International Journal of
Science Inventions Today
www.ijsit.com
ISSN 2319-5436
Research Article

PALEOENVIROMENTAL STUDIES OF NSUGBE FORMATION, ANAMBRA BASIN, NIGERIA

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ABSTRACT

Paleoenviromental Studies of the outcropping Tertiary Facies of the Anambra basin were carried out. The lithostratigraphic units in the study area is Nsugbe Sands-(Oligocene). These outcrops were exposed along the Onitsha-Otocha-Omor-Nsukka road and the Onitsha-Enugu Expressway. The univariate, bivariate, multivariate, pebble morphometry and sedimentary structures indicate that the sandstones were deposited in a variety of depositional settings such as fluvial, lagoonal, tidal and shallow marine environments. Petrographic and palaeocurrent results show that the sediments are derived from two sources namely the basement area and from pre-existing sedimentary terrain which exist east and northeast of the study area. The stratigraphic architecture shows various facies associations such as the tidally influenced channels, braided fluvial channels, flood plains and fluvial channels. The sands are medium-coarse grained mainly moderately sorted, subrounded, negatively to positively skewed and leptokurtic in distribution. The sands are mainly quartz arenites with a good to excellent reservoir quality hence have the potential to accumulate hydrocarbons. Tide dominated depositional system is proposed in this study based on integrated ichnological and sedimentological data.

INTRODUCTION

The Anambra Basin was formed following the Santonian tectonic pulse on a sub-basin formed by the differential subsidence of the fault block in the southern Benue Trough. It was a deltaic complex filled with a lithostratigraphic unit akin to those of the Cenozoic Niger Delta (Reijers, 1996).

The Niger Delta Basin was formed in the early Tertiary due to continued subsidence below the Anambra Basin which was then filled with transgressive-regressive cycles. The deposits are characterized by a series of Mega units referred to as depobelts which strike NW-SE and subparallel to the present day shoreline.

Several workers have studied the Anambra Basin and Niger Delta in terms of sedimentology, stratigraphy and sequence stratigraphic concepts (Nwajide and Reijers 1996; Obi, 2000). This authors studied the depositional model of the outcrops along Isele Azagba-Onitsha-Akwa areas of the northern Niger Delta and Anambra Basins. The analysis and interpretation of the data sets allow the reconstruction of sedimentary facies parameters, diagenetic histories, dominant controls on sequence development, and allow an added interpretation of the sediments of the northern Niger Delta and Anambra Basin reservoir qualities

AIM/OBJECTIVES OF THE STUDY

The aim of this research was to carry out a detailed study of the sedimentological and stratigraphic architecture of outcropping Tertiary facies of the Anambra and northern Niger Delta Basins, with a view to delineate the depositional model and to evaluate the outcropping units hydrocarbon potential.

Location of Study: The study area lies within latitudes 6^0 0' N and 6^0 30′ N and longitudes 5^0 30' E and 7^0 30' E. The area delineated for the present study stretches through Onitsha, Umunya, Akwa, Nanka, Ekwulobia all in Anambra State.

Previous Work: Ladipo (1988), Obi (2001, 2003) worked on sedimentary succession and response to tectonism in the Cretaceous Anambra basin. They concluded that the response of sediments to tectonism is dependent on overall facies organization in terms of transgressive-regressive cycles and synsedimentary soft sediment deformation.

Umeji (2003) obtained palynological data on the Ogwashi-Asaba Formation exposed at Ogbunike and from the studies distinguished six lithological units from base to top as follows: cross bedded medium grained sandstone, laminated carbobonaceus grey shale, medium grained sandstone, massive grey mudstone, and a thick overburden. She concluded that the boundary between the Nanka and Ogwashi Formations is a lateritised erosion surface i.e. a sequence boundary (SB), separating a highstand system tracts (HST) from a lowstand system tracts (LST).

Ladipo (1988) and Nwajide (1980) studied indices of tidal sedimentation and environments in the Anambra basin. They concluded that dominant cross stratification with herringbone structures, thick reactivation surfaces, tidal bundles and trace fossils *Ophiomorpha* and *Skolithos* are interpreted as tide dominanted sub-tidal foreshore to shoreface.

