Sedimentologic and Petrographic Study of Outcrops of Ajali Sandstone in Okigwe, Uturu and Isiukwuato, Anambra Basin Southeastern Nigeria.

ENYIOKO N.D., ONYEKURU S.O., IKORO D.O AND OGBONNA T.L.
Geology Department, School of Physical Sciences, Federal University of Technology Owerri,
Imo State, NIGERIA.

Abstract: - The Ajali Formation outcrops at Okigwe, Ihube, Onyekaba mine, Uturu and Isiukwuato in the Anambra Basin southeastern Nigeria were evaluated for an integrated field, sedimentologic and petrograpic methods. The study was aimed at presenting a better understanding of the depositional processes and provenance. Five lithofacies were altogether described namely: planar Cross bedded sandstone facies A, Massive sandstone facies B, Ferruginized sandstone facies C, herringbone cross bedded sandstone facies D, and Bioturbated sandstone facies E. The facies were deposited in a fluvially influenced shallow marine environment. The overall grain size interpretation shows that sediments from the study area are fine to coarse grained with values ranging from 0.2 to 2.0Φ, poorly sorted to very well sorted with range value of 0.28 to 1.2Φ, nearly symmetrical to strongly fine skewed with values of -0.04 to 0.59Φ and platykurtic to very leptokurtic with values of 0.79 to 2.46Φ. An inspection of the cumulative frequency curves of the studied samples shows that the sediment population is dominated by saltation population. Texturally, the sandstone sediments are sub-mature containing grains that are moderately to poorly sorted and not well rounded. The Mineral Maturity Index of the sandstone in the study area ranges from 24-49 which falls within the mature to super mature class. The high quartz content and insignificant amount of feldspar and rock fragments further support this assertion. The study suggest the sandstones must have been subjected to substantial high degree of reworking that resulted in the removal of the ferromagnesian minerals and feldspar typical of recycled sediments.

Key-Words: Basin, Ajali, Platykurtic, Paleobasin and Ferromagnesian

Received: June 19, 2021. Revised: March 12, 2022. Accepted: April 10, 2022. Published: May 9, 2022.

1 Introduction

The Maastrichtian Ajali Formation of the Anambra Basin has numerous geological information that could be useful for the Paleoenvironmental and Provenance studies of the primary sedimentary structures and textural features deposits at the time the sediments were deposited. Textural and structural features are spatially distributed within the formation. Cross stratifications are very common within the basin, and could present significant information.

In terms of areal coverage, the Maastrichtian Ajali Formation is a very vast area of sandstone body encompassing an extensive area of southern Nigeria basin. The study of Ajali Sandstone formation has received a considerable attention since Reyment (1965) described and formalized the sedimentary formation in southern Nigeria by many scholars (Hoque, Ezepue, 1977; Hoque, 1977 and Amajor, 1986) provenance secession; the formation was considered to have been obtained from the Post-Santonian Abakiliki Anticlinorium namely; (Nwachukwu, 1972; Murat, 1972; Amajor, 1987). On the basis of sedimentological analysis different researchers have inferred different paleoenvironmental settings for the sandstone, fluvial (Murat, 1972); fluvio-deltaic (Reyment, 1965; Hoque and Ezepue, 1977) and fluvio-marine (Amajor, 1987), fluvial (Onyekuru et al, 2017); marine/subtidal (Onuigbo et al, 2016) fluvio-tidal influenced (Ikoro et al, 2014).

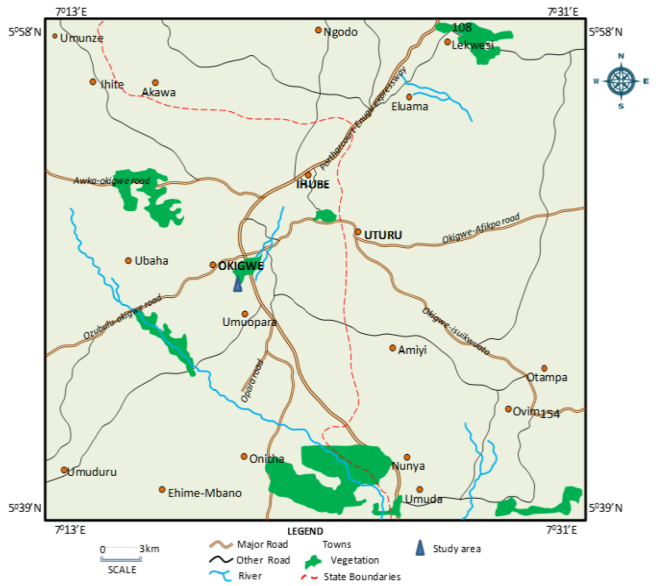


Fig 1. Topography and Accessibility Map of the study area. Inset is map of Nigeria

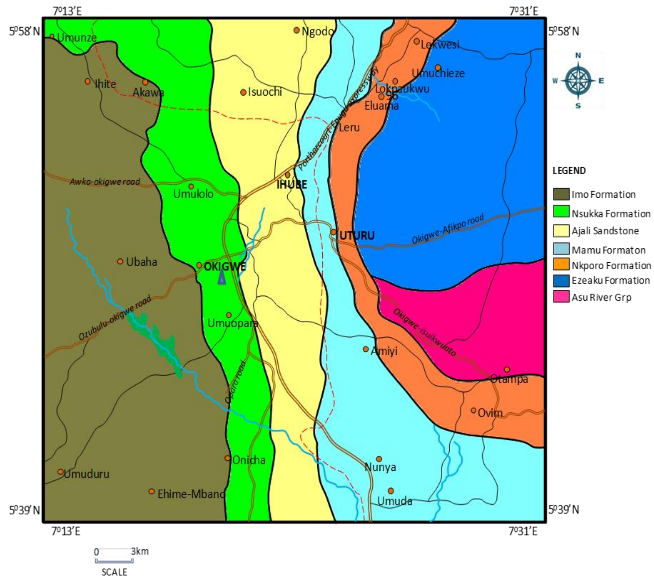


Fig. 2 Geologic map of the study area (modified after NGSA, 2004)

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.2), 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 in 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.

