



## Petro-physical Analysis of Well Logs for Reservoir Evaluation: A Case Study of Well 1 and 2 of the 'Ictorian' Field in the Niger Delta Basin

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**ABSTRACT:** This study presents the log analysis results of a suite of conventional wireline logs including gamma ray, density, neutron, and resistivity from two wells in 'Ictorian' Field located in the Niger delta with the aim of evaluating hydrocarbon prospect of the field. Results obtained showed presence of hydrocarbon in eleven (11) reservoirs from well 1, and four (4) reservoirs from well 2. Well 1 and 2 both had hydrocarbon reservoir bearing gas. Well 1 had Gas Water contact at 2497m and 2964m, while well 2 had Gas water Contacts at 1739m and 2510m. Effective porosities had values ranging from 26-16% in well 1. In well 2, effective porosities had values ranging from 22-17%. The values obtained show that the analysed reservoirs have good permeability. The calculated values indicate that porosity, permeability values from the hydrocarbon bearing reservoirs are good enough for commercial accumulation in the Niger Delta. It is recommended that for field optimization mud logging data and core data analysis should be integrated as part of the evaluation exercise.

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Petroleum in the Niger Delta is produced from sandstones and unconsolidated sands predominantly in the Agbada Formation. Recognized known reservoir rocks are of Eocene to Pliocene in age, and are often stacked, ranging in thickness from less than 15 meters to 10% having greater than 45 meters thickness. (Evam *et al.* 1978). Based on reservoir geometry and quality, the lateral variation in reservoirs thickness is strongly controlled by growth faults; with the reservoirs thickening towards the fault within the down-thrown block (Weber and Daukoru, 1975). A reservoir is a subsurface rock that has effective porosity and permeability which usually contains commercially exploitable quantity of hydrocarbon. Petrophysical logs interpretations used for the characterization of reservoir sands are very useful and important tools for selecting, planning and implementing operationally sound supplementary recovery schemes (Ekin and Iyabe, 2009). Furthermore, the pores and fractures have to be interconnected if the hydrocarbons will eventually be produced as such hydrocarbons are needed to flow towards production wells. Porosity and permeability are thus key reservoir parameters in this regard and as such parts of the Niger Delta opportunities have been captured at the shallow, intermediate and deep levels (Olowokere, 2009b). The search or economic accumulations of oil and gas starts with the recognition of likely geological provinces, progresses to seismic surveying, and the drilling of one

or more wild-cat wells. If one is lucky, these wells may encounter oil, and if that is the case, measurements made down the hole with wireline tools are used to assess whether sufficient oil is present, and whether it can be produced. Clearly, the evaluation of sub-surface formations requires the combined efforts of geologists, Petrophysicists, drilling engineers and even geophysicists. However, it is the geologist and Petrophysicist that has the most influence. The geologist is interested in the lithology, stratigraphy and depositional environment of the subsurface strata penetrated by the drilling bit. The exploration geologist uses wireline tool responses in a number of wells to create a large scale image of the sub-surface geology by correlating wireline responses that are characteristic of a given formation or horizon between formations. This picture is very useful when carrying out initial reservoir modelling and in the decision where to drill new wells. Later the production geologist carries out much the same process with much more well information, and adds any extra information that has been gathered to produce a detailed geological model of the reservoir and related sub-surface formations. This model will be the basis of reservoir modelling, and all major reservoir management decisions from primary drainage through to enhanced oil recovery and shut-down. The Petrophysicist's job is to use all available information to analyse the physical and chemical properties of the rocks in the sub-surface,

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and their component minerals, with particular emphasis given to the amount and distribution of those fluid minerals that we know of as water, oil, and gas. The petrophysicist will use extensively wireline log data and data from experiments done on cores extracted from the well, and will occasionally use other sources of information such as engineering and production logs, as well as mud logging data. Initially, it is the aim of the Petrophysicist to differentiate between oil, gas and water bearing formations, estimate the porosity of the formations and the approximate amount of hydrocarbons present in each formation. Ultimately, the Petrophysicist also uses laboratory data to estimate how easy it will be to extract the hydrocarbons in place, and to design reservoir management strategies to optimize long term oil recovery. There is a large database of information available to both the geologist and the Petrophysicist, and as time passes the amount and variety of

information increases. The formation evaluation and reservoir characterization of some parts of Niger Delta revealed the two major lithological units in the area to be sand and shale (Abe and Olowokere, 2013; Ologe, 2016); a good reservoir is one that is commercially productive if it produces enough oil or gas to pay back its investors for the cost of drilling and leaves a profit. This study is to evaluate the reservoir quality and production potential of the ‘Ictorian’ Field in the Niger Delta Basin. These are essential for both economic evaluations of the reservoir and production planning of an optimum recovery method.