Nwajide and Reijers (1996), investigated the sequence architecture of the Campanian Nkporo Group and the Eocene Nanka Formation and interpreted the development in the basins. They concluded that development of sequences in both locations was dependent on sediment supply, local tectonics and relative sea level changes.

Francisca *et al.,* (2005) studied the lithofacies, palynofacies and sequence stratigraphy of Palaeogene strata in southeastern Nigeria and subdivided the succession into five units.

Stratigraphic Succession: Deltaic sedimentation in the Anambra Basin was controlled by the morphologic proximity of sediment sources, sea movements during the Campanian to Eocene times, and the circulation system leading to a gradual reshaping of the coastline. Therefore the stratigraphic succession documents transgressive-regressive cycles and the coastline arrangement which relates to variations in sediment deposition

The Tertiary succession in the Northern Niger Delta basin includes: the Imo shales, the Ameki Group, Ogwashi-Asaba and the Benin Formation.

The oldest Formations (Palaeocene-Eocene) in the Niger Delta form an arcuate exposure belt along the delta frame. These are the Palaeocene Imo Shale (fossiliferous blue-grey shales with thin sandstones); the Eocene Ameki Group-fossiliferous, calcareous clays, sandstone and shales; the late Eocene-Early-Oligocene lignitic clays and sandstone of the Ogwashi-Asaba Formation and the Miocene-Recent Benin Formation (Coastal Plains Sands). These formations are diachronous and extend into the subsurface where they have been assigned different formational names. The Akata, Agbada and Benin Formations document prodelta, delta front and delta top environments respectively.

METHODOLOGY

FIELD WORK:

The aspects of the sedimentary rocks usually recorded include bed thickness, texture, composition, diagenetic features, sedimentary structures.

In this study, the spot sampling method was employed whereby the outcrops were sampled as they were encountered, ensuring that all the lithologies were duly represented. One hundred samples were collected from the various locations studied.

LABORATORY WORK:

Sieve analysis is a widely accepted form of mechanical analysis to determine grain size parameters of sand size sediments. (Krumbein and Pettijohn, 1961; Folk, 1974; Buller and McManus, 1979) Sedimentary petrography involves the studies of depositional and diagenetic fabrics from thin sections of samples collected from an outcrop or exposure. The analysis results in mineralogical composition, grain shape, grain orientation, compaction, cementation, mineral replacement, matrix and porosity changes. In this study, seventy (70) thin sections of representative samples were studied

Light Minerals: The modal compositions of the sediments are obtained by knowing the nature of the contained grains which is obtained by grain mineralogy and the proportions of these grains present in the sediment. Two main techniques are used in determining the proportion of different grains, viz: point counting and visual estimation.

Point counting is the most accurate method of determining the modal composition of a sediment. The method employed in this work is the spot identification of each gain, cement and clayey matrix to identify pore spaces. (Van der Plas and Tobi, 1965; Soloman and Green, 1966). 250 points were counted on each thin section to give a sufficient representation of the components present in a given thin section to show composition and textures.

Visual estimation involves the visual comparison of the thin section with visual comparators. The visual comparators include grains of different shapes and sizes (Terry and Chilingar, 1955) and computer - generated random percentages (Folk et al., 1970).

Heavy Mineral Analysis: Heavy minerals are seldom seen in thin section and in order to investigate them, they must be concentrated and isolated. In this study, the separation employed the gravity separation method which allows the heavy minerals to be separated from the lighter fraction using tetrabromoethane $CHBr_3$ of specific gravity greater than 2.9. The samples already sieved at $\frac{1}{2}$ ϕ interval were used in the range of - 1/16mm or 2 - 4ϕ. This is so because some heavy minerals occur as fine grains hence are more in fine grained sediments.

Biostratigraphic Analysis: Biostratigraphic analysis aims at finding out the microfossil and palynomoprhs present in the sample of the study area.

