Wireline Log Petrophysical Characterization of Selected Reservoirs in Zeta field, Niger Delta, Nigeria

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Abstract- This research was centered around making estimates of petrophysical measures in sandstone reservoirs in Zeta Field, Onshore Niger Delta. The petrophysical measures estimated were porosity, permeability, water and hydrocarbon saturation, volume of shale and net-to-gross variations. To this end, seven (7) well logs were analysed. The results of the analysis revealed the presence of 3 viable hydrocarbon-bearing sandstone reservoirs. Correlation of these sand bodies show that each of the sand units spreads through the field, varying in thickness and some units occurring at greater depth than their adjacent unit which is perhaps a sign of faulting. The thickness of each sand unit is highly variable, ranging between 82 and 350 ft. The fractional values of porosities within the three identified sandstone reservoir units ranged from 0.15 to 0.26, with estimates of permeability between 89.92 to 2552.67 mD. From estimates made, the shale volume within the reservoirs of interest ranged from 7.5% to 55.88%. The average estimates of fractional water saturation in the three reservoirs of interest ranged from 0.16 to 0.73, with an estimated value of net-to ratio ranging from 0.17 to 0.96 for the reservoirs rocks of interest. This showed that the sandstones in the study area are viable hydrocarbon-bearing reservoir units, that could be profitable for further exploration activities.

Index Terms- Reservoir, Petrophysical, Hydrocarbon, Zeta Field

I. Introduction

The evaluation and characterization of reservoir rocks relative to their porosity, water saturation and permeability determinations, enhances the ability to estimate hydrocarbon reserves and reservoir bed thickness, and to distinguish between gas, oil and water bearing strata, by observing their electrical resistivity and relative permeability value [1, 2]. Petrophysical analysis is a fundamental part of any reservoir characterization work, particularly in differentiation between the hydrocarbon and non-hydrocarbon bearing zones [3]. Wireline logs are usually employed in petrophysical analysis of any oil bearing rock [4]. This is quite convenient as wireline logs provide a chance to define the composition, variability and physical properties of the rocks surrounding the well-bore, creating a scenario for understanding the subsurface at a relatively cheaper cost [3, 5]. Usually, petrophysical analysis of any oil field could encompass reservoir fluid properties and reservoir rock properties which could play major roles in how much oil recovery and production can be achieved in the field of interest [6]. In practice, petrophysical analysis is done to convert the wireline log data into reservoir properties such as volume of shale, porosity, permeability, water and hydrocarbon saturation. Appropriate examination of these reservoir properties can significantly boost the ability to discriminate between the hydrocarbon and non-hydrocarbon bearing zones [7, 8]. Inaccurate characterization could lead to drilling dry holes, reserve over-estimation and inaccurate pore pressure prediction. This work is aimed at carrying out petrophysical characterization using well logs in Zeta Field situated in Greater Ughelli Depositional Belt of Niger Delta, Nigeria.

Richardson [8] utilizes a suite of borehole geophysical wire lines logs for the evaluation of the hydrocarbon potential of an oil field in Niger Delta. He showed that the reservoirs delineated in the study area have average porosity of 30.2%, water saturation of 19.7% and hydrocarbon saturation of 80.3%.

In their work, Eze *et. al.* [9] carried out a petrophysical analysis on a typical Niger Delta oil producing field. They did this by delineating reservoir units using available composite wireline log to determine geometric properties (porosity and permeability). They showed that the petrophysical characteristics of the reservoirs are good especially at the areas of interest (hydrocarbon zones).

Additionally, Edigbue *et. al.* [10] integrated 3D seismic and petrophysical data to evaluate hydrocarbon reservoir potentials of "Keke" field in the Niger Delta. Two sands units between 9127ft and 11152ft were correlated and mapped using gamma ray log while petrophysical parameters were obtained from other well logs. They discovered that the trapping mechanisms and the obtained Petrophysical parameters in "Keke" field are favorable for hydrocarbon accumulation.

