DEPOSITIONAL FACIES ANALYSIS OF THE EBENEBE SANDSTONE OUTCROPPING IN UGWUOBA, UMUOGBUEFI-EBENEBE AND ISIAGU AREA OF THE SOUTHEASTERN NIGERIA.

BY

OHWONA O. CHRISTOPHER and A.U OKORO

Reg. No. 2015506001F

Email: christopherohwona@gmail.com

Department of Geology Nnamdi Azikiwe University, PMB 5025, Awka, Anambra State

ABSTRACT

Evaluation of the paleogene litho-unit of the Ebenebe Sandstone in Ugwuoba and it environ was carried out within the Niger Delta basin with a view of deducing the depositional environment of the sediments based on lithofacies analysis and granulometry analysis. Field observations showed that lithofacies of the Ebenebe sandstone consists of fine-coarse grained sandstone, coarse-fine grained sandstone, mudstone and siltstone. Transport direction determined by the dominant large scale cross-beds indicated a north-westerly paleoflow transport direction. Six lithofacies typically of tidally-dominated shelf setting and tidal current processes characterized the Ebenebe Sandstone. The medium to coarse grained planar cross-bedded sandstone (Sxc), fine to coarse grained planar with herringbone cross-bed sandstone (Sxp), fine to medium grained cross-bedded sandstone (Sxc), fine grained planar bedded sandstone (Sxp), muddy heterolithic facies (Hm) and laminated mudstone (Mb). These lithofacies are deposits of subtidal channels and tidal point bars. The presence of Ophiomorpha isp and Skolithos isp burrows in the fine grained sandstone and laminated mudstone lithofacies are indicative of colonization by suspension feeders in the environment under low energy regime in the foreshore-shoreface shelf settings. The results of the grain size analysis showed that the mean grain size of the Ebenebe Sandstone is medium-coarse grained, moderately well sorted, coarsely skewed to near symmetrical, and the kurtosis values ranging from Platykurtic to leptokurtic. The result of Linear Discriminant Function showed that the Ebenebe Sandstone was derived from shallow marine environment.

Keywords: Depositional environment, Lithofacies, Ebenebe Sandstone, Niger Delta Basin.

1.0 INTRODUCTION

This work is based on the detailed facies analysis of the Ebenebe Sandstone. The Ebenebe Sandstone is a member of the Imo Formation, the oldest palaeogene lithostratigraphic unit in the Niger Delta basin. The sandstone of the Ebenebe outcrops at Ugwuoba, Umuogbuefi-Ebenebe and Isiagu areas respectively. The palaeogene succession of southeastern Nigeria consists of Imo Formation (~1000m), Ameki Formation (~1900m), and Ogwashi Asaba Formation (~250m) (Reyment, 1965; Nwajide, 1980; Arua, 1986; Anyanwu and Arua, 1990; Oboh-Ikuenobe *et al*., 2005; Ekwenye *et al*., 2014). The outcropping succession can be mapped southward into the subsidence Niger Delta Basin where the Imo Formation, Ameki Formation and Ogwashi Asaba Formation are equivalents of the hydrocarbon generating Akata Formation, reservoir-containing Agbada Formation and the Benin Formation respectively.

The Imo Formation was previously referred to as "Imo River shales'' (Tattam, 1944) or the "Clay-shales" (Grove, 1951). However, Reyment, (1965) formalized the name as Imo Shale with a type locality at the outcrops along the Imo River between Okigwe and Umuahia. The unit is widely distributed across southeastern Nigeria, and it outcrop area extends from the Calabar Flank, through the Afikpo area, across the River Niger and westwards to the Okitipupa ridge (Short and Stauble, 1967). The Imo Formation is referred to as the oldest stratigraphic unit in the Niger delta Basin (Petters, 1991), and it shows lateral variation of three different sandstone members, Ebenebe Sandstone, Umuna Sandstone and Igbaku Sandstone. These sandstone members of the Imo Formation outcrop up dip in the northern fringes of the Niger Delta basin. The Ebenebe Sandstone is basically clastic reservoir rock, comprising mainly of quartz arenites with a good to excellent reservoir quality (Acra *et al*., 2014). The studied area is bounded by latitudes ($6°19'0''$N and $6^0 10'30''$N) and longitudes ($7°06'0'$E and $7^0 10'0''$E).

Sedimentological studies within the Imo Formation have been carried by several workers; most of their studies have concentrated on the shaly facies and stratigraphy of the Formation. However, only few have discussed the Ebenebe Sandstone unit of the Imo Formation with contradictory interpretations of the depositional environments. According to (Anyanwu and Arua, 1990) depicts the depositional environment of the Ebenebe Sandstone to be delta front facies. Oboh-Ikuenobe *et al*, 2005 depicts the depositional environment of the Ebenebe Sandstone to be fluvial channel of the estuarine lithic fill, while (Ekwenye *et al*., 2014) as a large sandwaves deposited in a tidally offshore to shoreface settings respectively. But the stratigraphic succession indicates that the sandstone is enclosed in shallow marine shale and the sandstone clearly exhibits tidal signatures (Ekwenye *et al*., 2014).

The primary aim of this work is to provide sedimentological descriptions of the outcrops that would help to demystify the depositional environment of the Ebenebe Sandstone using lithofacies analysis, textural analysis/characteristics of the sediments with available sedimentological data to reconstruct the facies distribution of the outcrop litholog. This may provide a better understanding of the depositional heterogeneity of the subsurface Ebenebe Sandstone of the Niger Delta Basin. The results can serve as surface analog for subsurface facies of hydrocarbon explorations. This study may also benefit geosciences community in both academia and industry.
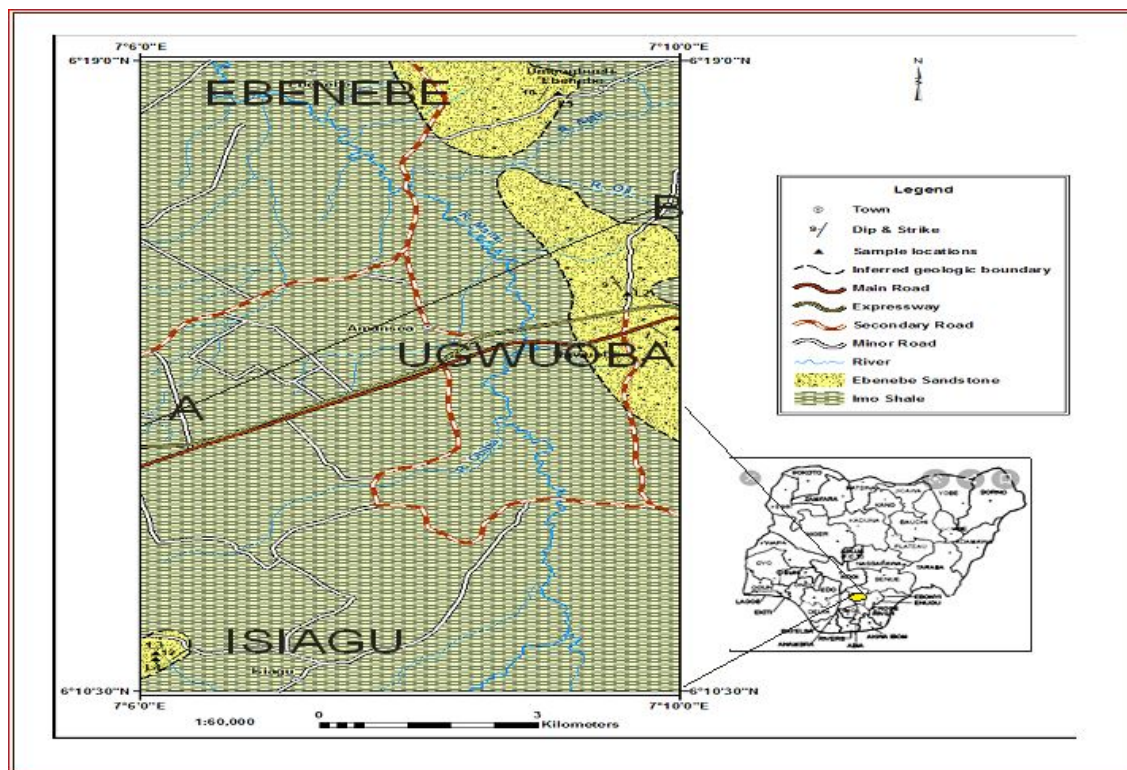

