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Enhanced Petrophysical Property Analysis and Characterization of Akos Field, Coastal Swamp Depobelt, Niger Delta, Nigeria

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Abstract Enhanced petrophysical property analysis and estimation have been successfully carried out using eight suits of composite well log data in Niger Delta field to assess the reservoir properties and hydrocarbon potentials of the field. Three zones of interest (Sand 1, Sand 2 and Sand 3) were delineated and correlated across the eight wells. The analysis of the well sections revealed that each of the sand units extends through the field and varies in thickness with some unit occurring at greater depth than their adjacent unit which possibly indicates an evidence of faulting. The petrophysical parameters calculated include total/effective porosity, water/hydrocarbon saturation, permeability, net-to-gross reservoir's thickness (netpay) and volume of shale. The petrophysical values obtained from the results were characteristic of the Niger Delta Formation and the reservoirs identified exhibited good qualities with Akos-004, Akos-010 and Akos-012 ST1 most outstanding. Generally we conclude that the hydrocarbon yield of the field is generally high, prolific and viable for production. This study also has proven that the estimation of petrophysical data is a key factor for effective productivity of hydrocarbons.

Keywords Reservoir rock, Petrophysics, Porosity, Permeability

Introduction

Petrophysical characterization is a key element in understanding reservoir rock properties, pore connectivity within the reservoir and also controlling the accumulation and migration of hydrocarbons trapped within the reservoir [1].

The petrophysical characterization of reservoir sands is achievable with the aid of petrophysical log interpretations [2]. These interpretations are very useful and important which enhances selection, planning and implementation and implementing operationally sound supplementary recovery schemes.

The petrophysical logs are normally used in exploration for correlation of sand bodies, isopach and structural mappings, for the determination of certain petrophysical properties of rock such as porosity, permeability, saturations, lithology identification and possibly pore geometry.

The evaluation of reservoir rocks in terms of their porosity, water saturation and permeability determinations, enhances the ability to predict abnormally pressured zones, 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 values [3-5].

Several authors made great contributions with respect to petrophysical characterization of reservoirs in the coastal swamp depobelts of the Niger Delta. [6] in their study posited that lithology and formation's depth of burial influences the petrophysical characteritics such as acoustic velocity, porosity density fluid content etc.

[7] in their study on the hydrocarbon characterization using well logs concluded that the improved quality of a reservoir is dependent on the increased porosity and permeability values (poroperm values)

Location and Geology of the Study Area

This study was carried out in the coastal swamp depobelt of the Niger Delta (Figure 1). The data (well logs and seismic volumes) used in carrying out this study is from a field codenamed AKOS located within the study area shown on the base map in (Figure 2). The Niger Delta forms one of the world's largest hydrocarbon provinces and it is situated on the Gulf of Guinea and extends through the Niger Delta provinces [8]. It covers an area within longitude 4°E - 9°E and latitudes 4°N - 9°N. It is composed of an overall regressive clastic sequence, which reaches a maximum thickness of about 12km [9]. From Eocene to the present, the Delta has prograded southwards, forming depobelts that represent the most active portion of the delta at each stage of its development [10]. These depobelts form one of the largest regressive deltas in the world with an area of about 300,000 km^2 [11] a sediment volume of about 500,000 m^3 [12] and a sediment thickness of over 10 km in the basin depocenter [13]. The Niger Delta province has been identified to have only one petroleum system referred to as the tertiary Niger Delta (Akata – Agbada) petroleum system [14].

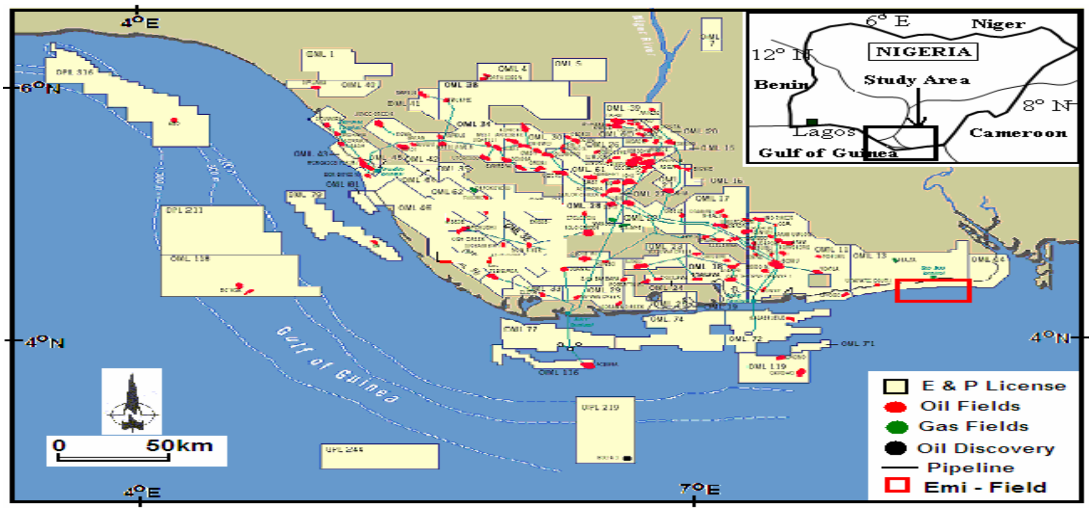

Figure 1: Location of the Field in the Niger Delta [2]