II. Location and geological setting of study area

The datasets (well logs) used for the study were acquired from "Zeta" field in Greater Ughelli Depositional Belt, Onshore Niger Delta field, Nigeria (Fig. 1). The field is located in Oil Mining Lease (OML) 58. The concession is situated Onshore, near Port Harcourt in Niger Delta, one of the world's largest hydrocarbon provinces [11, 12]. The latitudinal and longitudinal extents of the Delta lie along the coordinates 4°N to 9°N and 4°E to 9°E [13]. Only one petroleum system has been identified to be associated to the Niger Delta basin and it is known as the (Akata-Agbada) petroleum system [14]. Fig. 1 shows the Niger Delta Map & Base Map of the study area.
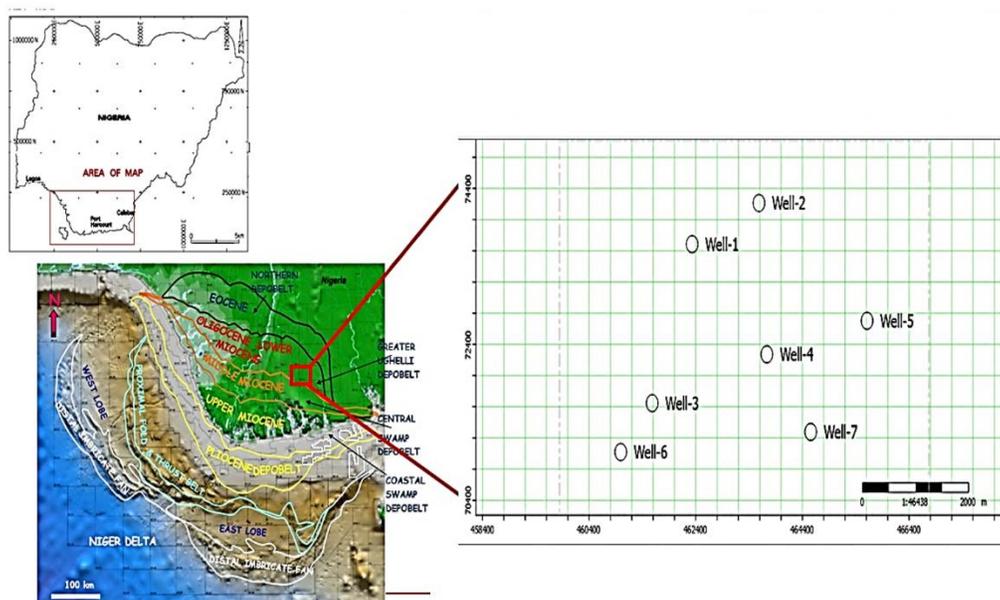
Figure 1: Location and Base Map of the Study Area

III. METHOD AND MATERIALS

Dataset from Seven (7) wireline logs are available in the field of study (Zeta). The logs consist of gamma ray, resistivity, density, sonic and caliper (Table 1 shows the Log Inventory of Available Wells in the Field). All the wells are vertical and most have a full suite of wireline logs over the target reservoir interval. The logs were loaded into the software and data conditioning (filtering) applied done. Using the de-spiking tool of the Hampson Russell Software, a median filter with an operator length of 3 was applied in order to cutoff the false effect caused by high frequency noise appearing as abnormal spikes in the log curves.

The methodology employed was detailed petrophysical evaluation to estimate reservoir properties and variation across the field was studied. First, the reservoirs are delineated and correlated across the field. Next, the various petrophysical parameters were calculated using already established models as follows:

A. *Determination of Volume of Shale (V_Shale)*

According to Larionov's [15], the volume of shale was estimated in the study using the relationship,

$$V_{Sh} = 0.083(23.7 I_{GR} - 1) \tag{1}$$

Where,

$V_{Sh} =$ Shale percentage in the formation

$I_{GR} =$ Gamma Ray index

The gamma ray index was computed using the GR log response according to Schlumberger relationship as seen in Paul *et. al.* [16]:

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \tag{2}$$

Where,

$GR_{log} =$ Gamma ray reading from log

$GR_{min} =$ Minimum gamma ray reading

$GR_{max} =$ Maximum gamma ray reading

B. *Determination of Total Porosity (Φ_T)*

Porosity was determined from the density logs as described by Wyllie *et. al.* [17],

$$\Phi_T = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}} \tag{3}$$

Where,

$\rho_{ma} =$ Matrix density ($2.69 gcm^{-3}$, Density of sandstone)

$\rho_b =$ Formation bulk density from density log (in gcm^{-3})

$\rho_{fl} =$ Fluid density ($0.87 gcm^{-3}$, Density of oil contained in the drilling mud)

C. *Estimation of Effective Porosity (Φ_eff)*

According to Dresser [18], effective porosity the delineated reservoirs of interest was estimated as

$$\Phi_{eff} = \Phi_T - (\Phi_{Sh} \times V_{Sh}) \tag{4}$$

Where,

$\Phi_{Sh} =$ Log reading in a shale zone

D. *Determination of Water /Hydrocarbon Saturation*

The formation factor was determined using Archie's [19] relationship,

$$F = \frac{a}{\Phi_T^m} \tag{5}$$

Where,

$F =$ Formation Factor

$a =$ Tortuosity factor taken to be 0.62

$m =$ Cementation factor which is 2 for sands

The water saturation for the uninvaded zone was determined using the Archie's [19] equation:

$$S_w = \sqrt{\frac{R_o}{R_T}} \tag{6}$$

Where,

$S_w =$ Water saturation of the uninvaded zone

$R_o =$ Resistivity of formation at 100% water saturation

$R_T =$ True resistivity of the formation

Hydrocarbon saturation, S_h, is given as

$$S_h = (100 - S_w)\% \qquad (7)$$

$$S_h = 1 - S_w \ (In \ Fraction) \qquad (8)$$

E. Determination of Permeability

Using the Wyllie and Rose [20] method, permeability (k) was estimated for the delineated reservoirs of interest such that,

$$K = \left(\frac{250 \times \Phi_T}{S_{wirr}}\right)^2 \qquad (9)$$

$$S_{wirr} = \sqrt{\frac{F}{2000}} \qquad (10)$$

Where,

$S_{wirr} =$ Irreducible water saturation

F. Determination of Net-to-Gross Thickness

The Net-to-Gross (h/H) Reservoir thickness is given as:

$$h/H = \frac{H - h_{Shale}}{H} \qquad (11)$$

Where,

$H =$ Gross reservoir thickness

$h =$ Net reservoir thickness

$h_{Shale} =$ Shale thickness

Table 1: Well Log Inventory of Available Wells in the Field

Well Information		Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7
Well Header		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Well Reservoir Tops		Yes	Yes	Yes	Yes	Yes	Yes	Yes
Well Deviation Sets		No	No	No	No	No	No	No
Well Checkshot		No	No	Yes	No	Yes	No	No
WELL LOGS	GR	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Sonic	Yes	Yes	Yes	No	Yes	Yes	No
	Shear	Yes	No	No	No	Yes	No	No
	Restiv.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Density	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Calliper	Yes	Yes	Yes	Yes	Yes	Yes	Yes

IV. RESULT AND DISCUSSION

A. Reservoir Delineation and Well Correlation

A total of twenty-one possible hydrocarbon-bearing zones (Sand A, Sand B & Sand C) across seven wells (Wells 1 to 7) were delineated using combination of gamma ray and resistivity logs. The tops, bases and thicknesses of the three identified reservoirs are listed in Table 1. The wells display a shale/sand/shale arrangement which is descriptive of the Niger Delta formation. Low gamma ray and high resistivities are sand lithologies. Shale lithologies were defined by the high gamma ray value. Gamma ray logs accounts for the degree of radioactivity of rocks in the well which are connected to clay mineral, oil source rock, organic matter and shale in reservoir rock

(Schlumberger, 1972). Shale-free sandstones normally have low radioactive concentrations representing relatively low gamma ray response. Resistivity is the property of a material or substance to resist the flow of electric current (Schlumberger, 1972). The deep resistivity log response against hydrocarbon-bearing zones as seen from the reservoirs were relatively high.