2 Materials and Method

This study involves different stages of field observations, and laboratory analysis. These stages and analyses are explained.

Field Study

The field study involves logging of outcrop, measuring attitudes of beds, delineating facies, taking photographs and collection of samples for laboratory analyses. Each outcrop location is referenced by the use of the GPS.

Sieving Analysis procedure

The representative oven-dried samples were weighed after crushing to disaggregate the particles. Crushing was done with the use of mortar and pestle. The stack of sieves were prepared in the order with the largest aperture size at the top, and smallest at the bottom. A receiver pan is placed under all the sieves in order to collect the samples. The ASTM mechanical shaker was used and vibrated for 15minutes. Each sieve retained is measured.

Thin Section Analysis

Sedimentary formations megascopic structures have been observed in the field (structures seen with the eye unaided). Some microscopic structures, on the other hand, are invisible to unaided vision. Samples of the rock are prepared in the laboratory following specified methods in order to observe them and detect certain other properties of the rock under the microscope. To achieve this, thin section analysis are carried out on these rock samples to produce slides and photomicrographs.

3 Result and Discussions

3.1 Facies Description

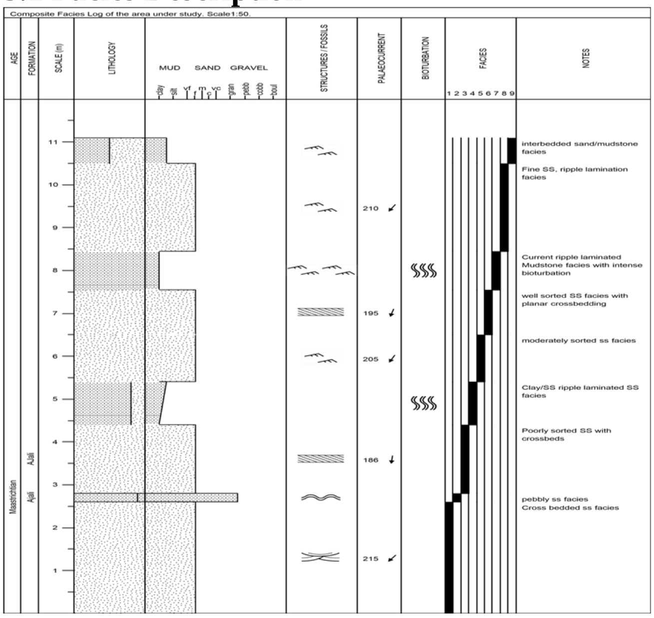


Fig. 3. Composite facies lithostratigraphy of the study area

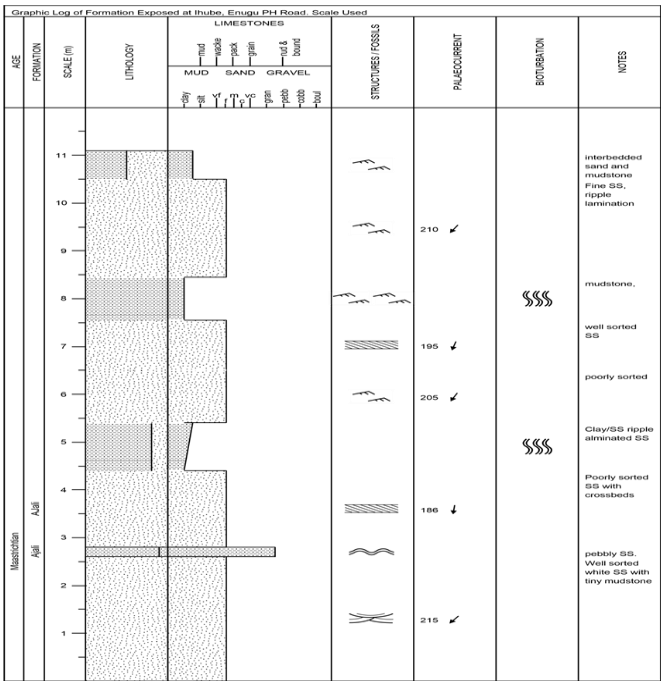


Fig 5. Lithologic profile of the exposure at Ihube 1

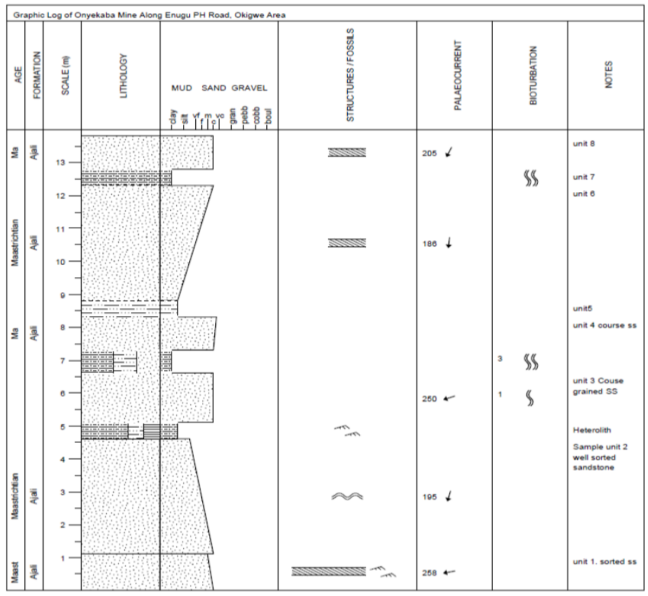


Fig 4. Lithologic profile of the exposure at Onyekaba mines Okigwe.

