Textural and Geochemical Characterization of Sandstone Sediments Associated with Nsukka Formation in Okigwe Area, Southeastern Nigeria

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ABSTRACT

Textural and Geochemical characteristics of the sandstone sediments associated with the parallic Nsukka Formation in Anambra Basin were investigated. The intent is to analyze the sandstone sediments in Nsukka Formation in terms of its textural and major oxides constituents with a view to delineate the depositional environment as well as infer the provenance. Field studies show that the sandstones are friable and white in freshly cut stone. Textural analysis using the concept of Folks 1968 and 1974 indicates that the sandstones range from fine to medium whereas statistical analysis gave sorting and kurtosis of 0.72θ and 0.07θ respectively, indicating moderately sorted sediments. On the basis of the values obtained for sorting and kurtosis, it is inferred that the sandstone sediments have not undergone much transport and were fairly deposited close to source area, possibly from the felsic rocks derived from the inverted depocenter of the adjacent Abakaliki Anticlinorium, indicating a fluvial environment. Geochemical analysis using the X-ray fluorescence method as well as the geochemical assay indicates an average of 1.92 ratio (SiO_2/Al_2O_3) and 2.29 ratio (Fe_2O_3/K_2O). These values are indicative of low chemically stable felsic (granitic) craton/shield source area and depict the mineralogical immaturity of the sandstone. The dominance of Fe_2O_3/K_2O over SiO_2/Al_2O_3 in the sandstone suggests that the sediments are typically iron-rich, thus, reflecting an oxidizing environment.

Keywords: Sandstone, Sorting, Kurtosis, Skewness, Sediments, Formation, Grain-size

INTRODUCTION

The Nsukka Formation (Upper Coal Measures) conformably overlies the Ajali Sandstone. It is overlain by the Paleocene Imo Shale. The type locality of the Nsukka Formation is Nadu River, fourteen (14) kilometres north of Nsukka in Southeastern Nigeria. The formation was formally known as the Upper Coal Measures (Tattam, 1994).

The lithology is mainly parallic, consisting of interbedded shales, siltstones, sands and thin coal seams, which have become lateritized in many places where they characteristically form resistant capping on mesas and buttes. The formation begins with coarse to medium-grained sandstones and passes upward into well-bedded clays, fine-grained sandstones and carbonaceous shales with thin bands of limestone (Reyment, 1965).

The Nsukka Formation spans upper Maastrichtian to Danian (diachronous) with depositional environment that has been suggested to be similar in many ways to the Mamu Formation (Lower Coal Measures) i.e. transitional/shoreline, mud flat and swamps, deposited during a largely regressive phase. The formation is about 350 meters thick, with bands of limestone which occur toward the top of the formation. Kogbe (1975) noted that the formation is Pro-Niger Delta, which advanced rapidly southward in the Anambra Basin and Afikpo Syncline.

The surface texture of sediments has often been studied, and attempts have been made to relate it to depositional processes. Also, weathering conditions at the source area, petrography as well as major and trace elements geochemistry provide useful insights into the provenance of sediments. Thus, this paper presents a textural and geochemical analytical data of the Maastrichtian siliciclastic sediments of Nsukka Formation in Okigwe area, with a view to assess the prevailing conditions at the source area and the processes that occurred before and after deposition. The possible provenances of the formation as well as the paleo-environmental and depositional trends are also inferred. Attempt is also made to assess the maturity of the sediments in order to determine their origin.

The Study Area

The study area (Ihube, Okigwe) is bounded by latitude 5°51'52" N and longitude 7°21'28" E, and has an altitude of about 300meters above sea level. The area is characterized by slightly undulating topography, and is largely drained by Imo River. The drainage pattern is mainly dendritic.

