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RESEARCH ARTICLE

SEDIMENTOLOGY OF EOCENE SANDSTONES AT OGBUNIKE AREA, SOUTHERN NIGERIA: INSIGHTS FROM PETROGRAPHIC AND GRANULOMETRIC ANALYSES

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ABSTRACT

The sedimentary facies exposed at Ogbunike Area belong to the Eocene Formation that made up the Anambra Basin. This research estimates the lithology, thickness, sedimentary succession, paleo-environment, reservoir quality and source area tectonics using geological mapping, petrography, grain size distribution and statistical analysis. Geological mapping shows that the section is approximately 27m thick and consists of sandstone, shale, siltstone and ironstone lithofacies. Granulometric analysis performed on selected samples shows that the sandstones are fine to medium grained (1.15 to 2.17 ϕ), moderately sorted (average 0.96 ϕ), fine skewed (average 0.16 ϕ) and leptokurtic (average 1.17 ϕ). Bivariate plot of skeweness against sorting and mean against sorting pinpoint a fluvial origin for the sandstones. The results from rose plot point to a bimodal-bipolar paleocurrent pattern while the bi-directional paleo-flow is in the northeastern-southwestern directions, which is an indication of tidal influence suggesting shore environment of deposition. Average permeability values derived from an empirical formula indicate good potential for reservoir rock. Deductions from field observations and petrographic analysis suggests that the sandstones are submature, with angular to sub-rounded quartz. The high percentage of goethite (average 30.4%) in the ferrugenized sandstones samples suggests an environment of low oxidation. Provenance and tectonic assessment reveal metamorphic source, humid climate, high relief, recycled orogeny, and derived primarily from Cameroon Basement Complex rocks.

KEYWORDS

Sandstone, Ameki Formation, Ogbunike, Provenance, Permeability, Tectonic

1. INTRODUCTION

Sandstones facies found around Ogbunike area constitute part of the Eocene Ameki Formation within the Anambra basin (Figure 1) in Southern Nigeria and it is made up of stepwise arrangement of sandstones, siltstones, mudstones, sandy shales and shales sandwitched with thin coal layers. These geologic units cover an area of about 40,000km^2 having an average thickness of 6km.

The tectonism associated with the evolution of Anambra Basin was reported by several researchers (Nwajide and Reijers, 1996). A previous researcher considered the trough as analogous to the tectonics structure in the Red Sea being a part of the unstable Ridge-Ridge-Ridge (RRR) triple plate junction as a result of plate dilation and opening of Gulf of Guinea in the Early Cretaceous (Nwajide, 1990). This was also supported by (Adegoke, 1969; Adegoke et al., 1980). The Eocene stage (Figure 2) was characterized by regressive phase that led to deposition of Ameki Group (Obi, 2000). The Ameki Group comprises predominantly Nanka Sand, Nsugbe Formation, and Ameki Formation, which are considered laterally equivalent (Nwajide, 1979). The formation age has been reported to be either early Eocene or early middle Eocene (Reyment, 1965; Berggren, 1960). Ameki Group and the younger Ogwashi – Asaba Formation are lateral equivalence of Agbada Formation in the Niger Delta Basin. Gradual accumulation of varying sediments in Anambra Basin during the Tertiary happens in areas where the proto-Niger Delta successions were deposited as a result of the Paleocene – Eocene transgression and deposition of the Imo Shale and the deltaic Oligocene – Miocene Ameki and Ogwashi – Asaba Formations as outcrop equivalents of the Niger Delta. The sedimentation process in the Anambra Basin was constrained by the morphologic proximity of sediment origin, transgression and regression during the Campanian to Eocene times coupled with the circulation system leading to gradual reshaping of the coastline. Hence, the stratigraphic succession provides a documentary history on transgressive-regressive cycles as well as the coastline arrangement which have to do with variations in sediment depositional pattern.

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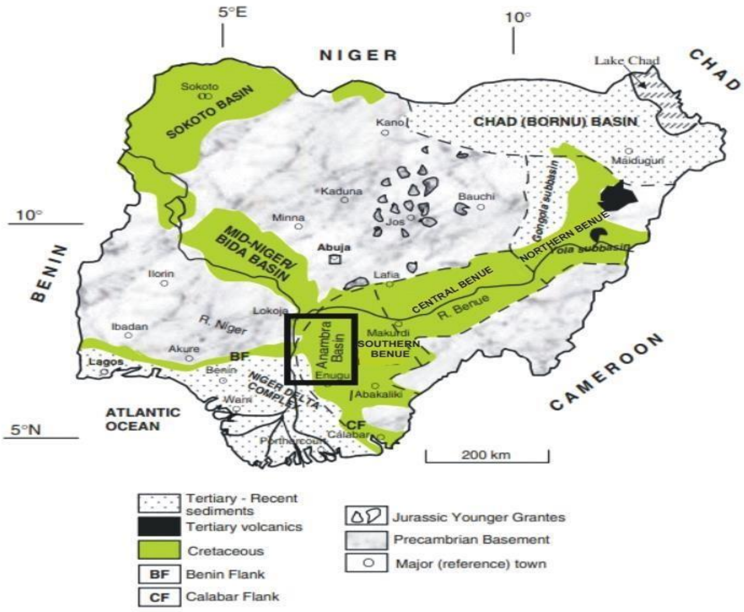

Figure 1: Geological sketch map of Nigeria showing Anambra Basin and other major geological components; Basement, Younger Granites, and Sedimentary Basins (Obaje, 2009)

