# Sedimentology and Reservoir Studies of Alo Well, Niger Delta Basin. Nigeria

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## ABSTRACT

Reservoir characterization of the ALO WELL was carried out using sedimentological attributes and integrated reservoir quality of the sandbodies The porosity values show good to excellent porosity and very good permeabilities. The reservoir quality which is excellent is dependent on the facies grain sizes and sorting which are fine to medium grained and a moderately depicting a moderately high energy environment. The bioturbation structures also enhance fluid flow, hence the high vertical permeability values. The various parameters above indicate deposition in a tidally influenced environment probably a distributary channel fill.

## INTRODUCTION

Reservoir characterization is an act of subdividing reservoirs into sub units in an attempt to assign useful physical properties (Amaefule, 1988). Fowler and others (1999) explained reservoir properties, geophysical and geological information on uncertainties in a spatial variation. Petrophysical attributes like porosity, permeability, fluid saturation and net thickness of sediments will give an enhanced understanding of the fluid flow and storage ability of the reservoir.

Hence, a complete sedimentological and petrophysical characterization will give a better knowledge of the reservoir in terms of storage, flow properties as well as lead to delineation of reservoir performance.

### Statement of the Problem

The Tertiary Niger Delta Basin has been worked on by several workers of sedimentology, sequence stratigraphy and petrophysics. Despite the proliferation of publications both quantitative and qualitative models, there very few that tend to characterize the reservoir based on logical and petrophysical parameters. Hence this study is integrating sedimentological and petrophysical parameters into characterizing a reservoir.

### Aim and Objectives

The aim is to ascertain the depositional environment and to evaluate the reservoir potentials of the Alo well.

### Location of Study Area

The area of study lies within latitudes 40 and 7° N and 3° and 9° E , 1982)

## STRATIGRAPHY OF THE NIGER DELTA BASIN

The established Tertiary sequence in the Niger Delta consists, in ascending order, of the Akata, Agbada, and Benin Formation. The strata composed an estimated 8,535 m (28000 ft) of section at the approximate depocenter in the central part of the delta.

### AKATA FORMATION

The Akata Formation (Fig. 1) which is the basal unit of the Cenozoic delta complex is composed mainly of marine shales deposited as the high energy delta advanced into deep water (Schlumberger, 1985). It is characterized by a uniform shale development and the shale in general is dark grey, while in some places it is silty or sandy and contains especially in the upper part of the formation, some thin sandstone lenses (Short & Stauble, 1967).

The Akata Formation probably underlies the whole Niger Delta south of the Imo Shale outcrop of the Paleocene age from Eocene to Recent (Short & Stauble, 1967). The Akata Formation has been penetrated in most of the onshore fields between 12,000 and 18,000 ft (~3,700 – 5,500 m) and in many of the offshore fields between 5,000 and 10,000 ft (~1,530 – 3050 m); however, the maximum thickness of the Akata Formation is believed to average 20,000 ft (~7,000 m).

For all practical prospecting purposes, the top of the Akata Formation is the economic basement for oil; however, there may be potential for gas dissolved in oil field waters under high pressure in the deeper formation (Schlumberger, 1985).

