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Research Article

HYDROCARBON POTENTIAL AND SEDIMENTOLOGY OF OUTCROPPING TERTIARY FACIES OF THE ANAMBRA BASIN

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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); Nanka Sandstone (Eocene); 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 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.

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)(Fig. 1).

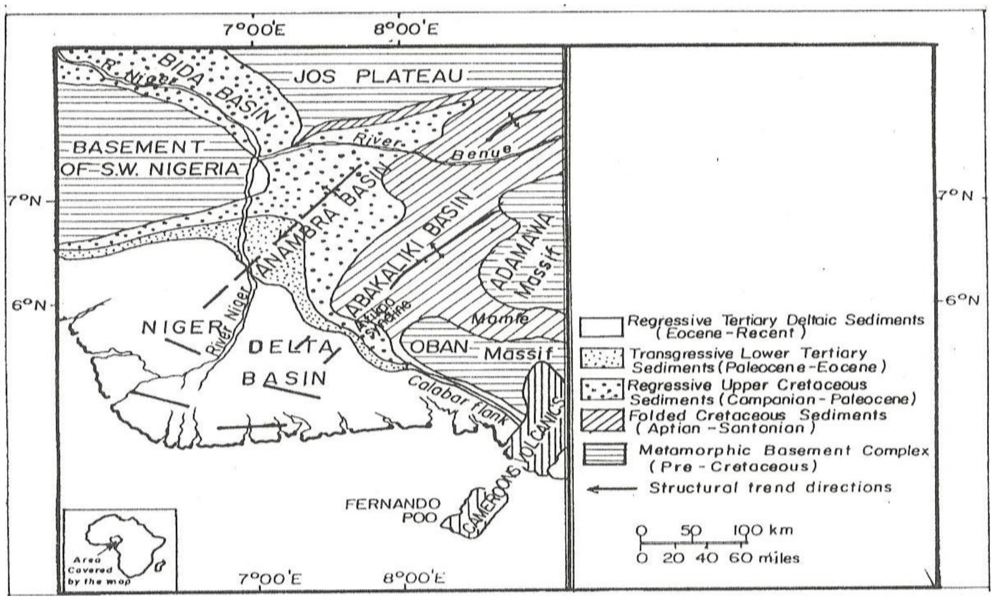

Figure 1: Four major structural domains in Southeastern Nigeria sedimentary (after Short and Stauble, 1967)

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 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/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, Ekwulobia all in Anambra State,Nigeria.

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 concluded that the sandstones were deposited in a tidal shelf environment based on process interpretation while Amajor concluded that they were deposited in a fluvio-marine setting.

The depositional model for the Campamain-Maastrichtian Anambra Basin were studied by Ladipo 1988, Mode (2000) and Obi (2000). In their various studies, they suggested various depositional setting such as fluvial channels, estuarine, proximal/distal lagoon, shoreface foreshore and tidally influenced channels.

MATERIALS AND METHODS

FIELD WORK:

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.

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.

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.

Sieve analysis: In this work, sieve analysis is particularly used for deriving the textural parameters since most of the samples are friable and would not yield suitable thin sections. The procedure of Friedman (1979) was employed for dry sieving. After a very careful disagregation, about 200 gm of each of the 100 samples was sieved at a mesh interval of $\frac{1}{2}$ and a time of 15 minutes using a Ro-Tap sieve shaker.

PETROGRAPHIC ANALYSIS (MINERALOGICAL ANALYSIS):

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

INTERPRETATION OF RESULTS:

OUTCROP DESCRIPTION:

Outcrop Description of the Ogwashi-Asaba Formation:

The outcrop exposure labeled OGI is located at km 13, Ogbunike along the Onitsha – Enugu express way. It is a road cut which exposes the formation although some section of the upper part has been eroded. The outcrop is about 24m thick from top to bottom. Four distinct lithofacies were distinguished from the outcrop, Figure 2.

Lithofacies Description:

Coarse grained-conglomeritic unit (5m thick): The unit consists of planar coarse grained sandstone which are friable coarsering upwards into pebbly sandstone with flat beddings. The coarse grained sandstone unit is about 4m thick while the conglomerate unit is about 1m thick. The alternation of these units continues throughout the section.

