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Research Article

OUTCROP SEDIMENTOLOGY AND RESERVOIR PROPERTIES OF THE OGWASHI-ASABA FORMATION, NIGER DELTA BASIN

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ABSTRACT

An elaborate sedimentological study was carried out on siliciclastic rocks of the Ogwashi-Asaba Formation, Niger Delta Basin to determine the reservoir potential of the rocks. Petrographic analysis was also carried out on the collected samples to determine the textural and mineralogical maturity of the outcropping sediments. The analzyed samples of the formation suggests immature to submature sediments. Although quartz makes up more than 60% of the entire framework with sub-rounded grains, the ratio of quartz to feldspar and lithic fragment suggest a mineralogical immature sediments.The ternary plot shows that the sandstones are litharenites to sub-litharenities. The mud-baffles observed across in 3-D could act as a seal to prevent the escape of hydrocarbon in the reservoir. In the tidal flat and fluvio-estuarine environments, the deposits are classified as potential reservoir flow or permeable strata. They are low to intensely bioturbated with cross-cutting structures and mud-filled burrows.

Keywords: Sedimentology, Reservoir, Outcrop, Sediments, Petrography

INTRODUCTION

Sedimentology, as a field of study is paramount in the petroleum industry because it is in typical sedimentary environments hydrocarbons are formed. On a global scale, sandy sequences are important parts of sedimentary basins as they make up petroleum reservoirs and potential aquifers (Ejeh, et. al., 2015).

The subsurface Cenozoic Niger Delta has its surface equivalents referred to as outcropping tertiary facies of Imo Formation, Ameki Group and Ogwashi-Asaba Formation (Frankl & Cordry, 1967; Short & Stauble, 1967; Petters, 1991; Nwajide, 2005; Reyment, 1965). These preceding reports shows that the sandstone bodies are enclosed firmly in a surrounding mass of mudrocks leading to the formation of stratigraphic traps in the subsurface (Ekwenye, 2014). These could constitute a major source of trapping configuration in the subsurface Paleogene strata packages. Hence, there is need for an elaborate sedimentological investigation to determine the reservoir potential that would aid in the reservoir characterization of the outcropping tertiary sediments of the Ogwashi-Asaba Formation.

Aim and Objectives:

The study aims to come up with a sedimentological description of the outcropping sediments which would aid a better understanding of the reservoir characteristics.

The research objectives include:

- To provide a detailed study of the sedimentary geology of the area (which includes structures)
- To provide a model for reconstructing the outcropping sediment source.
- To ascertain the sedimentary controls on the nature of the reservoir via sedimentological analyses from outcrops of the Ogwashi-Asaba Formation.

Scope of Study:

This study centers on an elaborate sedimentary outcrop descriptions of the structures of subsections of the formation; integrating field and laboratory studies to deduce the reservoir architectures.

Study Location:

The study area at Anwai lies within latitude N06^{0}14’38.1” and longitude E006^{0}42’00.2” while that of Ibusa lies within N06^{0}11’19.9” and longitude E006^{0}39’33.6” (Figure 1). Subsections of the formation such as Anwai Campus and Ibusa quarrying site was used as a framework that may represent regional model for basin-wide forecasts. The Ogwashi-Asaba Formation is identified among the outcropping Niger Delta, with the others being the Ameki Group and the Imo Formation (from distal to proximal delta) (Short and Stauble, 1967; Doust & Omatsola, 1990). These formations are delimited to the North by the Cretaceous Anambra Basin and a gentle gradation to the South into the Niger Delta Basin where they are commonly referred to as the Akata, Agbada and Benin Formations. Originally recognized as Lignite Series (Parkinson, 1907), the formation is seen largely around Benin, Asaba, Onitsha and Owerri.

Review of Previous Work:

Previous researchers have done justice to aspects of the Paleogene strata which include the petrography, lithofacies, environment of deposition, stratigraphy and micropaleontology.

As a result of the petroleum potential of the Niger Delta sedimentary basin several researchers have studied various aspects ranging from geophysical, biostratigraphic, paleontological, stratigraphic/sedimentological and components of the petroleum systems. Some of the works on the particular study location includes:

Bassey & Eminue, (2012) employed an incorporated scientific approach consisting of geochemical, sedimentological and petrographic studies of the Paleogene Ogwashi-Asaba Formation with the aim of infering source rock, sediment traanport history, emvironment of deposition and hydrocarbon prospect. Results showed that the sandstone were from various sources and a fluvial depositional environment suggested. The vitinite showed a potential source for gas.

Osokpor & Omo-Irabor, (2020) carried out sedimentological and preliminary evaluation on the commercial utilization of the shale facies in the Ogwashi-Asaba Formation utilizing geochemical and geotechnical analyses. Their result on the comparative analysis of shales shows that they have potential application in the manufacturing of various products if appropriate mineral processing is carried out on the shales to improve their economic values.

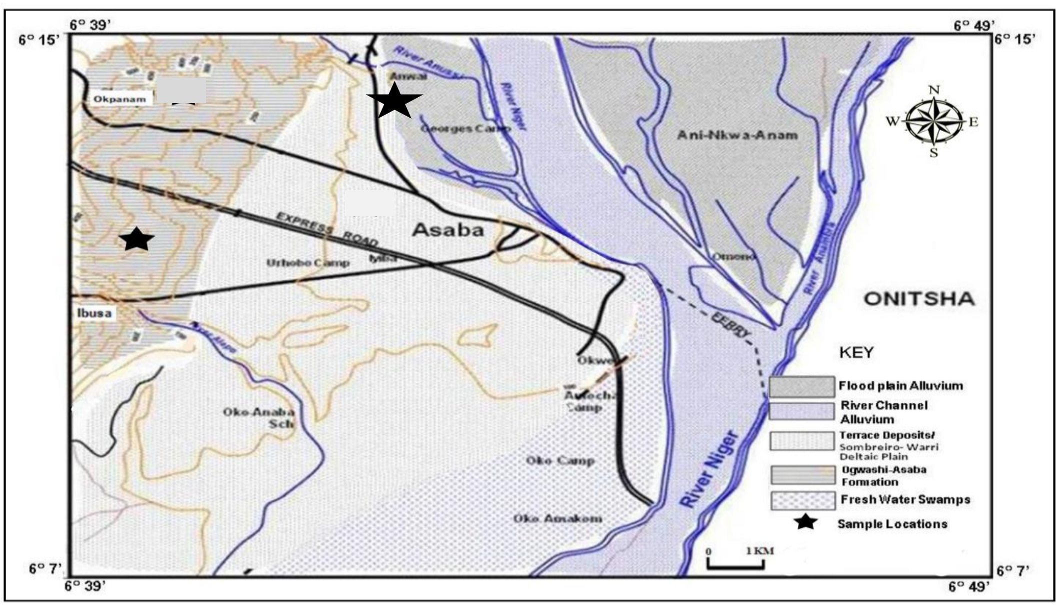

Figure 1: A Geologic map of Ogwashi-Asaba Formation After (Ejeh, et. al., 2015).

