Geology and Petrophysical Analysis of Oredo Oil Field in Niger Delta Basin, Southern Nigeria

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Abstract: ***As part of the IDSL expedition in 2008 to the southern Niger Delta, numerous well data were collected to evaluate the quality of reservoirs within the basin. Oredo field was explored accordingly. On the basis of regional lithostratigraphic studies from logging tools, a more highly reflective, coarse-grained sediment unit of late Miocene age is identified as the largest hydrocarbon reservoir. The Miocene reservoir is locally above present-day regional datum. Literature has suggested that oil and gas production can be expected at depth in Jurassic, Cretaceous and Tertiary source rocks, the presence of high-amplitude reflector packages within the reservoir unit is interpreted as an evidence of hydrocarbons. Six discrete reservoirs were encountered in two wells. Log signals indicated a thick seal just above the reservoir unit shown on both of Oredo-1 and Oredo-2 Well. Generally, the encountered reservoirs are of good quality. The average effective porosity from the wells ranges from 0.14 to 0.25 across the vertical successive reservoirs, implying fairly good porosity condition for commercial accumulation of hydrocarbon. The Permeability of the encountered hydrocarbon-bearing reservoirs are also generally good and range from 27 to 236 md and water saturation of between 51 to 87 in the areal acreage.***

Keywords: Reservoir, PowerLog, Gamma log, Hydrocarbon, Well log, Porosity, Permeability, Water saturation

1. Introduction

Oredo field is situated in one of the oil mining licenses in the central depo-belt of the Niger Delta. Located in the onshore, North-Western Niger Delta, about 85 kilometers South-West of Benin, Edo state, Nigeria. This study was carried out with data made obtained from Integrated Data Service Limited, IDSL, subsidiary of Nigerian National Petroleum Company, NNPC. This study evaluated and summarizes the petrophysical properties of the hydrocarbon bearing Miocene sands series evaluated with PowerLog. The objectives of this are to demonstrably showcase the robustness of Powerlog, an industry grade software in the Formation Evaluation and to understand the lithology of the of the Miocene oil producing reservoir unitof the Oredo oil field. Fig. 1 below shows geologic map of the study area and the location of the two wells where the data were collected.

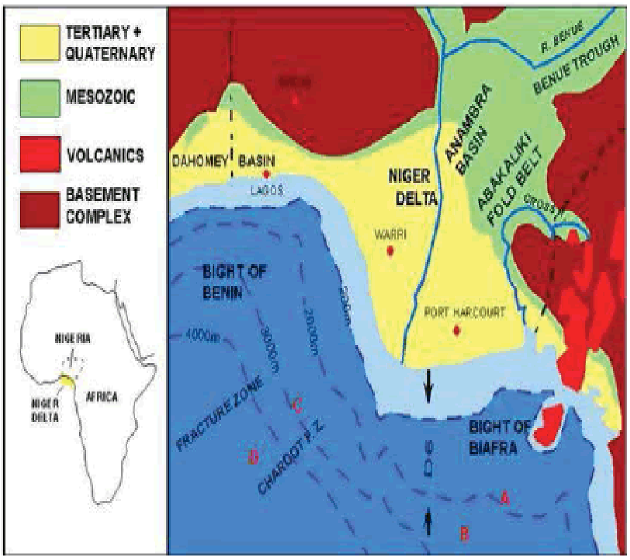

Figure 1: Geologic Map of the area showing Oredo-1 Well and Oredo-2 Well

2. Geologic Settings

The Oredo field is one of the oil producing fields in Niger Delta basin. The basin situated in the Gulf of Guinea which prograded southwestward, forming depo-belts that represent the most active portion of the delta at each stage of its development (Doust and Omatsola, 1990). These depo-belts form one of the largest regressive deltas in the world with a sediment thickness of over 10 km. Evolved during the Early Cretaceous epoch, the basin of Nigeria has witnessed at least three major depositional cycles. The first cycle began in pre-Albian time probably a double one involving mainly marine deposition within the entire basin. It was the Santonian Orogeny that brought an end to the deposition, with folds characterizing the phase. Campanian marine transgression marked the second cycle and it witnessed the growth of a proto-
Niger delta in the northern part of the basin. This ended with renewed widespread marine transgression in Paleocene time. The Niger Delta Province has only one identified petroleum system known as the Tertiary Niger Delta (Akata–Agbada) Petroleum System. Fig. 2 below shows the stages of delta growth in the basin.