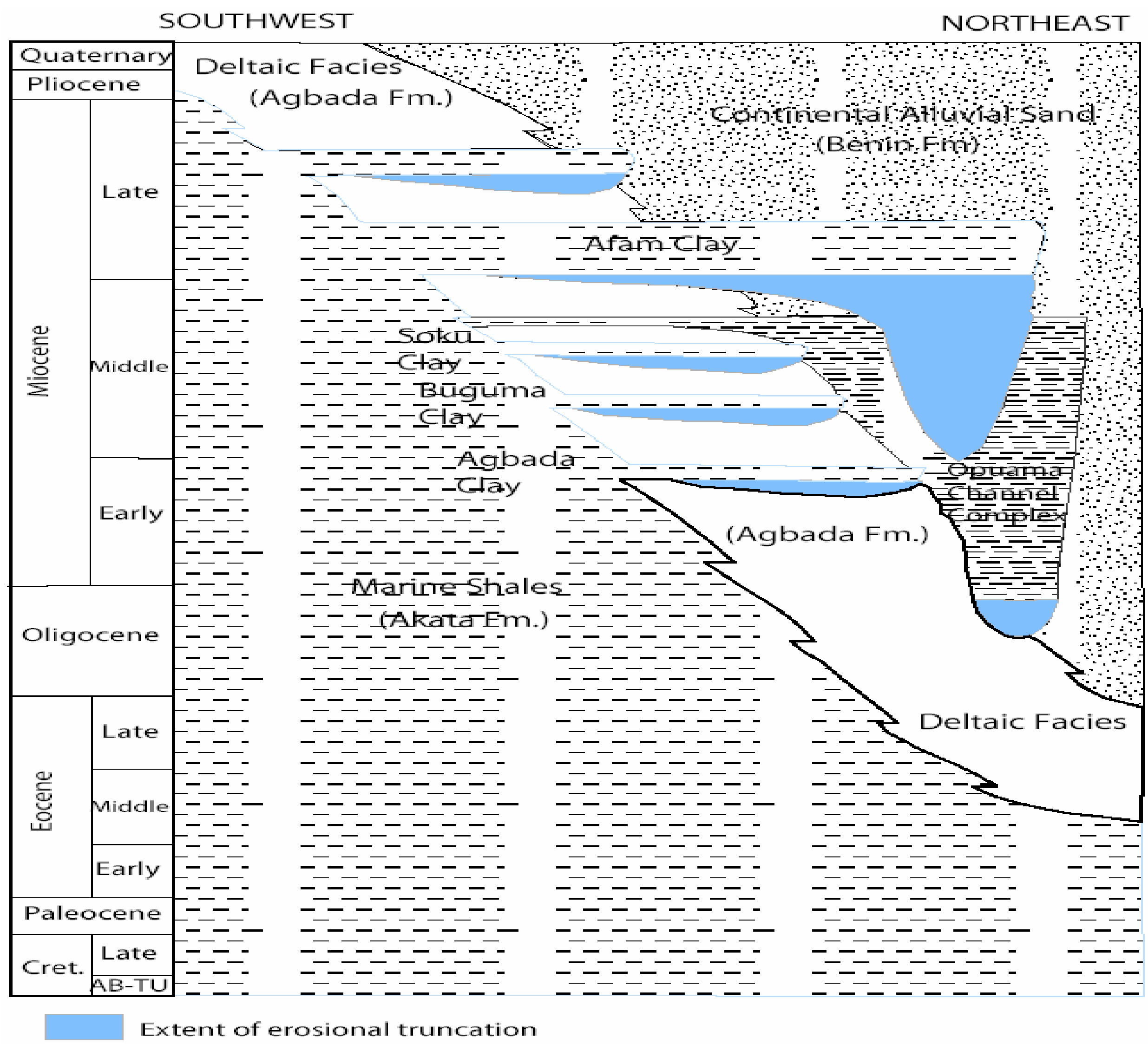


Figure 1: Stratigraphic column showing the three formations of the Niger Delta (Doust and Omatsola, 1990).

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## AGBADA FORMATION

The Agbada Formation (Figure 1) is a paralic succession of alternating sandstones and shales, whose sandstone reservoirs account for the oil and gas production in the Niger Delta (Nwachukwu and Odjegba, 2001).

The formation consists of an alternating sequence of sandstones and shales of delta-front, distributary-channel, and deltaic-plain origin. The sandstones are medium to fine-grained, fairly clean and locally calcareous, glauconitic, and shelly. The shales are medium to dark grey, fairly consolidated, and silty with local glauconite.

The sand beds constitute the main hydrocarbon reservoirs while the shale beds present form the cap rock. These shale beds constitute important seals to traps and the shales interbedded with the sandstones at the lower portions of the Agbada Formation are the most effective delta source rocks (Schlumberger, 1985). Petroleum occurs throughout the Agbada Formation of the Niger Delta.

Maximum thickness of the formation is 3,940m (12,000ft) at the central part of the delta, and thins northward and toward the northwestern and eastern flanks of the delta. The formation is poorly developed or absent north of the Benin city-Onitsha-Calabar axis. The age of the Agbada Formation varies from Eocene to Pliocene/Pleistocene.

## BENIN FORMATION

The Benin Formation (Figure 1) consists of predominantly massive highly porous, freshwater-bearing sandstones, with local thin shale interbeds, which are considered to be of braided-stream origin. Mineralogically, the sandstones consist dominantly of quartz and potash feldspar and minor amounts of plagioclase. The sandstones constitute 70 to 100% of the formation. Where present, the shale interbeds usually contain some plant remains and dispersed lignite.

