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ORIGINAL ARTICLE

Evaluation of Shale Effect on Saturation Exponent from Well Logs in an Offshore Field, Niger Delta.

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ABSTRACT

Hydrocarbon recovery is subject to various elements set to validate not only the availability of the type of fluid present at the subsurface, but also how saturated is the host rock with the fluid. A study on saturation was carried out on the hydrocarbon locked in reservoirs of the N-1 and D-1 wells. The water saturations were determined using various saturation equations by various authors from literatures. This evaluation led to the determination of the permeability of the reservoirs through the Timur equation and the values were within the range 222.8mD-2518.5mD in well N-1 and 434.4mD-2534.3mD in well D-1. The 7 pay zones of both wells showed a high correlation based on the petrophysical parameters which could be the basis of a conclusion of lateral continuity across the reservoir although the formations interpreted are characterized by clay fingering. An analysis carried out for the determination of the permissible range of the saturation exponent 'n' used and assumed as 2 which agrees with that in the basic Archie equation, but for the BOD-1b zone of D-1 with both values 1 and 2 perfectly matching.

Key words: Saturation, permeability, correlation, formations

Introduction

Generally, well logs provide a good estimate of porosity and saturations along the wellbore, but permeability is more difficult to obtain with an appreciable data with areal coverage Lenormand, and Fonta, (2007). However data from core samples and seismic volume could do justice to this evaluation. Formation evaluation is better based on logs with the help of side wall samples and wireline formation tests (Schlumberger, 1985). Saturation equations are developed models used to determine the water saturation in a zone based on the type of lithology. The Archie (1950) equation is based on the assumption that the zone is a clean sand formation, and it is therefore used on basic analysis. According to Ellis & Springer (2008), the equations are classified into two groups based on the parameters taken into consideration. The assumptions are as follows, firstly that the laminated sands which have sands and clays conduct independently, and secondly that clean shaly sands occurrence is present. The various saturation models were taken into consideration in the light of the above stated facts. Saturation exponents were varied for the models and a critical query was done to validate which exponent value will be appropriate for the two typical units that are often encountered in clastic reservoirs. The permeability of a rock is one of the most important parameter in reservoir characterization and management (Bloch, 1991), and for the purpose of this study, for consistency, the Timur (1968), model for permeability was adopted. All the Water Saturations calculated from the saturation equations was used to develop the different permeability curves which was used to define the best saturation equation that best models the field.

The utilized methodology in the study is generally based on industry standard practices, tested and have been used for various years in the Petrophysics industry. Although a few modifications were developed in the

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determination of some parameters, these were borne from basic assumptions to generate these logs. The methodology defines the process for petrophysical parameter evaluation in the absence of comprehensive well logs. And the objective of the study is to determine the range for the permissible value for the Water Saturation exponent 'n' for the reservoirs located from the well logs.

Materials and Methods

Quantitative evaluation and interpretation of data for reservoir characterization involves the integration of rock physics models, well data, seismic data and geological information to predict reservoir properties, be they rock, or fluid properties. According to Honarpour et al (2008), rock characterization involves quantification of porosity, permeability, capillary pressure, and relative permeability associated with various recovery processes. Reliable data acquisition requires a multidiscipline approach with experts to ensure rigorous steps during sampling and measurement stages while making use of company or industry databases as resources. Basically, the dataset used for this study are well logs amidst some other supporting data such as deviation data, and field and logging information. The wells used are located on the off shore depobelt of the petroliferous Niger Delta (figure 1).

