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Research Article

SEDIMENTOLOGICAL ATTRIBUTES AND STRATIGRAPHIC ARCHITECTURE OF EBENEBE FORMATION, ANAMBRA BASIN, NIGERIA

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ABSTRACT

Sedimentology and stratigraphic architecture of the outcropping Tertiary Facies of the Anambra basin were carried out using twenty lithologic outcrop units. The lithostratigraphic units in the study area include: Ebenebe Sand Member (Palaeocene). 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. A new model of a tide dominated depositional system is thus proposed in this study based on integrated ichnological and sedimentological data.

Keywords: Sedimentology, Anambra Basin, Stratigraphy, Outcrops, Lithostratigraphy,Facies.

INTRODUCTION

The Benue Trough is a linear NE-SW trending feature thought to have formed on the failed arm of a rift associated with the splitting of the Godwana super-continent. It is an intracratonic basin subdivided into the northern, central and southern parts (Murat, 1972; Burke, 1972; Nwajide and Reijers, 1996). 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 a kin 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 was then filled with transgressive-regressive cycles between, in the Tertiary. 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 author 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 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 (See Location 1).

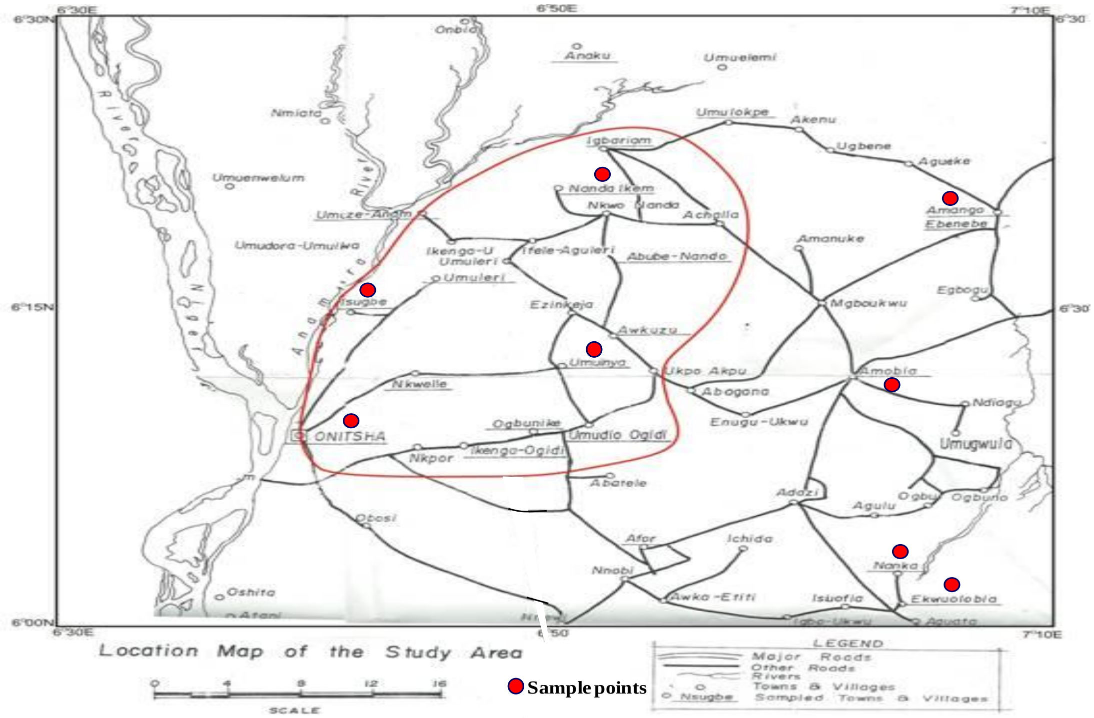

Figure 1: Location Map of the Study Area

Previous Work: Several workers have studied the Anambra and Niger Delta Basins. They include, Short and Stauble (1967); Adegoke (1969), Agagu *et al.,* (1980, 1986); Amajor (1986, 1987, 1991); Arua (1980, 1986); Avbovbo (1978); Benerjee (1981); Coleman and Ladipo (1988); Burke (1971); Ekewozor *et al.,* (1994); Hoque (1977); Ladipo (1988); Ladipo *et al.,* (1992); Knox *et al,* (1989); Koledeye *et al*., (2003); Nwajide (1980, 1996, 2004); Obi (2001, 2003); Reijers and Nwajide (1997).Ladipo (1986) and Amajor (1991) reported on the sedimentary facies and depositional mode of the Cretaceous Ajali Sandstone of the Anambra Basin.