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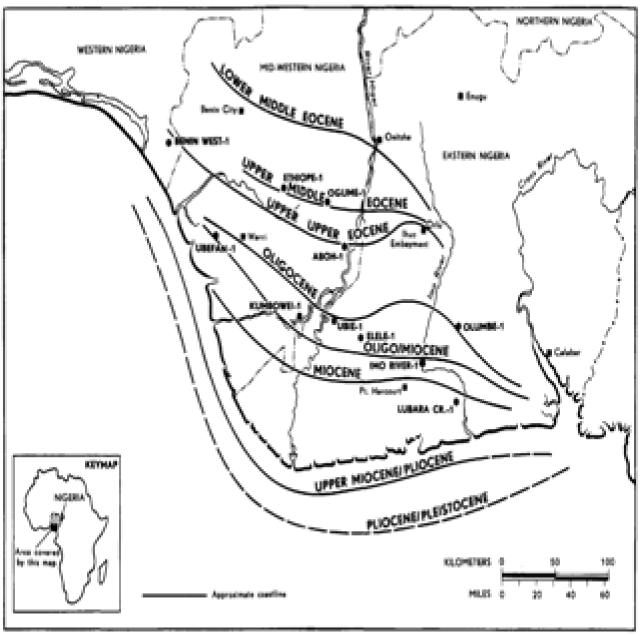

Figure 2: Paleogeography of Tertiary Niger delta—stages of delta growth (after Short and Stäuble1967)

2.1 Regional Stratigraphy

The Tertiary section of the Niger Delta is divided into three formations, these are the Akata, Agbada abd Benin Formations. They represent prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios. The Marine Akata Formation is at the base of the delta is comprises of thick shale sequences and turbidite sand (potential reservoirs in deep water), and minor amounts of clay and silt. It began in Paleocene and through to Recent. It is estimated that the formation is up to 7,000 meters thick (Doust and Omatsola, 1990). The formation underlies the entire delta, and is typically over pressured. Overlying the Marine Akata is the Agbada Formation, it represents the major petroleum-bearing unit, which began in the Eocene and continues into the Recent. The formation consists of silici-clastics over 3700 meters thick and represents the actual deltaic portion of the sequence. The clastics accumulated in delta-front, delta-topset, and fluvio-deltaic environments, Equal proportions, of shale and sandstone beds were deposited in the lower Agbada Formation, however, the upper portion is marked by deposition of sand with only minor shale interbeds. Overlying the Agbada Formation is the Continental Benin formation. It comprises of alluvial and upper coastal plain sands that are up to 2000 m thick dated Eocene to Recent (Avbovbo, 1978). Fig. 3 below presents the stratigraphy of Niger Delta basin.