Methodology:

The investigation procedure was executed and summarized in three (3) phases:

a) Field mapping
b) Laboratory investigation
c) Data incorporation and interpretation

The main distinctive features of the sedimentary succession recorded here include texture, composition, bed thickness, diagenetic features and sedimentary structures. The field study area includes the excavation site at Anwai Campus and the Ibusa Quarrying site.

In this field investigation, an “on-the-spot” sampling technique was utilized whereby the outcrops were examined as they were encountered, making sure that all lithologies were aptly represented. Twenty (20) samples were obtained from the two outcrops studied. The detailed fieldwork carried out included sedimentological evaluation which involved:

- Lithology recognition and description: the visible formation of rocks types and mineralogical framework.
- Texture: colour, size of grain, shape of grain (sphericity and roundness), sorting, grain-matrix relation and grain orientation.
- Bed thickness, lateral extent, bedding planes (sharp or gradational, scoured) and erosional surfaces. Variation of thicknesses of sand and clay were recorded for heteroliths.
- Sedimentary structures:
    - Physical structures: reactivation surfaces, bedforms, stratification, channels and deformational structures e.g. overburden crossbeds, water escapes etc.
    - Chemical structures: concretions, nodules, liesagang rings
    - Biogenic structures: burrows, fecal pellets, trails and tracks

The above sedimentological field investigations were used to:

- Understand the reservoir heterogeneity and architectural elements which involves
    - Sandstone geometry and surrounding mudrocks
    - Connectivity and geographical dispersal of the sandstone bodies and
    - Interior reservoir diverseness which behaves as permeability barriers, such as discontinuous finer-grained strata, drapes of muds, joint surfaces, accretion sets
- Predict the rock’s reservoir quality.

Procedure:

A significant aspect of sedimentological study of mineral grains is the analysis of the grains in thin section with the aid of a petrographic microscope. Hence the petrographic evaluation was carried out on the samples for mineral grain size analysis where the thin sections were viewed in both cross polarized and plane polarized light. The thin sections were prepared in the University of Calabar Geology laboratory.

The analytical procedure includes:

i. Chipping off a portion of each sample
ii. Smoothening the surface of the chip with the aid of a sandpaper.
iii. Subjected the smoothened samples to a temperature of about 70^0C with a hot plate.
iv. About 5g of Araldite Mixture A & B was daub on the surface of the heated samples.

v. After smearing on the surface the samples were extracted from the hot plate and allowed to cool.
vi. With the aid of abrasives F360 and F800 the surfaces of the cooled samples were polished, washed and repositioned on the hotplate.
vii. With abrasive F800 the surfaces of glass slides were polished and positioned on a hotplate.
viii. 5g mixture of Araldite A & B mixture was smudged on a dry glass slide to cover the surface area.
ix. A forceps was used to pick the dried samples, positioned on the smeared glass and tightly locked to get rid of air bubbles.
x. The mounted samples were allowed to cool on the mounting jig.
xi. With the aid of a grinding machine and abrasives F360 & F800 the mounted samples were crunched to about 30μm thickness
xii. Using a petrographic microscope, colors of minerals were visible at 30μm.
xiii. To wash the thin section slides a methylated spirit was utilized. The excess araldites were scratched off with a razor blade.
xiv. Finally, the slides were marked and their petrographic properties were observed under the microscope.

RESULTS AND DISCUSSION

Outcrop exposures that constitute the broad Ogwashi-Asaba stratigraphic successions were examined at different areas to represent a regional framework for the formation. The outcropping sections sampled are in quarrying site at Anwai Campus and Ibusa respectively [figure 1].

Location 1:

This section comprises of about 3m poorly sorted coarse grained sandstone characterized by planar cross and trough beds with a purple colour. The grains are angular and liesagangs were present with vertical and horizontal burrows [figure 2a]. This sections grades into a highly bioturbated, moderately sorted, medium to fine grain sandstone that thins out laterally [figure 2b]. Overlying this sequence is a medium to coarse grained sandstone of about 2m characterized by flaser and planar cross beds. At the top portion is a sub aerial exposure of iron concretion and at the base bounded by an unconformity.

