European Journal of Applied Sciences – Vol. 12, No. 06
Publication Date: December 25, 2024
DOI:10.14738/aivp.1206.17767.
Nwoye, J. T., Ikegbunam, I. C., & Nwoye, E. C. (2024). Reservoir Characterization of The Nsukka Formation in Anambra Basin Using Surface Outcrops. European Journal of Applied Sciences, Vol - 12(06). 554-608.

Reservoir Characterization of The Nsukka Formation in Anambra Basin Using Surface Outcrops

John T. Nwoye
Akanu-Ibiam Fedral Polytechnic Unwana, Ebonyi State, Nigeria

Ifunanya C. Ikegbunam
Akanu-Ibiam Fedral Polytechnic Unwana, Ebonyi State, Nigeria

Emmanuel C. Nwoye
Akanu-Ibiam Fedral Polytechnic Unwana, Ebonyi State, Nigeria

ABSTRACT

The results of grain size analysis, using bivariate and multivariate method of describing environment of deposition showed that Nsukka Formation was deposited by tidal processes. The field mapping of the areas and the bivariate plots of the Mean against Sorting, Skewness against Sorting and discrimination functions of the grains revealed that sediments of the delineated stratigraphic units were deposited in Beach/shallow agitated marine environment. This was based on their sedimentological characteristic. The grain size histograms are dominantly unimodal but few samples indicates bimodal distribution pattern. The Unimodality of these grains may be because the sediments were deposited in one phase and have not undergone much reworking or re-deposition. Petrographic studies of the representative sandstone units show that they are litharenite that exhibit the relic bedding features. The sandstones are classified as poorly - well sorted, angular – sub rounded, submature and mature grain-sized.Porosity and permeability assessment of the grain size indicated the average porosity and permeability value of 49-31 and 34.15-3.68 millidarcy respectively. This showed that the sandstones of Nsukka Formation has a high porousity and permeableabilty ratio. However, the sandstones of Nsukka Formation can serve as a good reservoir due to its excellent permeability, while the shale part of the Formation can also serve as a seal/cap to the reservoir due to its poor permeability.

INTRODUCTION

The Anambra Basin is a continuum of the Benue Trough. It is roughly triangular in shape and covers an area of about 40,000 Square kilometres with sediment thickness increasing southwards from 6000m to a maximum thickness of 12000m in the central part of the Niger delta. The southern boundary coincides with the Northern boundary of the Niger delta of which the Anambra basin is its main precursor. The sediment thickness of the Anambra basin consists of Cretaceous and Tertiary deltaic and shelf facies. (Whiteman, 1982; Reijers, 1996; Akaegbobi and Adeleye, 2001).

According to Reijers (1996), the Anambra Basin is a deltaic complex with lithostratigraphic units resembling that of the Niger Delta. The proximal parts of the Niger Delta lithostratigraphic units partially grade into the lithofacies of the Anambra Basin. Recently, increased interest in the economic importance of the Anambra basin which shares boundary with the Northern part of prolific Niger Delta has resulted in considerable research and improvement of our understanding of the fill basin patterns.

Nsukka Formation is one of the lithologic units which crop in the Anambra Basin, formally referred to as "upper coal measure"(Simpson,1954).The Nsukka Formation consist of Shales, Sandstones and Siltstones with thin coal seams at various horizons (Kogbe1976; Ladipo K. O., (1986), Ladipo K. O., Nwajide C.S., and Reijers,T.J.A.1997). It may have the ability to act as both reservoir and source rocks. It has been considered as the regional seal/cap rock over the Mamu and Ajali formation (Obaje et al 2004).

Reservoir characterisation will be undertaken to determine its capability to store and transmit fluid; using the following properties/parameters such as porosity (Θ), permeability (k), fluid saturation, and net pay thickness.

Reservoir characterization (RC) is a process for quantitatively assigning reservoir and fluid properties while recognizing geologic uncertainties in spatial variability (Mohaghegh et al. 1996). The most direct field data used in reservoir characterization is from core analysis, where rock core samples taken from a reservoir are analyzed in a laboratory. Core analysis data are accurate and are, thus, widely used as benchmark or validation data in reservoir characterization.

The improvement of reservoir characterisation techniques is one of the most important existing and emerging challenges to geoscientists. Logging tools response and core data are often used to draw inferences about the lithology of depositional environments alongside their fluid contents. These inferences are based on empirical models utilizing correlations among tools response, rock and fluid properties.

Aim and Objectives of the Study

The major prompting to undertake this research work is born out of the desire to contribute to this least studied basin through an extensive field work focused on the sedimentology, petrographic analyses and to evaluate the petrophysical properties of Nsukka Formation using outcrops, visible in some parts of Anambra Basin, with the view to updating the existing information on the Basin; compared to Niger Delta, which has been extensively studied. Other objectives are stated below:

Objectives

- To do a detailed field mapping identifying and sampling the outcrops of Nsukka formation in Anambra basin
- To infer the environment of deposition using detailed geologic and petrographic descriptions of the rock.
- To estimate the porosity and permeability of the rocks using Krumbien and Monk (1942) empirical equations
- Investigate the effect of diagenesis and clay minerals on the reservoir quality of Nsukka Formation.
- To use analysed results in updating information on the Nsukka formation.

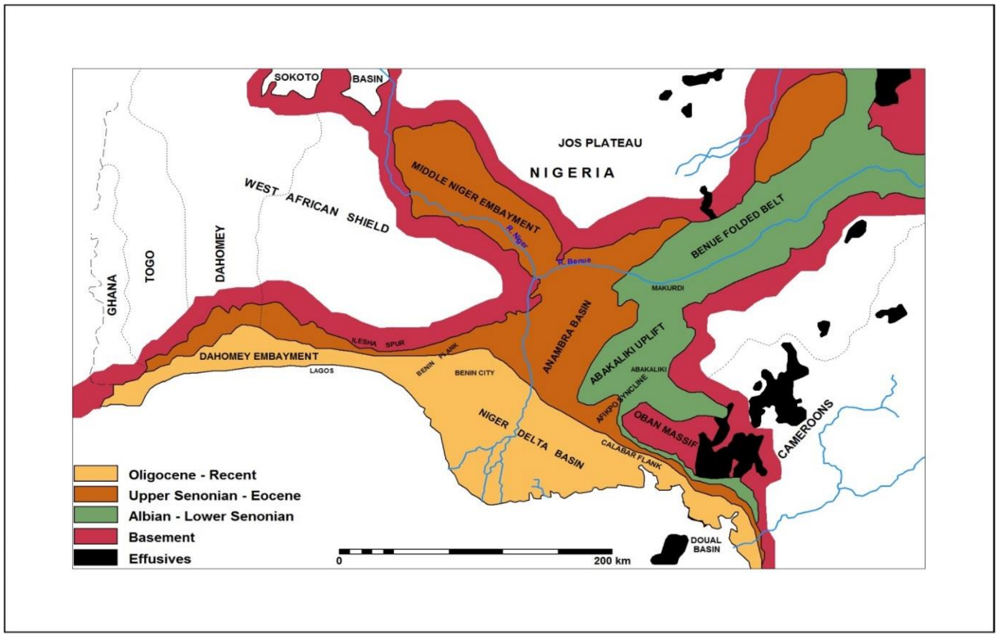


Fig 1: Geology Map of Eastern Nigeria

Scope of Study

The ambit of this independent unit study is limited to the inference of the outcrop properties, depositional environment(s). Microsoft excel will be used in the documentation of average net/gross, porosity and water saturation. For optimum result, Linear interpolation will be used to calculate the statistical parameters by the Folk and Ward (1957) graphical method and derive physical descriptions (such as "very coarse sand" and moderately sorted). The program will also provide a physical description of the textural group which the samples belongs to and the sediments name (such as "fine gravelly coarse sand") after Folk (1954)., Folk etal (1970).

- To identify and collect field samples at five locations over a defined area.
- To identify the visual characteristics of the rock grains.
- To carry out grain size and thin section analysis of the samples to determine their petrophysical characteristics
- To use cumulative curve graphs in calculating the statistical parameters (Folk and Ward, 1957).
- To use the results to determine if the outcrop can serve as a seal or a reservoir.

Location of the Study Area

The Anambra Basin is known to be faulted in many places but coming across outcrop size examples for the purpose of teaching is rare. Some areas where Nsukka Formation outcropped will be taking note of example the Nsukka Formation crop out at Ihube, located 76km, off the Enugu - Port-Harcourt expressway at Ihube (approaching Okigwe). The light grey colour observed at the formation suggests sediments deposited under an oxidizing marine environment. Location.2. The Nsukka Formation at Umulolo along Arondizuogu-Umulolo junction.3. The Nsukka Formation crop out at Onyekaba pit, near Okigwe junction in Imo state.4.The Nsukka Formation crop out at Umuasua village, Isikwuato Local Government Area in Abia state.5.The Nsukka Formation crop out at Ugwu Nkaluagu- Obukpa, at Nsukka, Enugu State.

Geological and Stratigraphic Setting of the Anambra Basin

This entails the geological overview, the structural province, stratigraphic framework tectonics and structural settings, lithology, hydrocarbon and reservoir rocks of the basin.

According to Murat (1972) the Anambra Basin evolved during the second tectonic phase in the evolution of Benue Trough and was filled during the Campanian to Maastrichtian Transgressive-Regressive episodes. The Campanian began with a short marine transgression in which was followed by regression in the mid Nupe Basin. An Eperc sea connected the Gulf of Guinea with the Mediterranean, and the arm of the sea passed into the Benue Trough. The Anambra Basin lies within the perccines of the middle Benue Trough, Nupe Basin, Abakaliki-Okigwe Anticlinorium and Niger Delta. The Basin reflects the features of the breaking of the Gondwanaland Supracontinent (Whiteman 1982, Reijers 1996; Akaegbobi and Schmitt, 1998; Akaegbobi and Adeleye, 2001).

During the Abian-Santonian, the Anambra proto-Basin was a platform covered by thin veil older sediments. The Santonian Orogeny during the Cretaceous uplifted the Abakaliki-Benue Trough and its environs resulting in the folding and westward translation that lead to tectonic inversion and deposition of a thin veil of sediment in the Anambra Basin and others (Reyment, 1965; Whiteman 1982). Deposition shifted westward from the Abakaliki-Benue Rift valley into the Anambra Basin with the formation of Enugu and Nkporo shales, the coal measures of the Mamu Formations and the fluvial deltaic Ajali Sandstone. The post Maastrichtian folding movement affected all the sediments in different parts of the Anambra Basin, along the ENE-WSW axes. This folding was more intense during the Santonian with the result that sediments were folded twice (Murat, 1972; Whiteman, 1982; Akaegbobi and Schmitt, 1998; Akaegbobi and Adeleye, 2001; Kogbe, 1989).

Recycle sediments input in the Anambra Basin were mainly sourced from the Abakaliki-Benue fold belt and partly from the highly weathered surrounding crystalline complexes of Oban Massif, Cameroun Basement granites and Ibadan craton (Reyment, 1965, Murat, 1972; Whiteman 1982). The sedimentary suite in this Basin reflects one mega facies region that received sediment load in two depositional cycles ranging from Campanian to recent (Whiteman 1982). Throughout the Post Santonian to Paleocene, the Anambra Basin was a depositional site of several pro delta cycles, until it was terminated by a major marine transgression culminating in the formation of Imo shale followed by a regressive deposition of the Ameki Formation (Whiteman, 1982; Kogbe, 1989; Ekweozor and Daukoru, 1994).

It was believed that sedimentation in Southern Nigeria was controlled by three major tectonic phases resulting in a complicated depositional history (Short and Stauble, 1967; Murat, 1972; Whiteman, 1982).

The first phase during Albian time, was characterized by movement along major NE-SW trending fault resulting in the formation of the rift- Abakaliki Benue Trough. To the North West, the limit of the Basin was Benue Trough hinge line (fault zone). Between this hinge and Abakaliki Trough, deposits were laid down on the Anambra platform.

The Second phase (Upper Santonian-Lower Campanian is characterized by compressional movement along the established North-East-South West trend result in the folding and uplifting of the Abakaliki Benue folding belt contemporaneously with the Abakaliki uplift, the Anambra platform subsided and the axis of the basin was displaced to a position South- West of the Benue folded belt and North West of the Abakaliki uplift, into a major depocenter of clastic infill.

The third phase (Eocene) resulted in the formation of large deltaic complex in the down dip of the basin (Short and Stauble, 1967; Murat 1970). The tectonic events suggest that the sediments in Anambra Basin were probably derived from Abakaliki-Benue fold belt and its adjacent areas. According to Burke et al (1971) the Santonian episode resulted in the erosion of more 2000m of ditritus from the folded beds and many become the major source of lithic infill of the Anambra Basin (Whiteman, 1982).

General Stratigraphy of Anambra Basin

According to Akaegbobi and Schmitt (1998) the geology and stratigraphy of the Anambra Basin has relatively been well established enormous volume of published and unpublished materials stashed in libraries of the oil industries and Universities. A summary of the basal lithostratigraphic units is present in fig. The Nkporo Shales, Enugu Shales and the Mamu Formation contributes the basal lithostratigraphic units in the Anambra Basin overlying the undifferentiated basement complex (Mebradu, 1990; Mode 1991; Agumanu, 1993; Akaegbobi and Adeleye 2001).

The Enugu Shale is lateral equivalent of the Nkporo shale while the Owelli Sandstone is the basal member of the Enugu shale, both of which outcrop towards the central parts of the Anambra Basin. These inner basin sediments are all shallow marine in the origin with frequent sharp facies changes (Reyment, 1965; Kogbe, 1972, 1976; Whiteman, 1982; Ladipo etal, 1992; Reijer, 1996).

Nkporo Shale

The Nkporo shale is the basal sedimentary unit that was deposited following the Santonian folding and the inversion in South-Eastern Nigeria. Although it is generally poorly exposed across the area, but has been described as a coarsening upward deltaic sequence of shales and inter-bedded sands and shales with occasional thin beds of limestone (Reyment, 1965; Kogbe, 1976; Whiteman, 1982; Ladipo, 1992).

The marine origin of the Nkporo Formation is also suggested by the occurrence of the Ammonite Libycoceras Afipkoensis together with Inoceramus, Crabs, Fish teeth, Broyozoans and Echinoid (Reyment 1965). The correlation subsurface section consists of dark grey, hard pyritic, silty and sand shale with occasional bands of fine and coarse sandstone and Limestone (Kogbe, 1976; Reyment, 1965; Whiteman, 1982; Ladipo et al 1992, Agaguet al 1985).

A Maastrichtianage was assigned to Nkporo Formation by Simpson (1954) based on molluscs and fish remains. Reyment, (1965) also described the Maastrichtian zone of Libycoceral Afikpoensis in the Nkporo Formation, while Murat (1972) used an upper Senonian age. (Mode 1991) suggested that Nkporo shale is assigned Maastrichtian based on the index fossil Foraminifera Afrobolivina afra and associated Ostracods.

Enugu Shale

The Enugu shales are restricted to the central and northern part of the Anambra Basin. Lithologically it consists mainly of Carbonaceous grey to black shales and coals with interbedded very fine-grained sandstone/silts deposited in a flood plain environments with poorly defined bedding (Kogbe 1972, 1976; Ladipo etal, 1992; Whiteman, 1982; Reijer 1996). It has yielded poorly preserved molluscs and plant remains. Diagnostic species of Pollens and Spores have been foundsuch as Cingulatisparites Ornatus, Tienebaensis Genmatriporite Ogwuashiensis, Lungaperi banee denburgi, tetradite SP, Tricolpite Synstriatus, dinoflagellate leaf cuticles and algal spores (Mode 1991). Libycocera angelense was also found in the lower parts of Enugu shales (Shell Bp data) indicating a Maastrichtian age (Reyment 1965; Whiteman, 1985; Mebradu 1990). According to Mode (1991), the miospore content of the Enugu shales is suggestive of an Upper Cretaceous age (Maastrichtian). In addition, it is believed to have been deposited during the transgressive phase in the Anambra Basin. Depositional environments suggest lower delta plain facies, with thick coal seams occurring commonly in the upper part of the succession which are mined at Orukpa and Onyema solid minerals.

Owelli Sandstone

The Owelli Sandstone is regarded as a facies of Enugu Shale (Whiteman, 1982; Ladipo etal 1992). It is soft, whitish and pyritic with fragment of fossil wood, thin bands of vitrinite and impure coals (Lawson, 1988; Agumagu; 1993). Several Maastrichtian agglutinated Foraminiferas have been reported by Petters (1979) as occurring in the Owelli Sandstone. The Owelli Sandstone, forms an elongate shore string sand body elongated to the north east defining a meander belt of distributary channel system (Ladipo et al, 1992; Reijers, 1996; Agumanu, 1993). It strikes northeast-southwest with gentle to moderate dips not exceeding 25®.It is massive, thick, crossed bedded, medium to coarse grained, whitish to brown, iron stone in some places dirty white and interbedded with shales, and laminated clays (Agumanu, 1993). It may attain 450mto 600 thickness south of Udi and interfere conformable between the Enugu shale and Awgu shale (Reyment, 1965; Whiteman 1982). A few Gastropod and Pelecypod shells have been recorded suggesting a marine incursion into the channel systems (Reyment, 1965; Whiteman, 1982; Lawson, 1988; Ladipo et al; Agumanu, 1993). The Enugu shales and the Owelli Sandstone are believed to have been deposited in a shallow marine that were alternatively storm and tide dominated (Ladipo et al, 1992; Reijers 1996).

Mamu Formation

The Mamu Formation succeeds the Enugu shales without a break in sedimentation and contain distinctive assemblage of Sandstone, shales, mudstone, and sandy shale with coal seams in several horizons (Reyment, 1965). Murat (1972), Petters and Ekweozor (1982) described Mamu Formation as a regressive deltaic off-lap sequence of sandstone, mudstone, shales and sandy shales with inter-bedded coal seams. It is about 400m thick and can be termed as representing a phase of deltaic lagoon environment. Mamu Formation is parallic in nature. Its thickness varies across the basin ranging from 75m to 1000m (Reyment, 1965; Ladipo et al 1992). The age ranges from lower to middle Maastrichtian (Ladipo et al 1992). Reyment (1965) restrict its age to Campanian - Maastrichtian based on the occurrence of Haplophragmoides pindigensis. A very good exposure of Mamu Formation can be seen along the Enugu-Onitsha road at the Millikeen Hill and around out skirt of Enugu (Kogbe, 1976).

Ajali Sandstone

Ajali sandstone has been variously referred to as the sandstone series, with false bedded sandstone and eagle rock sandstone (Reyment, 1965, Amajor 1986). The Ajali sandstone lies unconformably on the Mamu Formation. It consists of thick, friable, poorly sorted sandstone, cross- bedded and sometimes ironstone (Kogbe, 1976; Ladipo et al, 1992). Kogbe, 1976 suggested Ajali Sandstone to be fluvial and deltaic deposition of environment based on the lithology, the paleocurrent direction and the absence of marine fossils. Its depositional setting or environment is shallow marine or sand waves. The sedimentary and biogenic structures of Ajali sandstones are trough Cross stratifications, herring bone, cross bedding, tidal bundles and reactivation surfaces, black flow ripple structures, Ophiomorpha, Skolithos, escape burrows Ladipo et al (1992,2001).

Nsukka Formation

The Nsukka Formation succeeds the Ajali sandstone. It lies conformably on the Ajali Sandstone but is discontinuous across the basin possibly due to erosion. Nsukka Formation occur mostly on the gentle western slope of the transition from Udi plateaus to the Niger-Anambra low land. It consists of an alternating sequence of inter bedding shales, silt stones, and sand with thin coal seams at various horizon (Kogbe,1976; Ladipo 1992). The depositional environment of the Nsukka Formation is similar to that of Mamu Formation which is strain plain marsh origin with occasional fluvial incursion. In addition, beds of limestones occur towards the top of Nsukka Formation and contain Oyster shells and Vemllandatta which suggests an upper Cretaceous age (Kogbe,1976). The presence of Sphenoidiscus Studeri Reyment as well as casts of Pelecypods and Gastropods gives the age as Maastrichtian (Reyment, 1965; Kogbe, 1976). Good exposure of the Nsukka Formations is rare except around some of the west of Nsukka. The Nsukka Formation as delineated here is stratigraphically synonymous to the upper coal measure (Tattan, 1944; Simpson, 1948, 1954; Murat 1972). Marine influence is however higher in the Nsukka Formation into the overlying marine Imo Formation. This is obvious in the down dip subsurface section where the Nsukka Formation consists dominantly dark grey, silty, sand, pyrite, glauconitic and Calcarous shales with coaly plant remains.

