formed by the migration of bed forms with inclined depositional surfaces. There are various types of cross beds but the one located in the outcrops within the study area includes planar cross-beds and trough cross-beds

Thus, cross-beds may be used as paleocurrent indicators or indicators of ancient current flow direction while planar cross-beds are formed during deposition when the layering is inclined at an angle to the horizontal, dipping downward in a down- current direction. It indicates turbulence and is often associated with large rivers and large deltaic deposits. The trough cross-beds are formed during deposition when the layering usually curves at the bottom edge, become tangential to the lower bed surface. The upper edge of the individual inclined cross-beds is usually at a steep angle to the overlying bedding plane. These cross-beds are peculiar to Ajali Formation and where observed in Abor as a station 1 locality.

Reactivation surface is sign of records of erosion on a bedform from forest slope resulting from a rise and fall in the level of flow. After the erosion, the bedform reforms with the same orientation and shape and continues to migrate. This was observed at Onyeama mine between the siltstone and shale unit. The Ravienment Surface was also observed in location 1 along Abor between the sandstone and siltstone units. Laminations in the study area are common in shales and are products of episodic suspension in relatively quiet water where organic life is absent or restricted. This feature was observed in station 3, along Onyeama mine.

Some of the secondary sedimentary structures that form post-deposition during diagenetic stages in the formation and lithification of sedimentary rocks includes clay ironstone concretions, biogenic structures etc.

Clay ironstone concretions occur when clay rich sediments dehydrate, fracture and the infilling of the fractures by iron thereby forming rind pattern. These look like waffle irons and the pattern is known as liesengang weathering. This was observed in ferruginized sandstones along station 1 in Abor and station 3 in Obioma.

The biogenic structures such as marks, burrows, imprints, trails or traces made by organisms on rock surface during activities like feeding, dwelling or resting and mobility. This is also known as Ichnofossils or trace fossils. Trace fossils give information on the depositional environment like Ophiomorpha and Mallasinoides which was observed in station 2 (Onyeama mine).

This location Iyi-Ofe in Abor is one of the exposures of the Ajali sandstope. It is composed of sandstones, fine sands and siltstone (Fig. 3a). The sandstones are dominantly medium grained, and occasionally fine grained. Sorting is medium to high and the clay content is low. The sandstones are mineralogically mature being composed of almost quartz and stable minerals like zircon etc. Sedimentary structures found here include the presence of planar cross-beds, ravinement surfaces, Ichnofossils, etc.

The Location 2 is Onyeama mine in Enugu Ngwo on exposure composed of the Mamu Formation (Fig. 3b). The Mamu Formation is the main stratigraphic unit forming the Enugu escarpment. The cuesta is the most striking topographic feature, crossing the Anambra basin in a sigmoid curve. Road cuts and river channels afford relatively fresh and accessible exposures of the Mamu Formation. The sedimentary structures found here include reactivation surface and biogenic structures.

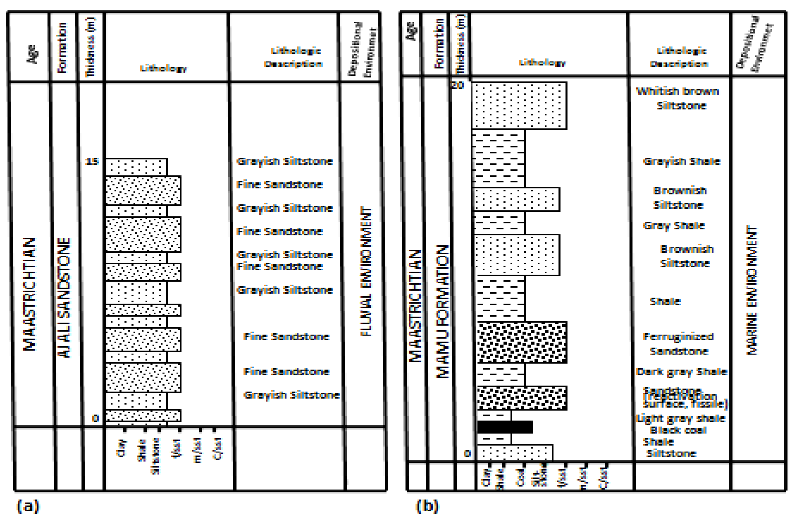

Fig. 3: a) The Lithology of Abor at Iyi-Ofe and b). Litholog of Station 2 Onyeama mine in Enugu Ngwo