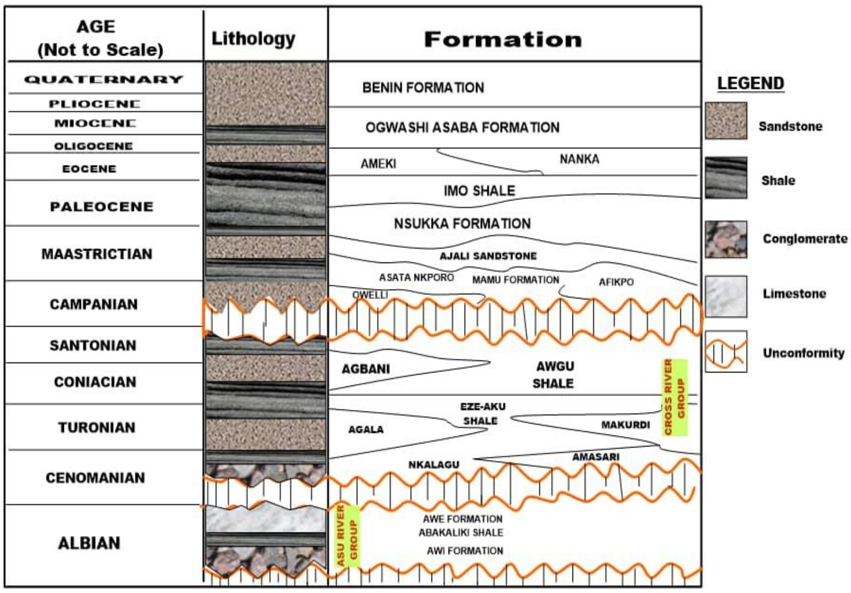

Figure 2: Stratigraphic Setting of Lower Benue Trough showing the position of Ameki/Nanka Formation in the Anambra Basin (Modified after Akaegbobi 2000)

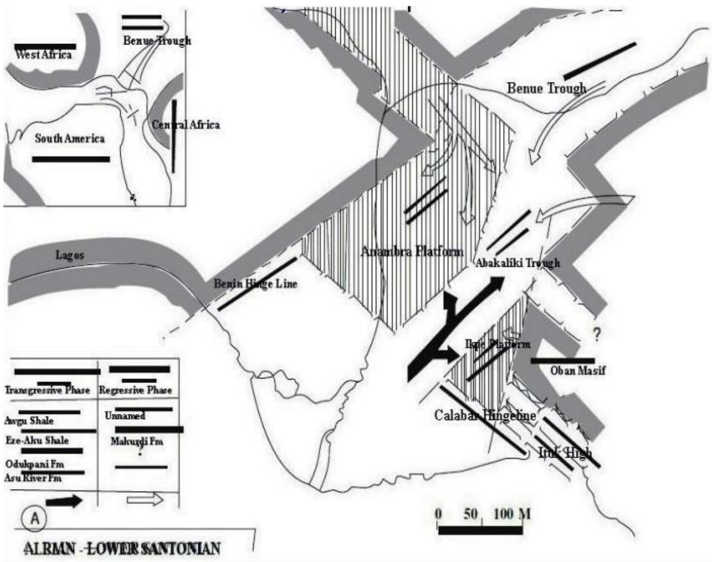

Figure 3: Tectonic map of southeastern Nigeria during Albian-Tertiary (adapted from Murat 1970)

Considerable attentions have been focused on the basin exposures in other areas aside Ogbunike axis in term of its sedimentology, paleontology, paleothermometric and geochemistry by several researchers especially in relation to petroleum prospectivity (Akande et al., 1992; Akande et al., 2007; Akaegbobi et al., 2000; Obaje, 2004; Ogala, 2011; Olatinpo et al., 2016a; Olatinpo et al., 2016b).

The study area lies around longitude $006^0 51^1$E and latitude $06^0 10^1$N where there is a lack of study focusing on the establishment of provenance region, paleoclimate, source area tectonic, energy of deposition, and paleoenvironment for the sandstones of the Ameki Formation exposed in Ogbunike area. This study therefore seeks to unravel the granulometric and petrographic properties of the sandstones and its implications on the paleoenvironment, provenance, and permeability. This will generate adequate knowledge regarding sandstone facies of Ameki Formation in Anambra Basin as it relates, but not limited to: transportation history, depositional environment, condition/energy of transportation, source area, paleotectonic, paleoclimate, and reservoir property.

2. Materials and Methods

2.1 Field Sampling

Geological field mapping was executed at Ogbunike quarry within parts of the Anambra Basin. Four (4) outcrops sections were encountered. At each section, the outcrop was described, logged while the strike and direction in which the planes dips downwards from the surface (dip) were measured. The lithologic profile at each section was sketched and the GPS reading taken as reference. Sandstones and other rock types were sampled, described, labelled and kept in a sample bag. Ten (10) sandstone samples were carefully selected for the grain size analysis while five (5) samples comprising of ferruginized sandstones and sandstone were selected for the petrographic study. Tilted beds were used for acquisition of paleocurrent measurements data, it was subsequently restored to paleo horizontal for both cross bed dip magnitude and direction for the true paleo flow azimuth (Table 1).

Table 1: Paleocurrent directions measured on the field

S/N	AZIMUTH(^{0})
1	020
2	022
3	360
4	054
5	358
6	258
7	346
8	026
9	042
10	022
11	032
12	140
13	168
14	034
15	184
16	032

2.2 Grain Size

Grain size analysis are indicators for paleoenvironment and reservoir quality evaluation. Fifteen sandstone samples selected for grain size distribution analysis were sieved according to the technique of a previous researcher (Friedman, 1967). Sieving was used as the particles are within the sand ranges (particles coarser than 0.063). The experiment was carried out in the sedimentology laboratory in the Department of Geology and Mineral Sciences, University of Ilorin, Nigeria.

