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Research Article

Sedimentological Characteristics and Geochemistry of Ajali Sandstone Exposed at Ofe-Jiji and Environs, Northern Anambra Basin, Nigeria

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Abstract: Textural, mineralogical and structural studies as well as outcrop mapping of sandstone in Ofe-Jiji and environs were carried out in order to interpret depositional environment of Ajali sandstone exposed at Ofe-Jiji and environs of the northern Anambra Basin. The sandstone is false bedded, medium-coarse grained (average of 1.13 mm in diameter), poorly sorted and strongly coarsely skewed with an average skewness value of -0.72. Chemical analysis indicates that the sandstone exhibits average SiO_2 contents ranging from 59.12 to 60.20% with an average value of 59.80% while alumina (Al_2O_3) content range between 2.51 and 2.75% with an average of 2.63%. The mineralogical composition shows on the average 56.98 quartz, 6.30 feldspar, 31.78% rock fragment and 4.93% matrix and cement. The major framework composition is Q_{56} F_6 L_{36} which classifies the sandstone as lithic arenite. The sub angular texture and the geochemical assay of 22.74 ratios (SiO_2/Al_2O_3) and 3.36 ratios (Na_2O/K_2O) indicate low chemically stable minerals in the sandstone and depict mineralogical immaturity. Also, the average ZTR% index of 52.36% with Tourmaline as the least abundant of ultra-stable minerals indicates sub-mature to immature mineralogy of the sandstone. The sandstone may be described as Fe-Sandstone based on Herron Classification Scheme. The dominance of Fe_2O_3 (26.57%) in the sandstone renders it ferruginous and reflects oxidizing environment. Ophiomorpha burrow in the upper unit of the beds strongly suggests fluvial origin.

Keywords: Fe-rich, fluvial origin, lithic arenite, Ofe-jiji, sandstone characteristics

INTRODUCTION

The Ajali Sandstone is an extensive stratigraphic unit conformably overlying the Lower Coal Measure (Mamu Formation) and underlying the Upper Coal Measure (Nsukka Formation) in the Maastrichtian. Various authors like: Simpson (1954), Reyment (1965), Hogue and Ezepue (1977) and Ladipo (1986) have discussed the environment of deposition; Simpson (1954) described the litho-stratigraphic units as false bedded sandstone; Reyment (1965) associated its type environs and named it Ajali Sandstone; Hogue and Ezepue (1977) evaluated its textural characteristics and inferred a fluvio deltaic depositional setting while Ladipo (1986) on the contrary argued for a tidally influenced regime in a shelf/shoreline environment. Furthermore, Adekoya *et al*. (2011) studied the Sedimentological characteristics of Ajali sandstone in the Benin flank of Anambra basin and reported deposition in shallow marine (littoral) environment as indicated by the shale facie as well as in fluvial environments as indicated in the attributes of the overlying tabular and ferruginous upper sandstone facie (Fig. 1). Hogue and Ezepue (1977) have classified Ajali sandstone as a quartz arenite on the basis of field work, petrographic and mineralogy using the four parameters: quartz (Q), feldspar (F), rock fragment (R) and matrix element (M). But, Ibe and Akaolisa (2009) reported that, using Herron (1988) classification Scheme which involves geochemical data, the Ajali sandstone in Ohafia, southeastern Nigeria has two distinct units: the quartz-rich lower unit and the overlying iron-rich variety which was contrary to the general classification of the sandstone as quartz arenite. Odigi and Amajor (2008) also argued that, the high mineralogical maturity association with the Ajali sandstone as opined by Hogue and Ezepue (1977) can only be upheld if supported by geochemical data. However, the present scheme encompasses studies on the basis of mineralogy (using the four parameters as earlier mentioned), geochemical data and log plots of Fe_2O_3/K_2O against SiO_2/Al_2O_3. The Fe_2O_3 separates lithic fragments from Feldspars in sandstone while the SiO2/Al2O3 ratio is used to distinguish between quartz-rich (high ratio) sandstone from other components as found by Herron (1988). This study focuses on the Sediments characteristics, Mineralogy and Geochemistry of Ajali sandstone exposed in Ofe-Jiji and environs in northern Anambra basin. The study area falls between latitudes 7°24ᴵ N and longitudes 7°19ᴵ E on Ankpa sheet 268 (scale 1:100,000).