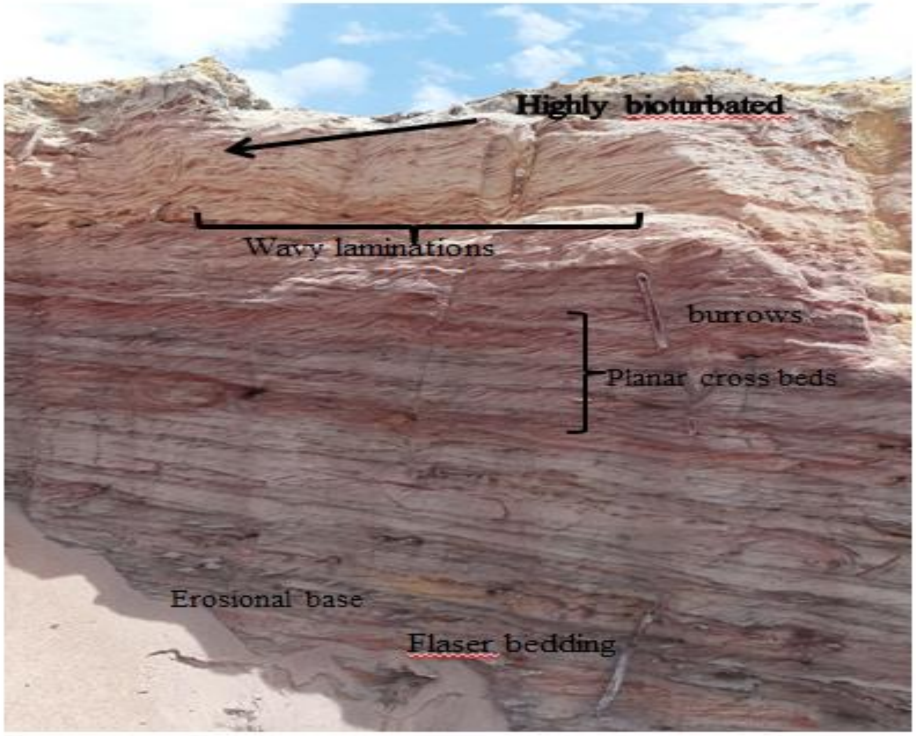

Figure 2a: showing sedimentary structures in outcrops at Anwai Campus

Figure 2b: Anwai 2 showing planar tabular cross beds and reactivation surfaces

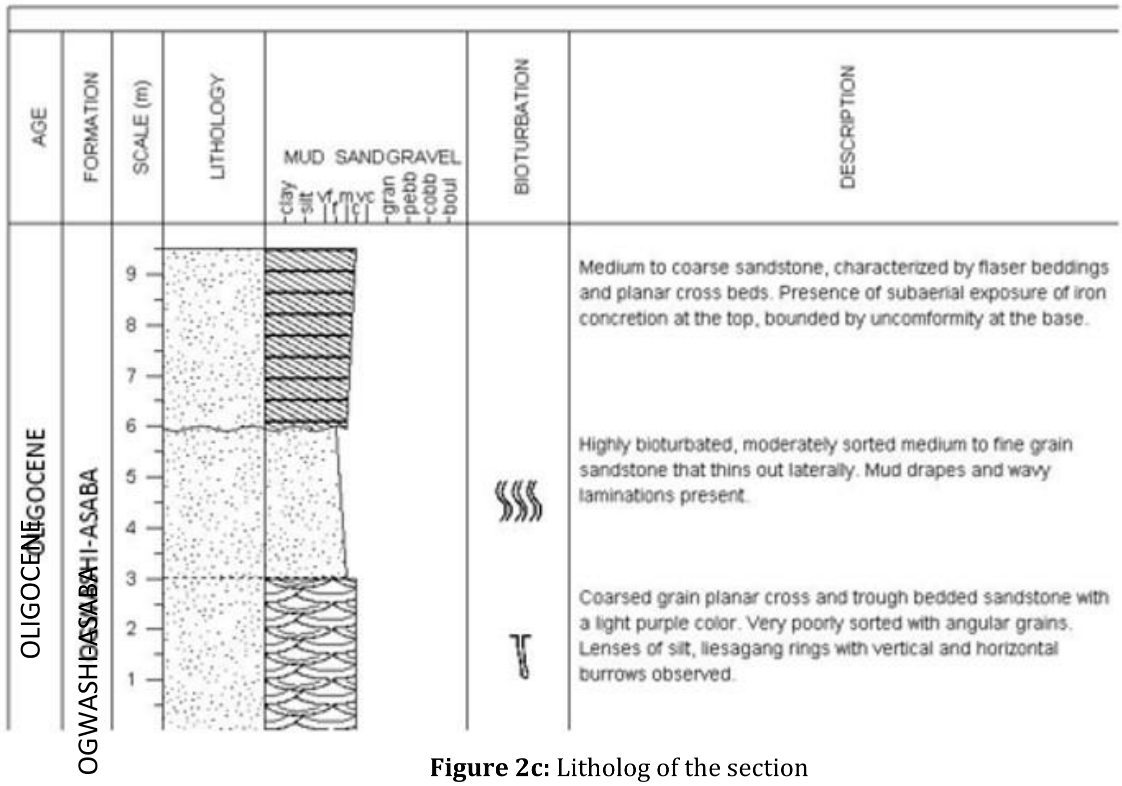

Figure 2c: Litholog of the section

Location 2:

This exposure is about 6m thick. The basal part comprises of a flaser and cross bessed sandstone with angular to sub angular, medium to coarse moderately sorted grains showing a yellowish colour. With the overlying medium grain cross bedded sandstone its shows a gradual contact. Overlying this is a 0.5m clay with lenticular bedding followed by a highly ferruginous, coarse to very coarse grain sandstone with subangular grains. They are poorly sorted. This was followed by a 2m thick medium grain sandstone. It is highly bioturbated relics with planar beds [figure 3a -3c]