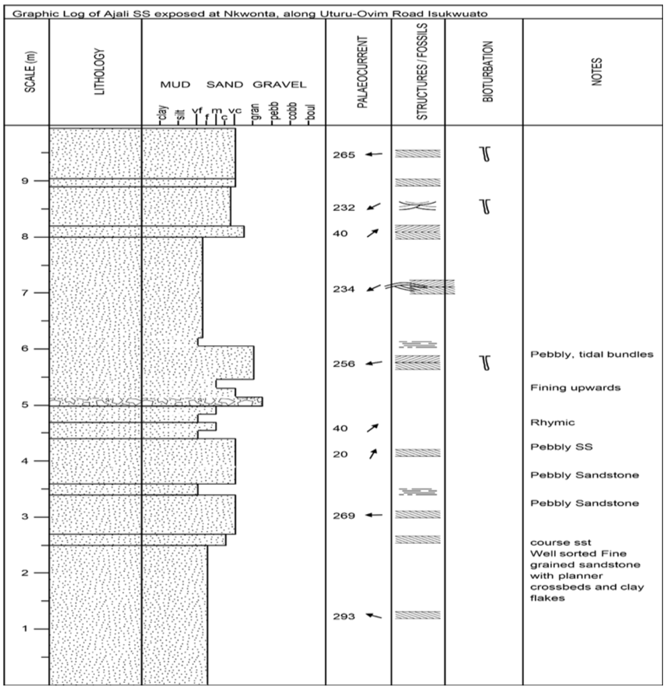
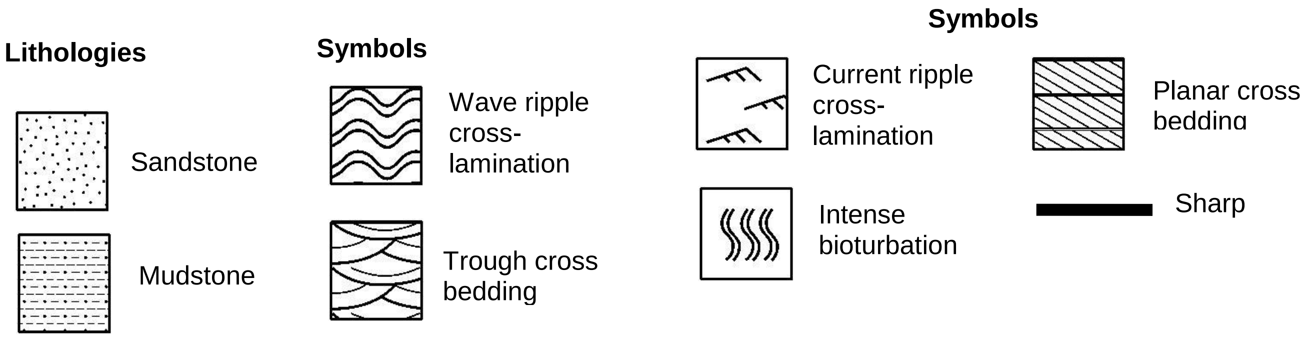


Fig 6. Lithologic profile of the exposure at Isiukwuato

LEGEND



3.2 Facies Analysis

Cross bedded sandstone facies A

Trough cross bedding

Cross bedded sandstones are the most common facies observed within Ajali Sandstone outcrops. These cross beds are exposed in different shapes as planar, trough, rippled, climbing and herringbone cross stratification as reported by (Amajor 1986). They have a thickness of about 1.7cm. Their grain sizes varies from coarse to medium grained sandstone, sorting of the lithology is angular to sub-rounded with finning upwards sequence, the finning upwards ends with a laminations and climbing ripple contact that has indices range of 5 to 6 which infers water current ripples according to Renick and Singh 1975. Their top and bottom set are identified by clay/siltstone drape lamination stained with iron.

Plate 1. Cross bedded sandstone facies for Uturu

Massive sandstone Facies B

The Facies is massive, white in color and medium to coarse grained, well sorted smooth to touch and the bed thickness is about 1.6m. With massive structure and makes a sharp upper and lower contact in the sections viewed. This bed has no visible sedimentary structures.

Plate 2: Facies C, Massive sandstone outcropping at Isiukwuato

Ferruginized sandstone facies C

This facies is reddish-brown in colour. In some locations, the ferruginized sandstone facie C is overlain by lateritic overburden. It is medium grained, massive and well sorted. This facies depict periodic exposure to the atmosphere prompting the oxidation of the iron to a ferric state.