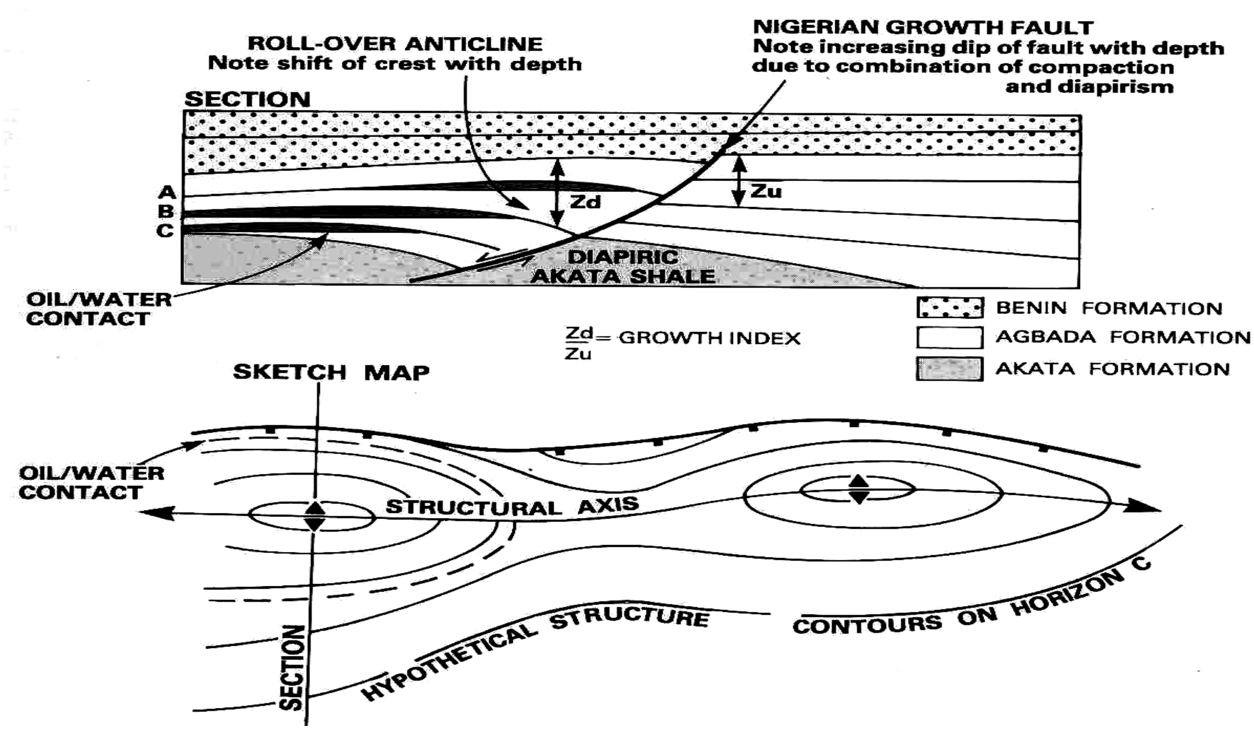

Figure 2 : Schematic section showing a map of simple growth Fault and rollover anticline (After Schlumberger, 1985).

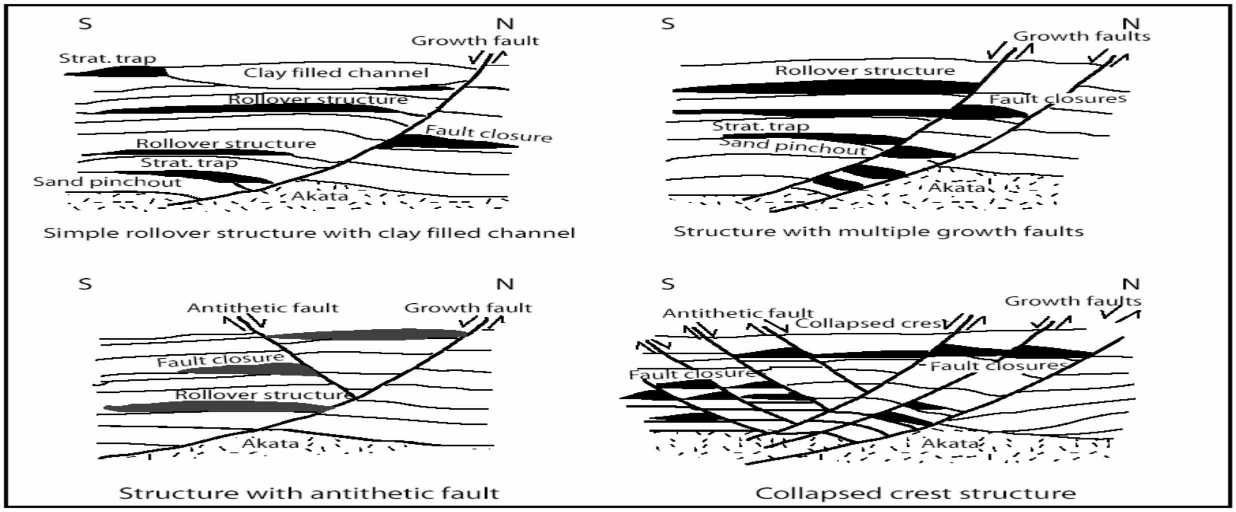


Figure 3: Principal types of oil-field structures in the Niger Delta with schematic indications of common trapping configurations. (Doust and Omatsola, 1990).

## RESEARCH MATERIALS AND METHODS

### Sieve Analysis

The sieve method is a more general and widely accepted form of mechanical analysis aimed at determining the grain size, kurtosis, skewness, sorting and median of an entire deposition through collected samples. The primary purpose of sieve analysis is to delineate particles size distribution in sands, so that one can have knowledge of:

• Frequencies of different sizes of particle present.

• Processes operating on the sediments at the time of deposition e.g. flow energy.

• Concentration of particles in suspension.

### Core Data Analysis

ALO Well was drilled to a total depth of 3245 ft. The sand bodies of interest were encountered at various depths 3157-3195ft and 3220-3232ft. the data for the study includes cores, cores photographs and wireline logs. It involves the use of a detailed core description, core photography and explanation of logs by the use of log motifs with correlation on a well to depth.

### Procedure of Core Description

A core is a representative reservoir specimen which yields fundamental for effective exploration, description and exploitation. A detailed sedimentological description involves a detailed characterization of the lithology, bed thickness, sedimentary structures, interpretation of ositional environment. This core description is useful for delineating rock type, thickness of facies, sedimentary structures, biogenic structures, texture and visible porosity type. These are the materials used for the analysis:

i. Core description sheet
ii. Shell Petroleum Development Company's grain size comparator and sorting comparator.

iii. Bottle containing 10% of Hydrochloric acid
iv. Ruler, Eraser and Pencil
v. Core photograph/horizontal plug cores
vi. Wash bottle of water
vii. Binocular microscope
viii. Picking needle
ix. Handles

Already, slabbed core of above 110ft were displayed on 3ft trays and described serially from top to bottom. This involved making a depth plot on the sheet, inserting core numbers and drawing lines across the sheet and denoting the boundaries of the beds. Areas of core loss and uncored areas that are drilled out were indicated on the sheet by diagonal lines.