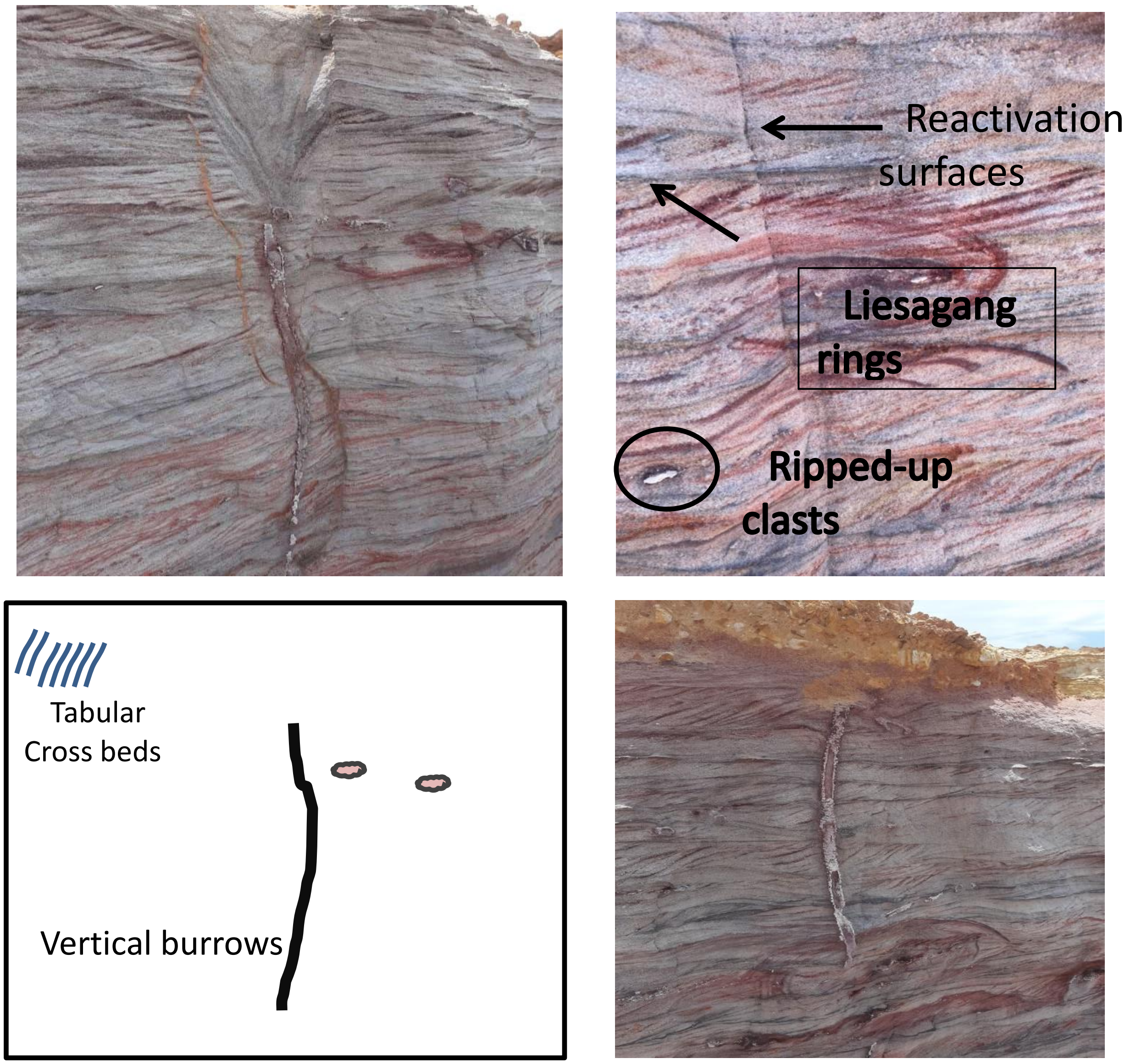

Figure 3a: Anwai 2 showing cross-bedded sandstone with reactivation surfaces, pockets of muds and burrows