**MATERIALS AND METHODS**

*Description of study area:* The study wells (well 1 and 2) of the “Ictorian” field are located within the oil province of the Niger delta basin, South South Nigeria.

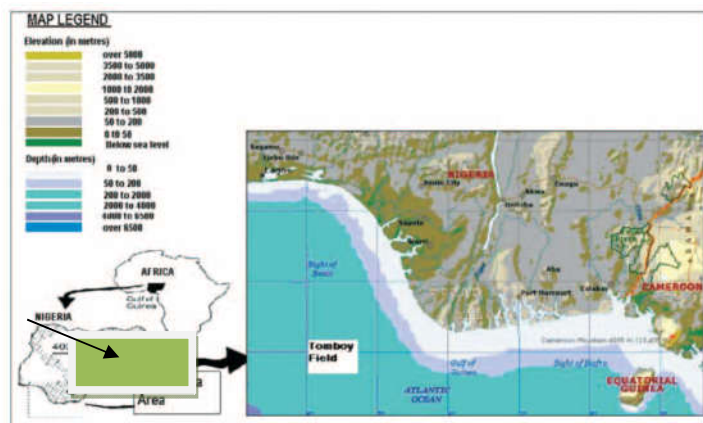


Fig 1: Location map of the study area (Modified from Owoyemi, 2004 and Microsoft Encarta, 2006)

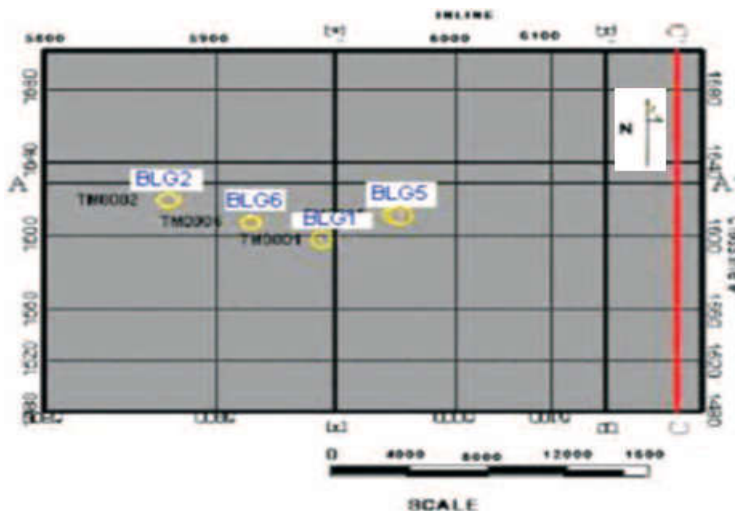


Fig. 2: Field base map of study area

*Estimation of Petro-physical Parameters:* The materials used for this study are from National Petroleum Development Company (NNPC), which include geophysical wire-line log data (gamma-ray log, neutron-density log and resistivity log). The analysis of the geophysical wire-line logs was done manually. Lithology was interpreted using the combination of the gamma ray and spontaneous potential logs of each well, followed by the lithostratigraphic correlation of the wire-line logs.

*Formation Evaluation of studied wells:* In the present study, the hydrocarbon bearing reservoirs was analysed from the resistivity log. Generally water bearing zones have very low resistivity since they are conductive and the hydrocarbon bearing zone had relatively high resistivity because they are non-conductive. The hydrocarbon was differentiated into oil and gas using the neutron-density combination log. The average porosity was estimated from the neutron density cross plot, the effective porosity was further deduced by introducing the shale volume percentage. Effective porosities were estimated and these effective porosities determine the permeability of the reservoirs. Water saturation and hydrocarbon saturation was estimated from the formation resistivity values gotten from the resistivity log.