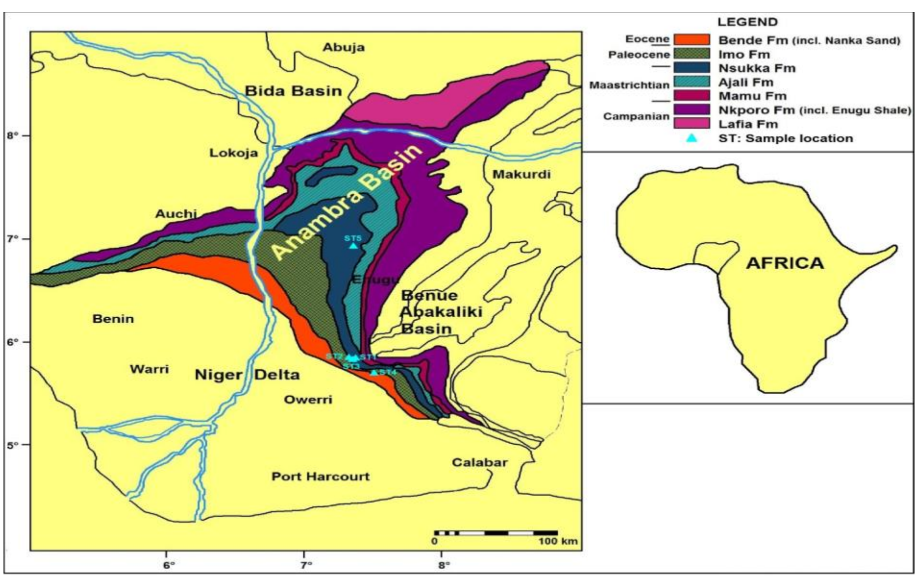


Fig 2: Geologic Map of Anambra Basin (ResearchGate 20)

Table 1: Lithostratigraphic units in the Study Area modified after Oboh-Ikuenobe *et al.* (2005)

Period	Epoch	Afikpo Basin	Study Area
Tertiary	Pliocene-Recent	Benin Formation	Benin Formation
	Miocene-Mid Eocene	Ogwashi-Asaba Formation	
	Mid-Upper Eocene	Ameki/Bende Sandstone	
	Paleocene	Imo Shale Nsukka Formation	Nsukka Formation
Cretaceous	Maastrichtian	Ajali Formation	Ajali Formation Mamu Formation
		Mamu Formation	Nkporo Shale
		Nkporo Shale/Afikpo Sandstone	
	Campanian	Enugu/Owelli Formation Agwu Formation	
	Santonian Coniacian		
	Turonian Cenomanian	Agbani Sandstone Eze-Aku Formation Odukpani Formation	
	Albani	Asu River Group	

Table 2: Correlation of Early Cretaceous-Tertiary Strata in Southern Nigeria (Modified After 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 Shale Nsukka Formation	Imo Shale Nsukka Formation	Nsukka Formation
Maastrichtian	Ajali Formation Mamu Formation	Ajali Formation Mamu Formation	Ajali Formation Mamu Formation
Capanian	Npkoro/Owelli Formation Enugu Shale	Nkporo Shale / Afikpo Sandstone	Nkporo Shale
Santonian			
Coniacian	Agbani Sandstone Agwu Shale	Non-Deposition (Erosion)	
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		

MATERIALS AND METHODS

The methodology applied for this research are standard method as applied in the field mapping, sedimentology, and sedimentary petrology. The research study involved detailed field work, particle size distribution, petrography of sandstone, heavy mineral studies and based on samples and data collected during the field mapping. The studies of the ancient depositional environments commonly begin with the field work and sample collection. (Walderhaug Olav 2000). Stratigraphic cross- sections are fundamental tools for portraying reservoir traps, Seal and Source rock relationship (Andeniran, 1985 and 1995). The descriptions of vertical sections through sedimentary rocks are traditionally used in determining environment of deposition (Miall, 1984 & 1992) and these environment of deposition and these depositional patterns may reflect vertical stacking, retrogradation and or progradation, or Overlapping stratigraphic responses which are completely related to rate of changes in sediment supply and dispersive forces (Visher,1999).

Data and Sample Collection

Spot sampling method was adopted for data collection during the field mapping for this research,(Davies,1973).Attention was given to accurate and detailed lithologic description and recording of parameters such as sedimentary structures, rock type and composition, biogenic structures, measurements of bed thicknesses, lateral extent of the outcrops in addition to pebble shapeation from measurement of strike and dip and geographic position system (GPS).Detailed of lithologic description were done for the outcrops where samples, were collected at various depths. All sample were properly labelled to avoid mix-up using codes (for example, L1S1 means location one sample one). Lithologic samples collected included very fine to coarse-grained sand/sandstone and shales.

Field Mapping

Detailed field mapping was undertaken to map the study area. The approach used was to document and describe the outcrops in detail to avoid are turn or repeat of the field mapping exercise in addition to methods modified from Miall (1984), Tucker (1988) and Reijers (1996), Friedman (1961,1967, &1979) Friedman etal (1992). Equipment used during the field mapping exercise include compass/clinometer, GPS. Measuring tapes, strong sample bags and sacks properly labelled, cellotapes, field notebook, camera, protective clothing and strong boot in addition topographic map indicating the position of the study area. The outcrops identified were examined for bedding contacts, bed thickness variation, sedimentary and biogenic structure as well as syn and post- depositonal structures.

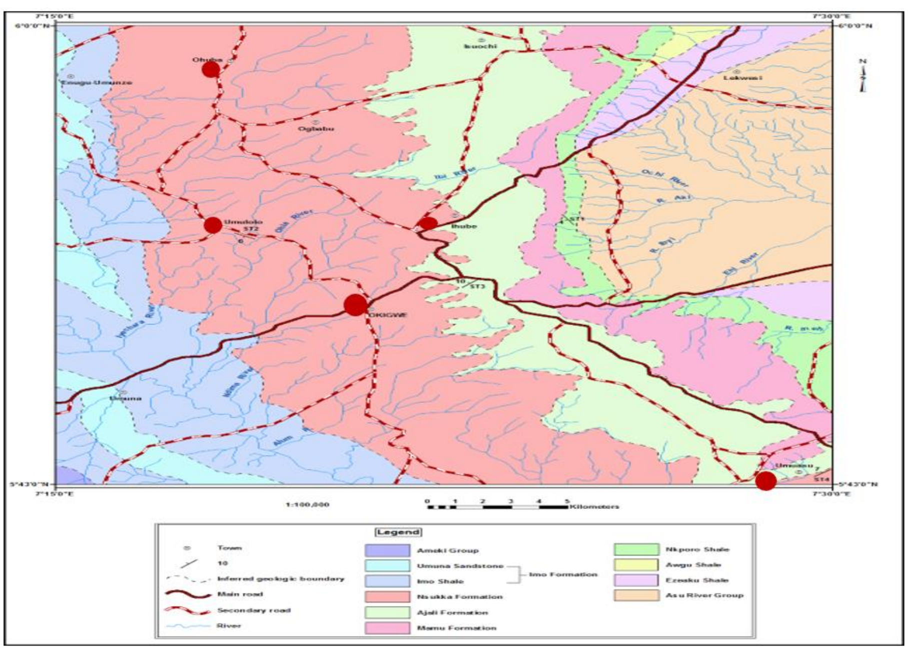


Fig.4: Geologic Field Map

The following procedures were adopted for each outcrop:

- Sketching of the outcrop including obvious structures.
- Systematic recording of physical and biological properties of each outcrop.
- Visually estimating the composition and rock type.
- Construction of stratigraphic sections taking into account areas that best describe the features observed.
- Taking note of textural features and details on fabric.
- Measurement of bed thickness including strike and dip.
- Collection of representative samples of lithologies already described.
- Preliminary field interpretation and establishing correlatable units.
- Photographing of the outcrop and areas of special interest.

Laboratory Method

Standard laboratory methods as applied in sedimentology and, petrology were adopted. Laboratory methods involved analyses for particle size distribution, petrography, and heavy mineral. Parameters used in these analyses were selected during the field mapping. The initial procedure in preparing the samples was systematic checking of the samples to ensure the identification numbers on labels were in place and legible to avoid mix-up of the samples in addition to removing undesirable materials (Tucker,1988) Friedman (1961,1967, &1979) Friedman et al (1992).

Grain Size Analysis

The general form of mechanical analysis was used to determine grain size (Buller and McManus, 1979; Tucker 1988). Sieving is the most common method for size determination of clasts for particles coarser than 0.063mm (Tucker, 1988 & 1991). According to Friedman (1979), Lewis and Maconchie (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, drying sieving method was adopted. The samples for analysis consist of sands, sandstone. The samples were first examined, to determine its condition by removing foreign materials such as roots, leave etc whenever present. In addition, each of the samples were then de-segregated into its component units by the use of 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 samples were friable, crushing was easy as the grains were neither broken nor shattered. The samples were then sorted to their various sizes using screen size most appropriate for the analysis. The minimum time used to sift the samples into 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 including smaller-than325mesh fraction. 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, 1991; Friedman et al, 1992; Pettijohn, 1956, 1975). Parameters computed are mean, median, standard deviation (sortin), skewness and kurtosis.

$$Media\ Md\ = P50$$

$$Mean\ Mz = \frac{\emptyset 5 + \emptyset 50 + \emptyset 84}{3}$$

$$Sorting\ Sd = \frac{\emptyset 84 - \emptyset 16}{4} + \frac{\emptyset 95 - \emptyset 5}{6.6}$$

$$Skewness\ Sk = \frac{\emptyset 16 + \emptyset 84 - 2\emptyset 50}{[2(\emptyset 84 - \emptyset 16)] + \frac{\emptyset 5 + \emptyset 95 - 2\emptyset 50}{[2(\emptyset 95 - \emptyset 5)]}}$$

$$Kurtosis\ k = \frac{\emptyset 95 - \emptyset 5}{[2.44(\emptyset 75 - \emptyset 25)]}$$

Petrographic Analysis (Thin Section)

Representative samples of friable sands and sandstones from the study areas were impregnated with epoxy resin and mounted on glass slides. 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 sand/sandstone. Each slide was labelled appropriately for petrography study. The prepared slides were studied under plane and crossed polarized lights in order to identify the constituent minerals in the sandstone and framework grains in it. Great care was taken in the procedure adopted because identification of the minerals and framework grains depend on the subtle characteristics interference colour (Milliken 2001, Curry etal, 1982). Photomicrograghs of the thin sections were taken.

PRESENTATION OF RESULTS AND INTERPRETATION

Field Work

The goal of every research based on fieldwork is the production of a geologic map containing field data gathered during reconnaissance and actual field work. The lithostratigraphic section produced at selected outcrop location are presented and discussed. The results of the field work are presented below.

Location 1(lhube Outcrop)

Location one is at the bye pass into Ihube Township, close to Umulolo junction about one and half kilometer from Okigwe junction along Enugu –Port Harcourt express way (Fig4.1). The average lateral extent of this outcrop 155m with average height of 23m all measurements obtained during field investigation. On the outcrop, the Nkporo shale, was exposed in this location. The general strike direction of the outcrop is 16NW/174SE.The outcrop has dip of 4 degrees and the bedding contacts between two measured stratigraphic sections are sharp to gradational with dip ranging from 6-8. degrees. The lithofacies unit of this outcrop are dark grey coloured shale, with wavy parallel laminae (0.1cm). The shale was fossiliferous, indurated and calcareous when tested with hydrochloric acid. Some evidence of trace fossils like Ophiomorpher, ironstone cretaceous were found within the shales in addition to biogenic structures produced by ichnofossils. From field relation and analysis, shows that the beds comprising the heterolithic thicken upwards while the shale beds thicken downwards. The thickness of each bed/unit was measured with reference to the ironstone bed, which formed a very conspicuous marker. At this location, as well as in others, the weathered bed (i.e Laterite claystone and Lateritic ironstone) are shale, siltstones and very fine-grained sandstone respectively. The lateritc unit are post depositional (Kogbe, 1979).

Fig. 5: Ihube Outcrop Section

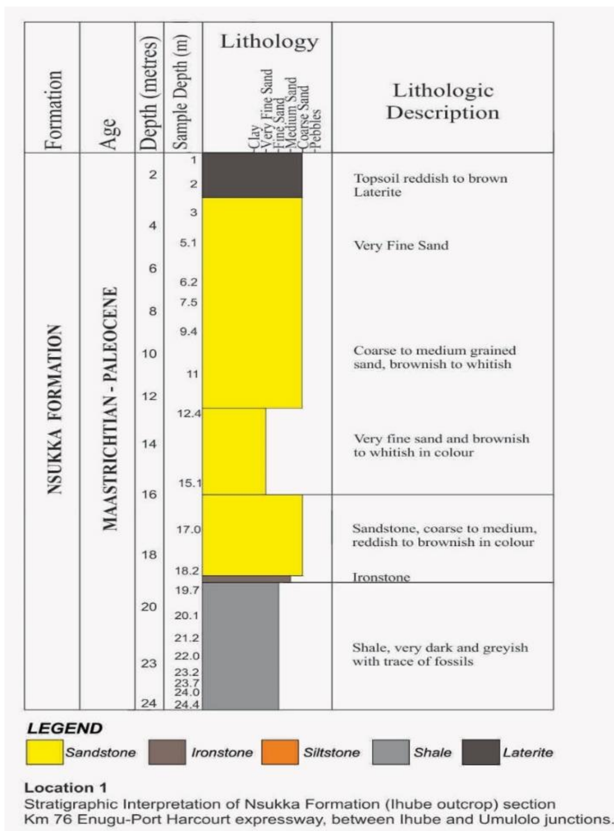


Fig 6: Stratigraphy of Ihube Outcrop

Lithologic Description

The lithologic description and photographs of Location 1 to 5 from field work are presented below.

Location 1 (lhube Outcrop)

- Strike: 16° -21°NW/174 SE Beds Dip2°-4° Elevation 229m, Long 07° 23.58.5'E, Lat 05°52'.087N

Thickness (m)	Lithologic Description
2.5m	Top soil, consists of sandy cla, laterite, reddish and brownish.
1.0m	Medium to coarse grained sand; clayey poorly.
2.1m	Medium to very fine sand, silty, very pooly sorted.
1.1m	Coarse to medium grained sand, brownish to whitish, matrix supported, poorly sorted, sub rounded to round. Ophiomorpher burrows are common.
1.3 m	Medium to coarse grained sandy, matrix supported- clay, whitish in colour.
1.6m	Coarse to medium sands. They are reddish to brownish, cross- bedded, and poorly sorted.
1.4m	Ironstone fragments and whitish sandstones.
5.4m	Clay, base of the outcrop, greyish to black.

Location 2 (Umulolo Outcrop)

The lithostratigraphic section of the outcrop of Nsukka formation located close to Umulolo police station along Umulolo - Arondizuogu Road. The outcrop is show in fig (4.2). The outcrop is well exposed and accessible. The general strike direction of the beds is 220NW/100SE.The outcrop extends about 27m with a thickness height of 32m.Two stratigraphic sections were measured, one on each side of the road. The two sections were correlated and a composite section of the two were presented in figure (2). The bed dip is 6 to 18 degrees. An indurated sandstone identified at location 1 was traced to location 2. They were correlated from field relations to be the same bed /unit. The lithofacies identified are bioturbated sandy heterolith interbedded with shale, shales, ironstone beds, siltstone and sandstone. The ironstone beds occurred at bedding planes separating the heterolithic facies and shale. The beds are moderately to intense bioturbated.

Fig. 7: Umulolo Outcrop Section Shale and Sandstone

Fig. 8: Umulolo Outcrop Section Shale

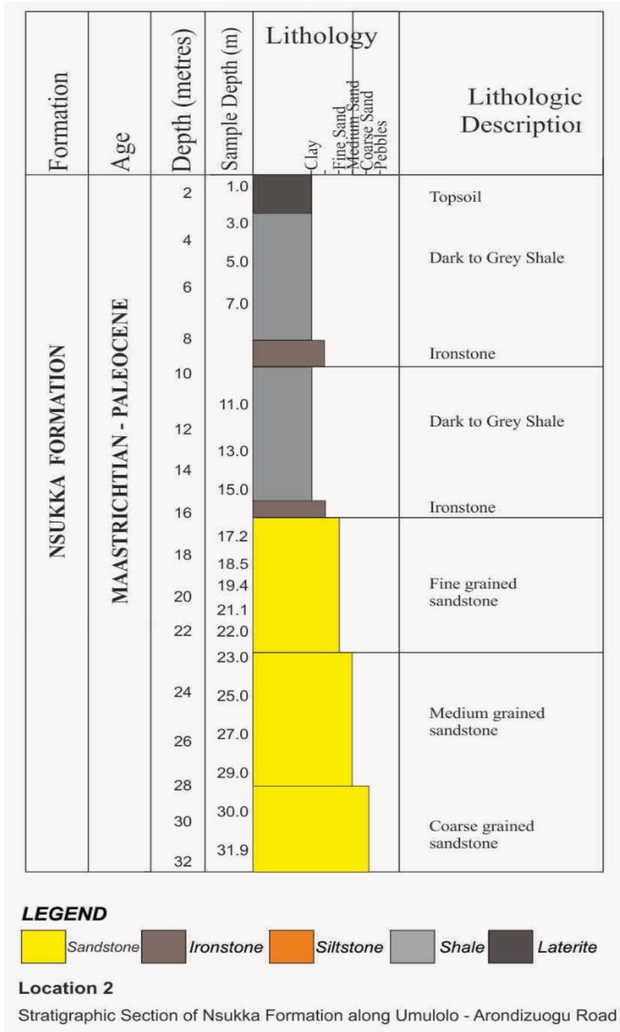


Fig 9: Stratigraphy of Umulolo Outcrop

Location 2Umulolo Outcrop

- Strike: 100 SE/220NW, Long 07°18'.695E, Lat 5°52'.270N, Elevation155m, Dip 4°-7°

Thickness (m)	Lthology Description
2.44m	Top soil, clayey, brownish with reddish patches structureless and weathered.
12.0m	Weathered shale greyish and fissile.
0.9m	Ferruginized ironstone
2.2m	Very fine to fine grained sand, clayey
1,3m	Fine to coarse grained sand, reddish to whitish
0.9m	Very fine sand.
0.9m	Very fine to fine grained sand.
1.0m	Coarse to medium grained sand and whitish.
2.2 m	Fine grained sand, clayey.
5.0 m	Medium to coarse grained sandstone, matrix support and poorly sorted.

Location 3 (Onyeka Pit)

The outcrop is well exposed, along this section of Port-Harcourt-Enugu Express way by the Okigwe junction (fig4.3). It consist of very fine grained sandstone, medium-coarse grained sandstone characterized by clay clasts at bed boundaries. An important feature of this facies association is two stacked channel (upper and lower channels). This facies in this outcrop which characterized the sandstone are fine to coarse grained. They have a finning upward motif and the presence of silt clast agrees with an erosive base. Bioturbation is rare and this indicates no animal activity at the outcrop. The medium to coarse grained sandstones indicates that the velocity of deposition is high. The depositional environment of this outcrop is interpreted to be a distributary channel based on the parallel lamination, cross bedding types and vertical grained size trend. The alternating sequence of very fine medium grained sandstone, clay and herringbone cross stratification suggest a tidal influence (Tyre etal, 1999, Law etal 1987).