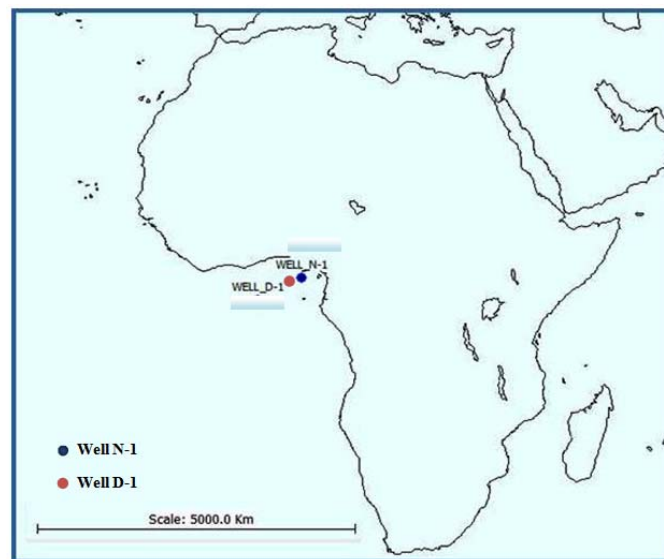


Fig. 1: Basemap of the study area showing location of wells.

Lithology identification was carried on the available Gamma Ray logs. Firstly, the logs are analyzed for inconsistency, and the log headers are reviewed to have the knowledge of the logging conditions, parameters and specifications. The various corrections were taken into consideration and adequately taken care of by the software used so as to obtain reasonable and accurate information.

The porosity logs used are the FDC/CNL log responses and they both serve as the basis for the various deduction. Observation and conclusions made stepped from results derived from the use of data extract of saturation for the various models worked with (figures 2 - 7). Hydrocarbon Identification in the oil industry is usually carried out using a combination of logs. The most common combination used is the density-neutron log interaction. The separation between these logs when plotted on the same log track is used to identify fluid type. The presence of hydrocarbon in the formation results in a decrease in density and an increase in the hydrogen index. Because of the densities, the separations of different fluid types will vary, such that the separation of gas is more than that of oil, and that of oil is greater than that of water (Ellis & Singer, 2008). The main parameter used for analysis of hydrocarbon saturation is resistivity of water (R_w) at that depth. R_w was determined in the uninvaded zone first, from where the water saturation (S_w) was then be determined from the R_w and then the S_{hc} was then determined.

Results and Discussion

Evaluating the potential pay zone reservoir unit BON-1a zone was initially based on the traditional sudden change of lithology logs signatures. The other indicators were the GR, Neutron Density overlay and Resistivity

logs with a cut-off of less than 65 GAPI, the separation between overlay and a resistivity of above 100 ohms (figure 2). The porosity values showed potential with a cut-off of 0.1p.u. The water saturation was then developed for the zone and this is also favourable to be a pay zone as all the models deliver a $S_w < 0.5$ which is the cut-off utilized. The permeability of the zone was used to actually define it as a pay zone, and the value was observed to be greater than 100mD. The n-exponent analysis shows the assumed value 2 to be accurate for the zone.