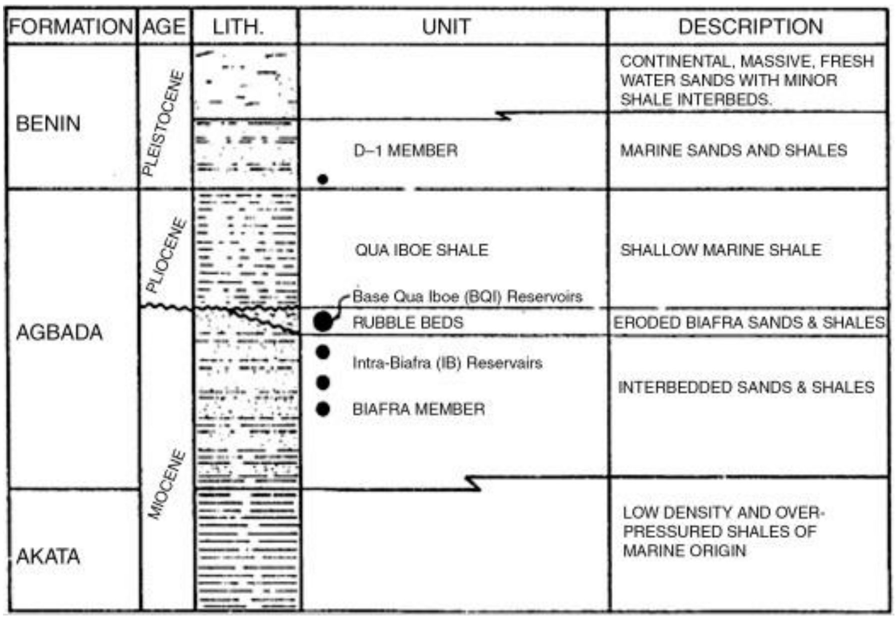

Figure 3: Stratigraphy of Niger Delta

3. Methodology

The well logs data used for this research were provided by IDSL Nigeria through the Department of Petroleum Resources (DPR). The logging contractor acquired MWD/LWD in the two (2) wells available; these are, Oredo-1 and Oredo-2. The well logs comprise gamma ray, resistivity, P-wave sonic (V_p), density (r), caliper, water saturation (S_w) and volume of shale (V_{sh}). The Well data were used to describe the lithology, fluid content, fluid contact and porosity (φ), Logs acquired such as GR, NEUT, RES AND DEN etc. are all in LAS format. The complete suite of logs acquired in this field is listed in table 1 below,

Table 1: Log availability

WELL	CALI	DT	GR	ILD	LLD	LLS	MSFL	CNL	FDC	SP	TEMP	SN
OREDO 1	√	√	√	√	√	√	√	√	√	√	√	√
OREDO2	√	√	√	√	√	√	√	√	√	√	√	√

3.1 Data Loading/QC

The data were first subjected to quality check, the two (2) well logs from Oredo-1 Well and Oredo-2 Well were imported respectively from project data file. After importation, both well logs were scanned and quality checked (QC) for any inconsistencies, editing and normalization. They were subsequently loaded. The Neutron log (CNL) was converted from porosity unit (pu) to decimal (dec). The well tops alongside deviation data were imported consequently deriving TVDSS and TVD from them.

Table 2 below summarizes the petrophysical parameters used in the evaluation.

Table 2: Evaluation summary

Formation	A1000, A2000, A4000, A7000 & A9000
Depth Interval	2359-3690 mSS
Lithology	Sand/Shale sequence
Reservoir Fluid Types	Gas, oil &water
Porosity Model	$\frac{\rho ma - \rho b}{\rho ma - \rho fl}$
Vshale Model	$\frac{X}{a-(a-1)*X}$
Permeability Model	*Timur:* K= 10000(ϕ⁵)/Swir
Saturation Model	(a*Rw / (φm * Rt))

3.2. Determination of log Parameters

Cut-offs for porosity, volume of shale, and permeability were determined. This is imperative for accurately determining cut-off values to be used for generating reservoir parameters average. Water saturation cut-off could not be determined due to relatively few reservoirs. Porosity and volume of shale cut off were determined by plotting them against storativity (ϕ_T*thickness). The Average gross reservoir was obtained by arithmetic averaging based on available gamma ray (GR) log. Average net reservoir was obtained by arithmetic averaging of gamma ray (GR) and resistivity (ILD) where available. Permeability across pay zones was obtained by arithmetic averaging of well data.

The Volume of shale was estimated from GR log. A histogram plot of GR log was used to determine clean sand GR values and shale GR values. Volume of shale log was created using Stieber (a=2) algorithm.

In determining the effective porosity, Formation density log was used. The total porosity (PHIT) was first determined, then the software provided the derivative effective porosity (PHIE). In the software, a grain density of 2.65 g/cc, typical of Niger Delta and densities of 1.0 g/cc for water, 0.9 g/cc for oil and 0.6 g/cc for gas were used.