PRESENTATION OF RESULTS

OUTCROP AND LITHOFACIES DESCRIPTION OF LOCATION 1:

Ferruginized Siltstone Layer: This location a road cut exposure is located along km 12, Onitsha-Omor road. It is about 18m thick with an extensive lateral extent. The exposure consist of ferruginized siltstone layer, clay/siltstone/sandstone heteroliths, medium-coarse grained ferruginized sandstone and a shale layer. The facies is reddish in colour, highly weathered and ferruginized. It has an average thickness of about 8.4m. The contacts with the underlying heterolithic bed is gradational.

Clay/Siltstone/Sandstone heterolithic unit: This unit consists of alternating claystone/siltstone with fine sandstone intercalations. The fine grained sandstone are laminated to planar cross beds at the base. The ratio of the clay/sand are almost equal depicting equal amount of deposition.

Medium-Coarse Grained Sandstone: This unit is about 5m thick with planar cross beds with an average dip of 7^{o} terminating in a clay sub unit at the base.

Shale Unit: This unit consists of shale predominantly with interbedded siltstones. It contains parallel lamination. It is about 4m thick.

OUTCROP AND LITHOFACIES DESCRIPTION OF LOCATION 2:

Lateritic Cover: This location is directly opposite the Nwafor Orizu College of Education. The average lateral extent is about 600m with an average height of 15m based a field relation. The general strike direction and dip is 230^{0} SW and 20^{0} NE.This unit is about 4m ranging with colours from reddish to pinkish patches. It is completely structureless with a sharp contact with the underlying ferruginized sandstone unit.

Medium-Coarse grained Sandstone: This unit is about 12m in thickness, laterally extensive. It is brownish in colour, showing a poorly sorted distribution and extremely consolidated. The sedimentary structures includes parallel lamination and herringbone structures.

Medium grained Sandstone: This unit is 3m in thickness and locally pebbly at the base, yellowish in colour and planar cross bedded. The contact with the unit below is sharp and scoured.

Conglomeritic Facies: This lithofacies consist of pebbles extending for about 5m and thinning to the eastern part of the exposure. No sedimentary structures are found.

Medium-Coarse grained Sandstone: This unit is 5m in thickness, ferruginized and planar cross bedded sandstone. The cementing material is identified as iron oxide.

FACIES ARCHITECTURE OF NSUGBE SANDSTONE:

Fluvial channels:The sandstone in this facies are ferruginized, medium to coarse grained and planar cross bedded. They are poorly to moderately sorted, subrounded to rounded. They represent deposition in a high energy environment of a fluvial origin.

Matrix supported conglomeratic facies: This facies unit consists of about 1m matrix supported conglomerate having a sharp contact with the underlying ferruginized sandstone layer. They are interpreted as braided river channel deposits.

Tidal bar channel:The tidal bar channel shows a planar cross bedded sandstone, occasionally flaser and lenticular bedding, current bidirectional reversals at the mid sections. The grain size range from medium to coarse indicating a fluctuation between moderate and high energy environment (Fig. 13).

GRAIN SIZE ANALYSIS/PROCESS INTERPRETATION:

Univariate Grain Size Parameters: The Nsugbe Formation at the exposed units has five samples each. This unit sample were analysed for grain size parameters.

Graphic Mean (GMϕ): The mean grain size of the sandstone units varies from 2.0 through 2.24ϕ in location 1 with an average of 1.64ϕ (medium) and 2.40 through 2.10ϕ in location II with an average of 1.7ϕ (medium).

Graphic Standard Deviation (GSϕ): The sorting of the units ranges from 0.51ϕ (moderately well sorted) to 1.10ϕ (poorly sorted) with an average of 0.68ϕ (moderately sorted) in location I and 0.68ϕ (moderately well sorted) to 1.18ϕ (poorly sorted) to 0.84ϕ (moderately sorted).

Graphic Skewness (GSKϕ): The skewness values ranges from 0.98ϕ (very positively skewed) to -0.28ϕ (negatively skewed) with an average 0.51ϕ (very positively skewed in location I and -1.21ϕ very negatively skewed through 0.04ϕ (near symmetrical) to 0.53ϕ (positively skewed) with an average of 0.29ϕ positively skewed) in location II.