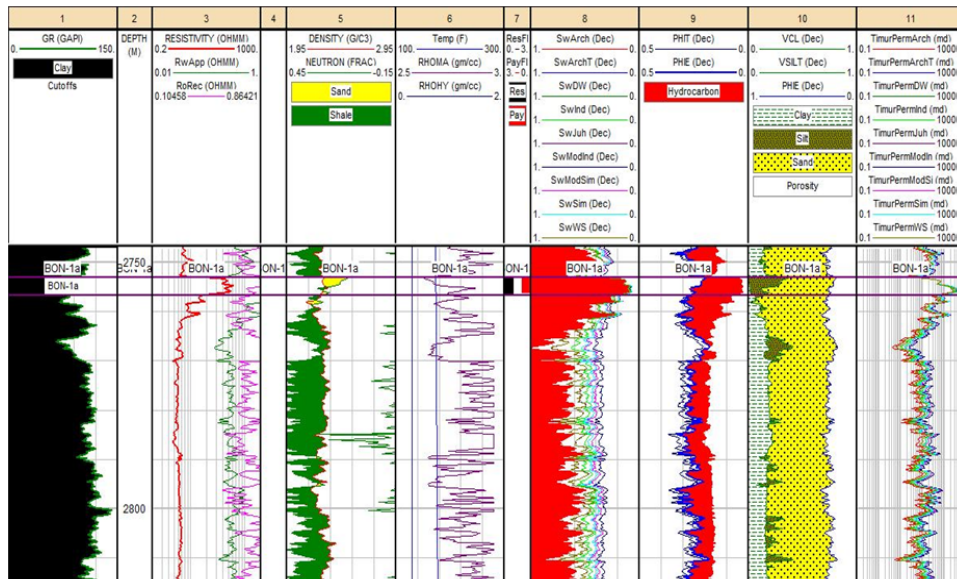


Fig. 2: Panel showing the composite log tracks generated for BON-1a zone

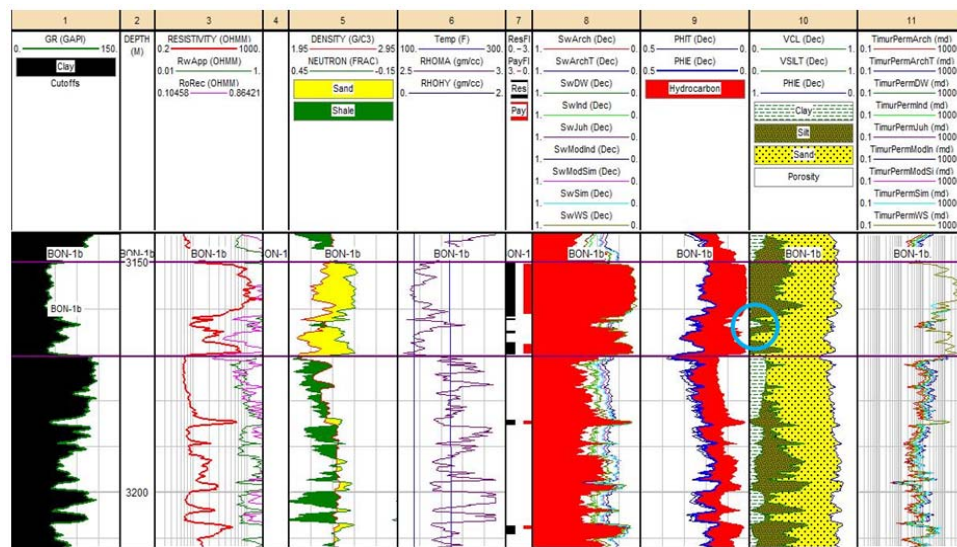


Fig. 3: Panel showing the BON-1b zone composite log tracks developed

Determination of the BON-1b zone as a potential pay zone was easier as it typifies a blocky upper portion and a seemingly fining upward lower part figure 2; the initial indicators were the GR, Neutron Density overlay and Resistivity logs with a cut-off of less than 65 GAPI, the separation between overlay and a resistivity of above 100 ohms. Although some shaly sand zones were located in the zone between 3162.6m - 3164.2m, the porosity values still showed potential with a cut-off of 0.1p.u. The shaly sands were defined using the volume of clay developed log. The water saturation developed for the zone makes it is also favourable to be a pay zone as all the models deliver a $S_w < 0.5\%$ which is the cut-off utilized. To validate this unit as a pay zone, the permeability of the zone was calculated to be above quite high Table 1. The n-exponent analysis of this zone shows the assumed value 2 to be accurate for the zone, but 1 gave the same results. This was due to the significant clay content present (blue ring) which does not conform to Archie's water saturation equation.