Fig 1.0: Geological of the studied area

2.0 GEOLOGICAL SETTINGS/STRATIGRAPHIC SETTINGS

Outcropping sediments of the Cenozoic Niger Delta Basin can be found in the Southeastern Nigeria, where they overlie sediments of the Anambra Basin (Figures 2). The geology of the sedimentary basins of southern Nigeria has received considerable attention since the discovery of oil in the Niger Delta Basin. The origin of these sedimentary basins is traced to the evolution of the Benue Trough in the early Cretaceous and was facilitated by the breakup of the African and South American continents leading to the formation of the Benue Trough (Burke *et al*., 1970; Benkhelil, 1989). The Anambra Basin developed as a result of the Santonian event which greatly affected the Benue Trough terminating sedimentation in the Abakaliki Basin. Sedimentation in

the trough was controlled by three major tectonic phases, giving rise to three successive depocentres (Murat, 1972; Oboh-Ikuenobe *et al*, 2005).

The first phase (Albian – Santonian) featured the deposition of the Asu River Group, Eze Aku and Awgu Formations within the Abakaliki-Benue Trough which was flanked to the east by the Anambra platform, and to the southwest by the Ikpe platform. The second phase (Campanian-Eocene) was characterized by compressive movements along the NE-SW axis which resulted in the folding and uplift of the Trough into an anticlinorium. This forced the Anambra platform to subside and the depocentre to shift south-westwards to the newly formed Anambra basin and the Afikpo syncline on the other side of the anticlinorium in the southeast. Towards the end of Eocene, the third phase commenced and was characterized by the structural inversion of the Abakaliki region further shifting the depocentre down dip (southwards) to form the Niger Delta Basin (Obi *et al*., 2001).

Outcropping stratigraphic units of the Niger Delta Basin overlying the Anambra Basin consists of four lithostratigraphic units: the Imo, Ameki Group, Ogwashi Asaba Formation and the Benin Formation with varied estimated thicknesses at the depocenter (Reyment, 1965; Nwajide, 1980; Arua, 1986; Anyanwu and Arua, 1990; Oboh-Ikuenobe *et al*., 2005; Ekwenye *et al*., 2014). The Imo Formation forms the basal outcropping stratigraphic unit of the Niger Delta Basin. It widens eastwards, swings southwards, and narrows and tapers off northwest of Odukpani, an area in Calabar Flank, where it is overlapped by the Benin Formation across an age gap of 15 Ma of the Ameki Group and the Ogwashi Formation (Nwajide, 2013). The facies of the Ameki Group conformably overlies the Imo Formation and contains three stratigraphic components: the Ameki Formation, the Nanka Formation and the Nsugbe Formation, which pinch out in both westwards and eastwards (Nwajide, 1980, 2013). The Imo Formation is the mappable equivalents of the Akata Formation, while the Ameki Group and Ogwashi Formation are the mappable equivalents of the Agbada Formation of the subsurface stratigraphic units of the Niger delta (Short and Stauble, 1967). The Imo Formation is the oldest stratigraphic unit in the Niger Delta Basin (Short and Stauble, 1967; Petters, 1991) and is composed of blue-grey shales with sand lenses, marl and fossiliferous limestones (Reyment 1965; Short and Stauble, 1967; Nwajide, 2013). The Benin Formation, which is the youngest stratigraphic unit of the Niger Delta Basin (Short and Stauble, 1967) (Figure 3) is composed of coastal plain sands with lenses of clay and mud (Tattam, 1944). The Benin Formation exists in both outcrops and the subsurface (Figure 3) and occupies an extensive area of southern Nigeria (Reyment, 1965; Short and Stauble, 1967; Nwajide, 2013) (Figure 2). Nwajide (2006) established that Abakiliki

anticlinorium is one of the sources of sediments for the Anambra and Abakaliki (Afikpo) Basins, which later became contributors to the Cenozoic Niger Delta Basin. Eastern Nigerian Oban Massif is also an important source for the Cenozoic sediments of the Niger Delta Basin (Ekwenye, 2015).
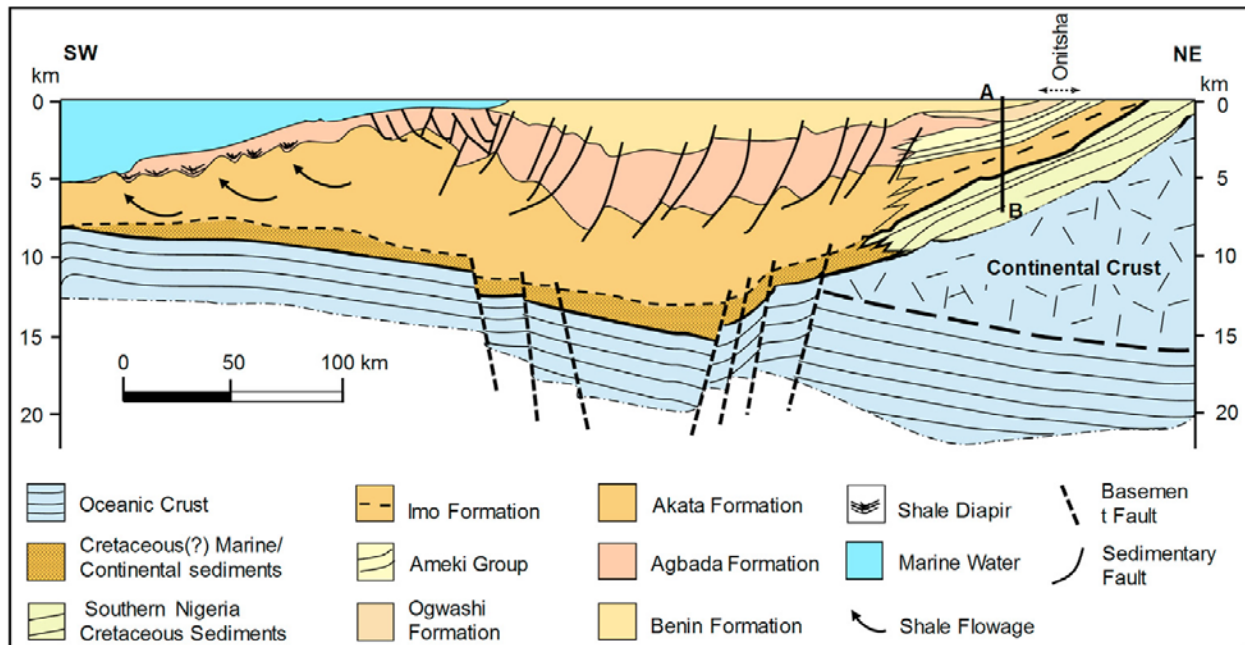