Well correlation which provides a knowledge of the general stratigraphy of the study field (Fig. 2). Twelve sand bodies marked reservoir Sand A to Sand C were correlated across the seven wells in the field. This analysis shows that each of the sand units extends through the field, varies in thickness and some units occurring at greater depth than their adjacent unit which is probably an indication of faulting.
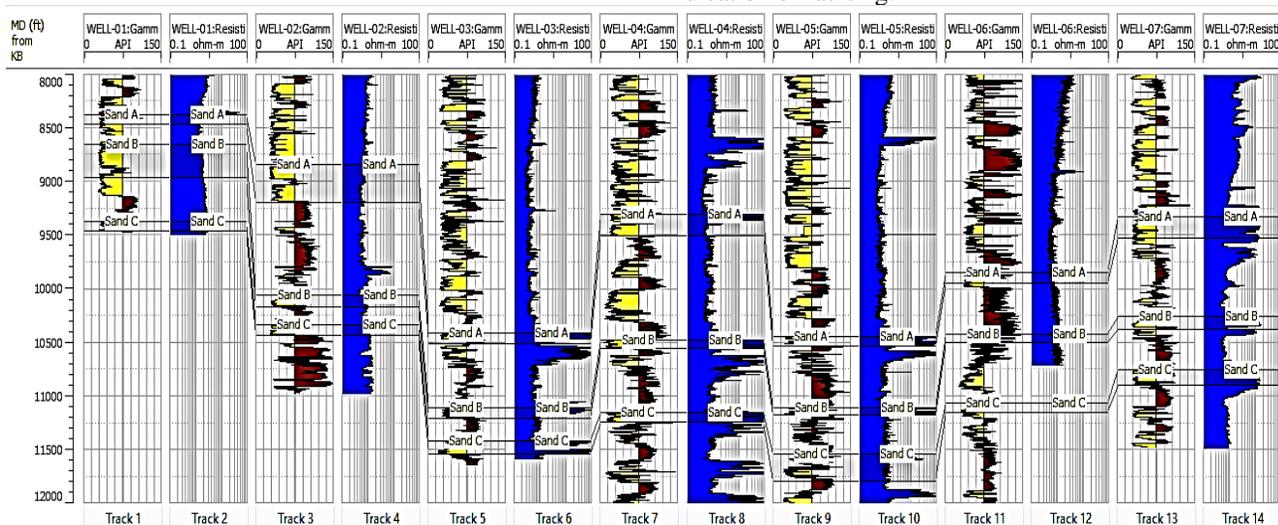

Figure 2: Well section window showing the correlation panel for all the sand bodies identified on well log

Table 2: Reservoirs of interests for Well 1 to 7 for Sand A, Sand B & Sand C.

Well	Reservoir Name	Top MD (ft)	Base MD (ft)	Thickness (ft)
WELL-01	Sand A	8329	8411	82
	Sand B	8605	8911	306
	Sand C	9321	9414	93
WELL-02	Sand A	8794	9144	350
	Sand B	10013	10119	106
	Sand C	10288	10392	104
WELL-03	Sand A	10364.7	10465	100.3
	Sand B	11064	11168	104
	Sand C	11374	11493	119
WELL-04	Sand A	9250	9446	196
	Sand B	10425	10507	82
	Sand C	11107	11189	82
WELL-05	Sand A	10399.4	10487	87.6
	Sand B	11063	11126	63
	Sand C	11500	11750	250
WELL-06	Sand A	9854.97	9946	91.03
	Sand B	10431	10509	78
	Sand C	11073	11160	87
WELL-07	Sand A	9326	9529	203
	Sand B	10256	10379	123
	Sand C	10764	10906	142