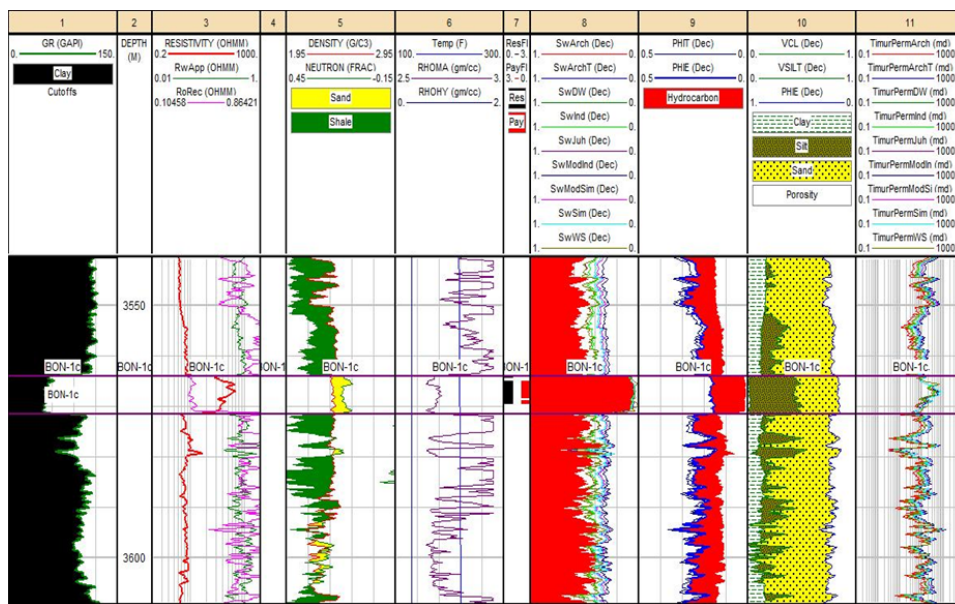


Fig. 4: Plot showing the final composite log tracks delineated showing BON-1c zone

In the BON-1c potential pay zone, the initial indicators that exemplifies reservoir candidates was adopted (figure 4). This unit is discovered to be 7.5m thick and hydrocarbon proficient. Petrophysical calculations showed porosity values (f) greater than 0.15 (Table 1). The water saturation developed for the zone proved favourable as all the models delivered a $S_w < 0.5\%$ which is the cut-off utilized. As a confirmation, the permeability of the zone was evaluated and found to be greater than 220mD on the average. The n-exponent analysis of this zone shows the assumed value of 2 to be accurate.

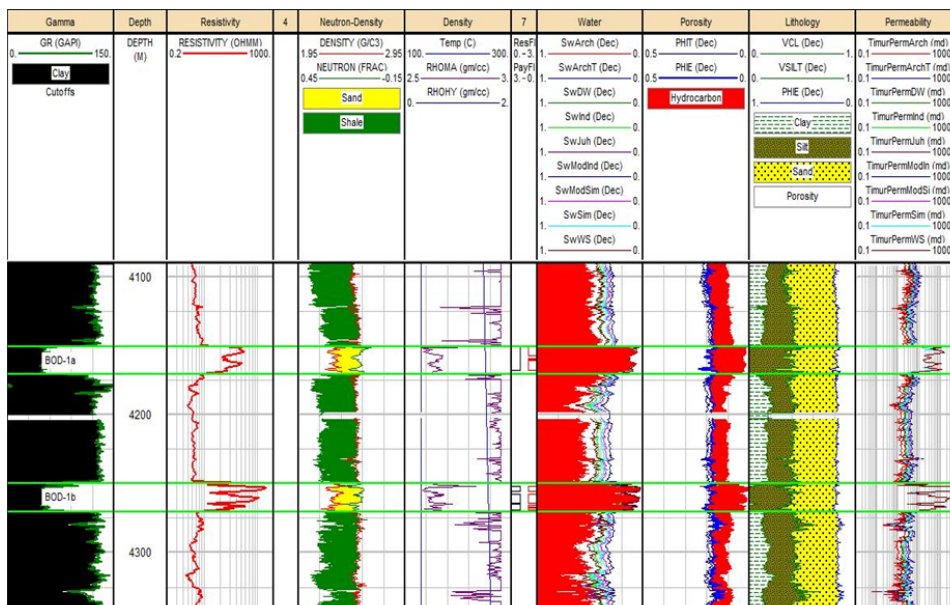


Fig. 5: Plot showing the final composite log tracks delineated showing BOD-1a and BOD-1b zones