Regional Geology and Tectonic Framework

Geological studies in the Anambra Basin of the Lower Benue Trough in which Okigwe and environs is situated have been reported widely in literature (Murat, 1972; Nwachukwu, 1972). The Anambra Basin was initiated during the late cretaceous movements in the Benue Trough. The Benue Trough of Nigeria formed as a result of series of tectonism and repetitive sedimentation in the Cretaceous time when South America separated from Africa with the opening of the Atlantic Ocean. Stages of sedimentation in the trough were in three cycles; the Pre-Cenomanian deposit of Asu River Group followed by the Cenomanian-Santonian sedimentation. The Proto-Anambra Basin was a platform that eventually became thin sediment trapped at the time the Abakaliki-Benue sector of the Benue Trough was being filled which occurred during Albian-Santonian (Nwajide and Reijers, 1997).

Extensive folding and faulting resulted in Abakaliki area becoming flexurally inverted to form the Abakaliki Anticlinorium. The Santonian tectonic pulses caused the displacement of the depocentres to the west and southeastwards thereby resulting in the formation of Anambra Basin and Afikpo Syncline (Murat, 1972; Burke, 1972). The anticlinorium later became a sediment dispersal centre from which mineralogically mature detritus was shed into

Anambra Basin and Afikpo Syncline (Akaegbobi and Boboye, 1999). Other sources of texturally mature sediments which finds its way into Anambra Basin include Southwestern Nigeria Craton, crystalline basement areas of the Oban Masif and Cameroun basement granites which had undergone prolonged chemical weathering (Hoque and Ezepue, 1977; Amajor, 1987). This tectonic episode differentiated the sedimentary successions into pre-santonian and post-santonian packages. The post-Santonian sediments are Campanian-Maastrichtian in age and are not found elsewhere in the Benue Trough except in the Anambra Basin and Afikpo Syncline (Murat, 1972; Burke, 1972).

Deposition of sediments in the Anambra Basin commenced during the Campanian, with Nkporo Group, Enugu Shale and Owelli Sandstone which are regarded as the Nkporo Group, constituting the basal beds of the Campanian period. Anambra Basin became the site of major deposition following the Santonian tectonics in the southeastern Nigeria. Compressional uplift of the lower Benue Trough succession (Albian to Coniacian) along a NE-SW axis was accompanied by tectonic inversion and downwarping of the Anambra platform. Estimates of total sediments thickness in the Anambra Basin from gravity measurements range from 1000-4500 meters (Ladipo, 1988), out of which between 3000-3500metres were deposited during the late Cretaceous (Upper Campanian to Maastrichtian). Figure1 and Table 1 show respectively, the Geologic map of the study area and the stratigraphy of Anambra Basin.