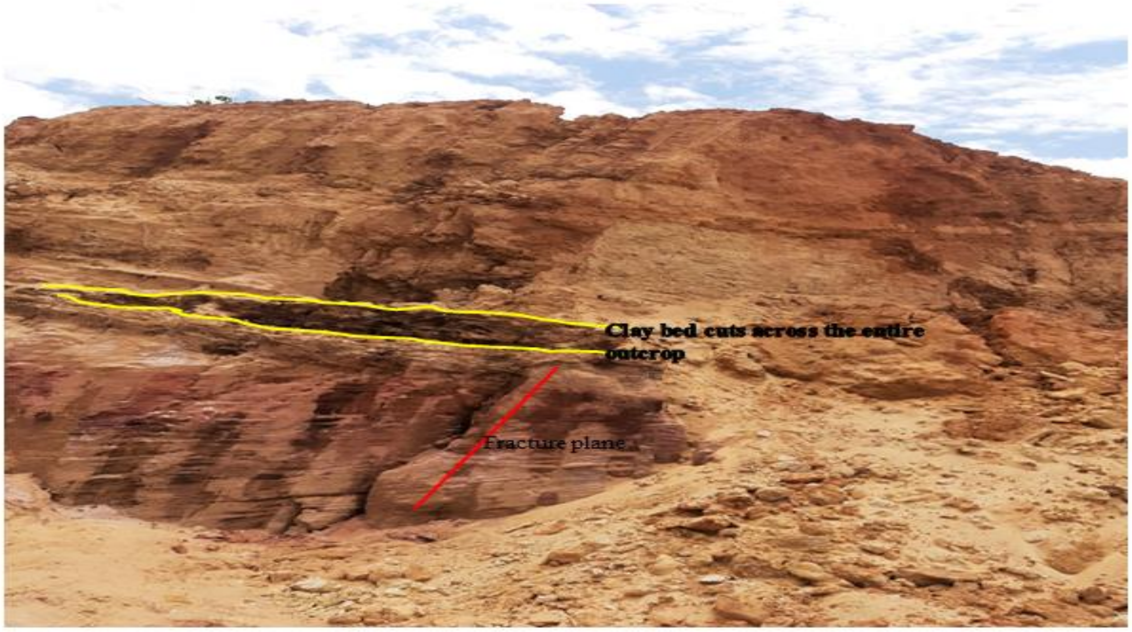

Figure 3b: Anwai (2b) showing laminated crossbeds, a clay bed and the litholog

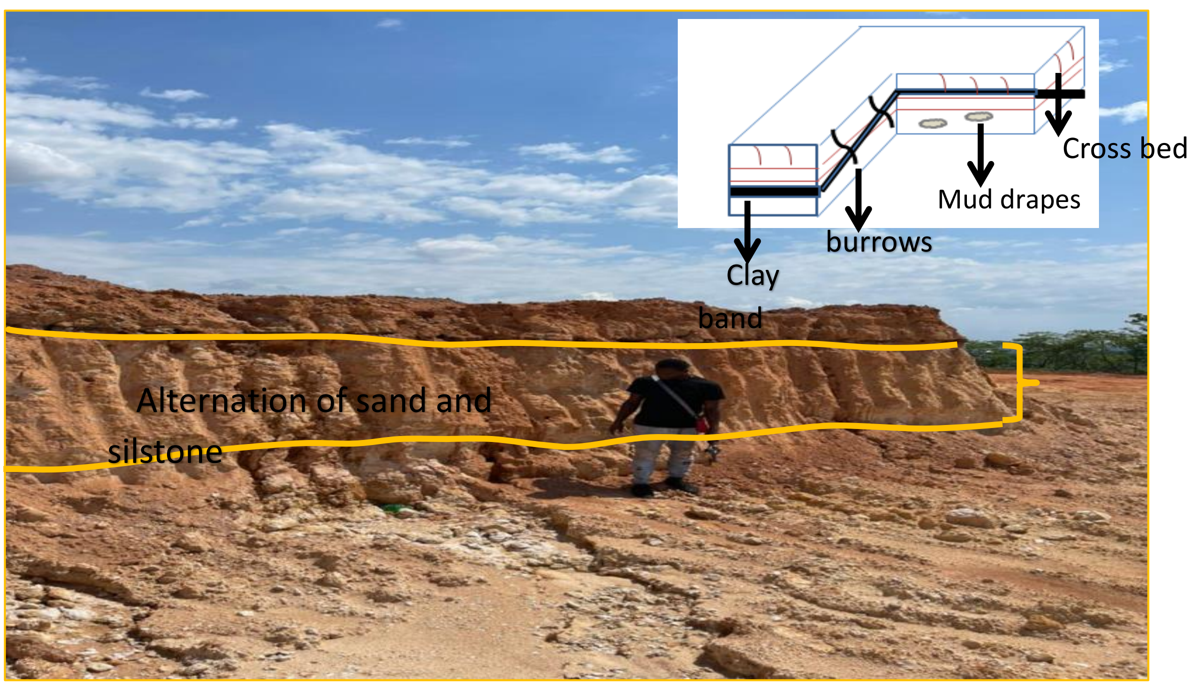

Figure 3c: Anwai 2b (rear) showing the clay bed that cuts across the exposure

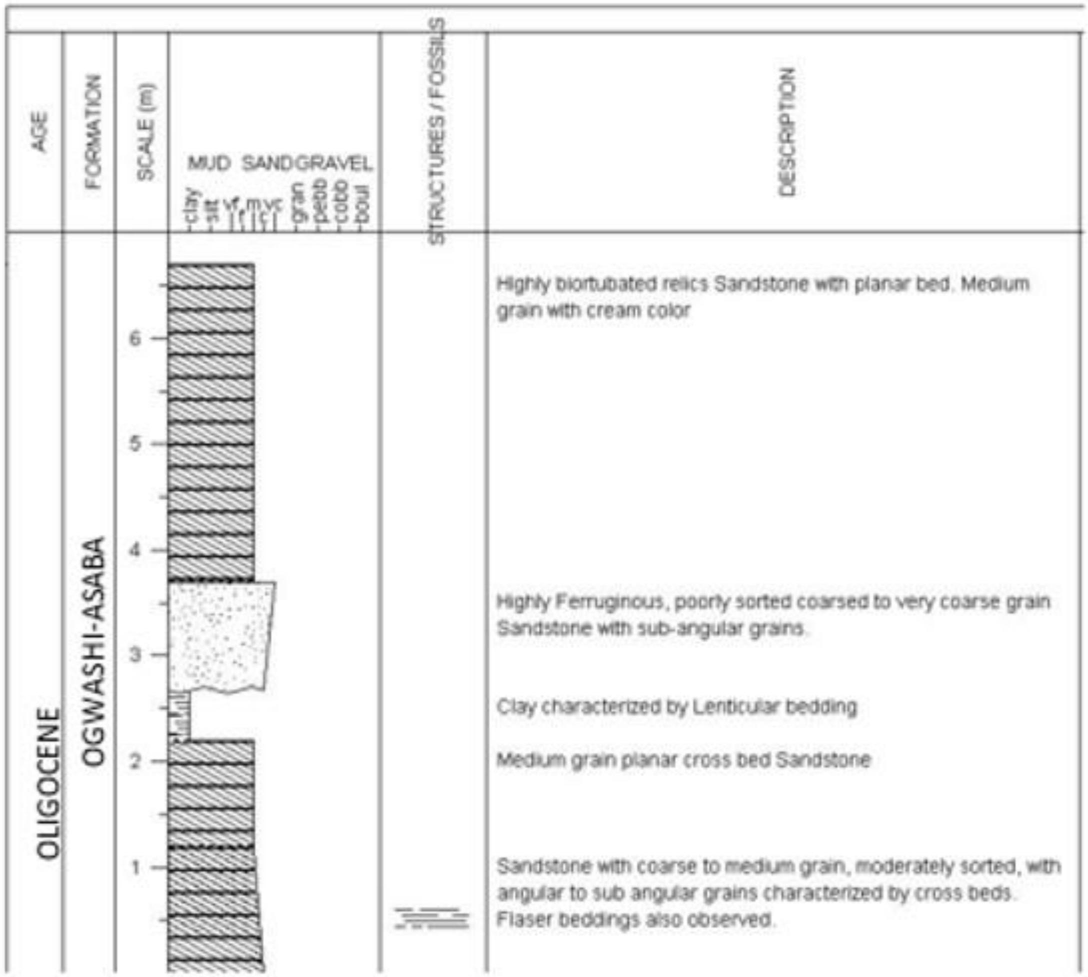

Figure 3d: litholog of the section

Location 3:

This exposure shows the rear of the outcrop. The basal part is a coarse grained moderately sorted sandstone with cross beds and yellowish in colour. It grades into a medium to coarse grained trough bedded sandstone of about 2m thick characterized by clay drapes. A fine grain planar clayey sandstone that shows a sharp contact overlies this unit followed by another planar clayey sandstone ranging from fine to coarse grain. This is bounded at the base by an unconformity and at the top by a visible sub aerial exposure of iron concretion. Overlying the iron concretion is a parallel laminated shale with lenticular bedding of about 0.5m thick followed by a 3m sandy to sandy-silty heterolith [figure 4.4a]. The topmost portion consist of shales of more than 2.5m thick with lenticular beddings [figure 4a].

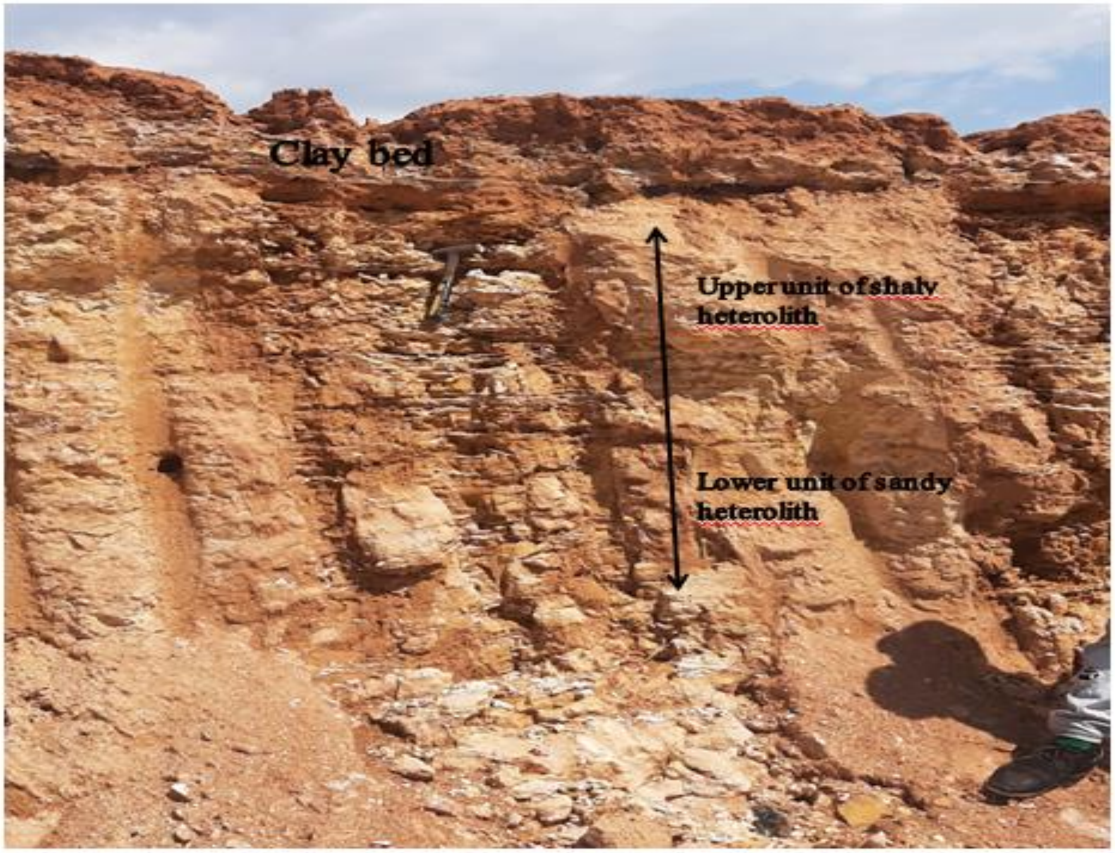

Figure 4a: Anwai 3 Heteroliths in tidally influenced deposit consisting of thinly interbedded sandstone and mudrock. Streaky laminae of very fine mudrock in sandstone.