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 carbonaceus 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

Stratigraphic succession in the Anambra and Niger Delta Basins: 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 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.

MATERIALS AND METHODS

The depth, scope and therefore methods employed in the study of sedimentary rocks are dependent on the purpose of study, time and fund limitations. However most sedimentological studies aim at interpreting the depositional environments and building the depositional model. This present work on Ebenebe Sandstone. is the unit studied. Stratigraphic sections were measured and related exposures examined for possible correlation.

Field work: The study of sedimentary rocks in the field is best done by observing, measuring and recording as appropriate. The ultimate aim of the study of sedimentary rocks/outcrops is the interpretation or reconstruction of ancient depositional environments, stratigraphic correlation all leading to palaeogeographic reconstruction. (Tucker, 1988; Miall, 1990).

During the field work, which involved first the reconnaissance and then the actual mapping exercise, several tools and aids were used: topographic/base maps, hammer, chisels, dilute acid, hand lens, penknife, tape for measurement, camera, field notebook, safety coverings, binoculars, masking tape, logging template, compass/ clinometer, sample bags.

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

(i) Sampling 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.

(ii) Graphic Logging Graphic logs were generated by measuring and recording data through vertical section: rock type, bed thicknesses/bed contacts, grain size, colour, sedimentary structures, palaeocurrent direction, thicknesses.

PRESENTATION OF RESULT

Outcrop Description of the Ebenebe Sandstone: The outcrop is located along the Onitsha-Omor-Nsukka Road at Igbariam and Nkem Nando. It is a road cut exposure which is about 25m thick and laterally extensive. The contacts are sharp to gradational. The lithofacies encountered are shale unit, fine-medium grained sandstone, gravelly unit, siltstone and lateritic cover

Lithofacies Description:

(a) Shale Unit: The shale sub unit is milky to grey in colour showing parallel lamination. It is about 4m thick.

(b) Fine-Medium Grained Sandstone: This unit consists of white, friable sand of about 12m thick. The sands are angular to sub angular and showing planar cross bedding with dips of about 25^0, clay laminae are very common within the sand and burrows of trace fossils belonging to chondrites. Thalassinoides, skolithos and Ophiomorpha are abundant. All these occur at the lower part of the unit while the upper part are barren of macrofossil.

(c) Siltstone Unit: This unit is only about 0.6m thick occurring as a lense which thins out at both sides of the exposure. It trends at 90^0 E-W and dips at 2^0. This siltstone unit grades upwards into the sandstone unit.

(d) Gravelly Unit: The gravel unit is about 0.8m thick. They are light coloured, essentially quartz arenites showing parallel alignment to the basin.

(e) Lateritic Cover: The unit is about 6m thick consisting of massive soil. The colour varies from yellowish to brick red.