**Table 1.** Qualitative evaluation of porosities.

Percentage Porosity	Qualitative Evaluation
0-5	Negligible
5-10	Poor
15-20	Good
Over 20-25	Very good
Over 30	Excellent

*Evaluation techniques:* The evaluation sequence used for the present study is given below. (1) Distinguish between reservoir and non-reservoir rock (Reservoir rock contains a reasonably high connected porosity.) (2) For the reservoir intervals only, distinguish between hydrocarbons and water filling the pores, hence calculate water saturation in reservoir rocks (Hydrocarbons are electrical insulators, while water conducts.) (3) For the hydrocarbon fraction, distinguish between oil and gas, hence calculate gas and oil saturations in reservoir rocks (Gas has a much lower density than oil.)

*Reservoir identification:* Lithology identification was done with the gamma ray log. A review of the Niger delta basin indicated sands as the major reservoir rocks. Within the gamma ray log strip, the beds with high GR readings were taken as shale while those with low GR readings were taken as sands. The GR level of the thickest shale bed is read and this reading is assumed to represent 100% shale and a straight line

drawn through this point is the shale line. Similarly a sand line was also drawn representing the average GR reading for a thick sand bed (100% clean sand) which is equal to the sand with the lowest gamma ray reading. A vertical line through the midpoint between the sand and shale line is constructed and is called the cut-off line. On the basis of this cut-off line all intervals where the GR log is on the left are assumed to be sandstones and any interval on the left is assumed to be shale.

During the evaluation of the logs, for well 1

- Sand line value was 22 API.
- Shale line value was 90 API.

For well 2

- Sand line value was 25 API.
- Shale line value was 100 API

*Reservoir thickness estimation:* The gamma ray log was also used in estimating the thickness of reservoirs. This was done with the aid of appropriate depth interval measurements (in meters) on the gamma ray log strip. The reservoirs were divided into zones and the thickness of the reservoir zone used in this calculation is the net sand. The net sand is the thickness of clean, permeable, hydrocarbon-containing sand in the reservoir zone. This is the thickness of sand in the reservoir zone irrespective of whether it is clean, its permeability or its fluid saturation. The *net to gross ratio* (thickness of net sand divided by the thickness of gross sand) is often used to represent the quality of a reservoir zone.

*Shale volume calculation:* The maximum and minimum of gamma ray were used to compute shale volume. This was done using the gamma ray log to get the sand and shale readings in API then estimate the volume of shale in the reservoir as follows:

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \times 100$$

*Porosity determination:* The relative amount of pore space to the bulk volume is denoted by the porosity  $\phi$ , where the *porosity* is the fraction of the bulk volume occupied by pore volume, and is expressed as a fraction or as a percentage;

$$\phi = V_{pore} / V_{bulk}$$

The porosity values were obtained using the both density and neutron log for accuracy and consistency and of porosities. This was done by plotting the bulk density ( $\rho_b$ ) and the neutron porosity (p.u) on the X-plot and determining the Lithology and porosity estimate on each lithologic line. The X-plot is very useful in correcting for porosities in gas bearing reservoirs. However, the fractional form is used in all calculations. The majority of rock volume is occupied

by the solid rock matrix, and the remainder is made up of the pore space between the minerals.

**Hydrocarbon detection:** This is established from the deep resistivity logs for a particular reservoir interval. This is in line with the principle that water bearing reservoirs have relatively low deep resistivity because water is highly conductive and hydrocarbon bearing reservoirs have relatively high deep resistivity because they are non-conductive. After detecting the presence of hydrocarbon a further distinction on the type of hydrocarbon present (oil or gas) is determined with the aid of the neutron density log. Gas has a signature balloon effect (large separation between neutron and density log) while oil a no balloon effect (a smaller separation)

**Hydrocarbon saturation:** In general the porosity is completely occupied by either water or hydrocarbon, where the saturation of the water is  $S_w$ , and that of the hydrocarbon is  $S_h$ , and  $S_w + S_h = 1$ . In most reservoirs the hydrocarbon has replaced all the water that it is possible to replace, and under these conditions the water saturation is termed the irreducible water saturation  $S_w$ . Now we can write the hydrocarbon saturation as  $S_h = (1 - S_w)$ .