This exposure is found at Ugwu-Oche stream at Obioma locality (Fig. 4a). Some sections occurs as friable whitish sand while some occurred as ferruginized sandstone. The presence of stream in the area indicates a good aquifer system. Sedimentary structures found here include clay iron concretions, burrows and bedding.

The vegetation on the outcrop from Iva Valley at Nsude locality (Fig. 4b) is sparse because of the overburden sand. Sedimentary structures seen here include fossils, fissility, etc.

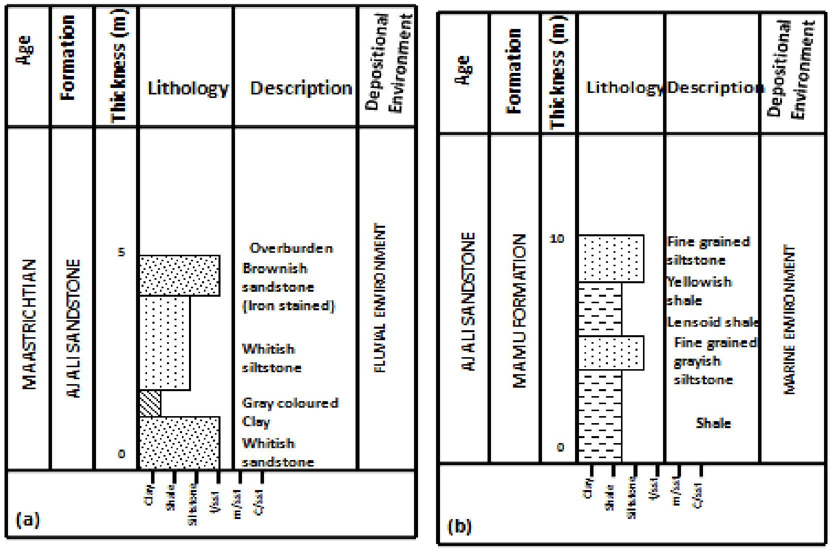

Fig. 4: a) Lithology of Station 3 from Ugwu-Oche at Obioma locality and b) Lithology of station 4 from Iva Valley at Nsude locality.

Grain Size Distribution

Four samples were collected from the stations and analyzed using the sieve analysis method. The phi (ø) values and the textural parameters are summarized individually in the tables 1 and 2. The cumulative percent frequency is plotted in figures 5a-d for grain size distribution.

Table 1: Summary of phi (ø) values of sieve analysis obtained from cumulative probability curves.

Sample N0.	$\varnothing_5$	$\varnothing_{16}$	$\varnothing_{25}$	$\varnothing_{50}$	$\varnothing_{75}$	$\varnothing_{84}$	$\varnothing_{95}$
1	0.15	0.80	1.05	1.85	2.55	2.65	2.95
2	0.1	0.6	0.8	1.5	2.35	2.6	2.90
3	0.6	1.35	1.65	2.20	2.55	2.65	2.80
4	1.45	1.90	2.15	2.50	2.65	2.75	2.90