Fossiliferous Sandstone Unit (5m thick): This unit consists of fine grained massive sandstone, friable, white to yellowish in colour. The sandstones grade from fine grained to medium sandstone and highly fossiliferous.

It makes sharp contact with the overlying shale – siltstone unit.

Siltstone – Shale Unit (8m thick): The unit begins with a 2cm thick siltstone layer which is hard and brownish. A shale sub unit overlies the siltstone that is grayish to greenish in colour containing some carbonaceous materials which makes the shale look pearl. On top if the shale sub unit is a siltstone layer about 1.5m thick ferruginized and fossiliferous. This unit terminates with a coarse grain massive sandstone sub unit of about 15cm thick.

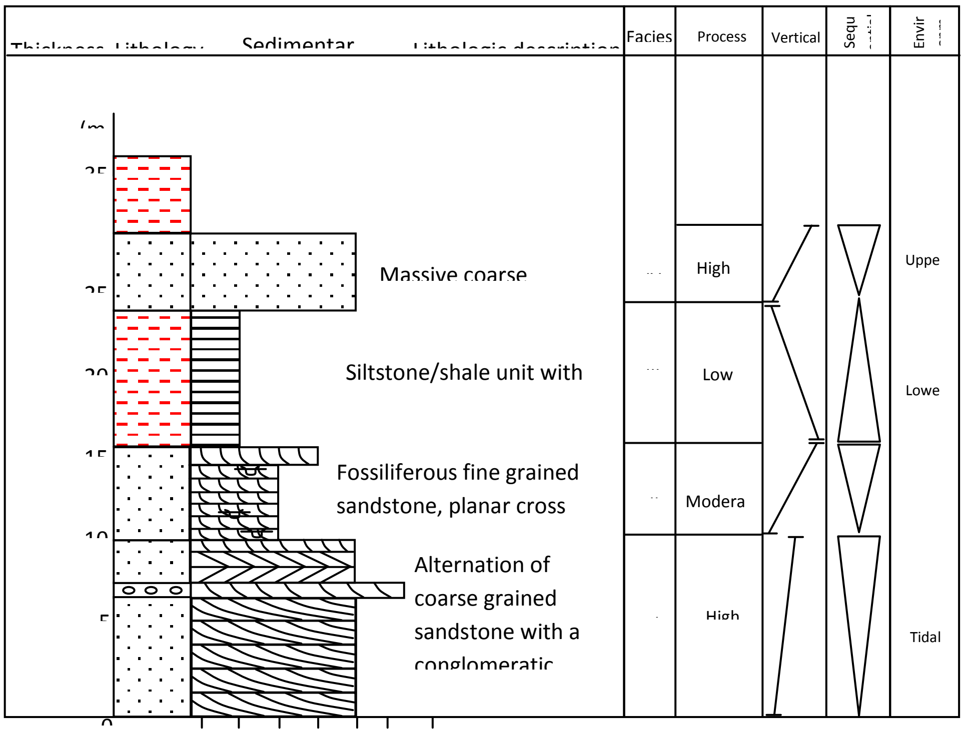

Figure 2: Lithologic Log of Ogwashi-Asaba Formation of

Location OG 1 (Ogbunike Toll Gate)

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:

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

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 barren of macrofossil.

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.

Sample no	**Mean**	**Sorting**	**Skewness**	**Kurtosis**
OG 1	1.8 medium sand	1.5 poorly sorted	0.43 very positively skewed	0.44 extremely leptokurtic
OG 2	1.7 medium sand	1.16 poorly sorted	1.4 very positively skewed	1.34 leptokurtic
OG 3	1.9 medium sand	1.01 poorly sorted	0.61 very positively skewed	1.00 mesokurtic
OG 4	0.4 coarse sand	0.91 moderately sorted	0.77 very positively skewed	1.09 mesokurtic
OG 5	1.2 medium sand	0.87 moderately sorted	0.85 very positively sorted	1.08 mesokurtic
OG 6	1.2 medium sand	1.06 poorly sorted	0.82 very positively skewed	1.02 mesokurtic
OG 7	1.7 medium sand	1.24 poorly sorted	0.57 very positively skewed	1.08 mesokurtic
OG 8	0.7 coarse sand	0.79 moderately sorted	1.23 very positively skewed	1.11 mesokurtic
OG 9	1.2 medium sand	0.87 moderately sorted	1.04 very positively skewed	1.08 mesokurtic
OG10	1.8 medium sand	1.47 moderately sorted	0.55 positively skewed	1.10 mesokurtic