B. Petrophysical Evaluation for Three Reservoir Intervals (Sand A, Sand B & Sand C)

i. Sand A

Table 3 shows the summary of the average petrophysical measures estimated for Sand A reservoir correlated across Well 1 to 7. The volume of shale was calculated from gamma ray index and the values range from 7.50% to 41.33% indicating that the fraction of shale in the reservoirs is quite low. This means the reservoir has a large volume of sand deposit than shale, therefore, possibly saturated with hydrocarbon according to Essien [21]. The reservoirs total porosity was estimated from density log (RHOB) using porosity formula and these values ranges from 0.26 to 0.31 indicating a very good reservoir quality and reflecting probably well sorted coarse grained sandstone reservoirs with minimal cementation [22, 23]. The permeability of the reservoir units' range was from 284.45 to 2291.89 mD. This implies that the permeability varies from very good to excellent and suggests that these could be reservoir horizon with high hydrocarbon exploration potential [24]. The hydrocarbon saturation of the reservoirs ranges from 52.74 to 71.00 indicating that the proportion of void spaces occupied by water is low, which could consequently be indicative of high hydrocarbon saturation and high hydrocarbon production. The net-to-gross ranges from 0.46 to 0.84. These results imply that the reservoir is highly porous and permeable. It also contains high hydrocarbons that is very viable for production.

ii. Sand B

Table 4 shows the summary of the average petrophysical evaluation for Sand B reservoir correlated across Well 1 to 7. Average volume of shale values ranges from 11.97 to 55.88%. Low volume of shale signifies that the fraction of shale in the reservoirs is quite low, which means large volume of sand deposit than shale. Porosity values ranges from 0.17 to 0.27 indicating a very good reservoir quality [22, 25]. The permeability of the reservoir units' range was from 89.92 to 1010.16 mD. This implies that the permeability varies from very good to excellent. The water saturation of the reservoirs' ranges from 0.20 to 0.73. High values of water saturation were observed in Well 2. This implies that those some parts of this reservoir rock contain low hydrocarbon saturation and potentially low hydrocarbon production. The net-to-gross ranges from 0.61 to 0.82.

iii. Sand C

Table 5 shows the summary of the average petrophysical evaluation for Sand C reservoir correlated across Well 1 to 7. Average volume of shale values ranges 23.30 to 34.33%. Low volume of shale signifies that the fraction of shale in the reservoirs is quite low, which means large volume of sand deposit than shale. Porosity values ranges from 0.15 to 0.25 indicating a very good reservoir quality. The permeability of the reservoir units' range was from 260.58 to 2552.67mD. This implies that the permeability varies from very good to excellent [22, 25]. The hydrocarbon saturation of the reservoirs ranges from 0.34 to 0.80 indicating that the proportion of void spaces occupied by water is low but high in Well 1. Well 1 contains little concentration of hydrocarbons. However, the other wells in this reservoir have high hydrocarbon saturation and high hydrocarbon production. The net-to-gross ranges from 0.34 to 0.68.

Table 3: Petrophysical evaluation for Sand A reservoir correlated across Well 1 to Well 7

	Unit (ft)	Well 1		Well 2		Well 3		Well 4		Well 5		Well 6		Well 7	
		Top 8329	Base 8411	Top 8794	Base 9144	Top 10364.7	Base 10465	Top 9250	Base 9446	Top 10399.4	Top 10487	Base 9854.97	Top 9946	Base 9326	Top 9529
Gross Thickness	ft	82		350		100.3		196		87.6		91.03		203	
Shale Volume	%	25.95		7.50		24.39		17.60		41.33		33.25		15.10	
Net Thickness	ft	45.72		335.92		66.70		142.64		25.74		46.80		157.11	
Net-to-Gross	Frac	0.56		0.96		0.67		0.73		0.29		0.51		0.77	
Total Porosity	Frac	0.29		0.24		0.20		0.26		0.25		0.24		0.31	
Eff. Porosity	Frac	0.23		0.22		0.23		0.22		0.16		0.17		0.27	
Water Sat	Frac	0.35		0.54		0.26		0.34		0.31		0.49		0.16	