A visual estimate of percentage of shale was plotted in the description sheet and grain size analysis done using a comparator for grain size and thus plotted on the logging sheet. The diluted acid (HCI) was used to delineate the presence of carbon. Carbonate cementation was also determined and graded into different degrees as medium, hard or very hard. Other sedimentary structures like lenticular bedding, cross bedding, flaser bedding and ripple laminations were observed and plotted. Irrespective of intensity Bioturbation features was seen.

Using the above parameters in conjunction with Reijers (1995), lithofacies scheme and with the help of grain size trends, the lithofacies were determined. Major erosional breaks/boundaries were recorded using upright and inverted triangles to indicate coarsening upward and fining upward sequences respectively.

**Well log description**

Well logs are essential for the characterization of depositional environment sandbodies. They show a correlation tool to evaluate reservoir continuity and an important source of quantitative data on the environment.

**Lithologic Logs (Gamma-Ray Log)**

The log reflects the shale content in sedimentary formations because shale and clay contains radioactive element. Clean formations usually have a very low level of radioactivity except radioactive sands and radioactive contaminants such as granite wash or volcanic ash. The Gamma log is preferred to SP log due to its degree of resolution and also substitutes the SP log in wells drilled with salt mud, air or oil based muds. Gamma ray log is recorded in API units and is used for correlation and bed boundary termination, environment of deposition, evaluation of the content of shale in a formation, mineral analysis and perforating depth control for the tracing of radioactive fluid movement.

## RESULTS AND INTERPRETATION

**Lithofacies Description**

A lithofacies is a rock body which has distinct characteristics based on composition, bedding, textures, sedimentary structures, colour and biogenic structures. With reference to the features of the cored section of the ALO WELL, seven lithofacies were identified from cores

**A. Dark Grey Laminated Mudstone (MSd)**

This lithofacies consists of a dark grey finely laminated mudstone containing sideritic nodules, shell fragments and a rip up clast structure originated due to quiet deposition. And if well preserved, the mudstones will form vertical permeability barriers and baffles.

**B. Bioturbated Sandy Heterolith (SI)**

This lithofacies are of greyish erosive base bioturbated clayey fine grained sandstone. The biotubation predominates the entire unit. The vertical burrows indicates Ophiomorpha hence delineates a channel influenced by tide.

**C. Bioturbated Sandstone (Sb)**

This unit is characterized by grey to brown alternation of erosive base very fine grained sandstone with siltstone. It consist of predominate vertical, inclined and horizontal burrows of Rhizocorallium, Diplocratarion, Ophiomorpha with horizontal beds. It delineates deposit of a shallow marine.

**D. Lenticular Bedded Heterolith (Mst)**

This unit is brownish and sharp base very fme grained sandstone and siltstone. Horizontal beds are common with low angle cross lamination and lenticular bedding. Vertical and inclined burrows of Ophiomorpha and I Rhizocorallium are common.

**E. The Sand/Siltstone heteroliths**

The sand/siltstone heterolith is a centimeter thick sequence of beds exhibiting a fabric with variation in grain sizes within the individual beds. They are wave rippled laminated with streaks of lenticular beds, tarbonaceous with occasional siderite nodules. This unit is a fluctuating, environment probably a shallow marine or a lake setting.

**F. Fine ripple well sorted sandstone (SIF)**

This lithofacies consist very-fine to fine grained well sorted micaceous d in 0.1-1 .25m. The sediments contain planar and ripple lamination grain size distinction. The biogenic structures are Diplocratarion, Ophiomorpha and a reactivation surface. The suites of biogenic structures delineate a tidal setting with reactivation surfaces.

**G. Carbonaceous Mudstones**

Lithofacies is centimeter-scale laminated mudstones without sand lenses. It contains a soft sediment structure e.g. water escape structure as a consequence of liquefaction of the loose grains because of poor water escape which causes the rearrangement of grains leading to deformation of existing laminations to form new structures. This unit delineates sedimentation in an environment of low energy, either of a lake or shallow marine setting.

**Lithofacies and Stacking Pattern**

The Alo Well used in this work with the cored section seven district lithofacies. The common lithofacies scheme used (Reijers, 1995) combines depositional pattern, entire rock properties and fluid flow. Considering the above therefore, five main sandstone reservoirs are identified with two non reservoir bodies. The sandstone reservoir bodies are:

1. Bioturbated sandy heterolith
2. Bioturbated sandstone
3. Wavy bedded sandy heterolith
4. Fine grained mm scale laminated sandstones
5. Lenticular bedded heterolith

The entire cored section is dominated by various stacking patterns ranging a coarsening upward sequence, overlain by a fining upward sequence.

The individual cycles tend to display other sequences but an overall major upward sequence was displayed

**Grain Size Analysis**

Grain size analysis was carried out on the fifteen (15) representative samples from the horizontal core plugs 1 and 2 and statistical parameters were calculated and interpreted using Ward and Folk equation (1957)

(a) Mean (Mz)

The mean of a sediment indicates the average diameter. From the analyzed samples, the mean values range from 3.194) (very fine) — 2.284ϕ (fine) with representative value of 2.89ϕ) (fine sand). From the analysis, it is inferred that deposition of sediments is in a low-energy environment.