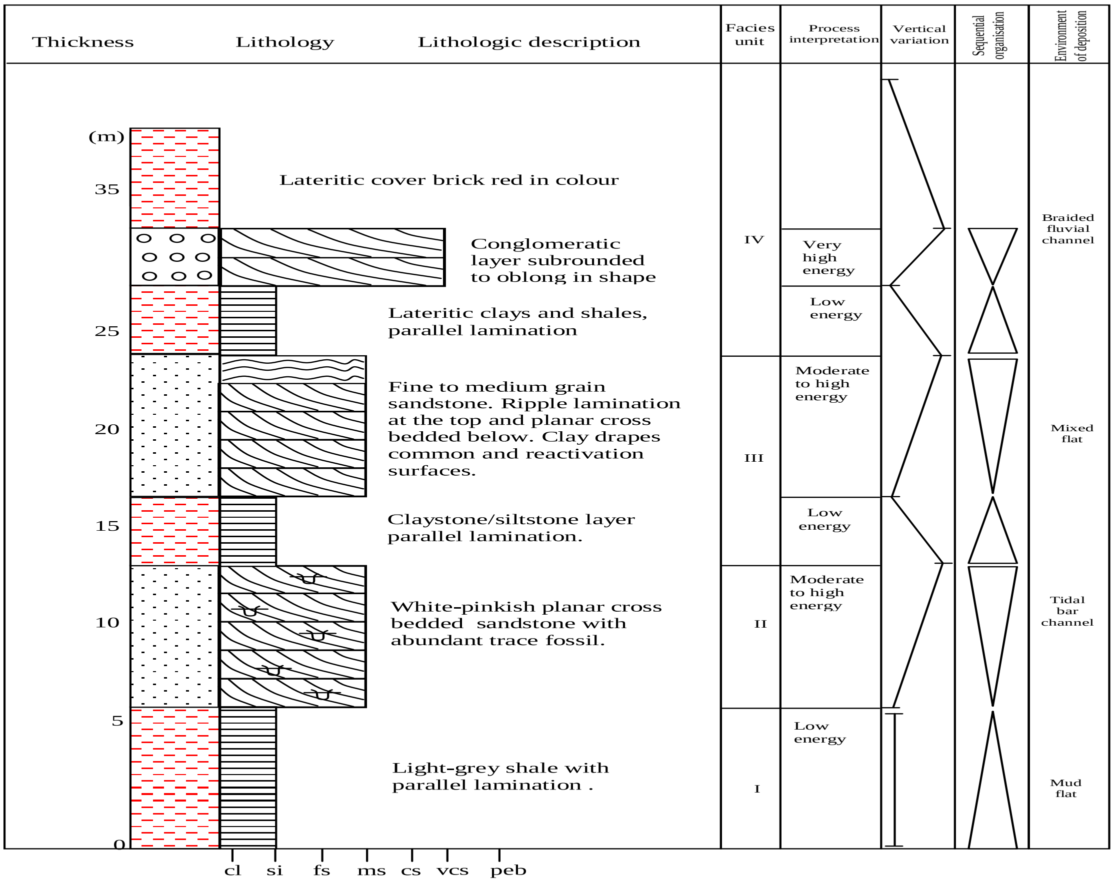

Figure 2: Lithologic Description of Ebenebe Sandstone at Nkem Nando

Facies Architecturte of the Ebenebe Sandstone:

(i) Fluvial braided channels: This unit constitute the topmost facies consisting of subrounded to oblong conglomerate, largely compact bladed with planar cross bedding. They are poorly sorted and no evidence of trace fossils. They are interpreted as braided channel.

(ii) Tidal bar channel: This is the lower part of the formation showing medium to coarse grained sands with numerous clay drapes, reactivation surfaces and ripple lamination. Lower in the section, herringbone structures are abundant with numerous bioturbation. The sands are moderately to well sorted and they are interpreted as sand bar channels

Univariate Grain Size Parameter:

(a) Graphic Mean (GMϕ): This is a measure of the average diameter of grains in the sediment. The interpretation of Folk and Ward (1957) was use ;. -1.0 – 0.0 Very coarse sand, 0.0 – 1.0 Coarse sand, 1.0 –

2.00 Medium sand, 2.0 – 3.0 Fine sand, 3.0 – 4.0 Very fine sand, 4.0 – 5.0 Coarse silt

The analysed samples show that the sediments range from 0.88ϕ (coarse sand) to 1.7ϕ (medium sand) with an average (1.25ϕ) medium sand. The samples are mostly medium to coarse which represents a high energy environment with fluctuation of low energy at some periods of deposition (Pettijohn, 1975).

(b) Graphic Standard Deviation (GSϕ) : This is a measure of the sorting or spread of the distribution around the mean. Using Folk and Ward (1957) in Tucker (1988) interpretation. < 0.35Ø Very well sorted, 0.35 – 0.51 Well sorted, 0.51 – 0.71 Moderately well sorted, 0.71 – 1.00 Moderately sorted, 1.00 – 2.00 Poorly sorted, 2.00 – 4.00 Very poorly sorted, > 4.00 Extremely poorly sorted.

The samples range from (0.64ϕ) moderately well sorted to (0.86ϕ) moderately sorted with an average of (0.74ϕ) moderately sorted. The result shows that hydrodynamic condition operating is high at the time of deposition.

(c) Graphic Skewness (GSKϕ): The skewness measures the degree of asymmetry of the distribution. The results range from (0.10ϕ) positively skewed to (0.28ϕ) negatively skewed and (0.4ϕ) very negatively skewed with an with an average of (-0.02ϕ) nearly symmetrical. This indicates that the sediments are fair to uniformly skewed.

(d) Graphic Kurtosis (KGϕ): The kurtosis parameter measures the peakedness of the distribution. The results of the analysed samples show values ranging from (0.54ϕ), very platykurtic through (0.94ϕ), mesokurtic to leptokurtic (1.12ϕ), leptokurtic with an average of (1.10ϕ) that is, mesokurtic. This is suggestive of a generally better sorting at the tails than the central portion of the distribution.