The dry sieving method was deployed and water was used in the disaggregation of samples. 100 g of each disaggregated sample was measured out and subjected to standard grain size analysis using a set of sieves. The mechanical shaker (Ro — Tap) was arranged descending order of sieve openings with the coarsest grains retained on top and the finest at a pan placed beneath the lowest sieve. The remnant retained in each successive sieve was weighed. Cumulative frequency curve was plotted for the fifteen samples and parameters such as graphic mean, median, mode; inclusive graphic standard deviation, graphic inclusive skewness, and graphic kurtosis were calculated. The derived parameters were utilised in curves characterization and numerical comparison between samples (Tucker, 1990). The bivariant plots of a researcher were helpful in environmental interpretation while another researcher was also helpful to further discriminate the environment (Friedman, 1967; Sahu, 1964). Several research were employed in analysing the permeability of the sandstone facies (Krumbrien and Monk1942; Vrbka et al., 1999).

2.3 Petrographic Studies

Thin sections were prepared from samples and photomicrograph taken and analysed to determine the mineralogical composition and provenance of the Sandstone. The experiment procedure was undertaken in the petrology laboratory in the Department of Geology and Mineral Sciences, University of Ilorin, Nigeria. The sandstone samples selected for test were oven dried. They were placed in a cut glass tube and heated, followed by impregnation using epoxy under vacuum and the small samples were cast into blocks which were more convenient for the sawing and hand holding while grinding the face on abrasive paper. Selected areas of the faced samples were marked with water insoluble felt tip pen before cutti16ng and trimming to avoid rock overhanging slide. The slices then mounted on chuks with a sponge backing to accommodate different thickness and irregular specimens. Coarse abrasives were left out since the faces of the samples were grinded with 600F carborundurn powder using water as a lubricant for approximately thirty- five minutes when the faces approach optical flatness. After these, the slices for standard thin sections were removed and bonded to glass using epoxy resin.

2.4 Empirical Correlations

The linear discrimination functions for environmental interpretation and the method of which uses all the grain size parameters in the form of a single linear equation in which Yu = 0.2852 MZ - 8.760451 - 4.8932ski + 0.0482KG was deployed (Sahu, 1964). calculated values of Yu > - 7.419, denote shallow marine deposits while value of Yu < - 7.419 pinpoints fluvial deposits.

3. Results and Discussions

3.1 Geologic Mapping

The litho-section at the Ogbunike axis was properly mapped, paleocurrent measurements recorded and the thickness was found to be approximately 27.41m. Mapping revealed that the section consists of a lithostratigraphic sequence which can be divided into four (4) distinct facies on the basis of lithological and sedimentary characteristics namely: Sandstone facies, Siltstone facies, Shale facies and Ironstone facies (Figure 4).

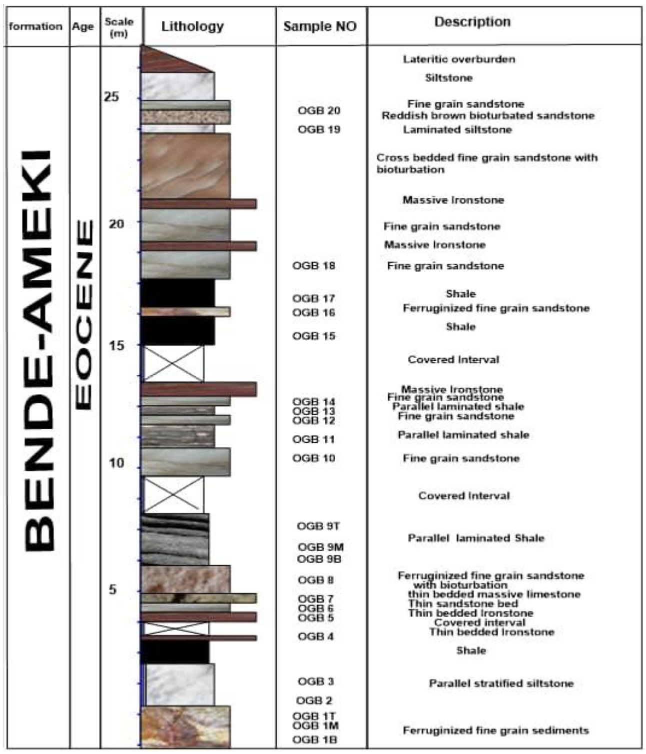

Figure 4: Lithologic section of Nanka Formation at Ogbunike Area

The base of the section at Ogbunike is occupied by fine grain sandstone, which is conformably overlain by siltstone. The middle of the section contains laminated shale and towards the top of the section are an alternation of sandstones and siltstones. The overall section is capped at the top by lateritic overburden (Figure 4). The Sandstones in this section are medium-fine grained texture with bioturbation on some of the beds. This was inferred to be as a result of biological activities on the sandstones in the course of sediment deposition. Some of the sandstone beds have cross bedding structure (Figure 5 and Figure 6) with paleocurrent direction between 0 and 168 degrees. Some of the sandstone beds are ferruginized with reddish brown colour that indicate the presence of iron rich minerals.

Figure 5: Cross bedding in sandstone close to the top of the planar cross

Figure 6: Stratified sandstone bed underlying section bedded sandstone

The rose plot (Figure 7) of cross beds azimuth directions of the Ogbunike sandstones show bimodal paleocurrent pattern with southwest and northeast directions but more on the southwest direction. Hence, the sandstones were derived more from the southwest. This could be a pointer that the sediments may have been derived essentially from an origin located northeast-southwest parts of the study area. Interpretation of the paleocurrent plots for the sandstones predicts bimodal paleocurrent distribution patterns, pinpointing a shore environment of deposition.