3.3 Water Saturation (S_W)

An estimation of resistivity of formation water R_W is required for calculating water saturation S_w. However, due to lack of formation fluid sample, R_W was calculated from Pickett plots of clean water bearing sands adjacent the hydrocarbon bearing reservoirs. The derived R_W was then used in zones of interest to calculate S_W. True formation resistivity R_t was derived from ILD log. Pseudo PHIT log was generated from PHIT_D and GR logs relationship (PHIT=0.318326-0.00113883*GR). Pseudo PHIT log was spliced with PHIT_D to create a single log that runs throughout the wells. Consequently, S_W was then estimated using Archie's method. Figure 4 shows R_w in A7000 Oredo-1 Well and the average water saturation is shown in Table 3.

4. Results and Discussion

The Petrophysical analysis started with identifying the lithology, it was done and established from assessment of the well logs. From the well log in fig. 4 below, both Oredo-1 and Oredo-2 are composed of sandstones with intervals of shale and mudstone/siltstone. The wells penetrated Miocene strata of the oil producing Niger Delta oil Province. Table 3 summarizes both the estimated and the parameters used in the study.

Table 3: Estimated and Calculated Parameters used

Parameter	Description	Value	Source
ρma	Density of rock matrix	2.65	Niger Delta Average
ρb	Bulk density	Density log	PowerLog
`ρfl(gas)	Fluid Density	0.6	Niger Delta Average
ρfl(oil)	Fluid Density	0.9	Niger Delta Average
ρfl(water)	Fluid Density	1	Niger Delta Average
R_w	Formation Water Resistivity	0.19-0.24 ohmm	PowerLog: Pickett Plot
R_t	Formation Resistivity	Deep Resistivity Log (ILD)	PowerLog
a	Tortuosity Factor	1	Niger Delta Average
m	Cementation Factor	2	Niger Delta Average
n	Saturation Exponent	2	Niger Delta Average
ϕ	Porosity Cut-off	≥ 0.1	Sensitivity Analysis.
Vshale	Vshale Cut-off	≤ 0.5	Sensitivity Analysis.
S_w	Water Saturation	≤ 0.8	Sensitivity Analysis.
Perm	Reservoir Permeability	≥ 1	Niger Delta Average