Graphic Kurtosis (KGϕ): The analysed samples have a grain mean size of 1.64ϕ on location 1 and 1.70ϕ in location II. They are moderately sorted, positively skewed and leptokurtic in distribution. These results suggest that the environment of deposition as one of a moderate energy condition and its winnowing action are low to moderate. Hence moderately sorted sediment with unimodal to bimodal distribution suggests a fluvial process with an influence of a tidal incursion.

Pebble Morphometry for Nsugbe Sandstone: The pebble morphometric results of the Abata Nsugbe sandstone shows that mean values of Elongation ratio ranges from 0.600 – 0.920 with an average of 0.915. The values for flatness ratio ranges from 0.520 – 0.806 with an average of 0.703. While the values for maximum projection sphericity ranges from 0.155 – 0.287 with an average of 0.176 and oblate-prolate index range from -2.672 – 5.100 with an average of -3.276. The coefficient of flatness range from 64.25 – 84.10 with an average of 70.18. From the results, the pebbles show an Elongation value of 0.915 indicating fluvial origin, flatness ratio of 0.703 also indicating a fluvial origin. The maximum projection sphericity index (MPSI) ratio of 0.176 indicates a beach process, while the oblate-prolate index (OPI) value of -3.276 also indicates a beach origin. The coefficient of flatness value of 70.18 indicates a fluvial origin and roundness value of 60.10 indicates a high wave energy beach. The deposition of the pebbles show that the setting is of a shallow marine environment.

Pebble Geometric form for Nsugbe Sandstone: Several diagonistic classes shape occur in the classification of pebbles. Beach pebbles are platy, very platy, bladed and very bladed. While river pebbles are compact, compact bladed and compact Elongate, Gale (1990).

The result shows that the pebbles of the Nsugbe sandstone are dominantly platy and very platy. These shapes indicate that the beach processes lead to the deposition of the pebbles.

PETROGRAPHIC ANALYSIS:

Petrographic Analysis for Nsugbe Sandstone: Petrographic (light and heavy mineral) analysis results are presented in Table 1 and 2.

Light Mineral Analysis:

Location	Mineralogical composition	Texture	Type of quartz	Type of extinction	Type of contact	Maturity
NS 1	Quartz 249% Feldspar – Nil RF – Nil Cement – iron oxide	Subangular to subrounded moderately sorted	Mono- crystalline	Undulose	Point	Matured
NS 2	Quartz 98% Iron oxide cement 2%	Subangular to subrounded	Mono-crystalline	Undulose	Point	Matured
NS 3	Quartz 99% Iron oxide cement 1%	Subrounded	Mono- crystalline	Sharp	Point	Matured
NS 4	Quartz 98% iron oxide cement 2%	Subangular to subrounded	Mono- crystalline 94% Poly-crystalline 6%	Non-Undulose	Point	Matured

Table 1: Summary of this section analysis for light mineral for the Nsugbe sandstone

Heavy Mineral Analysis:

	% Non opaques									% opaque mineral	Total
Location	Zr	Trm	Rut	Ap	Gmt	Kya	Silli	Stan	Spn		
I	10	8	6	-	-	-	-	-	4	72	100
II	20	14	10	-	-				6	56	100

Table 2: Abundance of heavy minerals in the sandstone of the Nsugbe Formation at Onitsha-Omor Rd and Abata Nsugbe

The sandstone units of Location I and II were analysed for heavy minerals. The results are presented in Table.

Biostratigraphic Analysis for Nsugbe Formation:

Selected samples of the exposure were analysed for microfossils and palynomorphs.

Micropalaeontological Analysis: The samples analysed from the siltstone-shale horizon in location I were barren of microfossils. The absence of microfossil may be due to hostility of the environment.

Palynological Analysis: The results of the analysis in Table 3 shows that only the siltstone shale unit contain palynomorphs. These include *Leotriletes adriennis* spores, *Bombacaceae* and *Anecardiadiacare* pollens, dinocysts, dinoflagellates xylem and phloem vessels. This suite of spores and pollens with their low abundance and diversity is characteristic of tidal environment. The presence of xylem and phloem can be attributed to nearness to the source of sediments of the environment.