Fig 2.1: Schematic northeast (NE) – southwest (SW) cross-section of the Cenozoic Niger Delta Basin showing the subsurface formations and their outcropping stratigraphic equivalents overlying the Cretaceous sediments of the Anambra Basin in southeastern Nigeria (Reprinted from Ogbe, 2020).
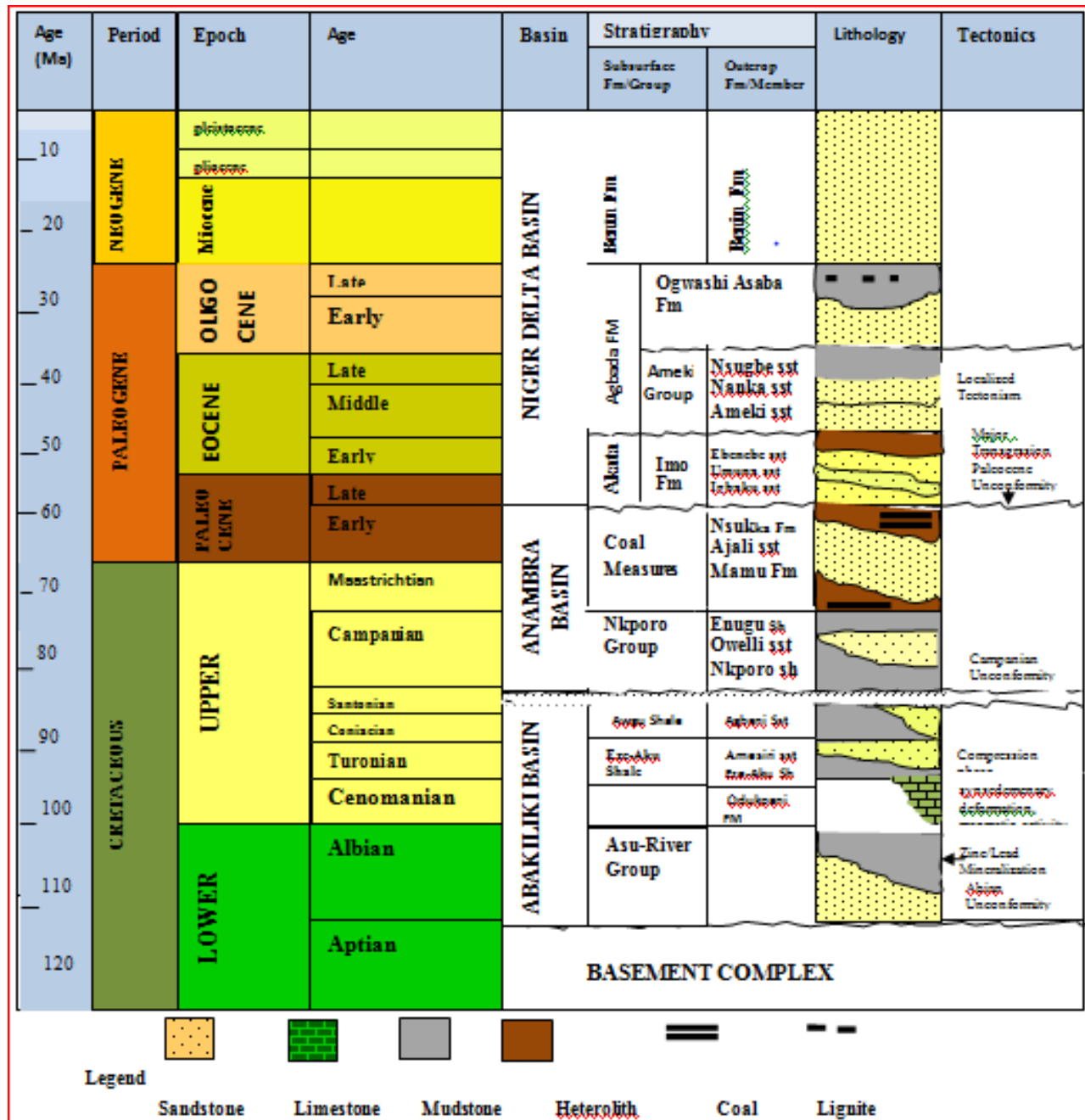
Age (Ma)	Period	Epoch	Age	Basin	Stratigraphy		Lithology	Tectonics
					Subsurface Fm/Group	Outcrop Fm/Member		
10	NEOGENE	Miocene	pleistocene.		Benin Fm	Benin Fm		
20			pliocene.	NIGER DELTA BASIN				
30	PALEOGENE	OLIGOCENE	Late			Ogwashi Asaba Fm		
			Early		Agbada FM			
40		EOCENE	Late			Ameki Group	Nsugbe sst / Nanka sst / Ameki sst	Localized Tectonism
			Middle					
50			Early		Akata	Imo Fm	Ebenebe sst / Umuna sst / Ighabo sst	Main Transgression Paleocene Unconformity
60		PALEOCENE	Late					
			Early	ANAMBRA BASIN		Coal Measures	Nsukka Fm / Ajali sst / Mamu Fm	
70	CRETACEOUS	UPPER	Maastrichtian					
80			Campanian			Nkporo Group	Enugu sh / Owelli sst / Nkporo sh	Campanian Unconformity
			Santonian	ABAKILIKI BASIN		Owelli Shale	Sdkani sst	
90			Coniacian					Compression
			Turonian			EzeAku Shale	Amasiri sst / EzeAku Sh	
100			Cenomanian				Odukani FM	wrnch deformation
		LOWER	Albian			Asu-River Group		Zinc/Lead Mineralization Albian Unconformity
110								
120			Aptian		BASEMENT COMPLEX			

Legend

Sandstone   Limestone   Mudstone   Heterolith   Coal   Lignite

Fig 2.2: Stratigraphic succession of the Niger Delta and the Anambra basins (redrawn and modified from Short and Stauble, 1967; Nwajide, 2005; Ohwona, 2021).

3.0 METHODS

3.1 Field Study

Detailed geological mapping of the study area was carried out basically to identifying the rock types and establishing stratigraphic succession of the rocks on the basis of their field relationships. A GPS receiver was used to get accurate coordinates of outcrops exposures. Characteristically, sandstones, mudstone and claystone were well exposed. Field data from grain

sizes, textures, colours, grains orientation, sorting, mineralogical composition, measurements of paleocurrents directions, dips and strikes of cross-beddings, in-situ measurements of thickness of lithofacies, lateral extent of beds, photographs of important sedimentary structures and logging of exposed vertical sections of the outcrops were gotten from the field study.

3.2 Textural Analysis

Ten (10) selected samples were collected from the studied localities. Ugwuoba (4), Isiagu (3) and Umuogouefi-Ebenebe (3), and were used for grain size analysis in Delta State University, Abraka. The samples were thoroughly mixed and a representative fraction of the sample was obtained by quartering. This was weighed in a dial spring balance and mechanical sieve shaker was employed to sieve 100g of sandstone for 15 minutes and allowed to separate properly. Weight retained in each sieve was weighted and recorded in the sieve analysis report sheet. Statistical plots of the cumulative frequency on both arithmetic and log probability sheets were done. Critical grain sizes percentiles (5th, 16th, 25th, 50th, 75th, 84th, & 95th) were obtained and used to calculate the graphic mean (Mz), standard deviation (sorting) (σ_1), inclusive graphic skewness (Ski) and graphic kurtosis (KG) for each sample.