Parameters	**Mean ϕ**	**Sorting ϕ**	**Skewness ϕ**	**Kurtosis ϕ**
	0.88 – 1.70	0.64 – 0.86	0.10- 1 - 0.28	0.54 – 1.13
Average value ϕ	1.25 ϕ medium sand	0.74 moderately sorted	- 0.02 nearly symmetrical	1.10 Mesokurtic

Table 1: Summary of Results (Univariate grain size)

Sample No	Mean	Sorting	Skewness	Kurtosis
EB 1	1.15 medium sand	0.84 moderately sorted	-0.23 negatively skewed	1.08 mesokurtic
EB 2	1.40 medium sand	0.93 moderately	-0.29 negatively	1.23 leptokurtic
EB 3	1.46 medium sand	0.82 moderately sorted	0.14 nearly symmetrical	1.09 mesokurtic
EB 4	1.33 medium	0.75 moderately sorted	0.013 symmetrical	1.02 mesokurtic
EB 5	1.63 medium sand	0.76 moderately sorted	-0.21 negatively skewed	1.03 mesokurtic
EB 6	1.22 medium sand	0.76 moderately sorted	-0.09 negatively	1.05 mesokurtic
EB 7	1.4 medium sand	0.81 moderately sorted	-0.06 negatively	0.92 mesokurtic
EB 8	0.8 coarse sand	0.83 moderately sorted	-0.03 negatively	1.06 mesokurtic
EB 9	0.85 coarse sand	0.87 moderately sorted	-0.05 negatively	1.09 mesokurtic
EB10	0.87 coarse sand	1.10 poorly sorted	0.104 negatively	1.13 leptokurtic

Table 2: Size frequency parameters for the Ebenebe sandstone

Mean grain size:

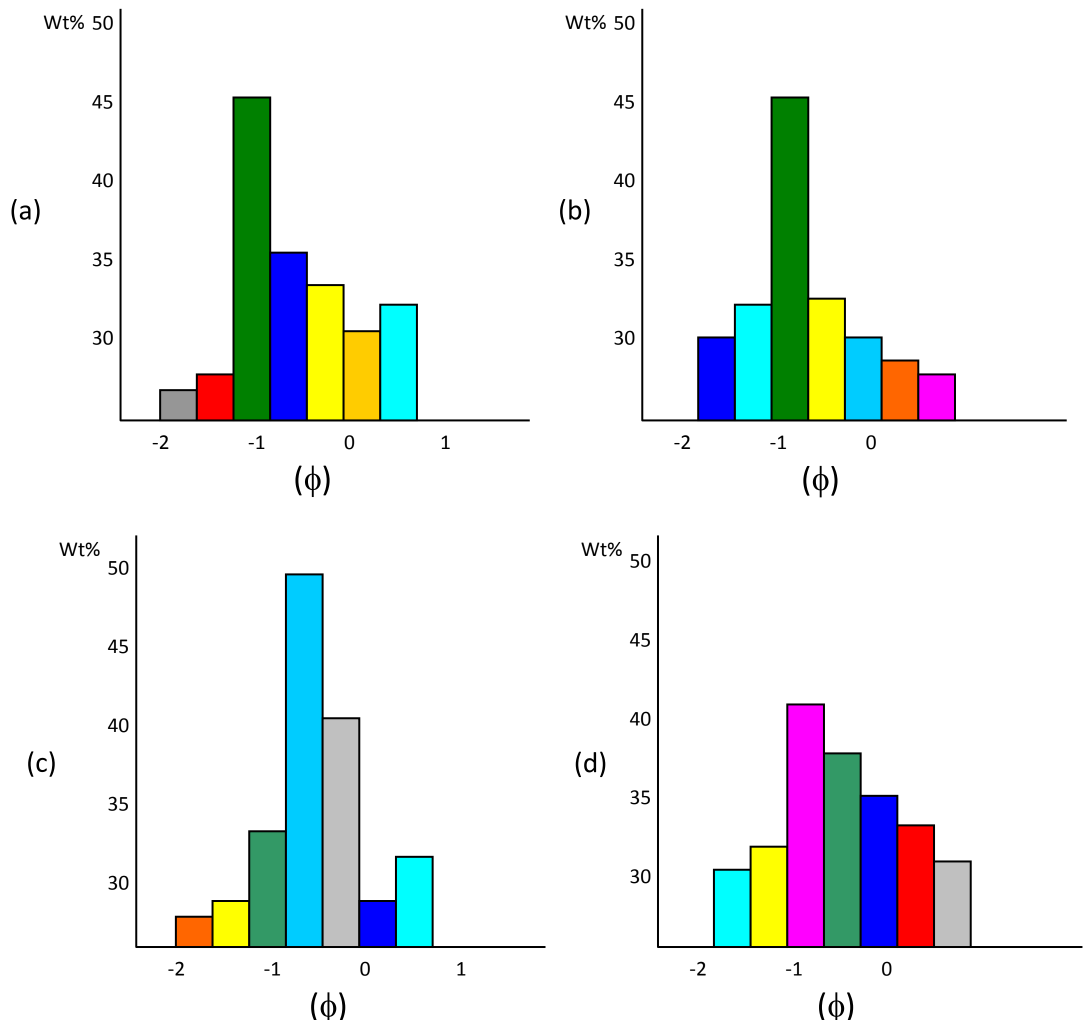

Figure 3(a-c): Historgrams of the Ebenebe Sandstone at Nkem Nando

The above histograms show unimodal-bimodal distribution indicating deposition in more than one phase or cycle probably of a tidal environment.

Bivariate Analysis: This is a plot that discriminates between fluvial, beach and dune processes. The plot of skewness against standard deviation and plot of mean grain size against standard deviation were used.

Multivariate Discriminate Analysis for Ebenebe Sand Member: The linear discriminate analysis of Sahu,(1964) was employed in this study. The result confirms that the Ebenebe sand member was deposited by dominantly fluvial process influenced by tidal incursion hence a fluvio marine environment.

(a) Pebble Morphometry for Ebenebe Sandstone:

For the average computed result from the pebble morphometric analysis . The values of flatness ratio $\left(S/L\right)$ ranges from 0.422 through 6.46 with a mean of 0.592; the values for elongation ratio $\left(I/L\right)$ ranges from 0.540 through 0.852 with a mean of 0.735; the values for Oblate-prolate index ranges from -0.231 through 6.822 with a mean of 3.200, the values for coefficient of flatness ranges from 42.44 through 64.10 with a mean of 54.55.

Trends in the maximum sphericity projection (MPS) and Oblate-prolate index (OPI) of 0.755 and 3.20 all indicates a fluvial origin for the pebbles. This result confirms the work of Dobkins and Folk (1970); Hubert, (1968); Snead and Folk, (1958) and Stratten (1974) that the maximum sphericity projection of pebbles are generally higher for fluvial process and lower for surf processes where pebbles whose values fall below the magic line of 0.65 denotes beach and those above 0.66 indicates a fluvial origin. Also Dobkins and Folk, (1970) show that in a suite of pebbles and the oblate-prolate falls below -2, then it is 87% sure that they are from the beach whereas if the oblate-prolate ranges from -1 to +5%, then it is 69% sure that the pebbles are fluvial in origin. Dobkins and Folk (1970), noted that first cycle beach gravels tend to be discoidal in shape whereas gravels in rivers are rod like in shape. They estimated the average maximum sphericity projection in pebbles to be 0.68 for rivers, 0.64 for low wave energy beaches and 0.58 for high energy beaches. Roundness average 0.38 for rivers, 0.47 for low wave energy beaches and 0.55 for high wave energy beaches. The oblate-prolate index average of +0.8 (prolate, rods) for rivers, -0.18 for low wave energy beaches and -2.13 (oblate, disc) for high wave energy beaches. Hence this study indicates a fluvial environment influenced by tidal incursions.

Parameter	Value	Interpretation
Flatness ratio $\left(S/L\right)$	0.592	Beach
Elongation ratio $\left(I/L\right)$	0.735	Fluvial
MPSI	0.755	Fluvial
OP index	3.200	Fluvial
Roundness	42.8	Fluvial
Coefficient of flatness FI	54.55	Fluvial

Table 3: Mean values of Morphometric analysis for 240 Pebbles of the Ebenebe sandstone at Nando-Omor Rd.

Bivariate Plots: The plots of MPS vs OPI Dobkins and Folk, (1970); and MPS vs FI Stratten, (1974) are employed in this study since the method discriminates between fluvial and beach processes. Plots of MPSI vs FI indicate a complete dominance of 100% fluvial process. Plots of MPSI vs OPI indicate a slightly different result. About 92% of the samples plotted within the fluvial field while about 8% plotted within the beach field. This result could be explained by the fact that there was a tidal incursion in the environment of deposition.