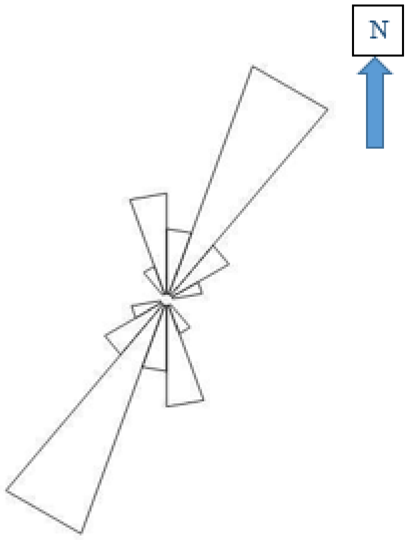

Figure 7: Rose diagram plot of the paleocurrent directions

3.2 Granulometric and Statistical Analyses

Ten Sandstone samples were subjected to grain size analysis and the results used in depicting the depositional environments, energy of transportation and history of the sediments.

3.2.1 Histograms

Analysis of histogram reveals that all the samples show bi modal distribution. This may be due to the missing of the sediments from different provenance or sub-populations.

3.2.2 Frequency Curves

Frequency curves show positive, negative as well as nearly symmetrical distribution. Such highly variable nature of the frequency curves indicates fluctuation in the energy condition at the time of deposition of these sediments.

3.2.3 Cumulative Frequency Curves

Cumulative frequency curves plotted on the probability ordinate scale do not form continuous straight line. Curves plotted for the present data show two, three or more straight line segments. Each segment has different slope that indicates the presence of more than one population of grains. This indicates the highly variability in competency of the transporting agency. Each of this population is related to different mode of transportation (traction, siltation, and suspension). Cumulative frequency curves implicate siltation as the controlling factor of transport though traction and suspension have also played some role during deposition of these sediments. In most of the curves, the breaks are not sharp, which suggest the mixing of detritus carried by currents with different energy. This mean that the sandstones may be the products of different provenances.

3.2.4 Statistical Parameters

The data revealed by histograms, frequency curves and cumulative frequency curves have pectoral value and gives general idea about the sediments. Various statistical methods were applied to arrive at detailed comparisons. In the present study, graphic measures like median, mean, standard deviation, skewness and kurtosis indicate high variability as presented in Table 2. Mean size of the study ranges between 1.15ɸ and 2.17ɸ with average value of approximately 1.78ɸ. This variation in grain size is a clear indication of the variation in the kinetic energy at the time of deposition. The average mean and median values indicate medium grained sandstone and dominant of medium grained particles respectively. In case of skewness, they range from -0.22 to 2.35 which is pointing to coarse to strongly fine skewed, with an average value of approximately -0.16 which suggests coarse skewed. It means both coarse tail distribution and fine tail distribution are common and that suggests high to low kinetic energy of the depositional basin which is an indication of both coarse and fine fraction. Standard deviation values range from 0.53ɸ to 1.34ɸ and suggest that the sandstones are moderately well sorted to poorly sorted. The average standard deviation (sorting) value is approximately 1.0ϕ which pinpoint a poorly sorted material. However, poorly sorted nature of the samples signifies sediment deposited in the fluvial environment (Friedman, 1967). The poorly sorted nature also points to the dominance of higher energy over lower energy regime and so fluctuation in energy condition since finer sands tend to settle at lower energy. The consideration of the various sub-populations namely suspension, solution and traction are indication of fluctuating (pulsating) energy condition of the depositional environment.

Table 2: Summary of the calculated results of grain size analysis

Sample No	Mean(Φ)	Sorting(Φ)	Skewness(Φ)	Kurtosis(Φ)	Remark
OGB1B	2.17	0.73	-0.27	0.82	Fine grained, moderately sorted, coarse skewed, platykurtic
OGB2	1.88	0.94	-0.22	0.88	Medium grained, moderately sorted, coarse skewed, platykurtic
OGB6	1.80	1.34	-0.36	0.76	Medium grained, poorly sorted, strongly coarse skewed, platykurtic
OGB8	1.67	0.72	2.35	1.08	Medium grained, moderately sorted, fine skewed, mesokurtic
OGB10	1.73	1.22	0.11	1.20	Medium grained, poorly sorted, fine skewed, leptokurtic
OGB12	1.68	1.05	0.24	1.11	Medium grained, poorly sorted, fine skewed, mesokurtic
OGB14	2.03	1.22	-0.33	1.00	Fine grained, poorly sorted, strongly coarse skewed, mesokurtic
OGB16	2.13	1.19	-0.37	1.92	Fine grained, poorly sorted, strongly coarse skewed, very leptokurtic
OGB18	1.51	0.53	0.33	1.37	Medium grained, moderately well sorted, strongly fine skewed, leptokurtic
OGB20	1.15	0.63	0.16	1.52	Medium grained, moderately well sorted, fine skewed, very leptokurtic