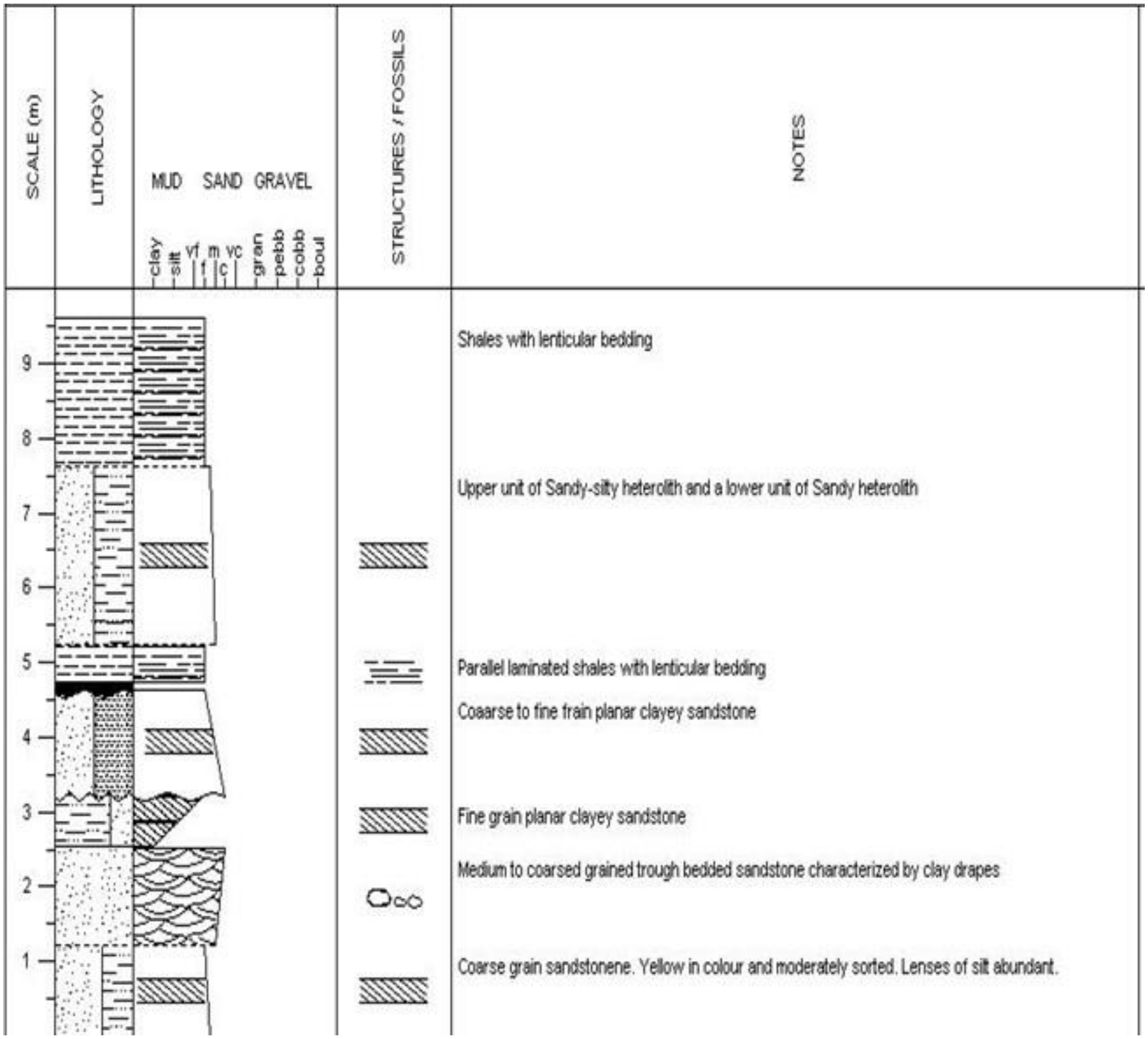

Figure 4b: Litholog and description of Anwai 3

Petrographic Analysis:

The Ogwashi-Asaba Formation comprises mainly of sandstone and mudrock deposits in nearly equal proportion. The sandstone deposit is more in facies association 1, 2 and 4. They are poorly to moderately sorted and ranges in grain sizes from medium to coarse grain with angular to sub-angular grains. The mudrocks are restricted to facies association 2 and 3. The petrographic evaluation herein provides information on the minerals present, shape and orientation of grains.

Mineralogical Composition:

Quartz:

From the analyzed samples quartz is the predominant mineral comprising about 66% - 76% of the rock's total composition. The quartz are mainly sub-angular in shape [figure 5]. Observed were monocrystalline grains (exhibiting a partial and straight undulose extinction) and polycrystalline grain with a medium and coarse texture. The dominance of unstrained monocrystalline quartz indicates displacement of the unstable polycrystalline-strained quartz during transport (Boggs, 1995). According to Suttner, et. al., 1981; Amajor, 1987, this buttresses the sediment's multi-cycle origin. Also observed in the quartz grains were fluid and solid inclusions. From observation some of the grains appear cloudy and are fractured.

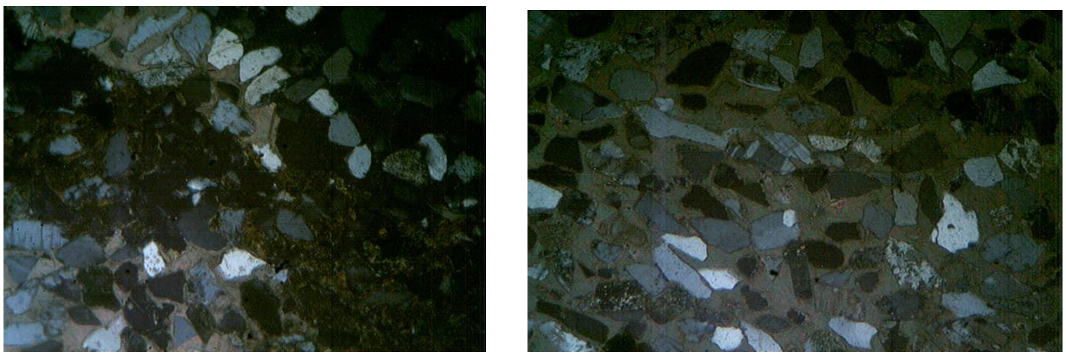

Figure 5: Sorting – moderately sorted; Grain size – medium to coarse grain; Shape – sub-angular. Sediments are polycrstalline. Quartz are indicated by red arrows while blue arrow indicates quartz overgrowth

Feldspar:

During weathering feldspar can change easily to clay minerals after long distance of transport and intensed abrasion. Hence their relatively insignificant appearance may indicate that the deposits are accumulated from a recycled provenance (Helmold, 1985) [figure 6].

