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SEDIMENTOLOGICAL CHARATERISTICS OF THE AJALI AND BENIN FORMATIONS AROUND AROCHUKWU – ODORO IKPE AXIS SOUTHEAST NIGERIA

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ABSTRACT

The crop-outs of Ajali and Benin Formations within the Arochukwu – Odoro Ikpe Axis Southeast Nigeria, was studied for sedimentological characteristics. Standard methods applied in fieldwork and sedimentological studies were used for this study. The results of the particle size distribution of the Ajali Formation is as follows grain size (0.73- 2.23, mean 1.38); sorting (0.9 - 2.7, mean 1.29); Skewnes (-0.06 - 0.67, mean 0.03); kurtosis (1.19 - 1.39, mean 1.27); grain size distribution – Unimodal to Polymodal. Benin Formation, grain size (-1.92 to 1.16, mean -0.35); sorting (0.60 to 2.24, mean 1.45); Skewnes (-0.22 to 0.76, mean 0.19); kurtosis (0.60 to 1.80) and grain size distribution is Unimodal to Polymodal. Both formations are coarse to very fine and pebbly (mean median grain size), poorly sorted, negatively skewed to strongly finely skewed (mean nearly symmetrical) and leptokurtic Also both formations are very poorly to poorly sorted, have similar mode of transportation which generated these sediments at the time of deposition, which seems to be traction and rolling – typical of fluvial setting. Petrographic analysis of the Ajali and Benin Formations show that quartz is the dominant mineral in both formations (75% - 90%), followed by rock fragments (5% - 25%) and feldspars (0% - 5%). The sediments are interpreted as quartz arenites; this agrees with earlier work on both formations. The dominant sedimentary structures within the Ajali Formation are herringbone cross-stratification, crossbedding, heteroliths and skolithos; bed boundaries are sharp to erosional; with pebble lags. Whereas the dominant sedimentary structures in the Benin Formation are crossbedding and large-scale forest beds; bedding contacts are gradational to erosional with pebble lags. The similarity in sedimentological characteristics of both formations is suggestive of similar origins – the Oban Massif and Obudu Plateau and conditions at the time of deposition. Both formations have similar depositional environments interpreted as fluvial – stream deposits except the upper part of the Ajali Formation which has marine character – tidal.

Key Words: Ajali Formation, Benin Formation, Quartz arenites, sedimentological characteristics

INTRODUCTION

The Benue Trough is believed to have formed during the separation of the African and the South American Plates (Cretaceous times) in which sedimentary sequences deposited (Burke et al., 1971; Olade 1975).

According to Murrat (1972), the southern part of the Benue Trough was longitudinally faulted with its eastern half subsiding preferentially to become the Abakaliki depression - the precursor basin of the Afikpo and Anambra Basins. The thermo-tectonic event during the Santonian created the Afikpo Basin to the and Anambra Basin to the west of the Okigwe-Abakaliki Anticlinorium that separated both basins. Within the created basins, all Pre-Santonian beds were folded, faulted, and uplifted NE-SW including the Okigwe-Abakaliki Anticlinorium (Burke et al., 1971; Murrat, 1972; Olade, 1975). Murat (1970), identified three major structural cycles in southeastern Nigeria. These are: (a) The Aptian – Early Santonian, related to the initial rifting of the southern Nigerian continental region and opening of the Benue Trough. This phase produced two principal sets of faults trending NE – SW and NW – SE. The NE – SW set of faults bound the Benue Trough while the NW – SE deformed the Calabar Flank. (b) The Turonian – Santonian, which was characterized by compressional movements resulting in the folding of the Abakaliki Anticlinorium and the complimentary Afikpo Basin. (c) The Late Campanian – Middle Miocene phase produced rapid subsidence and uplift in alternation with subsequent progradation of the Niger delta sedimentary sequences. The stratigraphic of the Lower Benue Trough, according to Short and Stauble (1967) and Murat (1972) was characterized by three sedimentary phases, the Abakaliki – Benue phase (Aptian -Santonian), the Anambra – Benin phase (Campanian – Mid Eocene) and the Niger Delta Phase (Late Eocene - Pliocene). Majority of the sedimentary beds in the Lower Benue Trough, were deposited in a NE – SW direction while others were deposited in a NW-SE direction. The paleocurrent analysis of the cross-bedded sandstone in the basins of the Lower Benue Trough suggests two separate provenances, the NE source probably from the Hawal Massif and the NW source possibly from the Nigerian Basement Complex (Chikani et al., 2010). Imprints of tectonism on the sediments in the Lower Benue Trough area were preserved as series of joints trending NW-SE. The ranges of depositional environment typical of the Lower Benue Trough are marine, continental, and transitional represented by the Asu River Group, Eze Aku Group, Nkporo, Mamu, Ajali, Nsukka, Imo, Ameki Formations Nanka Sands and Benin Formation; these sequences are typically found in the study area and the stratigraphic framework is summarized in Table 1.0.

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Table 1: Lithostratigraphic units in the Study Area compared with the Correlation Chart for Early Cretaceous-Tertiary Strata in Southern Nigeria (Modified after Oboh-Ikuenobe et al (2005) and Nwajide, 1990).

Age	Abakaliki/Anambra Basin	Afikpo Basin	Study Area
Oligocene	Ogwashi-Asaba Formation	Ogwashi-Asaba Formation	Benin Formation
Eocene	Ameki/Nanka Formation	Ameki Formation	
Paleocene	Imo Formation Nsukka Formation	Imo Formation Nsukka Formation	Nsukka Formation
Maastrichtian	Ajali Formation Mamu Formation	Ajali Formation Mamu Formation	Ajali Formation Mamu Formation
Campanian	Nkporo/Owelli Formation Enugu Shale	Nkporo Shale/ Afikpo Sandstone	
Santonian			
Coniacian	Agbani Sandstone/Agwu Shale	Non-Deposition (Erosion)	Nkporo Shale
Turonian	Eze-Aku Group	Eze-Aku Group Amaseri Sandstone	
Cenomanian Albian	Asu River Group	Asu River Group	
Aptian Banenanian Hauterivian	Unnamed Units	Basement Complex	Basement Complex
Precambrian	Basement Complex		

This research, using field data and laboratory analyses, seeks to resolve these controversies and present a concise sedimentology, and geologic map of the study area incorporating the research findings. This study is restricted to mainly outcrops and boreholes in the study area. The study area is located within the Lower Benue Trough- the Afikpo Basin and covers parts of Ikono and Ini Local Government Areas of Akwa Ibom State and Arochukwu Local Government Areas of Abia State - South-eastern, Nigeria. The study area is approximately 348.7 Km^2 and located within longitudes 7° 44'E - 8° 03'E and latitudes 5° 15 N - 5° 28'N (Figures 1.0 – 2.0). According to Lambiase (1980), It has long been recognized that grain size distribution, reflect the hydrodynamic environment where sediments are transported and deposited. Approaches used in interpreting depositional environments from grain size distribution are graphs of skewness vs sorting (Friedman, 1961), comparing the coarsest fraction to median grain size and analyzing cumulative curve shapes (Passega, 1964). In addition to exploiting the relationship between grain size distribution and hydraulics (Middleton, 1976; Sagoe and Visher, 1977), this approach emphasizes the effects of the transporting medium on sediments and provides a basis for interpreting hydraulic conditions from grain size distribution data.