		Well 1		Well 2		Well 3		Well 4		Well 5		Well 6		Well 7	
HC Sat	Frac	0.65		0.46		0.74		0.66		0.69		0.51		0.84	
Permeability	mD	1701.00		395.54		1340.15		849.27		994.71		284.45		2291.89	

Table 4: Petrophysical evaluation for Sand B reservoir correlated across Well 1 to Well 7

	Unit (ft)	Well 1		Well 2		Well 3		Well 4		Well 5		Well 6		Well 7	
		Top	Base	Top	Base	Top	Base	Top	Base	Top	Top	Base	Top	Base	Top
		8605	8911	10013	10119	11064	11168	10425	10507	11063	11126	10431	10509	10256	10379
Gross Thickness	Ft	306		106		104		82		63		78		123	
Shale Volume	%	11.97		40.02		31.52		46.28		55.88		41.36		37.10	
Net Thickness	Ft	249.09		41.31		43.29		22.86		10.42		19.76		14.87	
Net-to-Gross	Frac	0.81		0.39		0.42		0.28		0.17		0.48		0.40	
Total Porosity	Frac	0.26		0.17		0.27		0.20		0.18		0.24		0.27	
Eff. Porosity	Frac	0.23		0.12		0.19		0.13		0.09		0.15		0.21	
Water Sat	Frac	0.51		0.73		0.20		0.49		0.55		0.42		0.44	
HC Sat	Frac	0.49		0.27		0.80		0.51		0.45		0.58		0.56	
Permeability	mD	729.16		182.02		996.69		1264.20		297.17		89.92		1010.16	

Table 5: Petrophysical evaluation for Sand C reservoir correlated across Well 1 to Well 7

	Unit	Well 1		Well 2		Well 3		Well 4		Well 5		Well 6		Well 7	
		Top	Base	Top	Base	Top	Base	Top	Base	Top	Base	Top	Base	Top	Base
		9321	9414	10288	10392	11374	11493	11107	10507	9321	9414	10288	10392	11374	11493
Gross Thickness	Ft	93		104		119		82		250		87		142	
Shale Volume	%	33.66		23.30		28.95		33.29		33.78		34.33		26.28	
Net Thickness	Ft	42.78		70.72		58.31		36.08		117.5		29.58		85.2	
Net-to-Gross	Frac	0.46		0.68		0.49		0.44		0.47		0.34		0.60	
Total Porosity	Frac	0.19		0.22		0.28		0.30		0.20		NIL		0.32	
Eff. Porosity	Frac	0.15		0.17		0.20		0.21		0.15		NIL		0.25	
Water Sat.	Frac	0.66		0.50		0.27		0.25		0.46		NIL		0.20	
HC Sat	Frac	0.34		0.50		0.73		0.75		0.54		NIL		0.80	
Permeability	mD	595.75		260.58		526.95		1711.34		290.02		NIL		2552.67	

V. CONCLUSION

This study was designed to predict petrophysical properties in a target oil field (the Zeta field in this case, located in the Niger Delta region of Nigeria). Estimates of porosity, permeability, water saturation, volume of shale etc. derived from log measurement were estimated for the study area. The following conclusions were arrived at.

i. Three (3) reservoir sands were delineated from the seven delineated well logs in the study area.

ii. Porosities tend to be lower in deeper and older (consolidated) formations, due to cementation and overburden pressure stress on the rock. The fractional values of porosities estimated within the study area ranged from 0.15 to 0.26.

iii. The values of shale volume obtained for the study area ranged between 7.5% to 55.88%.

iv. The fractional values of water saturation estimated in the three reservoirs of interest ranged between 0.16-0.73.

v. The permeability of the reservoir units estimated ranged from 89.92 to 2552.67 mD.

vi. The values of net-to-gross (NTG) ratio estimated for the study area ranged from 0.17 to 0.96.

vii. From these estimates, the reservoirs within the study area are potentially hydrocarbon bearing and could be viable for further exploratory activities.

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