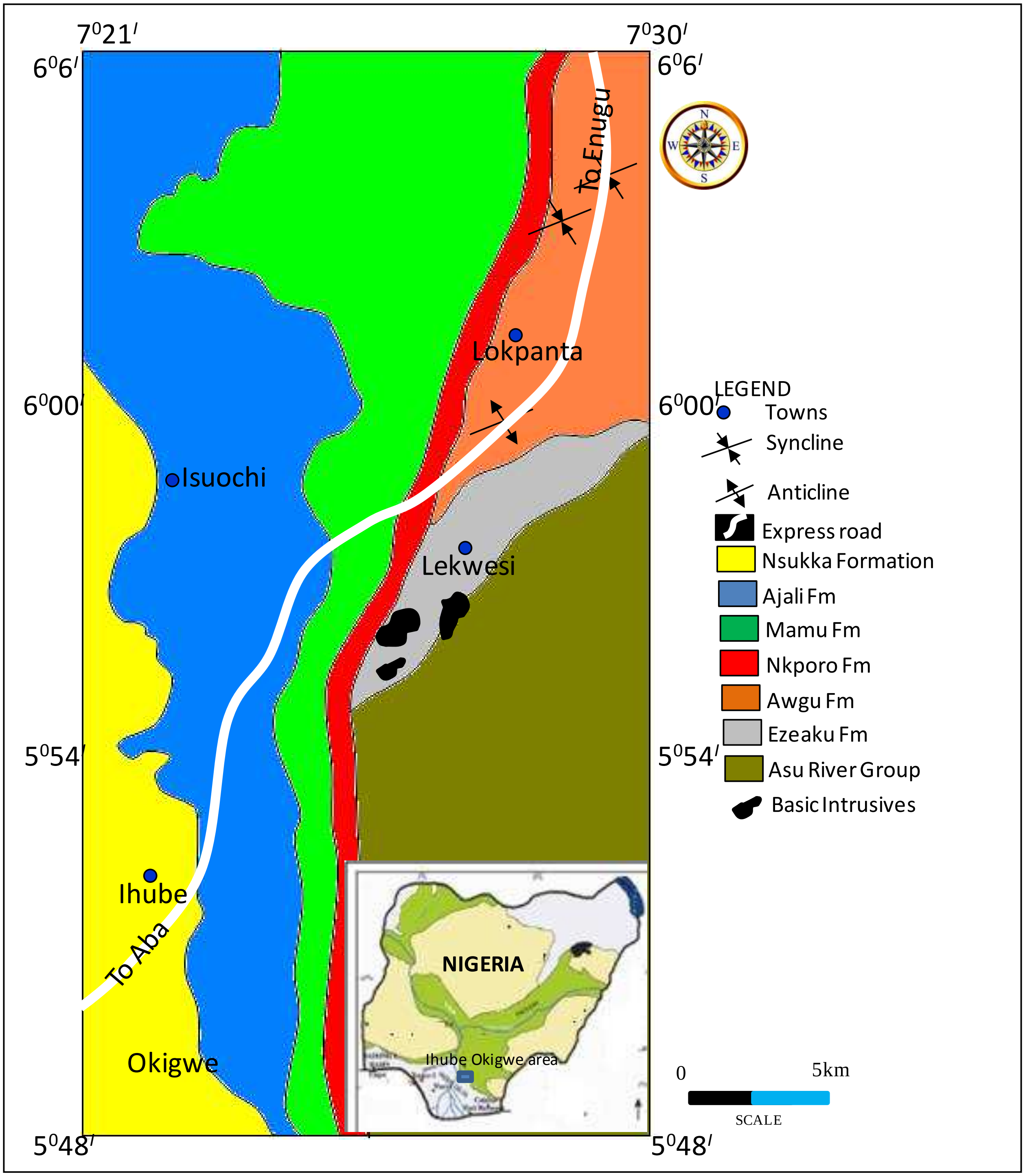

Figure 1: Geologic map of the study area showing the various geologic formations (adapted from Uduji *et al*., 1994).

Table 1: Stratigraphy of Southern Benue Trough and Anambra Basin (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	
	Santonaian-Coniancian	Awgu Formation	2nd Cycles of sedimentation
	Turonian	Eze-Aku Group, Makurdi, Agala and Amasiri Formation	
	Cenomanian	Odukpani Formation	
Lower cretaceous	Albian	Asu River Group	1st Cycle of sedimentation
Precambrian		Basement Complex	

MATERIALS AND METHODS

Grain-Size Analysis

Methods of investigation involved both field study and laboratory analyses. Examination of lithostratigraphic profiles was done in the field. As part of laboratory analyses, grain size and geochemical analyses were done at the sedimentological Laboratory of the Quality Control Department, Arab Contractors O.A.A. Nig. Ltd.

Samples for grain-size analysis were sun-dried and disaggregated with hands due to the loose friable nature of sandstone unit of the Nsukka Formation. The samples were subsequently weighed and sieved for particle-size distribution following standard laboratory procedures using Ro-tap shaker machine. From the average GSA results from the two samples, percentage passing were plotted against mesh sizes, followed by determination of statistical parameters such as sorting, skewness, and kurtosis based on the concept of Folk (1974), and uniformity coefficient based on Holtz and Kovacs (1981).

Geochemical Analysis

The determination of the major oxides composition of the sandstone units was carried out using X-ray fluorescence (XRF) methods. Fresh samples were subjected to appropriate treatment by homogenization of 2g of each sample with 4g of analytical spectroflux powder and 0.6g $LiNO_3$ salt in agate mortar. The respective mixtures were subjected to heat-fusion and glass beads preparation in platinum plate (3.5cm diameter) using bead and fuse sampling machine (model TK-410, Rigaku-Tokyo). Subsequently, the respective glass beads were used for the determination of major oxides using automated XRF machine (model Rigaku ZSX).