Plate 3: Ferruginized sandstone at onyekaba Mine

Herringbone cross bedded sandstone facie D

This is a light yellowish white fine to very fine grained sandstone, with herringbone cross stratification as its major primary sedimentary structure. It has a thickness of about 4.4 meters with a sharp upper contact and a gradational lower contact. This is shown in the figure below; Herringbone cross beds are indication of bidirectional flow typical of tidal environment (Allen, 1964).

Plate 4. herringbone cross bedded facies at Isiukwuato

Bioturbated sandstone facies E

This facies was observed at Ihube section showing vertical and sub horizontal burrows typical of *Ophiomorpha and skolithos ichnogenus*. Burrows were often seen cutting across clay drapes deposited during slack period in the current. Often observed in tidal environments.

Plate 5. Bioturbated sandstone facies at Ihube showing vertical burrows

4 Results of Grain Size Analyses

4.1 Univariate Analysis

Table 1: Estimated Percentiles from Cumulative Freq Curve

Sample ID	φ5	φ 16	φ 25	φ 50	φ 75	φ 84	φ 95
ON1	-0.5	0.2	0.6	1.2	2	2.3	2.5
ON2	0.3	1	1.3	2.5	2.7	2.8	3.2
ON3	0.2	0.5	1.2	2.8	2.9	3	4
IH1U2	-0.8	0.1	0.2	0.3	0.9	2	2.8
IH2 U1A	0.3	1.1	1.5	2.1	2.4	2.5	2.9
IH2 U1B	0.1	0.3	0.5	1.3	1.7	2.2	2.7
ISU1	0.2	0.3	0.5	1.1	1.7	2	2.5
ISU2	-0.6	0.2	0.3	1	1.5	2	3
UTU1	1.6	2	2.1	2.2	2.3	2.4	2.8
UTU2	-0.6	0.2	1.1	1.6	2.1	2.2	2.6
UTU3	-0.6	0.4	0.5	1.5	2	2.2	2.8
UTU4A	0.7	1.4	1.8	2.1	2.2	2.3	3
UT U4B	-1	-0.5	0.1	0.6	1.7	2.2	3
UTU5	-0.4	0.3	0.6	1.5	2.1	2.3	3.5

Table 2: Calculated grain size parameters

Sample No	Mean	Sorting	Skewness	Kurtosis
ON1	1.23	0.98	-0.04	0.88
ON 2	2.10	0.89	-0.59	0.85
ON 3	1.43	1.20	-0.60	0.92
IH 1U2	0.36	1.02	0.59	2.11
IH2 U1A	1.34	0.74	-0.41	1.18
IH2 U1B	0.78	0.87	0.01	0.89
IS U1	0.69	0.77	0.14	0.79
ISU2	1.13	1.00	0.11	1.23
UT U1	1.67	0.28	0.00	2.46
UTU2	0.84	0.98	-0.39	1.31
UTU3	0.88	0.97	-0.23	0.93
UTU4A	1.42	0.57	-0.39	2.36
UT U4B	0.28	1.28	-0.25	1.02
UTU5	0.86	1.09	-0.09	1.07
Average	**1.07**	**0.90**	**-0.15**	**1.28**

Table 3: Grain Size Parameters and Interpretation Chart

Mean Grain size Interpretation					
Grain size (Φ)	-1 – 0.0	0.0 – 1.0	1.0 – 2.0	2.0 – 3.0	3.0 – 4.0
Verbal description	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand
Kurtosis Interpretation					
Kurtosis	<0.67	0.67 – 0.90	0.90 – 1.11	1.11 – 1.50	1.50 – 3.00
Verbal description	Very Platykurtic	Platykurtic	Mesokurtic	Leptokurtic	Very leptokurtic
Skewness Interpretation					
Skewness	+1.00 to +0.30	+0.30 to +0.10	+0.10 to -0.10	-0.10 to -0.30	
Verbal description	Strongly fine skewed	Fine skewed	Near symmetrical	Coarse skewed	

4.2 Bivariate Analysis

Friedman's (1967) and Moiola and Weiser, (1968) discrimination diagram for differentiating sediments of Beach or Fluvial (River) origin was applied to the sandstone samples collected in the study area (Fig 6 and 7). In both scenario, there is a dominance of fluvial regime over beach processes.

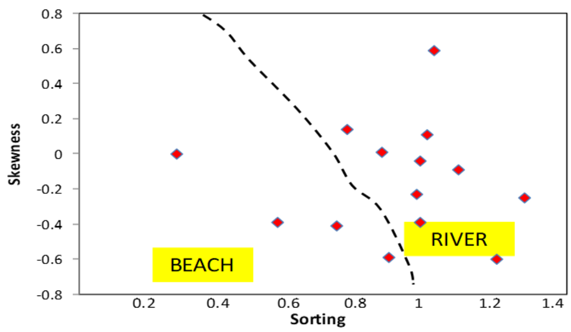


Fig.7: Bivariate plot of Skewness versus Sorting for sandstone samples (After Friedman, 1967)

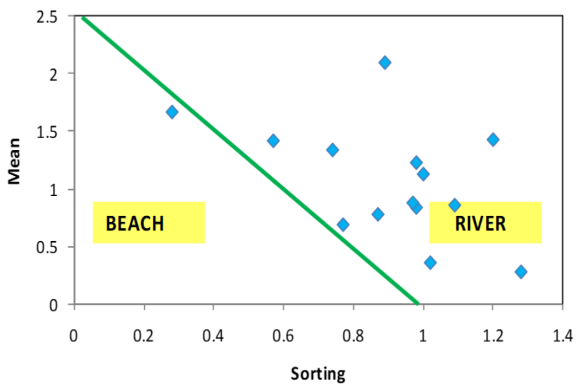


Fig.8. Bivariate plot of Mean versus Sorting for samples (After Moiola and Weiser, 1968)