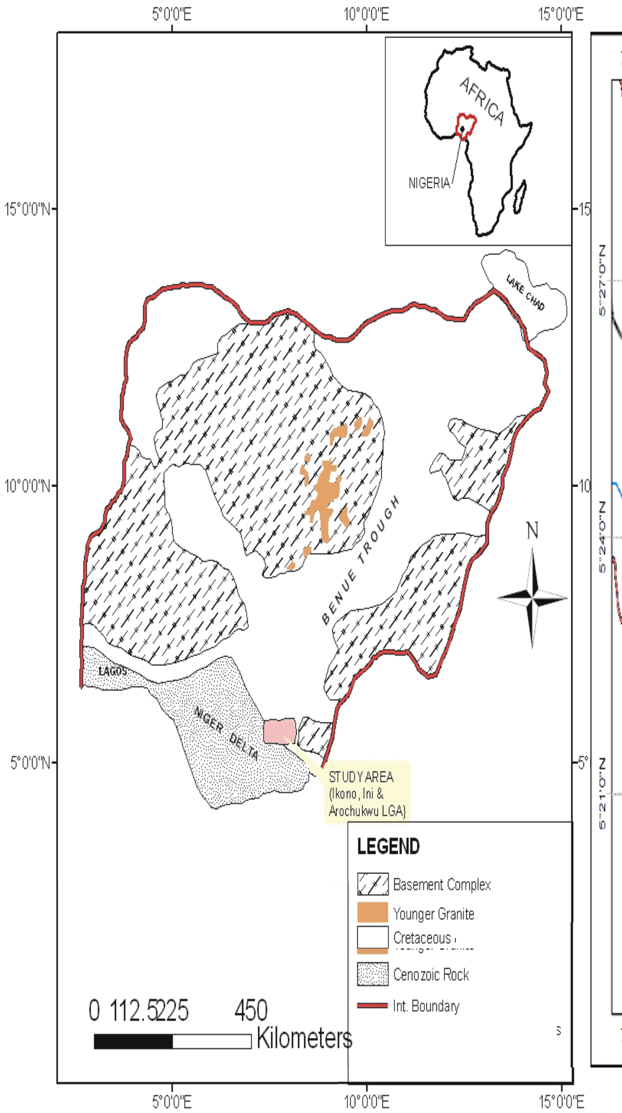

Figure 1 Geologic map of Nigeria indicating the study area (Inset map of Africa showing the position of Nigeria). (Ideozu, 2014)

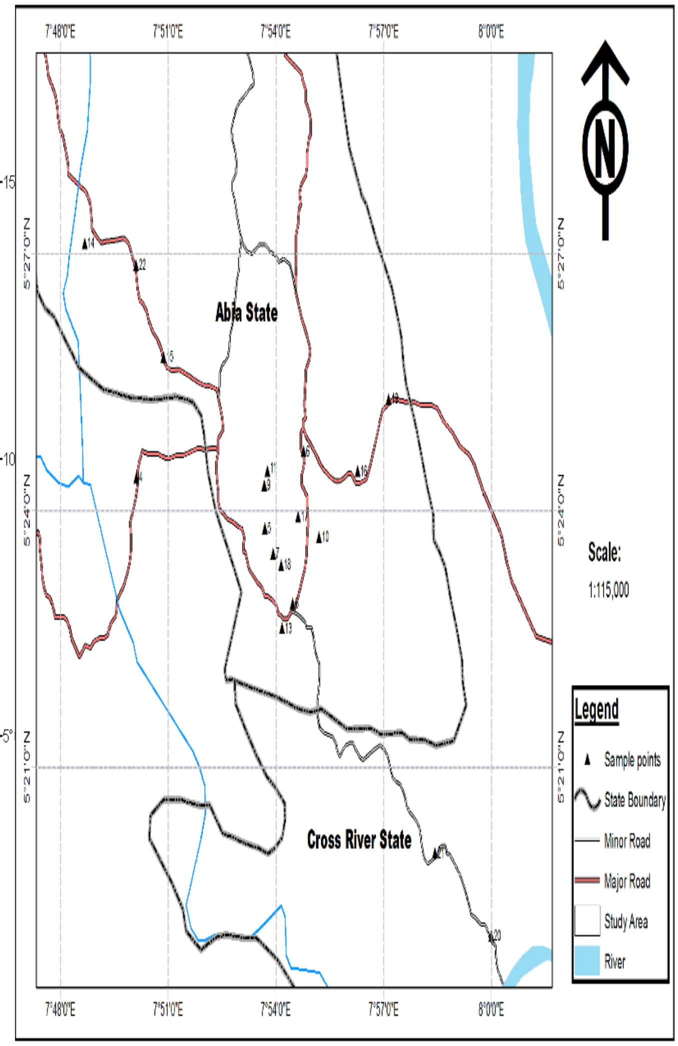

Figure 2 Location map of the study area (L= Sample Location). (Ideozu, 2014)

Numerous authors have suggested that cumulative frequency curves are composed of two or more logs – normally distributed grain populations and that the shape of a cumulative frequency curve is a function of the relative proportion of these populations (Tanner, 1959, 1964; Spencer, 1963; Visher, 1969). Other researchers, have advanced the idea that each grain population is related to different sediment transport mechanisms and thus grain size parameters are indicators of hydraulic conditions of sediment transport paths (Fuller, 1961; Moss, 1962; Sagoe and Visher, 1977). Lambiase (1980) in his work demonstrated the relationship between grain size distribution and hydraulics in the Avon River Estuary and submitted that the hydraulic environment control sediment distribution while grain size reflects this control. In addition, hydraulic sorting affects the reliability of some parameters with the result that cumulative frequency curve characteristics as determined by graphical means into normal components are better indicators of hydraulic environment than are textural

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parameters from moment measures. Petrographic studies of sand/sandstones from Ajali and the Benin Formations have been undertaken by many researchers. The results of their petrographic studies show that the Ajali and the Benin Formations have been classified as quartz arenites with the composition of quartz exceeding 90.0% and feldspars less than 5.0% -this indicates a predominantly basement source (Tijani et al., 2010). According to Ibe and Akaolisa (2010) in their work on Sandclass Classification Scheme for the Ajali Formation around Ohafia area, showed that the formation can be classified as iron – rich quartz arenitic sandstone units taken as one unit but field and geochemical data indicate that the two major sandstone units are grouped as quartz arenites and ironstone. Results of heavy mineral studies by Orubima (2009) showed that the heavy mineral assemblage within the Benin Formation (Ndot Ikpe and Odoro Ikpe areas) comprises zircon, garnet, hornblende, rutile and hematite. He also interpreted the provenance of the sands/sandstones as igneous and metamorphic terrains from the Oban Hills and Obudu Plateau. Several opinions have been proffered as to the origin, composition and depositional environments of the Ajali and Benin Formations in the study area.

MATERIALS AND METHOD

The methodologies applied for this research work are standard methods as used in sedimentological studies and it involved field mapping and data sampling from outcrops and boreholes. The spot sampling method was adopted for data collection during the field mapping (Davies, 1973). Attention was given to accurate and detailed geological description and recording of parameters such as sedimentary structures, rock type and composition, measurements of bed thicknesses, lateral extent of the outcrops in addition to information from measurement of strike and dip. Materials used during the field mapping include compass/clinometers, Geographic Positioning System (GPS) and measuring tape, field notebook, camera and topographic map indicating the position of the study area (Ikot Ekpene sheet 322 on a scale 1: 50,000). The outcrops identified were examined for bedding contacts, bed thickness variation, sedimentary and biogenic structures as well as syn- and post-depositional structures in detail (Miall, 1984; Tucker, 1988).

Grain Size Analysis

The standard form of mechanical analysis was used to determine grain size distribution (Tucker, 1988). Sieving is the most common method for size determination of clast for particles coarser than 0.063mm (Tucker, 1988). According to Friedman (1979), Lewis and McConchie (1994) the primary purpose of grain size analysis is to determine particle size distribution because it has a direct relationship with the concentration of particles in suspension, availability of different sizes of particles present and processes operating at and when the sediments were deposited. For the present study, dry sieving method was adopted. Seventy-six samples consisting of sands, sandstone and pebbly sand/sandstone were analyzed. The samples were first examined and each of the samples were then disaggregated into its component units using mortar and rubber-tipped pestle for samples that are lithified after heating in a conventional oven and drying in a moisture free environment. Since most of the samples were friable, disaggregation was easy as the grains were neither broken nor shattered. The samples were then sorted to their various sizes using screen sizes most appropriate for the analysis. The minimum time used to sift the samples into their various sizes was twenty minutes. The percentage of samples retained in each screen size was calculated gravimetrically based on the final sample weight after sieving. From the data obtained, numerical curves were plotted such as cumulative curves and histograms from which quantitative graphical parameters using the Folk and Ward (1957) formulae were calculated. The statistical data were computed using cumulative weight percentage and computed phi (Tucker, 1988; Friedman et al,. 1992; Pettijohn, 1975). Parameters computed are median, mean, standard deviation, Skewnes and kurtosis.