SEDIMENTARY STRUCTURES OF THE STUDY AREA:

Parallel Stratification: Parallel stratification within the study area See plate 1 shows a lower regime flow condition since they are well preserved and distinct hence the laminations range from parallel, parallel continuous to wavy or lenticular beddings. The distinctness and preservation of these lamination are related to the quietness of the water in which the sediments were accumulated because a slight change in bottom currents would destroy any precious laminations, the salinity of the water and the activity of benthic organisms. Therefore laminations are records of deposition below wave base, Pettijohn, (1975).

Plate 1: Shows parallel lamination

Horizontal Stratification: Horizontal bedding consists of tabular sets of laminae in a sandsize sediment, Harms and Fahsnesstock, (1965). They may also consist of lamina sets made up of a group of conformable laminae forming a distinct structure within the bed, Campbell, (1967). Horizontal lamination are related to the upper flow regime which is the rapid flow forming plane beds.

In the study area, for example the Nanka sand, (See Plate 2) the horizontal strata show a homogenous lithology which commonly medium – coarse grained with the boundaries being erosional and planar. Horizontal lamination may be formed by swash and backwash action of waves in a tidal environment.

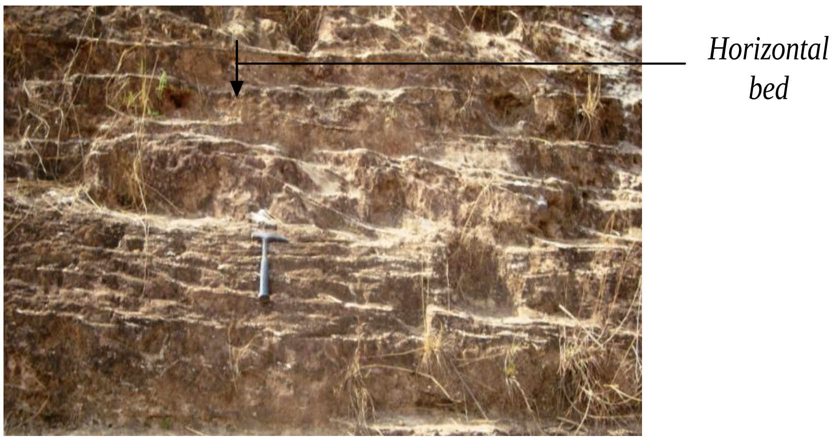

Plate 2: Shows horizontal bedding

Planar Cross Bedding: Planar cross beds are formed when bedforms develop from low flow velocity with low sinuosity and upper flow regime where a perfectly straight ripple generates cross laminae all dipping in the same direction. These bedforms are lying in the same plane where the surface at the bottom of the cross beds is flat and close to horizontal because of the absence of scouring in the trough, Nicols, (1999) The planar parallel cross beds as they occur in the study area are characterized by bounding surfaces that are also planar and occasionally undulatory hence they are erosional or non-erosional (See plate 3). Nwajide, (1982). The planar cross beds, occur both in the lower flow regime and in the upper flow regime. The planar cross bedding are the commonest sedimentary structures occurring with moderate angles of between 18^0 – 28^0.