(b) Pebble Geometric form for Ebenebe Sandstone:

The pebble geometric forms describe its three dimensional aspect and particular shape occurs more in one environment than the other Sneed and Folk, (1958). The diagnostic shape classes for beach pebbles are platy, very platy, and very bladed while the shape classes for fluvial action are Compact, Compact Bladed and Compact Elongate Sneed and Folk, (1958); Dobkins and Folk, (1970); Gale, (1990).

From the plots, about 99% of pebbles of the Ebenebe sand member are largely compact bladed, compact elongate and compact indicating a fluvial origin while about 1% show non-diagonistic feature of any environment, that is, they are bladed. The bladed forms may show a transition or an interaction between fluvial and surf processes that are common in a deltaic setting .

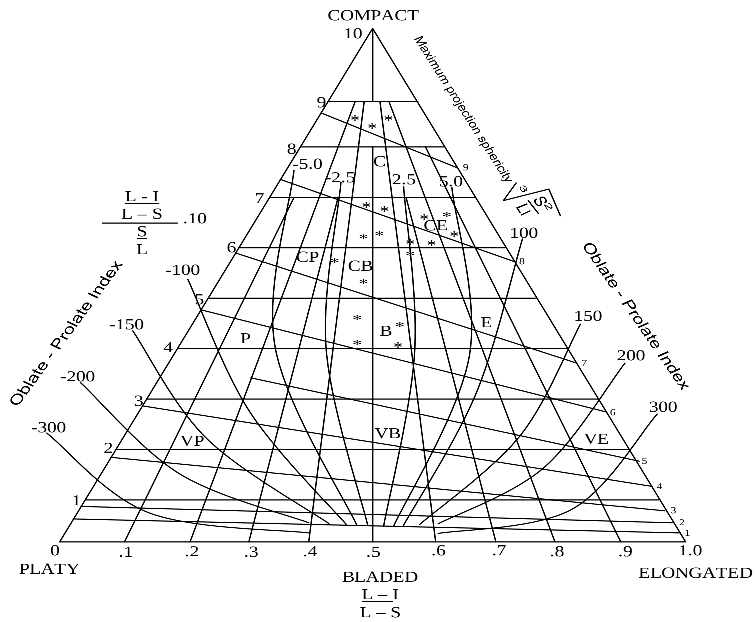

Figure 4: Maximum sphericity, oblate-prolate index form for Ebenebe sand member at Nando-Omor Rd (after Dobkins and Folk, 1970)

Petrographic Analysis for Ebenebe Sandstone: Petrographic studies were carried out to ascertain the light and heavy mineral in the samples. A total of eight thin sections were studied.

Light Minerals: The Ebenebe sandstone consists of primarily quartz as the dominant light mineral with iron oxide and little silica as cements (See Table 4).

Sample No	**Mineralogical**	**Texture**	**Type of quartz**	**Type of Extinction**	**Contact type**	**Maturity**	**Diagenesis**
EB 1	Quartz = 98% Felds = Nil Silica cement = 1% Clay matrix = 1%	Sub rounded moderately sorted	Mono-crystalline	Undulose	Point	Matured	Inclusion and bubbles
EB 2	Quartz = 96% Felds = 1% Rk frag = 1% Clay matrix = 2% Silica cement	Sub rounded moderately sorted	Mono-crystalline	Undulose	Point	Matured	Inclusion and bubbles
EB 3	Quartz = 99% Silica cement and clay matrix = 1%	Sub rounded well sorted	Mono-crystalline	Undulose	Point	Matured	Inclusion and bubbles
EB 4	Quartz = 84% Rk frag = 2% Feldspar = 4% Clay matrix	Sub angular to sub rounded	Mono-crystalline 65% poly-crystalline 35%	Non-Undulose	Sutured	Mineralogically matured and texturally immature	Iron oxide cement authigenic quartz overgrowth

EB 5	Quartz = 96% Felds = 1% Clay matrix = 4% Silica cement = 1%	Subangular to sub rounded poorly sorted	Mono-crystalline	Undulose	Point	Matured	Iron oxide cement and inclusion

Table 4: Thin section analysis for Light Mineral of the Ebenebe Sandstone

The thin section analysis presented in Table 4 shows that quartz is the dominant mineral with the grain being mostly monocrystalline over polycrystallinity. The grain shows mostly undulose extinction, sub-rounded and has undergone little or no diagenetic processes.