4.3 Paleoenvironmental Conditions and Depositional Settings

Discrimination of the depositional environments of the arenaceous rocks was done using the bivariant scatter plots as suggested by a previous researcher (Friedman, 1967). Bivariant plots of the study area indicate all the samples were deposited in the fluvial environment. Mean size vs standard deviation (Figure 8) implies that samples were deposited in the fluvial environment. Skewness vs standard deviation plot (Figure 9) suggests that all the samples fall in the field of fluvial environment. Most of the sandstones are leptokurtic pinpointing a single depositional history and negatively skewed suggesting a continental shelf environment of deposition (shallow marine environment). The sorting and grain size of the sandstone may probably be due to deposition in a medium energy environment. The coarsening upward sequence of the lithofacies as observed from the field suggests a deltaic environment. The massive siltstone facies with well parallel lamination thus suggesting a quiet water environment of deposition of a deltaic setting where there is low energy of water below wave influence. The poly modal nature of the grain size distribution charts using histogram and frequency curve reveals that the sands were derived from more than a single source area. The average skewness value of the sample is -0.16ϕ and it suggests the sample is coarse-skewed. The particles show a tail of excess coarse particles which combine to its poorly sorted nature. The sediments' negatively skewed nature is indicative of high energy conditions. The average standard deviation value for all the samples is 1.56ϕ which in reference to [29] falls in poorly sorted bracket. The poorly sorted nature shows less winnowing, an abrasion, hence the grains retain the original configuration and texture `which is also proportional to the velocity of depositional current. The poorly sorted properties of sediment is an indication of rapid deposition and short episodes of transportation and water level fluctuation of the depositing current reflecting a fluvial setting (Friedman, 1967).

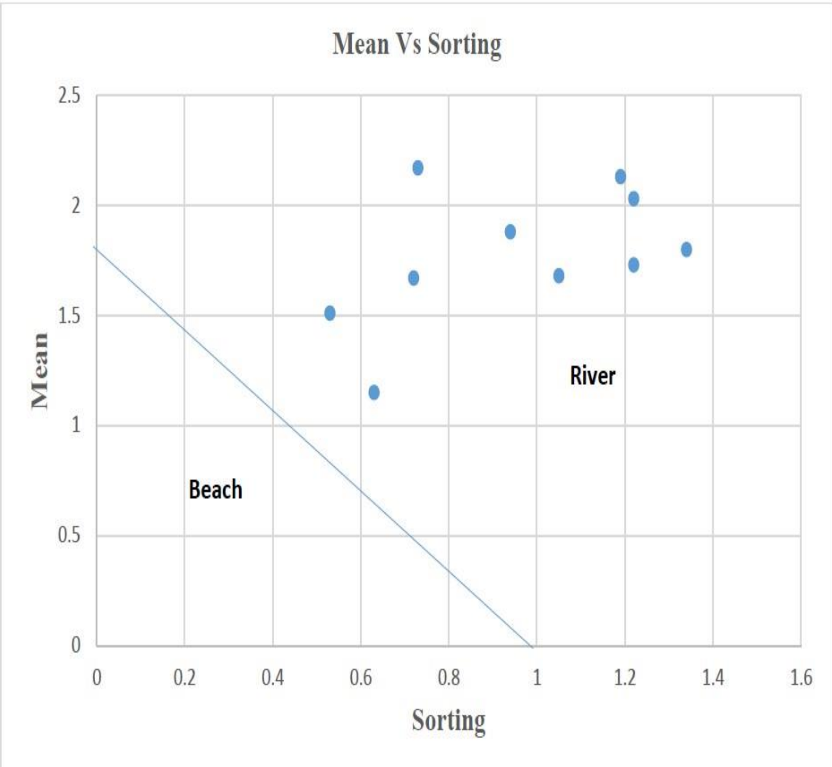

Figure 8: Bivariant plot of mean versus sorting

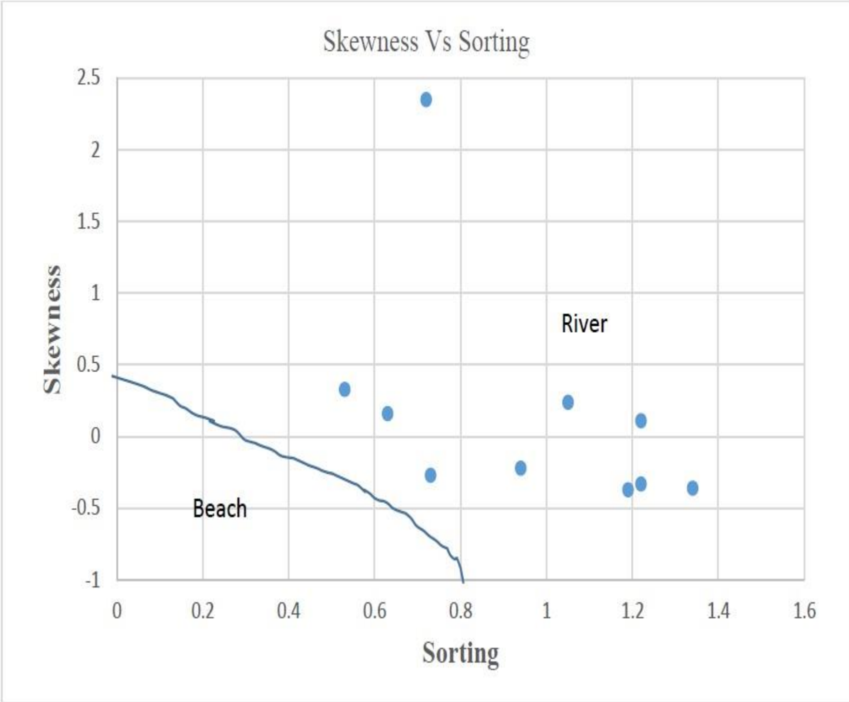

Figure 9: Bivariant plot of skewness versus sorting

Changes in energy and fluidity factors have correlative significance with various processes and depositional environments. Analysis of data generated from the discrimination function as shown in Table 3 reveals that the sandstones in the study area were deposited under two essential environments (Sahu, 1964). Maximum numbers of samples show combine effect of fluvial and shallow marine environment of deposition.