Figure 5 shows a screen shot panel of interpretation carried out to determine the BOD-1a and BOD-1b zones as potential pay zones. GR log signatures are massive in the two zones with appreciable corresponding Resistivity log responses. Porosity values recorded are 0.18 and 0.19 respectively. On the various Saturation models, reservoir unit BOD-1a has a stable value of 0.107, which falls slightly below the BOD-1b value – 0.114. These values make these zones acceptable. It was observed that all average values are the same, showing no variation due to the water saturation models. To corroborate this permeability estimates made for

the reservoir unit BOD-1a has an average value of 590mD, which falls below the value for BOD-1b – 2534mD. These values make these zones acceptable. The n-exponent analysis of this zone shows the assumed value 2 to be accurate for the zone.

Table 1: Summary of tables showing averages of determined petrophysical parameters for Well N-1

Pay SUMMARY										
Zn	Zone Name	Φ_{avg}	Archie Model		Archie Total Model		Waxman-Smits Model		Indonesia Model	
			S_{wavg}	K_{avg}	S_{wavg}	K_{avg}	S_{wavg}	K_{avg}	S_{wavg}	K_{avg}
#			Ari		Ari		Ari		Ari	
1	BON-1a	0.212	0.123	665.343	0.12	719.204	0.12	720.646	0.122	679.261
2	BON-1b	0.206	0.072	2518.404	0.072	2524.454	0.072	2524.602	0.072	2520.128
3	BON-1c	0.167	0.126	222.839	0.116	262.017	0.116	263.037	0.123	231.964
		0.198	0.094	1583.75	0.089	1631.995	0.089	1633.572	0.093	1592.255
			Juhasz Model		Modified		Modified Simandoux		Simandoux	
					Indonesia Model		Model		Model	
Zn	Zone Name	Φ_{avg}	S_{wavg}	K_{avg}	S_{wavg}	K_{avg}	S_{wavg}	K_{avg}	S_{wavg}	K_{avg}
#			Ari		Ari		Ari		Ari	
1	BON-1a	0.212	0.12	720.646	0.117	810.179	0.116	859.162	0.116	855.289
2	BON-1b	0.206	0.072	2524.602	0.071	2534.104	0.071	2539.006	0.071	2538.516
3	BON-1c	0.167	0.116	263.037	0.103	335.61	0.097	389.366	0.098	386.239
		0.198	0.089	1633.572	0.084	1712.692	0.081	1768.489	0.081	1763.749

The Dual Water model and the Archie Total model give the same results; therefore the Dual Water model is not represented in the table above