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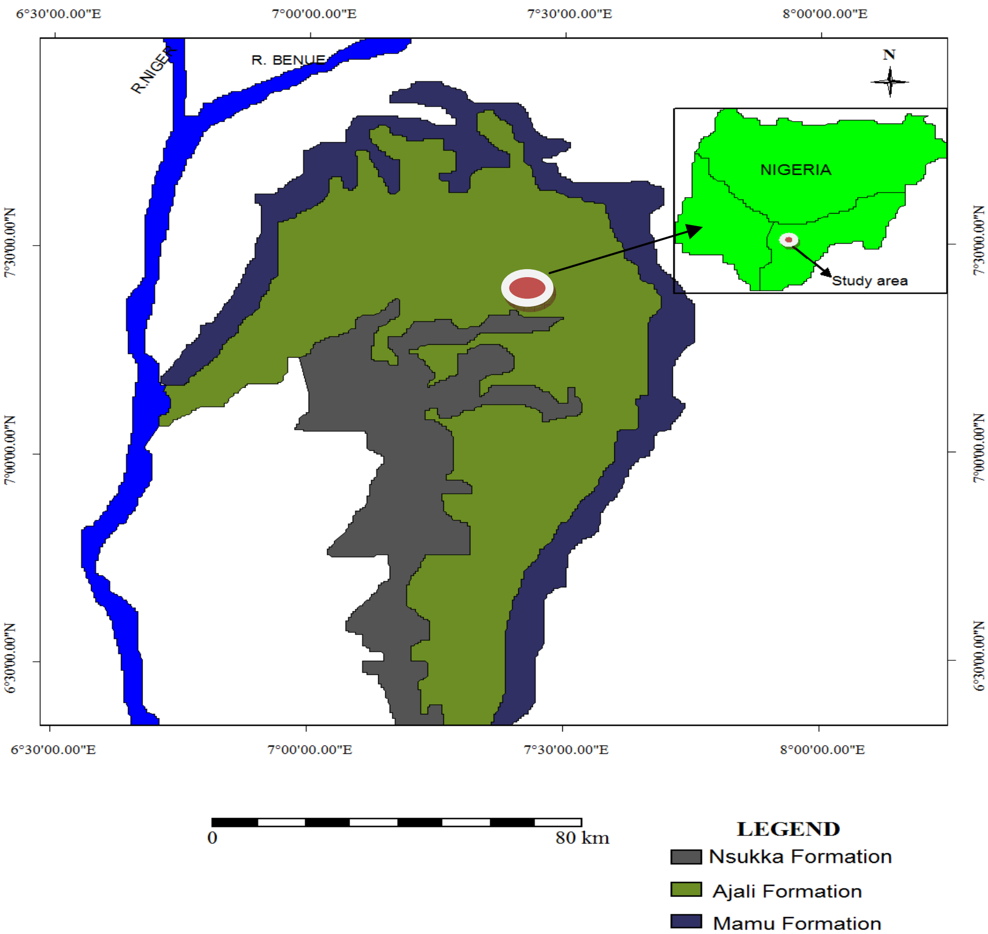

Fig. 1: Geological map of Anambra Basin showing location of study (Obianuju, 2005) Insert: Map of Nigeria showing the study area

Table 1: Stratigraphy of Southern Benue trough (Obaje, 2009)