Table 1: Size Frequency Parameter for Ogwashi-Asaba Formation

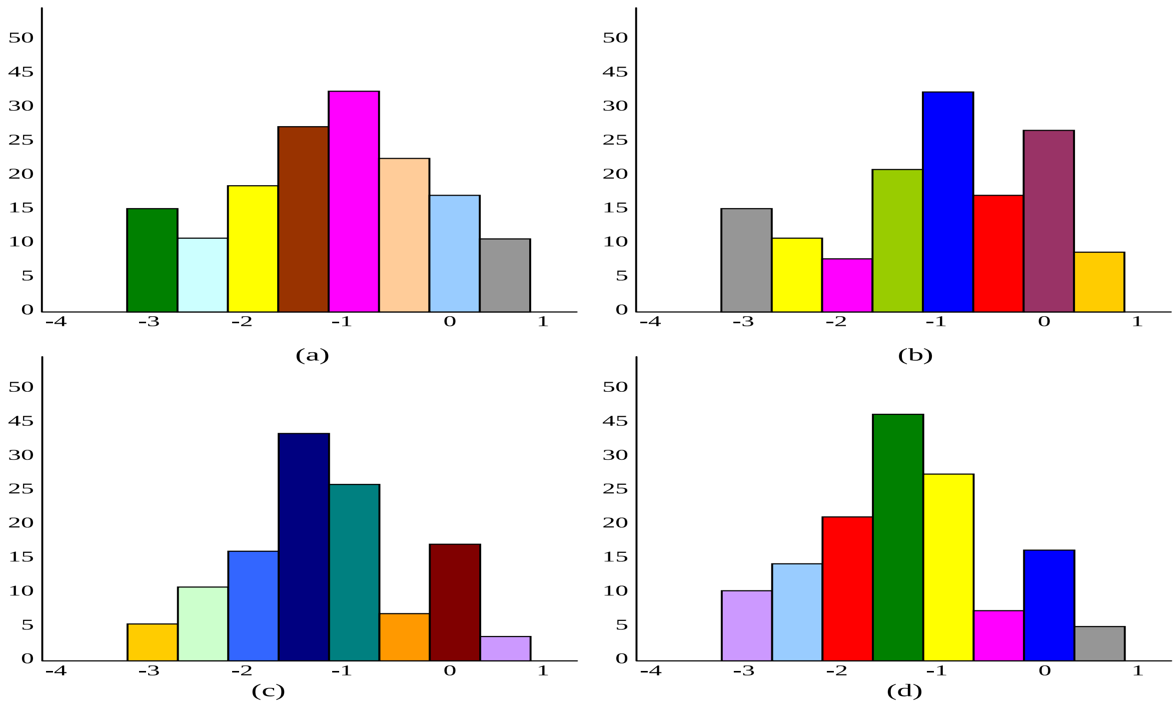

Figure 3: Histograms for the Sandston of the Ogwashi-Asaba Formation at Km 13, Ogbunike along Enugu-Onitsha Express Way

The histograms for the sandstone of the Ogwashi-Asaba Formation Fig 15 shows that the sandstone members have a wide range covering all ϕ (phi) diameter values that is, all grain sizes (fine - coarse) are represented. The majority of the analyzed samples have their maximum ϕ values in the 1 2ϕ indicating medium grained. The analysed samples show unimodal and bimodal distribution suggesting more than one phase of deposition and probably a reworking or redeposition of the sediments.