(b) Heavy Mineral Analysis: Heavy mineral analysis was carried out on selected samples. (See Table 5)

Sample No	**Zn**	**Trm**	**Rut**	**Apt**	**Sph**	**Grn**	**Kya**	**Non opaques**
EB 1	15	22	10	9	4	5	5	30%
EB 3	16	12	10	10	-	4	3	45%
EB 5	10	15	8	8	2	5	5	45%

Table 5: Abundance of Heavy Minerals in Analysed Samples

Zr (Zircon), Trm (Tourmaline), Rut (Rutile), Apt (Apatite), Sph (Sphere), Grn (Garnet), Kya (Kyanite), Sil (Sillimanite), Sta (Stand lite). The Table 5 above shows that 55% of the mineral are the non-opaques while 45% are the opaque minerals with zircon, Tourmaline and Rutile being the most dominant.

DISCUSSION OF RESULTS

(A) PALAEOCURRENT ANALYSIS OF THE STUDY AREA: Palaeocurrent are current direction deduced from the study of sedimentary structures or fabrics hence they are set of data that provide information on the direction of sediment transport into a basin. The analysis of the set data results in knowing the pattern of sediment dispersal, its relationship to sand body geometry, location of source area and direction of palaeoslope. Palaeocurrent data are deduced from a variety of observation such as type of mineral assemblage, presence or absence of boulders scalar properties such grain size, roundness, thickness etc and directional properties such as height of flow, groove marks, ripple crests, imbrication, cross stratification and flute marks. The directional properties are better used in palaeocurrent analysis since they contain more information about a sedimentary basin, Potter and Pettijohn, (1977).

The most common sedimentary structures for paleocurrent analysis in the study area is cross stratification. The foresets represent the formal slip faces of bedforms that migrated in the direction of foreset dip and the average local flow direction with geometrical variability mirroring the natural variability of bedforms. The cross beds, range from large scale planar and trough types to small ripples and herringborne cross strata.

The bounding surface of the cross bedded units are almost horizontal (between 0 and 5^{o}), hence tilt direction of dips are not necessary. Selly (1979) has proposed that tilt correction of dips for low values have no significant effect on the interpretation. The average thickness of cross beds is about 50cm and the foresets contacts vary from gradational to sharp parallel surface.

The azimuthal reading of the cross strata dip directions encountered were measured because a paleocurrent system may not be specified by a single type of cross bed in term of dynamic and directional aspect, Allen, (1965). The measurement pattern proposed by Potter and Olsen (1954), was used in this study since the variability at an outcrop is usually greater between cross beds than within cross beds. Also the method provides the best estimate of foreset direction for a specified number of measurement, Potter and Pettijohn, (1977).

Palaeocurrent measurement for four outcropping units:

Parameters Locality	**Pattern**	**Mean vector azimuth (MVA)**	**Variance**	**Vector Strength**
Igbariam	Bipolar, unimodal	233	600	0.38
Nando	Bimodal-Bipolar	262	3894	0.65

Table 6: Ebenebe Sands Palaeocurrent Parameters

To determine the degree of sediment dispersion and current direction, the above data was treated as vectors in order to obtain the dominant mean direction. The vector components were resolved to give the vector means using the formula

The paleocurrent distribution of the outcropping units show a dominant bipolar-bimodal orientation or pattern with a vector strength of high dispersion except for the Ebenebe which is low. The primary mode is in the Northeast direction approximately 50^0 and the secondary mode in the southwest direction which shows the types of cross bedding that occur in the study area. These results agree with the N-S regional paleocurrent trend established for the Anambra basin and in the study area, Hoque and Nwajide, (1984); Amajor, (1987); Nwajide and Reijers, (1996). The rose diagram for low angle dips (less than 20^0) and high angle dips (greater than 20^0) for cross stratification are also constructed. These show that low angle cross beds are unimodal to the Southwest while the high angle cross beds show northeasterly mode.

The sediment dispersal trend shows that the bimodal-bipolar orientation trending NE-SW is indicative of a probable ebb and flood tide in a tidal flat environment, which may be normal or parallel to the shoreline. This suggest that the original depositional environment of the sands may have a similar shape and orientation with the paleoslope, paleocurrent system and the sediment dispersal pattern as they are all parallel to one another. The northeasterly mode of the distribution is indicative of a subtidal zone while the smaller modes may be due to the filling of the tidal channel

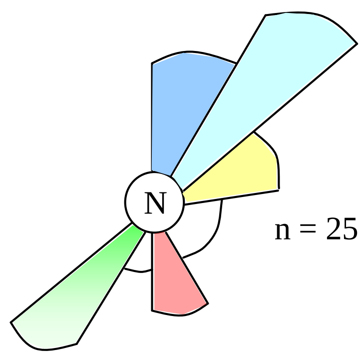

Figure 5: Current rose diagram for Ebenebe Sandstone

(B) Depositional Model for Ebenebe Formation: The depositional mode of the Ebenebe sandstone can be deduced from the study of grain size, composition, sedimentary structures and pebble morphometry.