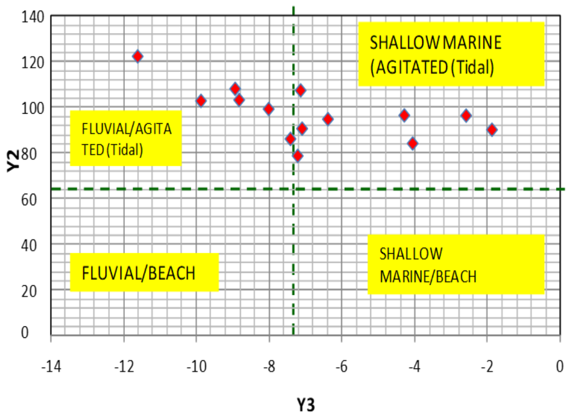
4.3 Multivariate Plots

The linear discrimination functions of Sahu (1964) adopted from Onuigbo, et al , (2012) for finding the relation between variances exhibited by parameters were used to discriminate the environment.

(a) For the discrimination between Aeolian processes and littoral (intertidal) environments, the discriminate function used is given below:

$$\textbf{Y1 = -3.5688 MZ + 3.7016}\ \delta 1^2\ \textbf{- 2.0766 SK1 + 3.1135 KG}$$

Where MZ is the grain size mean, δ1 is inclusive graphic standard deviation (sorting), SK1 is skewness and KG is the graphic kurtosis. When Y1 is less than -2.7411, Aeolian deposition is indicated whereas if it is greater than -2.7411, a beach



environment is suggested.

(b) For the discrimination between beach (back-shore) and shallow agitated marine (subtidal) environment, the discriminate function used include;

$$\textbf{Y2 = 15.6534 MZ + 65.7091}\ \delta 1^2\ \textbf{+ 18.1071 SK1 + 18.5043 KG}$$

If the value of Y2 is less than 65.3650 beach deposition is suggested whereas if it is greater than 65.3650 a shallow agitated marine environment is likely.

(c) For the discrimination between shallow marine and the fluvial environments, the discriminate function below was used.

$$\textbf{Y3 = 0.2852 MZ - 8.7604}\ \delta 1^2\ \textbf{- 4.8932 SK1 + 0.0482 KG}$$

If Y3 is less than -7.419 the sample is identified as a fluvial (deltaic) deposit, and if greater than -7.419 the sample is identified as a shallow marine deposit.

Result of the plots show that there is a dominance of tidal influenced fluvial to shallow marine process for the Y2 against Y3 discrimination diagram and a beach/shallow agitated marine processes in Y1 against Y2 plot. (Fig 6 and 7). The calculated functions is shown in table 4.

Table 4: Calculated grain size discrimination Functions

SAMPLE ID	Y1	Y2	Y3
ON 1	-3.59	99.2	-8
ON2	-8.07	96.39	-4.27
ON3	-4.77	107.4	-7.12
IH1U2	-2.85	122.4	-11.6
IH2 U1A	-6.57	84.01	-4.04
IH2 U1B	-2.31	86.02	-7.4
ISU1	-1.78	78.54	-7.2
ISU2	-3.93	108.1	-8.92
UT U1	-12.6	90.06	-1.86
UTU2	-4.26	94.72	-6.37
UTU3	-2.92	90.55	-7.08
UTU4A	-11.1	96.29	-2.57
UTU4B	0.044	102.8	-9.86
UTU5	-2.55	103.2	-8.81

Fig.9: Function plots of Y2 against Y3 for sandstone samples in the study area (After Sahu, 1964)

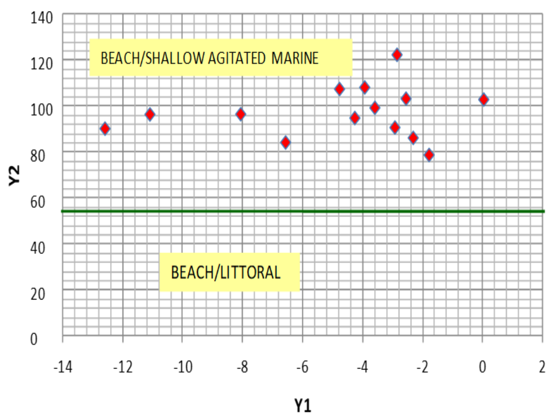


Fig.10: Function plots of Y2 against Y1 for sandstone samples in the study area (After Sahu,1964)

4.4 Result of Thin Section petrography

The photomicrographs of thins sections from analysed samples is shown in plate 9, while the modal composition and recalculated QRF composition is shown in table 5 and 6 respectively. Result shows that the sandstone samples exhibited simple mineralogical composition dominated by quarts which is ≥ 95% with minor feldspar and rock fragments < 3% in all samples. The sandstone samples were also classified using the Folk (1980) Scheme (Fig 8). The sandstone samples were also subjected to textural and mineralogical maturity evaluation as shown in table 7 and 8. By visual appraisal, the sandstone are moderately sorted, sub angular to sub rounded mostly showing floating contact.