**Petro-physical characteristics of the reservoirs:** The petro-physical parameters calculated and used for the hydrocarbon analysis include:

**Table 2.** Summary of the Petro-physical properties of the reservoirs

Petro-physical properties	Formula applied
<b>Porosity (average)</b>	$\bar{\phi} = \frac{\sum \phi_i h_i}{\sum h_i}$ ; Where $\phi_i$ is the individual porosities for all the blocks of the reservoir zone and $h_i$ represents the thickness of each block.
<b>Effective porosity</b>	$\bar{\phi}_e = \phi(1 - Vsh)$
<b>Resistivity of water</b>	$R_w = \frac{R_o}{\phi^{-m}}$ ; Where $R_o$ is the resistivity of the water bearing zone (from the log) and $m$ is the cementation factor
<b>Formation resistivity factor</b>	$F = \frac{a}{\phi^{-m}}$ ; $a$ = tortuosity factor (From archies equation $a = 0.81$ ) and $m$ = cementation factor which is taken as =2
<b>Water saturation</b>	$S_w = \left(\frac{aR_w}{\phi^m R_t}\right)^{\frac{1}{n}}$ ; Where $R_t$ = the formation resistivity; $n$ = saturation exponent
<b>Hydrocarbon saturation</b>	$S_{hc} = (1 - S_w)$
<b>Bulk volume water</b>	$Bvw = S_w \times \bar{\phi}$
<b>Volume of shale</b>	$Vsh = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \times 100$ ; Where, $GR_{log}$ = GR of formation measured from log; $GR_{min}$ = Least GR in zone of interest, $GR_{max}$ = Maximum GR reading in formation of interest, $Vsh$ = Volume of Shale

## RESULT AND DISCUSSION

Table 3 and 4 presents the results of the log analysis.

**Table 3.** Results of average petro-physical parameters of the eleven (11) reservoirs of well 1

Reservoir	Depth interval (m)	Thickness (m)	Net reservoir (m)	Net/gross reservoir	Lithology	Fluid present	Net pay thickness	LLD Rt (Ωm)	FDC (g/cm <sup>3</sup> )	NPHI (p.u)	Average total porosity φ (%)	VSH (%)	Effective porosity (%)	RW	S <sub>w</sub> (%)	S <sub>hc</sub> (%)	F	BVW
1	2405-2435	30	22	0.73	sand	gas	22	200	1.90	7	32	18	26.24	0.13	8	92	7.9	2.56
2	2438-2452.5	14.5	9	0.62	sand	gas	9	43	2.00	16	32.2	41	19	0.13	17	83	7.8	5.47
3	2462.5-2477.5	15	11	0.73	sand	gas	11	53	2.09	17	29	34.5	18.9	0.25	24	76	9.6	6.96
4	2485-2511	26	24.5	0.94	sand	gas	10	70	2.08	18	30	15	22.5	0.25	20	80	9.0	6.00
5	2590-2617	27	18	0.67	sand	gas	18	60	2.13	22	29.8	37	18.77	0.25	17	83	9.1	5.07
6	2875-2910	35	27.5	0.79	sand	gas	27.75	80	2.13	18	28	37	17.64	0.17	16	84	10.33	4.8
7	2921-2964	43	38.25	0.89	sand	gas	38.25	63	2.22	19	25	36	16	0.17	21	79	12.96	5.25
8	3248-3275	27	21	0.77	sand	gas	21	175	2.17	15	26	14	22.36	0.28	15	85	11.98	3.98
9	3276-3290.5	14	10	0.71	sand	gas	10	62	2.28	14	20	19	16.2	0.28	30	70	20.25	6.0
10	3292.5-3316.5	24	22.5	0.94	sand	gas	22.5	210	2.20	12	23	16	19.32	0.28	15	85	15.31	3.63
11	3317-3335	18	13.25	0.75	sand	gas	13.25	186	2.19	16	24	17	19.92	0.28	16	84	14.1	3.84