Petrographic Analysis

Representative samples of friable sands and sandstones (seventy-five – 75) from the study area were impregnated with epoxy resin and mounted on glass sides. They were trimmed and polished to the required thickness of 0.03mm, suitable for optical microscopy. Manual laboratory techniques were employed in the preparation of loosely consolidated sands and sandstone. Each slide was labeled appropriately for petrographic study. The prepared slides were studied under plane – and cross-polarized light to identify the constituent minerals in the sandstone. Great care was taken in the procedure adopted because identification of the minerals and framework grains depend on the subtle characteristic interference colors (Curry et al., 1982). Photomicrographs of the thin sections were taken.

RESULTS AND DISCUSSION

Fieldwork

The lithostratigraphic logs of the study area have been described in terms of the sedimentology from fieldwork, are presented Figures 3.0 – 4.0 and Plates 1.0 – 4.0. The lithologic units in the study area are Mamu, Ajali, Nsukka and Benin Formations respectively. The Ajali Formation, cropped out at Obotme, Obikinta, Mbiabong Ito, Amanangwu, Akama, Utughgwu, Agbagwu and Ubila/Ametiti (Ututu). Whereas the Benin Formation, outcropped at Mbiabong Ikon II, Odoro Ikpe and Ndot Ikpe

Obikinta – Arochukwu

Outcrop: 16 m; 5° 23.361’ N, 7° 54.141’ E 32° NE / 212’ SW; Dip 8° SE
Lithostratigraphic Unit: Ajali Formation

Sedimentology

The Ajali Formation consists of very fine to medium-grained cross-bedded sandstone and medium to coarse-grained trough cross-bedded sandstone. The sedimentary units have bedding contacts that are sharp, moderately well-sorted and reddish to brownish. Evidence of skolithos and ironstone concretions also abounds in addition to herringbone cross stratification. Joints abound in the unit indicative of tectonic imprints.

Utughugwu

Borehole 16.10 m and Outcrop 8.00 m; 5° 23. 479’ N 7° 53.920’ E Strike 356° NW / 176° SE Dip: 30° SE
Lithostratigraphic Unit: Ajali Formation

Sedimentology

The lithostratigraphic unit in this location is the Ajali Formation. It is 8.0 m in outcrop while it is 16.01 m in the borehole. It consists of a sequence of fine grained sand,

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clay and clayey sand, pebbly sand and laminated clays. From outcrop; the pebbles are well rounded in the pebbly sand bed and very poorly sorted, the fine to very fine grained sandy beds are cross bedded with skolithos, very well to moderately well sorted and the clay beds are laminated, in addition to joints observed; the bedding contact in outcrop is sharp to erosional with pebble lags. Whereas in the borehole, the pebbly sandy bed consists of angular iron stone, indurated fragments of sandstone – angular to sub-angular in a clayey matrix. The fine to coarse–grained sandy beds are moderately well sorted to very well-sorted. In both outcrop and borehole, the Ajali Formation is moderately well sorted to very poorly sorted, reddish to whitish and this section of the formation is fluvial in character – braided stream deposit. See Plates 1.0 and 2.0.

Plate 1.0

Plate 2.0

Plate 1.0 Ajali Formation along Ututu road-Arochukwu, showing evidence of skolithos. Plate 2.0 Basal bed of Ajali Formation along Ututu road, showing contact between the Mamu and Ajali Formations. The sandstone has millimeter scale beds of silt, clay and very fine-grained sandstone-Heteroliths.

Ugwuakuma - Arochukwu
Outcrop: 8.22 m, 5°24.671' N 7°54.740'E, Strike: 44° NE / 268° SW and Dip 4° – 30°
Lithostratigraphic Unit: Ajali and Nsukka Formations

Sedimentology
The Ajali Formation at Ugwuakuma is overlain by a member of the Nsukka Formation, consists of the pebble grits of Reyment (1965), clays, sand and pebbly sand beds and lenses of iron stone ranging from 0.30 – 5.58 m, the bedding contact between the Ajali and Nsukka Formations is sharp to erosional. The pebbly sand beds of the Ajali Formation are matrix supported with abundant breccia, very poorly sorted. The sandy beds are medium to coarse-grained, moderately well-sorted. The bedding contacts are sharp to gradational. The iron mineral content of this formation is very high in this locality. Generally, the beds have brownish to reddish coloration because of the abundant iron minerals (Plates 3.0 – 4.0).

Mbiabong Ito
Outcrop: Average height 32.06 m: 5°23.673' N 7°55.208'E: Strike: 340°NW/160°SE, Dip 10° – 70°

Lithologic contact: Sandstone / shale. Lithologic Unit: Ajali and Nsukka Formations.

Sedimentology

The average thickness of the Ajali Formation at this outcrop is 27.76 m while the average thickness of the Nsukka formation is 4.30 m. The bed contact between both formations is sharp to erosional. The shale unit Nsukka Formation pinches out from the right of the outcrop to the left where the pebble grits of Reyment unconformably overlies the Ajali Formation defining an unconformity. There is evidence of tectonics in this outcrop, the Ajali

Plate 3.0

Plate 4.0

Plate 3.0 The pebble grit of Reyment (1965), a member of the Nsukka Formation consists of angular indurated ferruginised sandstone with abundant ironstone fragments at Utughugwu.
Plate 4.0 Massive ironstone boulders within the Nsukka Formation, at Utughugwu

Formation is folded and faulted. The Ajali Formation has thickness ranging from 0.10 – 5.67 m comprising a sequence of sand and clay drapes. The sand beds of the Ajali Formation are mainly very fine to medium grained, clayey, with cross beds of planar to herring bone cross -stratification, very well sorted to moderately sorted, skolithos ichnofacies are common. The clay drapes are whitish made up of clay minerals, probably kaolinite. Trace fossils are common on the clay drapes with abundant fecal pellets. The bed contacts are sharp to gradational but the presence of ichnofacies such as skolithos suggests a shallow marine environment and the herringbone cross stratification. The Nsukka Formation comprises the pebble grits of Reyment (1965) and a shale unit. The pebble grits comprise boulders and cobbles of iron stone, gravels and granules (sometimes well rounded to very angular) in a clayey matrix with sands; in addition to angular ironstone and ferruginised sandstone fragments. These pebble grits are extremely very poorly sorted and has a very high content of iron minerals. They are reddish to brownish. The shale unit is greyish and inaccessible. See Plates 5.0 – 6.0 and Figure 3.0

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Plate 5.0 Plate 6.0

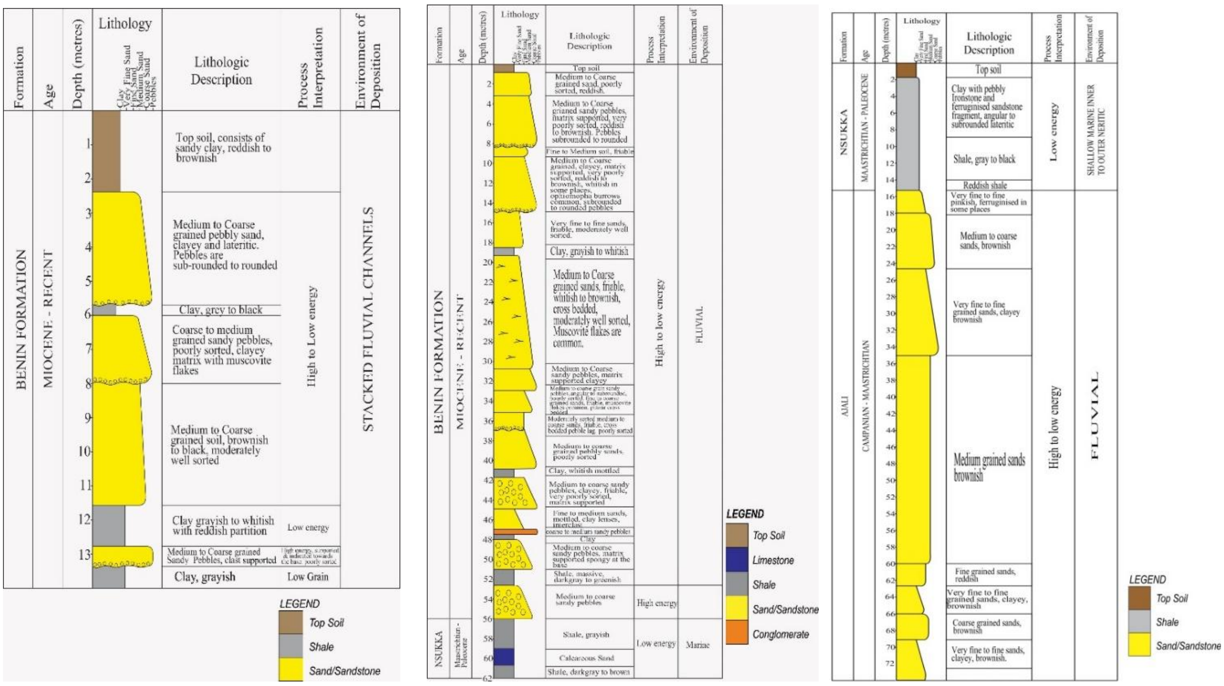
Plate 5.0 Ajali Formation showing herringbone cross-stratification and skolithos Mbiabong Ito. Plate 6 Outcrop of Ajali Formation at Mbiabong Ito

Mbiabong Ikon II

Outcrop: 15.80 m: 5°15.105'N, 7°45.390'E: Strike: 42° NE/312°°SW Beds Dip: 2°-4° SW. Lithostratigraphic Unit: Benin Formation.