Table 2: Summary of Sieve analysis result

Sample N0.	**Graphic Mean**	**Graphic Kurtosis**	**Graphic standard deviation (sorting)**	**Graphic skewness**
1	1.77 Medium Grained sand	0.77 platykurtic	0.87 Moderately well sorted	-019 Negatively skewed
2	1.57 Medium grained sand	0.74 Platykurtic	0.92 Poorly sorted	0.08 Symmetric
3	2.07 Fine grained sandstone	1 Mesokurtic	0.66 Moderately well sorted	-0.38 Very negatively skewed
4	2.38 Fine	1.12	0.43 Well sorted	-0.43 Very

	grained sand	Leptokurtic		negatively skewed

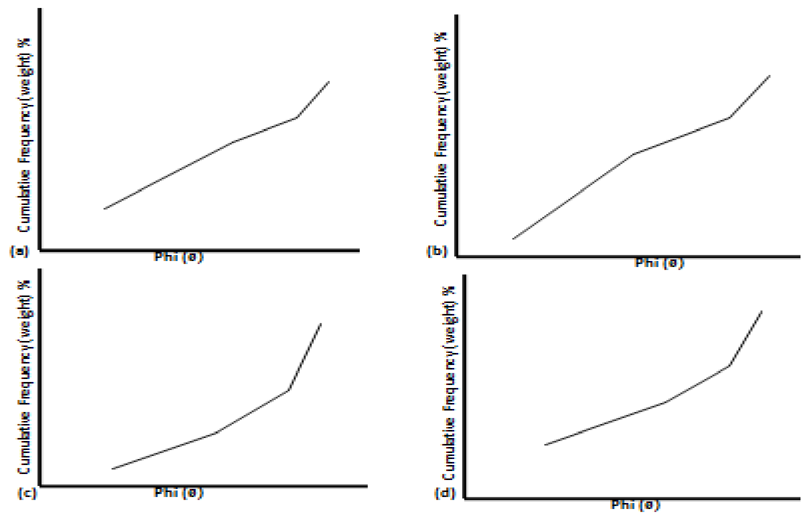

Fig. 5: Plot of cumulative weight % against phi (ø) value: a) Location 1, b) Location 2, c) Location 3 and d) Location 4

Generally, five lithofacies have been established for the Maastrichtian Ajali Sandstone around the Agbogugu Junction area on the basis of lithological and sedimentary characteristics, observed at outcrop sections. Stratigraphically, the facies includes coarse – pebbly grained facies (basal); cross – stratified, medium – coarse grained facies; fine – medium grained facies; siltstone/shale facies; and coal/carbonaceous mud facies (topmost). These indicate excellent reservoir qualities (high porosity and permeability) for the sandstones.

The basal coarse – pebbly grained sandstone facies are characterized by alternating sequence of brown to milky-white and iron stained colour. It is moderately to well sorted and consists of trough cross beds with a concave up erosional base indicating an environment in a river channel lag deposit. The cross stratified, medium – coarse grained sandstone facies conformably overlies the coarse – pebbly grained sandstone facies. The colour ranges from brown to red. It consists of local trough cross – beds, ferruginized and scattered pebbles. Its environment of deposition is sublitoral. The common presence of the ophiomorpha burrows of the skolithos ichnofacies in this facie is an indication of deposition in a fluviatle to shallow marine (sublitoral) environments.

The fine – medium grained sandstone facies overlies the cross – stratified, medium – coarse grained facies. It has a variety of colours from milky-white, brown, beige, and iron – stained. It consists of fine to medium grained sandstone and a fining upwards sequence of friable sandstone with occasional presence of some bands of black grey shale. It is moderately sorted and consists of well jointed and massive structures denoting transportation by strong current into shallow nearshore or continental environment.

The siltstone – shale unit is composed of variety of colour from red, brown, grey and dark grey with occasional occurrence of few intercalations of thin fine grained sandstone beds. If lacks both fossils and microfauna bat consists of few worm burrows trace fossils. On the basis of its trace fossils contents, it is suggested to have been deposited in shallow marine environment. The topmost coal/carbonaceous mud facies is characterized by wood fragments, leaf, impression, vitrinite thin beds and impure coal which is an indication of a flood plain that was quiet, warm, humid, and suitable for plant colonization.

Pebble Morphometry

This refers to the description of the form, roundness and surface texture of a pebble. Twelve pebbles were sampled and the value of the Maximum Projection Sphericity (M.P.S), Oblate-Prolate Index (O.P.I) and Flatness Index (FI) was used to determine the type of environment that prevailed during the time of deposition (Table 3).