4.0 RESULTS AND DISCUSSIONS

A detailed lithofacies description was carried out on the outcrop at Ugwuoba, Umuogbuefi-Ebenebe and Isiagu localities in the eastern part of Nigeria (Fig. 1.0). The thicknesses of the outcrops were (6m and 394ft above sea level, 8m and 423ft above sea level and 7m, 263ft above sea level) in Ugwuoba, Isiagu and Umuogbuefi-Ebenebe respectively. The outcrops are located along the road where quarries and mining activities were taking place (Figure 4.0).
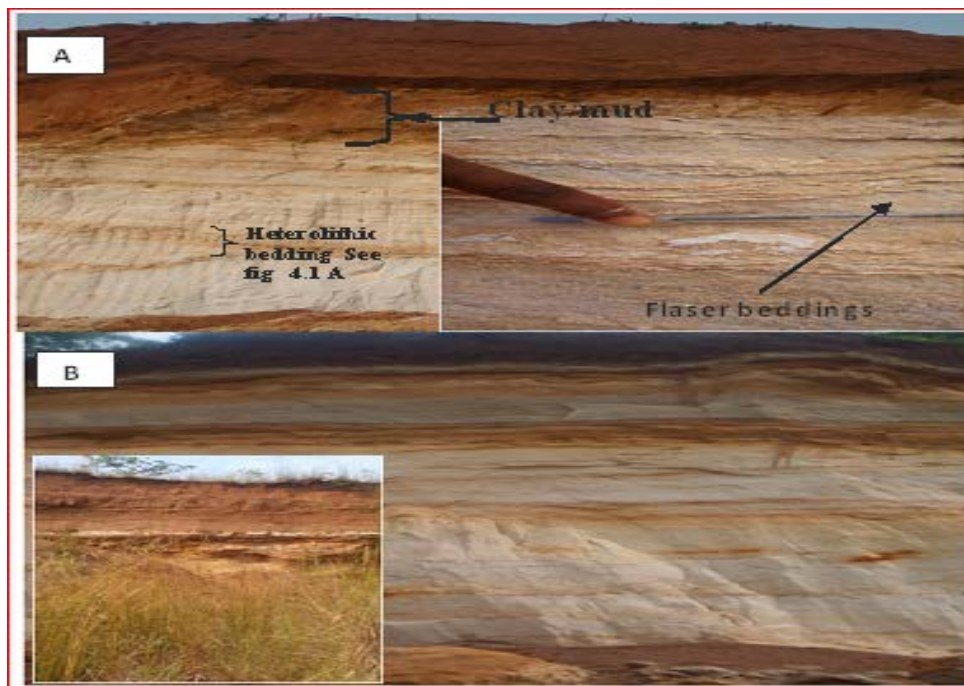
Fig. 4.1: (A) Exposed outcrop of Ebenebe Sandstone at Ugwuoba showing heterolithic and flaser beddings, and **(B)** Isiagu composed of mudstone, siltstone, fine grained sandstone, and fine to coarse grained sandstone

4.1 LITHOFACIES ANALYSIS

The lithofacies of the Ebenebe Sandston was analyzed based on the lithology, grain size, sedimentary structure and fossil content. Six lithofacies were identified in this study: (1) Medium to coarse grained sandstone (Sxc), (2) Fine to coarse grained planer cross-bedded sandstone lithofacies (Sxp), (3) Fine to medium grained cross-bedded sandstone lithofacies (Sxc), (4) Fine grained planar bedded sandstone lithofacies (Sxp), (5) Muddy heterolithic facies (H_m), (6) laminated mudstone lithofacies (Mb). This lithofacies were further subdivided into two lithofacies association.

4.1.1 Medium to Coarse Grain Sandstone Lithofacies (Sxc)

This lithofacies outcrops in three localities, fully exposed at Ugwuoba old Enugu road, Umugbuefi-Ebenebe and Isiagu. It consists of medium to coarse grained, moderately sorted to well moderately sorted sandstone. It colour ranges from white, yellow to light brown. It is characterized by thin trough and thick heterolithic cross-bedding (figure 4.1A). The cross beds include small low angle cross beds and high angle cross beds with graded foresets, clay drapes and mud chips are common. Other sedimentary structures include tidal bundle and composite bundles. This lithofacies display subtle fining upward sequence. The lithofacies is interpreted as subtidal channel deposited under the influence of high energy phase of tidal regime. The coarse

detrital materials may have been deposited in the shallow self settings while the finer materials winnows away by the wave energy.

4.1.2 Fine to Medium Grained Cross-Bedded Sandstone Lithofacies (Sxc)

This lithofacies outcrops in Ugwuoba and Isiagu localities. The lithofacies consists of fine to medium grained, white to brownish colour and moderately sorted. It is bioturbated with some burrows of *skolithos* that are nearly vertical, showing planar and cross bedded sedimentary structures. Other sedimentary structures include flaser bedding, wavy bedding and clay draping (Fig.4.0A). This lithofacies is interpreted as deposits of near shore of the tidal point bar under the influence of high energy association with tidal flow regime.

4.1.3 Fine Grained Planar Bedded Sandstone Lithofacies (Sxp)

This lithofacies consists of very fine grained sandstone, occasionally medium grain with few scattered pebbles and much unconsolidated. This lithofacies occurs in Umuogouefi-Ebenebe, Ugwuoba and Isiagu localities. It is whitish to grey in colour with parallel laminations. This lithofacies also occur in association with cross bedded facies unit in Umuogouefi-Ebenebe localities. It is generally moderately sorted to well sorted. The facies shows bioturbations borrows (Fig. 4.1E). The trace fossils include *skolithos* and *ophiomorpha isp.* The facies is overlain by thin bed of ironstone and mudstone at Isiagu. This lithofacies can be interpreted as tidal flat

4.1.4 Muddy heterolithic facies (H$_m$)

This lithofacies consists of thin interbed of mudstone/siltstone with fine to medium grained sandstone in the lower portion of the outcrops studied especially in Ugwuoba Old Enugu road and Isiagu localities. This lithofacies is commonly characterized by flaser beddings and wavy laminations. The sands within the horizontal bedded units are well graded and moderately sorted. This lithofacies is interpreted as intertidal shallow shelf deposits under a low current energy.

4.1.5 laminated mudstone lithofacies (Lm)

This lithofacies is well exposed at Ugwuoba Old Enugu road and Isiagu localities. It occurs at the top of the outcrops and grades downwards into siltstone at Isiagu. The facies shows black to grey colour mudstone. It is laminated and shows burrows of bioturbation such as *ophiomorpha* existent (Fig. 4.2). Mudstones are typically deposits of low energy regimes and it occurs occasionally with silts. The mudstone is underlain by fine grained micaceous sandstone brownish with thin bed of ironstone at Isiagu. According to Walker and Plint (1992) mudstones typically represent lower shoreface to offshore depositional environments.