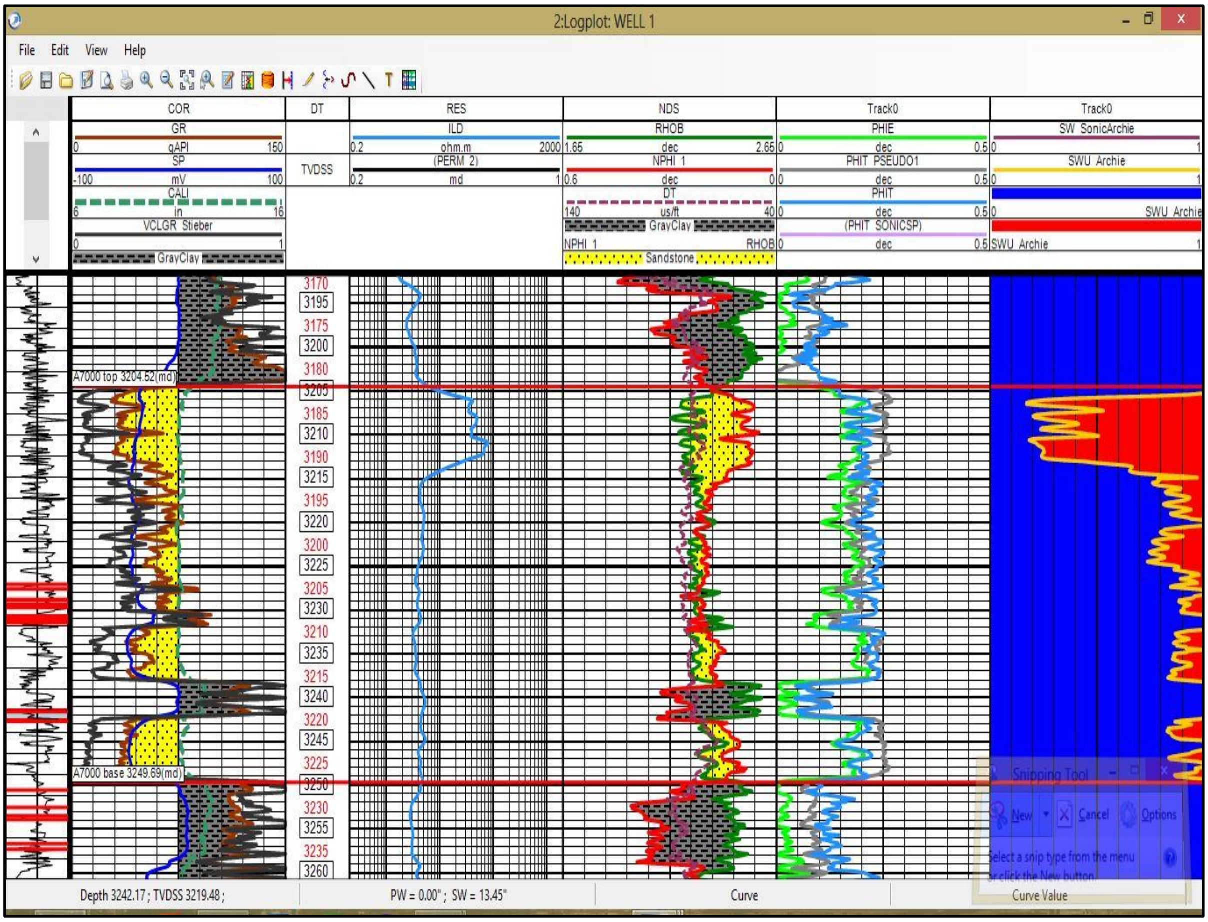

Figure 4: Log from OREDO-1 Well A7000 showing reservoir thickness, resistivity, fluid type, porosity and water saturation

4.1 Fluid Type and Contact

Fluid identification was carried out in both Oredo-1 and Oredo-2 using deep resistivity log (ILD) beginning with A7000 in well 1 until all hydrocarbon bearing intervals were identified. The Fluid contacts were established from density and neutron logs. A summary of fluid type/contact and average distribution plot is presented in Table4 and figure 5 respectively.

Table 4: Fluid Type and Contact Summary

Reservoir	Contact Type	Fluid Contact m SS	Remarks
A1000	GWC	GUT @ 2359 GWC @2375	From Oredo-2 Well
A2000	OWC	OUT @ 2408 OWC @2412	From Oredo-2 Well
A4000	GWC	GUT @ 2462 GWC @ 2467	From Oredo-2 Well
A7000	GWC GOC OWC	GUT @ 3182 GWC @ 3193 GUT @ 3059 GOC @ 3065 OWC @ 3073	From Oredo-1 Well From Oredo-1 Well From Oredo-2 Well From Oredo-2 Well From Oredo-2 Well
A9000	ODT	OUT @ 3672 ODT @ 3690	From Oredo-1 Well

