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Depositional Environment and Facies Controls of Odirin Well, Eastern Niger Delta

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Abstract— *The lithofacies stacking pattern of the study area shows a cycle of fining-upward-coarsening upward and fining 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 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 inferred to be a shallow marine environment or a distributary channel fill.*

I. INTRODUCTION

Sedimentological depositional processes characterization gives an understanding of the geometry, grain size variation, stacking patterns based on facies changes and internal reservoir architecture of the individual reservoir horizons to discern a depositional model for the well.

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.

Aim and Objectives of the Research work

- To identify and redefine various lithologies, textures, sedimentary structures and geometries of the sand bodies in the well.
- To establish the reservoir qualities of the sediments in the well.
- To reconstruct the processes of deposition and establish the depositional environment.
- To evaluate the reservoir potentials of the well.

Justification of Study

The results of the study will allow for the understanding of the reservoir geometry, architecture and litho facies distribution and quality of the ones help in determining reservoir performance.

Location of Study Area

The area of study lies within latitudes 40 and 7° N and 3° and 9° E) in the Niger Delta, Nigeria

Scope of the Study

The scope of the study is to carry out sedimentological characterization and reservoir quality using various core data. The characterization is focused on the properties of the reservoir that affects fluid flow and producibility of the reservoir.

II. LITERATURE REVIEW

Previous Work

Reservoir studies have been performed by various workers in the Tertiary Niger Delta basin. Stauble and Short (1967); Weber and Daukoru (1975); Avbovbo (1978) studied various sections of the delta in terms of structure, stratigraphy and prospectivity. Short and Stauble (1967) recognized three (3) main formations for the Tertiary Niger Delta Subsurface which were deposited under marine, transitional, and continental environments.

Evamy (1978) studied the dynamics, petroleum generation, migration and accumulation of the Niger delta. They concluded that the environments are diverse, ranging from coastal barrier islands bounded by salt and freshwater mangrove swamps and coastal plains.

Folk (1974); Moila (1968); Pettijohn (1972); Reineek and Singh (1973); Ahamaefule et al (1994); Reijers (1995) Omoboriowo and Soronnadi-Ononiwu (2011) studied the environment of deposition of deltas using textures, lithology, paleocurrent and fossils. They characterized delta as a geomorphic unit of unique set of processes acting at specific time and space.

Etu-Efeotor and Selley (1997) also indicated that the Niger- Delta “gross reservoir” properties are solely dependent on sand/shale ratio. “Akaegbobi and Tegbe (2000), Omoboriowo et al (2012) worked on reservoir heterogeneity and formation eva1uation and concluded that stratigraphic and structural controls will enhance formation performance”.

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III. 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.

i. Graphic Skewness (GSK ϕ)

This parameter is a measure of the degree of symmetry of the distribution curve. It is a deviation from the normality.

$$\frac{\Phi 84+16-2(\Phi 50)}{2(\Phi 84\ -\ \Phi 16)}\frac{+\Phi 95+5-2(\Phi 50)}{2(\Phi 95\ -\ \Phi 5)}$$

GM ϕ Values	Interpretation
1.00 – 0.30	Very positively skewed
0.30-0.10	Positively skewed
0.10-0.10	Nearly symmetrical
-0.10 - -0.30	Coarsely or negatively skewed
-0.30 - -1.00	Very coarsely skewed

ii. Graphic Kurtosis (KG ϕ)

This is a measure of the peakedness of the distribution curves. It is spread of the tail and centre of the distribution curve.

$$\frac{\Phi 95-5}{2.44(\Phi 75\ -\ \Phi 25)}$$

GM ϕ Values	Interpretation
>0.67	Very platykurtic
0.66 – 0.90	Platykurtic
0.90-1.11	Mesokurtic
1.11 – 1.50	Leptokurtic
1.50 – 3.00	Very leptokurtic
>3.00	Extremely leptokurtic

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.

Resistivity Logs

The resistivity of a formation is a major parameter in delineating saturation of hydrocarbon. It involves the voltage measurement of one amp required to through a cube of face area one metre square. The log unit is in ohm we2. The log is primarily considered a permeability indicator and it is used for delineation of porosity, bed boundaries, recognition of permeable zones, and recognition of oil-water contacts, recognition of fracture and vug porosity and for the measurement of mud from a mud log.

Porosity Logs

The traditional logging porosity tools are the sonic, neutron and density logs.

➢ *Sonic Log*

This is the velocity measurement of acoustic wave trend in rock formations. The velocity of compressional waves is dependent on the density and rigidity of a material. Porosity varies indirectly to velocity.

App1ication: for calculating porosity, identify minerals and depth-convert seismic data acquired in time. Computation of porosity requires lithology and saturating fluid.

➢ *Density Log*

This tool provides an estimate of the bulk density by estimating Gamma ray attenuation between a source and a receiver. Gamma ray is scattered and absorbed depending on the electron density within the formation which is closely related to the bulk density.

The relationship is $\varphi = \frac{\rho ma - \rho b}{\rho ma - \rho f}$

Where φ = porosity, ρb = bulk density, ρ*f* = fluid density
ρma = matrix density

Applications: Apart from its quantitative use in calculating porosity, it is applied in identifying lithologies.

➢ *Neutron Log*

The device estimates formation absorption rate of fast neutrons continuously ed into a formation by a radioactive source. Neutron is sensitive to formation lithology because matrix contributes to slowing and capture of neutrons. The neutron tool is particularly sensitive to the available gas which measures formation total porosity and gives an indication of richness in hydrogen generally called Hydrogen Index.