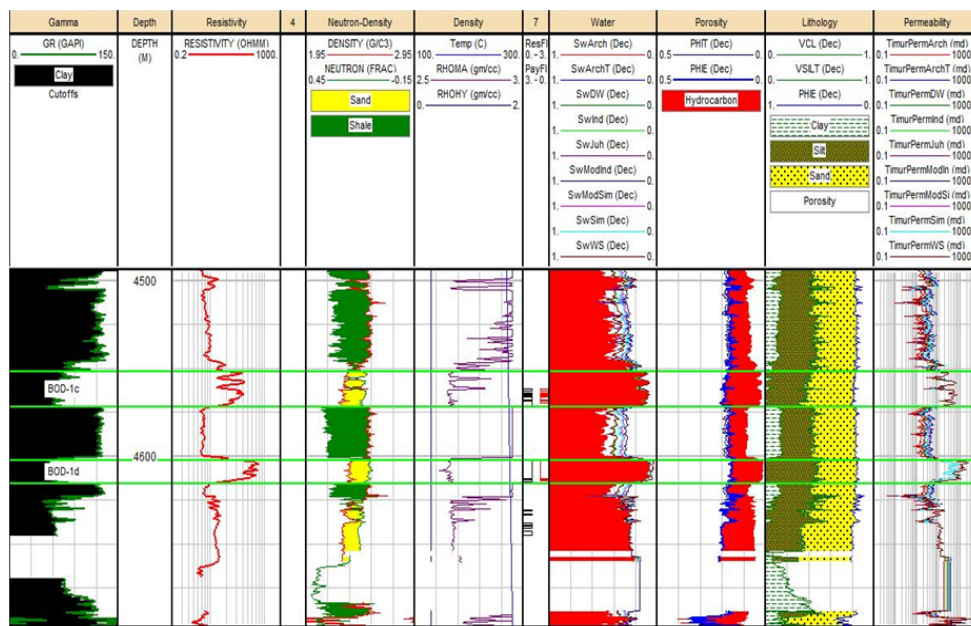


Fig. 6: Plot showing the final composite log tracks delineated showing BOD-1c and BOD-1d zones

A semi-blocky form typifies the units chosen as potential BOD-1c and BOD-1d reservoir units (figure 6). Petrophysical evaluations for porosity and permeability shows some level of dispersion as opposed to what was observed in the units interpreted above. Average Porosity value of 0.2 and 0.16 were respectively recorded. The water saturation developed for the zone confirms the viability of this pay zone as all the models deliver a S_w of < 0.3 (Table 2). Across both zones, all average values are the same, except the developed Waxman-Smits derived permeability which is ridiculously lower than the others showing the effect of the derived B in the equation. To underscore the above, the permeability of the zone calculated was found to be admissible as non fall below 400mD. The n-exponent analysis of both zones shows the assumed value 2 to be accurate for the zone.

BOD-1e zone is characterized by near massive bed signature with serrated upper portion as observed in the GR log. This potential pay zone was delineated some distance down-hole and it turned out to host water.

From the panel display in figure 7, and the 11th track, it is observed to be more silt than sandy and appreciable clay content was also recorded. However, porosity values showed little potential because it barely made the cut-off of 0.1p.u. The water saturation was then developed for the zone and this confirmed the absence of hydrocarbons because of the high water saturation of S_w of > 0.6 . The n-exponent analysis was not determined for this zone because the zone is of no importance in oil potential.

Table 2: Summary of tables showing averages of determined petrophysical parameters for D-1

Pay SUMMARY										
Zn	Zone Name	Φ_{avg}	Archie Model		Modified Indonesia Model		Modified Simandoux Model		Simandoux Model	
			S_{wavg}	K_{avg}	S_{wavg}	K_{avg}	S_{wavg}	K_{avg}	S_{wavg}	K_{avg}
#			Ari		Ari		Ari		Ari	
1	BOD-1a	0.184	0.107	590.016	0.107	590.016	0.107	590.016	0.107	590.016
2	BOD-1b	0.189	0.069	2534.345	0.069	2534.345	0.069	2534.345	0.069	2534.345
3	BOD-1c	0.195	0.114	513.726	0.114	513.726	0.114	513.726	0.114	513.726
4	BOD-1d	0.158	0.085	434.403	0.085	432.198	0.085	432.125	0.085	432.119
5	BOD-1e	---	---	---	---	---	---	---	---	---
		0.187	0.089	2088.029	0.089	2081.321	0.089	2081.319	0.089	2081.314
Waxman-Smits Model										
Zn	Zone Name	Φ_{avg}	S_{wavg}	K_{avg}						
#			Ari							
1	BOD-1a	0.182	0.104	601.86						
2	BOD-1b	0.189	0.069	2510.368						
3	BOD-1c	0.195	0.114	513.726						
4	BOD-1d	0.157	0.059	1019.051						
5	BOD-1e	---	---	---						
		0.186	0.082	2176.294						

