Depositional Sequence and Lithostratigraphic Units of Southern Niger Delta, Nigeria, from Gamma Ray and Electric Logs

Eke, Peter Ogochuku

Abstract— Gamma ray and electrical resistivity/spontaneous potential logs of Southern Niger Delta of Nigeria, obtained from the Directorate of Petroleum Resources (DPR) Nigerian, has been used to analyze the depositional sequence and the lithostratigraphic unit of the sedimentary unit of the basin lying between the depths of 2,100 and 2,730 meters. By careful inspection of the logs and correlation of points, the nature of the log signatures have been used to identify the various sand units, depositional environment-types and trending of the sand bodies in a SW-NE direction. The results reveal genetic, amplified and hybrid sand bodies of point bars, barrier bars, shales, and delta marine fringe deposits that occurred under transgressive and regressive regimens.

Index Terms — Electric Logs, Depositional Environment, Gamma Ray Log, Genetic Sand Units, Amplified Sand Units, Hybrid Sand Units, Stratigraphic Correlation

1 Introduction

THE Niger delta of Nigeria is one the most prolific hydrocarbon reservoirs in the world as evident from the daily production rate in the area for the past twenty years [1]. The region has distinct tripartite lithostratigraphic sedimentary deposits which have been growing from the Paleocene to the Recent [2]. These consist of sandstones and shales, all of cyclic marine sequence and fluvial deposits in various environments and patterns. These sedimentary deposits have thickness ranges of zero, close to the sea shores, to over twelve thousand meters in the central part of the delta [3]. The structural and stratigraphic geology of the area has also been documented by several authors using different geophysical methods and more research is continuously done in the region to improve on its geological understanding and in exploiting the hydrocarbon. Most of these works are with seismic data with inputs supplemented from other geophysical methods depending on the need, such as environmental and facies analysis [4].

Geophysical methods that can be used for environmental and facies analysis include electric logs and gamma ray log which can be used for lithologic estimation, lithostratigraphic pattern sequence recognition and depositional environment analysis as demonstrated by [5], [6], [7]. They are among the major tools for geophysical exploration and subsurface determination by geologists. Telford *et al*., [8] and Reynolds [9] states that they and other well logs can generally be used to infer subsurface conditions as structural, stratigraphic and depositional sequence; fractures and faults; determination of petrophysical properties, rock strength, fluid content and types. The log signatures produced from the continuous measurement downhole of the earth's electric parameters of resistivity/spontaneous potential and radiations from rocks coupled with their genetic implications can be used to infer internal characteristics of porosity and permeability; and external characteristics of thickness, shape, trending, inter-bedding distribution, depositional environment and soil continuity of a sand body. As indicated in [10] and [11] when these sand units are compiled vertically, they represent a sequence of environments produced by a specific over-all sedimentary process such as regression or transgression and these depositional sequences can be used as a model for interpreting the sedimentary history of any stratigraphic section in a region. The shape of these trends can reveal sand bodies types as alluvial and barrier bars, distributary channel deposits and fringe sands. All these are based on the premise that a sand body deposited under a particular set of tectonic and depositional condition has a particular vertical sequence of sedimentation or properties, a distinct external form and a preferred distribution/orientation to the depositional framework of the basin [11].

In this work, electric and gamma ray logs from the central part of the Niger delta of southern Nigeria lying between the depths of 2,100 and 2,730 meters has been used to interpret the external depositional features of the formations and correlate the general trending of the sand units in the study area based on the above premise.

• *Peter Ogochuku Eke is a Senior Lecturer in the Department of Physics, Ignatius Ajuru University of Education, Port Harcourt, Nigeria. E-mail: author_peter.eke@iaue.edu.ng*

2 Geology and Lithology of Study Area

The structural and stratigraphic geology of the Niger Delta (Fig. 1) has been discussed by several authors [12], [13], [14]. The sediments cover an approximate area of 105,000 square kilometers according to [3] with deposit thickness of over 12,000 meters in some regions. The sediments form three major formations whose evolution were controlled by pre- and syn-sedimentary tectonics as described by [12], [15], 16] with

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composition of sands, silts, clay and shales.