Finally, estimations of Silicon ratio (SR) using SiO_2, Al_2O_3 and Fe_2O_3 abundance were done to determine the mineralogical maturity and source area whereas cross-plots were employed for the assessment of compositional characteristics.

DATA ANALYSIS AND DISCUSSION

Granulometric and Textural Analysis

The results of the average grain-size distribution curve of the sandstone units from an outcrop location are presented in Table 2.

Table 2: Average of two results obtained from the textural analysis of the soil samples.

WEIGHT OF SOIL TAKING FOR SIEVE ANALYSIS:						735g			
WEIGHT OF SOIL TAKEN FOR WET WASHING (g):						800g			
	Pass 4.76mm sieve				B.S Sieve (mm)	MESH NO.	Retained (g)	Retained (%)	Passed (%)
Determination of moisture	Bowl no	g	MC = Water / 100% dry soil		38.1	1½"			
	Wet soil + bowl	g			25.4	1"			
	Dry soil + bowl	g			19.5	¾"			
	Bowl alone	g			12.5	½"			
	Water alone	g			9.52	3/8"	-	-	100
	Dry soil alone	g			6.4	¼"	4.6	0.6	99.4
Determination of dry soil	Bowl no	g			4.76	3/16"	8.0	1.0	98.4
	Wet soil + bowl	g			2.36	7	6.6	0.8	97.8
	Bowl alone	g			1.18	14	41.0	5.1	92.5
	Wet soil alone	g			600mic	25	334.6	41.8	50.7
	Dry soil	g	G		425mic	36	145.0	18.1	32.4
	Washed soil + bowl	g	<	B	300mic	52	37.4	4.7	27.9
	Bowl alone	g			150mic	100	112.8	14.1	13.8
	Washed soil alone	g	< G		75mic	200	38.0	4.8	9.0
Washing Trough	Outwashed soil<0.075mm	g		C	Passing	200	72.0	9%	

As shown in Table 2 and graphically presented in Figure 2, the sandstone is predominantly medium to fine-grained with some fractions of silt, depicting that the depositional energy (as deduced from the graphic mean) was low which indicates a transitional/shoreline environment. This is clearly supported by the graphic mean (Gm) of 0.68θ, suggesting a wider range from poorly sorted to moderately well sorted. According to Krumbien and Sloss (1963), sorting is indicative of the range of velocities and degree of turbulence operating in the transporting medium and to some extent, is indicative of the distance of travel. The degree of sorting depends upon how much transport the sediment has undergone. Moderately sorted indicates consistent energy, wave action, long transportation and sub-mature sediments whereas poorly sorted implies fluctuation or inconsistent energy. Within this context and considering that the sandstone sediments are moderately sorted, it is an evidence that the sediments were fairly deposited close to the source area, i.e. have not undergone much transport; possibly from the felsic rocks derived from the inverted depocenter of the adjacent Abakaliki Anticlinorium, indicating a fluvial environment.

Statistical parameters from textural studies of granular sediments have been successfully employed in sedimentology to reveal the transportation history, sedimentary processes as well as the characteristics of the depositional environments (Folk and Ward, 1957; Folk, 1974; Friedman, 1969; Olugbemiro and Nwajide, 1997). From the graphical plot of the percentage passing against sieve sizes (see Figure 2), the critical Phi values as basis for determining the relevant statistical parameters for characterizing sandstone population (sorting, skewness, kurtosis) using appropriate relations (Folk, 1968) and descriptions (Folk, 1974) are presented in Table 3. The graphic skewness of 0.3θ obtained for the sediments implies very positively skewed arrangement. Most shoreline and shelf sands (tidal waves) tend to have negatively skewed grains and are better sorted since fine components have been removed by water current. The value obtained for kurtosis (degree of peakedness) is 0.07θ, indicating very platykurtic population. This suggests that the depositional environment is transitional/shoreline in origin.