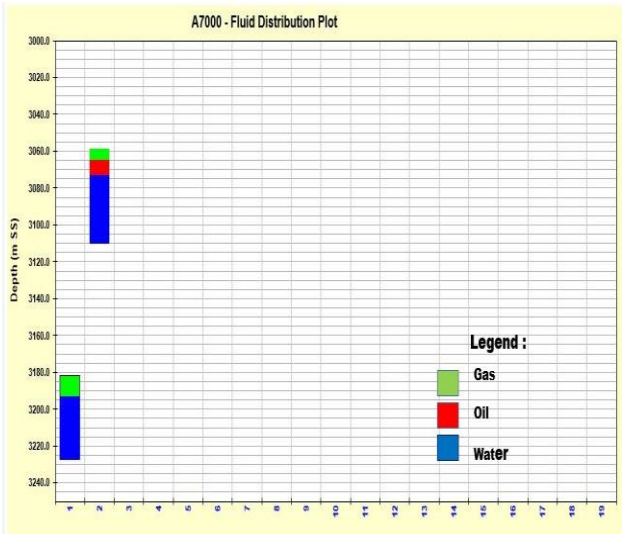

Figure 5: A7000 fluid distribution plot

4.2 Volume of Shale

Volume of shale was estimated from GR log. A histogram plot of GR log was used to determine clean sand GR values and shale GR values. Stieber (a=2) algorithm best suit the model in creating the Volume of shale log using the powerLog software. In the two wells, most of the reservoirs indicated a very low Vshale cut-offs, implying the sands are clean, even though the cut-offs do not represent the entire field. Low shale content occurrence recorded within these reservoirs indicates the presence of hydrocarbon reservoir, which is very clean. The resistivity log captured by the log in fig. 4 confirms the accumulation of hydrocarbon as high resistivity values of 1100 Ohmm was noted. The reservoir is capped by approximately 50m thick layer of shale, that began at 3170m and end at 3202m in the well as seen from the gamma ray log in fig. 4 above.

4.3 Water Saturation (S_W)

The Pickett plots of clean water bearing sands adjacent the hydrocarbon bearing reservoirs is shown in fig. 6 below. From the figure, the derived resistivity of water R_W from the ILD log is 0.18. With this value from Pickett plot, the software permits the derivation of True formation resistivity R_t from ILD log. The generated Pseudo PHIT log from PHIT_D and GR logs relationship was PHIT=0.318326-0.00113883*GR. Fig. 6 isthe Pickett plot showing R_w value of 0.18 in A7000 Oredo 1.

The average water saturation data is shown in Table 5 below.