Age		Southern benue/anambra basin	Cycle of sedimentation
Tertiary	Eocene	AMeki/nanka formation	
	Paleocene	IMO shale	
	Maastrichtian	Nsukka formation	3rd Cycles of sedimentation
		AJALI formation	
		Mamu formation	
	Campanian	Enugu/nkporo formation	
	Santonian-Coniacian	Awgu formation	2nd Cycles of sedimentation
	Turonian	Eze-aku groupkeana, makurdi, agala and amaseri formation	
	Cenomanian	Odukpani formation	
Lower cretaceous	Albian	Asu river group	1st Cycle of sedimentation
	Aptian		
Precambrian		Basement complex	

GEOLOGICAL SETTING AND STRATIGRAPHIC UNITS

The failed arm of the triple radial rift system involving the separation of the South African and African Continents gave birth to the southern section of NE/SW aulacogen (Oladele, 1975). 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 lead 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 forms the terminal units of the Cretaceous series (Table 1).

By sequence, Ajali Formation which is about 330 m thick is underlain by Mamu and Nkporo Formations that are 400 and 200 m thick, respectively. 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 whereas; 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 Ofe-Jiji environs in the Ankpa flank of Anambra basin is the object of this study. The area is bound to the north by North Central highlands, to the south by Niger Delta basin, to the east by Abakaliki fold belt (anticline) and to the North West by Bida/Nupe basin.

MATERIALS AND METHODS

Methods of investigation involved both field study and laboratory analyses. Bedding characteristics in term of texture and lithology were studied on the field. Laboratory investigations of samples included grain size analysis, petrography and geochemical analysis. Fifteen sandstone samples were collected from Ofe-Jiji and environs: 3 samples each from 5 locations (Fig. 2). Each sample was divided into 3 parts: One part for grain size analysis, another for heavy minerals petrographic studies and the third part for geochemical analysis. The grain size distributions were mechanically determined in Sedimentology Laboratory of Earth Sciences Department, Kogi State University, Nigeria and using Durham Geo-Slope shaker for 20 minutes agitation of 200 g sample component. British Standards were employed with a sieve set in the order of mesh sizes: 5, 10, 35, 60 and 125 which translates to 4.00, 1.68, 0.25, 0.125 and 0.06 mm, respectively (Table 2). The fraction of each mesh size was weighed for statistical analysis based on the procedure of Folks and Ward (1957). The results of the statistical data obtained from sizes distribution was used to deduce the mode of transportation and depositional environment of the sandstone.

Heavy minerals petrographic analysis was carried out in order to access the maturity of the sandstone.

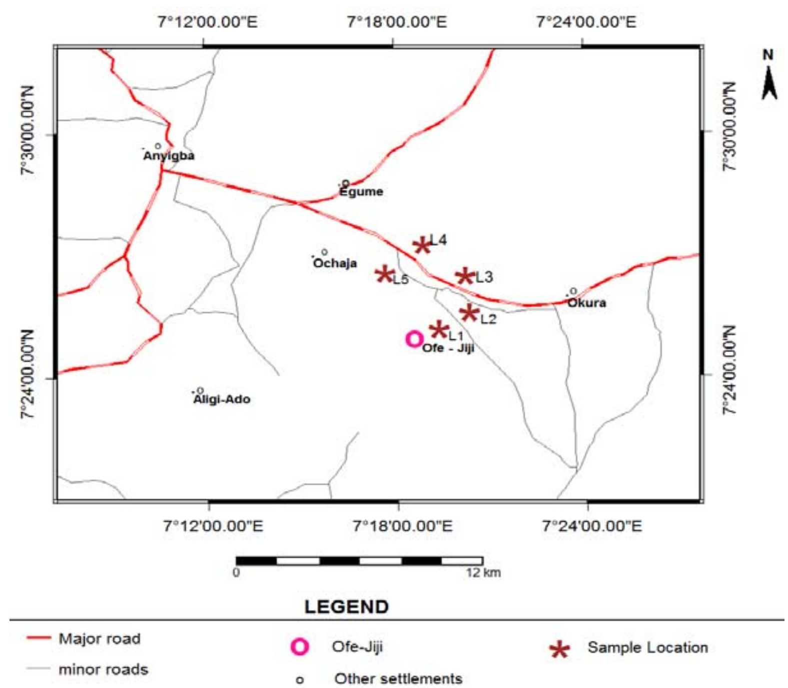

Fig. 2: Map of the study area showing sample stations (Google Earth-Map, 2012, Www.Google/Map/Terrain)