4.2. FACIES ASSOCIATION (FA)

4.2.1. FA1: Subtidal Channel

This lithofacies association consists of medium to coarse grained sandstone, moderately sorted to well sorted with scattered pebbles. It is characterized by large and small scale cross bedded sets with subordinate of planar cross beds. It also displayed fining upward facies. The cross beds include small low angle cross beds and high angle cross beds with graded foresets, clay drapes and mud chips are common (Fig. 4.1A). Other sedimentary structures include composite bundles, flaser bedding, ripples, horizontal laminations and few bioturbations (Fig. 4.1E). The basal portions displayed medium to coarse grained with erosive lag gravels and pebbles (Fig 4.4). It also shows some clay laminations. The coarse lagged gravels and pebbles deposits may have been deposited during high energy regime. This lithofacies association can be interpreted as subtidal channel.

4.2.2. FA2: Tidal Point Bar

This facies association consists of fine to coarse grained planer and cross-bedded sandstone, poorly to moderately sorted with scattered pebbles, the colour ranges from white, yellow to light brown colour.

This facies association is characterized by sedimentary structures such as herringbone cross structures, tidal bundles, and flaser bedding (Fig 4.0A & 4.1D). This facies association displayed fining upward sequence. It is interpreted as tidal point bar deposited under medium to high energy regime cycles.
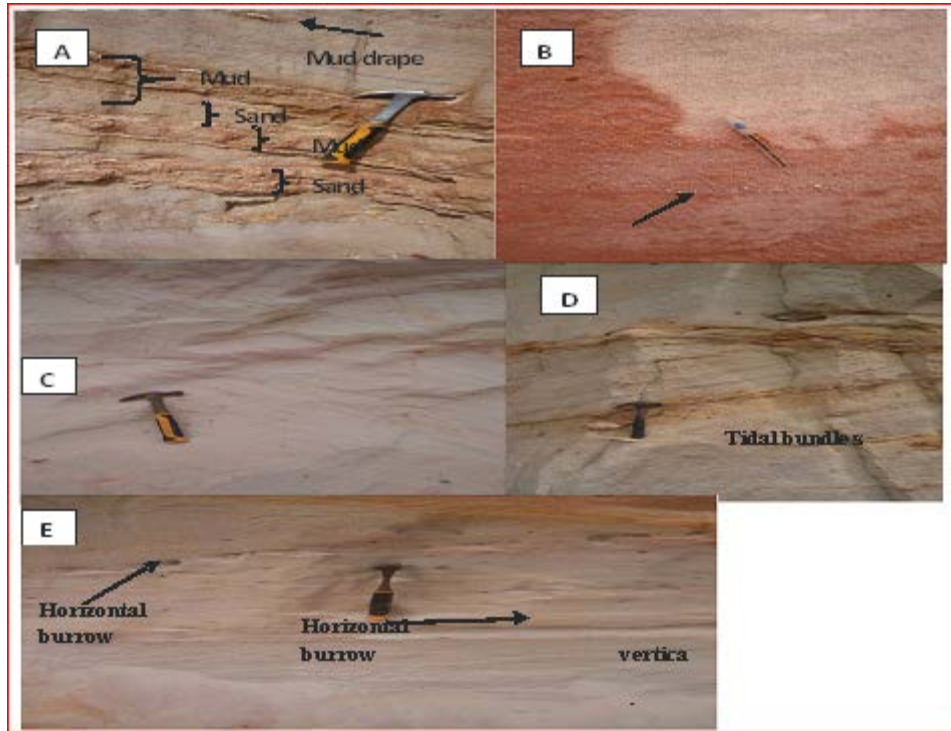
Fig. 4.2: *Flaser bedding at Awka Enugu old road, Ugwuoba. (B) Coarsed lag and pebbly deposits at Ugwuoba old Enugu road. (C) Multiple Herringbone cross-beddings at Umuogbuefi-Ebenebe (D) Clay lamination of tidal bundle at Isiagu. (E) Burrows of skolithos and ophiomorpha isp in a very fine grained sandstone at Umuogouefi-Ebenebe.*

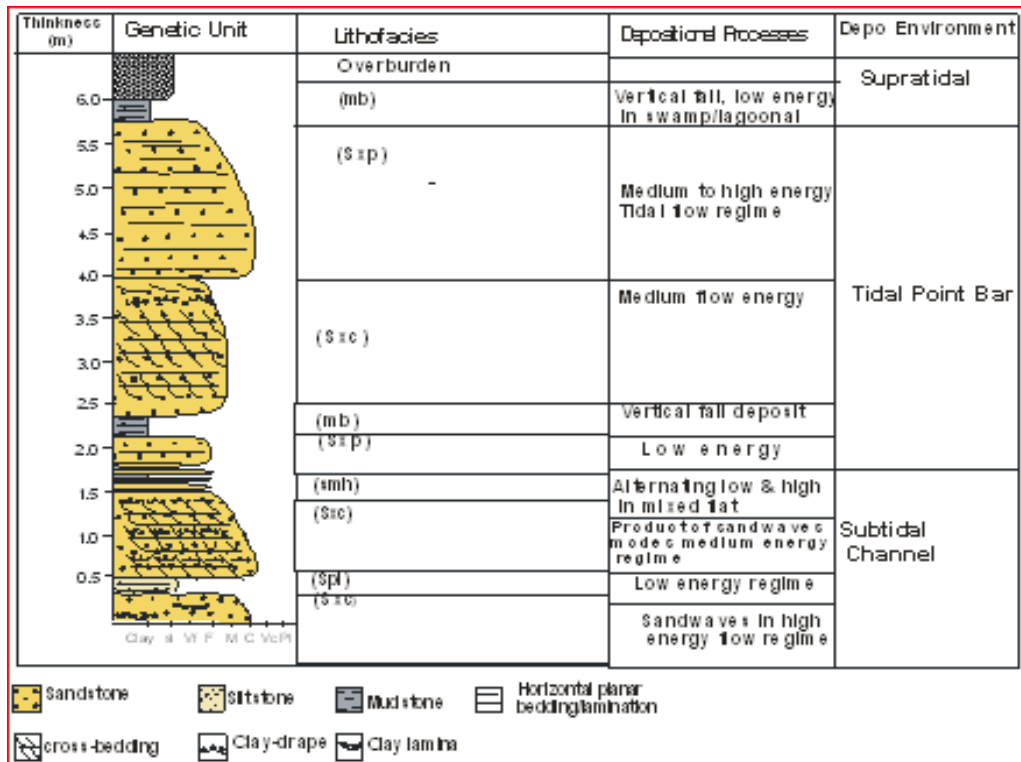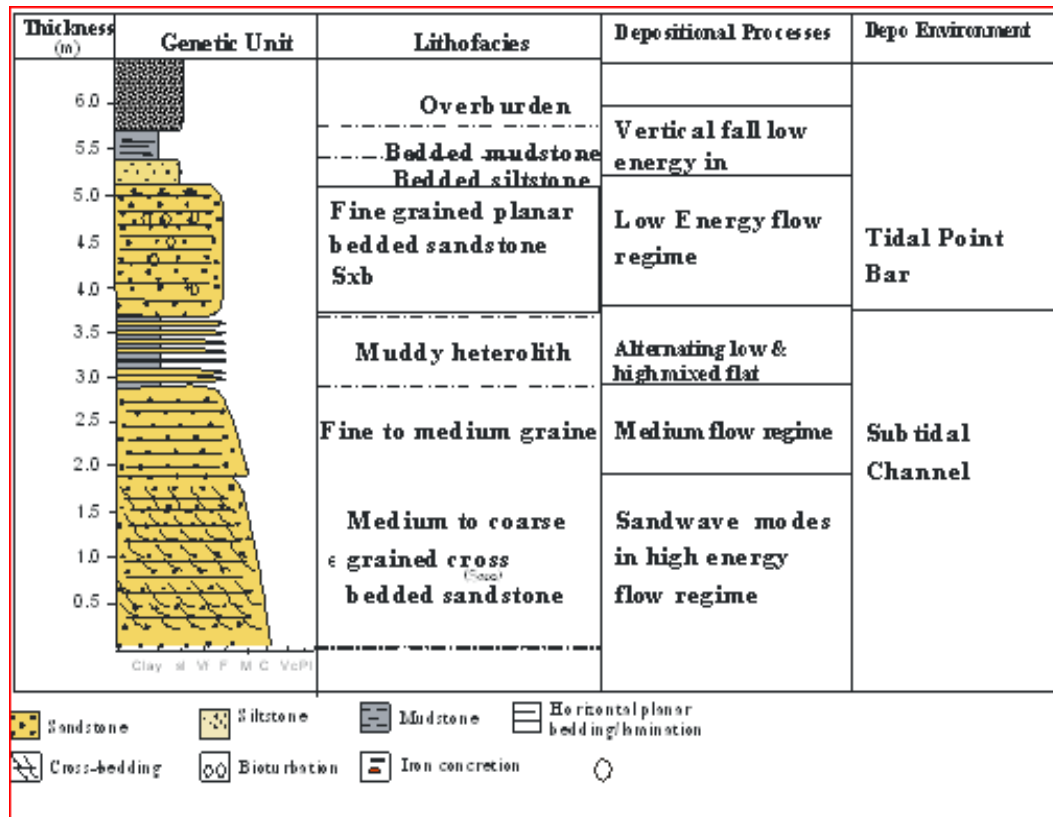Fig. 4.3: Mudstone showing burrows of *Ophiomorpha isp.*