Fig. 10: Onyekaba Pit Outcrop Section

Fig. 11: Onyekaba Pit Outcrop Section

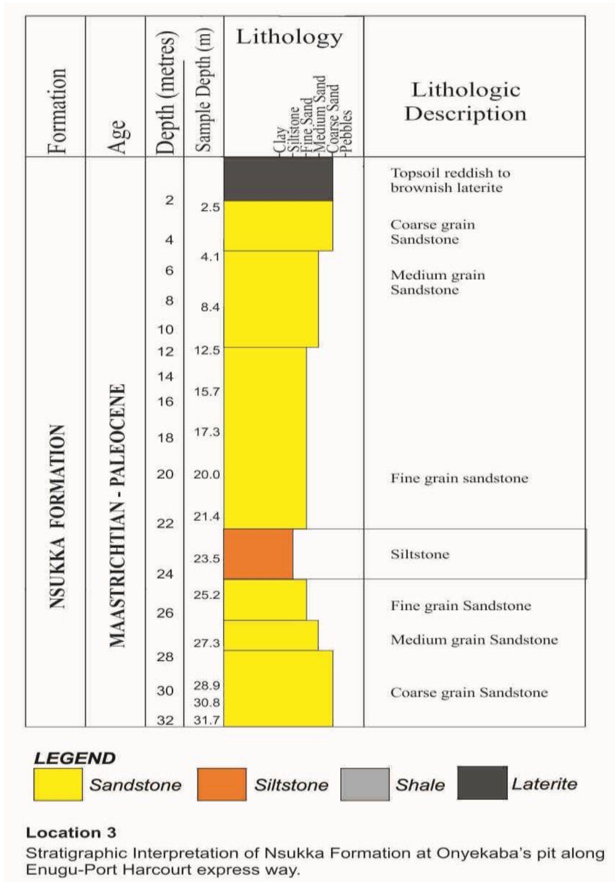


Fig 12: Stratigraphy of Onyekaba's Outcrop

Location 3 Onyekaba pit

- Strike: 46° NE 224SW, Lat 5°55'.088'N, Long 7°20'.198" E, Elevation 450ft, Dip 6°-10°

Thickness (m)	Lithologic Description
2.7m	Top soil, reddish lateritic soil.
2.5m	Fine to medium grained sand.
1.6m	Medium grained sand, brownish.
4.3m	Very fine to fine grained sand.
4.1m	Coarse grained and whitish sand.
3.2m	Very fine to fined grained sand, reddish with whitish patches.
1.6m	Silt with dark brownish colour.
2.7m	Fine grained sand, whitish in colour.
1.4 m	Fine grained, reddish to whitish.
2.1m	Medium grained sand whitish in colour.
1.7m	Medium grained sand whitish in colour.
1.6m	Coarse grained sand
1.9m	Coarse grained sand
0.9m	Coarse grained sand.

Location 4 (Umuasua Outcrop)
Location 4 is located at the Umuasua town behind Umuasua Central Primary School, opposite Isiukwu Local Government Area, in Abia state (4.4). The average lateral extent of this outcrop is 123m with an average height is 38.10m based on field relations and correlation of five measured stratigraphic sections. One major geologic facies namely the Nkporo shale, was encountered in this location. The general strike direction of the outcrop is 17SE/256SW.The bed dip 7 and the bedding contacts at the five stratigraphic sections are sharp to gradational with dips ranging from 5-7 degrees. The age of this geologic unit is Campanian -Maastrichtian. The lithofacies unit of this outcrop are lateritic claystone, muddy/sandy heteroliths interlaminated and interbedded by shales ironstone concretion were found within the shales in addition to biogenic structures produced by ichnifossils. From field relations and analysis, the beds comprising the heteroliths thicken downward while the shale beds thicken downwards also. The lithofacies were rare to moderately bioturbated, found at the bed boundaries between the shale and the very fine grain sandstone beds were brown to black carbonaceous leaf imprint, plantremain, load cast.

The thickness of each bed /unit was measured with reference to the ironstone bed, which formed a very conspicuous marker. At this Umuasua location, shale is abruptly truncated by 50cm thick ironstone. These features may record a palaeosol along the bedrock erosional surface of the palaeo-valley (Wright, 1986; Retallack, 1988; Kraus and Brown, 1988) suggesting that the basal surface was sub-aerially exposed to weathering before deposition of the overlying valley-fill sediments. This surface is also considered transgressive surface erosion.

Fig. 13: Umuasua Outcrop Section One

Fig. 14: Umuasua Outcrop Section Two

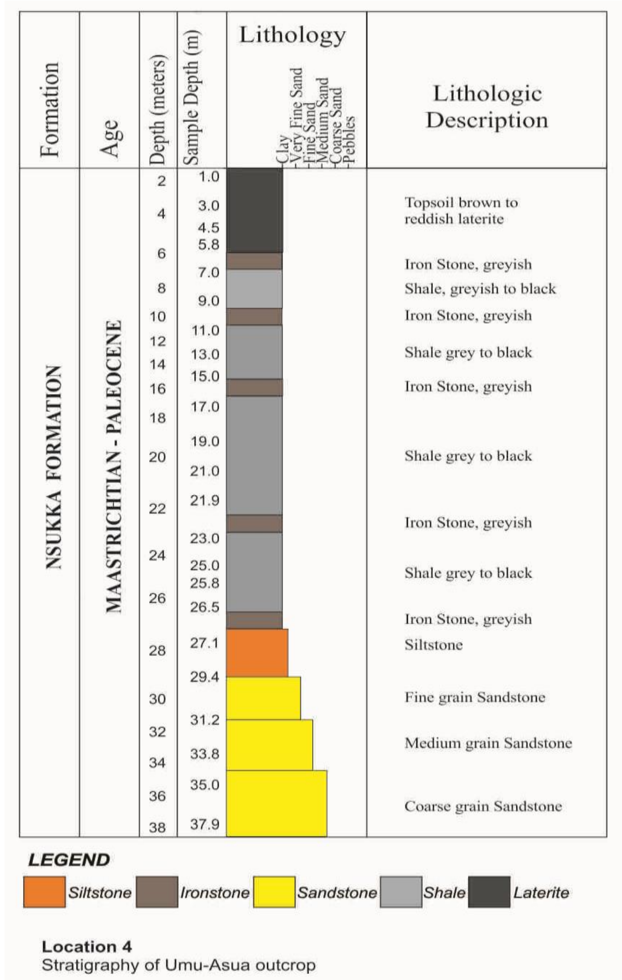


Fig 15: Stratigraphy of Umu-Asua Outcrop

Location 4 Umuasua Outcrop

- Strike: 40°NE 256 SW, Dip 7°,Long 7°29'57.7E, Lat 5°43', 23.8'N

Thickness (m)	Lithologic Description
6.0 m	Top soil, reddish
0.43 m	Thin Ironstone bed greyish.
4.0 m	Dark grey shale.
0.35 m	Thin ironstone bed, greyish in colour.
3.0 m	Dark grey shale.
0.41 m	Thin irontone, greyish to brown in colour.
5.0 m	Shale, grey to dark in colour.
0.43 m	Thin elongated ironstone bed; grey to reddish in colour.
3.0	Dark grey shale.
0.53	Thin elongate ironstone, bed.
2.0 m	Very fine to medium grained sandstone, clayey to brownish in colour.
10.0 m	Very fine, medium to coarse grained sandstone.

Location 5 (Ugwu Nkalagu Obukpa)

Location 5 is an outcrop located at Ugwu Nkalagu Obukpa, close to the Obukpa stream, in lgboeze South Local Government of Enugu State (4.5). The outcrop is well exposed and accessible with general strike of 14SE/286NW; Lateral extent of about 250m with an average height of 12.7m. Lithofacies identified are lateritic claystone, bioturbated sandy, heteroliths interbedded with shale, shale and Sandstone beds, ferruginized sandstones. The ironstone bed occur at bedding plane separating the heterolithic facies, shale and ferruginized sandstone. The beds are Moderately to intense bioturbated.

Fig. 16: Ugwu Nkalagu Obukpa Outcrop Sandstone

Fig. 17: Ugwu Nkalagu Obukpa Outcrop Shale

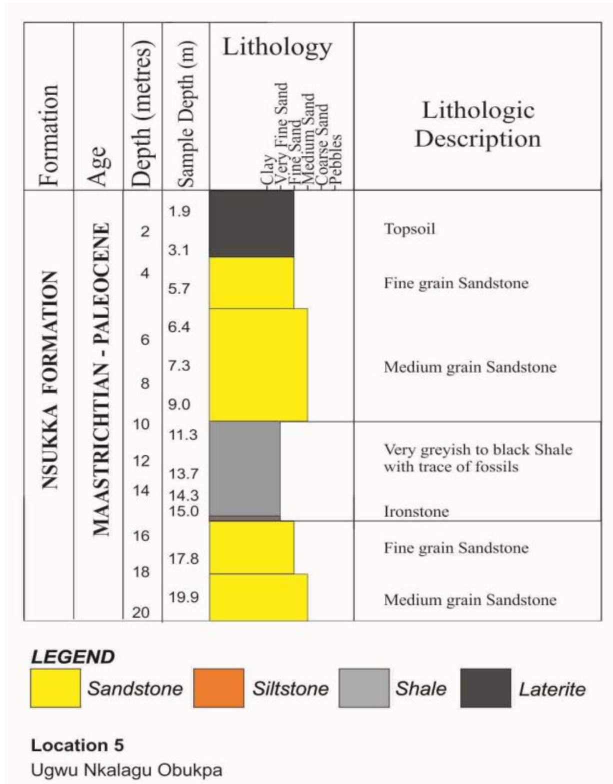


Fig 18: Stratigraphy of Ugwu Nkalagu Obukpa Outcrop

Location 5Ugwu Nkalagu Obukpa

- Stike 14SE/286°NW, Dip 6°-8°, Elevation 347m.Long 07°20’55.5, Lat N 06 56° 48.4

Thickness (m)	Lithologic Description
2.7m	Top soil, clayey, lateritic, reddish to brownish in colour. Weathered.
2.6m	Fine grained sand
0.7 m	Fine grained sandstone.
0.9m	Medium grained sandstone.
2.3m	Medium grained sandstone.
2.3m	Medium grained sand.
3.7m	Grey shale.
2.3m	Fine to medium grained sandstone.
4.2m	Ironstone and ferruginised sandstone fragment.

Stratigraphic Correlation of the Study Area (Lithostratigraphic Logs)

Fifteen stratigraphic sections were constructed for the study areas and were used to correlate the lithostratigraphic units of the five identified outcrops/locations. The key lithostratigraphic units are lateritic claystone, ironstone, shale, siltstone, sandstone and heterolithic facies. The correlation of the stratigraphic section was based on lithostratigraphy, identifiable sedimentary and biogenic structures and facies. The outcrops exposed in the study areas allow for a reasonable correlation and interpretation of the stratigraphic sections. Correlations means, to establish the mutual relations or equivalence existence existing between the stratigraphic sections (Outcrops). When used in the context of lithostratigraphic unit, it implies that the beds or group of beds are physically continuous rock bodies that can be traced from one outcrop to another (Maill,1984; Lemon 1990).

The key factors in correlating (identification process) is identifying beds or group of bed can be correlated from one outcrop to another because it is fundamental to evaluation, determination of the environment of deposition and recognizing architectural elements (Hurst etal 1999). The best correlations are based on widespread maker beds and the geologist must develop visual skills on pattern recognition, placing stratigraphic sections beside each other and comparing all the attributes present, judging which correlation permit the closest fit (Miall,1984).

According to Miall (1984), in attempting correlation without supporting biostratgraphy or chronostratigraphic information, the following conditions must be met.

- The beds or group of beds should physically be traced out on the group or between very closely spaced sub surface sections.
- The beds or group of beds are distinct and have readily recognizable marker beds or where facies studies indicate that, there is lateral bed continuity.
- Spencer (1963), suggests that if a group of beds identified are continuous laterally and vertically having similar porosity, permeability and bed characteristics, they may be regarded as a reservoir flow unit.
- 5-18m thick very fine grained sandstone bed with a close to 13 kilometers lateral extent traceable from location 1 through to location 5.
- 28 to 38m thick shale more than a 100m lateral extent traceable from location, 1,2,4& 5.
- 5m to 40m thick of very fine to coarse grained sandstone with more than 120m lateral extent traceable from location 1- 5.

Other criteria used were lithology, sedimentology, biogenic sedimentary structures, based on the above discussions, these beds were correlated in addition to meeting the conditions set by Mail (1984) even though the beds have been fractured, faulted and folded at location 2&4 respectively. The fault (normal) is believed to be the result of Pre and Post Santonian events, which is consistent with the regional trend in the Benue Trough (Burke et al, 1971; Cratchely and Jones, 1965; Wright, 1986; Whiteman, 1982). The fault may be expressions of deep seated structure.

Combining the stratigraphic sections and correlating the lithostratigraphic units, a composite stratigraphic sections is presented showing that the study area have an average outcrop exposure of comprising.

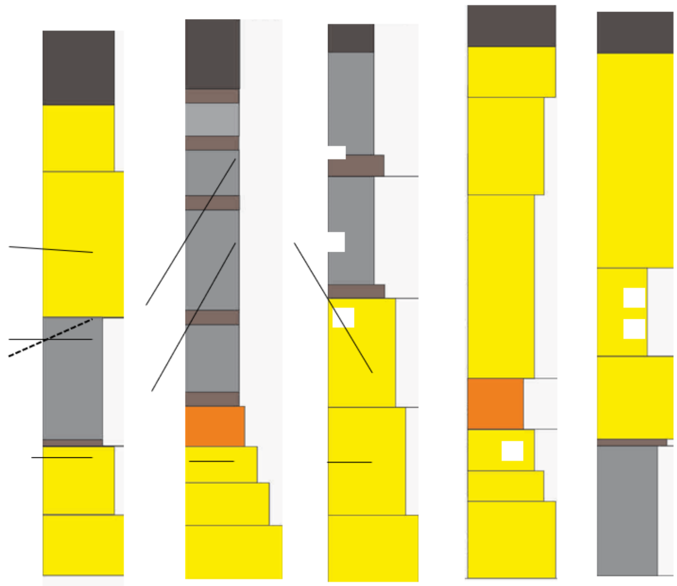


Fig. 19: Correlation of the Lithologs

Lithofacies Association

The recognition of lithofacies association is an important part of facies analysis as it is most commonly the facies associations which provide clues to the environment of deposition (Coleman, (1981). According to Nicoles (1991) once all the beds in the succession have been assigned to facies, patterns in the distribution of these facies can then be investigated. The procedure of facies analysis, he suggested is a two stage process: the identifications of facies which can be interpreted in terms of processes and establishing facies associations which reflect combinations of processes and environment of deposition. Based on this, three lithofacies associations were identified for the study areas. These are Floodplain, Coastal plain and Distributary channel lithofacies associations.

Flood Plain Lithofacies Association

This lithofacies association consist of the following lateritic claystone, Bioturbated muddy, and sandy Heterolithics shales and lateritic ironstone unit. It is laterally extensive and cover a very long distance from location 1 through location 2 and 4in the study areas. The occurrence of lateritic claystone facies within the study area is widespread and is interpreted as having been formed by the decomposition of the rocks especially shales. According to Kogbe (1979), this offer a possible mechanism for the mode of formation (increase in temperature and percolation fluids of the lateritic claystones as clays are impermeable by virtue of their position in the stratigraphic sequence.

The lateritic ironstones are well developed in the shale than in the sandstone unit. Kogbe (1979) suggests that the conformable nature of these unit bedding as well as that characteristic relic primary structures exhibited has a primary origin rather than being superficial products of weathering. These lateritic claystones and ironstones are both post depositional in origin, while the lateritic ironstone is of primary origin which resulted from mobilization of ferric iron by infiltrating fluids in the shale and subsequent conversion to ferrous iron at the appropriate temperature, PH and pressure. Inference from the above indicates that they were formed in reducing environment.

According to Visher (1969; 1999) depositional patterns may reflect vertical stacking, retrogradation, and progradation or overlapping stratigraphic responses. These pattern are complexly related to changes in accommodation space, sediment supply and dispersive forces. The cyclical nature of bedding in this facies association reflects variability in current velocities such that current ripple laminated vary fine –grained sandstones are representation of most vigorous currents. The velocities are interpreted to have been much lower than those associated with coarser cross bedded sandstone with mud drapes (Power, 1982).

Analysis of outcropping Virgilian-Sakmarian depositional sequences reveal major changes in the nature of cyclothermic scale and the patterns of cyclicity is believed to have resulted from allocyclic as well as autocyclic mechanism (Broadman,1999). These thin layers generated, may be because of the processes, which record annual seasonal changes. For examples, a darker denser layer was deposited during the rainy season or heavy rain(which is associated with rise in sea level)which carriers clay/mud from land to the sea and a light fluvial layer(Sandstone) was deposited during the dry season by the bottom current (Campton,1977).This cyclic sequence represented by very fine grain sandstone, clay/muds/shale laminae could be used to interpret the original depositional environments by making used of the layers thickness, components of layers and fabric features to determine the depositional processes that operated within the environment (Camptom1977;Robinson and Mccabe 1997; Power, 1982; Broadman 1999).

The factors responsible for the formation of these cyclics sequence are tides climates and varying influx of materials over time from river systems. These lateral variations are recorded of shifts of a vast inland sea that occupied these region during the Santonian. These lateral variation are not usually presented in sediment because of the bottom dwelling organisms, which destroy them by burrowing and ingesting it in shallow marine environments. In deeper marine environments, these laminations are preserved because only few bottom dwelling organisms can live in some water that have less than 0.5 parts per oxygen (Campton 1977;). Thick- thin alterations (cyclic sequence) of silt and clay have been interpreted to represent tidal influence in inner estuarine sediments (Kuecher et al, 1990). The silt layers represent traction deposits from ebbs and flood tides while clay layers represent deposition from suspension during slack water (Shanmugan et al, 2000). The pattern of distributions is characteristics of tidal flat environments; the reason for these extensive patters of sedimentation tidal flats are the energy and partly transportation mechanisms. In addition, the sedimentary structures exhibited confirm a tidal flat environment. The most convincing evidence for a tidal flat environments are very low velocity and the abundance of bioturbation structures, flaser, wavy and lenticular bedding. Reineck and Winderlich 1968; Reineck and Singh 1980; Weimer et al 1992; Shanmugenet al 2000; Power 1982 and Kogbe, 1979).

The burrows within this facies association suggest that the energy level rapidly decreased following sand deposition, thereby allowing deposition of mud from suspension and colonization by infuana (Putnan et al 1990). The presence of key form of ichno genera in the study area such as teichichmus, Arenicollites, thalossinoides and Ophiomorpha, diplocraterion, Skolithos, ligillities and planolites, indicates shallow marine and the dominance brackish water conditions (Cazier et al 1997). Dinoflagellates collected from mudstones indicates marine conditions. The lack of calcareous foraminifera, the presence of terrestrially derived pollen and spores corroborate brackish conditions. Studies by (Mebradu 1990) in the study area, reveal the presence of dinoflagellates, abundant pollens and spores, and the absence of calcareous foraminifera which corroborate (curry 1982) work as being marine and suggests that the environment of deposition is a flood plain within a shallow marine environment (Van Wagnoner etal, 1990; Permberton etal, 1992, Mac Eachern and Permberton 1992)

A flood plain environment is interpreted for the upper section of the Enugu Shales on the presence of abundant plant debris and carbonaceous material (Kogbe, 1979). According to Kogbe (1979) tidal flats develop along gently dipping sea coast with marked tidal rhythms from high to low water level. Present study reveals that the beds dip 4®- 15®, which suggest a gentle dipping coast. Regional studies revealed that the Anambra Basin was a platform or embayment during the Cretaceous (Whiteman, 1982) where tidal currents would have played a significant role with marine incursion during the Albian-Lower Santonian.

Putnan et al (1997) interpreted these type of cyclic deposits to have formed in response to stage fluctuations within tidal environment. From observations made in the study area, and examples cited above, the environment of deposition is a flood plain. With a tidal influence in a shallow marine setting. The presence of lignite streaks, heterolithic facies and carbonaceous remains cannot be divorced from the flood plain environment when one considers the differences in thickness of sandstones bodies in the lower shoreface and flood plain environment.

The heterolithic facies compose of approximately equal proportions of very fine grained sandstone and mudstone shale are interpreted as flood plain deposits extending laterally above the shallow marine shales. They are distinguished from abandoned channel fill deposits by weakly developed laminations, abundant roots, burrow etc (Robinson and McCabe 1997) and can be reliably traced and correlated from one outcrop to another for kilometres.