Table 3: Computation of the Long, Short and Intermediate axis.

S/N	L	S	I	T/L	S/I	FORM	LIS	S2	LI	L-I	L-S	S/L	MPS	OPI	FI
1	1.25	0.7	0.85	0.68	0.82	Equi-axial	0.74	0.49	1.06	0.40	0.55	0.56	0.74	-0.16	56.00
2	1	0.7	0.75	0.95	0.93	Equi-axial	0.53	0.49	0.75	0.25	0.30	0.70	1.05	0.12	70.00
3	1.3	0.5	0.9	0.69	0.56	Oblate	0.59	0.25	1.17	0.40	0.80	0.38	0.54	-0.12	38.00
4	1.7	0.55	0.95	0.55	0.58	Bladed	0.89	0.30	1.62	0.75	1.15	0.32	0.42	-0.91	32.00
5	1.1	0.7	0.8	0.73	0.88	Equi-axial	0.62	0.49	0.88	0.30	0.40	0.64	0.40	0.03	54.00
6	1.15	0.65	0.85	0.74	0.76	Equi-axial	0.64	0.42	0.98	0.30	0.50	0.57	0.77	-0.28	57.00
7	1.1	0.5	0.9	0.82	0.56	Oblate	0.50	0.25	0.99	0.20	0.60	0.45	0.63	-0.78	45.00
8	1.25	0.75	0.9	0.72	0.83	Equi-axial	0.84	0.56	1.13	0.35	0.50	0.60	0.73	-0.13	60.00
9	1.25	0.55	0.7	0.56	0.79	Prolate	0.48	0.30	0.88	0.55	0.70	0.44	0.76	-0.35	44.00
10	1.3	0.5	0.9	0.69	0.56	Oblate	0.59	0.25	1.17	0.40	0.80	0.38	0.54	-0.82	38.00
11	1.3	0.75	0.75	0.58	1.00	Prolate	0.73	0.56	0.98	0.55	0.55	0.58	0.85	0.14	58.00
12	1.15	0.55	0.9	0.78	0.61	Oblate	0.57	0.30	1.04	0.25	0.60	0.48	0.65	-0.62	48.00
													ΣMPS= 8.08	ΣOPI= -3.88	ΣFI= 600

The mean values of 1.05 in M.P.S, -0.38 in O.P.I and 50.83 in F.I respectively indicated a fluvial environment of deposition for all the parameters.

Paleocurrent Analysis

This involves the measurement of dip and azimuth of the planar cross-bed which are then grouped into frequency distribution using a convenient class interval. The dip and azimuth was gotten from a cross bedded sandstone in station 1, Abor. The calculated mean value for variance (MVA) is 89.08 or 269.08, vector strength is 3.260 while variance is 210.20 (Table 4). The variance for the value is less than 6000 which indicates a fluvial environment.

Table 4: Computation of the dip and azimuth from the cross-bedded sandstones at station 1.

S/N	AZ (ºC)	DIP (ºC)	SINE A	COSINE A	COSINE D	$(A-MVA)^2$
1	270	22	-1	0.00	0.9271839	0.8464
2	260	30	-0.9848078	-0.1736482	0.8660254	82.4464
3	272	20	-0.9993908	0.0348995	0.9396926	8.5264
4	260	25	-0.9848078	-0.1736482	0.9063078	82.4464
5	230	20	-0.7660444	-0.6427876	0.9396926	1527.2464
6	254	22	-0.9612617	-0.2756374	0.9271839	227.4064
7	252	18	-0.9510565	-0.3090170	0.9510565	291.7264
8	287	19	-0.9563048	0.2923717	0.9455186	321.1264
9	260	22	-0.9848078	-0.1736482	0.9271839	82.4464
10	260	24	-0.9848078	-0.1736482	0,9135455	82.4464
11	274	26	-0.9993908	0.0348995	0.8987940	8.5264
			∑10.5726799	0.1699672		2715.1904

Using the Rose diagram for class interval of 45 (Table 5), a table was draw and the frequency distribution was compiled. The shape of the rose diagram is unimodal and thus indicates a fluvial environment (Fig. 6) supported by the result of pebble and paleocurrent analyses.