The oldest deposits in this region, formed during the Paleocene age, consist of; shales, turbidite sands and small amounts of silt and clay with thickness of over 7,000 meters in some region [17]. The Agbada Formation, formed in the Eocene age with marine facies of about 3,700 meters thickness, is the major oil and natural gas-bearing facies in the basin. The younger and topmost formation, deposited during the Oligocene, is the Benin Formation and is composed of continental flood plain sands and alluvial deposits with estimated thickness of 2,000 meters.

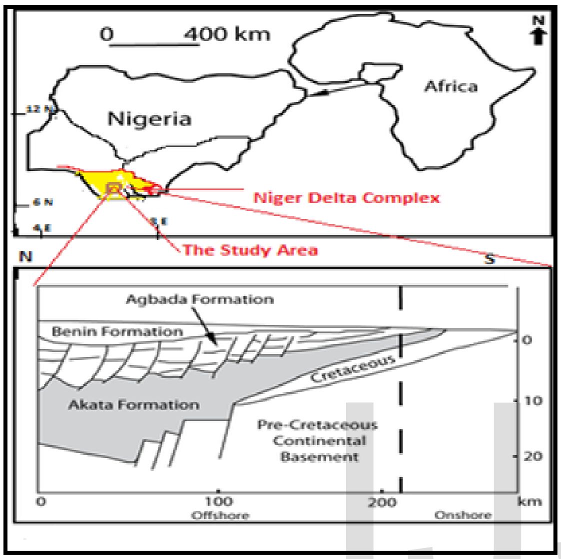

Fig.1: Location and Lithostratigraphy of the Niger Delta (modified from [16], [18])

Three major depobelts, with the three cycles of overall regression sequence, were recorded throughout these periods of depositions as the sediments change from deep sea mud sized grains to fluvial denser sand sized grains [3]. The oldest rock in the region is composed of basalt which forms the oceanic basement rocks. The dominant geological structures are thrust faults, diapers, syncline and anticline bodies with concentric facies elements [14], [19], [20].

3 Material and Method

This work used electric well-logs of resistivity and spontaneous potential logs and gamma ray logs of five locations in the southern Niger Delta of Nigeria obtained from the Directorate of Petroleum Resources (DPR) Port Harcourt.

Resistivity operation is based on ohms law from which the apparent resistivity for a non-homogenous formation and from [9] is

$$\rho a = R K \qquad 1.$$

Where; $R = \delta V/I$, V is the applied voltage, I is the current through the formation and K is the geometric factor which depends on the configuration used.

The Spontaneous Potential log is based on the theory that the SP signature for sand and shale formations is a function of the electrochemical (diffusion) potential caused by the combination of the liquid-junction potential and membrane potential of the system and the electro-kinetic (shale) or flow potential due to the passage of mud filtrate into the permeable formation. Accordingly, [9] explains that these two potentials in formations are recorded as

$$E_d = -RT \frac{[I_a - I_c]}{nF[I_a + I_c]} \ln C_1 / C_2 \qquad 2$$

And when $I_a = I_c$,

$$E_s = -\frac{RT}{nF} \ln C_1 / C_2 \qquad 3$$

I_a and I_c, are the mobilities of the anion and cation. R is the universal gas constant, T the absolute temperature, n the ionic valence, F Faraday's constant, C_1 and C_2 are the solution concentrations.

Gamma rays record the total radiation present in rocks and are used to determine the shale content in formations as radioactive minerals tend to concentrate in them.

The values of these logs can be used to obtain the internal formation characteristics of permeability and porosity and other related properties while their signature in formations can be used to obtain the external characteristics of trending, thickness, shape, interbedding distribution and formation correlation. The methodology adopted in obtaining the external formation characteristics of the fields, were by careful examination of the resistivity, SP and gamma ray curve shapes of the sand bodies down the borehole from which the depositional sequence and processes of formation were inferred. Funnel shaped, bell shaped, serrated shaped, cylindrical shaped and other shapes at various depths were identified and interpreted accordingly as sands, shales and sandy-shales, and their depositional environmental features/conditions, thickness and trending as in [5], [9], [10], [21].