The high content of ferruginous cements in these lithofacies association within the study area (primarily composed of iron oxide minerals such as hematite, geotithe and or limonite), suggest a reducing a tropical condition which are frequently encountered in flood plain deposits. In addition, alternating wet and dry (usually also reducing and oxidizing) conditions will lead to the introduction of iron in solution followed by its oxidation to iron bearing minerals in sandstone which at the right conditions, may yield up their iron to form cement (Moorehousse 1959).

Distributary Channel Lithofacies Association

This facies association outcrops only at location 3 and consist of very fine grained sandstone, fine-stones characterized by clay clayst at bed boundaries. An important features of this facies association is the establishment of a finning upward motif and two stacked channels (upper and lower channels).

The facies in this lithofacies association which characterize part of the study area (Onyekaba pit) reveal that the sandstone are fine to coarse grained, locally with clay clasts which separating each of the stacked channel fill deposits. They have a finning upward motif and the presence of clay clasts agrees with an erosive base. Bioturbation is rare to moderate, an indication of low animal activities and velocity of deposition for the very fine-fine grained sandstone. The medium to coarse-grained sandstones indicates that the velocity of deposition is high.

The depositional environment of this facies association is interpreted to be a distributary channel based on the ichnofossil suites, parallel lamination, cross bedding types and vertical grain size trend. The alternating sequence of very fine-medium grained sandstone, clays and herringbone cross stratification suggests a tidal influence (Tyres et al; 1999, Lawson; 1988.)

Grain Size Particle Distribution.

Particle Size Distribution (PSD) results including summary tables are presented in both tabular and graphic formats. Each of the cumulative curves provides a graphical representation of the grain size distribution (Nicole,1999) enabling the statistical evaluation of the following parameters: Mean (MZ), Median (MD), Standard Deviation (SD), Skewness (SK), Kurtosis (k) based on (folks and Ward 1957) formula (Pettijohn,1975; Lewis and McConchie, 1994; Kogbe 1989). The grain size distribution is determined to some extent by the processes of transport and distribution of the sediments and this provides quantitative inquired from sediments deposited within a known environment.

Grain Size Aanalysis Result

Location 1

Table 3: (Ihube Outcrop) L1S1 Depth= 1m, Weight of Sample=142.02g

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve+Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	529.3	539.9	10.6	7.5	7.5
1	0	474.8	490.7	15.9	11.2	18.7
0.5	1	443.5	488.6	45.1	31.76	50.46
0.256	2	413.3	454.5	41.2	29	79.46
0.106	3	403.6	421.2	17.6	12.4	91.86
0.063	4	398.7	405.1	6.4	4.51	96.37
Pan	5	370.7	375.9	5.2	3.7	100.07

Table 4: L1S2 (Ihube Outcrop) Depth= 1m, Weight of Sample=162.3(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve + Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	529.3	532.4	3.11	1.92	1.92
1	0	474.8	490.3	15.53	9.57	11.49
0.5	1	443.5	473.8	30.35	18.70	30.19
0.256	2	413.3	469.9	56.70	34.94	65.13
0.106	3	403.6	442.8	39.27	24.20	89.33
0.063	4	398.7	412.5	13.82	8.51	97.84
Pan	5	370.7	374.2	3.51	2.16	100
Total		3033.9	3195.9	162.3	100	

Table 5: L1S3 (Ihube Outcrop) Depth= 1m, Weight of Sample=151.1(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve+Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	529.3	533.1	3.8	2.51	2.51
1	0	474.8	493.2	18.4	12.18	14.69
0.5	1	443.5	497.0	53.5	35.41	50.10
0.256	2	413.3	466.5	53.2	35.21	85.31
0.106	3	403.6	417.4	13.8	9.13	94.44
0.063	4	398.7	406.2	7.5	4.97	99.41
Pan	5	370.9	371.6	0.9	0.6	100.01
		3033.9	3185	151.1	100.01	

Table 6: Location2 (Umulolo Outcrop) L2S1Depth =2m, Weight of Sample =133.4(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve +Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	528.9	533.6	4.72	3.54	3.54
1	0	474.9	500.7	25.92	19.43	22.97
0.5	1	444.1	476.5	32.55	24.40	47.37
0.256	2	413.3	456.3	43.19	32.38	79.75
0.106	3	403.6	419.5	15.97	11.97	91.72
0.063	4	398.6	404.3	5.73	4.30	96.02
Pan	5	370.7	376.0	5.32	3.99	100.01
		3034.1	3166.9	133.4	100.01	

Table 7: L2S2 Depth = 2m, Weight of Sample = 132.3(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve+Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	528.9	534.9	6.00	4.54	4.45
1	0	474.9	484.6	9.70	7.33	11.87
0.5	1	444.1	480.0	35.90	27.14	39.01
0.256	2	413.3	466.2	52.9	39.98	78.99
0.106	3	403.6	422.8	19.2	14.51	93.50
0.063	4	398.6	403.4	4.8	3.63	97.13
Pan	5	370.7	374.5	3.8	2.87	99.13
		3034.1	3166.4	132.3	100	

Table 8: L2S3 Depth = 1m, Weight of Sample = 107.9(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve+Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	528.9	532.2	3.3	3.06	3.06
1	0	474.9	498.4	23.52	21.8	24.86
0.5	1	444.1	499.9	55.85	51.76	76.62
0.256	2	413.3	427.9	14.61	13.54	90.16
0.106	3	403.6	407.1	3.50	3.24	93.4

0.063	4	398.6	401.9	3.30	3.06	96.46
Pan	5	370.7	374.5	3.80	3.52	100
		3034.1	3141	107.9	100	

Table 9: L3S1 Depth=2.2m, Weight of Sample=77.9(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve+Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	529.2	530.3	1.1	1.41	1.41
1	0	474.8	476.8	1.99	2.55	3.96
0.5	1	443.9	459.1	15.16	19.46	23.42
0.256	2	413.7	461.5	47.68	61.21	84.63
0.106	3	403.4	412.4	8.98	11.53	96.16
0.063	4	398.7	401.1	2.39	3.07	99.23
Pan	5	370.6	371.2	0.6	0.77	100
		3034.3	3112.4	77.9	100	

Table 10: L3S2 Depth= 1.4m, Weight of Sample =130.0(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve+Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	528.9	531.4	2.52	1.94	1.94
1	0	474.7	485.1	10.29	7.92	9.86
0.5	1	444.1	474.5	30.66	23.58	33.44
0.256	2	413.3	466.6	53.75	41.35	74.79
0.106	3	403.6	425.2	21.78	16.75	91.54
0.063	4	398.6	406.0	7.46	5.74	97.28
Pan	5	370.7	374.2	3.53	2.72	100
		3034.1	3163	130	100	

Table 11: L3S3 Depth= 2.1m, Weight of Sample =163.6(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve+Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	528.9	531.0	2.11	1.29	1.29
1	0	474.9	480.4	5.52	3.37	4.66
0.5	1	444.1	470.7	26.68	16.31	20.97
0.256	2	413.3	487.8	74.73	45.68	66.65
0.106	3	403.6	443.0	39.52	24.16	90.81
0.063	4	398.6	407.5	8.93	5.46	96.27
Pan	5	370.7	376.8	6.12	3.74	100.01
		3034.1	3197.2	163.6	100.01	

Table 12: L4S1, Depth= 0.6m, Weight of Sample =156.4(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve+Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)

2	-1	528.9	530.1	1.21	0.77	0.77
1	0	474.9	477.7	2.82	1.8	2.57
0.5	1	444.1	458.7	14.68	9.39	11.96
0.256	2	413.3	435.0	21.82	13.95	25.91
0.106	3	403.6	481.8	78.65	50.29	76.20
0.063	4	398.6	422.4	23.94	15.29	91.51
Pan	5	370.7	383.9	13.28	8.49	100
		3034.1	3189.6	156.4	100	

Table 13: L4S2, Depth= 2.3m, Weight of Sample =173.9(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve (g)	Weight of Sieve+Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	528.9	530.6	1.71	0.98	0.98
1	0	474.9	496.2	21.47	12.35	13.33
0.5	1	444.1	490.2	46.47	26.72	40.05
0.256	2	413.3	460.6	47.68	27.42	67.47
0.106	3	403.6	435.0	31.65	18.20	85.67
0.063	4	398.6	414.9	16.43	9.45	95.12
Pan	5	370.7	379.1	8.47	4.87	99.99
		3034.1	3206.6	173.9	99.99	

Table 14: L 4S3, Depth = 1.8m, Weight of Sample =224.2g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve +Sample (g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	528.9	531.6	2.7	1.57	1.57
1	0	474.9	482.8	7.9	4.60	6.17
0.5	1	444.1	498.8	54.7	31.80	37.97
0.256	2	413.3	487.1	74.0	43.00	80.97
0.106	3	403.6	428.7	25.1	15.00	95.97
0.063	4	398.6	404.8	6.2	3.60	99.57
Pan	5	370.7	371.9	1.2	0.70	100.27
		3034.1	3157.6	172	100.27	

Table 15: L5S1, Depth= 1.9m, Weight of Sample =198.04(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve+ Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	528.9	531.2	2.30	1.80	1.80
1	0	474.9	499.0	24.10	19.30	21.1
0.5	1	444.1	476.0	31.90	26.00	47.1
0.256	2	413.3	454.0	40.70	32.60	79.70
0.106	3	403.6	416.4	12.80	10.26	89.96
0.063	4	398.6	406.2	7.60	6.09	96.05
Pan	5	370.7	375.3	5.30	4.25	100.30
		3034.1	3158.1	124.70	100.30	

Table 16: L5S2, Depth= 2.6m, Weight of Sample =149(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve+ Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	528.9	534.0	4.10	2.81	2.81
1	0	474.9	497.9	23.10	15.50	18.31
0.5	1	444.1	498.7	55.20	37.01	55.32
0.256	2	413.3	453.4	40.10	26.90	82.22
0.106	3	403.6	418.5	14.90	10.00	92.22
0.063	4	398.6	403.7	5.10	3.42	95.64
Pan	5	370.7	377.2	6.50	4.36	100.00
		3034.1	3164.6	149.00	100.00	

Table 17: L5S3, Depth= 0.9m, Weight of Sample =179(g)

Sieve Diameter(mm)	Sieve diameter(phi)	Weight of Sieve(g)	Weight of Sieve+ Sample(g)	Weight of Sample(g)	Weight (%)	Cum weight (%)
2	-1	528.9	531.2	2.30	1.80	1.80
1	0	474.9	499.0	24.10	19.00	20.80
0.5	1	444.1	476.0	31.90	26.00	46.80
0.256	2	413.3	454.0	40.70	32.60	79.40
0.106	3	403.6	416.4	12.80	10.26	89.66
0.063	4	398.6	406.2	7.60	6.09	95.75
Pan	5	370.7	375.3	5.30	4.25	100
		3034.1	3158.1	124.70	100.00	

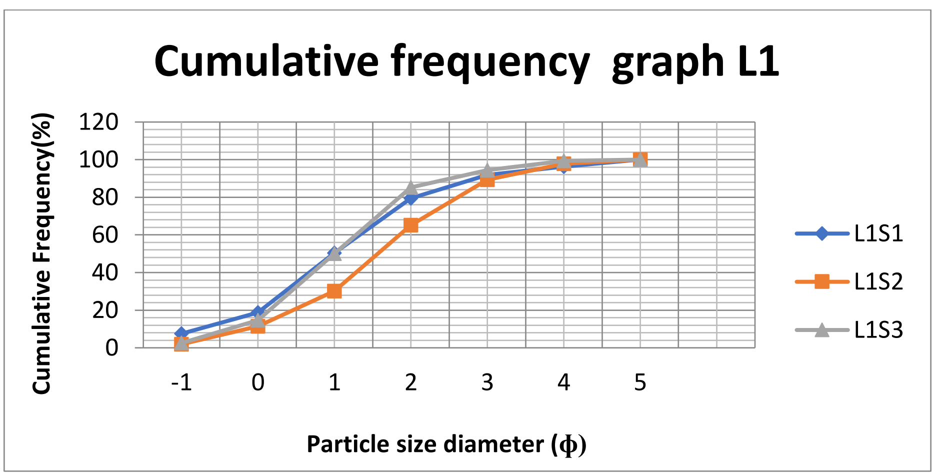


Fig 20: Location 1 Graph

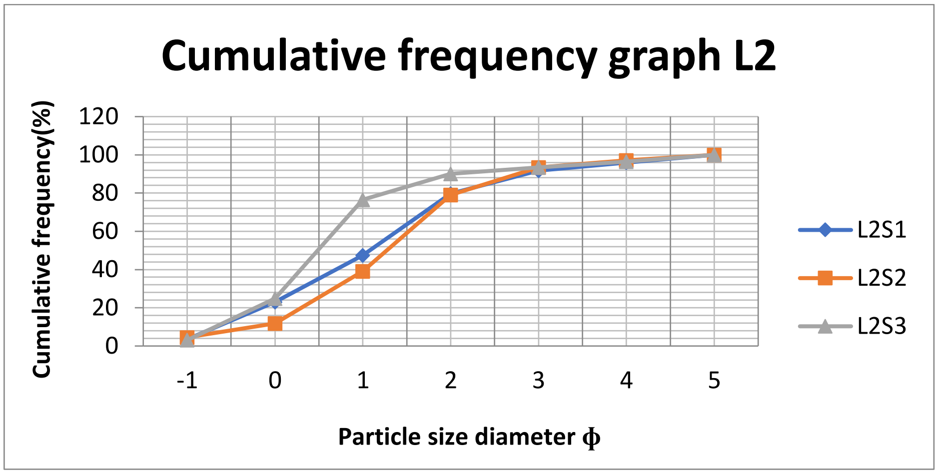


Fig 21: Location 2 Graph

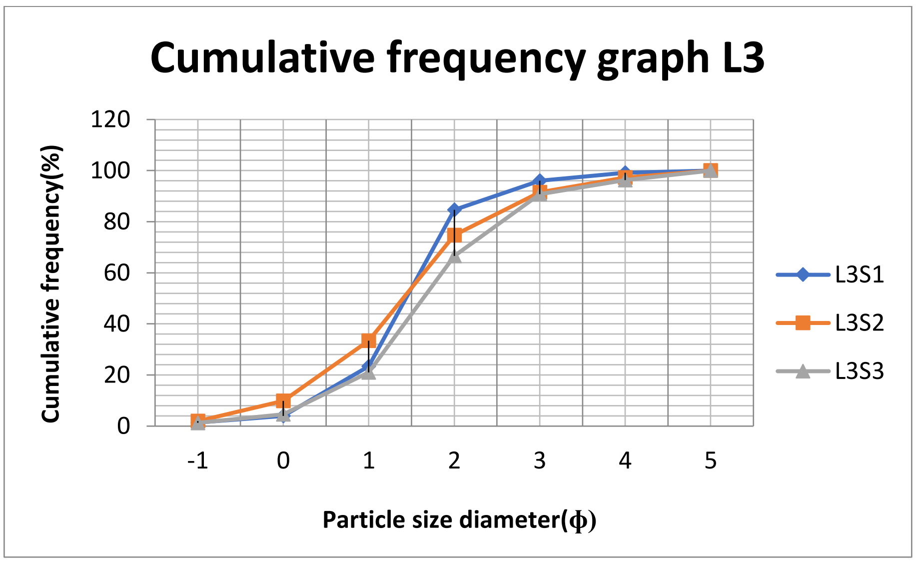


Fig 22: Location 3 Graph

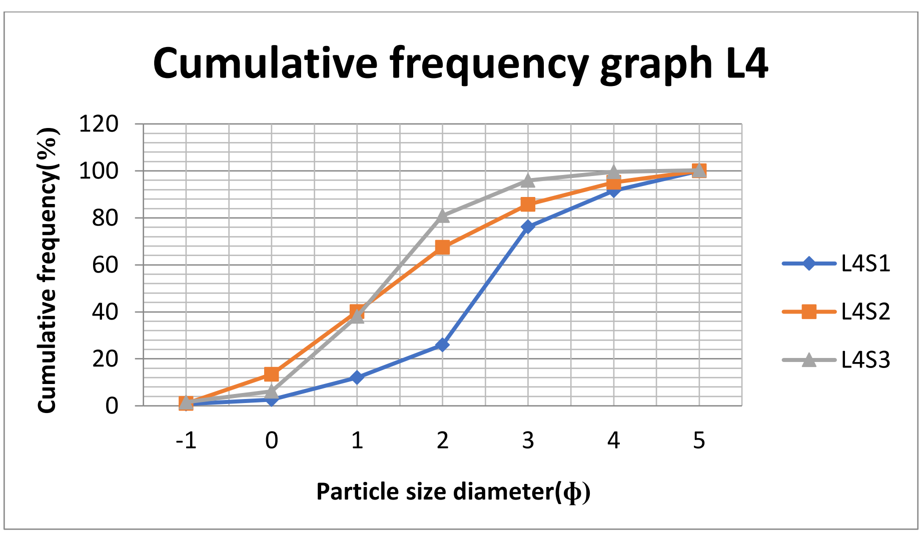


Fig 23: Location 4 Graph

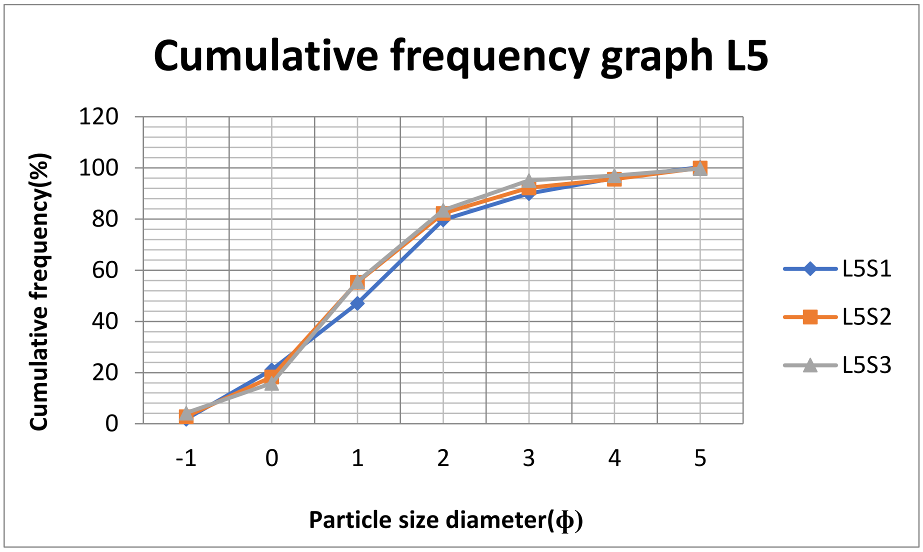


Fig 24: Location 5 Graph

Histograms

The histograms have a wide range of uses, covering all phi(Ø) diameter values (Kogbe,1979). The analysis of the histogram plots of each of the size fraction fig25 shows the grain size distribution to be predominantly unimodal for all the samples analysed. The unimodality of the histograms may be because the sediments were probably deposited in one phase and have not undergone much reworking or re-deposition (Kulcal, 1971). The results reveal that the sediments are dominated by medium to coarse grains fraction with a smaller percentage of fines, which were deposited by strong currents.