Fig. 4.3: *Log of Ebenebe sandstone exposed along old Awka -Enugu road, Ugwuoba*

S/N	Lithofacies	Descriptions	Lithofacies Association
	Mb	Bedded mudstone	Tidal Point Bar
	Sxp	Fine to coarse grained horizontal planar bedded sandstone.	
	Sxc	Fine to medium grained planar cross-bedded sandstone with clay drape	
	Mb	Bedded mudstone	
	Sxc	Fine grained horizontal planar bedded sandstone	
	Smh	Sandy Heterolithic	
	Sxc	Fine to coarse grained cross-bedded sandstone with clay drapes	Subtidal Channel
	Spl	Parallel laminated siltstone	
	Sxc	Medium to coarse grained sandstone with clay drapes	

Fig. 4.4: lithofacies descriptions

4.5: *Log of Ebenebe sandstone fully exposed at Isiagu*
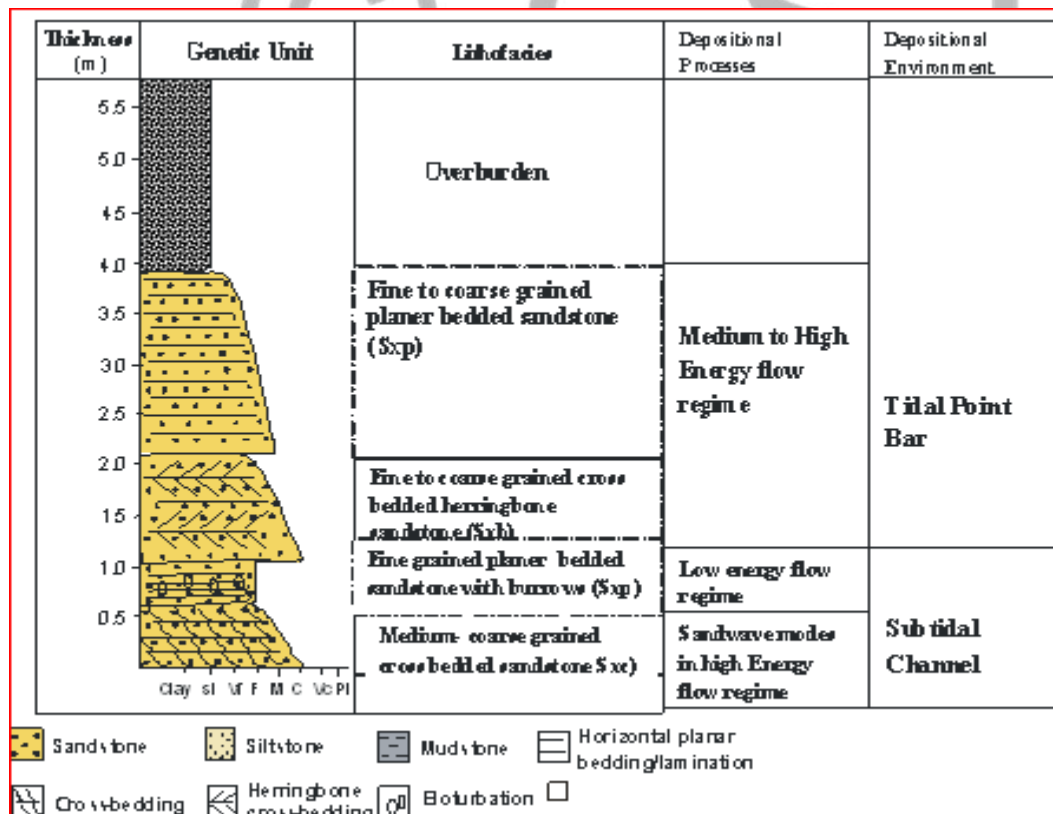

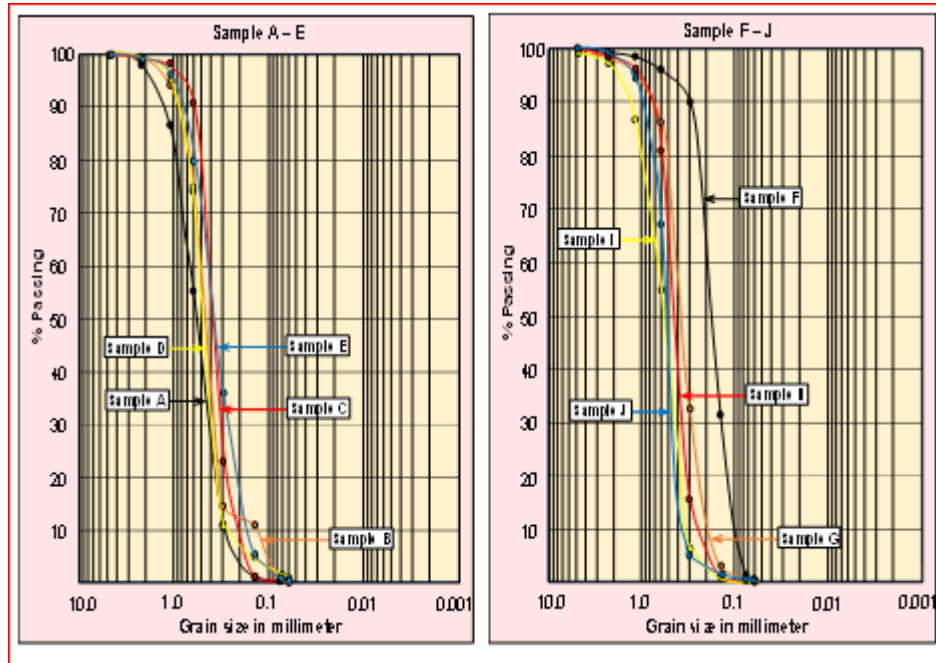**Fig. 4.6**: *Log of Ebenebe sandstone exposed at Umuogbuefi-Ebenebe*