Application: Density-neutron combination presents the most frequently utilized logging tool for porosity determination. The tool is an excellent discriminator between oil and gas.

Core Data Analysis

Odirin Well 1 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.

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IV. 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 Odirin Well 1, seven lithofacies were identified from cores using the method of classification by Reijers (1995). The Lithofacies are;

A. 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.

B. 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, carbonaceous with occasional siderite nodules. This unit is a fluctuating, environment probably a shallow marine or a lake setting.

C. 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.

TABLE 1. A Niger Delta Lithofacies scheme (after Reijers, 1995).

Sediment type		Facies description	Facies code	Facies number	
Sandstone <20% clay		Pebbly sandstone	PS	1	Reservoir sands
		Medium-to coarse-grained cm-scale cross-bedded sandstone	Sx.m	2	
		Fine-grained mm-scale laminated sandstone	Sl.f	3	
		Fine-grained mm-scale laminated sandstone with clay laminate and drapes	Slc	4	
		Bioturbated sandstone	Sb	5	
Mixed sand and clay (Heteroliths)	Sand-rich heteroliths 20-50% clay	Wavy bedded sandy heterolith	Smw	6	
		Bioturbated sandy heterolith	SMb	7	
			SMshg	8	
20-80% clay		Glauconitic or shelly muddy sandstone			
	Mud-rich Heteroliths 50-80% clay & silt	Lenticular bedded muddy heterolith	MSt	9	Non-reservoir sands
		Bioturbated muddy heterolith	MSb	10	
Mudstone >80% clay		Bedded or massive mudstone	Mb/Mm	11	
		Sideritic bedded mudstone	Msd	12	

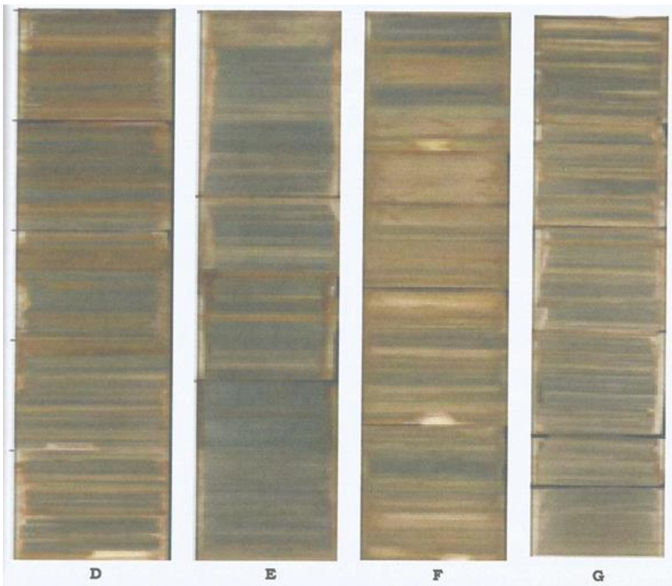

Fig. 1. Core pictures (d) Wavy bedded sandy hetrolith, (e) Laminated mudstone, (f) Fine grained laminated sandstone, (g) Lenticular bedded muddy heterolith

Grain Size Analysis

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

(a) 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.

(b) 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

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.

TABLE 2. Size parameter for the core.

Sample No	Depth	Core porosity data	Core permeability data
85H	3219.90	35.7	1020
86H	3220.26	36.4	683
87H	3221	36.4	863
88H	3222	36.1	2400
89H	3223	32.7	2200
90H	3224	31.2	829
91H	3227	34.4	911
93H	3225	30.9	472
94H	3229	36.4	854
95H	3230	38.1	1450
96H	3231	32.5	256
97H	3332	22.5	133
98H	3233	20.5	18.9

TABLE 3. Summary of core porosity and core permeability values.

Sample No.	Depth	Median	Mean	Sorting	Skewness	Kurtosis
1	3219	2.89	2.90	0.84	0.02	1.04
2	3220	2.88	2.89	0.67	0.01	1.01
3	3221	2.54	2.54	0.00	0.98	0.71
4	3222	2.28	2.25	0.68	0.01	0.97
5	3223	2.91	2.91	0.60	0.00	0.99
6	3224	2.95	2.94	0.74	-0.03	1.05
7	3225	3.15	3.16	0.63	0.01	1.00
8	3226	2.81	2.81	0.63	0.00	1.00
9	3227	3.30	3.29	0.64	-0.04	1.02
10	3228	2.88	2.85	1.03	-0.05	0.99
11	3229	3.05	3.04	0.67	-0.01	1.02
12	3230	2.87	2.87	0.65	0.02	1.01
13	3231	3.19	3.19	0.61	-0.01	1.00
14	3232	2.36	2.45	1.23	0.15	1.06
15	3233	2.86	2.89	0.69	0.08	0.99

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 furmel 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.

Facies Control on Reservoir Quality/Fluid Flow

The quality of a reservoir is dependent on facies types and distribution. Summary of core porosity and core permeability values for cores are present in table 3.

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 Odirin well sandbodies are adjudged to be good reservoirs.

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 Odirin Well has a good reservoir quality and will produce maximally.

The finding provides requisite data for further development of a depositional environmental model for this part of the Niger delta. Based on the lithofacies, physical sedimentary structure, biogenic structures and the dominant fining upward sequences, the erosive bases, a distributary channel environment is proposed for the Odirin Well.

Directly deriving from this study, it is recommended that a complete set of data be used in the evaluation of the well for a better accurate result. For a proper development of the well, volume estimation of the reservoirs interval should be carried out.

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