Table 2: Grain size analysis

	Percentage finer (%)				
Sieve diameter(mm)	L1 N = 3	L2 N = 3	L3 N = 3	L4 N = 3	L5 N = 3
4.00	98.28	96.11	98.57	95.36	99.10
1.68	64.04	60.31	68.47	74.45	79.15
0.25	32.17	29.00	36.05	45.00	41.66
0.12	23.10	22.11	24.50	30.00	28.22
0.06	13.78	12.10	17.45	15.25	16.37
0.04	9.40	10.87	12.00	10.21	13.40

N = Number of samples analysed

Each sample was made into solution with water in glass cylinders, properly agitated and left for 10 minutes to aid segregation. Then, 30% hydrogen peroxide (H_2O_2) solution was used to soak the sample for total disintegration. Hence, the heavy minerals were separated by panning and mounted in glass slide for petrological observation.

For geochemical analysis, samples were crushed into aggregates, oven dried at 100°C and ground into powder. The powdered samples were then sieved through sieve #60 micron size and the oversize was ground again until no larger than 60 micron was left. Sieve made of nylon was used to avoid contamination by metals. Each ground sample was homogenized and pressed into pellet with a binder of chromatographic cellulose in a proportion of 1:10 by weight and loaded into the inner chamber of Minipal-4 ED Version XRF Analyzer at the Central Research Laboratory of Federal University of Technology, Akure, Nigeria.

RESULTS AND INTERPRETATION

Field characteristics: The investigated sediments in the entire sandstone outcrops at of Ofe-Jiji and environs consist of one main lithofacie: the false bedded ferruginised sandstone. The beds display brown and reddish colours. The sediments are friable, poorly cemented and fine to coarse grained in texture. The beds are marked with syn-depositional primary structures such as false beddings. An Azimuth of NNE-SSW direction which described the paleocurrent was observed in all the locations. Ophiomorpha burrows were found at the upper section of the sandstone bed (Plate 1), which suggests fluvial origin of deposition.

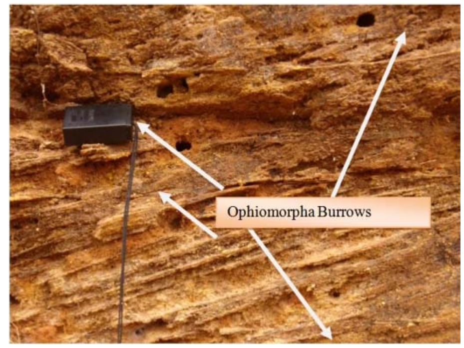

Plate 1: False bedded ferruginised fine to medium grained sandstone in Ofe-Jiji

Grain size analysis: Table 2 shows the percentage finer values for the respective sieve diameter while Fig. 3 shows plot of particle size distribution of samples from the locations. The investigated particle sizes range from 0.82 to 1.36 mm which classifies them within the medium and coarse grained sizes with an average of 1.13 mm, which generally put the sandstone as medium grained. The standard deviation (measure of dispersion sorting) is 1.23 which indicates poorly sorted grains. The skewness values are between 0.63 and -0.93 with an average of -0.72, showing that, the grain size distribution of the sandstone is strongly coarsely skewed.