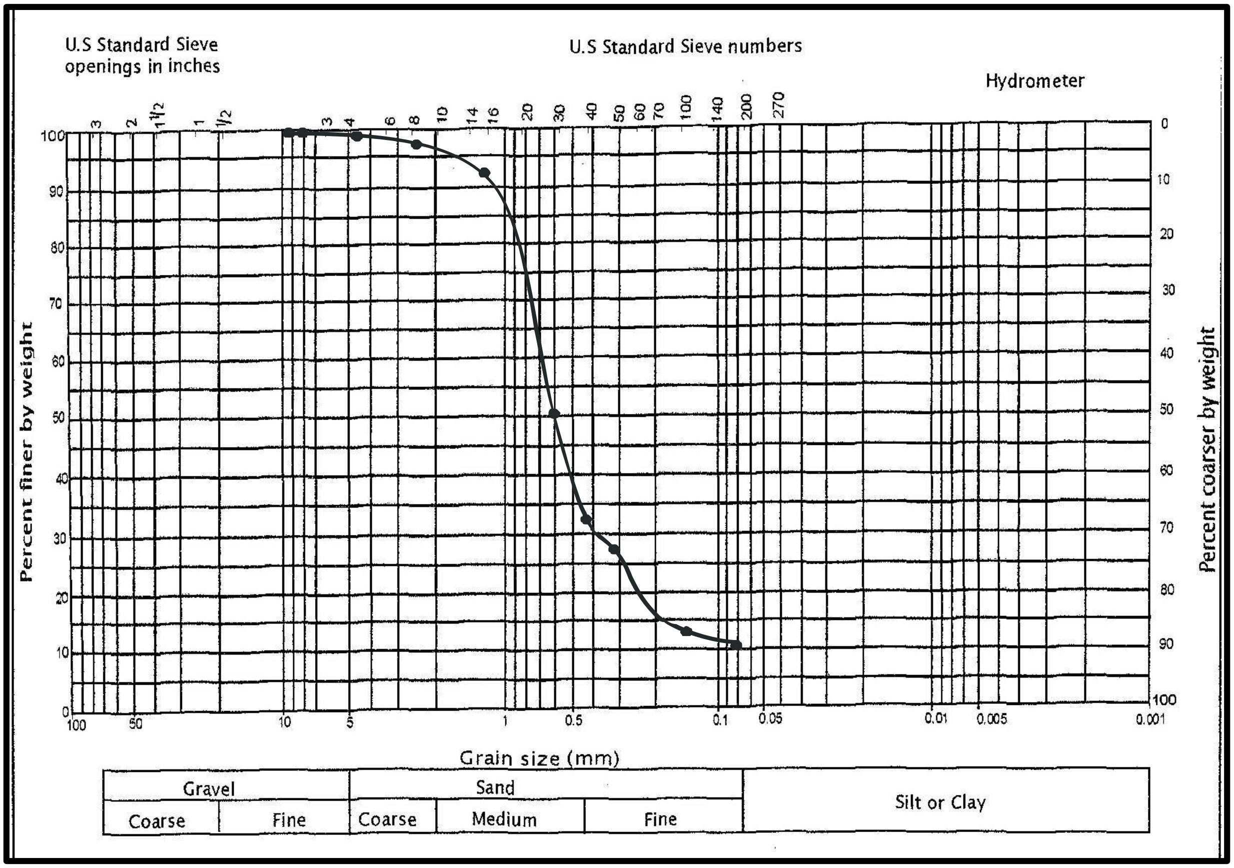

Figure 2: Average grain-size distribution curve of the sandstone samples from Nsukka Formation.

Table 3: Critical Phi values for estimating statistical parameters of the sandstone population.