Table 5: Modal composition of Sandstone Samples

Sample	Quartz %	Feldspar %	Rock Fragments %	Opaque Minerals
ON 1	93	2	1	4
IH1	95	1	1	3
IH2	98	2	-	2
IH3	92	3	2	3
UT 1	97	1	1	1
UT2	97	-	2	1
IS 1	96	1	1	2

Table 6: Recalculated Q-F-R composition of Sandstone Samples

Sample	Quartz %	Feldspar %	Rock Fragments %	Mineralogical Maturity Index %	Interpretatio
ON1	97	2	1	32.3	Super Mature
IH1	98	1	1	49	Super Mature
IH2	98	2	0	49	Super Mature
IH 3	96	3	1	24	Super Mature
UT 1	98	1	1	49	Super Mature
UT2	98	0	2	49	Super Mature
IS1	98	1	1	49	Super Mature

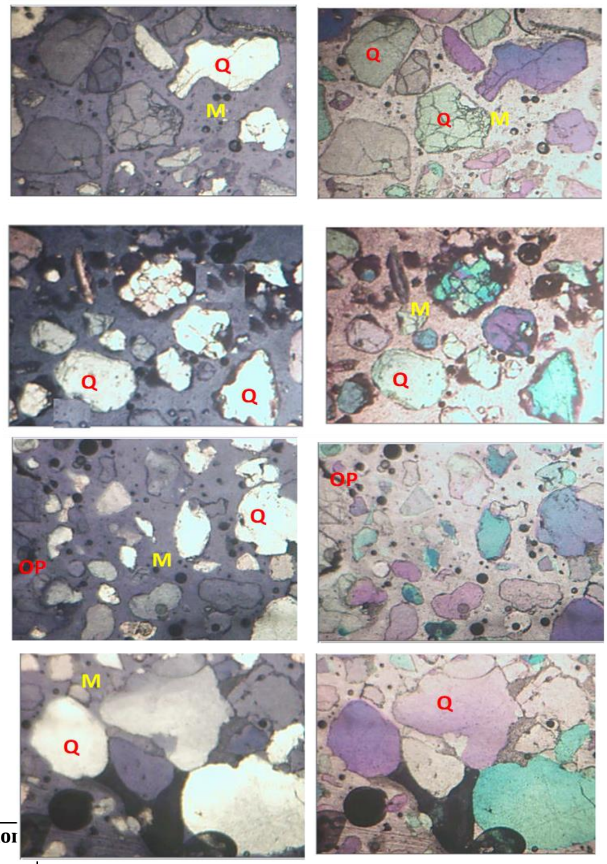


Plate 6. Photomicrographs of Representative Sandstones in the study area. Q = quartz, M = Matrix, OP = Opaque minerals.

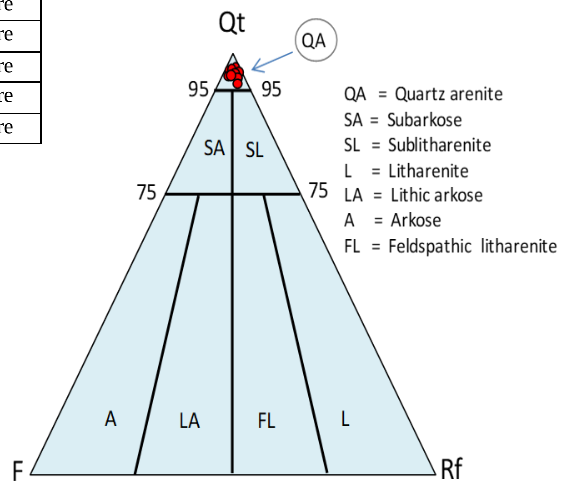


Fig 11. Triangular diagram for the classification of the sandstones (after Folk,1980)

4.5 Textural and Mineralogical Maturity

Table 7: Stages of Sandstone Maturity

Stages Of Maturity	Description
Immature Stage	Sediments contains greater than 5% matrix, grains are poorly sorted and not well rounded.
Sub Mature Stage	Sediments contains less than 5% clay matrix, grains are poorly sorted and not well rounded.
Mature Stage	Sediments contains little or no clay matrix grains are well sorted but not well rounded.
Super Mature	Sediments contains no clay, grains are well sorted and well rounded

Mineralogical Maturity Index

The mineralogical maturity of sandstone is commonly expressed as the ratio of quartz/feldspar. The mineral maturity is calculated using the mineralogical maturity index (IMM) of Nwajide and Hoque (1985).

MMI) given by MMI =

$$\frac{Proprtion of Quartz (Q)}{Proportion of Feldspar (F) + Proportion of Rock Fragment (RF)}$$

The Mineral Maturity Index of the sandstone in the study area falls within the super mature class. The high quartz content and absence of labile components further support this assertion.

Table 8. Mineralogical Maturity Index

Maturity Index	Description
>19	Super Mature
4-19	Mature
3-9	Submature
<3	Immature

5 Discussion

5.1 Environment of Deposition

After inspection of the lithe sections, they were subdivided into lithofacies. Delineation of each lithofacie was based on lithologic, geometric, biogenic content/activities and sedimentary structures. Five lithofacies were altogether described namely: planar Cross bedded sandstone facies A, Massive sandstone facies B, Ferruginized sandstone facies C, herringbone cross bedded sandstone facies D, and Bioturbated sandstone facies E.

The sedimentary environment is the complex of physical, chemical and biological conditions under which sediment accumulates. This complex largely determines the properties of sediments deposited within the environments. Thus depositional sedimentary environments is a geomorphic unit representing he place of deposition which is characterized by some unique set of physical, chemical and biological processes operating at a specified rate and intensity (Krumbin and Sloss, 1963, Allen, 1965). Depositional environments can be established from the facies, facies association, facies sequences and facies cycles.