Figure 4.7a&b: Graph of cumulative passing versus grain size (mm)

Table 4.0: Calculated results of the sieve analysis in (Phi (φ) scale)

Sample	φ5	φ16	φ25	φ50	φ75	φ84	φ95	Median (M_d)	Mean (M_z)	Sorting (σ)	Skew. (S_{ki})	Kurtosis (K_G)
A	-0.8	-0.1	0.2	0.85	1.38	1.59	2.1	0.85	0.78	0.86	-0.13	1.0
B	-0.3	0.4	0.7	1.1	1.5	1.7	2.15	1.1	1.06	0.69	-0.11	1.25
C	0.5	0.85	1.0	1.3	1.7	1.9	2.4	1.3	1.2	0.60	0.20	1.1
D	-0.2	0.4	0.7	1.18	1.6	1.9	2.7	1.18	1.16	0.81	0.004	1.32
E	-0.1	0.59	0.84	1.4	2.05	2.3	2.7	1.4	2.47	0.85	-0.008	0.95
F	1.5	1.85	2.05	2.4	2.85	3.18	3.78	2.4	2.36	0.67	-0.02	1.17
G	-0.1	0.8	0.98	1.4	1.9	2.19	2.6	1.4	1.46	0.75	0.013	1.2
H	-0.1	0.6	0.8	1.2	1.59	1.75	2.3	1.2	1.18	0.65	-0.06	1.24
I	-0.9	-0.1	0.2	0.8	1.25	1.45	1.78	0.8	0.71	0.79	-0.21	1.0
J	-0.2	0.3	0.5	1.0	1.39	1.5	1.7	1.0	0.93	0.58	-0.20	0.87

Table 4.1: Multivariate results of the Ebenebe Sandstone in the study area

Sample	M_d	Mz	σ	S_{ki}	K_G	Y_1	Y_2	Y_3	Interpretations
A	0.85	0.78	0.86	-0.13	1.0	3.3	77.73	-5.57	Shallow Marine
B	1.1	1.06	0.69	-0.11	1.25	2.1	70.07	-3.27	Shallow Marine
C	1.3	1.2	0.60	0.20	1.1	-0.05	67.61	-3.74	Shallow Marine
D	1.18	1.16	0.81	0.004	1.32	2.38	86.93	-5.04	Shallow Marine
E	1.4	2.47	0.85	-0.008	0.95	-3.17	106.04	-5.54	Shallow Marine
F	2.4	2.36	0.67	-0.02	1.17	-3.08	90.08	-3.11	Shallow Marine
G	1.4	1.46	0.75	0.013	1.2	0.58	83.71	-4.52	Shallow Marine
H	1.2	1.18	0.65	-0.06	1.24	1.34	69.27	-3.01	Shallow Marine
I	0.8	0.71	0.79	-0.21	1.0	3.23	52.10	-4.20	Shallow Marine
J	1.0	0.93	0.58	-0.20	0.87	1.06	49.88	-1.6	Shallow Marine

Table 4.2: Percentage of samples calculated from the multivariate results of (Y1, Y2 & Y3)

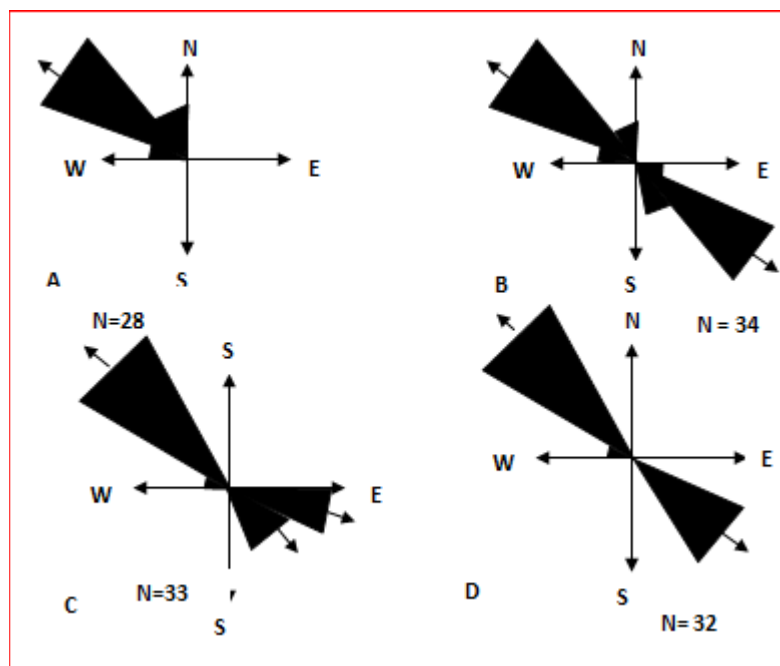|	Y1%		Y2%		Y3%	
	Aeolian	Beach	Beach	Shallow agitated marine	Fluvial	Shallow marine
	2	7	2	8	0	10
No. of Samples (A to J)	10	10	10	10	10	10
Total percentage of Samples	20%	80%	20%	80%	0%	100%

FIGURE 4.8: Paleocurrents directions of the Ebenebe Sandstone

4.3 Discussion of Results.

The results of the textural analysis by sieving method are shown in (Table 4.0). The cumulative frequency graph were plotted in (Fig.4.6) to determine the statistical parameters such as mean (Mz), skewness (Ski), kurtosis (KG) and standard deviation (σ_1) (sorting) using Folk and Ward 1957 equations (Table 4). The measured mean grain sizes of the sandstones ranges from 0.71 (coarsed grained) to 2.47 (fine grained) with an average of 1.33 (medium grained).

The inclusive standard deviation (sorting) measures the degree of sorting or scatter distributions around the mean and the greater the scattering, the higher the standard deviation and the poorer the sorting. The more clustering of the distributions around the mean, the smaller the standard deviation and better sorting of the sediments. The standard deviation (sorting) of the sediments ranges from 0.58 (moderately well sorted) to 0.86 (moderately sorted) with an average of 0.72. Deducing from (Table 4.0) on the relationship between grain size and sorting, the sample analyzed are mostly medium to coarse sand ranges and fewer fine sands, also, moderately well sorted sediments. This implies that the medium to coarse grained of the sediments were deposited under high energy current with fluctuation of low energy at some periods of deposition (Pettijohn, 1975). The finer grain implies the distance of transportation, i.e, the finer the grain

size, the greater the distance of transportation. Moderately well sorted of the Ebenebe Sandstone indicates that it may have been transported over a long constant variable energy conditions.

The values of skewness ranges from -0.21 (coarse skewed) to 0.2 (fine skewed). Table 6 shows that the sediment is coarse skewed to near symmetrical, i.e. large proportion of the coarser materials are negatively skewed and tend to the negative tail. The negative coarse-skewed implies high velocity than normal during the time of deposition. This indicates that the sediments are fair to uniformly skewed. The higher the calculated skewness values deviate from zero, the more the skewness. The kurtosis measures the outliers or the degree of clusters around the tails or the peak of the curve. The kurtosis values ranging from 0.87 (platykurtic) to 1.32 (leptokurtic) with an average of 1.11(mesokurtic). This is suggestive of a generally better sorting at the central portion than the tail ends of the distributions. Using Sahu, (1964) discriminant function. Linear discriminant functions of Y1 (Aeolian, beach), Y2 (Beach, shallow agitated marine environment) and Y3 (Fluvial, shallow marine) were used to interpret the environment of deposition of the Ebenebe Sandstone (Table 4.1 and 4.2). On the bases Y1, 80% of the samples were identified as beach sediments while only 20% were identified as aeolian deposits. The value of Y2 calculated was 80% for shallow agitated marine environment while only 20% was identified as beach sediments. The value of Y3 was 100% which indicates that all of the collected sediments samples are derived from shallow marine environments. This can be deduced that the sediments of the Ebenebe were deposited in the shallow marine environment. The Paleocurrents distribution of the study areas shows bimodal-bipolar orientation patterns of the Ebenebe Sandstone with low angle of dip less than 25^0. The paleoflow trends in the direction of (NW and SE).