Thin-section petrography: The grains of the sandstone range from angular to sub angular shape. They are mainly polycrystalline and most of the grains are not in contact. Cementing materials are mainly iron oxide coatings and silica in form of quartz. The rock is composed of 56.98 quartz, 6.30 feldspar, 31.78 rock

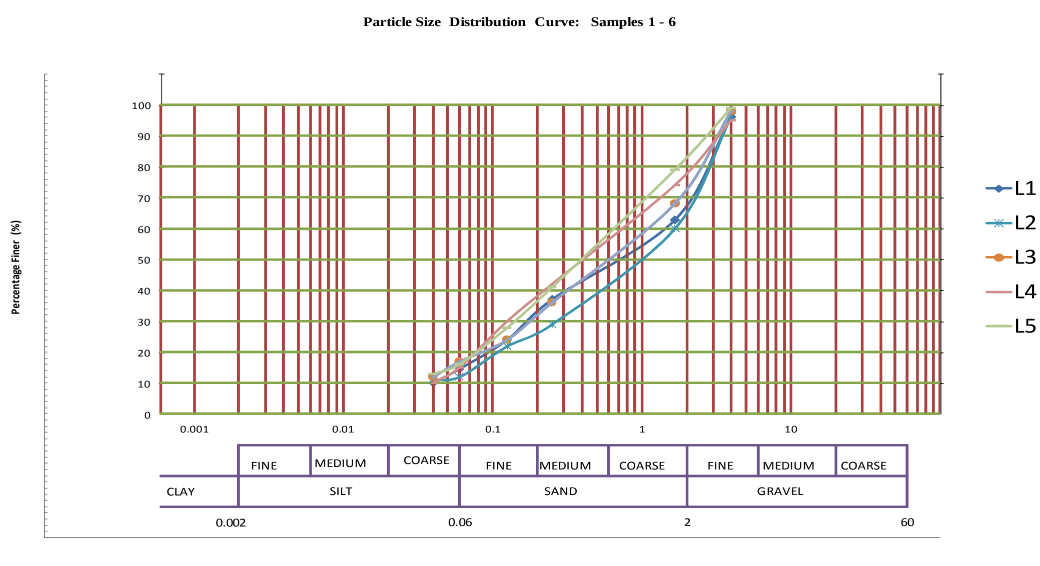

Fig. 3: Plots of particle size distribution curve for Ajali sandstone at Ofe-Jiji and environs

Table 3: Mineral composition of Ajali sandstone from thin-section study

	Counts	L1	L2	L3	L4	L5	Total	% Composition
Quartz	1st	15	12	10	17	14	68	56.98
	2nd	14	18	14	12	16	74	
	3rd	17	12	11	13	13	66	
Feldspar	1st	2	1	0	2	2	7	6.30
	2nd	1	0	2	2	3	8	
	3rd	3	0	1	3	1	8	
Rock fragment	1st	5	11	6	6	7	35	31.78
	2nd	10	4	7	6	11	38	
	3rd	6	10	8	7	12	43	
Matrix and cement		2	2	1	1	0	6	4.93

Table 4: Composition of heavy mineral suits for Ofe-Jiji and environs sandstone

	Tourmaline	Rutile	Staurolite	Sphene	Zircon	Kyanite	Total	ZTR	ZTR index (%)	Opaque
L1	1.00	2.00	1.00	1.0	2.0	1.0	8	5	62.50	13.00
L4	1.00	2.00	0.00	2.0	1.0	3.0	9	4	44.40	12.00
L5	0.00	1.00	1.00	1.0	2.0	1.0	6	3	50.00	10.00
Total	2.00	5.00	2.00	4.0	5.0	5.0			156.9	35.00
Percent composition	3.45	8.62	3.45	6.9	8.62	8.62				60.34