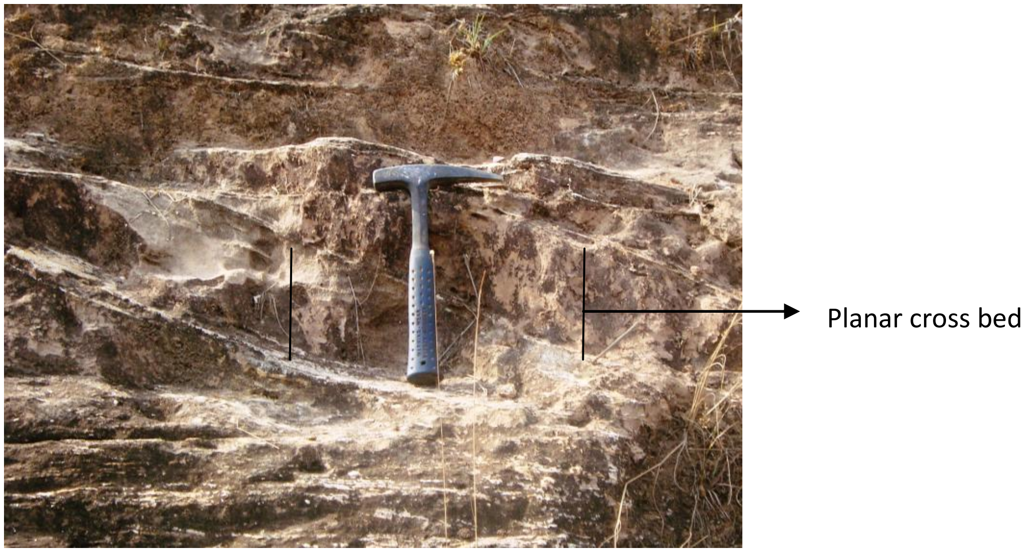

Plate 3: Show planar cross beds

Biogenic Sedimentary Structures:

Ophiomorpha* Burrows:Ophiomorpha* is formed by different organisms, which are mainly suspension feeders in high-energy environments. They are actually the dwelling tubes of shrimps, which belong to the genus Upogebia and Callianasa, Van de Graaff, (1972); Frey *et al,* (1978). They thrive more in beaches and intertidal environments, Seilacher, (1976); Pemberton, Maceachem and Frey (1992).*Ophiomorpha* burrows as they occur in the study area are indicative of a range of environment – tidal pools, intertidal and shallow sublittoral environments (See Plate 4) . The various range of environment is as a result of the fluctuations energy condition at the time of deposition in the area. Nwajide and Hoque (1979), describe the environments as intertidal to shallow sublittoral marine environment

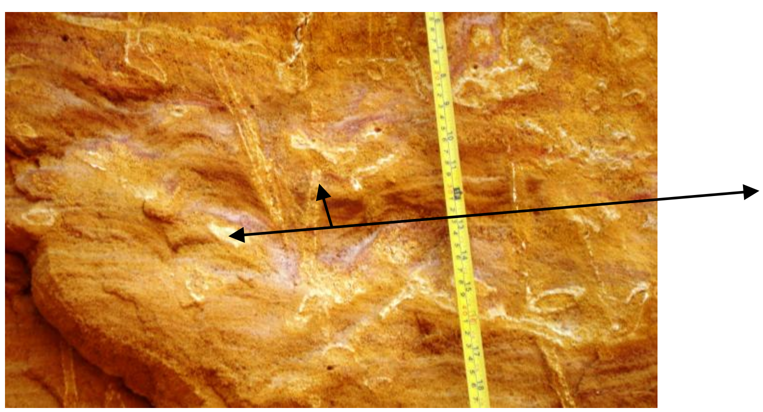

Plate 4: Shows vertical burrows of the Ophiomorpha

Skolithos Burrows: These are straight, unbranched vertical burrows that occur in the sandstone Units 1, 11 and 1V. The burrows have diameter of about 1-2cm and about 10cm in length. The burrow in-fill is structuresless with the same fabric as the host sandstones. *Skolithos* are burrows of suspension feeders – inhabiting high energy environment, Ekdale et al, (1984). These environments include foreshore, shoreface zones of breaches, bars, tidal flats, tidal deltas, estuarine and point bars, Frey and Howard, (1984). These burrows also indicate a high energy shallow marine environment.These burrows are found in units which shows fluctuation of energy indicative of a flood tidal delta.

DISCUSSION OF RESULT

This research work was carried out with the aim of a detailed study of the sedimentological and stratigraphic architecture with a view to evaluating the study area hydrocarbon potential. The major facies element of the outcropping units include – fluvial channels, braided fluvial channels, tidally influenced channels and flood plain deposits. The outcropping units have the potential to accumulate hydrocarbons based on its hydrocarbon characteristics and migration pathways with the older palaeocence shale of the Imo Formation serves as its source rock.