Grain Size Analysis Result (Histogram)

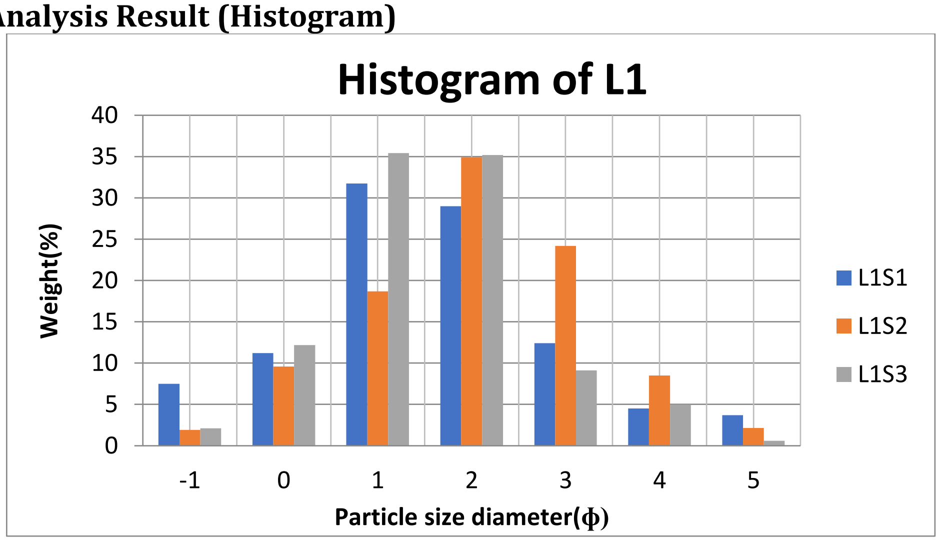


Fig 25: L1 Weight percent vs Grain Size

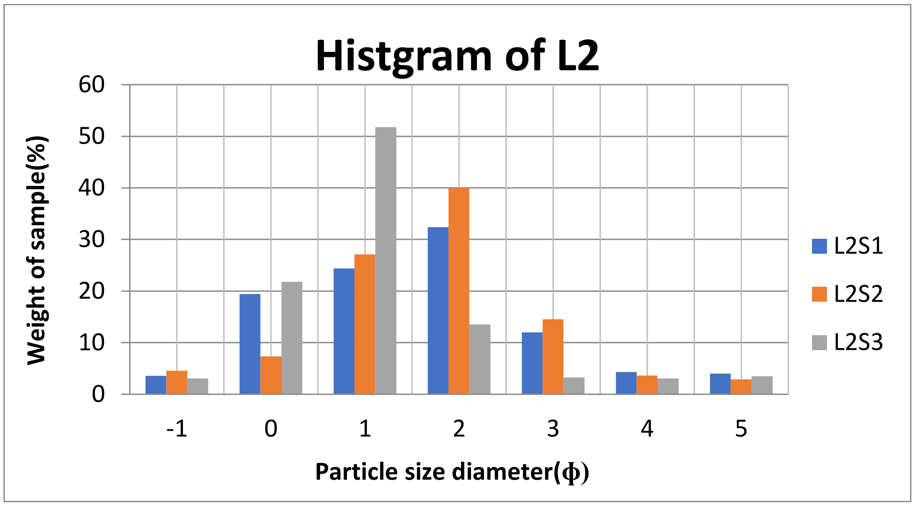


Fig. 26: L2 Weight percent vs Grain Size

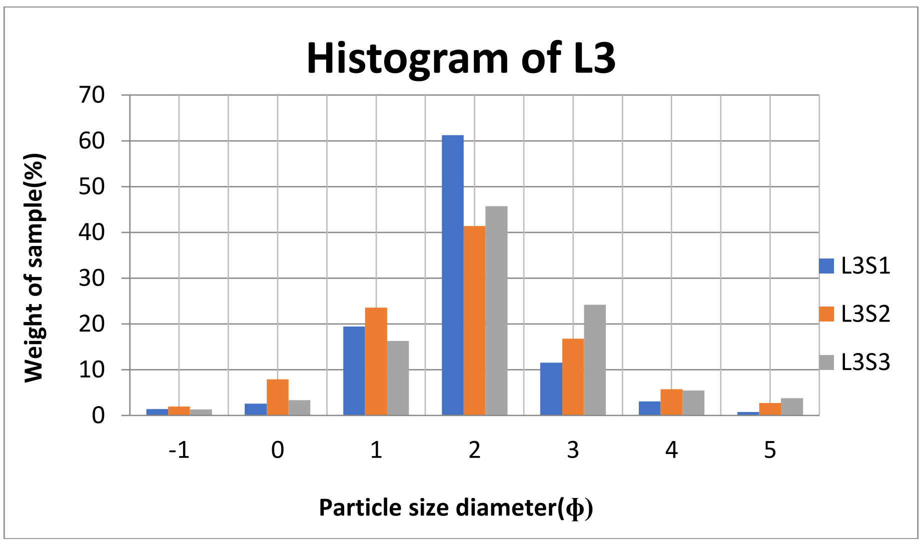


Fig. 27: L3 Weight percent vs Grain Size

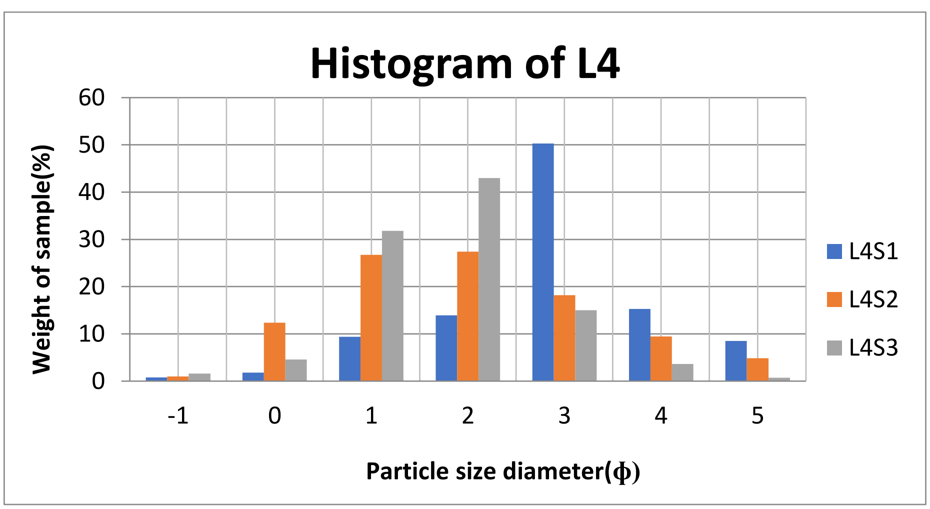


Fig 28: L4 Weight percent vs Grain Size

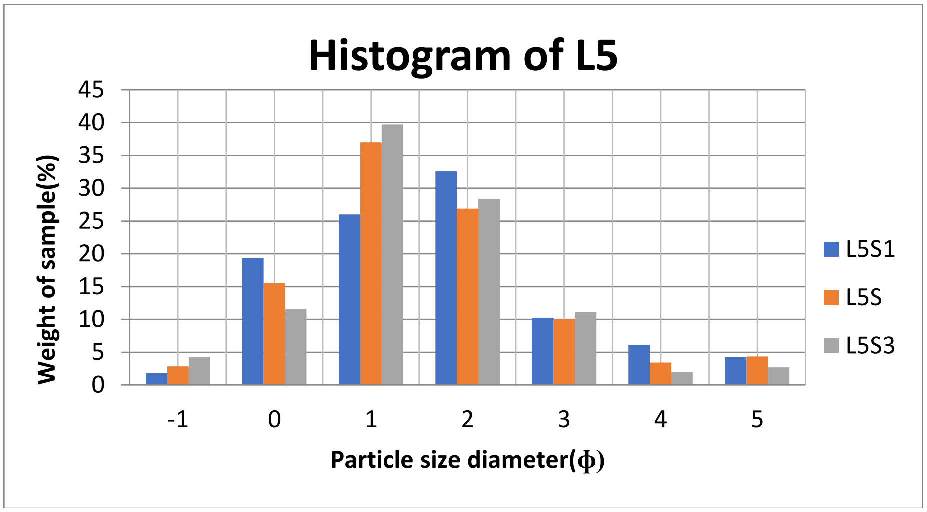


Fig 29: L5 Weight percent vs Grain Size

Interpretation of Grain Size Statistical Parameter

Table 18: Visual Observations of Samples

Location	Sample	Sorting	Average Size	Roundness	Sphericity	Type Material
1	1	Moderately sorted	Medium Size	Sub rounded	Angular	Sandstone
1	2	Moderately sorted	Medium Size	Sub angular	Angular	Sandstone
1	3	Moderately sorted	Medium Size	Sub angular	Angular	Sandstone
2	1	Moderately sorted	Medium Size	Sub angular	Angular	Sandstone
2	2	Moderately sorted	Coarse Size	Sub angular	Angular	Sandstone
2	3	Moderately sorted	Coarse Size	Sub rounded	Angular	Sandstone
3	1	Well sorted	Medium Size	Sub rounded	Sub angular	Sandstone
3	2	Moderately sorted	Medium Size	Sub rounded	Sub angular	Sandstone
3	3	Well sorted	Medium Size	Sub rounded	Sub angular	Sandstone
4	1	Well sorted	Fine size	Sub rounded	Subrounded	Sandstone
4	2	Moderately sorted	Medium Size	Sub angular	Subrounded	Sandstone
4	3	Well sorted	Very Coarse Size	Sub angular	Subrounded	Sandstone
5	1	Well sorted	Coarse size	Sub rounded	Angular	Sandstone
5	2	Well sorted	Coarse size	Sub rounded	Angular	Sandstone
6	3	Moderately sorted	Coarse size	Sub rounded	Angular	Sandstone

Graphic Mean (GM Ø):

The graphic mean gives a measure of the average diameter of the grains present in a particular sedimentary deposits (Folk and Ward, 1957). It is the best graphic measure for determining overall size. It corresponds very closely to the mean as computed by the method of moments, yet is much easier to find. It is much superior to the median because it is based on three point and gives a better overall picture.

The mean is significant in that it provides clues to the conditions of formation of clastic sediments especially the competence and energy of the depositing medium (Kogbe, 1976).

From the results of the grain size analysis, the sediment are predominantly medium to coarse grained sand .47% or 7 samples are medium grained,47% or 7samples are coarse grained and

7% or 1 sample sand was very fine to fine grained. Most of the samples analysed belong to the coarse to medium grained size grade, which is indicative of a high energy depositional environment while the other sand grained (very fine to fine grained sand) indicates a lower energy environment of deposition. Pettijohn (1956) and Reineck-Pettijohn 1973 suggest that probably a high energy environment fluctuated a low energy environment.

The mechanism for this sequence is indicative of fluvial environment with some tidal influence (Reineck and Singh, 1973; Weimer et al 1982)

Standard Deviation (Sorting)

The standard deviation is a measure of sorting of the sediment within a deposit (Pettijohn, 1975) Friedman et al 1992; Tucker, 1988) or the spread of the distribution around the (Kogbe, 1989). Lambiase (1980) suggests that each grain population was transported at different rates that the suspended grain travelled faster than the grains moved by traction according Eistein's theory. In addition, the real distribution transport paths combined with differential transport rate of each grain produced hydrocarbon sorting. 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 transports as well as the degree of turbulence (Krumbien and Sloss, 1963; Reineck and Singh 1980).

Table 19: A Guide to the Interpretation of Sorting Data

Value	Interpretation
very well sorted	Under 0.35 phi
well sorted	0.35 to 0.50 phi
moderately well sorted	0.50 to o.71 phi
moderately sorted	0.71 to 1.0 phi
Poorly sorted	1.0 to 2.0 phi
Very poorly sorted	2.0 to 4.0 phi
Extremely poorly sorted	Over 4.0 phi

Sorting: (from inclusive graphic standard deviation)

From the interpretation above, 40% or 6 samples are well sorted, 20% or 3 samples are moderately sorted and 40% or 6 samples are poorly sorted.

Graphic Skewness.

The skewness of the distribution of the sediment is indicative of whether the grain size is symmetrical or skewed (Positively or Negatively) to a high percentage of coarser or finer materials (Pettijohn,1975; Lewis and McConche,1994).

Positively values indicates a tailing of the curve to the right of the mean (excess of coarse particles where as a negative value indicates a tailing of the curve to the left (an excess of fine particles) (Friedman etal,1992). The interpretation of graphic skewness is as presented below based on Folk and Ward(1957) equation.

Table 20: GSK Value Interpretation

Strongly fine skewed	-1.00 to + 0.30
Fine skewed	+0.30 to 0.10
Nearly symmetrical	+0.10 to 0.10
Coarse- skewed	0.10 to 0.30
Strongly coarse- skewed	0.30 to 1.00

Sorting skewness: from inclusive graphic skewness)

From the results, 13% or 2 samples are nearly symmetrical, 40% or 6 samples are finely skewed, 47% or 7 samples are coarsed skewed. According to Friedman (1967) the sediments which have positively skewed to nearly symmetrical skewness are characteristics of fluvial sediments. From the results of the study areas, 87% of the samples are finely to coarse skewed, based on Friedman (1967) the sediments are characterised as shallow marine and deposited in shallow marine environment because sediment of the shallow marien origin are generally finely to coarse skewed. In addition, the approach used in interpreting depositional environment from grain size analysis is to plot skewness verses sorting(Frieman,1961) and comparing the coarsest fraction to median grain size (Passega,1964) and exploiting the relationship between grain size distribution and hydraulic (Middleton,1976;Sagoe and Visher,1977).This approach emphasizes the effect of the transporting fluid on sediment grains and provides the basis for interpreting hydraulic conditions from grains size distribution.

Graphic Kurtosis (KØ)

The kurtosis is a parameter which measures the degree of peakedness of a distribution, usually taken to a normal distribution (Friedman et al 1992, Kogbe 1989). According to (Kogbe 1989), it describes the departure of the distribution from normality by comparing the sorting at the tails with the central portions quantitatively. It also indicates whether the histogram has a sharp peak or flat top (Pettijohn, 1975, Lewis and McConchic 1994) a distribution having a relatively high peak is leptokurtic while flat topped curved is platykurtic. A normal distribution which is neither peaked nor very flat topped is said to be mesokurtic and based on (Folks and Ward 1957) equations the following interpretations are made. 27% or 4 samples are very leptokurtic, 53% or 8 samples are leptokurtic, 7% or 1 sample was mesokurtic, 13% or 2 samples are plakurtic.

Table 21: Graphic Kurtosis (KØ)

KØ Values	**Interpretation**
Very platykurtic	< 0.67
Platykurtic	0.67 to 0.90
Mesokurtic	0.90 to 1.11
Leptokurtic	1.11 to 1.50
Very leptokurtic	1.50 50 30
Extremely lepyokurtic	>3.00

Table 22: Summary of Calculated Statistical Parameters

Statistical calculations			
(Location 1)	**Sample 1**	**Sample 2**	**Sample 3**
Grain size mode	1	1	1.5
Median	1	1.7	1

Mean	1.03	1.6	0.95
SD	0.625	0.775	0.475
Skewness	0.42	0.09	0.08
Kurtosis	1.42	1.33	0.82
(Location 2)	**Sample 1**	**Sample 2**	**Sample 3**
Grain size mode	2	2	1
Median	1.3	0.8	1
Mean	1.23	0.73	0.97
SD	0.5	0.5	0.63
Skewness	-0.1	0.08	0.03
Kurtosis	1.23	2.39	1.01
(Location 3)	**Sample1**	**Sample 2**	**Sample 3**
Grain size mode	2	2	2
Median	1.3	1.3	1.7
Mean	1.33	1.33	1.33
SD	0.33	0.2	0.73
Skewness	0.11	0.09	-0.19
Kurtosis	1.43	1.4	1.23
(Location 4)	**Sample 1**	**Sample 2**	**Sample 3**
Grain size mode	3	1.5	1
Median	2.4	1.3	0.5
Mean	2.4	1.43	0.73
SD	0.5	0.7	0.33
Skewness	0	0.18	0.38
Kurtosis	1.91	0.94	0.88
(Location 5)	**Sample 1**	**Sample 3**	**Sample 3**
Grain size mode	1	1	1
Median	0.9	0.8	0.9
Mean	0.9	0.83	1
SD	0.45	0.18	0.58
Skewness	0.04	0.22	0.23
Kurtosis	1.45	3	1.38

Table 23: Summary of Interpretation of Calculated Statistical Parameters for All the Location Outcrops.

Sample description for L1			
Statistical parameters	**Sample 1**	**Sample 2**	**Sample 3**
Mode	Medium grained	Medium grained	Medium grained
Median	Medium grained	Medium grained	Medium grained
Mean	Medium grained	Medium grained	Coarse grained
Sorting	Poorly sorted	Poorly sorted	Well sorted
Skewness	Fine skewed	Nearly symmetrical	Nearly symmetrical
Kurtosis	Leptokurtc	Leptokurtic	Platykurtic
Sample description for L2			
Statistical parameters	**Sample 1**	**Sample 2**	**Sample 3**
Mode	Medium grained	Medium grained	Coarse grained
Median	Medium grained	Coarse grained	Coarse grained
Mean	Medium grained	Coarse grained	Coarse grained

Sorting	Moderately sorted	Moderately sorted	Poorly sorted
Skewness	Coarse skewed	Coarse skewed	Coarse skewed
Kurtosis	Leptokurtic	Very Leptokurtic	Leptokurtic
Sample description for L3			
Statistical parameters	**Sample 1**	**Sample 2**	**Sample 3**
Mode	Medium grained	Medium grained	Medium grained
Median	Medium grained	Medium grained	Medium grained
Mean	Medium grained	Medium grained	Medium grained
Sorted	Well sorted	Well sorted	Poorly sorted
Skewness	Fine skewed	Fine skewed	Fine skewed
Kurtosis	Leptokurtic	Leptokurtic	Leptokurtic
Sample description for L4			
Statistical parameters	**Sample 1**	**Sample 2**	**Sample 3**
Mode	Fine grained	Medium grained	Coarse grained
Median	Fine grained	Medium grained	Coarse grained
Mean	Fine grained	Medium grained	Coarse grained
Sorting	Moderatelysorted	Poorly sorted	Well sorted
Skewness	Fine Skewed	Fine skewed	Coarse skewed
Kurtosis	Very leptokurtic	Mesokurtic	Platykurtic
Sample description for L5			
Statistical parameters	**Sample 1**	**Sample 2**	**Sample 3**
Mode	Coarse grained	Coarse grained	Coarse grained
Median	Coarse grained	Coarse grained	Coarse grained
Mean	Coarse grained	Coarse grained	Coarse grained
Sorting	Well sorted	Well sorted	Poorly sorted
Skewness	Coarse skewed	Coarse skewed	Coarse skewed
Kurtosis	Leptokurtic	Very leptokurtic	Very leptokurtic

MD= MEDIAN DIAMETER, CS=COARSE SAND, VCS=VERY COARSE SAND, MS=MEDIUM SAND, MST= MODERATE SORTING, PS=POORLY SORTED, VPS=VERY POORLY SORTED, VWS=VERY WELL SORTED, MWS=MODERATELY WELL SORTED, NYSM=NEARLY SYMMETRICAL, FSKW=FINELY SKEWED, SFSKW=STRONGLY FINELY SKEWED, CSKW=COARSE SKEWED, SCSKW=STRONGLY COARSELY SKEWED, PSKW=POSITIVELY SKEWED, VPSKW=VERY POSITIVELY SKEWED, LEPT=LEPTOKURTIC.

Grain Size Result

The grain size analyses carried out on the sand/sandstone in the study area presented in appendices. Below are summaries of the results:

- **Grain size**: 47% or 7 samples are coarse grained; 47% or 7 samples are medium grained. In addition, 6% or 1 sample was very fine to fine grained.
- **Sorting**: 40% or 6 samples are well sorted, 40% or 6 samples are poorly sorted, 20% or 3 samples are moderately sorted.
- **Skewness**: 47% or 7 samples are coarsed skewed, 40% or 6 samples are fine skewed, 13% or 2 are nearly symmetrical.
- **Kurtosis**: 27% or 4 samples are very leptokurtic, 53% or 8 samples are leptokurtic, 7% or 1 sample was mesokurtic, 13% or 2 samples are plakurtic.

In this study, 94% of the samples fall within the medium to coarse grained where as 6% of the samples are within the very fine to fine grained fraction. The result of the grain size analysis indicate that the coarse tail fraction make up 47% of the sediments.

The results of the grain size analysis, suggests that a strong competent river may have deposited the sediments and the environment of deposition of the sedimentary suites reflects a Beach/Shallow marine deposit setting. An insight into the unfolding environment of deposition with the study areas, Ihube outcrop, Umulolo outcrop, Onyekaba pit outcrop, Umuasua outcrop and Ugwu Nkalagu Obukpa outcrop reflect (Friedman's 1976) thought that beach sands are grouped into three populations deposited by (a) Rolling or sliding (b)Saltation and (c)Suspension. Beach sands are generally poorly sorted with predominance of the coarse grained. Medium grained clasts are deposited by saltation, whereas the fine grained clast are usually trapped among the coarse grained or are deposited with them as current slacked (Power, 1982)

Bivariate Scatter Graphs of Grain Size Parameters

Several bivariate plots were plotted for the various statistical parameters deduced from grain size analysis data such as, Mean grain size against Standard deviation(sorting), Skewness against Standard deviation (sorting). Combination of grain size parameters have been advocated by number of authors as a method suitable to distinguish between sediments deposited by different processes. This method is based on the assumption that different processes of transportation result in variations in grain size distribution. These are reflected in the statistical parameters which when plotted as scatter graph, produce bivariate cluster of samples affected by the same process, and separation of those samples influenced by different process.