(b) Sorting (So)

The sorting coefficient measures the span of distribution of the sediments around the mean value. The samples analyzed show a range of 1.23ϕ (poorly sorted) to 0.30ϕ (very well sorted) with a mean of 0.69ϕ moderately well sorted. The result shows that the deposition of sediment is in a moderate energy environment.

(c) Skewness (SK)

This parameter tends to measure the degree of asymmetry of the distribution. From the analyzed samples, the values range from 0.01ϕ negatively skewed to 0.10ϕ positively skewed with a mean of 0.08ϕ positively skewed. From the results, positive skewness indicates that coarser admixture exceeds the fine admixture suggesting deposition in a fluctuating environment due to winnowing.

(d) Kurtosis (K)

Kurtosis is a measure of peakedness or sharpness of the distribution and also compares the sorting at the tails to that of the central portions. The analyzed samples range from 1.06ϕ Mesokurtic to 0.71ϕ Platykurtic with a mean value of 0.99ϕ Mesokurtic. The result show that various modal fraction are brought into the depositional environment and also indicate a short distance of travel for the sediments

**Depositional Processes**

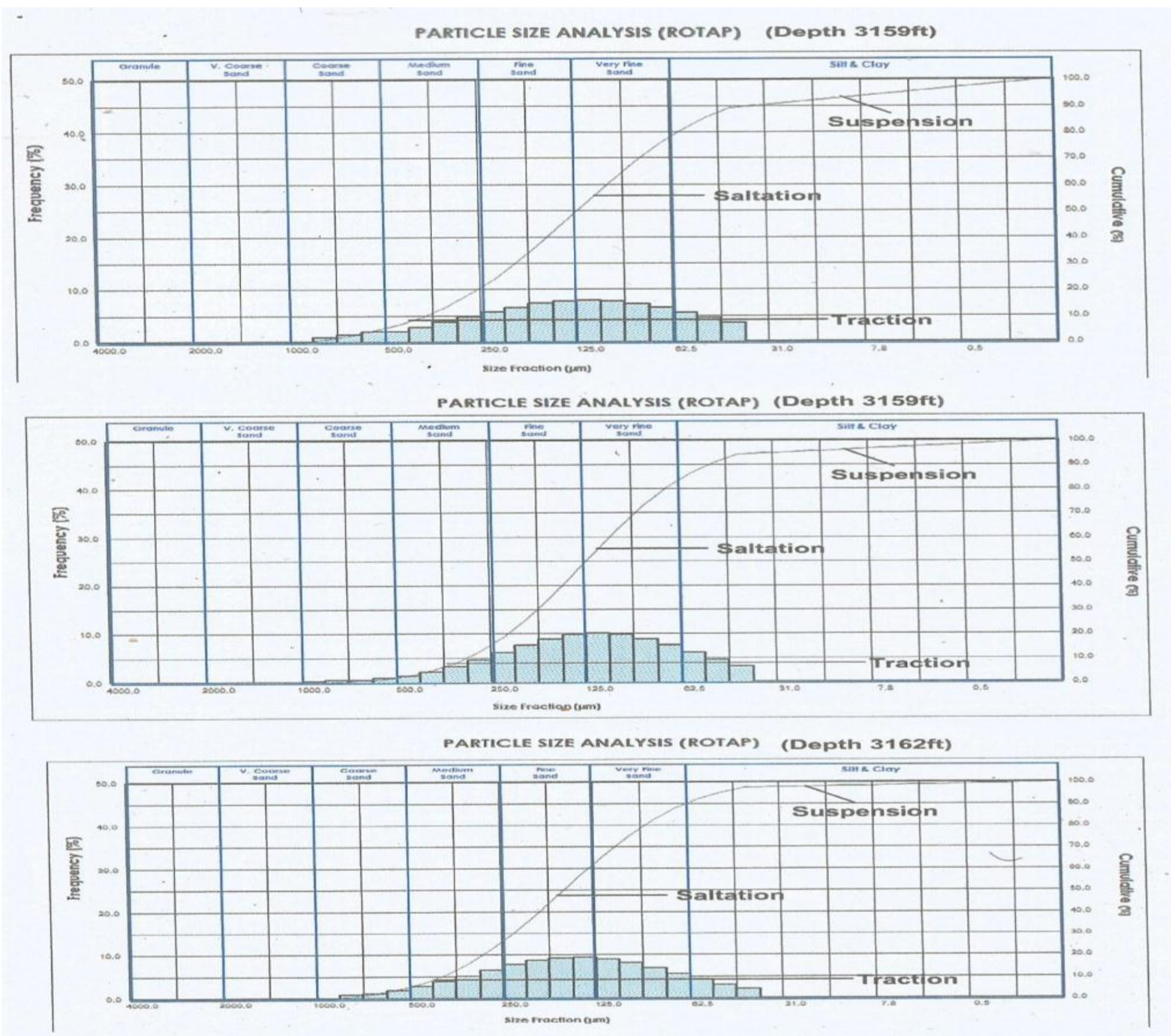


Figure 4; Grain frequency curve of 15 selected samples from core 1 and 2

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The depositional process in a clastic environment is dependent on the hydrodynamic conditions operating at the time of deposition. Cumulative frequency curves were generated. From this study three major processes are identified from the curves. Traction or bed load, suspension load segment and saltation.