The planar cross-stratification results from the migration of 2D bedform like mega ripple and sand wave under lower flow regime conditions (Harms et al., 1982, Boggs, 2006). This facies indicates sediment transport by strong traction currents. Internal sedimentary structures strongly suggest that the associated features of the sandstone units are of shoreline /coastal marine process. The massive sandstone facies is interpreted as a water-laid deposit. Most longitudinal bars are stable bedform at flood stage, when all the bedloads is in motion. Bi-directional orientation in several sandstone units indicates reversal of flow of the depositing currents typical of tidal process (Nichols, 2009).

The ferruginized sandstone facies is depicted by extensive liesengang structure comprising of iron cemented sandstone strips enclosing massive bedded sandstone often defining a lobe structure. They are often brownish. Under oxidizing conditions most of the Fe will be $Fe^{+3}$and give the sediment a red coloration as in Hematite (Fe_2O_3). The ferruginization process suggest surface exposure and oxygen-rich environment. The intense preferential reworking and the preponderance of diagenetic structures on surfaces of this facies probably suggests epigenetic mineralization (Dill, 2012).

The overall grain size interpretation shows that sediments from the study area are fine to coarse grained with values ranging from 0.2 to 2.0Φ, very well sorted to poorly sorted with range value of 0.28 to 1.2Φ, nearly symmetrical to strongly fine skewed with values of -0.04 to 0.59Φ and platykurtic to verly leptokurtic with values of 0.79 to 2.46Φ. The range of values suggest fluctuation of energy level during deposition (Allen, 1967)

The Histogram plots of the individual weight percent against the phi scale show that the sandstones in the study area are dominantly unimodal. An inspection of the cumulative frequency curves of the studied samples shows three grainsize populations namely: Suspension population with break usually at 4Φ, saltation population with break usually at 0 to 1Φ and a traction population with break at -1Φ. From inspection, the sediment population is dominated by saltation population.

Friedman’s (1967) and Moiola and Weiser, (1968) discrimination diagram for differentiating sediments of Beach or Fluvial (River) origin was applied to the sandstone samples collected from the sediments in the study area. In both scenario, the sandstone sediments suggest tidal influenced fluvial to shallow marine depositional environment.

5.2 Sediment Maturity and Provenance

This is a measure of mineralogical and textural maturity. The distance/time from the source area to the depositional site is measured by textural maturity. Many elements are considered in this effect, including the weathering climate, transportation, and the rock's mineralogical makeup. The silt becomes more mature as the distance and time it takes to convey it increases. Texture (textural maturity), mineralogy, and other factors can all be used to determine maturity (mineralogical maturity). Immature, sub mature, mature, and super mature are some of the terms used to describe maturity.

The sandstone sediments are sub-mature in texture, with less than 5% clay matrix, moderately to poorly sorted grains, and not well rounded edges. (Folk) (1982). The sandstone in the area is essentially quartz sandstone or quartz arenite based on petrographic analysis Onyekuru et al (2017). Thin section analysis of pebbles shows this sediments consist mainly quartz and low amounts of feldspar which is an indication of granitic rock derivative Ikoro et al (2014).

The mineralogical maturity of sandstone is commonly expressed as the ratio of quartz/feldspar. The Mineral Maturity Index of the sandstone in the study area ranges from 24-49 which falls within the super mature class. The high quartz content and insignificant amount of feldspar and rock fragments further support this assertion. The study suggests the sandstones must have been subjected to substantial high degree of reworking that resulted in the removal of the ferromagnesian minerals and feldspar typical of recycled sediments.

6 Conclusions

This study of the Ajali Sandstone of Okigwe-Uturu area and its environments have examined five outcrops that cut across the Maastrichtian sediments of Ajali Formation, with respect to lithostratigraphy, depositional settings and sedimentary structures. The formation was found to be Fine-to-coarse grained, bioturbated sandstones capped by thin mud layers. Large-scale planar cross-bed sets with graded fore sets, and occasional herringbone cross beds indicate tidal action. Fine- to coarse-grained sandstones, with smaller scale mud-draped trough cross beds and ripple laminations with occasional gravel lags at the base of channels indicate fluvio-tidal influences. The values Calculated from hydrodynamic parameters shows that the rocks within this study area are products of mild hydrodynamic and sedimentary processes which are seen only during an un-destructive sedimentary event at present. Concluding from the known volumes of the Coarse Sandstone-clay sequence and the already calculated specific discharge of sediments, it can be deduced that Ajali sandstone sequence was a stratigraphically long-term process (Several millions of years).

References:

[1] Allen, R., L. (1986). Lower Cretaceous Tide Revealed by Cross Bedding with Mud drapes. Nature No. 286, p. 579-581.

[2] Amajor, L., C. (1986) Sedimentary Facie Analysis of Ajali Sandstone (Upper Cretaceous) in the Southeastern Benue Trough Nigeria Nigeria, Bull., Nig. Journal of Mining Geosciences Society vol. 21, p.171-176.

[3] Dill, H., G. (2012) Diagenetic and Epigenetic Mineralization in Central Europe Related to Surfaces and Depositional Systems of Sequences Stratigraphic Relevance. Journal of Sedimentary Research Vol.77, p.702-715

[4] Einsele G., (2000) Sedimentary Basins: Evolution, facies and sedimentary budget. Springer, Berlin, Germany.