The cumulative results show that all modes of transport of sediments are involved. The segment show a moderately sorted traction sediment load of about 25%, a moderately sorted saltation load making up of about 25 – 80% and a well sorted suspension load of about 45% of the total population. These curves suggest that a moderate energy takes place probably from fluvial to tidal currents in the environment of depositi

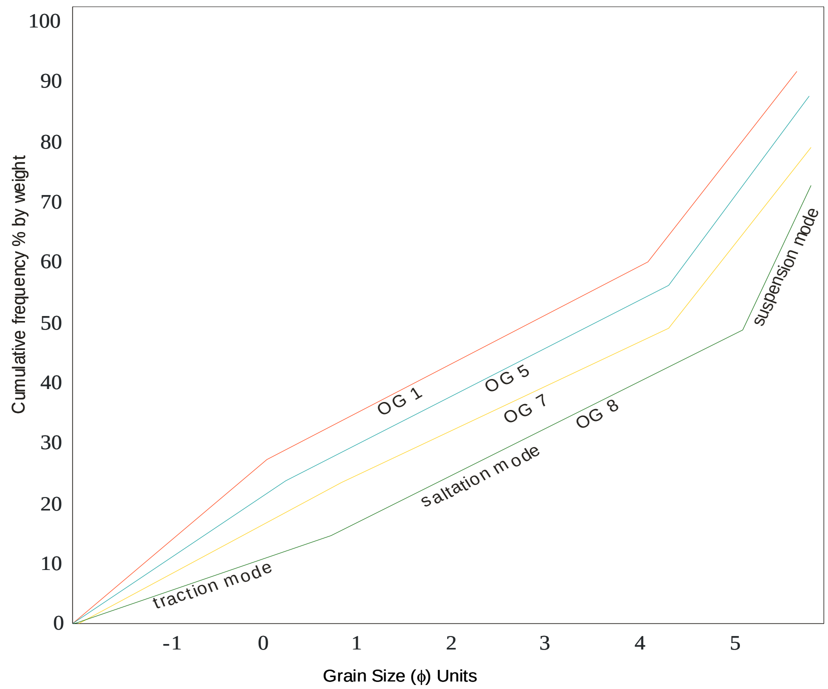

Figure 4: Frequency plots for the Sandstone of the Ogwashi-Asaba

PETROGRAPHIC ANALYSIS

Petrographic Analysis for Ogwashi Formation:

Petrographic analysis for the Ogwashi-Asaba Formation includes the light mineral microscopy and heavy mineral analysis..

Light Minerals: The analysed samples shows that quartz consist of about 94-99% of the framework grains. Quartz overgrowths are absent to rare, water droplets also present. The quartz also show distinct straight boundaries and this suggest that there are less or no overburden pressure high enough to cause pressure solution or tectonic stress, Ehrenberg (1997); Hart Kamp *et al.,* (1993). The quartz grains show dominance of monocrystalline nature over polycrystalline types with undulose extinction although sharp and non-undulose types also exist. The high predominance of monocrystalline, unstrained grains suggest selective destruction of less stable polycrystalline and strained monocrystalline forms during transport and recycling, Boggs, (1995). This led credence to a multicycle origin of the sediments, Suttner *et al.,* (1981); Amajor, (1986).

Sample No	Mineralogical composition	Texture	Type of Quartz	Type of Extriction	Type of Contact	Maturity
OG1	Quartz- 98% clay matrix	Subangular to subrounded poorly sorted	monocrystallire	Unduloze	Point	Matured
OG2	Quartz – 97% clay matrix	Subrounded poorly sorted	Monocrystllire 75% polycrystallire 25%	Non-unduloze	Point	Matured
OG3	Quartz – 99% silicacerent clay matrix	Subrounded moderately sorted	Monocrystallire	Sharp	Point	Matured
OG4	Quartz – 97% silica cerent	Subangular to subrounded moderately sorted	Monocrystallire	Unduloze	Point	Matured
OG5	Quartz – 98% clay matrix	Subrounded poorly sorted	Monocrystallire 88% polycrystallire 12&	Sharp	Point	Matured
OG6	Quartz – 99% clay matrix	Subangular to subrounded poorly sorted	Monocrystallire	Undulose	Point	Matured
OG7	Quartz – 94% clay matix	Subangular to subrounded poorly sorted	Monocrystallire	Unduloze	Point	Matured
OG8	Quartz – 99% clay matrix 0.08%	Subrounded poorly sorted.	Monocrystallire	unduloze	Point	Matured

Table 2: Thin Section Analysis for Light Mineral of the Ogwashi-Asaba Formation at Km 13, Onitsha Enugu Expressway

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.