Size (mm)	0	0.15	0.28	0.6	0.8	1.0	1.2
Ø values	$Ø_5$=0	$Ø_{16}$=2.73	$Ø_{25}$=1.83	$Ø_{50}$=0.73	$Ø_{75}$=0.32	$Ø_{84}$=0	$Ø_{95}$=0.26

For a sand to be classified as well graded, the coefficient of uniformity (Cu) must be greater than 6(Holtz and Kovacs, 1981). From the result of the analysis, the Cu is 0.8/0.075 = 10.67. This indicates that the sediments underwent short transportation before they were deposited because as current velocity decreases, the larger or denser particles are deposited first, followed by the smaller or fine particles. The short transportation of sediments prior to deposition as inferred from the value of Cu obtained is in line with the depositional environment deduced from the degree of sorting of the sediments.

Major Oxides Analysis

The results of the major elemental distribution obtained from four samples of the sandstone unit are presented in Table 4. As shown in Table 4, the analysed samples are dominated by silica with average of 41.20% wt, while other major oxides are generally below 22.00% wt in the samples.

Table 4: Results of the geochemical analysis of the sandstone sediments of Nsukka Formation

	S A M P L E S				
Major Oxides (%)	**1**	**2**	**3**	**4**	**Average (%)**
SiO_2	40.00	41.00	42.60	40.61	41.20
Al_2O_3	21.50	21.40	21.50	21.50	21.50
Fe_2O_3	8.79	8.79	8.78	8.79	8.79
K_2O	3.83	3.84	3.84	3.84	3.84
Na_2O	6.81	6.82	6.83	6.81	6.82
MgO	5.98	5.99	5.99	5.99	5.99
MnO	0.02	0.02	0.03	0.02	0.02
CaO	10.89	10.89	10.88	10.89	10.89
TiO_2	0.59	0.57	0.59	0.59	0.59
P_2O_5	0.03	0.03	0.03	0.02	0.03

The composition of the sandstone can be described as Fe-Sandstone based on Herron (1988) classification scheme (Figure 3). The scheme is based on log plots of Fe_2O_3/K_2O against SiO_2/Al_2O_3, and has an added advantage of isolating shales from sandstones and lithic sands from feldspathic sands. Whereas the Fe_2O_3/K_2O ratio separates lithic fragments from feldspars in sandstones, the SiO_2/Al_2O_3 ratio is used to distinguish between quartz-rich (high ratio) sandstones from clay-rich (low ratio) shales as pointed out by Braid (1993).

Pettijohn, Potter, and Siever (1972) and Herron (1988) also noted that the two ratios are mineralogical maturity indicators.