Table 3: Multivariate result of sandstones of Nanka Formation in the study area

Sample No	Results	Interpretation
OGB 1B	-6.782	Shallow marine
OGB 2	-7.105	Shallow marine
OBG 6	-6.448	Shallow marine
OGB 8	-19.731	Fluvial
OGB 10	-8.747	Fluvial
OGB 12	-9.401	Fluvial
OGB 14	-6.518	Shallow marine
OGB 16	-6.250	Shallow marine
OGB 18	-9.879	Fluvial
OGB 20	-9.142	Fluvial

4.4 Petrographic Study

The petrographic analyses of the sandstones show that quartz, feldspars and rock fragment as framework elements (Table 6). The cement is composed of clay, iron oxide and calcite while the matrix is composed mainly of unrecrystallized clay and silt–size quartz. Other minerals present include hematite, goethite and limonite (Table 5). The polycrystalline quartz constitutes about 60% of total quartz while monocrystalline quartz is about 40%. The relative abundance of the constituent minerals in the sandstone samples of the Nanka Formation at Ogbunike is presented in Table 6. Under microscopic examination, iron oxides are opaque: hematite appears in a variety of forms and is red in reflected light. Goethite and limonite are yellowish brown in thin-section and are anisotropic (Figure 11, 12, 13 and 14). Goethite is a predominant component and it ranges from 28% to 35% with average of 30.4% in five samples. Hematite composition ranges from 10 to 20% with an average of 16.6% in five samples. Limonite also has appreciable abundance (average 9.6%). The high amount of goethite and moderate amount of hematite is an indication of low oxidizing condition.

The quartz composition ranges from 25% to 28%, with average of 26.4%, they are mostly angular to sub-rounded. These grains are not in contact, though point contact is visible in some samples. The low amount of feldspar (average 13%) in the ferrugenized sandstone sample is an indication of chemical alteration. All indicate that the sandstone is texturally immature. Whereas it is safe not to conclude on the mineralogical maturity of these sandstones in this work because the samples analysed for petrography are highly ferruginised sandstones. The relative abundance of quartz, feldspar as well as rock fragments is interpreted to mean that the sandstones of the Ogbunike area to be lithic arenite.

4.5 Reservoir Quality

Sieve size plotted on semi-log sheet was used to determine the 50th percentile or median diameter (d50) and the sorting. These data substituted into the empirical formula (($K= C_oD_m^2e^{-1.31\sigma}$) proposed by to estimate permeability (Table 3) of the sandstone; Where k = permeability (millidarcies), Co = an empirical constant (760 darcies /mm^2), Dm = median diameter (mm), and σ = sorting. The permeability for reservoir unit were calculated using empirical relationship between permeability and porosity in sandstone as outlined by Kriesa *et al.,* (1999). The calculated permeability values were used with the standard (Figure 10) in the work of several researchers to suggest the flow properties of the sandstone for reservoir rock potential characterization as shown in Table 3 (Vrbka et al., 1999; Olatinpo et al., 2016a). The sandstone facies in the study area is regarded as good potential for reservoir rock. The average permeability value of the sandstones samples is 12.6darcy and this indicates that the sandstones of the Eocene Ameki Formation have good reservoir potential. However, the permeability generally ranges from moderate to good flow characteristics i.e., 5.03 to 24.33 darcy (Table 4).

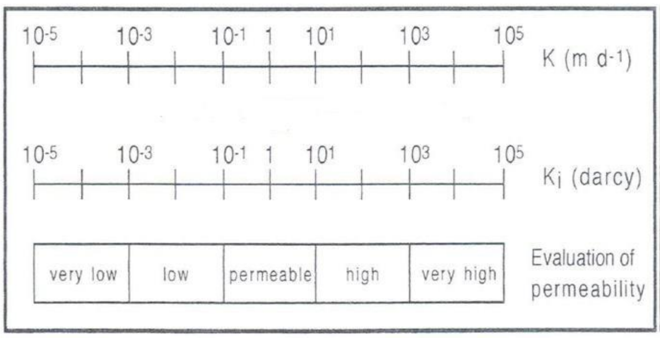

Figure 10: Evaluation of Permeability Based the Hydraulic Conductivity (K) and Intrinsic Permeability (Ki) (After Vrbka et al., 1999)

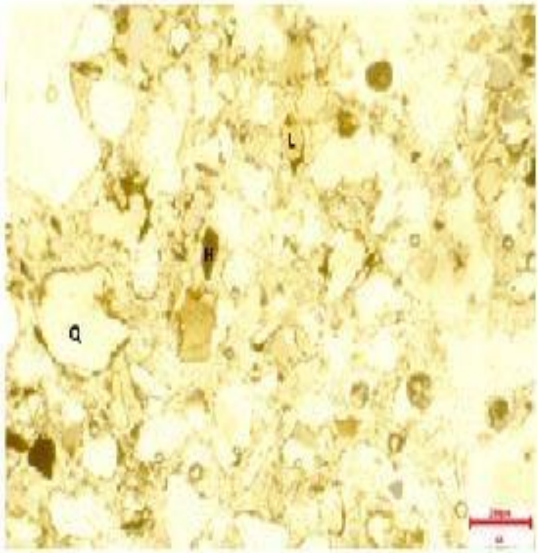

Figure 11: Photomicrograph of Sample OGB 1B under plane polarized lightshowing Quartz (Q), Hematite (H) and Limonite (L)