The thin section analysis 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.

Mineralogical (Compositional) Maturity:

The mineralogical maturity of clastic sediment is a measure of the proportion of resistant or stable minerals present in the sediment. Quartz being the most stable and durable light mineral is usually used as a measure of mineralogical maturity. Analytical evidence from the mineralogical composition study shows that quartz is the most abundant light mineral in the study area with a total average of 95% - 99%, thus forming the entire framework. This criterion infers that the outcropping units are mineralogically mature. Evidence from the heavy mineral study shows that the ultral stable heavy mineral suite of zircon, tourmaline and rutile are more abundant. These indicate that the ultrastable minerals have survived many chemical and mechanical reworkings, hence suggesting a mineralogical maturity to the outcropping units, Pettijohn and Potter, (1972); Pettijohn, (1975).

Provenance Studies: Provenance studies may be single and comprise of only one dominant rock type or it may be complex where there is more than one source area, and/or sediments which are recycled from other sediments. Lateral changes in composition within a sedimentary unit usually reflect different source rocks or source areas, Mack, (1977). In this study, as rock fragments and feldspars are absent, quartz and heavy mineral content are used for provenance reconstruction.

Heavy Minerals: The heavy minerals found in the study area includes the opaques – limonite and ilmenite and the non-opaques – zircon, tourmaline, rutile, kyanite, staurolite and probably sillimanite. The opaque minerals are not useful for provenance studies. Zircon encountered in this study are rounded hence they may be from paragneises, paraschists and reworked sediments, Blatt *et al.,* (1972). Zircon has also been encountered in the Precambrian rocks of the Obudu area and the Oban massif, Orajaka, (1963); Ekwueme, (1982). The tourmaline found is the pale brown species which indicates a low grade metamorphic terrain, Krynine, (1946) in Pettijohn, (1975); Blatt *et al.,* (1972). In elucidating further the provenance of the sediments in the study area, the best indicator is the occurrence of the metamorphic mineral suite of kyanite – staurolite and probably sillimanite. This suite or assemblage is highly diagnostic of a metamorphic terrain, Folk, (1974); Pettijohn, (1975); Mason, (1990). Kyanite, staurolite and sillimanite indicate medium to high grade metamorphic provenance rocks. Hence it is reasonable to conclude at this point that a larger part of the sands foun in the study area are derived from a source comprising crystalline, medium to high grade metamorphic rocks and metasediments while the remaining parts are rework sediments. This observation gives credence to the multiple origin deduction given in the present work.

Foraminifera Analysis for Ogwashi-Asaba Formation:

Samples from the clay, shale and siltstone-shale layers were analysed for microfossil and only the siltstone unit were found to contain microfossils. The result is presented in Table 3.

Microfossil	Species diversity	Population count
Ammobacculites	6	4
Amber	-	-

Table 3: Abundance and Species Diversity for the Ogwashi-Asaba Formation at Km 13 Onitsha Enugu Expressway

The results show that only Ammobacculites sp and Amber are presented in the sample analysed with an absence of calcareous Foraminifera. This indicates an oxygen deficient environment, the presence of Ammobacculites and Amber (Fossil resin) indicates a marginal marine or a continental environment.