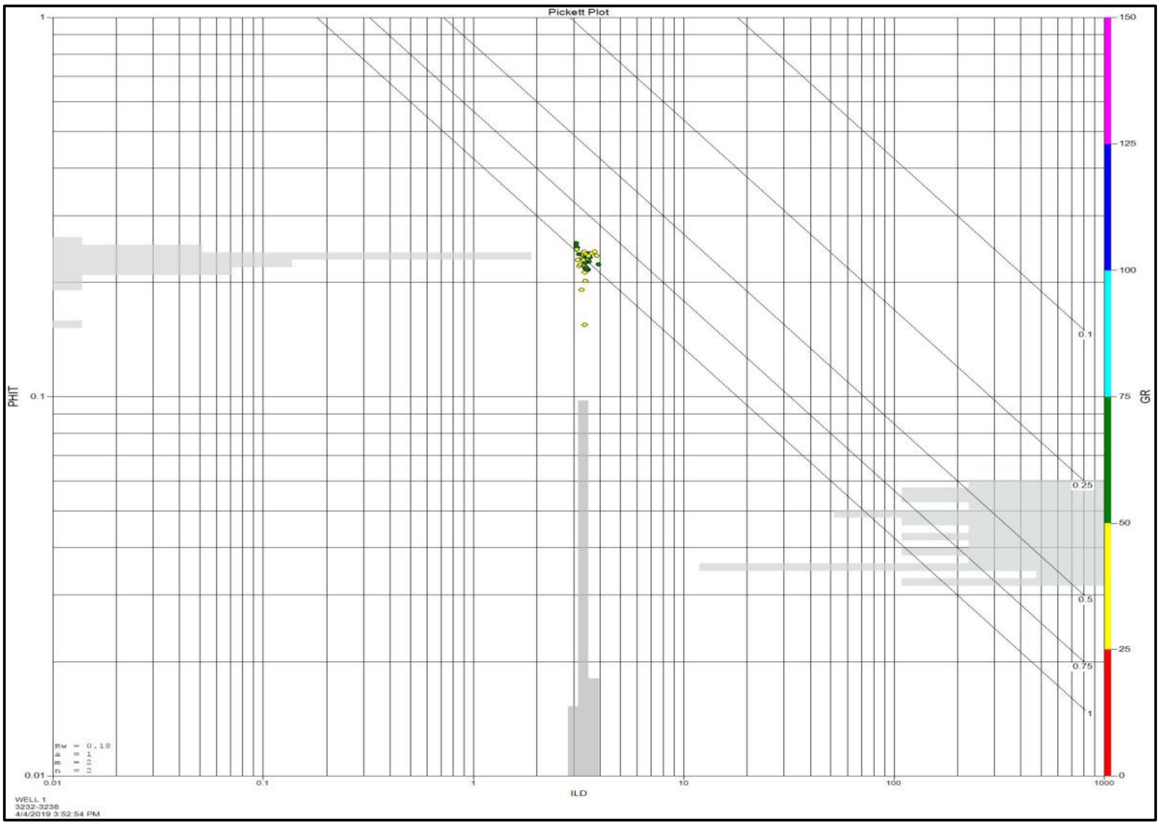

Figure 6: Oredo-1 Well Pickett plot showing R_W = 0.18 in A700

4.4 Permeability (K)

Even though estimation by poro-perm relationship is usually the most preferred method calculating permeability. However, there is no core data available for this study. Therefore, empirical formula that was used to calculate permeability in reservoirs of interest is the Timur's permeability formula. Irreducible water saturation for each hydrocarbon-bearing reservoir was determined by assuming the lowest water saturation as the irreducible water saturation. Average permeability across all hydrocarbon-bearing intervals are presented in Table 5 below.

4.5Average Reservoir Parameters

Table 5: Average reservoir parameters across the wells

Reservoir	Gross Res (m)	Net Res (m)	N/G (frac)	Porosity (%bv)	VSh (%)	S_w (%pv)	Permeability (md)
A1000	20.91	20.91	1	23	11	51	141.70
A2000	6.28	6.28	1	24	13	69	133.57
A4000	7.88	7.88	1	25	8	77	236.82
A7000	48.03	38.82	0.81	19	21	87	49.77
A9000	17.04	14.15	0.83	14	11	54	27.22

Table 5 shows all the average reservoir parameters in the hydrocarbon-bearing intervals encountered. From table 5 above the net reservoir thickness is nearly the same as the thickness of the gross reservoir. It is only the deeper portion beyond the A7000 accounted for the variation in the two thicknesses. The permeability of the reservoir is ranges from 27.22md to 236.82md, which implies good permeability condition. Porosity values within the sandstone reservoir is fairly uniform and the average effective porosity from the wells ranges from 0.14 to 0.25 implying fairly good porosity condition for commercial accumulation of hydrocarbon.

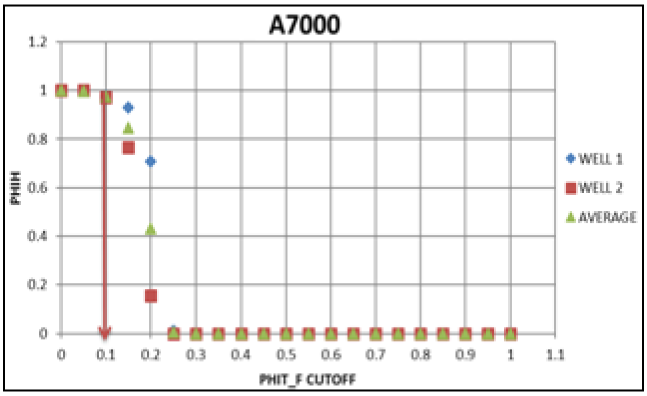

Figure 7: Storativity (PHIH) and porosity (PHI_F) plot showing porosity cut-off at 0.1 (red arrow) for A7000

5. Conclusion

The 'Oredo' field petrophysical logs were interpreted using PowerLog software. Reservoir parameters; porosity, volume of shale, water saturation, net-to-gross etc. were calculated using modules and equations provided within the PowerLog software. The study revealed almost exclusively clastic sequences of deltaic to fluvial deposits as major constituents of the reservoir rock. Log signals have also revealed the presence of marine sandstone and shale. These deltaic sequences are characterized by Syn-depositional signals such as the relatively gently folded anticlines, growth faults and rollovers. Six discrete reservoirs were encountered by the two wells in the 'Oredo' field. Generally, the encountered reservoirs are of good quality with good porosities ranging between 0.14 and0.25 running vertically across reservoirs. Permeability in the hydrocarbon-bearing reservoirs encountered falls between 27 and236 md aptly suggesting good reservoir permeability condition.

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