Plots of fifteen (15) samples show that all three processes occur within the depositional environment with saltation mode as the dominant process. The moderate standard deviation of the sample may be as a result of secondary interstitial materials which also tend to affect the size distribution (modified from Friedman, 1967). Fluvial sands are found to be deposited by suspension, traction, saltation and processes. While shoreface, tidally influenced channel sands and channel floor deposits are deposited by dominant saltation process.

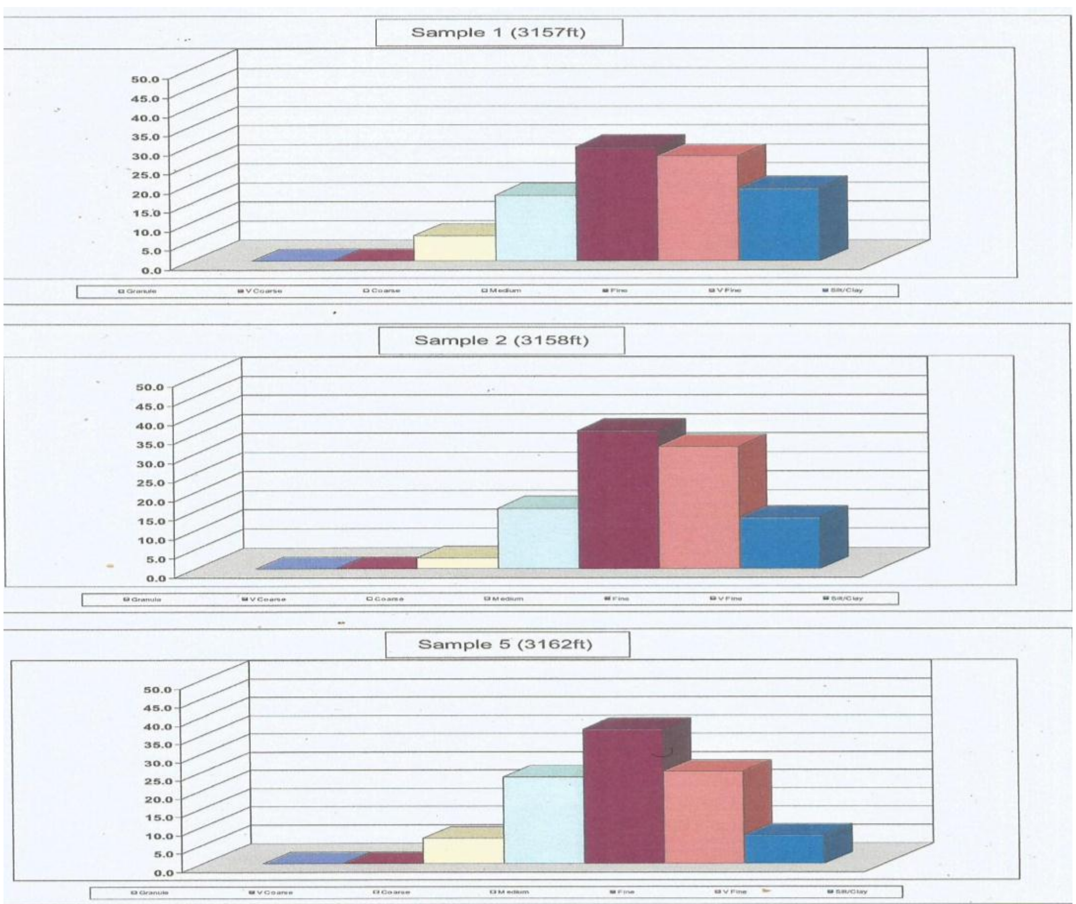


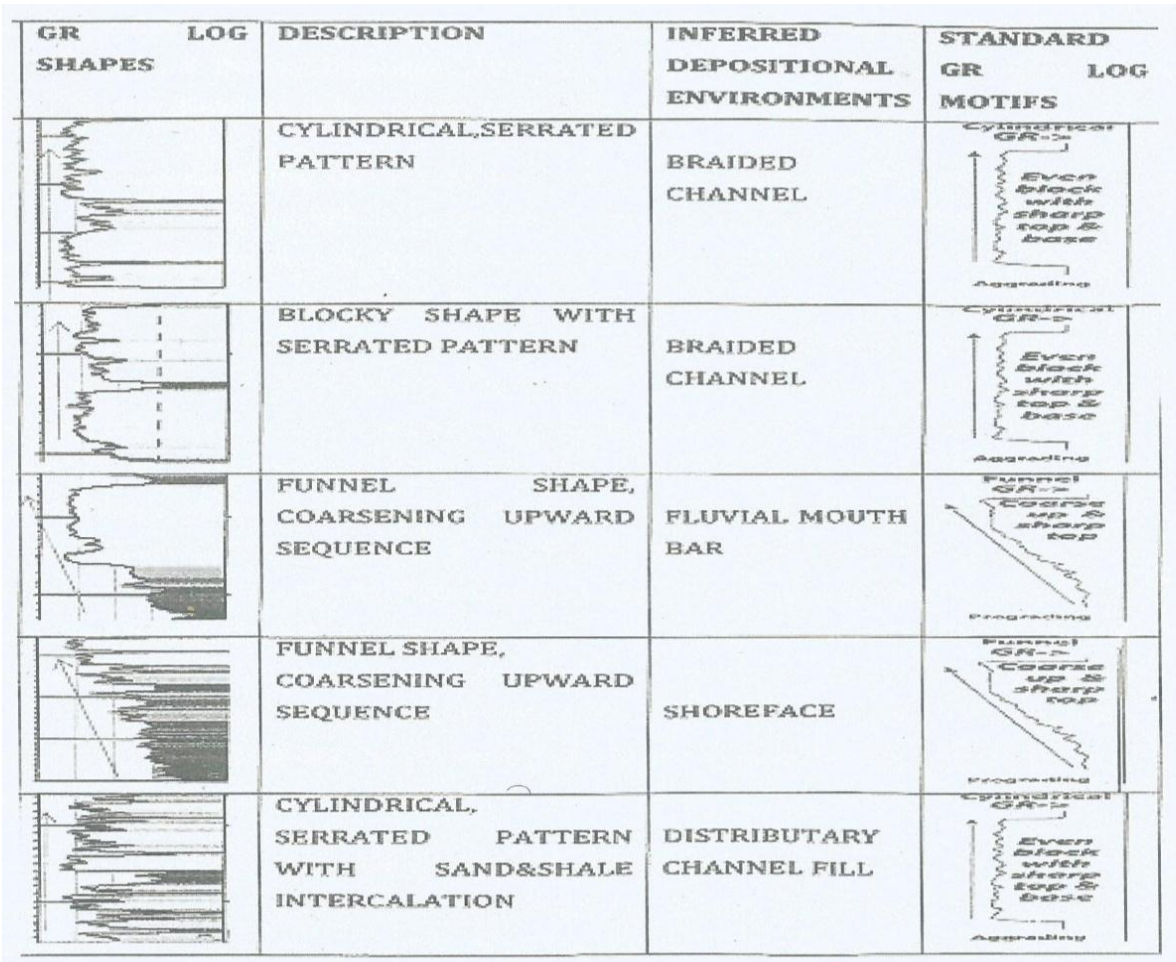

**Figure 5; Histogram of 15 representative samples from core 1 and 2**

**Log Motiff (Patterns)**

Log motif could be considered in terms of geometry, shape, curve characteristics, the nature of lower and upper contacts. Since the percentage of clay or shale has vertical variation effects, it creates these diagnostic shapes which can be used to delineate the genetic sand bodies and their depositional environment.

Three basic principle shapes obtained are the funnel, Bell and cylinder. The funnel shaped curve indicates an upward decrease in the amount of dispersed clay or structural shale, the bell shaped curve is indicative of an upward increase in the amount of dispersed clay or structural shale while the cylinder indicates a constant volume, usually of low dispersed clay or structural shale throughout the sand. Laminated shale, in a sandy body indicates a break in the depositional regime and produce serrations on an otherwise smooth curve.

In the deltaic environment, the funnel shape will represent a regressive depositional sequence or a prograding delta while the bell shape is indicative of a transgressive depositional sequence. The cylinder shape can represent either of these sequences.



| GR LOG SHAPES | DESCRIPTION | INFERRED DEPOSITIONAL ENVIRONMENTS | STANDARD GR LOG MOTIFS |
|---|---|---|---|