Table 5: Chemical composition of sandstone at Ofe-Jiji and environs

Major oxides	L1 N = 3	L2 N = 3	L3 N = 3	L4 N = 3	L5 N = 3	Average N = 15
SiO_2	59.120	60.150	59.970	60.200	59.55	59.80
Al_2O_3	2.6700	2.5400	2.6800	2.5100	2.750	2.630
Fe_2O_3	26.980	27.090	28.100	27.550	28.99	27.74
MgO	0.2200	0.3200	0.2900	0.0300	0.330	0.240
CaO	0.5100	0.4100	0.3800	0.4000	0.390	0.420
MnO	0.0600	0.0400	0.0300	0.0600	0.060	0.050
Na_2O	0.1400	0.1500	0.0900	0.1000	0.210	0.140
K_2O	0.0500	0.0400	0.0400	0.0300	0.030	0.040
TiO_2	1.8500	1.9700	1.9900	2.0200	1.950	1.960
P_2O_5	0.3800	0.4500	0.4400	0.4000	0.410	0.420
LOI	7.7900	6.6800	5.9900	6.6500	5.330	6.490
Total	99.770	99.840	100.00	99.950	100.0	99.91
SiO_2/Al_2O_3	22.140	23.680	22.380	23.980	21.65	22.74
Fe_2O_3/K_2O	539.60	677.25	702.50	918.33	966.33	730.05
Na_2O/K_2O	2.8000	3.7500	2.2500	3.3300	7.000	3.630
Log (SiO_2/Al_2O_3)	1.3400	1.3700	1.3500	1.3700	1.330	1.350
Log (Fe_2O_3/K_2O)	2.7500	2.8300	2.8500	2.9600	2.980	2.860

*Results presented are averages of 3 samples at each location

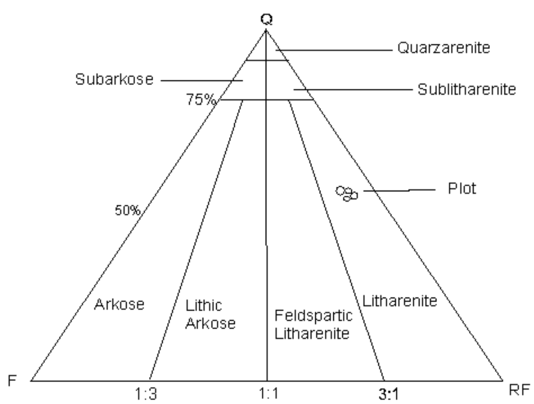

Fig. 4: Sandstone classification of Pettijohn (1975) showing plot of Ajali Sandstone at Ofe-Jiji and environs with the field of Litharenite

fragment (containing 5.21% mica) and 4.93% matrix and cement, respectively, on the average (Table 3). Using the Pettijohn (1975) Classification Scheme, the sandstone framework composition consists of Quartz (Q), Feldspar (F) and Rock Fragment (L) which classified it as lithic arenite with composition $Q_{56.98}$ $F_{6.30}$ $L_{31.78}$ (Fig. 4).

Heavy minerals petrography: Heavy mineral suite consists of both opaque and non-opaque forms. The opaque minerals constitute 60.34%, on the average while the non-opaque has the following composition: tourmaline (3.45%), rutile (8.62%), stanrolite (3.45%), sphene (6.90%), zircon (8.62%) and kyanite (8.62%) (Table 4). The average ZTR% index is 52.36% with Tourmaline as the least abundant of ultra-stable mineral. This value indicates sub-mature to immature mineralogy of the sandstone.

Geochemical analysis: The result of the geochemical analysis of Fifteen (15) sandstone samples from the study area is shown in Table 5. The analysis indicates that the sandstone exhibits average SiO_2 contents ranging from 59.12 to 60.20% with an average value of 59.80% while alumina (Al_2O_3) content range between 2.51 and 2.75% with an average of 2.63%. The sandstone is therefore not highly siliceous. Low alumina might be indicative of dearth of alumino-silicate minerals, high mobility of aluminum or low intensity of chemical weathering in the province. Generally, SiO_2 and Al_2O_3 constitute 63.43% of the entire composition indicating that the sandstone is chemically sub mature to immature, probably as a result of its enriched chemically unstable minerals.