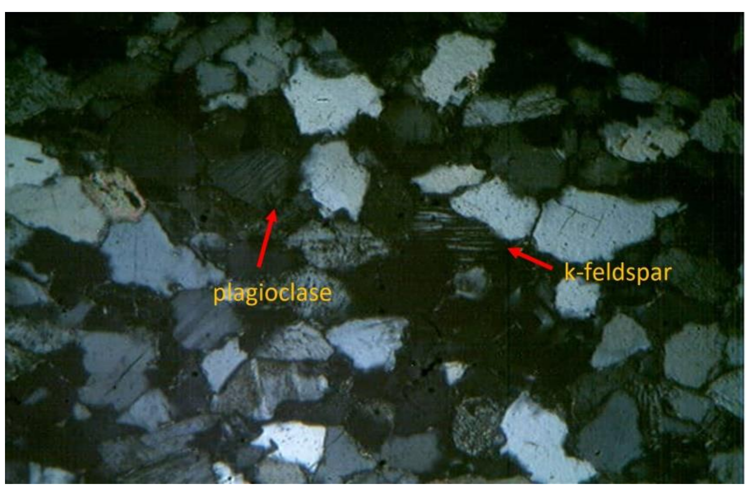

Figure 6: Poorly sorted, angular, coarse grain polycrystalline immature sediment

Lithic Fragments:

These are a mixture of both sedimentary and minor metamorphic rock fragments. They have sub-rounded grains ranging from medium to coarse. The fragments of the sedimentary rocks comprise of siltstone and shale dominant in the tidal flats facies (above 20%). The fragments of the metamorphic rocks maybe derived from basement rocks (schist and quartzite) and they make up less than 3% of the rock composition [figure 7].

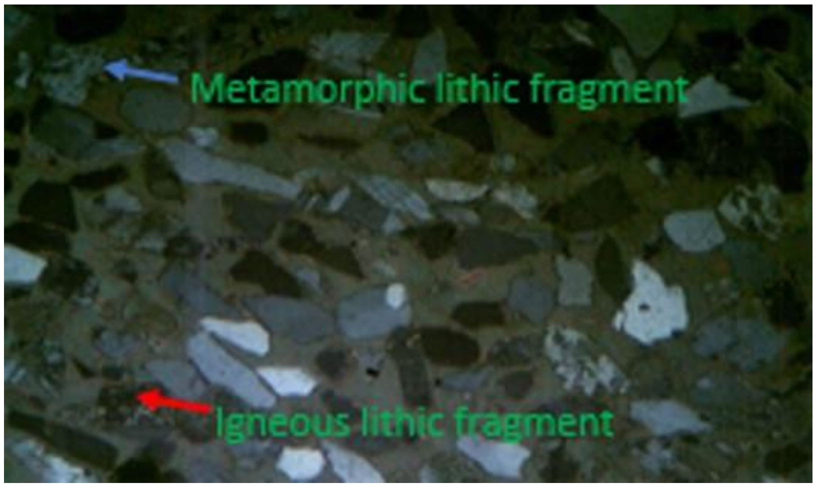

Figure 7: showing rock/lithic fragment of igneous origin.

Accessory minerals and cement:

The minor terrigenous component are Micas and they make up less than 4% of the total composition and they are limited to the tidal flats. The major types of cement found are ferruginous (mainly haematite) and argillaceous cements. They also make up about 4% of the rock's total composition and they form on the edge of the grains [figure 8].

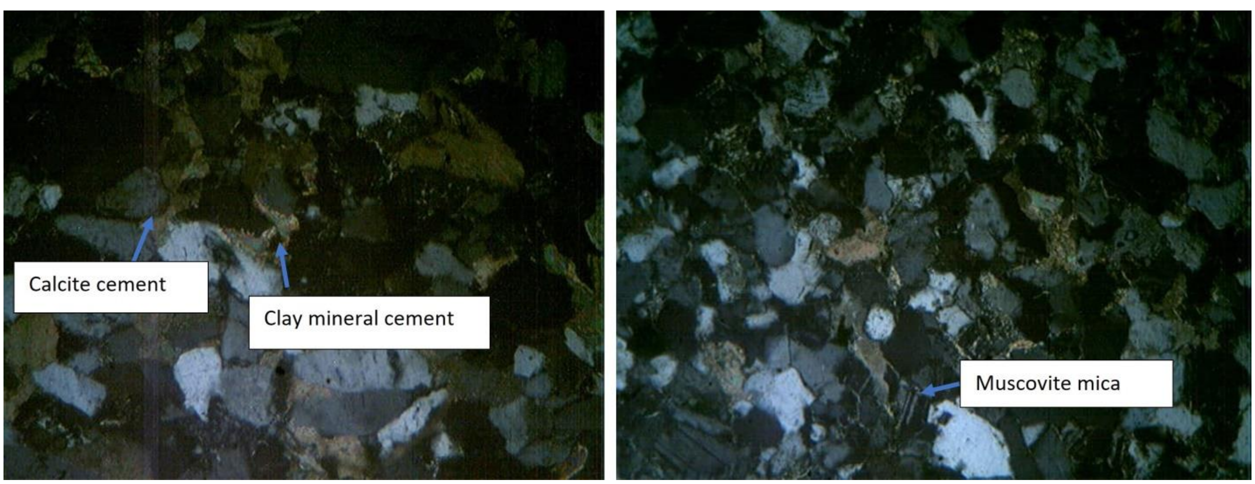

Figure 8: Photomicrograph thin section showing cement and accessory minerals

Maturity Index of the outcropping sediments of the Ogwashi-Asaba Formation:

A measure of the degree to which the detritals have changed compared to the initial stage Pettijohn, (1975). By textural maturity, Folk (1980) highlighted three distinct stages, viz:

i. Clay materials removal: the clay content in the sands were relatively low, <5%.
ii. Sorting: the standard deviation shows a poor (1.7) to moderately sorted (0.7) in phi scale.
iii. Quartz grain roundness: shows a sub-rounded grain.