The Archie, Archie Total, Dual Water & Indonesia models all give the same results; therefore they are not shown in the table

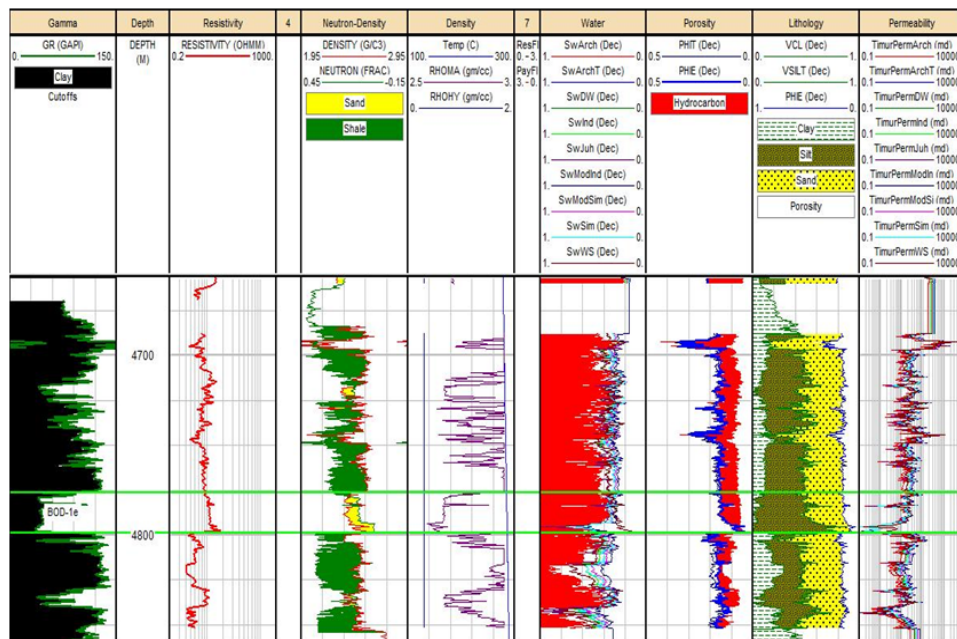


Fig. 7: Plot showing the final composite log tracks delineated showing BOD-1e zone

Saturation evaluation

Saturation exponent 'n' in Archie's water saturation equation is the exponent value in water saturation model. This establishes the relationship between water saturation of the rock to the ratio of fluid filled rock resistivity to the actual rock resistivity. Most theoretical derivations show that there is no exponent or that 'n' is equal to 1. However, decades of results from core analyses and open-hole log analyses show 'n' greater than 1 and most often assumed to be 2.

In practice, the n-exponent is based on various factors, one of which is rock type. The significance of n is proved, and its permissible range is evaluated. Hence, this interpretation has been effected on the reservoir candidates with not less than 70% sand constituent and proven to host hydrocarbon (i.e. BON-1a, BON-1d and BON-1b).