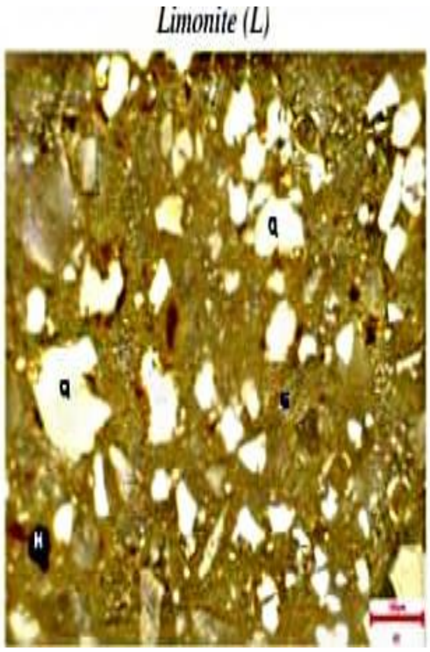

Figure 12: Photomicrograph of Sample OGB 1B under cross polarized light showing Quartz (Q), Hematite (H) and Goethite (G)

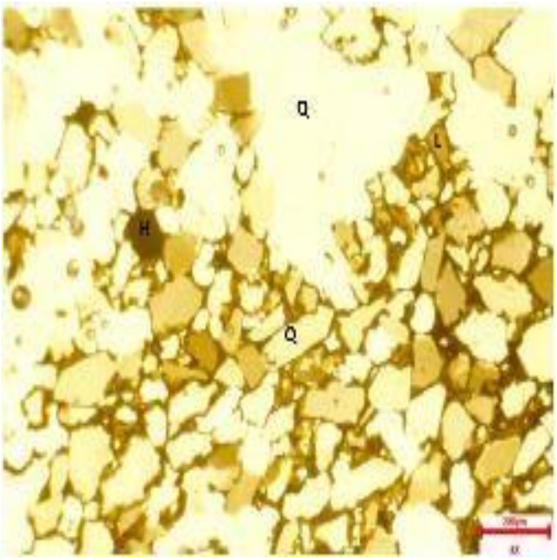

Figure 13: Photomicrograph of Sample OGB 1M under plane polarized light showing Quartz (Q), and Hematite (H)

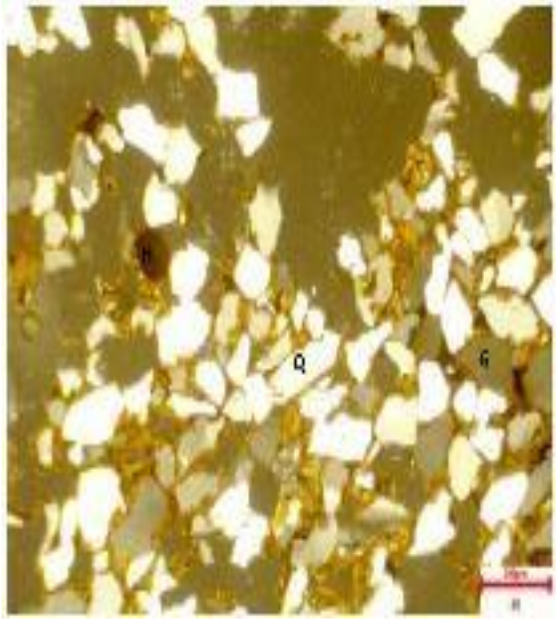

Figure 14: Photomicrograph of Sample OGB 1M under plane polarized light showing Quartz (Q) and Hematite (H)

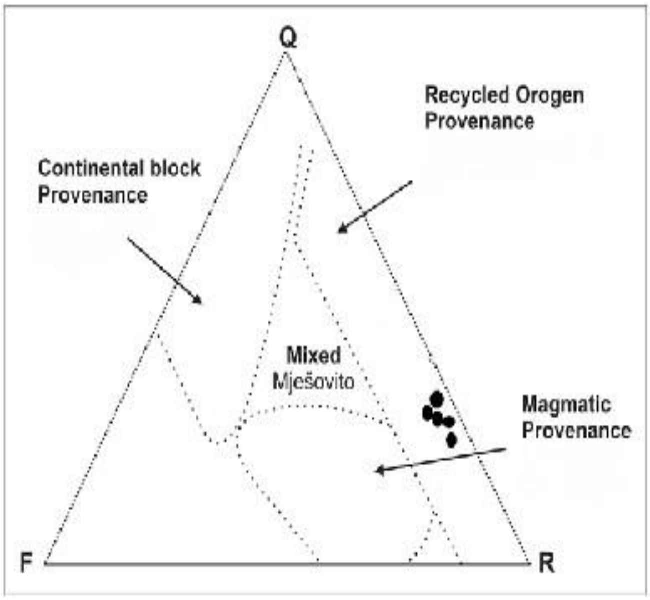

Figure 15: Ternary Plot of framework models for sandstones of Nanka Formation exposed at Ogbunike area (modified after Dickinson, 1988)

Table 4: Permeability Values and the Flow Characteristics of the Sandstones in Nanka Formation

Sample No	Permeability (darcy)	Flow Characteristics
OGB 1B	5.10	Moderate
OGB 2	10.27	Good
OBG 6	9.37	Moderate
OGB 8	5.03	Moderate
OGB 10	23.22	Good
OGB 12	22.48	Good
OGB 14	7.69	Moderate
OGB 16	7.51	Moderate
OGB 18	11.35	Good
OGB 20	24.33	Good

Table 5: Total composition of sandstone of Nanka Formation in Ogbunike area							
Sample No	**Quartz**	**Feldspar**	**Cement**	**Hematite**	**Geothite**	**Limonite**	**Matrix**
OGB 1B	27	13	6	10	28	10	6
OGB 1M	25	3	2	15	30	12	13
OGB 3	28	4	3	20	29	11	5
OGB 5	26	4	3	18	30	10	9
OGB 7	26	5	4	20	35	5	5

Table 6: Framework composition of Ogbunike sandstones			
Sample No	**Quartz**	**Feldspar**	**Rock Fragment**
OGB 1B	27	13	60
OGB 1M	25	3	72
OGB 3	28	4	68
OGB 5	26	4	70
OGB 7	26	5	69

4.6 Provenance Evaluation

The high composition of polycrystalline quartz indicates metamorphic parentage rather than plutonic source. Polycrystalline quartz is not as stable as monocrystalline quartz; thus, they are texturally immature. Transportation history, transportation distance, reworking and cycle of deposition encompass maturity of sandstones. Monocrystalline quartz is thus more matured. The higher the ratio of polycrystalline to monocrystalline, the more immature the sediment or crystal grain and vice versa.