Table 1: Modal composition of the sandstones at Anwai and Ibusa

Texturally, the above attributes is suggestive of an immature to submature sediment for the analzyed samples of the formation [Table 1].

Mineralogical Maturity is the measure of resistant minerals in a sediment and quartz is commonly used as an index for mineralogical maturity. Although quartz makes up more than 60% of the entire framework with sub-rounded grains, the ratio of quartz to feldspar and lithic fragment suggest a mineralogical immature sediments [Table 2].

Sample location	MMI	Description
AW 1	2.3	Immature
AW 2	3.1	submature
AW 3	2.8	Immature
IB 1	1.9	Immature
IB 2	2.4	Immature
IB 3	2.2	Immature

Table 2: Mineralogical Maturity Index

The sediments' provenance from the QFL ternary plot shows that the sandstones are litharenites to sub-litharenities [figure 4.18] derived from combined origin which may include interiors of cratons and continental blocks in transition coupled with reworked orogenic activities, after (Dickinson, 1985)

The principal source of the cratons and continental sands are granitic exposures and gneisses which gives credence to the Oban Massif and Western Nigerian Massif as a significant sediment source for the paleogene strata. Reworked orogenic activities involves settings where strata are deformed, uplifted and subsequently eroded (Dickinson, 1985). This is seen in the formation of the Abakaliki Anticlinorium from folding and uplifting during the Santonian event that resulted to the depocenters of Anambra and Afikpo. For the Anambra and Afikpo Basins, the anticlinorium became a source and subsequently joined the Niger Delta Basin as contributors during its formation (Nwajide, 2005).

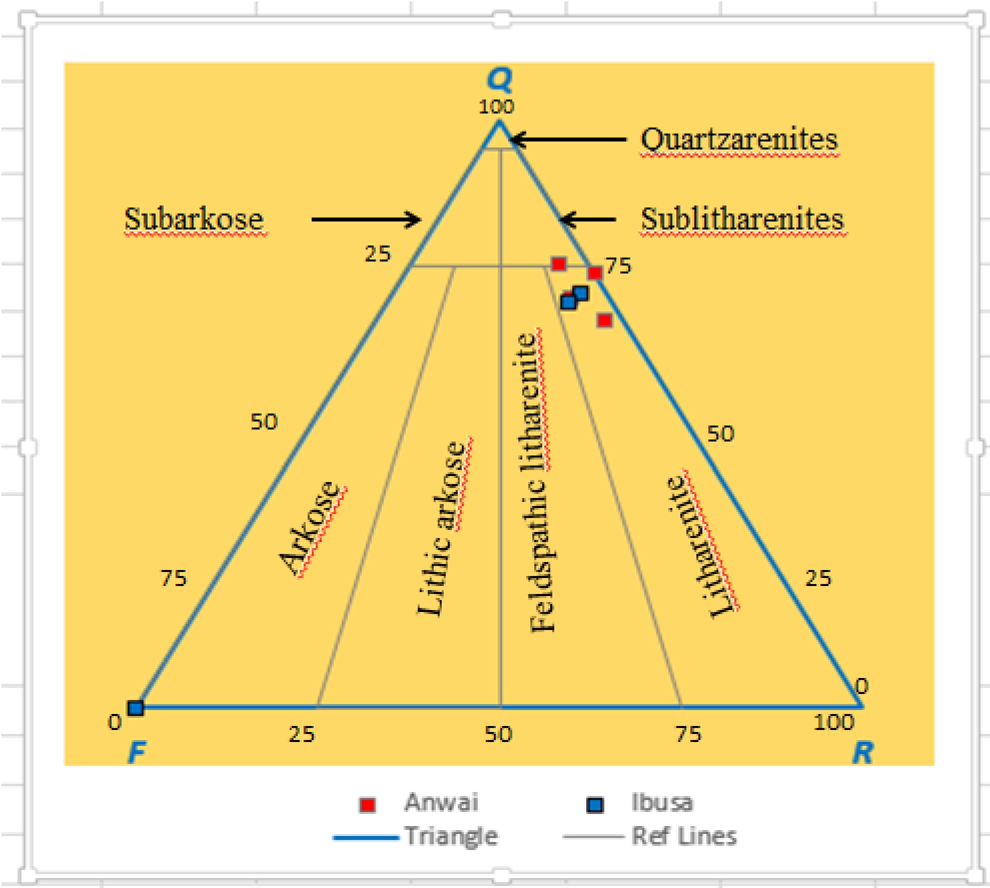

Figure 9: Petrographic composition of the outcropping sediments of the Ogwashi-Asaba Formation plotted on QFL diagram after (Folk, 1980).

Reservoir Quality of the Outcropping Sediments of the Ogwashi-Asaba Formation:

The sandstone unit are restricted to the coastal plain deposits, tidal channel and fluvio-estuarine deposits. The sands are poorly sorted and ranges from medium to very coarse grained sandstone. They are also bioturbated and contains mud clasts and lens. The sandstones in the Ibusa and Anwai portion of the Formation are characterized petrographically as sublithic arenites. They are low to intensely bioturbated with cross-cutting structures and mud-filled burrows. The mud-baffles observed across in 3-D could represent a seal to prevent the escape of hydrocarbon in the reservoir.

In the tidal flat and fluvio-estuarine environments, the deposits are classified as potential reservoir flow or permeable strata.

- They include moderately to well sorted, medium to coarse grain sandstones with minor occurrence of mud drapes. They are low to moderately bioturbated with sand-filled burrows. The sand-fill burrows can increase permeability in the reservoir since they can act as channel for migration of fluids (Buatois, et. al. 1999; Gingras, et. al., 1999). They clay matrix are less thereby causing heterogeniety in the reservoir which ultimately makes them good reservoir.

- A moderately burrowed sandy heterolithic unit that comprise of wavy mud laminae. The fluvio-estuarine environment indicates a strong marine influence. The sediments shows mouth bar sands along a coastal plain environment.

CONCLUSION

The tidal channel deposits in parts of Ibusa are made up of unidirectional planar stratified sandstones exhibiting sheet-like structure ranging from medium to coarse grain. Bioturbation is low and there are sparse mud drapes, mud lens and mud bands. This channel consist of good reservoir sands, however compartmentalization of the reservoir could occur due to the mud bands at the bounding surfaces. Migration of fluids could be restricted by the mud drape forsets.

Thus, sediments of this unit were deposited in a coastal plain, shallow marine and a continental to marginal marine settings respectively. The sand bodies of the tidal channel and the fluvio-estuarine are considered the major reservoirs in this unit.

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