The mean grain size of the sandstone are medium to coarse which suggest a moderate to high hydraulic energy environment. The observed general coarsening upward trend reflects the progressive shallowing of the environment and the fining upward trend at the midpoint shows some fluvial processes which may be the result of lateral migration of the fluvial channels, Pettijohn, (1975).The variation in sorting which ranges from moderately well sorted to poorly sorted sediments indicates water turbulence and current velocity variation although with a mean of moderately sorted sands which shows smooth and stable flow. The values for skewness show a nearly symmetrical trend which represents a broad spectrum of fluctuation indicating a shallow marine (upper shoreface-foreshore) and littoral zones. This is in agreement with the work of Duane (1964) who shows that the winnowing action of waves and tidal currents produces coarse skewed distribution in littoral beach and tidal inlet environments.

The asymmetrical to symmetrical shapes of histograms and frequency distribution in this study with variation in sorting suggests a fluvial process characterized by fluctuating energy of a deltaic setting.

The sandstones are texturally and mineralogical matured which suggests deposition in a high energy environment. The pebble morphometric result indicates that about 90% of the pebbles are from fluvial origin while about 10% indicates a marine environment. This also confirms the lateral migration of fluvial channel and the incursion of tidal wave/tidal action. The primary sedimentary structures which include planar and trough cross beds, parallel and horizontal lamination, From the above discussions, therefore, the Ebenebe sandstone was deposited in a tidally influenced shoreline of the shallow marine environment.

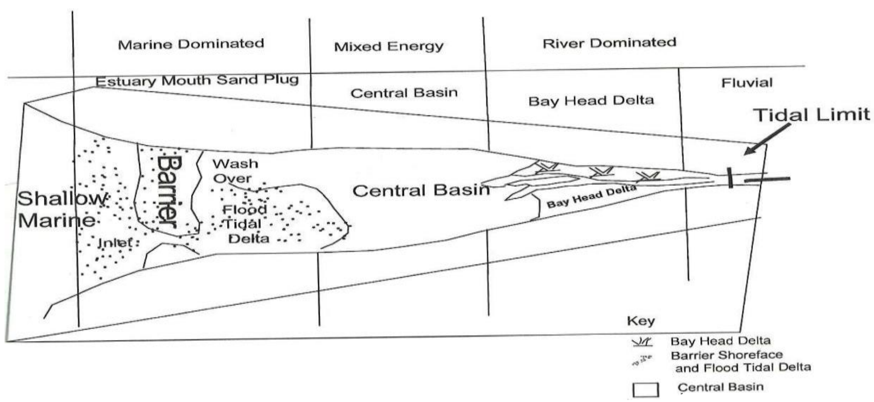

Figure 6: Depositional Model of Ebenebe Formation.

(C) Reservoir Quality for the Ebenebe Formation: The reservoir quality of a sandstone is dependent on both depositional and diagenetic fabrics i.e. grain size, shape, sorting, compaction, cementation, dissolation and replacement. Hence in this study the method of Patrick et al, 2007, using stratigraphic, petrographic as petrophysical techniques was employed since they concluded that porosity and permeability distribution within a given reservoir system is dependent on the diagenetic and depositional fabrics. In this assessment, the coefficient of variance and petrographic analysis was used.

The qualities of the reservoir of the Ebenebe sandstone were studied based on using the coefficient of variance, petrographic and stratigraphic analysis. The results obtained are presented.

If CV ≤ 0.5 homogeneous or good sorting

If CV ≥ 0.5 ≤ 1heterogeneous or poor sorting

If CV ≥ 1very heterogeneous or very poor sorting.

From the results, the samples sorting ranges from very heterogeneous, (1.26ϕ) through heterogeneous (0.73ϕ) to homogeneous (0.47ϕ). The plot of coefficient of variance against mean grain size Figure 70 place the samples to be moderately sorted in more than a half of the sampled area. Hence the porosity in interpreted as good.

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