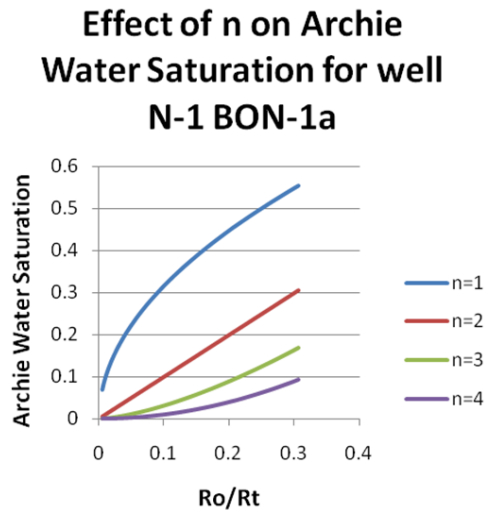


Fig. 8: Impact of n on calculated Archie S_w in BON-1a

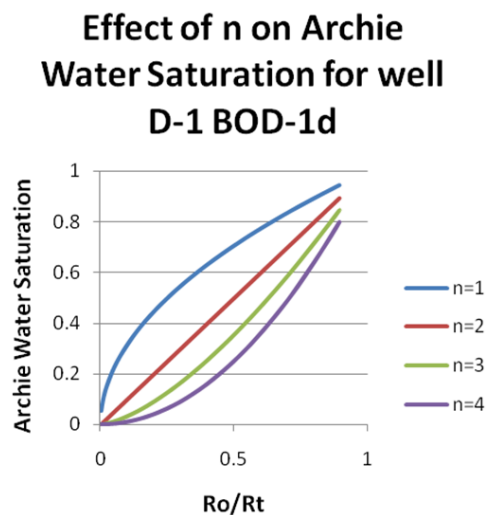


Fig. 9: Impact of n on calculated Archie S_w in BOD-1d

The plots in Figure 8 - 10 shows the various plots of the Archie water saturation vs. resistivity index. This plot is utilized to determine the appropriate n-exponent value to be utilized in the determination of R_w from the Pickett plot. The Figure 8 and 9 both follow the ideal Archie's n-exponent of 2 because the plot at n=2 gives straight lines which is an indication of the inverse relation of saturation and resistivity index. For BON-1a of well N-1, the saturation exponents n=1, and n=2 both give straight lines. This excludes the Archie ideal model from being completely correct for the well. The ideal saturation model is based on the formation being a clean sand formation. Therefore, the modified Archie model which has the n-exponent =1 is used showing the zone is a potentially shaly sand. This is confirmed from the Volume of Clay calculations which show all other formations having a $V_{cl}=0$ except that of BOD-1a with a V_{cl} of 0.2. This is signified by the blue ring shown in the log track 9 of the figure 3.

Conclusion:

The wells N-1 and D-1 has 7 potent hydrocarbon zones within the depths mapped, the sand zones are separated by shale's of different compositions. Porosity values inferred is between 0.15 and 0.2. A very high average permeability value of about 2500mD across the various water saturation models for well N-1

The well D-1 is a more composite lithological with the mapped formations revealing silt and clay intercalations in tandem with the sand. 4 potent zones identified along the well have an average of 24m thickness. The zone of high importance along well D-1 is the BOD-1b zone with averages of 0.189 as porosity, 0.069 as water saturation. The permeability determined from all the saturation models all give the same permeability values except the Waxman-Smiths Saturation equation which gave a permeability of 2510.4mD. Convolving these zones in terms of their intrinsic lithological types to test for the admissible saturation exponent value resulted in some agreement to the Archie 'n' value of 2 for BON-1a, BOD-1d and BOD-1b

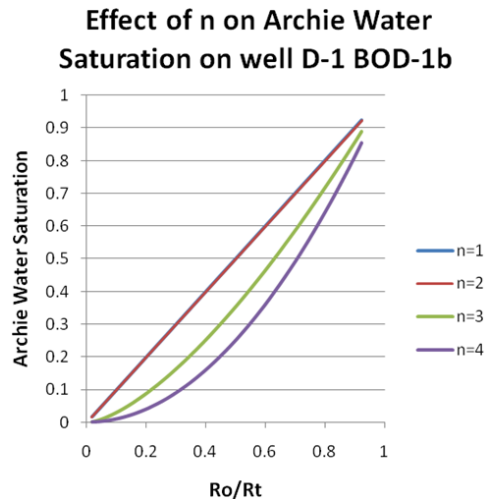


Fig. 10: Impact of n on calculated Archie S_w in BOD-1b

Acknowledgements

The authors would like to appreciate SNEPCO, for the release of data used for this study. The efforts of members of faculty in the Petroleum engineering department, covenant university is also valued.

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