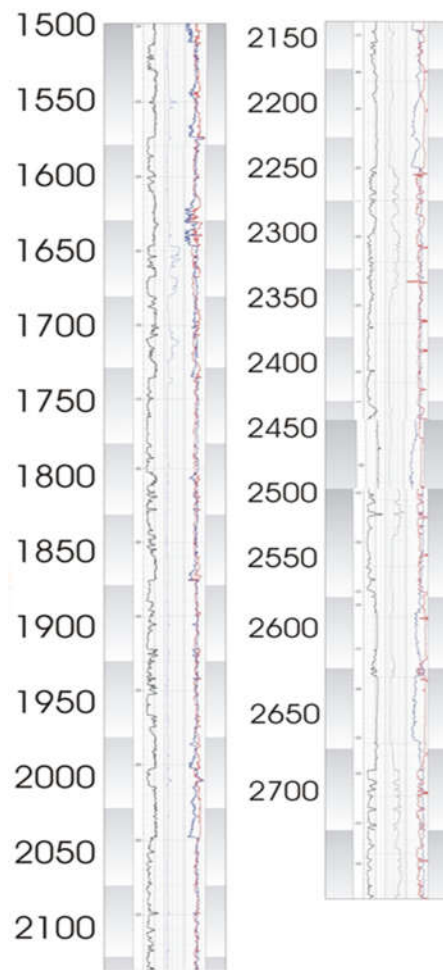
**Table 4.** Results of average petrophysical parameters of the four (4) reservoirs of well 2

Reservoir	Depth interval (m)	Thickness (m)	Net reservoir (m)	Net/gross reservoir	Lithology	Fluid present	Net pay thickness (m)	LLD Rt (Ohm)	FDC (g/cm <sup>3</sup> )	NPH (p.u)	Average total porosity $\phi$ (%)	VSH (%)	Effective porosity (%)	KW	Sw (%)	Sbc (%)	F	BVW
11	1646-1661	15	11.5	0.76	Sand	Gas	11.5	297	2.05	0.25	24	10.5	21.5	0.18	10	90	14.1	2.4
22	1667.5-1689	21.5	15.5	0.71	Sand	Gas	13	70	2.05	0.26	24	8	22	0.81	21	79	14.1	5.04
33	1708-1724	16	11.5	0.72	Sand	Gas	11.5	63.5	2.07	0.27	23	23.4	17.6	0.81	23	77	15.3	5.29
44	2478-2505.5	27.5	17.5	0.64	Sand	Gas	17.5	82	2.09	0.34	22	9	20	0.81	21	79	16.7	4.62



**Fig 3:** Gamma ray, Neutron Density and Resistivity logs of Well 1

*Interpretation:* The litho-stratigraphic correlation is a visual process which provides knowledge of the general stratigraphy of an area (Amigun, 1998). Interpretation was carried out on two well logs from wells drilled on the ‘Ictorian’ field. For the purpose of this study only the hydrocarbon bearing reservoirs were assessed. Sand package intervals were evaluated and the individual reservoirs within these packages were analyzed.



**Fig 4:** Gamma ray, Neutron Density and Resistivity logs of Well 2

From this, the Net reservoir was estimated, and then the Net/Gross reservoir estimated. Net reservoir thickness was estimated from the gamma ray logs. The net pay oil and gas thickness was estimated from the resistivity logs and neutron-density logs. The fluid contents were analyzed from the resistivity log. Generally water bearing zones have very low resistivity since they are conductive and the hydrocarbon bearing zone had relatively high resistivities because they are non-conductive.