| | CYLINDRICAL,SERRATED PATTERN | BRAIDED CHANNEL | Cylindrical GR-> Even block with sharp top & base Aggrading |
| | BLOCKY SHAPE WITH SERRATED PATTERN | BRAIDED CHANNEL | Cylindrical GR-> Even block with sharp top & base Aggrading |
| | FUNNEL SHAPE, COARSENING UPWARD SEQUENCE | FLUVIAL MOUTH BAR | Funnel GR-> Coarse up & sharp top Prograding |
| | FUNNEL SHAPE, COARSENING UPWARD SEQUENCE | SHOREFACE | Funnel GR-> Coarse up & sharp top Prograding |
| | CYLINDRICAL, SERRATED PATTERN WITH SAND&SHALE INTERCALATION | DISTRIBUTARY CHANNEL FILL | Cylindrical GR-> Even block with sharp top & base Aggrading |

**Figure 6 ; Logs shapes and depositional environment**

**Depositional Environment**

The reconstruction of the Palaeoenvironment is based on sedimentologic, stratigraphic and faunal features. The main tool for delineating depositional condition of sediments is based on lithofacies interpretation.

The lithofacies stacking pattern shows a cycle of fining-upward-coarsening upward and fming upward sequences which indicates a transgressive-regressive sequence and also a fluctuating environment in terms of energy processes. The mean grain size 2.280 (fine sand) shows sedimentation of a moderate energy environment. The sedimentary structures which include wave rippled, lenticular bedding and reactivation surface is indicative of a moderate or fluctuating energy of an environment of deposition. The occurrence of burrows or trace fossils of Paleophycus, Diplocratarion, Ophiomopha indicate sedimentation in a tidal influenced environment. The overprint of the primary structures may be as a result of a better oxygenation with lower deposition rates. The Gamma log shape of dominant cylindrical or serrated shape indicates sedimentation in a sand-shale intercalated and moderate energy environment probably a braided fluvial channel or distributary channel fill. Therefore, from the structures above, the depositional environment is probably a shallow marine environment or a distributary channel fill.