Sedimentology

The Benin Formation is the only lithostratigraphic unit encountered at Mbiabong Ikon II is 15.00m thick. It comprises a sequence of pebble, sand and clay beds with thickness ranging from 0.10m to 3.70m. The bed boundaries are sharp to gradational. The pebble beds comprise medium to coarse–grained sandy pebbles and medium to coarse–grained pebbly sands, matrix supported made up of clays and sands. In addition, muscovite flakes were wound within the clays that bound the pebbles.



A Mbiabong Ikom II B Odoro Ikpe C Mbiabong Ito

Figure 3.0 Lithostratigraphic Logs of Mbiabong Ikom II, Odoro Ikpe and Mbiabong Ito Showing Ajali and Benin Formations in the study Area (Ideozu, 2014).

The colour is Whitish to reddish, indicating intense weathering of feldspars with high iron content. The pebbles are rounded to very well-rounded indicating long distance of travel. This suggests that when the strong currents that deposited the pebbles waned, the matrix became deposited in the interstices of the pebbles. The medium to coarse grained sandy pebbles are clayey, lateritic, and reddish to brownish. The pebbles are sub-rounded to round, poorly to very poorly-sorted; with large-scale forest beds are conspicuous. The medium to coarse grained sandy beds, are clayey, poorly sorted to moderately well sorted, reddish to brownish and black. The clay beds are greyish to black and based on the sedimentological characteristics, the environment of deposition fluvial (Braided stream). See Pates 1.0 – 2.0. Medium to coarse grained sandy pebbles; clayey, lateritic, and reddish to brownish. The pebbles are sub-rounded to round. Very poorly sorted, large-scale forest beds are conspicuous. See Figure 3.0

Odoro Ikpe

Outcrop: 64.18 m: Borehole (water well): 64.00 m: 5°30.000'N 7°45.078' E Strike and Dip for Nsukka Formation is 60° NE / 240° SW, 14° SW; Strike and Dip for the Benin Formation is 32° NE / 212°SW: 4° SW. Lithologic contact: Sandstone / shale: Lithostratigraphic Units: Nsukka and Benin Formations

Sedimentology

Two lithostratigraphic units were observed in the outcrop and borehole drilled 500 m from the outcrop- Nsukka and Benin Formations. The Nsukka Formation is unconformably overlain by the Benin Formation and an unconformity was established based on high dip values and biostratigraphy (Ideozu, 2014). The borehole penetrated all the beds in the outcrop. The Nsukka Formation is 4.92 m comprising shale and limestone with thickness ranging from 0.91 m – 3.40 m and have sharp to gradational contacts. The shale is greyish to greenish, massive and fractured in outcrop, in the borehole the shale is greyish. Whereas the limestone, is whitish to brownish, and mainly composed of lime mud and sand fractions. The Benin Formation is 53.73 m comprising a sequence of pebble, sand and clay beds with thickness ranging from 0.10 – 12.33 m. The bedding contacts are gradational to erosional with pebble lags. The Benin Formation in this location is friable, poor to very poorly sorted, angular to well-rounded especially the pebbles, whitish to reddish with sedimentary structures such as planar crossbeds. The pebble beds are, friable, round to very well rounded, poorly to very poorly sorted and matrix supported (comprising mainly clay, sand and silts), muscovite flakes are common especially in the clayey matrix. The sandy beds fines to coarse grained sands – clay clast is common, clayey, and friable and poorly to very well- sorted. Iron stone fragments are common; in addition, the sandy beds are whitish to brownish. The clayey beds have thicknesses, ranging from 0.10 – 0.90 m. They are whitish with reddish patches, mottled with bedding contacts being sharp to erosional (Plates 7.0– 8.0.). See Figure 3.0.

Obotme

Outcrop: 56.92 m: 5° 24.381' N 7° 50.123' E: Strike: 76° NE / 272° SW Dip 4°-6°. Lithologic contact: Sandstone / shale. Lithostratigraphic units: Mamu, Ajali and Nsukka Formations.

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Sedimentology

The Mamu Formation in this location is 4.0 m thick made up of only shale. It is gray to dark gray, finely laminated, massive and hard. When split breaks along conchoidal fractures, trace fossils and fecal pellets are rare. Sedimentologically, it is composed of sub-angular to rounded quartz grains 60%, rock fragments 10%, pyrites 10%, coal fragments 3%, muscovite flakes 10% and fossils 3%. Age diagnostic taxa were recovered for both foraminifera and palynomorphs; the age of the Mamu Formation is interpreted as Late Maastrichtian (Ideozu, 2014). The Ajali Formation is 14.6 m thick covered with flora; the exposed section showed that the formation is very fine to medium-grained, lateritic and reddish to brownish. The lithologic boundary between the Mamu and Ajali Formation is sharp, in addition a spring was observed at this contact. The Nsukka Formation is 38.32 m, comprising shale and limestone occurring as lenses. The shale is gray to black, fissile and very fossiliferous. Sedimentological analysis shows that the shale comprises 38.2 % quartz grains, 16.0 % rock fragments, 3.6 % fecal pellets, 12.4 % coal fragments, 3.4 % muscovite flakes, 20.0 % pyrite, 2.4 % rootlets, 1.8 % glauconite, 1.0 % gastropods and fossil content 2.2 %. The limestone is bioclastic with abundant bivalves, gastropod, ostracods and shell fragments and whitish to greyish towards the base where it has contact with shale.

Plate.7.0

Plate 8.0

Plate.7.0 Pebble bed of the Benin Formation at the base of the outcrop of Odoro Ikpe. Plate 8.0 Medium to coarse-grained pebbly sand, Benin Formation showing crossbedding at Odoro Ikpe

Stratigraphy of the Study Area

The stratigraphy of the study area is similar to the stratigraphy of the Afikpo Basin. It was synthesized from fieldwork, results of the biostratigraphic analyses and correlation of lithostratigraphic sections constructed from outcrops and borehole -wells (Ideozu, 2014) see Figures 4-5 and Table 1. The lithostratigraphic units identified include Mamu, Ajali, Nsukka and Benin Formations. Imo Shale is absent from the stratigraphy of the study area, this may have been eroded by the Benin Formation or there was no deposition implying an unconformity (Ideozu, 2014). The sedimentary sequences comprise clays/shale, sand/sandstones, pebbly sand/conglomerates and limestone and make up the Mamu, Ajali, Nsukka and Benin Formations in the study area. This study reveals that the Nsukka, Ajali and Mamu Formations (Cretaceous sediments) are overlain by the Benin Formation. There is lateral continuity of the Nsukka Formation from Arochukwu to Odoro Ikpe areas, based on field relations and biostratigraphic data (Ideozu, 2014).

Grain Size Analysis Results

The grain size analyses carried out on the sand/sandstone and pebbly sand from the Ajali and Benin Formations in the study area are presented in Figures 5.0 – 11.0 and Tables 2.0 – 3.0. Ajali Formation has the following results grain Size (0.73 to 2.23, mean 1.38), sorting (0.90 to 2.07, mean 1.29), Skewnes (-0.06 to 0.67, mean 0.03), kurtosis (1.19 to 1.39, mean 1.27). Grain size distribution of the Ajali Formation is Unimodal to Polymodal whereas the Benin Formation has the following results grain size (-1.92 to -1.16, mean -0.35), sorting (0.60 to 2.24, mean 1.45), Skewnes (-0.22 to 0.76, mean 0.19) and kurtosis (0.60 to 1.80, mean 1.01). See Figures 6.0 – 11.0. The Grain size distribution of the Benin Formation is Unimodal to Polymodal. Interpretation of the grain size analysis results of the Ajali and Benin Formations shows that the Ajali Formation is coarse to very fine (mean medium grained), poorly sorted, negatively skewed to strongly finely skewed (mean nearly symmetrical) and leptokurtic whereas the Benin Formation is very coarse to medium grained (mean very coarse), moderately well sorted to poorly sorted (mean poorly sorted), negatively skewed to strongly finely skewed (mean) and platykurtic to very leptokurtic (mean mesokurtic). The summaries of the interpretation of grain size statistical parameters for the Ajali and Benin Formations are presented in Tables 2.0 – 3.0.