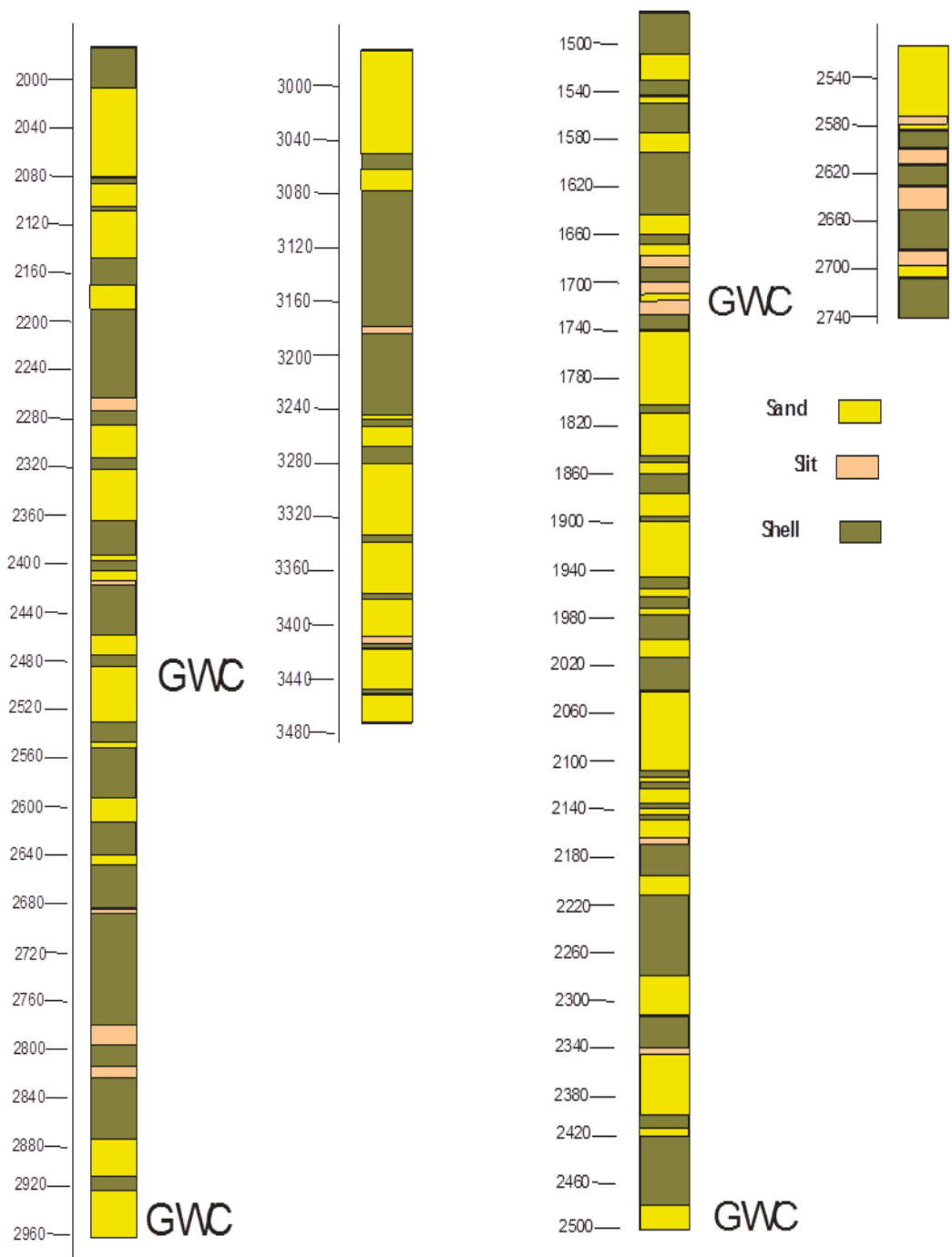


Fig 5: Lithology of well 1

Fig 6: Lithology of well 2

Sand packages intervals were evaluated and the individual reservoirs within these packages were analyzed. From this, the Net reservoir was estimated, and then the Net/Gross reservoir estimated. Net reservoir thickness was estimated from the gamma ray logs. The net pay oil and gas thickness was estimated from the resistivity logs and neutron-density logs.

The fluid contents were analyzed from the resistivity log. Generally water bearing zones have very low resistivity since they are conductive and the hydrocarbon bearing zone had relatively high resistivity because they are non-conductive. The hydrocarbon was differentiated into oil and gas using the neutron-density combination log.

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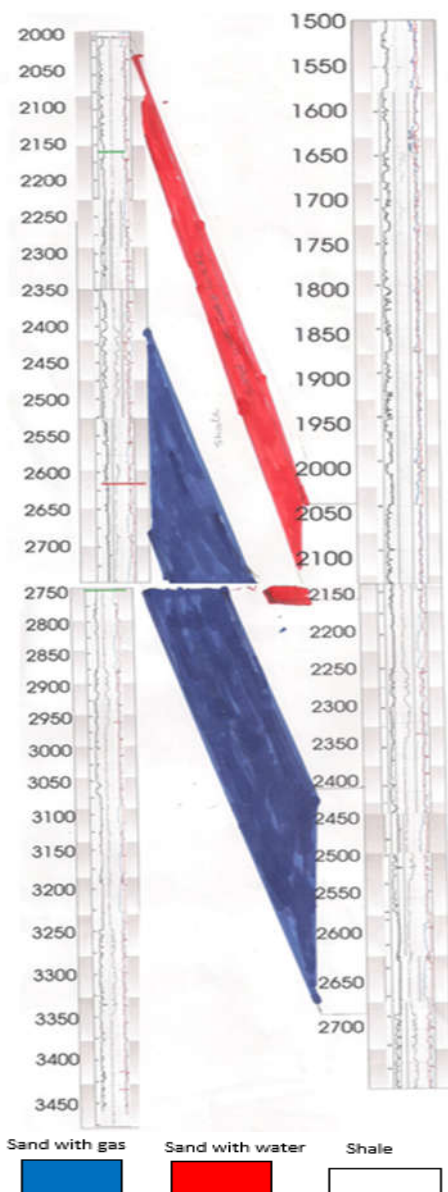