Table 5: Computation of frequency distribution

Class Interval	Tally	Frequency
1 – 45	-	0
46 – 90	-	0
91 – 135	-	0
136 – 180	-	0
181 – 225	-	0
226 – 270	IIIIIIII	8
271 – 315	III	3
316 – 360	-	-

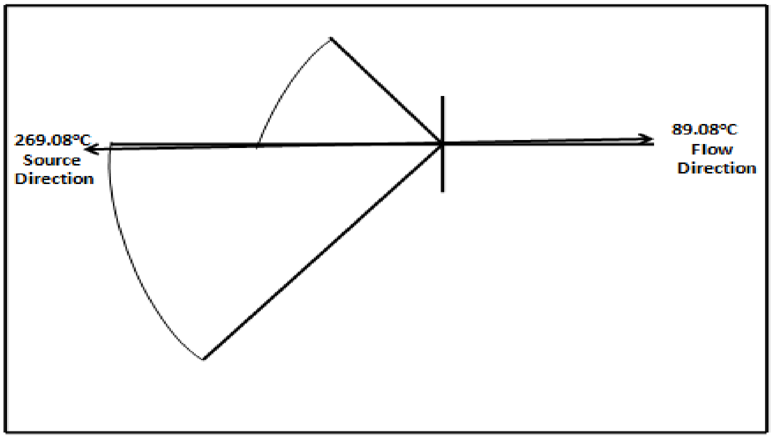

Fig. 6: A Rose Diagram

Reservoir Quality:

Possible reservoirs for this system in the Anambra Basin are mainly Maastrichtian formation of the Ajali Sandstone constituting local reservoirs where individual beds are stacked and where porosities and permeabilities are diagenetically and mechanically enhanced. Generally, the Ajali Sandstone include moderately well sorted, loosely cemented and thickly developed trough and planar cross-bedded, as well as, hummock cross-stratified medium to coarse grained sandstones that are occasionally pebbly and graded bedded (Abubakar, 2006). Granulestones are also present. These sandstones show coarsening upward cycles at the base, but are fining upward towards the top. The sandstones represent shoreface and fluvial sedimentation at the lower and upper parts of the sandstones respectively (Abubakar, 2006). These sandstones may extend for over 10km and occur over the entire eastern Anambra Basin. The presences of these sandstones in the sub-cropping part of the western part of the basin are possible and have been proved. Although porosity and permeability data may be lacking, these sandstones constitute excellently reliable aquifers that provide constant supply of a large volume of water needs of the Enugu town for semi-artesian wells. They form also highly productive aquifers in the area with water yield of over 5.80-7.10/sec (Dike and Maigari, 2009). These indicate excellent reservoir qualities (high porosity and permeability) for the sandstones. The deltaic sandstones, on the other hand, is made up of thickly developed and fairly extensive distributary mouthbars, and distributary and fluvial channels. These sandstones are moderately well sorted and mostly very fine grained. Porosity and permeability are likely to be highly variable. However, globally the porosities and permeabilities of deltaic sandstone reservoirs range from 11-35% and 250-8000md respectively (Morse, 1994).

CONCLUSION

The Ajali sandstone was studied in two lithologic units consisting of siltstone and false-bedded sandstones. Pebble morphometry and paleocurrent analyses were used to reconstruct the paleoenvironment. Both indicated fluvial origin which gives credence to the fact that Ajali Sandstone originated from a fluvial environment.

Five lithofacies have been established for the Maastrichtian Ajali Sandstone around the Agbogugu Junction area on the basis of lithological and sedimentary characteristics, observed at outcrop sections. Stratigraphically, the facies includes coarse – pebbly grained facies (basal); cross – stratified, medium – coarse grained facies; fine – medium grained facies; siltstone/shale facies; and coal/carbonaceous mud facies (topmost). The high porosity and permeability indicated excellent reservoir qualities for the sandstones.

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