[5] Folk, R., L., (1980). Petrology of Sedimentary Rocks. Hemphill Publishing, Austin, Tx, 184p.

[6] Friedman,G.M. (1967) Dynamic processes and Statistical Parameters Compared for Size Frequency Distribution of Beach and River Sands. Journal of Sedimentary Petrology, Vol. 37, p.327-354

[7] Haughton, P.D., Todd, S.P., Morton, A.C., (1991). Sedimentary provenance studies. In: Morton,A.C., Todd, S.P., Haughton, P.D.W. (Eds.), Developments in Sedimentary ProvenanceStudies, *Geological Society Special Publication* ,57(2)., pp. 1-11.

[8] Hoque, M. (1977) Petrographic Differentiation of Tectonically Controlled Cretaceous Sedimentary Cycles, Southeastern Nigeria. Sedimentary Geology, 17, 235-245

[9] Hoque, M., and Ezepue M., C., (1977) Petrology of the Sanstone. Journal of Mining Geology. 14:pp.16-22.

[10] Hoque, M., & Nwajide, C.S., (1985). Tectono-sedimentological evolution of an elongate intracratonic basin (aulacogen): The case of the Benue Trough of Nigeria. *Journal of Mining and Geology* 21,19–26.

[11] Ikoro, D. O., Amajor, I. C., Iwuagwu, C. J., Ubechu, B., Israel, H. O., Onyekuru, S.O., Ekeocha, N. O. (2014). Pebble morphormetric

analysis as aid to environmental determination, a case study of Ajali Sandstone in Nkpololu Southeastern Nigeria. International Journal of Engineering Trends in Engineering and Development Available. Issue 4, volume_3. ESSN 12496149.

[12] Ikoro, D. O, Amajor, L. C, Inyang, D. O, Okereke, C. N, Ekeocha, N. O. (2014) Facies Model Determination Using Markov Chain Analysis: A case study of Ajali Sandstone in Ohafia – Igbere Southeastern Nigeria. International Research Journal of Geology &Minning 4(7) 198, 2014.

[13] Julien, P. Y., (1995). Erosion and Sedimentation, New York: Cambridge University Press, 1995.

[14] Miola, R., J. and Weisser D., (1968) Textural Parameters: and Evaluation. Journal of Sedimentary Petrology. Vo. 38. P. 45-53

[15] Murat, R., C. (1972). Stratigraphy and Paleogeography of the Cretaceous and lower Tertiary in Southern Niogeria. In Dessauvagic T.T.S., and Whiteman, A.J. (Eds), African Geology University of Ibadan Press, Nigeria, P. 251-266.

[16] Nwachukwu S., O., (1972) The Tectonic Evolution of the Southern Portion of the Benue Trough, Nigeria: Geology Magazine, Vol. 109, p. 411-419.

[17] Nwajide CS (2006). A guide for geological field trips to Anambra and related sedimentary basins in South-Eastern Nigeria. Great AP Express Publishers Ltd., Nsukka

[18] Onyekuru, S. O., Iwuagwu, C. J., Nwankwor, G. I., Onu, N. N., Ukaonu C. E. (2013). Dispersal Patterns of the Late Cretaceous to Early-Tertiary Sediments in the Southern Anambra Basin, Southeastern Nigeria. *International Journal of Geosciences*, 4, 588-604

[19] Onyekuru, S.O, & Iwuagwu, C.J (2010). Depositional Environments and Sequence Stratigraphic Interpretation of the Camano-Maastrichian Nkporo Shale Leru-Okigwe axis Anambra Basin, Southeastern Nigeria, Australian Journal of Basic and Applied Sciences, 4(12) 6623_6640.

[20] Onyekuru S., O., Opera K., D., Iwuagwa C., J., Opera A., I. (2015). Diagenetic Study Sandstone Sediment in Parts of Anambra and Afikpo Basins Southeastern Nigeria. Futon Journal Series (FUTOJNLS), 2015 volt, P-ISSN, 2467-83255; e-ISSN: 2476-8456.

[21] Onyekuru S. O, Okoro E. M, Opera K. D, Agunmanu A. E, Ikoro D. O (2017) Paleoenvironment and Provenance Studies of Ajali Sandstone in Igbere Area Afikpo Basin, Nigeria. International Journal of Engineering and Science 6, 19-30, 2017

[22] Reineck, H., E., and Singh, I., B. (1975) Depositional Sedimentary Environments with Reference to Terrigeneous Clastics. Springer-Verlag, Berlin. P. 4-27.

[23] Reyment, R., A. (1965) Aspects of the Geology of Nigeria the Stratigraphy of the Cretaceous and Cenozoic Deposits. Ibadan University Press, 133p.

[24] Simons, D.B., Richardson, E.V., Nordin Jr., C.F., (1965). Sedimentary structures generated by flow in alluvial channels. In: Middleton, G.V. (Ed.), Primary Sedimentary Structures and their Hydrodynamic Interpretation, SEPM Special Publication, 12, pp. 34-52.University of Ibadan Press, Ibadan, pp 635–646

[25] Weltje, G.J., Von Eynatten, H., (2004). Quantitative provenance analysis of sediments: review and outlook. Sedimentary Geology 171, 1-11

Contribution of individual authors:

Enyioko N.D and Ikoro D.O prepared the script and laboratory analyses of the study.

Onyekuru S.O and Ikoro D.O proof read the entire work.

Ogbonna T.L prepared the figures, plates, tables and the page setting of the entire work.

This study was self-sponsored.