DISCUSSION

The study area falls within Ajali Formation of Anambra basin which is an extension of the stratigraphic unit that is conformably overlying the Mamu Formation and underlying the Nsukka Formation. These Formations were deposited during the Maastrichtian (Hogue and Ezepue, 1977). Field observation shows that, sedimentation processes of grains distribution in the study area might be a product of by-passing of relatively smaller size grains through coarse fraction of grain particles transported in the fluvial setting. Meanwhile, Hogue and Ezepue (1977) opined that, the particles were derived from fragmentation of polycrystalline rock during fluvial transportation. The sandstone consist one major lithofacie: the false bedded ferruginised sandstone. Texturally, it consists of fine to coarse grained particles that are poorly sorted and strongly coarsely skewed based on Pettijohn (1975) classification chart. The mean grain size value of 1.13 mm of the sandstone indicates a prevalence of medium grain sizes and the wide range of grain sizes, ranging from fine to coarse could be a reflection of variable current velocities and turbulence of the transporting medium (Amaral and Pryor, 1977). However, the dominance of NNE-SSW orientation of the paleocurrent direction as shown in the false-bedding strongly implies a single source.

Mineralogically, the Ajali sandstone in Ofe-Jiji and environs consists on the average 56.98% Quartz, 6.30 Feldspar 31.78 Rock Fragment and 4.93% clay matrix and cement fraction. The low quantities of quartz and feldspar classify the sandstone as Lithic Arenite ($Q_{56.98}$ $F_{6.30}$ $L_{31.78}$) based on Pettijohn (1975) sandstone classification (Fig. 4). This composition gives maturity index ratio Q/(F+L) as 1.53, meaning that, the sandstone is of sub-mature to immature mineralogy (Pettijohn, 1975). Compositionally, the sandstone from the study area may be described as Fe-Sandstone based on Herron (1988) classification scheme (Fig. 5). Therefore, the Ajali sandstone at Ofe-Jiji can be referred to as Fe-rich lithic arenite. The Ajali sandstone at Ohafia, southeastern Nigeria has also been described as Fe-rich using Herron (1988) classification scheme and termed Lithic Arenite, owing to its low Quartz and feldspars content. It was also termed immature due to its low assay level of 21.93 (SiO_2/Al_2O_3) (Adekoya *et al*., 2011). Also, Adekoya *et al*. (2011) reported ferruginous sandstone facie in the uppermost bed of Ajali sandstone in the Benin flank of Anambra basin. Ferrugenization could have resulted from precipitated Fe^{2+} and Fe^{3+} within the sediments particles as a result of changes in pH and Eh of the inter-particulate fluid. The geochemical Assay indicates 22.74 ratios (SiO_2/Al_2O_3) and 3.36 ratios (Na_2O/K_2O). These values, according to Jenner *et al*. (1988) are indicative of low chemically stable minerals in the sandstone. Heavy mineral petrographic studies reveal opaque mineral constituents of about 60.34% which is dominantly Haematite and non-opaque mineral suite of Tourmaline, Rutile, Stanrolite, Sphene, Zircon and Kyanite. The calculated average ZTR% index of 52.36% with Tourmaline as the least abundant of ultra-stable minerals indicates sub-mature to immature mineralogy of the sandstone. These heavy minerals