Palynological Analysis:

Few samples were selected for this analysis from the clay, shale and siltstone shale unit. The siltstone-shale unit only shows evidence of palynomorphs. The results show the presence of Bombacaceae sp and anecardiaccae pollens with Lecotriletes adriencsis in low abundance indicating a tidal environment. This agrees with the work of Gemaraed *et al,* (1968); Jean du chene *et al,* (1978); Umeji, (2001). According to Gemaraed, (1968), the association of some environmentally restricted marker species such as Sphinozocolpites baculites, Acrostrichum aureum, Proxerperiletes curcus, Pslatricolpo-rites, crassus and a few Dinoflagellate cysts are indicators of a coastal plain environment and suggest that the sediments may have been deposited in a marshy or swappy environment.

Spores	**Pollens**	**Dino Flagellates (Dinocysis)**	**Fungal Algal**
Acrotichum aureum (10)	Clenolophniles costatum (10)	Dinocysts and dinoflagellates	Leaf cuticles phloem parenchyma
Germmatriporite Ogwashensis (8)	Sphinozonocolpites baculatus (8)		
Psilatricolporites rotundiporos (6)	Mangocolporites faveoleitus (24)		
Lecotrieletes adriennis (6)	Psilatricoporites benueenis (8)		
	Proxerpertiles cursus (28)		
	Perinetitricoporites anambraensis (6)		
	Gematriporites Ogwashiensis (8)		
	Pslatricolporites crassus (20)		
	Proxerpentiles cursus (30)		
	Grinusdalea Polygonalis (4)		

Table 4: Palynomorphs for the Sandstone of the Ogwashi-Asaba Formation at Km 13, Onitsha Enugu Expressway

SEDIMENTARY STRUCTURES OF THE STUDY AREA:

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, 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.

Figure 5: 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. 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