Consequently, the low content of feldspar in the sandstone samples is congruent with the submission transport through high relief and very intense chemical and mechanical weathering depleted the feldspar probably within the basin of deposition. High relief tend to favour quick dissolution of a material, this can cause intense erosion which can aid quick attribution and abrasion of the minerals. Erosional process in high relief areas often yields immature and poorly sorted sediments due to turbulence and rapid deposition. However, in areas of high altitudes (relief) but with relatively flat zones, some inter-stream areas may remain. Erosional activities in such terrain generate maturely weathered detritus. This is usually associated with river system that opens into a platform or shallow basin above sea level. More so, in a shore environment there is always a to and fro movement of the sand by waves and currents that are depositing them before they are finally covered by the sediments. Taking all these into consideration, the Cameroon Basement Complex rocks and Oban Massif are hereby implicated as the probable source of the sand grains.

4.7 Paleoclimate and Source Area Tectonics

The framework composition and structures of quartz are of paramount importance in paleoclimate interpretation. The key indicator suggesting past climatic condition for sandstones is detrital feldspar. The low incidence of feldspars in these sandstones from Ogbunike area suggests that they are derived and deposited under humid and warm climatic condition. Feldspar and lithic fragments are generally susceptible to chemical as well as mechanical weathering. They are consumed much quicker in humid and hot climate even under minimal transportation and high relief. Consequently, the low content of feldspar in this sandstone unit could be attributed to:

1. High intensity of agitation during deposition and very intense chemical and mechanically weathering which depleted the feldspar probably within the basing of deposition.

2. Source and deposition area are of high chemical activity accelerated by high humidity in both areas.

Rapid sedimentation rate with corresponding equal fast subsidence favours preservation of feldspar against dissolution.

Quiet or tectonic stability tend to expose materials to long period of physical and chemical reaction that cause depletion. The sandstones of Ogbunike area may be suggested to be deposition during low sedimentation rate with possible quiet tectonic.

The generation of sands from continental settings is associated with two tectonic processes. If the continental block has recently split as a result of continental rifting, the sands will be quartzo-feldspathic with high ratios of alkali feldspar to plagioclase. If the sands are derived from high topographic areas located long distances from the depositional areas, the sands will be more quartz rich, showing a higher degree of mineralogical maturity. However, if the source area has recently undergone a major orogenic event, the sands will contain a significant fraction of lithic fragments, with more lithic fragments being derived from parts of the orogenic belt rich in oceanic components and less lithic rich sands from continental sources. It is on this note that a recycled orogeny is suggested as paleotectonic for Ogbunike sandstones. The ternary plot of framework modes (QFR) for sandstones of Nanka Formation revealed their tectonic to be a reworked orogen provenance (Figure 13). This provenance is thought to be reworked materials from a molasse trough formed between the basin and the craton. This is consistent with the report of lithic sandstones at the interior tectonic lands (in contrast to craton) associated with molasses facies resulting from orogenic uplift of a geosyncline or subduction margins. This observation is connected to the uplift of the Ikang Trough in the Calabar Flank as well as the subsequent sedimentary deposition in upper delta front of the Niger Delta Basin (Whiteman, 1982) which has significance correlation with the Tertiary sediments of Anambra Basin.

5. Conclusion

1. Geologic mapping, Petrography, sedimentological, statistical and empirical studies have revealed the paleonevironment, provenance and reservoir quality of sandstones within Ameki Formation exposed at Ogbunike area in Anambra Basin. Geologic mapping revealed that the Ogbunike section of the Formation which approximate 27m comprises of four lithofacies which include sandstones, shale, siltstone and ironstones with the sandstone.

2. Granulometric analysis showed that the sandstone units were fine to medium grained, moderately sorted, fine to coarse skewed and platykurtic to very leptokurtic. Averagely coarse skewed implies that the velocity of current that deposited the coarse was higher that the prevailing current.

3. Generally, the sands showed moderate to poor sorting and predominance of sedimentary rock fragments which indicates a brief transport history from high relief.

4. The Bivariate plot of skeweness against sorting and mean against sorting indicate a fluvial depositional environment for the sandstones.

5. Empirical correlation showed that the permeability generally ranges from moderate to good flow characteristics with range of 5.03 to 24.33 darcy and average of 12.6 darcy suggesting potentially good reservoir rock. Rose plot of the paleocurrent directions shows a bimodal- bipolar paleocurrent pattern for the cross bedded sandstone, which is an indication of tidal influence.

6. Petrographic analysis showed that the Sandstone is mineralogical immature and is suggestive of lithic fragment. It further reveals that the samples have high amount of goethite which is evidence of oxidation.

7. It is therefore submitted that the sandstones of Ogbunike area belong to metamorphic source and was deposited under humid climate and high relief with a recycled orogen which can be linked to uplift of Ikang Trough in the Calabar Flank which was derived from nearby Cameroon Basement Complex and the Oban Massif.

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