Fig 7: Well Correlation between well 1 and well 2 using Gamma ray, Neutron Density and Resistivity logs of both wells.

The average porosity was estimated from the neutron density cross plot, the effective porosity was further deduced by introducing the shale volume percentage. Effective porosities were estimated and these effective porosities determine the permeability of the reservoirs. The values obtained show that the analysed reservoirs have good permeability. This can be attributed to the friable nature of the Niger delta sands. Water saturation and hydrocarbon saturation was estimated from the formation resistivity values gotten from the resistivity log.

The hydrocarbon was differentiated into oil and gas using the neutron-density combination log. The average porosity was estimated from the neutron density cross plot, the effective porosity was further deduced by introducing the shale volume percentage. Effective porosities were estimated and these effective porosities determine the permeability of the reservoirs. The values obtained show that the analyzed reservoirs have good permeabilities. This can be attributed to the friable nature of the Niger delta sands. Water saturation and hydrocarbon saturation was estimated from the formation resistivity values gotten from the resistivity log. Only the hydrocarbon bearing reservoirs were assessed in this study.

**Table 5: Qualitative evaluation of porosities.**

Percentage porosity	Qualitative evaluation
0-5	Negligible
5-10	Poor
15-20	Good
Over 20-25	Very good
Over 30	Excellent

For well 1: Eleven (11) reservoirs bearing hydrocarbons (oil and gas) were identified. The volume of shale had values ranging from 36- 14%. The volume of shale in each reservoir had a direct effect on the effective porosity and the zones with high volume of shale had a reduced porosity. Effective porosities had values ranging from 26-16%. These effective porosities determine the permeability of the reservoirs, the values obtained show that the analysed reservoirs have good permeability. This can be attributed to the friable nature of the Niger Delta sands. Reservoir 1 -7 and Reservoir 8-11 contained gas. Well 1 had Gas Water contact at 2497m and 2964m. The sands within the pay zones were fairly homogenous. Below the oil bearing reservoirs, the presence of thick shale bed acted as a seal. Below the shale lithology, there was an occurrence of another gas bearing reservoir.

For well 2: Four (4) reservoirs bearing hydrocarbon were identified. All the sands within the pay zones of this well were satisfactorily homogenous. The volume of shale had values ranging from 23- 10%. Effective porosities had values ranging from 22-17%. Reservoir 1-4 contained gas all through. Well 2 had Gas Water Contacts at 1739m and 2510m. The analysis of the GR log shows that the overall lithology is an alternating sequence of sands and shales. The porosity values obtained from the reservoirs varied from those obtained by Edwards and Santogrossi (1990), therefore it is suggested that the reservoirs are different in age as compared to those analysed by Edwards and Santogrossi (1990). The results showed that all the hydrocarbon zones within well 1 and 2 are producible since they all have hydrocarbon saturations greater

than 65% and porosity values ranged from good to excellent. The calculated values indicate that porosity, permeability values from the hydrocarbon bearing reservoir are good enough for commercial accumulation in the Niger Delta.

*Conclusion:* The results showed that all the hydrocarbon zones within well 1 and 2 are producible since they all have hydrocarbon saturations greater than 65% and porosity values ranged from good to excellent. The calculated values indicate that porosity, permeability values from the hydrocarbon bearing reservoir are good enough for commercial accumulation in the Niger Delta. Borehole pressure data should be in use for accurate determination of fluid contacts. The GWC and GOC were all estimates deduced from the depth intervals of the gamma ray, neutron density and resistivity logs.

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