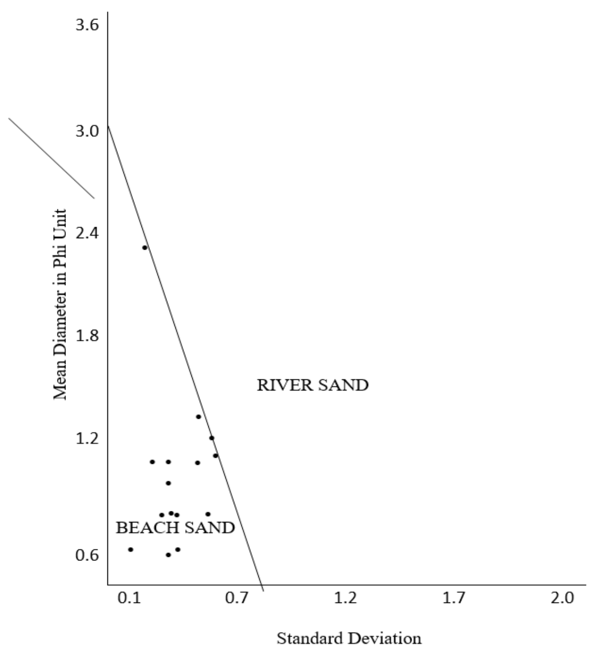


Fig. 30 Scatter Plot of Mean Grain Size VS Standard Deviation (after Molola and Weiser, 1968). The point on the right represent River marine deposit while the points on the left of the line represent Beach fields.

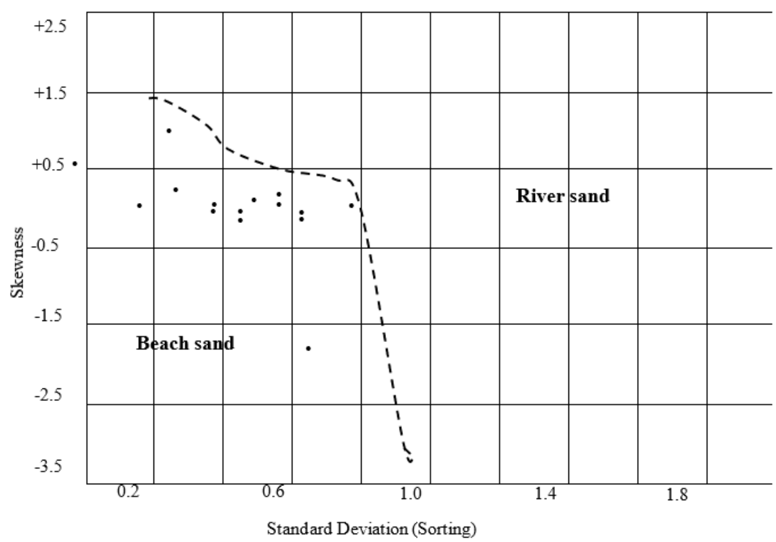


Fig.31: Scatter Plot of Skewness Diameter VS Standard Deviation (after Friedman,1961). The point on the left represent Beach sand while the points on the right of the line represent River sand fields.

The Particle Size Distribution

Environment of deposition can be discriminated using various statistical measures. The scatter-graph of grain size parameters have been employed by sedimentologist for years. The use of bivariate plots of the grain size parameters in environmental discrimination was on the assumption that the statistical parameters reliably reflect differences in the fluid-flow mechanism of sediments transportation and deposition (Alsharhan and El- Sammak, 2004).

Environmental Discrimination

The discrimination function (Y_1, Y_2 & Y_3) of Sahu,1964 cited in (Alsharhan and El-Sammak,2004) were applied to the grain size data from the sandstones in order to characterize the depositional setting.

- For the discrimination between Aeoliaon process and littoral (intertidal) environments, the discriminate function used given below

$$Y_1 = -3.688Mz + 3.701\sigma_i^2 - 2.0766SK + 3.113KG,$$

- Where MZ is the grain size mean, 8 is inclusive graphic standard deviation (Sorting), SK_1 is skewness and KG is the graphic Kurtosis.
  When Y_1 is less than -2.7411, Aeolian deposition is indicated whereas if it is greater than -2.7411, beach environment is suggested.
- For the discrimination between beach (Back shore) and shallow agitated marine (Subtidal)

Environment, the discriminate function used include

$$Y_2 = 15.634Mz + 65.7091\sigma_i^2 + 18.10871SK + 18.5043KG.$$

- If the value of Y_2 is less than 65.3650 beach deposition is suggested whereas if it is greater than 65.3650 a shallow agitated marine environment is likely.
- For the discrimination between shallow marine and the fluvial environments, the discriminate function below was used

$$Y_3 = 0.2852Mz - 8.7604\sigma_i^2 - 4.8932SK + 0.0482KG$$

- If Y3 is less than -7.419 the sample is identified as a fluvial (deltaic) deposit, and if greater than7.419 the sample is identified as a fluvial (deltaic) deposit, and if greater than -7.419 the sample is identified as a shallow marine deposits.7.419 the sample is identified as a shallow marine deposits.

Table 24: Environmental Description

Sample Number	Y1	Environment of Deposition	Y2	Environment of Deposition	Y3	Environment of Deposition
L1S1	1.3188	Beach	54	Beach	-5.115	Shallow marine deposit
L1S2	0.2755	Beach	90.75	Shallow agitated marine	-5.18	Shallow marine deposit
L1S3	-0.1684	Beach	46.32	Beach	-2.0575	Shallow marine deposit
L2S1	0.6673	Beach	57.18	Beach	-1.9	Shallow marine deposit
L2S2	5.6	Beach	50.6	Beach	-2.26	Shallow marine deposit
L2S3	1.09	Beach	60	Beach	-3.3	Shallow marine deposit
L3S1	-0.12	Beach	56	Beach	-1.04	Shallow marine deposit
L3S2	0.43	Beach	66	Shallow agitated marine	-2.36	Shallow marine deposit
L3S3	1.5	Beach	75	Shallow agitated marine	-3.3	Shallow marine deposit
L4S1	-170	Beach	89	Shallow agitated marine	-1.42	Shallow marine deposit
L4S2	-0.55	Beach	75	Shallow agitated marine	-4.72	Shallow marine deposit
L4S3	-0.075	Beach	42	Beach	-2.57	Shallow marine deposit
L5S1	1.97	Beach	55	Beach	-1.64	Shallow marine deposit
L5S2	6.04	Beach	75	Shallow agitated marine	-1	Shallow marine deposit
L5S3	1.5	Beach	68	Shallow agitated marine	-3.7	Shallow marine deposit

The value of Y_1 from the results calculated from the Nsukka formation varies from -7.441 to 6.05. Over 100% from the locations have Y_1 value that are greater than -2.7411 (table and this suggest beach environment B/E).The average values of Y_2 calculated for the Nsukka formation less than 65.3650 thus suggest a beach environment (BE).53% suggest beach environment and 47% suggest shallow agitated marine. (Subtidal environment). Following the result of this analysis, Y3 ranges from-1.0 to-5.115 suggestive of deposition in marine enrironment.100% of the samples haveY3 greater than -7.419 which is suggestive of Shallow marine environment. Plotting of the three discriminate functions (Y_1, Y_2, andY_3) as bivariate scatter plot was used to improve the success rate and refinement of the discrimination of the depositional environment. Figure43 shows the scatter plot ofY_2 against Y_1.Based on the classification of depositional environments 100% samples are plotted within the field of beach/shallow environment and Y_3 against Y_2 provided a bases for better discrimination of the environment.

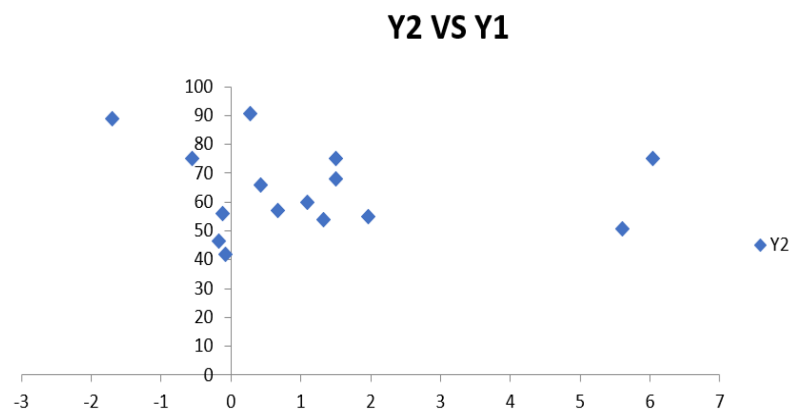


Fig.32: Scatter plot of Y_1 Beach Environment vs Beach/shallow agitated environment. The point on the left represent Shallow Marine while the points on the right of the line represent beach field.

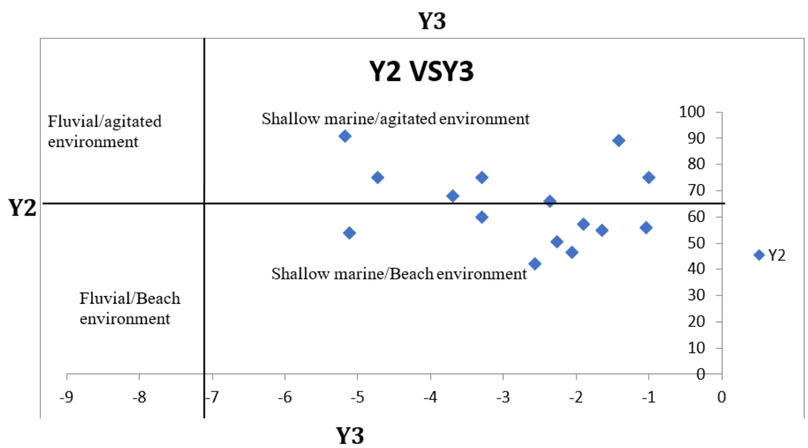


Fig. 33: Scatter plot of Shallow Marine Environment Y_3 VS Y_2 Beach/Shallow Agitated Marine Environment. The point on the left represent shallow marine Environment while the points on the right of the line represent Beach/Shallow agitated marine environment.

Petrography and Reservoir Properties

A total of 15 slides/thin section were petrographically analysed while 15 photomicrograph were made from that characterized the type, structure and composition of the rock encountered in the study area. Only sandstones facies were analyzed from Nsukka formation of the different locations.

Interpretation

The results show that Sub-litharenite is the dominant mineral in all the sample (83%) followed by lithic fragment (4.9%), Feldspars (5.7%) and diagentic minerals (6%) in all the locations of the study areas. The sand/sandstones are interpreted as lith-arenites based on Pettijohn's (1975) classification scheme.

Table 25: Summary of samples from Nsukka formation petrograpically analysed inthe study area.

Location	Sample number	Quartz (%)	Feldspars (%)	Lithic Fragment (%)	Diagenetic Minerals and cement	Minerals	Formation
1	1	80	7	5	8	Heamatite/silica	Nsukka Fm
1	2	90	4	2	6	Heamatite/silica	Nsukka Fm
1	3	91	4	3	2	Heamatite/silica	Nsukka Fm
2	1	90	5	2	3	Heamatite/silica	Nsukka Fm
2	2	83	6	5	6	Heamatite/silica	Nsukka Fm
2	3	85	5	5	5	Heamatite/silica	Nsukka Fm
3	1	89	7	2	4	Heamatite/silica	Nsukka Fm
3	2	65	10	15	10	Heamatite/silica	Nsukka Fm
3	3	65	5	15	15	Heamatite/silica	Nsukka Fm
4	1	84	7	4	6	Heamatite/silica	Nsukka Fm
4	2	89	5	1	5	Heamatite/silica	Nsukka Fm
4	3	85	5	3	7	Heamatite/silica	Nsukka Fm
5	1	85	5	5	5	Heamatite/silica	Nsukka Fm
5	2	79	6	5	10	Heamatite/silica	Nsukka Fm
5	3	90	5	2	3	Heamatite/silica	Nsukka Fm
Total average		83	5.7	4.9	6.3		

The nearly absence of feldspars and the abundance of iron minerals in all the samples may indicate intense weathering as a result of effects of humid climate that may have persisted from the Maastrichtian times to Recent (Kogbe,1979). The mineralogical composition of the iron minerals are dominated by geothites and heamatites which make up the iron contents of the ferruginized sandstones around Ihube and Umulolo areas(Oti,2007). The Litharinite grains from petrographic studies have been cemented by these iron minerals and silica and the original quartz grains have been etched, corroded and partially to totally replaced by goethite and heamatite hence the quartz grains often appear to be angular or sub rounded as seen in Appendix 4 and Table 4.

The mechanism for this replacement is attributed to diagenetic corrosion (Oti;2007). The occurrence iron minerals within the study areas (mainly geothite and heamatites) is widespread within the study areas and is interpreted as having been formed by the decomposition of clays and shales (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 the study areas. The abundant iron minerals in the samples suggests that they are post depositional, a weathering product that may be primary in origin as a result of 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 an oxidizing environment (Mason and More, 1982).

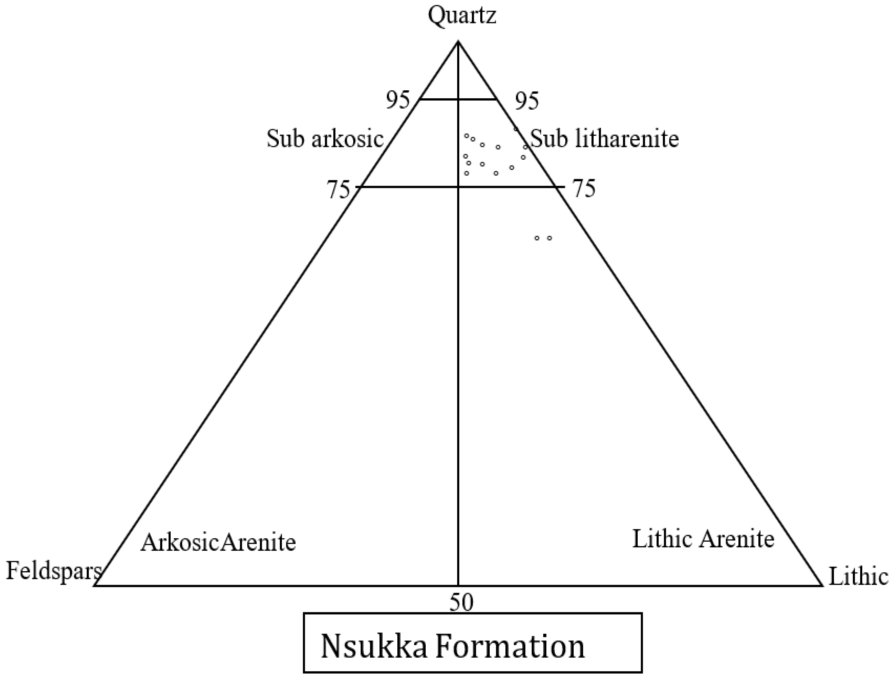
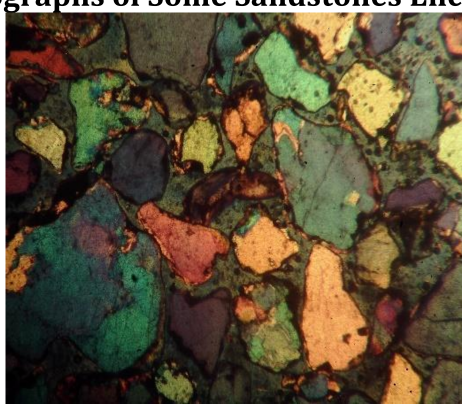
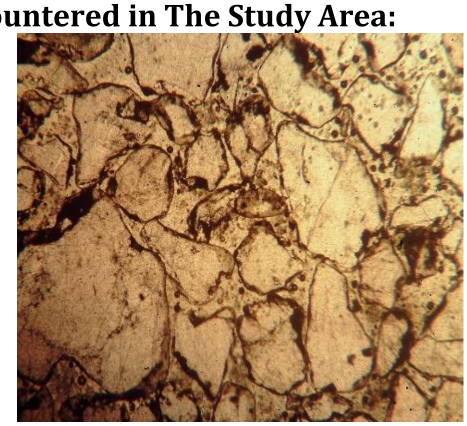


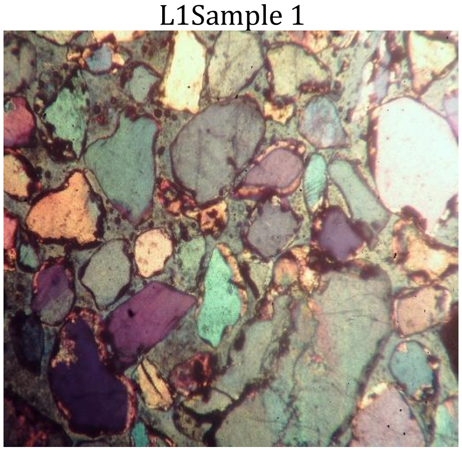
Fig. 34: Triangular Modal composition of sandstone in the study area (After Pettijohn, 1975)

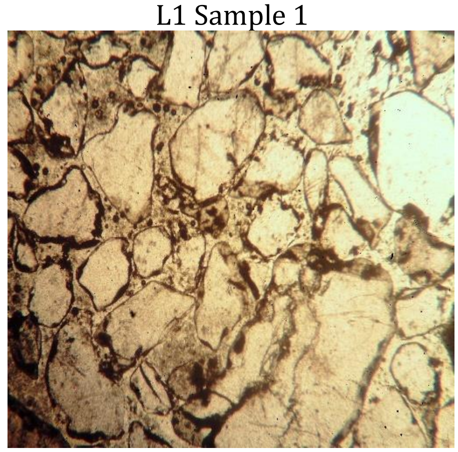
Location 1 Ihube Outcrop

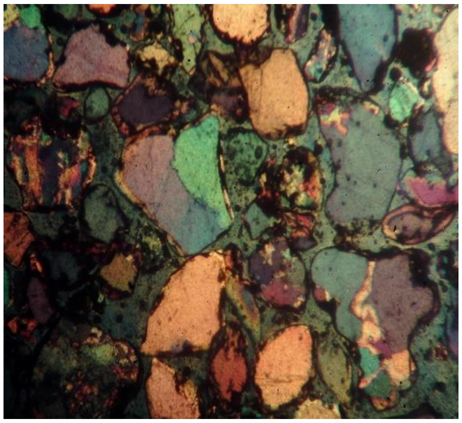
Photomicrographs of Some Sandstones Encountered in The Study Area:


L1Sample 1

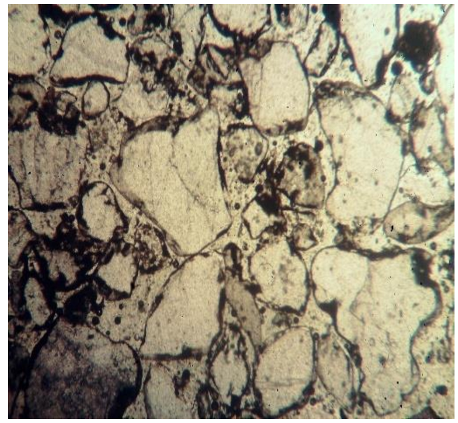

L1 Sample 1


L1Sample 2


L1 Sample 2

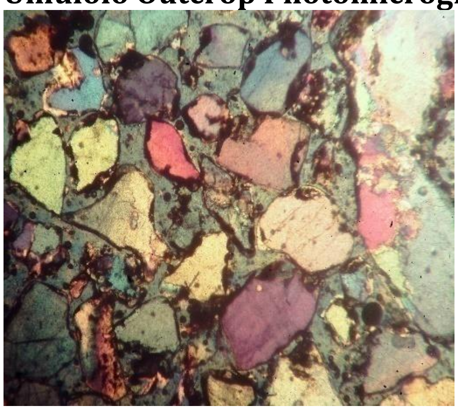


L1Sample 3

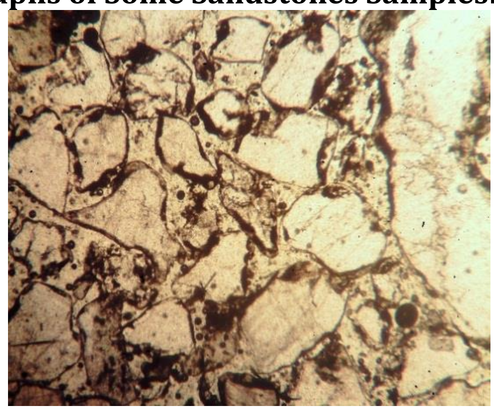


L1Sample 3

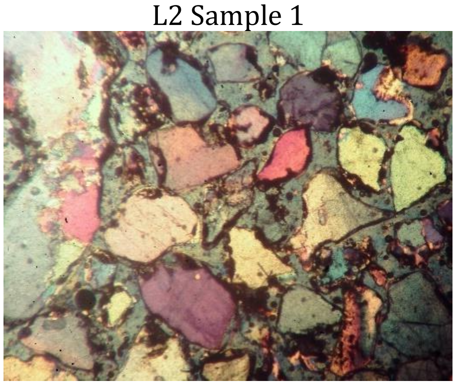
Location 2 Umulolo Outcrop Photomicrographs of Some Sandstones Samples:



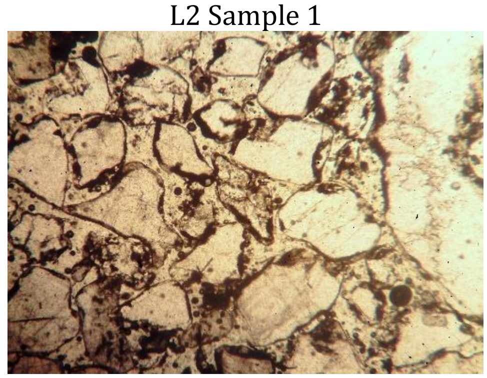
L2 Sample 1



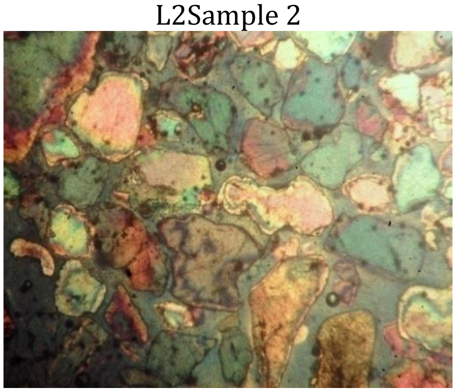
L2 Sample 1



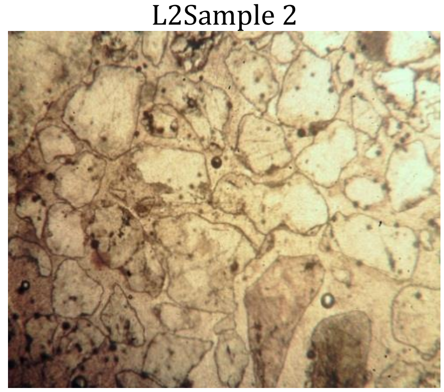
L2Sample 2



L2Sample 2

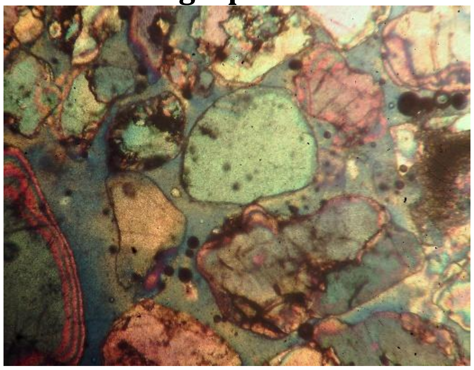


L2Sample3

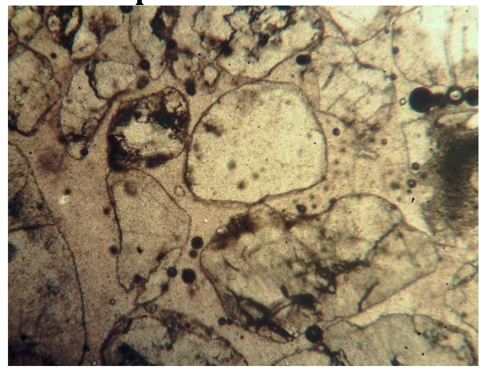


L2Sample 3

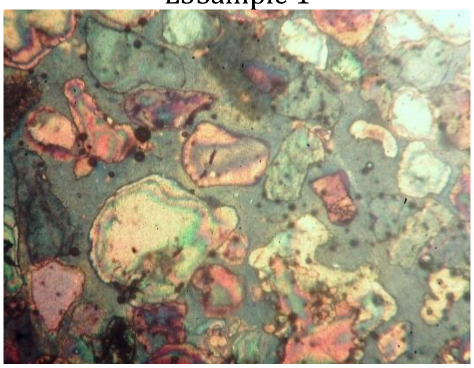
Location 3 Photomicrograph of Some Sandstones Samples:



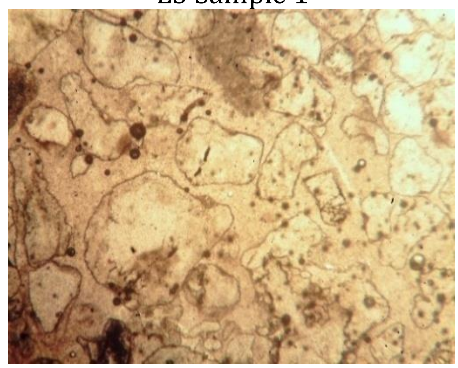
L3Sample 1



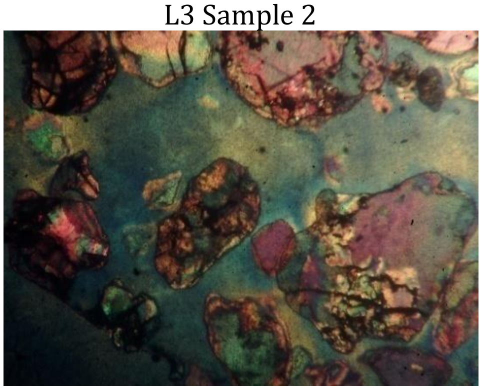
L3 Sample 1



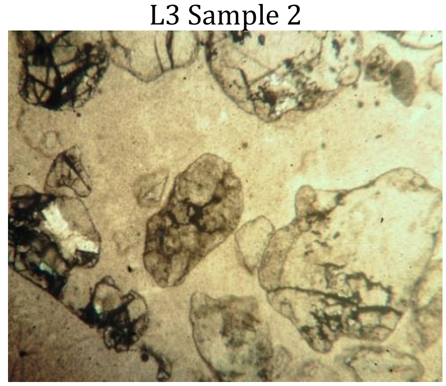
L3 Sample 2



L3 Sample 2

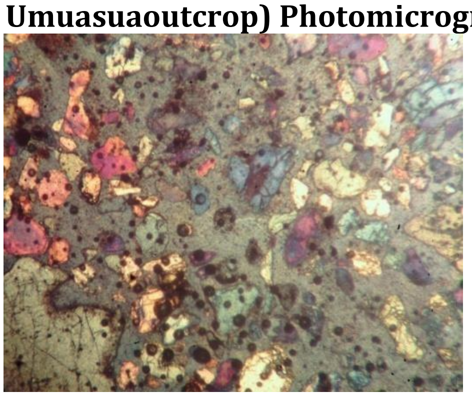


L3 Sample 3

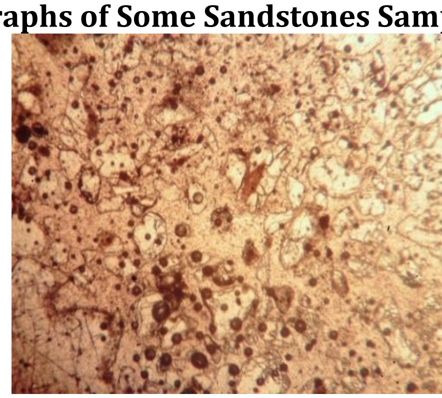


L3Sample 3

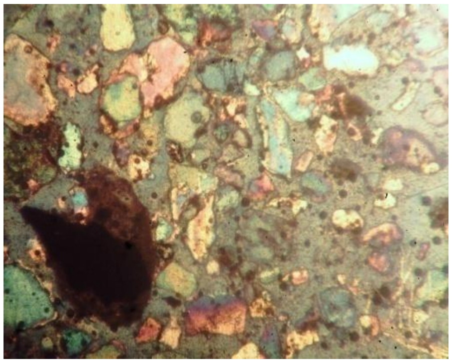
Location 4 (Umuasuaoutcrop) Photomicrographs of Some Sandstones Samples:



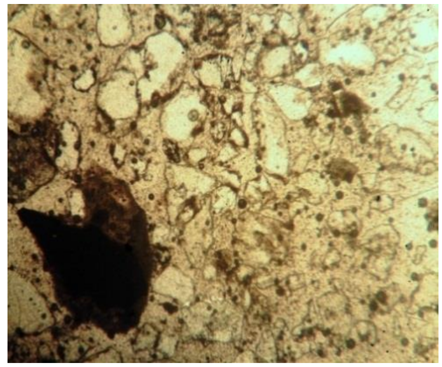
L4Sample 1



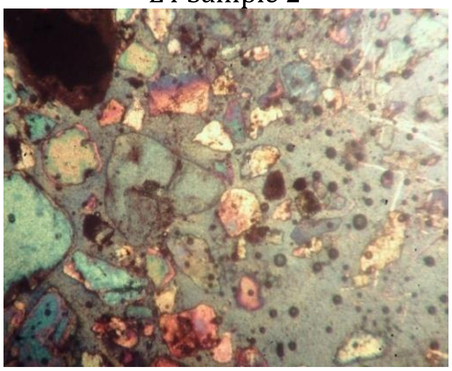
L4 Sample 1



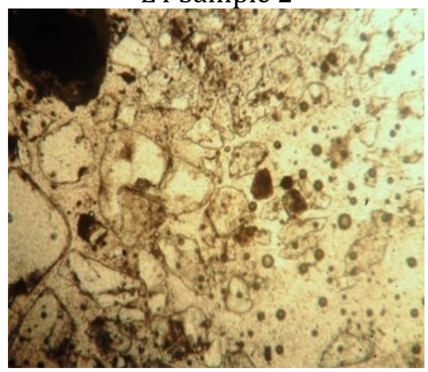
L4 Sample 2



L4 Sample 2

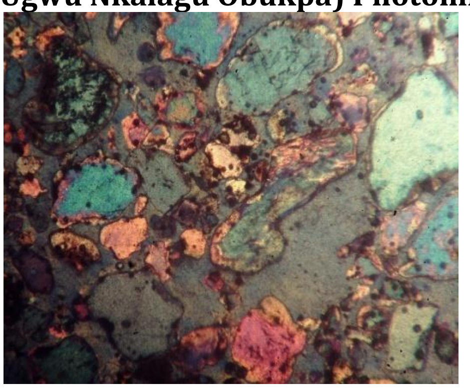


L4 Sample 3

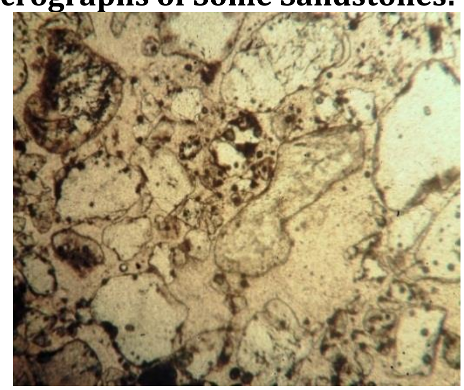


L4Sample 3

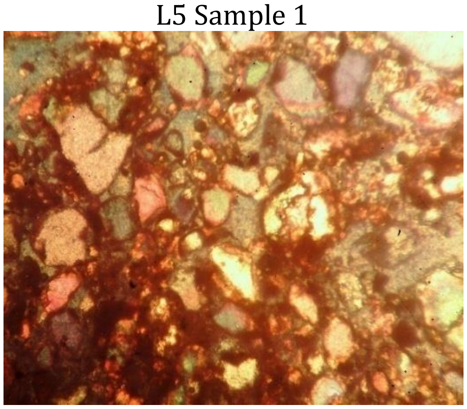
Location 5 (Ugwu Nkalagu Obukpa) Photomicrographs of Some Sandstones:



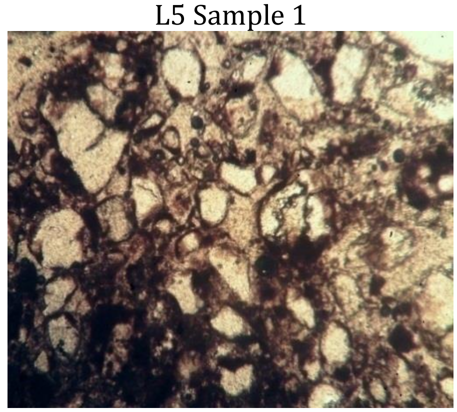
L5 Sample 1



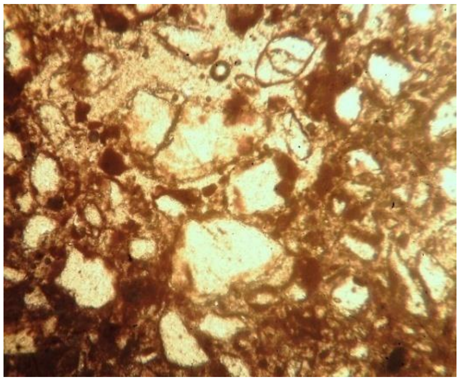
L5 Sample 1

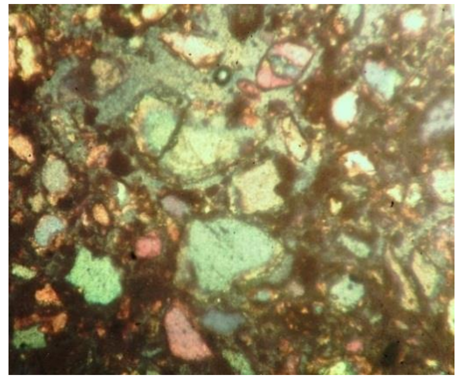


L5 Sample2



L5Sample 2


L5Sample 3


L5 Sample 3

Influence of Sorting on Porosity and Permeability

Sorting strongly affect porosity and permeability of both consolidated and unconsolidated sandstones (Beard and Weyl, 1973). Porosity increases with increase in sorting and vice-versa. As sorting decreases, the pores between the larger framework forming grains are in-filled by smaller particles. Permeability decreases for the same reason (Beard and Weyl, 1973).

The initial porosities of wet unconsolidated sand show a range of 28-44% porosity for poorly sorted to well sort grains. Well sorted grains tend to have a higher percentage of quratz than the poorly sorted sands, and they tend to maintain higher porosity and permeability during burial. Poorly sorted sands have more clay fractions and non-quartz (ductile grains) which deform easily during diagenesis to reduce porosity and permeability.

Petrophycal Analysis

This is the examination of rock petrophysical properties. These properties include porosity and permeability. The porosity was determined from thin-section by point count method according to (Berner 1980). Permeability is a function of grain size and sorting. The most important parameters for reservoir quality assessment are porosity and permeability. The results of the calculated reservoir permeability parameters using (Krumbein & Monk 1942) empirical equation in Table (26)

Based on the known fact, k=$760dw^2\, e^{-1.31}\, \sigma$

Where

- k=Permeability
- dw^2=Median value in mm
- $e^{-1.31}$=Exponential
- 760= Constant
- σ =Sort in value in ϕ
- n=porosity function. The porosity estimation (n) used in this research derived from Isotomine (1967)
- n=0.255(1+0.83^{μ}) where μ is the co-efficient of uniformity =sorting

Table 26: A scale of Porosity and Permeability given by J.O Etu-Efeotor (1997) is shown below

Table 26a: Porosity(ϕ)

Percentage porosity	Qualitative evaluation
0-5	Negligible
5-10	Poor
15-20	Good
Over 20-25	Very Good
Over 30	Excellent

Table 26b: Permeability (k)

Average Permeability value(k)	Quantitative Description
<10.5	Poor to fair
15.50	Moderate
250-1000	Good
>1000	Very Good

Table 26c: Porosity and Probability Result Table

Sample number	Porosity(ϕ) %	Permeability(k) millidarcy
L1S1	40	32.04
L1S2	42	15.05
L1S3	34	24.34
L2S1	49	16.91
L2S2	32	33.82
L2S3	49	32.30
L3S1	40	11.16
L3S2	40	16.76
L3S3	36	14.18
L4S1	31	3.68
L4S2	32	23.67
L4S3	45	33.83
L5S1	36	26.50
L5S2	42	12.18
L5S3	40	34.15
RANGE	40	30.47

The porosity of the sandstones ranges from 0.49-0.31 with average values of 0.40 while permeability (k) range from 34.15-3.68 with average value of 30.47 millidarcy. The permeability is attributed to presence of diagenetic mineral grained deposits.

Composition

The average composition of the major clast type is Sub-litharinite (83%), Feldspar (5.7%), lithic fragment (4.9%) and Diagenetic minerals and cement (6.3%) Table (4.8). The percentage compositions were usually estimated using percentage estimation chart. (Folk et al 1970), which combines the visual comparator of (Terry and Chillingar 1955) with computer generated visual comparators(Tucker,1988). Based on the average composition of the sandstones, they have been classified as Sub litharenites.

Table 27: Texture: A scale of mineralogical maturity given by Nwajide and Hoque (1985) is shown below

Limiting percentage of Q & (F+L)	Matrix Index & storage
Q ≥ 95% & (F+L) <5%	MI index ≥ 19.0 Supermature
Q 95 – 90% & (F+L) 5-10%	MI 19.0 - 9.0 Mature
Q 90 – 75% & (F+L) 10-25%	MI 9.0 - 3.0 Sub-mature
Q 75 – 50% & (F+L) 25-50%	MI 3.0 – 1.0 Immature
Q <50% & (F+L) >50%	MI < 1.0 Extremely immature

The sandstone in the study areas were very medium grained to coarse grained, poorly to well sorted, angular to sub- rounded with tangential, planner, concave-convex and sutured contacts especially in the polycrystalline quartz grain.

Maturity:
Roundness is an index of sediment maturity and sums up the abrasion of transport history of clastic grain. Roundness is controlled by the hydrodynamic conditions that prevailed at the time of sediment transport and deposition(Pettijohn,1956).Relatively sub roundness (based on visual comparison chart for estimating roundness and spherity from Tucker 1988) for the Nsukka formation revealed that these sediment have travelled short distance from the source while the spherecity tend to suggest the sediments had been re-worked (Kogbe,1979,Tucker 1988).Evidence of angular to sub rounded grains indicates that the sediments are texturally sub-mature but mineralogically mature. This suggests that the transport and depositing medium had low energy. The maturity rating of an environment depends on how much mechanical energy were exerted on the sediments after it had been transported to its final resting place by process operating at the depositional site (Kogbe,1979).

The presence of muscovite in some of the sandstone facies suggest that these sediments have been in suspension in the transporting medium for a long time, which also indicates that the texturally mature sediment gas witness re-working.

Diagenetic Evolution:
Evidence of mechanical compaction abound in the sandstone of Nsukka Formation. Present study revealed that most of the grains have been cracked/fractured; they have plano convex and structured contacts. Most of the muscovite flake are broken and bent, which is attributable to shearing of the grains as a result of the Pre and Post- Santonian event during the Cretaceous. Diagenetic mineral encountered in the Nsukka formation sandstone are unidentified clays, quartz in the form of quartz intergrowths and recrystallized quratz, iron oxides (Heamatite).