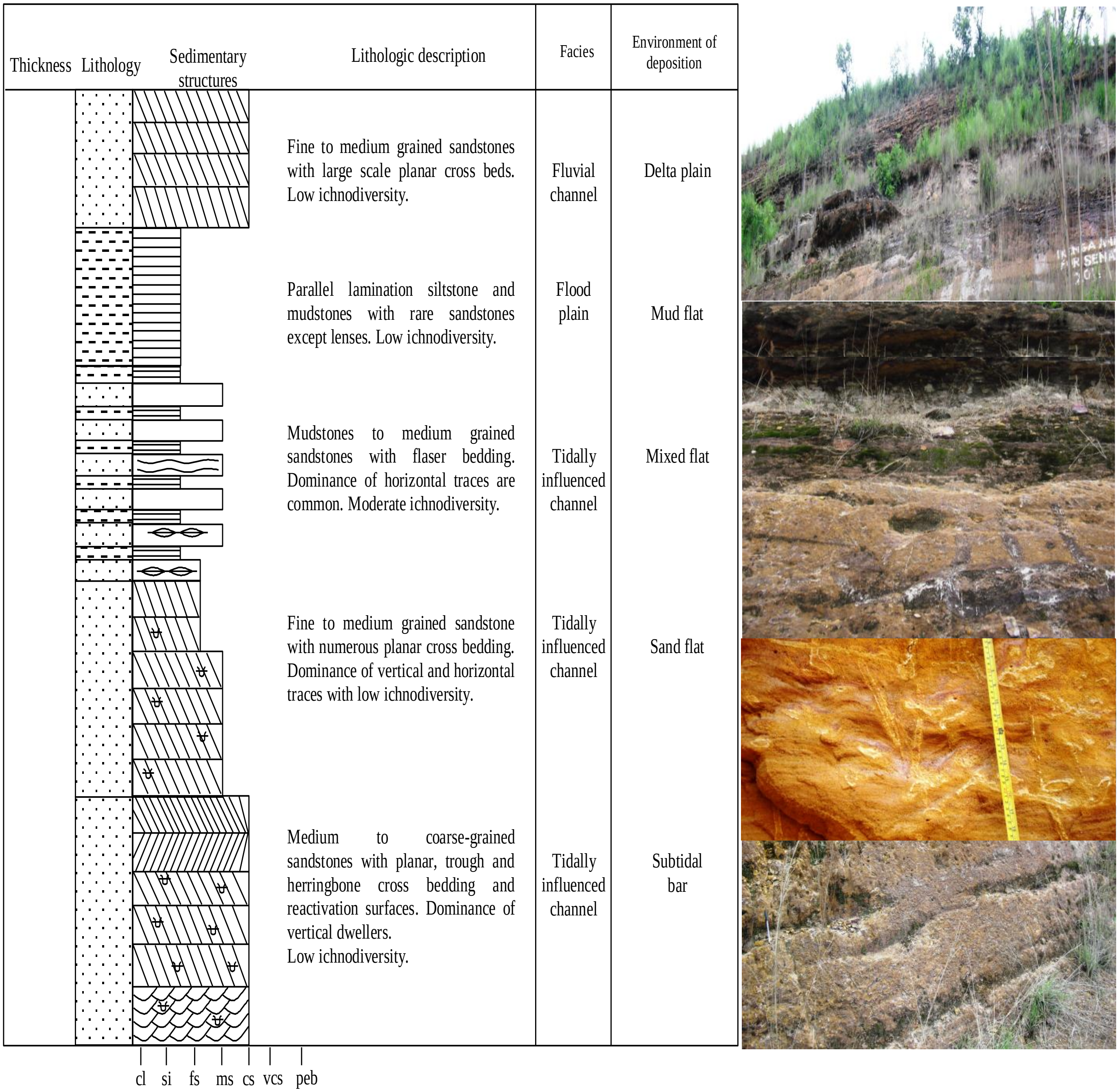

Figure 6: Shows integrated sedimentological, stratigraphic sequences and ichnological vertical model for the outcropping Tertiary sediments (modified after Buatois and Mangano, 2004)

RESERVOIR QUALITY

Reservoir Quality of Ogwashi-Asaba 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 facrics. In this assessment, the coefficient of variance and petrographic analysis was used.

The result obtained shows coefficient of variance discriminates between samples in terms of sorting.

If Cv ≤ 0.5 = homogenous or good sorting

If Cv ≥ 0.5 ≤ 1= heterogeneous or poor sorting

If Cv ≥ 1 = very heterogeneous or very poor sorting

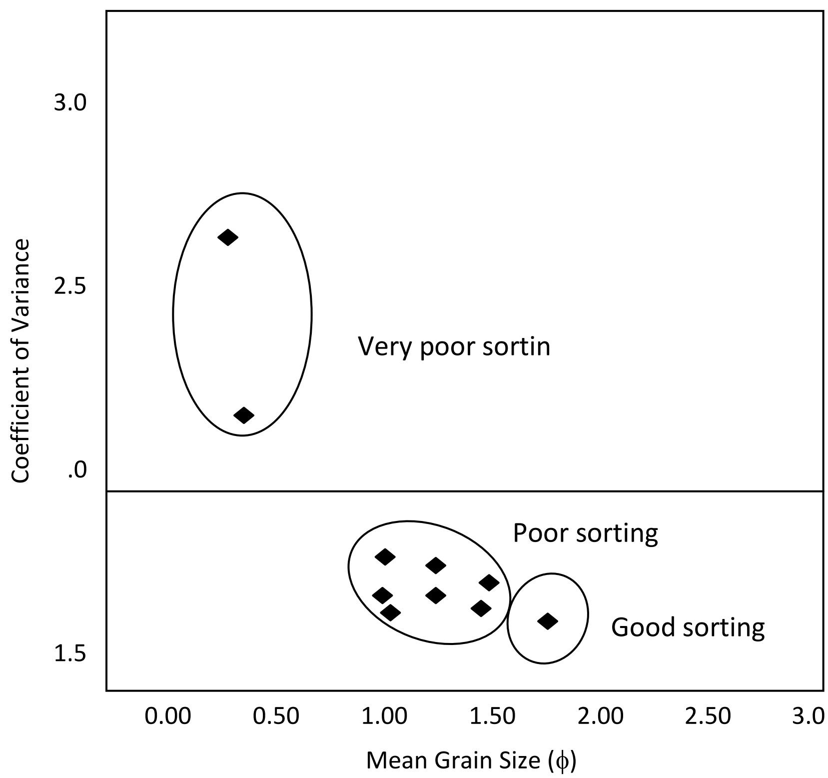

Figure 7: Plot of Coefficient of Variance against Mean

Grain Size for the Ogwashi-Asaba Formation:

From the results obtained for the Ogwashi-Asaba Formation, the sample ranges from very heterogeneous (2.28) to heterogeneous (0.88) and homogenous (0.45) and on the average shows heterogeneous character. The plot of coefficient of variance against mean grain size shows more than a half of the analysed samples are poorly sorted. Hence the porosity is to interpreted as fair to good.