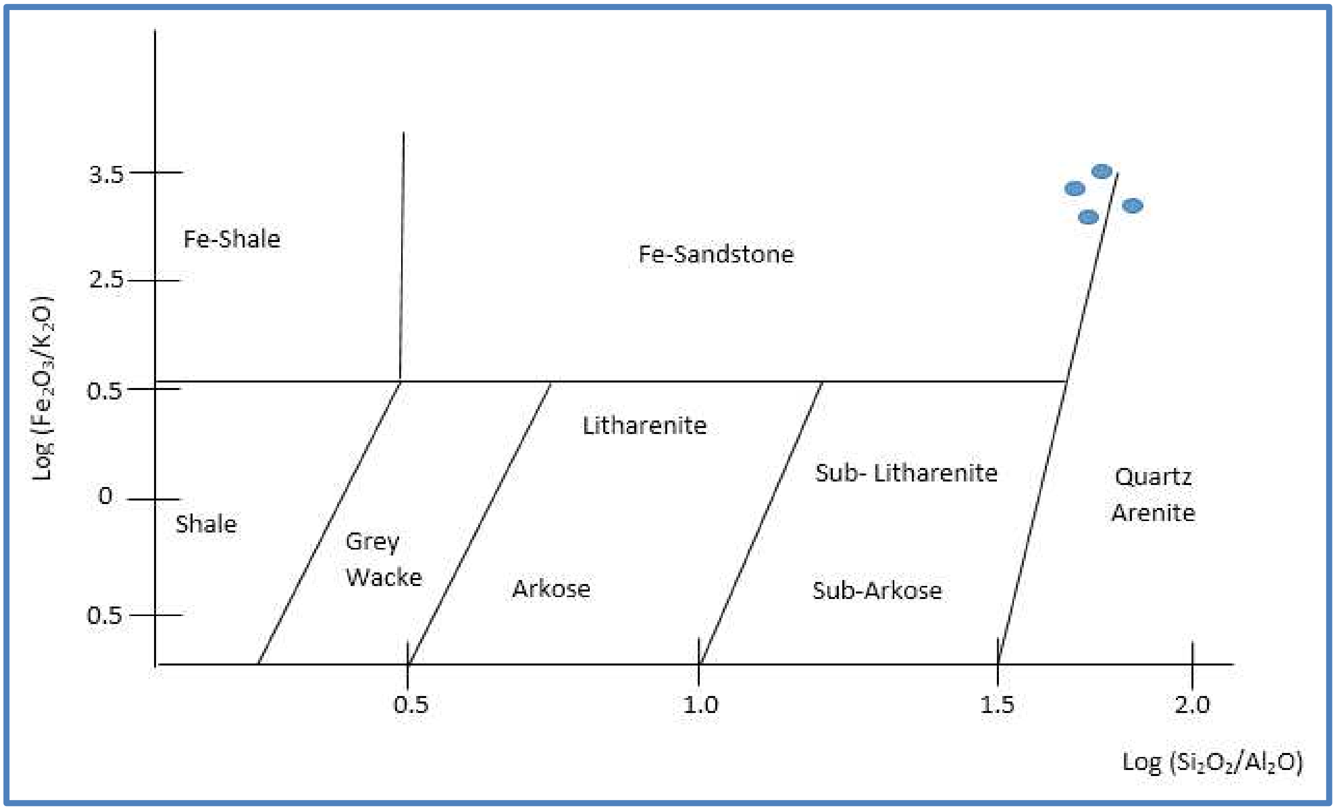

Figure 3: Geochemical characterization of the sandstone samples using Herron (1988).

The geochemical Assay (see Table 5) indicates an average of 1.92 ratio (SiO_2/Al_2O_3) and 2.29 ratio (Fe_2O_3/K_2O). These values are indicative of low chemically stable felsic (granitic) craton/shield source area and depict the mineralogical immaturity of the sandstone. The textural immaturity of the sandstone is revealed by their sub-angular edges. The dominance of Fe_2O_3/K_2O over SiO_2/Al_2O_3 in the sandstone suggests that the sediment is typically iron-rich and renders it ferruginous, thus reflecting an oxidizing environment. This report conforms to the conclusion of Uzoegbu, Uchebo, and Okafor (2013) that the Nsukka Formation in Okigwe area reflects transitional/shoreline environment.

Table 5: Log ratios of the major oxides in the samples

Sample No.	Log (SiO_2/Al_2O_3)	Log (Fe_2O_3/K_2O)
1	1.89	2.29
2	1.92	2.28
3	1.98	2.29
4	1.89	2.28

CONCLUSION

From the textural and geochemical analysis, it can therefore be concluded that the sandstone sediment associated with Nsukka Formation in the Anambra Basin, Southeastern Nigeria was deposited in a major phase of fluvio-deltaic and shallow marine environment dominated by marine regression that began close to the end of the Maastrichtian and continued during the Paleocene. It can therefore be deduced from the trace element geochemistry that the source area of the formation is related to predominantly felsic rocks characterized by unstable continental environment with possible contribution of recycled materials from intrusive units of the uplifted Abakaliki Anticlinorium as earlier stated.

Summarizing the foregoing discussions, it is evident that the unconsolidated friable nature of the sandstone unit associated with Nsukka Formation clearly excludes metamorphic remobilization as a controlling process. However, possible interplay of grain-size and density-controlled hydraulic sorting as well as the obvious geochemical/mineralogical composition and degree of weathering of the source area on the other hand can be regarded as dominant controlling factors for the sandstone unit of the Nsukka Formation. Also, the depositional environment may be suggested to be similar in many ways to the

Mamu Formation (Lower Coal Measures), i.e. parallic or transitional/shoreline, mud flat and swamps, deposited during a largely regressive phase.

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