The diagenetic minerals may be post depositional; they partially or fully fill pore throats or are emplaced in cracks/fractures of the framework grains giving the sample as brownish to reddish coloration. There is no evidence of dissolution of feldspar or replacement of framework grains. The unidentified clays could be allogenic or authogenic in origin due to their relatively abundance. The alteration of detrital feldspar assemblage into clays may be attributable to weathering because the sediments may not be deeply buried as they may have undergone extensive alteration through some unknown combinations and dissolution (Pettijohn 1973).

CONCLUSION

A synthesis results of this research based on data generated from the work analysis, points to beach/shallow agitated marine environment origin for the sand/sandstones. Reservoir quality assessment of the grains indicates 47% of the sandstone has good porosity and permeability while 53% of the sandstone has good porosity but poor permeability due to the presence of abundant matrix minerals which are deleterious to flow. The Sandstone in spite of its good porosity is potentially a good reservoir due to its permeability and the shale part of the Formation can serve as a seal or cap due to its poor permeability. The Ajali sandstone is the basal unit of the Nsukka formation. The Ajali sandstone serves as a reservoir while the shale of the Nsukka Formation serves as a seal to the reservoir.

Contribution to Knowledge

The follow is the contribution to knowledge of this research.

- The origin and environment of deposition of the pebble beds (Nsukka and Ajali Formations) in the study areas now shows Ajali as the basal unit of the Nsukka formation shales.
- The composition of the pebbles is established as quartzite (Quartzite –pebble).
- Sedimentological, paleontological and palynofacies evidence reveals that Nsukka formation shales are tidally influenced flood plain and coastal plain deposits. Dominant ichnofossils recorded are *skolithos, planolites and Ophiomorpha.*

Recommendation

1. Geological maps are outdated and need updating to include recent landmarks such as roads, houses, schools, hospitals etc
2. Addition work is highly recommended especially in realm of sequence stratigraphy with the aim of understanding in detail the geological potential of the area.
3. Further work on the petroleum potential of the study area using more advanced geo-chemical

References

Adeniran, B.V., (1988). Sedimentary Sequences from the Mamu Formation (Lower Coal Measure), Anambra Basin, South eastern Nigeria. Msc Dissertations, Department of Geology and Mineral Sciences, University p.125.

Adeniran, B.V., (1995). Transitional Deposits of the Mamu Formation from South eastern Nigeria. NAPE Annual Conference, Book of Abstracts.

Agagu, O.K., Fayose, E.A., Peters., (1985). Stratigraphy and Sedimentation in the Senonian Anambra Basin of Eastern Nigeria. Nig. Journal. Min.% Geol V.22 P25-36.

Agumagu A.E., (1993). Sedimentology of Owelli Sandstone (Campanian-Maastrichtian) Southern Benue. G mina and geol. Vol29 No2 pp21-34.

Akaegbobi M.I., and Adeleye, A.M., (2001). Diagenesis and 1st implication on the Reservoir Quality of parts of Ajali sandstone in the Cretaceous Anambra Basin, Southeastern Nigeria. AAPG Annual Meeting, Denver, Colorado. June 3-6,2001.

Akaegbobi, M.I., and Schmitt, M., (1998). Organic Facies, Hydrocarbon Source Rock Potential and Reconstruction of Depositional Paleo environment of the Campanian – Maastrichtian Nkporo Shale Cretaceous Anambra Basin, Nigeria. NAPE Bull. Vol. 13. No1 p1-19.

Alsharhan, A.S. and El-Sammak A.A., Grin-Size Analysis and Characterisation of Sedimentary Environments of the United Arab Emirates Coastal Area. (2004), 465-477.

Amajor, L.C., (1986). Sedimentary Facies Analysis of the Compano-Maastrichtian Ajali Formation.SE Nigeria Bull. Nigeria Mining and Geoscience.Vol.21. p 171-176.

Beard D.C., and Weyl P.k., (1973). Influence of Texture on Porosity and Permeability of Unconsolidated Sands. AAPG Bull. VOl.57, p349-369.

Bhattacharya J.P., and Willis B.J., (2001). Lowstand Delta in Frontier Formation, Powder River Basin Wyoming: implications for Sequence Stratigraphy Models. AAPG Bull. Vol85 No2n pp 261-294.

Broardman. D.R., (1999). Changes in Patterns of Cyclicity in Upper Carboniferous through lower Pennsylvanian (Virgilian-Salemarin) Depositional sequence in the North American Mid- Continent AAPG Bull Vol 83 No7 p1193 Ass.

Buller, A.T., and McManus, J., (1979). Sediment Sampling. In: Estuarine Hydrogrsphy and Sedimentation by K.R. Dyer (Ed). Cambridge Univ. Press. P 87-130.

Burke, K. C., Dessauvagie, T. F.J., and Whiteman, A. J., (1971). The Opening of the Gulf of Guinea and the Geological History of Benue Depression and Niger Delta. Nature Phys.Sci. 233 (38) P 51 – 55.

Campton R.R., (1977). Interpreting the Earth. Pub. Harcourt Brace Jovenovich Inc. New York p 128, pp51-55

Cazier E.C., Cooper M.A., Geoffeatin S., Pulhum A.J., (1997). Basin Development and Tectonic History of the Illonois Basin, Eastern Cordillera and Middle Magdalena Valley, Colombia; reply. AAPG Bull Vol 81 No 8 pp 1332-1335

Coleman, J.M, (1981). Deltas-processes of deposition and models for exploration(2nd Ed) Minneapolis, MN, Burges pub.com,p124.

Cratchely, C.R., and Jones G.P., (1965). An interpretation of the Geology and Gravity Anomalies of the Benue Valley, Nigeria. Overseas Geol. Surv. Geophysics paper 1 p 26.

Curry etal., (1982). Undetr the Microscope, Blandford Press, Poole. P234.

Curry, J. (1995). Disposition of solar radiation in sea ice and the upper ocean. Journal of Geophysical Research: Oceans 100 (C8), 15965-15975

Davis. J.C., (1973). Statistical Data Analysis in Geology. Pub. John Wiley and Son in New York.

Etu-Efeotor J.O., (1997). Fundamental of petroleum Geology. Paragraphic publications, Port Harcourt, Nigeria.135pp.

Ekweozor, C.M., and Daukoru. E.M., (1984). Petroleum source-bed Evaluation of Tertiary Niger Delta-Reply: AAPG Bull Vol.68 pp 390-394.

Folk R.L., and Ward W.C., (1957). Brazos Rivers Bar; A study of the significance of grain size parameters.Journ.Sed.Petrol.Vol.27 pp23-38.

Folk, R. L., (1954). The Distinction between Grain Size and Mineral Composition in Sedimentary Rock Nomenclaeture.Jour.Geol.42,P344 -359.

Folk, R.L., Andrews, P.B., and Lewis, D.W., (1970). Detrital Sedimentary rock classification and nomenclature for use in New Zealand.N.Z.J Geol. Geophys. Vol.13,pp937-968.

Friedman, G. M., (1979). Differences in Size Distribution of Population of particles among Sand of Various Origins. Sedimentology. McMillan New York.

Friedman, G.M., (1961). Distinction between Dune, Beach and River Sands from their Textural Characteristics. Journal of Sedimentary Petrology,31, P 514 -529

Friedman, G.M., (1967). Dynamic Processes and Statistical Parameters Compared for Size Frequency Distribution of Beach and River Sands. Journ.Sedim.Petrol.37,P 327 - 354.

Friedman, G.M., Sanders, J.E., and Kopapaska-Merkel, D.C., (1992). Principles pf Sedimentary Deposit: Stratigraphy and Sedimentology. McMillan New York.

Hurst, A., Verstralen. L., Cown. B., Hartle Y.A., (1999). Sand-rich fairways in-deep-water clastic reservoir; Genetic units, capacity uncertainty and new approach to reservoir modelling. AAPG Bull.Vol83 No7, pp1096-1118.

Kogbe, C.A., (1989). Geology of Nigeria,2nd Edition P 325 – 334.

Kogbe, C.A., (1972). Geology of the Upper Cretaceous and Lower Tertiary sediments of the Nigerian Sector of the Iullemmeden Basin (West Africa), Geologische Rundschau.

Kogbe, C.A., (1976) Paleogeographic history of Nigeria; Kogbe C.A(ED) Elizabethan Pub. Lagos, P 232-252.

Kogbe,C.A.,(1979).The Cretaceous and Paleogene sediments of Southern Nigeria in Kogbe C.A(ed) Geology of Nigeria. Elizabethan Pub. Co. Lagos pp3-282.

Krezia R.D., Joiner S.D., Leininger S.C and Unoma G.I (1988). Define Reservoir- rock properties, deep-water depositional facies, Paleocene, Nigeria SPE Bull.SPEN9804.PP11-115.

Krumbien, W.C. and Monk, F.J., (1942). Manual of sedimentary petrology. Applton-Century Crofts, New York.

Krumbein, W. and Sloss, L. (1963) Stratigraphy and Sedimentation. W.H. Freeman and Co., San Francisco, 660 p.

Kuecher G.J. *et al.* (1990). Sedimentary Geology, Evidence old eposition rom individual tides and of tidal cycles from the Francis Creek Shale (host rock to the Mazon Creek Biota), Westphalian D (Pennsylvanian), northeastern Illinoi. Pages 11-137, 1239-143

Kulcar, Z. Crocetti. G.M., Lemkau, P. V. et al, (1971) Selected aspects of the edpidemiology of psychoses in Crotia, Yogoslavia II Pilot studies of communities. American Journal of Epidemiology 94, 118-25

Ladipo K. O., Nwajide C.S., and Akande S.O., (1992). Cretaceous and Paleogene Sequence in the Abalilki and Anambra Basins SE Nigeria. A Filed guide International Symposium on Geology of Deltas, Port Harcourt, May,1992.

Ladipo, K.O., (1986). A conceptual framework for the Anambra Basin paleogeography.22nd Ann. conf. Nigerian Min. Geosciences Society; Port Harcourt, Abstract vol.2 p71-72.

Lambiase J.J., (1980). Hydraulic control of Grain-Size Distribution in Microtidal Estuary. Sedimentology vol27, pp433-446.

Lawson, D.T., (1988). The Geology of Port -Harcourt-Enugu Express Road between47km-22km.A field Mapping Project presented to the Dept of Geology UNIPORT (unipub) pp5-22.

Lemon R.R., (1990). Principles of Stratigraphy. Pub. Merrill publishing Co. Columbus Ohio U.S.A pp7-25.

Lewis, W.D., and McConchie, D., (1994). Practical Sedimentology, 2nd Ed. Chapman and Hall, Pub. New York. P 213.

MacEachern J.A., Aitlin. B.A., and Pemberton, (1998). High-Resolution Sequence stratigraphy of early Transgressive deposits, Viking Formation, Joffre field, Alberta Canada. AAPG Bull. Vol 82 No5 pp 729-756.

Mail, A.D., (1984). Principles of Sedimentary Basin Analysis. Springer-Verlag, Berlin. P 490.

Mason, B., and Moore, C.B., (1982). Principles of Geochemistry (4th Edition), Pub. Wiley Eastern Limited. P 147-168.

Mebradu.S., (1990). Palynofacies of Enugu/Iva Valley Shales in Anambra State. Nigeria Jour. of Mining and Geol. Vol 27, No Pp 13-20.

Miall, A.D., (1992). Alluvial deposit. In walker, R.G., James, N.P (Eds), Facies Models: Response to Sea Level Change. Geological Association of Canada, pp.119-142.

Middleton, G.V., (1976). Hydraulic interpretation of Sand Size Distributing. Jour. Geol. Vol 84, P 40-426.

Milliken. K.L., (2000). Diagenetic Heterogeneity in Sandstone at Outcrop Scale. Breathitt Formation (Pennsylvanian) Eastern Kentucky. AAPG Bull. Vol; 85 No 5, Pp795-815.

Mode. A.W., (1991). Assemblage Zones, Age and Paleo environment of Nkporo Shale. Akanu Area, Ohafia SE Nigeria. Jour. Of Min. and Geol. Vol 27, No 1, Pp 107-114.

Mohaghegh, S., Arefi, R., Ameri, S., Aminiand, K., and Nutter, R., (1996). "Petroleum reservoir characterization with the aid of artificial neural networks." *Journal of Petroleum Science and Engineering*, 16(4), 263-274.

Moorehouse N.W., (1959). The study of rock in thin Sections. Pub. Harper and Row New York P 349.

Murat,R. C.,(1970). Stratigraphy and palegeography of Cretaceous and Lower Tertiary in Southern Nigeria: In Dessauvagie - T.F.J. and Whiteman, A.J (ed.) African Geolo. University of Ibadan Press. P 251-266.

Murat,R. C.,(1972). Stratigraphy and palegeography of Cretaceous and Lower Tertiary in Southern Nigeria: In Dessauvagie – T.F.J. and Whiteman, A.J (ed.) African Geolo. University of Ibadan Press. P 251-266.

Nicols Gary., (1999). Sedimentology and Sequence stratigraphy pub. Blackwell Science L.t.d pp 16-22

Nwajide C.S., (1990). Cretaceous Sediments and Paleogeography of Central Benue Trough. In Ofoegbu, C. O (ed). The Benue Trough, Structural Evolution, 19-38.

Nwjide C.S., & Hoque M., (1985). Problems of classification and maturity evaluation of a digenetically altered fluvial sand stone (1985).

Nwajide, C.S., and Reijers, T.J.A. (1997). Sequence architecture of the Campanian Nkporo and Eocene Nanka Formations of the Anambra Basin, Nigeria. Nigerian Association of Petroleum Explorationists Bull. vol.12, n.01, p. 75-87.

Obaje, N.G., Wehner, G.H., Scheeder, G., Abubakar, M.B., and Jauro, A., (2004). Hadrocarbon Prospectivity of Nigeria's Inland Basins: From the View Point of Organic Geochemistry and Organic Petrology. AAPG Bull. Vol.88. No.3 P325 – 353.

Oboh-Ikuenobe, F.E., Chuks G.O., and Jaramilo C.A., (2005). Lithostratigraphic Units of Anambra Basin. Correlation Chart Cretaceous Tertiary Strata in Southern Nigeria. Journ of Africa Earth Sci.Vol.41 P101-112.

Oti, MN., Postuma, G. (Eds), 1995. Geology of Deltas. A.A. Balkema, Rotterdam, p. 315.

Passega, R., (1964). Grain Size Representation by CM Patterns as a Geological Tool.Jour.Sediment.Petrol.Vol.34,P 830 - 847

Pemberton. S.G., MacEachern, J.A., Frey, R.W., (1992). Trace fossil facies models: environmental and allostratigraphic significance. In: Walker, R.G., James, N.P., (Eds), Facies Models: Response to Sea level Changes. Geological Association of Canada, pp 47-72.

Petters, S. W., (1979). Paralic Arenaceous Foraminifera from the Upper Cretaceous of the Benue Trough, Nigeria. Acta Palaeontological polonica Vol.24 No 4P 451-471.

Petters, S.W., and Ekweozor, C.M., (1982). Petroleum Geology of the Benue Trough Southeastern Chad Basin, Nigeria. AAPG Bull.Vol.68. No.8 P1141-1149.

Pettijohn E.J., (1956). Sedimentary Rock,2nd Ed.Harper and Bros.P 526

Pettijohn E.J., (1975). Sedimentary Rocks: Pub. CBS, P21-521.

Pettijohn E.J., Potter P.E., and Siever R, (1973). Sands and Sandstone. Springer-vertag, New York, p618.

Power, M.C., (1982). Comparison Chart for Estimating Roundnessa and Sphericity: AGI Data Sheet 18, American Geological Institute.

Reijiers, T. J.A., (1996). Selected Chapters in Geology. Shell Petroleum Development Company, Warri, Nigeria. P 87-90.

Reinick. H.E., Singh I.B., (1980). Depositional Sediments 2ndEdition.Pub. Springer-Varlag, New York pp 35-455.

Reyment R.A., (1965). Aspects of the Geology of Nigeria. University Press Ibadan.

Robinson J.W., and McCabe P.J., (1997). Sandstone and Shale-Body Dimensions in a Braided Fluvial System: Salt Wash Sandstone Member (Monson formation) Gar field County. AAPG Bull. Vol 81 No 8. Pp1267-1291.

Sagoe, K.M.O., and Visher, G.S., (1977). Population Breaks in Grain Size Distributions of Sands-A Theoretical Model.Jour.Sediment.Petrol.Vol.47 P 285 -310.

Salem A.M., Morad .S., Mato. L.F., and Al-Aasm. I.S., (2000). Diagenesis and Reservoirs quality Evolution of Fluvial sandstone during profession burial and uplift; evidence from the upper Jurassic Biopeba member Reconcauo Basin NE Brazil AAPG Bull.Vol.8 No 7 pp1010-1040.

Shanmugam G., Poffenberger. M., And Toro Alva J., (2000). Tide-Dominated Estuarine Facies in the Hollin and Napo (T and U) Formations (Cretaceous), Sacha Field, Oriented Basin Ecuador. APPG Bull. Vol 84 No 5 PP 652 – 682.

Short, K.C., and Stauble, A.J., (1967). Outline of the Geology of Niger Delta. AAPG Bull. Vol. 51(5) P 761-779.

Simpson, S., (1954). The Nigeria Coal Field. The Geology of parts of Onitsha, Owerri, and Benue provinces, Geol.Surv. Nogeria, Bull.No.24.

Spencer, D.W., (1963). The interpretation of Grain Size distribution Curves of Clastic Sediments. Journ of Sedim.Petrol.33, 180 - 190.

Tanner. W.F., (1964). Modification of Sediment Size Distributions. Journ. of Sedim.Petrology,34,P 156- 164.

Tattam, M., (1944). A review of Nigerian Stratigraphy. Report of Geol. Surv. of Nigeria.P27-46.

Tucker., Muarice E., (1991). Sedimentary Petrology, 2nd Ed. Pub. Blackwell Science Ltd. Oxford. P 260.

Tucker., Muarice E., (1988). Techniques in Sedimentology Pub. Blackwell science Ltd. Massachusette U.S.A pp,1-121.

Tyes R.S., Bhattacharya J.P., Lovsory J.A., Sindelar S.T., (1999). Geology and Stratigraphy of fluvio deltaic deposits in Vishak formation, application for development of Prudhoe Bay Field Akatk AAPG. Bull Vol 83 No10 pp1588-1623.

Van Hoeken – Klinkenberg, P.M.J., (1964). A palynological Investigation of some Upper Cretaceous Sediment in Nigeria. Pollen and Spores, Vol.6 No.1, P 209 – 231.Pl.1-7.

Van Wagoner, J.C., Mitchum Jr.,R.M., Campiom,K.M., Rahmanian, V.D.,(1990). Siliciclastic Sequence Stratigraphy in Well Logs, Cores an Outcrops: Concepts for High-Resolution Correlation of Time Facies. American Association of Petroleum Geologist Methods in Exploration Series 7-55.

Visher G.S., (1999). The Origin of Stratigraphic sequence. AAPG Bull Vol 83 No 7 p1205 Abs.

Visher, G.S (1969): GrainSize Distribution and Depositional Processes. Jour. Sedim. Petrol. 39, P1074 – 1106

Walderhaug Olav., (2000). Modelling Quartz Cement and Porosity in Middle Jurassic Brent group sandstones of the Kvitebjqrn fields North Sea. AAPG Bull Vol 84 No9 pp1325-1339.

Whiteman. A., (1982). Nigeria, it's petroleum Geology, Resources and Potential Vol 1, Pub.Graham and Trotman L.t.d London. pp26-220.

Wiemer, R.J., (1992). Developments in Sequence Stratigraphy: Foreland and Cratonic Basins. AAPG Bull. 76, P 965-982.

Wilson, R.C., and Bain A.D., (1928). The Nigerian Coalfield Section II. Part of Onitsha and Owerri Provinces: Bull. Geological Survey of Nigeria 12-54.

Wilson. M.D., and Pittman E.D., (1977). Authigenic clays in Sandstone Recognition and influence in reservoir properties at Paleo-environment analysis. Journal of Sed. Petrology Vol4 No7 pp3-33.

Wright, V.P., (Ed), (1986). Paleosols: Their Recognition and interpretation. Blackwell Scientific Publications, Oxford, p315.