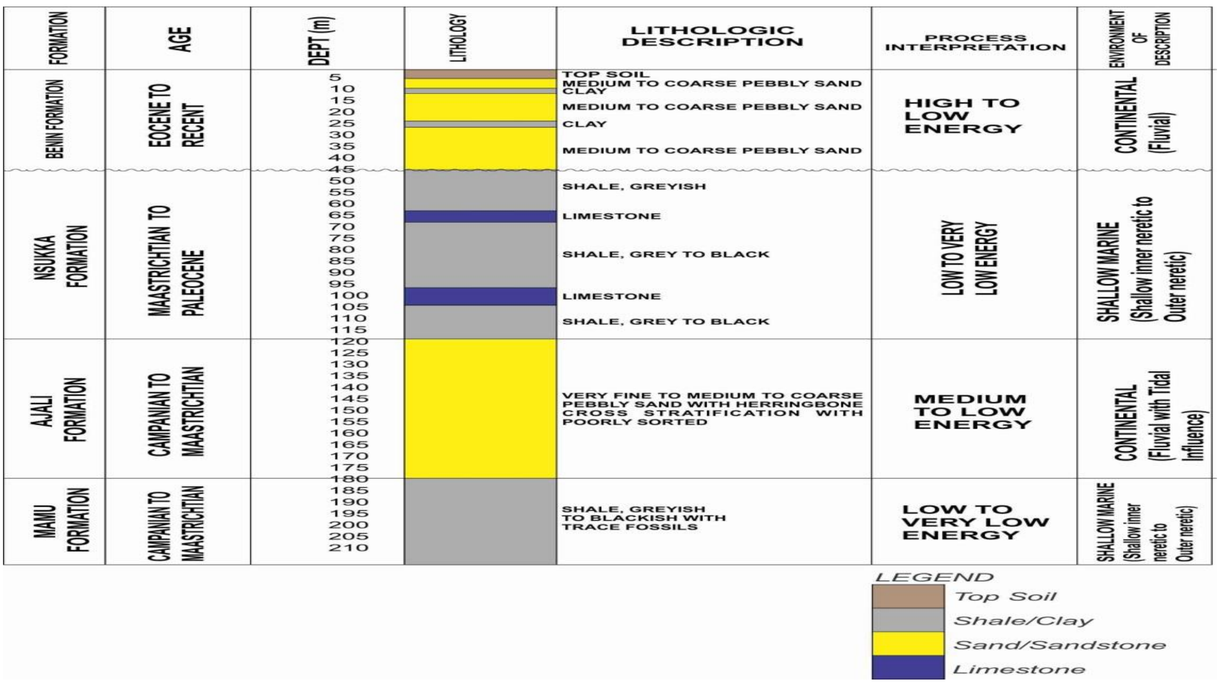

Figure 4.0 Composite log of the study area showing lithostratigraphic units of the Study area based on correlation of lithologic logs and biostratigraphic data (Ideozu, 2014).

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Petrographic Analysis Results

The results of the petrographic analysis of the Ajali and Benin Formations are presented in Plate 9.0 and Tables 5.0 – 6.0. Quartz is the dominant mineral in all the samples (75% - 90%), followed by rock fragments (5% - 25%) and feldspars (0% - 5%) in both the Benin and Ajali Formations. The sands/sandstones are interpreted as quartz arenites based on Petition's (1975) classification scheme.

Based on the sedimentological analysis carried out on both Ajali and Benin Formations in the study area, the sediments are predominantly very coarse to coarse grained sand and pebbly sandstone beds. 70% of the samples are very coarse to coarse grained and may represent a high-energy environment whereas 30% of the samples very fine to clay grade and may also represent a low energy environment. This suggests that the sediments may have been deposited in a predominantly high energy environment, while the low energy fluctuations reflect the deposition of fines as distinct units. From the results of the analyses, 47.5% samples are poorly sorted, 25% samples are very poorly sorted, 15% or 6 samples are moderately sorted, and 10% samples are moderately well sorted, while 2.5% sample is well sorted.72.5% of the samples analyzed are very poorly to poorly sorted. This gives an insight of the mode of transportation which generated these sediments at the time of deposition, which seems to be traction and rolling. In addition, it also gives an idea of the range of settling velocities, distance of transport as well as the degree of turbulence (Krumbien and Sloss, 1963). The data obtained from grain size analysis, shows that all samples analyzed have all three modes of distribution.

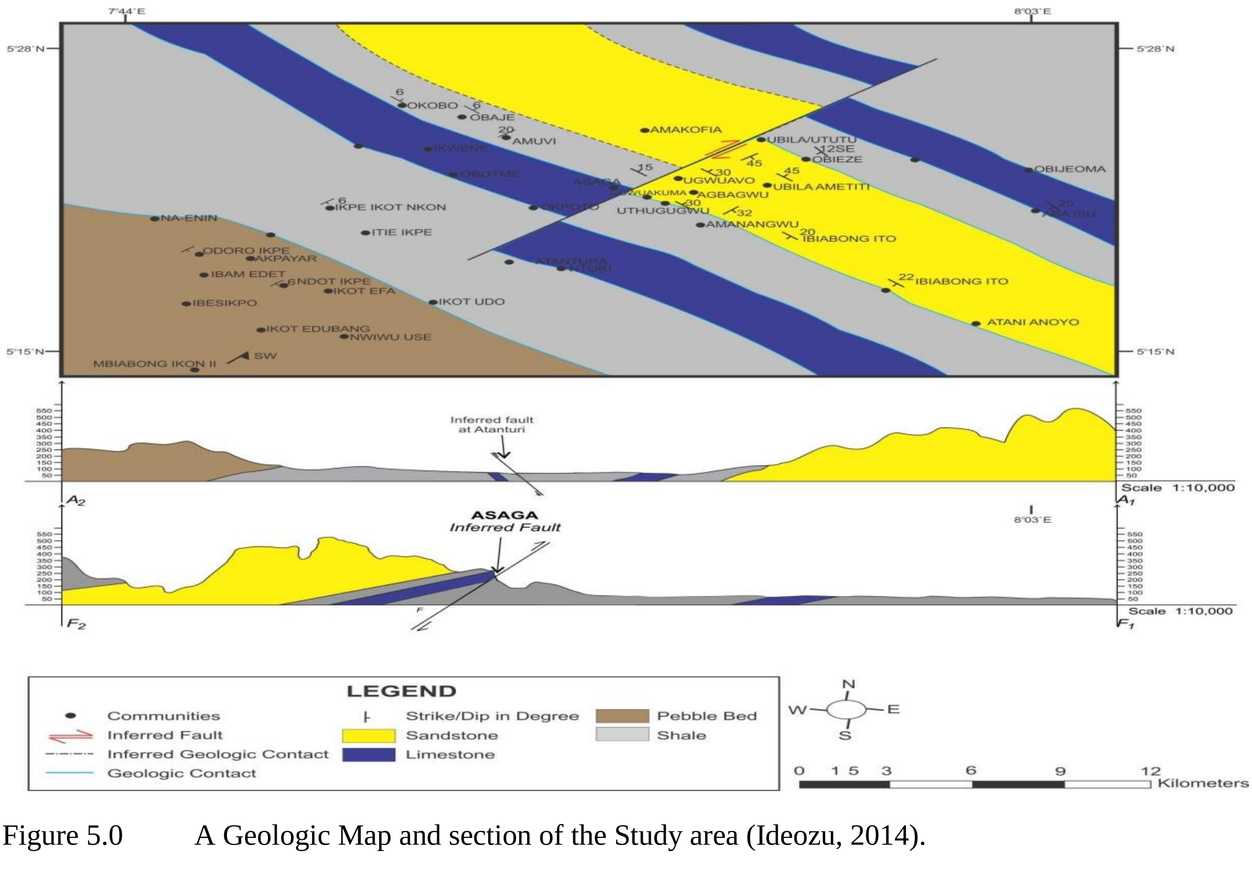

Figure 5.0 A Geologic Map and section of the Study area (Ideozu, 2014).