Reservoir Quality for the Ebenebe Formation:

The plot of coefficient of variance against mean grain size place the samples to be moderately sorted in more than a half of the sampled area. Hence the porosity in interpreted as good.

DISCUSSION

This research work was carried out with the aim of a detailed study of the sedimentology with a view to evaluating the study area hydrocarbon potential.

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 four outcropping units – Ogwashi-Asaba 1.70ϕ, Ebenebe 1.25ϕ, 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.

The standard deviation (sorting) of the four outcropping units – Ogwashi-Asaba 1.33ϕ (poorly sorted), Ebenebe 0.74ϕ (moderately sorted),. The dominant moderately sorted sediments indicate a fairly high energy depositional environment with the sediments losing largely their original texture and configurations due to abrasion. The poorly sorted sediments show slack energy condition. Similarly the skewness values of the four outcropping units – Ogwashi-Asaba 0.01ϕ (symmetrical), Ebenebe -0.02 (nearly symmetrical The positively skewed suggests that the coarse admixture exceeds the fine sediments, that is, the tail of the distribution extends into the positive direction. Poor sorting and positive skewness are consistent with river sands while beach sands are generally well sorted and negatively skewed, Friedman, (1979). However, the sediments in the study area are largely with a range of skewness – symmetrical, nearly symmetrical, negatively and positively skewed and moderately sorted which suggest that the depositional environment was fluctuating (pulsating) and dwindling in energy. The kurtosis value of the four outcropping units – Ogwashi-Asaba 1.15ϕ (Leptokurtic), Ebenebe 1.10ϕ (MesokurticThis result agrees with Mason and Folk's (1958) observation that most sands consist of one predominant population with a very subordinate coarser or finer population hence a better sorting at the tails than the central portion of the distribution. Generally, a mixture of one predominant population with a subordinate one results in a leptokurtic distribution, Folk and Ward (1957), Friedman, (1962, 1979) also observed that most sands are leptokurtic and positively or negatively skewed as in this study area.

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, Elliott and Gardiner (1981); Klein (1970); de Raaf and Boersma (1971); Dairymple *et al,* (1978, 1992). 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..

The trace fossils *ophiomorpha* and *skolithos* belong to the same *ichnofacies* namely *Skolithos lchnofacies*, Seilacher, (1967); Frey *et al,* (1990), although due to the mode of occurrence and similar shape characteristics. *Ophiomorpha* is being considered as a distinct *Ichnofacies*, Radwaniski, (1970). It indicates deposition in a range of environment – tidal pools, intertidal and shallow sublittoral as a result of fluctuating energy condition. The *Skolithos ichnofacies* is indicative of a relatively high level of wave or current energy as in the study area and typically developed in a slightly muddy to clean, moderately to well sorted loose or shifting particulate substrate which enhances physical reworking and preservation of physical sedimentary structures. Also, changes in rates of deposition, erosion and physical reworking of the sediments are frequent. It is indicative of a flood and ebb delta.

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 sediments of the study area also show permeability obstruction such as baffles (clay draped cross beds) and barriers (reactivation surfaces). These barriers and baffles impede vertical and horizontal flow of fluids, although the presence of burrows would enhance the vertical flow of fluids in the area. Usually vertical and horizontal flow of fluids are dependent on the sedimentary structures which are the primary depositional control.

RECOMMENDATION: I strongly recommend that more surface outcrop studies be carried out to simulate its reservoirs and subsurface wells be drilled so that a very detailed study of the hydrocarbon prospectivity of the area will be achieved.

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