A new depositional model is hereby proposed based on integrated sedimentologic, stratigraphic and ichnological attributes. An evaluation of the sieve analysis results of the the outcropping units of Nsugbe is 1.78ϕ according to the size scale of Wentworth, (1922) in Tucker (1988). The mean grain size in a sediment is largely a function of the energy of the processes controlling transport and deposition, that is, the particles are segregated according to their hydrodynamic behaviour which depends on size, specific gravity and shape. Hence the medium to coarse fraction indicates a high energy environment and the fine fraction shows a low energy of deposition or due to the morphological maturity of the source rocks, Adeleye, (1974). The depositional mechanism of this sequence indicates a tidally influenced environment.

From the mechanical analysis results, the results shows wide range of all grain sizes (fine, medium - coarse) being represented. The majority of the analyzed samples show a size range of (0-2ϕ) which is equivalent of medium – coarse grains. They show unimodal to bimodal modes of distribution with a strongly unimodal mode. The unimodality of some of the histograms imply that the sediments might have been deposited in one phase and have not undergone much reworking or a deposition, Kukal, (1971).

The sedimentary structures observed in the study area include parallel, horizontal, cross stratifications and biogenic structures. The parallel stratifications are preserved as lamination, which indicates a lower flow regime condition and are related to the quietness of the water as the sediments are accumulated. They are therefore a record of deposition below wave base, Pettijohn (1975). Horizontal stratification, a result of upper flow regime, forms plane beds, which show a homogenous lithology commonly medium - coarse grain with either erosional or planar boundaries. These stratifications may occur due to swash and backwash action of waves in a tidal environment, as is the case in the study area.

The planar cross beds indicate the major transport direction, which is dominantly northeasterly and occasionally southwesterly. The trough cross beds represent smaller bed forms of tidal bars. The differences in direction of the planar and trough cross beds suggest a waning and fluctuating current direction which forms the smaller bedforms as the strength of the current decreases, Allen and Collison, (1986). The ripple bedforms, which are asymmetric indicate that the sediments are loose and unconsolidated, Reineck and Singh, (1973); Potter and Pettijohn, (1978). The trough cross beds are often associated with sand wave deposits hence they indicate a tidal origin.

In the bathymetric zonation of trace fossils, the *skolithos ichnofacies* is assigned the littoral sand assemblage i.e. shallow marine, Sellacher, (1967). Hence *ophiomorpha* and *skolithos* are diagnostic of the shallow marine environment.

The mineralogical study of the samples reveals that quartz is the most dominant light mineral, which exclusively forms the framework. The quartz grains are both monocrystalline and polycrystalline with undulose and sharp extinction. The degree of undulosity in monocrystalline and polycrystalline quartz grains indicates strain due to progressive disorientation of the grains during metamorphism hence the sediments of the study area are partly derived from a basement origin. The evidence from heavy minerals shows that zircon, tourmaline, rutile, kyanite and staurolite are all present indicating a plutonic and a metamorphic terrain probably a basement complex. Also the high sphericity of the quartz grains, size, sub angular to subrounded class, high percentage of monocrystalline quartz, rare microline, rare quartz overgrowth, indicate that the sediments have been in suspension hence witnessed a reworking which is in agreement with Suttner et at, (1981). Therefore part of the sediments of the study area was probably deposited through a multicycle origin.

The complete absence or rare presence of feldspars indicates an intense chemical weathering in a humid climate. This result is in agreement with the work of Hoque, (1976) on the Tertiary Anambra Basin. This complete removal of feldspars from the sediments of the study area occurred in the basin of deposition due to the high energy within the depositional environment. Hence the sediments in the study area were therefore deposited in a warm humid climate.

The outcropping units show a high potential of reservoir qualities if the right traps and source rocks are available. The coefficient of variance against mean grain size shows that more than a half of the sediments are moderately to very well sorted hence the porosity is interpreted as good to excellent.

The facies architecture of the study area shows they are tidally influenced channels and flood plain deposits all being deposited at varying environments based on high, moderate or low energy fluctuation and the dominant system either fluvial or tidal incursions.

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