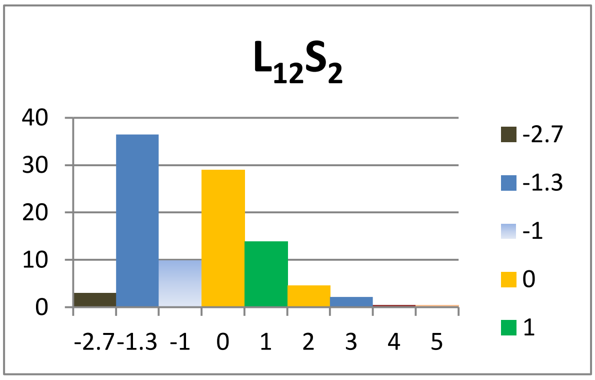

Figure 6.0 Weight percent (%) on y – axis and Grain size (phi) on the x – axis (Location 1). Histogram

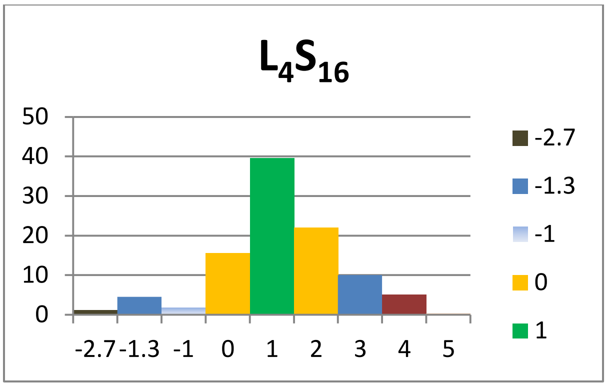

Figure 7.0 Weight percent (%) on y – axis and Grain size (phi) on the x – axis (Location 2). Histogram

The Unimodal distribution pattern dominates in the study area as this may be attributed to the fact that the sediments were deposited in one phase had not undergone much re–working or re-deposition whereas the bi–modal and poly–modal pattern of distribution of half of the sediments may be due to the dynamics of the depositing medium or mixtures of two or more materials in more than two or more phases. The bi – modal and poly – modal mode of distribution are mixtures of two or more sub – populations relating to different modes of transport (Pettijohn, 1975). According to Friedman (1967), river sands are grouped into three populations; particles deposited by rolling or sliding, saltation and suspension. Thus, from the results, all three modes of transport are observed in the samples analyzed. Lambiase (1980) in his work suggested that each of the grain population were transported at different rates, the suspended grains travel faster than grains moved by traction and rolling.

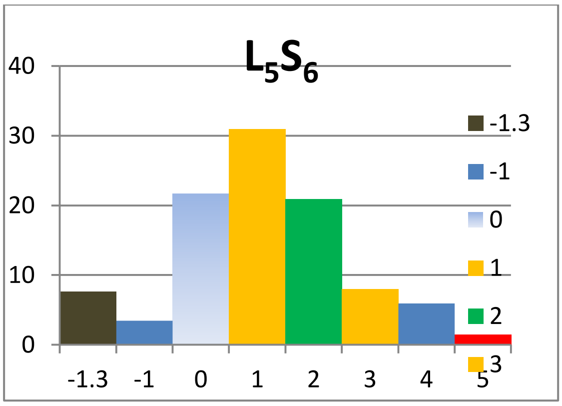

Figure 8.0 Weight percent (%) on y – axis and Grain size (phi) on the x – axis (Location 3).

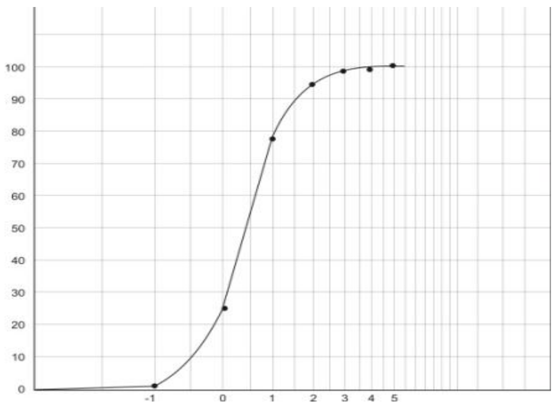

Figure 9.0 Cumulative weight percent (%) on y – axis and Grain size (phi) on the x – axis (Location 1). Cumulative frequency curve.

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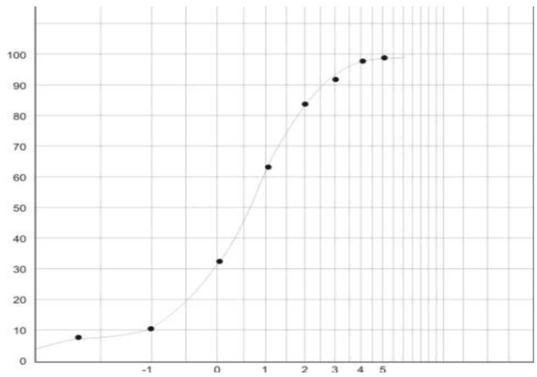

Figure 10.0 Cumulative weight percent (%) on y – axis and Grain size (phi) on the x – axis (Location 2). Cumulative frequency curve.

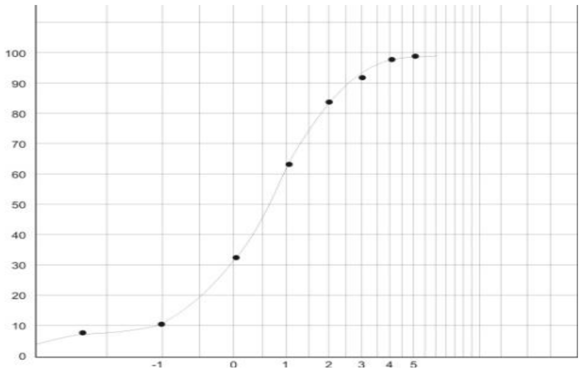

Figure 11.0 Cumulative weight percent (%) on y – axis and Grain size (phi) on the x – axis (Location 3). Cumulative frequency curve.

The areal distribution transport paths combined with different rates of each grain population produces hydrodynamic sorting. The standard deviation gives a clue to the sorting and is suggestive that hydrodynamic conditions operated in the depositing medium during transport (Krumbien and Sloss, 1963; Reineck and Singh, 1980). The alternating sequence of fine grained sediments and coarse grained sediments probably suggests a high-energy environment fluctuated by a low energy environment (Pettijohn, 1956; Reineck and Singh, 1980). The mechanism for this type of sequence suggests a braided river – distributary channel model with some tidal influence based on sedimentary structure – herringbone cross stratification (Reineck and Singh, 1980; Weimer, 1992). The results of the computed standard deviation (a range of 1.31 to 1.77 and mean of 1.47) shows that the sand/sandstone and pebbly sand/sandstone units of the Ajali and Benin Formations are poor to very poorly sorted. They have an average very positive skewness. From the results, the grains are mainly medium to coarse grained and pebbly in the pebbly sandy beds, thus only a very strong current must have deposited these sediments. The fines were deposited in the interstices of the medium to coarse grained and pebbly clast when the velocity of the depositing medium reduced probably at the coastal fringes (Pettijohn, 1975; Friedman et al., 1992; Lewis and McConchie, 1994). The results of the grain size analysis, suggests that a very strong competent river may have deposited these sediments and the environment of deposition of the sedimentary suite reflects a fluvial setting. An insight into the unfolding environment of deposition, within the pebble belt axis (Odoro Ikpe – Ndot Ikpe – Mbiabong Ikon axis) and conglomeratic beds of the Ajali Formation (Arochukwu axis) reflects Friedman's (1976) thought that river sands are grouped into three populations, deposited by (a) rolling or sliding, (b) saltation and (c) suspension (Ideozu, 2014). River sands are generally poorly sorted with predominance of the coarse-grained and pebble clast deposited by sliding or rolling. Medium grained clasts are deposited by saltation, whereas the fine-grained clast is usually trapped among the coarse-grained or are deposited with them as current slacked (Power, 1982). In this study, 97.5% of the samples are within the medium to very coarse grained and pebbly sand while 2.5% of the samples are within the very fine to fine grained fraction. The results of the grain size analysis indicate that the coarse tail fractions make up 70% of the sediments. Several bivariate plots were plotted for the various statistical parameters deduced from grain size analysis data such as median diameter-, mean grain size-, Skewnes-, and first percentile vs standard deviation (Figures 12.0 -15.0).