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4 Results and Discussion

Figure 2 shows the identified depositional environments for the study area that includes their thickness, depth of occurence and type of sand unit. By careful examination of the log signatures, we can identify the following classes of deposited sand units; genetic sand units, amplified sand units and hybrid sand units.

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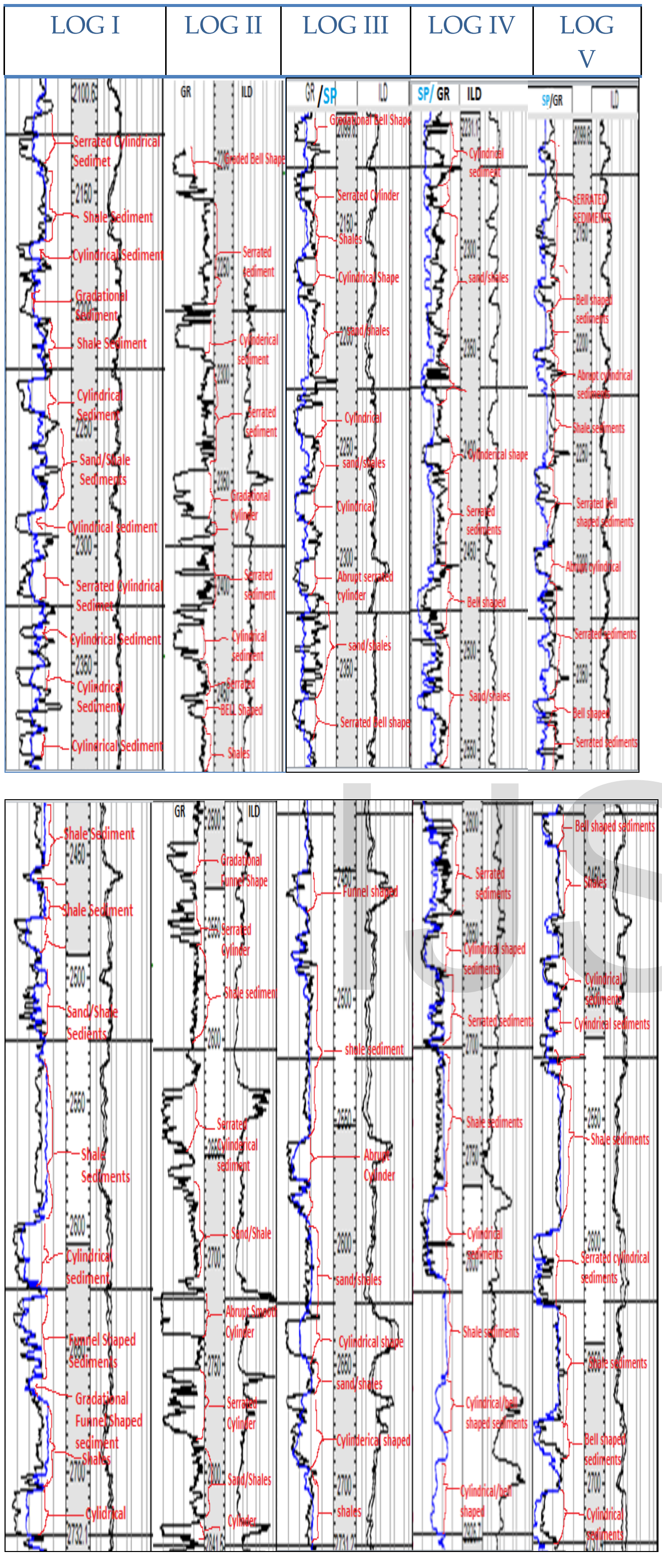

Fig. 2: Depositional Environments from Log Signatures for the study area.

The genetic sand unit Formations deposited during a single depositional regimen that resulted in transgressive delta-marine fringe build-up sand units of alluvial point bars, barrier bars and marine fringe deposits can be identified in the log signatures as either smooth or serrated funnel and bell shaped signatures which can be seen in the regions identified in the logs as shown in Table 1.