4.3.1 Depositional Environment and Model

. The depositional model of the Ebenebe sandstone was deduced from the study of lithofacies analysis, granulometric analysis, Paleocurrents and sedimentary structures. The mean grain sizes of the sandstones are medium to coarse grained which suggests moderate to high hydrodynamic energy environment. The values for skewness shows coarse skewed to near 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 showed that the winnowing action of waves and tidal currents produces coarse skewed distributions in foreshore-shoreface of the tidal environment. The sorting varies from moderately sorted to moderately well sorted sediments, this indicates smooth and stable flow. The sandstones are texturally and mineralogical matured which suggests deposition in a high energy environment.

Using (Sahu, 1964) to discriminate the depositional settings, it can be deduced that the sediments of the Ebenebe were deposited in the shallow marine environment (Table 4.1 & 4.2). The occurrence of tidal bundles, herringbone cross stratification, mud draped foresets, flaser beddings, ripple and horizontal laminations in the lithofacies studied within the Ebenebe Sandstone indicates presence of different flow regimes in the tidal systems (Allen 1980; Pettijohn 1975 and Boggs'1995).

Herringbone cross bedding is a product of tidal cycle characterized by two vertically adjacent cross- beds with opposing foresets dip directions. It has been documented as one of the sedimentary structures typical of tidal setting (Klein, 1970a; Visser, 1980; Allen. 1980; Clifton, 1983; Smith, 1988; Dalrymple *et al*., 1992). Tidal currents tend to be channelized into largely bidirectional currents in nearshore areas. Such bi-directional currents always show some degree of asymmetry (i.e. flow in one direction is stronger than that in the other direction) during tidal cycle. This is interpreted as ebb- flood tidal current flow in a single ebb- flood cycle. The subtidal channel facies association exhibits a fining upwards characteristics consisting of sandstone with sharp basal contacts, medium to coarse grained and fine grained sandstone at the topmost part of the succession. Facies association of this lithofacies with structures such as tidal bundles suggests deposition in a subtidal setting (Boersma and Terwindt, 1981; Visser, 1980; Allen, 1981a; Yang and Nio, 1985). The sandstone can be attributed to the reworking by tidal current played by ebb and flood tide in the deposition and reworking of the sandstones is evidenced on the occurrence of bipolar/bimodal paleoflow structures (like the herringbone cross bedding). The presence of trace fossil suites consisting dominantly of *Skolithos* ichnofacies (*Skolithos* isp. and *Ophiomorpha* isp.) are indication of colonization by suspension feeders in the Ebenebe Sandstone. This corroborates with the interpretation of tidally influenced shallow shelf environment (Nwajide 1984; Amajor 1984 and Mode 1991).

The tidal point bar facies association is characterized by fine to coarse grained sandstones with sedimentary structures such as herringbone cross structures and tidal bundles which distinguished bidirectional bipolar deposits from unimodal fluvial point bars. This facies association displayed fining upward sequence. The top of the facies association is marked by siltstone/mudstone facies. However, tidal point bars may exhibit distinct facies reflecting the alternation between fluvial versus tidal influences in the estuarine-tidal zone (Van den Berg *et al.*, 2007). Therefore, tidal point bars may have developed under the influence of mutually evasive ebb and flood flows during each tidal cycle (Hughes *et al.*, 2012, 2014). The bed load material almost always displays a residual or net movement in the direction of the fastest current

(Faguerazzi *et al.*, 2004; Li *et al*., 2008; Hughes, 2012). This could be attributed to marine transgression of the Imo Formation.
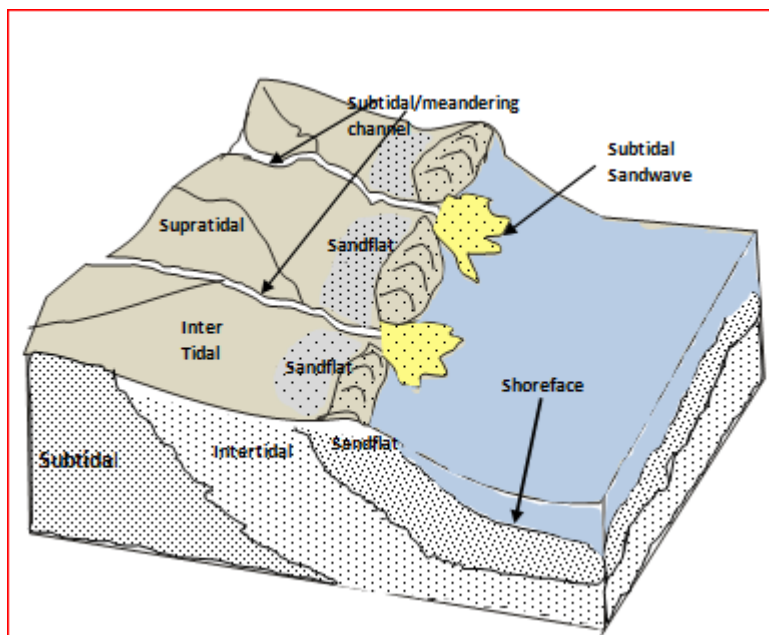

Fig 4.9: Conceptual Model for the Environment of Deposition of the Ebenebe Sandstone

5. CONCLUSION

Lithofacies analysis and grain size analysis have provided essential and unequivocal clues for interpreting the paleodepositional environment of the Ebenebe Sandstone in Ugwuoba areas, Southeastern Nigeria. Six lithofacies belonging to two lithofacies associations were identified, described and interpreted. The subenvironment for the sandstones was distinguished based on the sedimentary structures, textures, lithologies and vertical successions of the lithofacies. The two lithofacies associations depicting the Ebenebe Sandstone were subtidal channel and tidal point bars which may have been influenced and controlled by tidal current processes in the shallow shelf depositional environments. The Ebenebe lithostratigraphic unit of the Imo Formation is composed of sedimentary structures typically of tidal systems. The tide-generated structures in the units are tidal bundles, herringbone cross stratifications, clay drapes planar foreset beds, flaser beddings, wavy/ ripple laminations and trace fossil suites of *Skolithos* and *Ophiomorpha* ichnofacies which are indication of colonization by suspension feeders during low energy regime in the Ebenebe Sandstone.

5.3 RECOMMENDATION

There are more studies on the Imo Formation especially on the shaly facies than the sandstone bodies. Therefore it is recommended that;

1. Further studies should be carried out on the sandstones of the Imo Formation especially on the Ebenebe Sandstone since fewer studies have been done on the area

2. Research works on the hydrocarbon potentials should be carried out to ascertain it petrophysical properties of the sandstone.

3. Some of the outcrops studied in this work were not fully exposed and most of the outcrops were completely buried, effort should be made to excavate the mine site for thorough geological works

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