Table.2 Summary of Calculated Statistical Parameters for Benin Formation at Mbiabong Ikom

Location	Thickness (m)	MD	MZ	Sorting	Kurtosis	Skewness
L1S1	3.7	0.5	0.57	0.77	1.28	-0.04
L1S2	0.4	-3.2	-1.63	2.34	0.95	0.59
L1S3	1.8	-3.3	-2.03	2.07	0.78	0.57
L1S4	0.3	-0.9	-0.50	1.27	1.01	0.10
L1S5	2.4	-2.1	-1.38	2.41	0.60	0.23
Mean		-1.8	-0.99	1.77	0.92	0.30

Table 3 Summary of calculated Statistical Parameters for Ajali Formation at Mbiabong Ito.

Location	Depth(m)	MD	MZ	Sorting	Kurtosis	Skewness
L10S1	0.34	2.50	2.23	0.90	1.23	-0.29
L10S2	2.74	1.20	1.17	0.91	1.19	-0.06
L10S3	15.40	1.50	1.37	2.07	1.39	-0.22
L10S5	0.91	0.10	0.73	1.27	1.26	0.67
MEAN		1.33	1.38	1.29	1.27	0.03

The first percentile versus the standard deviation demonstrates that in the in the first percentile, the range of the size frequency distribution in river sands generally have coarser fractions than beach sands, hence the tailing of the curve. The results show that the environment of deposition of the pebbly sand/pebble conglomerate is fluvial. This is demonstrated by the high volume of clast in the range of -3.5 to -5.4 phi (Ideozu, 2014). The skewness changes in the depositional energy levels of the depositing medium may be attributable to the waxing and waning current velocity and the sorting which typifies fluvial sands (Armaral and Pryor, 1977). According to Friedman (1961), river sands are generally positively skewed and the negatively skewed samples may have been inherited from beach sands. This corresponds to the scenario in the study area especially within the Benin and the Ajali Formations. The high competence of the depositing medium may have eroded the Imo Shale and the Ameki Formation around the Odoro Ikpe – Ndot Ikpe – Mbiabong Ikon II axes (consisting mainly of medium to coarse grained pebbly sands/sandstone) and the top portion of the Ajali Formation which has an erosional surface in the study area, consisting of the pebble grits of Reyment (1965). The Ajali Formation around Utughugwu has an erosional surface lined with pebbles suggesting a fining upward motif – a channel or meandering stream deposits. Comparing the various plots (Figures. 12.0 – 15.0) with similar work done by Friedman (1967), Moiola and Wieser (1968) as well as Jones (1970) majority of the samples plot in the fluvial field suggesting that, the depositional environment is fluvial for both formations in the study area. The results of the

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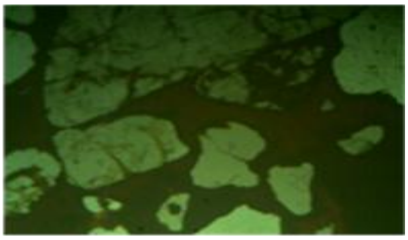
petrographic analysis of the Ajali and the Benin Formations show that based on Pettijohn's (1975) scheme they are classified as quartz arenites this conclusion is in agreement with the results reached on Ajali Formation in the Anambra Basin by Ekwueme (2003) Tijani et al (2010) and Ibe and Akaolisa (2010). The results of the petrographic analyses show that quartz is the dominant mineral in all the samples, followed by rock fragments and feldspars in both the Ajali and Benin Formations. The sands/sandstones are classified as quartz arenites based on Petition's (1975) classification scheme. The near absence of feldspars and the abundance of iron minerals in all the samples may indicate intense weathering as a result of the effects of the humid climate that may have persisted from the Maastrichtian times to Recent (Kogbe, 1979). The mineralogical composition of the iron minerals are dominate by geothites and hematites which make up the iron contents of the ferruginised sandstone around Arochukwu and Odoro Ikpe areas (Oti, 2007). The quartz grains from petrographic studies have been cemented by these iron minerals and silica and the original quartz grains have been etched, corroded and partly to totally replaced by goethite and hematite hence the quartz grains often appear to be angular or sub – rounded as seen in Plate 9.0, Figures 12.0 – 15.0 and Tables 5.0 – 6.0. The mechanism for this replacement is attributed to diagenetic corrosion (Oti, 2007). The occurrence iron minerals within the Benin and Ajali Formations (mainly geothites and hematites) is widespread within the study area and is interpreted as having been formed by the decomposition of clays and shale (Oti, 2007). According to Kogbe (1979), this offers a possible mechanism for the mode of formation (increase in temperature and percolating fluids) of the iron minerals in both formations. The abundant iron minerals in the samples suggests that they are post depositional, a weathering product that may be primary in origin resulting from the mobilization of ferric iron by infiltrating fluids and subsequent conversion to ferrous iron at the appropriate temperature, pH and pressure because iron minerals formed in a oxidizing environment (Mason and More, 1982). The similarity in the paleoenvironmental and sedimentological characteristics of both Ajali and Benin Formations suggests that they have the same source area (Oti, 2007; Ideozu, 2014; Ideozu and Ikoro, 2015). The Benin Formation may have been reworked Ajali Formation.

Table 4: Summary of samples of the Ajali Formation petrographically analysed in the study area

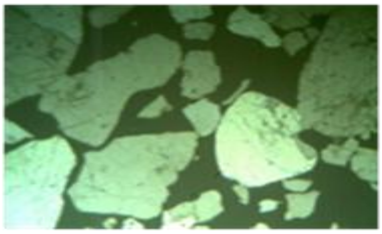
Location	Sample No.	Quartz %	Feldspar%	Lithic fragments %	Diagenetic minerals and cement	Formation
Ugwuakuma	1	90.0	5.0	5.0	Hematite /Silica	Ajali
	2a	80.0	5.0	15.0	Hematite /Silica	
	2b	75.0	5.0	20.0	Hematite /Silica	
	3a	75.0	0.0	25.0	Hematite /Silica	
	3b	90.0	5.0	5.0	Hematite /Silica	
	4	75.0	0.0	25.0	Hematite /Silica	
Average Composition of Ajali Formation in the study area		78.3	2.50	20.2	Total 100%	

Table 6.0 Summary of sandstone samples of Benin Formation petrographically analysed in the study area.

Location	Sample No.	Quartz %	Feldspar%	Lithic Fragments %	Diagenetic Minerals and cement	Formation
Mbiabong Ikon	L11S1	95.0	0.0	5.0	Hematite	Benin Formation
	L12S1	95.0	0.0	5.0	Hematite	
	L12S2	80.0	0.0	20.0	Hematite	
	L13S1	85.0	0.0	15.0	Hematite	
	L13S2	90.0	0.0	10.0	Hematite	
Ndot Ikpe	L3S5	75.0	5.0	20.0	Hematite /Silica	
Odoro Ikpe	L2S4	75.0	0.0	25.0	Hematite /Silica	
Average composition of Benin Formation in the study area		85.6	0.71	14.3	Total 100%	