**Fades Control on Reservoir Quality/Fluid Flow**

The light brown very fine grained, well sorted sandstone (U2) have a porosity of 23-40%. While the light yellow dark grey sandstone/silt heterolith (U3) have a porosity range of 15-28%. The permeability of the light brown very fine grained, well sorted sandstone (U2) are above l000md and the light yellow dark grey sandstone/silt heterolith are below I 000md (929.99). The variation of permeability and porosity of the well is dependent on whole grain and matrix supported. Therefore, the Alo Well sandbodies are adjudged to be good reservoirs.

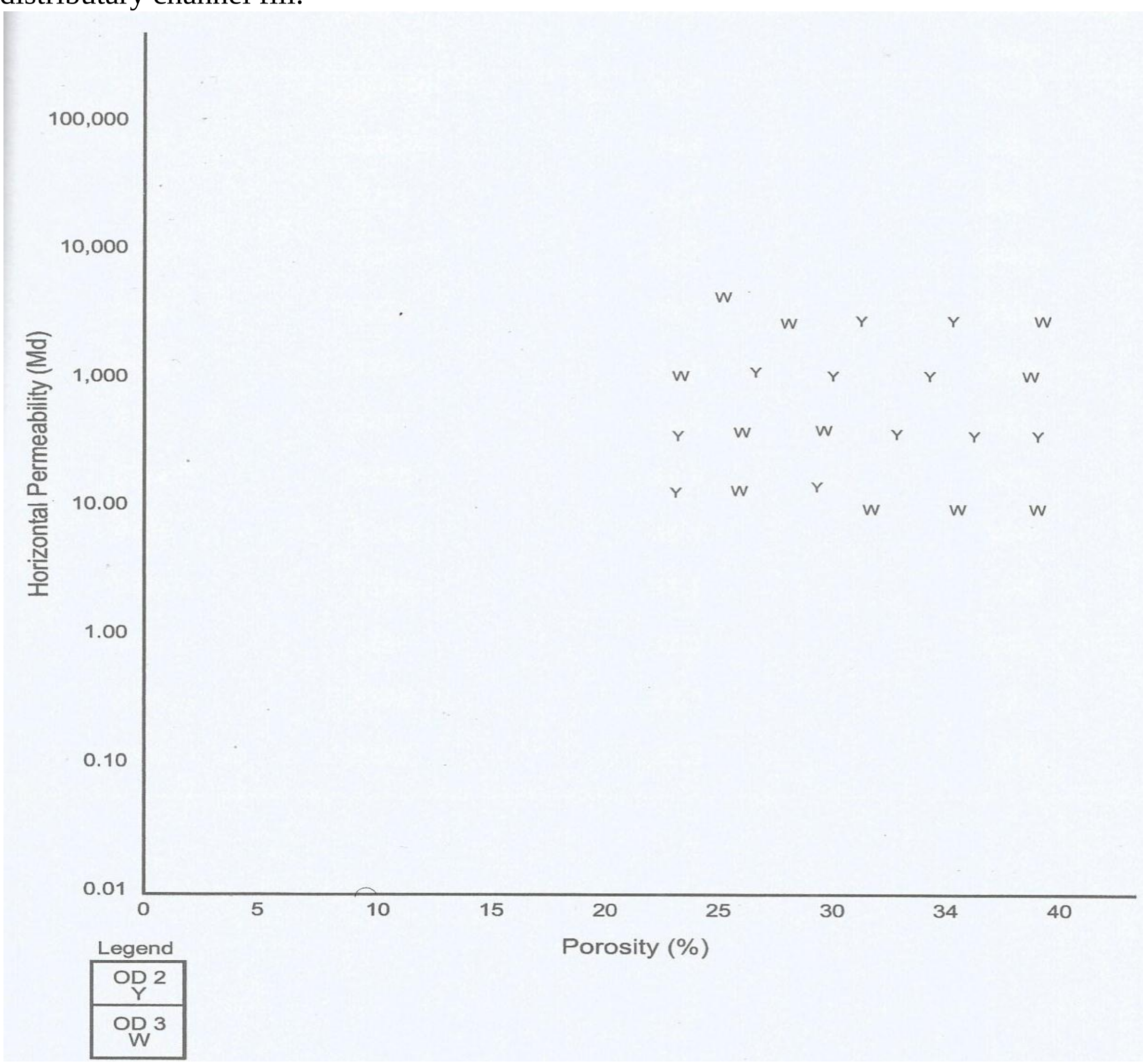


Figure 7: A plot of Permeability vs. Porosity by lithofacies core 2

**Summary**

The detailed reservoir- characterization of Alo Well was carried out based on the combination of core data and well logs available. The lithofacies identified, the grain parameter viz sizes, sorting, skewness and kurtosis with the various sedimentary structures and biogenic structure delineates deposition in a tidal influenced channel with erosive bases and dominant bell shaped log results. The strong grain size results which tend to a fine-medium grained, moderately sorted grains with good to excellent porosities and average permeability indicate that the Alo Well has a good reservoir quality and will produce maximally.

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