Log	Depth/m	Log Signature Shape	Descriptive Environment
1	2140-2160	Serrated	Shale Sediments
	2210-2235	Serrated	Shale Sediments
	2250-2285	Serrated	Point Bar
	2295-2325	Gradational Bell Shape	Transgressive Sand on Unconformity
	2425-2480	Serrated	Shale sediments
	2480-2495	Bell shaped	Barrier bar
	2625-2660	Gradational funnel	Point bar
2	2240-2270	Serrated	Sand/shales
	2300-2345	serrated	Sand/shales
	2510-2535	Gradational funnel	Point bar
	2550-2610	Serrated	Sand/shales
	2650-2715	Serrated	Sand/shales
	2795-2840	Serrated	Shales
3	2320-2370	Serrated	Sand/shales
	24550-2470	Funnel shaped	Point bar
4	2255-2345	Serrated	Sand/shales
	2410-2460	Serrated	Sand/shales
	2670-2770	Serrated	Sand/shales
	2810-2850	Serrated	Sand/shales
5	2100-2155	serrated	Sand/shales

2165-2175	bell shape	Point bar
2420-2435	bell shape	Point bar
2530-2595	serrated	Sand/shales
2675-2700	serrated	Sand/shales
2675-2730	funnel shape	Point bar

The amplified sand unit Formations formed as aggradational superposed sands deposited during reoccurrence of particular depositional regimen can be identified as serrated funnel shaped log signatures appearing as point bars and turbidity buildup graded beds appearing as cylindrical shaped signatures as can be seen at depths shown in Table 2 for the various logs.

Table 2: Descriptive Environment and Log Signature Shapes at Various Depths for Amplified Sand Units

Log	Depth/m	Log Signature Shape	Descriptive Environment
1	2115-2140 2160-2210 2285-2295 2350-2375 2595-2625 2710-2732	Serrated Cylinderical Cylindrical Cylindrical Cylindrical Cylindrical Cylindrical	Marine Fringe Buildup Sands Turbidity Buildup Sands Alluvial Point Bar Alluvial Point Bar Turbidity current build up sands Alluvial Point Bar
2	2220-2235 2270-2290 2345-2365 2450-2465 2540-2550 2610-2650 2715-2755	Cylinderical Cylinderical Serrated Funnel shaped Serrated cylinderical Serrated cylinderical Cylinder	Turbidity current buildup sand Turbidity current build up sands Delta marine fringe buildup sands Alluvial point bar Delta marine fringe buildup sand Turbidity current build up sands Alluvial point bar
3	2100-2120 2120-2150 2170-2180 2555-2575 2650-2615	Cylinderical Serrated bell shape Cylinderical Cylinderical Cylinderical	Turbidity current buildup sands Barrier bar Turbidity current buildup Alluvial point bar Alluvial point bar
4	2460-2500 2650-2670 2770-2810 2850-2927	Bell shaped Cylinderical Cylinderical Cylinderical	Barrier bar Alluvial point bar Delta marine Delta marine
5	2435-2465 2435-2500 2700-2730	Cylinderical Serrated cylinderical Cylinderical	Alluvial point bar Delta marine fringe buildup sand Alluvial point bar

The hybrid sand unit Formations of superposed sand and shales deposited in more than one kind of depositional regimen appears in the log signatures as serrated sand units identified at depths shown in Table 3.

Table 3: Descriptive Environment and Log Signature Shapes at Various Depths for Hybrid Sand Units

Log	Depth/m	Log Signature Shape	Descriptive Environment
2	2425-2445	Cylinderical	Progradational alluvial over delta marine sands

Figure 6 shows a correlation of the sand bodies in the various wells and their trending in a SW-NE direction of the study area. This reveals the general lithostratigraphy of the study area between depths of 2100 m and 2730 m which are identified with the numbers 1 to 7.