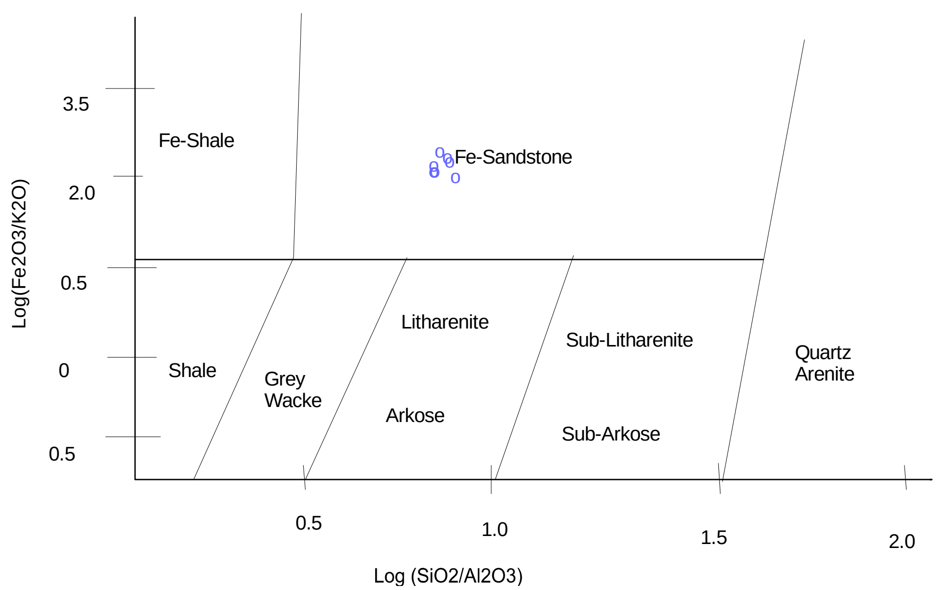

Fig. 5: Sandstone classification scheme (Herron, 1988) showing plot of Ajali sandstone at Ofe-Jiji and environs with the field of Fe-sandstone

suites occur as basement complex of igneous and metamorphic rocks sediments derivatives. The high percentage of haematite reflects oxidizing environment of deposition while Ophiomorpha burrows and the attributes of the beds strongly suggest fluvial origin. This report conforms to Adekoya *et al*. (2011) who reported that the Ajali sandstone in the Benin Flank reflects fluvial environment but in contrary with Hogue and Ezepue (1977) and Ladipo (1986) who inferred fluvio-deltaic environment and tidal shelf environment, respectively. The conclusions are obviously a reflection of lateral facie changes of the extensive stratigraphic unit.

CONCLUSION

The exposed sandstone beds at Ofe-Jiji environs are part of the extension of the Maastrichtian Ajali sandstone of the Anambra Sedimentary basin. The sandstone indicates 1.13 mean grain size value, which imply a prevalence of medium grain sizes. The grain sizes range of fine to coarse could be a reflection of variable current velocities and turbulence of the transporting medium. The NNE- SSW orientation of the paleocurrent direction strongly implies a single source. Texturally, the false-bedded sandstone consists of fine to coarse grained particles that are poorly sorted and strongly coarsely skewed. The mineralogical composition shows on the average 56.98 quartz, 6.30 feldspar, 31.78% rock fragment (containing 5.21% mica) and 4.93% matrix and cement. The low quantities of Quartz and feldspar classify the sandstone as lithic arenite ($Q_{56.98}$ $F_{6.30}$ $L_{31.78}$) based on Pettijohn (1975) sandstone classification. The composition of the sandstone can be described as Fe-Sandstone based on Herron (1988) classification scheme. The geochemical Assay indicates 22.74 ratios (SiO_2/Al_2O_3) and 3.36 ratios (Na_2O/K_2O). These values are indicative of low chemically stable minerals in the sandstone and depict the mineralogical immaturity of the sandstone. The textural immaturity of the sandstone is revealed by their sub angular edges. Also, the average ZTR% index of 52.36% with Tourmaline as the least abundant of ultra-stable minerals indicates sub-mature to immature mineralogy of the sandstone. The dominance of Fe_2O_3 (26.57%) in the sandstone renders it ferruginous and reflects oxidizing environment. Ophiomorpha burrow in the upper unit of the beds strongly suggests fluvial origin. This report conforms to Adekoya *et al*. (2011) who reported that the Ajali sandstone in the Benin Flank reflects fluvial environment but in contrary with Hogue and Ezepue (1977) and Ladipo (1986) who inferred fluvio-deltaic environment and tidal shelf environment, respectively. The facie changes of Ajali sandstone is reflected in the interpretation of the earlier workers, notably, Hogue and Ezepue (1977) as well as Ladipo (1986). The former inferred a continental fluvio-deltaic depositional setting while the latter referred to the depositional environment as tidal shelf. The different interpretations were consequent to the dominant Sedimentological characteristics in the different localities of investigations as a result of lateral facie changes.

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