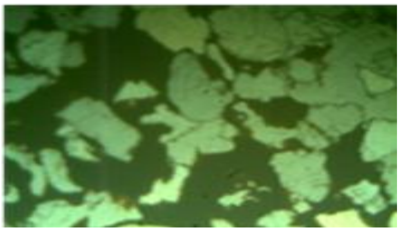


A

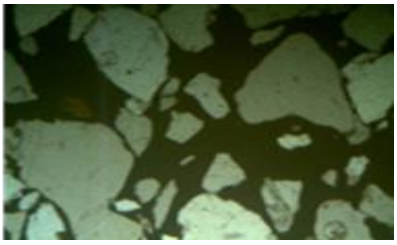


B

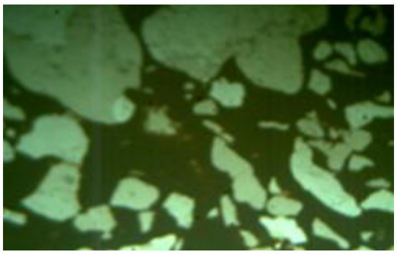
C



D



E



F

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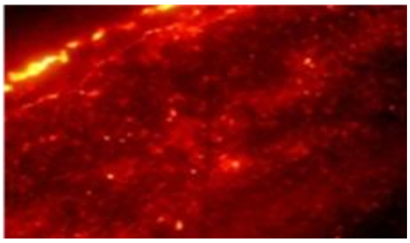
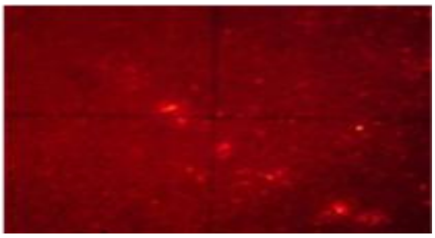

G


H

A-F Principal minerals are quartz and iron oxide minerals, some of the quartz grains have been etched and partial replacement by iron oxide minerals such as geothite and hematite as a result of diagenetic corrosion (Oti, 2007). The quartz grains are angular to sub – angular and mainly monocrystalline quartz. Some the quartz grains exhibit wavvy extinction characteristic of stressed quartz grains of metamorphic origin. G-H Principal mineral is iron oxide mineral, the quartz grains have been totally replaced by iron oxide minerals such as geothite and hematite as a result of diagenetic corrosion (Oti, 2007). Ironstone.

Plate 9.0 Photomicrographs of some sandstone samples in the study area (A – F iron oxide cemented sandstone, G-H ironstone).

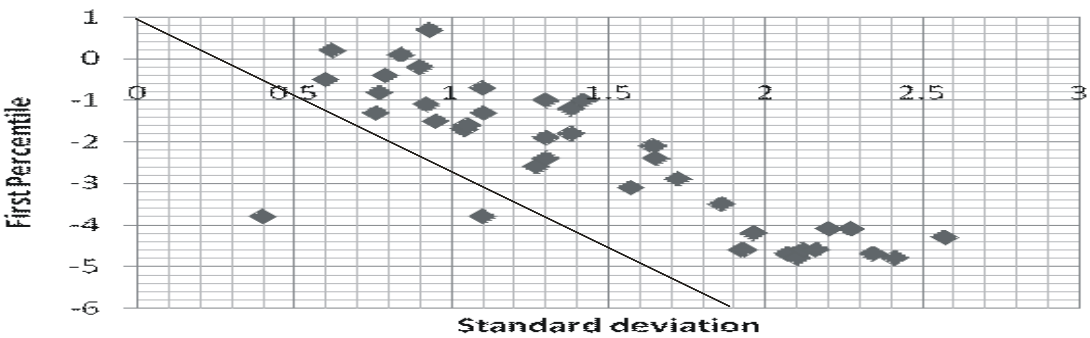


Figure 12.0 Scatter Plot of First Percentile VS Standard Deviation (sorting). The points on the right represent fluvial while the points on the left of the line represent beach fields

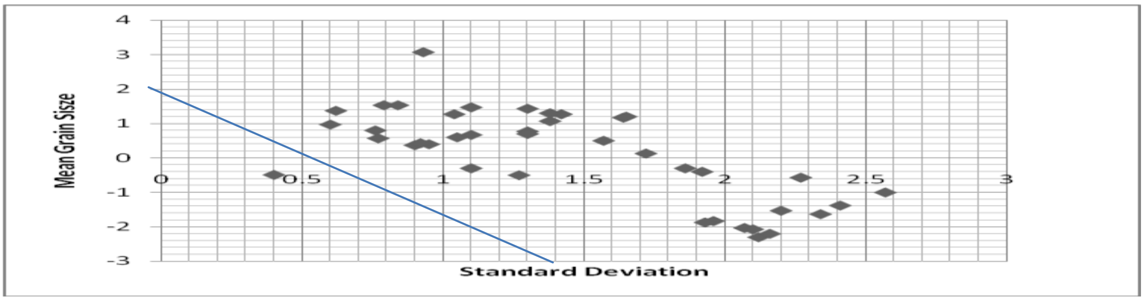


Figure. 13.0 Scatter Plot of Mean Grain Size VS Standard Deviation. The points on the right represent fluvial while the points on the left of the line represent beach fields

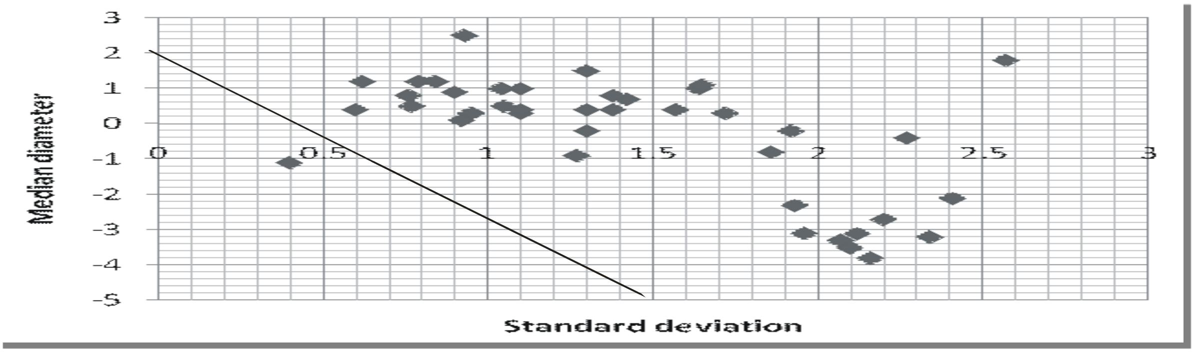


Figure 14.0 Scatter Plot of Median Diameter VS Standard Deviation. The points on the right represent fluvial while the points on the left of the line represent beach fields

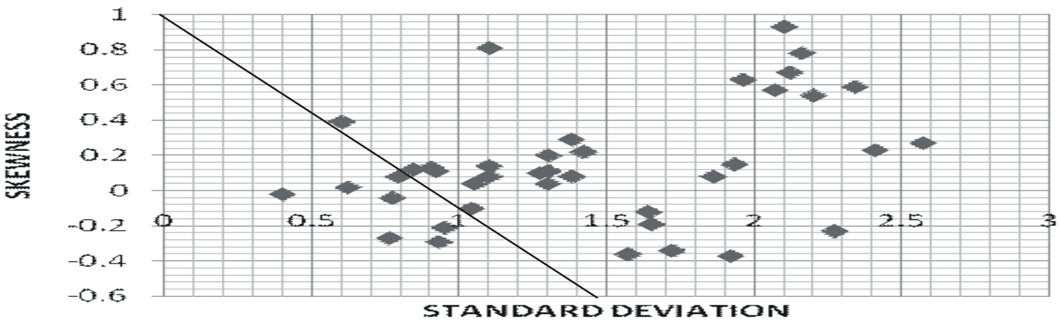


Figure 15.0 Scatter Plot of Skewness VS Standard Deviation. The points on the right represent fluvial while the points on the left of the line represent beach fields

A synthesis of the results of this research based on data generated from field work and laboratory analyses, points to a fluvial origin for the sand/sandstone and pebbly sand/sandstone for both Benin and Ajali Formations. The pebbly sandstone beds are poorly sorted and matrix supported, and the sandstone beds moderately to well sorted angular to rounded (indicating that they are texturally immature to mature), the absence of feldspars is indicative of intense weathering and mineralogical maturity. The major cements in these samples are iron oxide minerals suggesting an oxidizing environment. The sandstones (of both Benin and Ajali Formations) are classified as quartz arenites. The similarity in the paleoenvironmental and sedimentological characteristics of both Ajali and Benin Formations suggests that they may have the same source area -the Oban Massif and Obudu Plateau or the Benin Formation may have been a reworked Ajali Formation. The depositional environments of both formations are interpreted as fluvial – stream deposits except that some portions of the Ajali Formation have marine character – tidal which is in agreement with earlier works.

This work is an extract of Sedimentology of Post - Santonian Sediments in Parts of Afikpo Basin Southeastern Nigeria (Unpublished PhD Dissertation). University

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of Port Harcourt, Nigeria by DR. Richmond U. Ideozu.

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