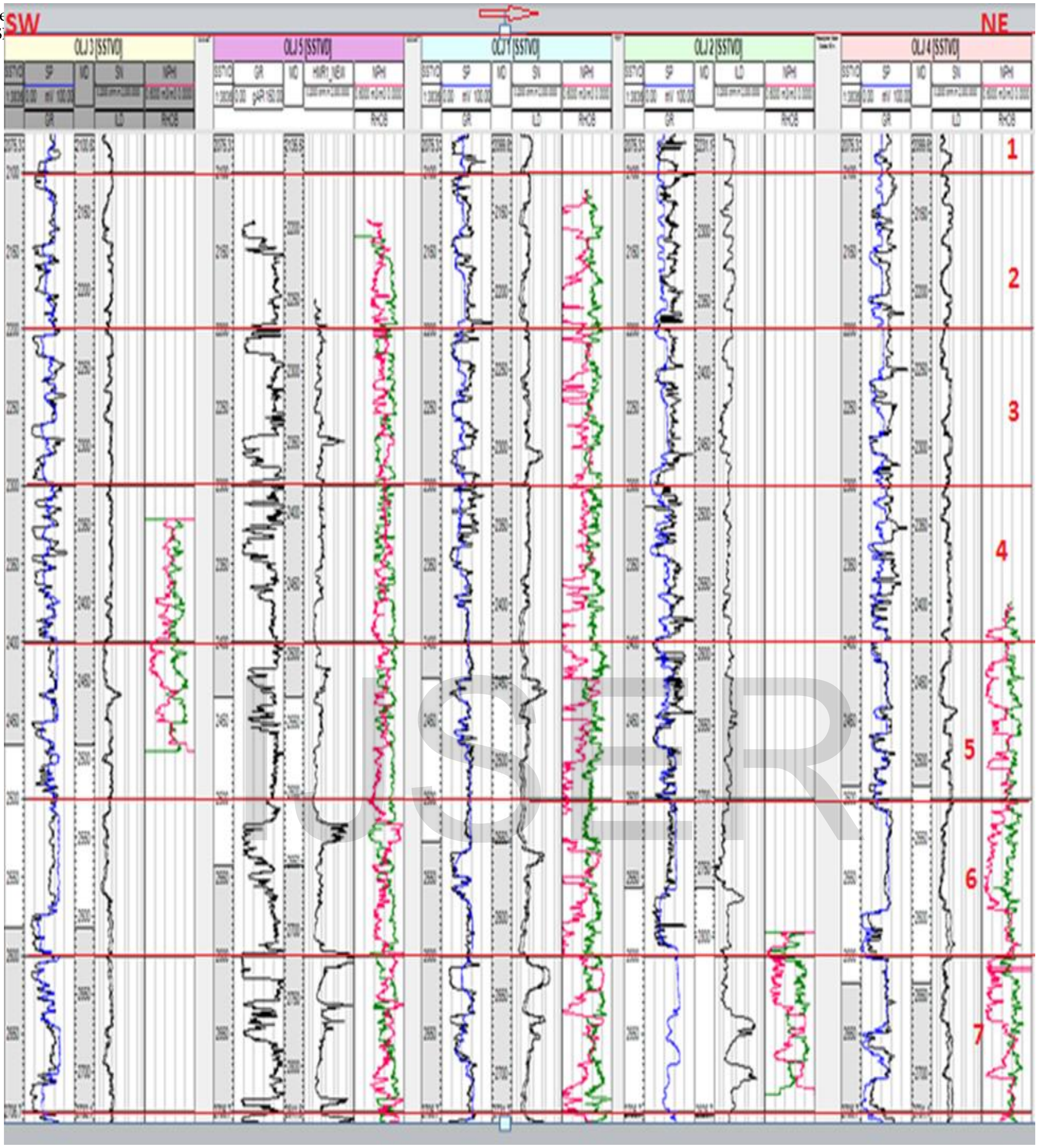

Fig.6: Correlation of Wells in a SW-NE direction showing the Lithostratigraphic trending in the study area

4 Conclusion

This work has identified the depositional environments and the general lithostratigraphic trending, between the depths of 2,100 and 2,730 meters, in the study area using electric logs of resistivity/spontaneous potential and gamma ray logs from five wells. The sand units identified are genetic, amplified and hybrid sands with descriptive environments of point bars, barrier bars, delta marine fringe sediments of sand and shales, deposited in turbidity current buildups, transgressive and regressive regimes.

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