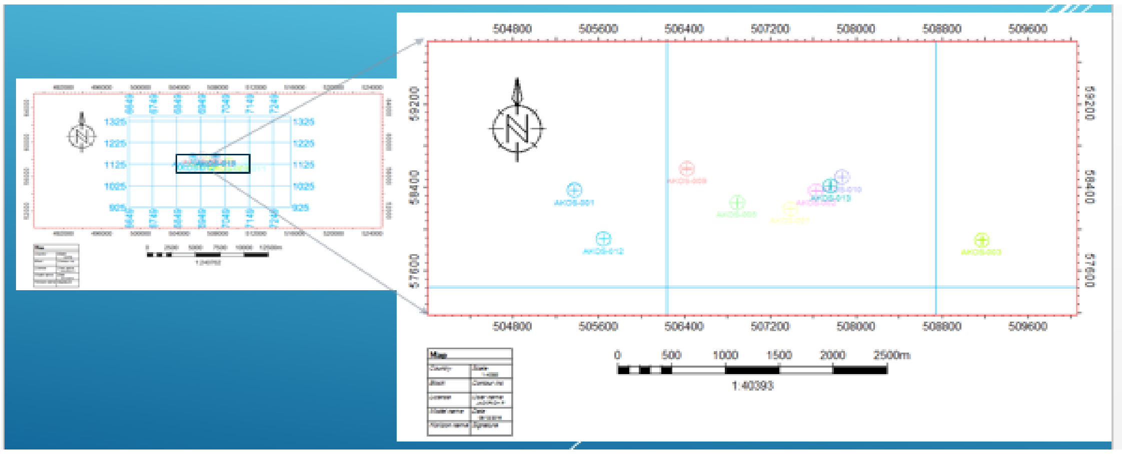

Figure 2: Base Map showing well position in the field

Materials and Methods

The study methodology focuses on carrying out a comprehensive examination on petrophysical analysis to determine the porosities, saturations, permeabilities, net thickness toreservoir's gross thickness and shale volume. Eight composite well logs AKOS-001, AKOS-002, AKOS-004, AKOS-007, AKOS-008, AKOS-009, AKOS-010, and AKOS-012ST1 was used for the study in determining the petrophysical parameter of interest within the study area.

Delineation of Reservoirs

The first step is usually mapping the zones of interest representing the producing interval using the resistivity log, gamma ray log, porosity, water saturation curves in the wells. This is based on the principle that logs respond in a unique way due to different lithologies. Gamma ray logs was used to delineate shale/sand lithologies. High gamma ray value indicates shale lithology. Shale lithologies cause the deflection of acoustic impedance curve to the right and resistivity to the far left due to its high conductive nature. Low gamma ray, high resistivity, and water saturation mapped as sand lithologies. Shale volume logs represent the volume fraction as measured or inferred from formation properties. It can be calculated from gamma–ray log. The purpose of this is to obtain the reservoirs that have relatively thick depth which used for further characterization.

Estimation of Formation Parameters

The petrophysical parameters include Volume of shale, Total/Effective Porosity, Water/Hydrocarbon Saturation and Permeability. The various models used are shown below:

Volume of Shale (Vshale)

Vshale is derived from the gamma ray log first by determining the gamma ray index I_{GR}

$I_{GR} = (GR_{log} - GR_{min}) / (GR_{max} - GR_{min})$ (1)

Where I_{GR} = gamma ray index;

GR_{log} = gamma ray reading of the formation;

GR_{min} = minimum gamma ray reading (sand baseline);

GR_{max} = maximum Gamma ray reading (shale baseline)

We applied theLarionov's (1969) volume of shale formula for tertiary rocks was used.

$V_{sh} = 0.083(23.7*I_{GR} - 1)$ (2)

Where V_{sh} is the percentage of shale in the formation.

Total Porosity

This was calculated from density porosity log using the equation:

$$\mathbf{\Phi_T} = \frac{\rho_{ma}-\rho_b}{\rho_{ma}-\rho_f} \quad (3)$$

Where ρ_{ma} = matrix density which is taken to be 2.65g/cc for sandstones [4]

ρ_b = Bulk density read directly from the log

ρ_f = The fluid density which is taken to be 1 for gas and 0.87 for oil.

Effective Porosity

This is usually based on an adjustment of total porosity by means of estimated shale volume (content).

$\emptyset_{eff} = \emptyset_T - [\emptyset_{sh} * V_{sh}]$ [4] (4)

Where

$\emptyset_{eff}$ = effective porosity, $\emptyset_T$ = total porosity, $\emptyset_{sh}$ = log reading in a shale zone and V_{sh} = volume of shale.

Formation Factor, Water Saturation and Hydrocarbon Saturation

The formation factor was determined by Archie equation, 1942.

$F = \frac{a}{\Phi^m}$ [15] (5)

Where F is formation factor, Φ = porosity, a = constant (Tortuosity) which is taken as 0.62, m = cementation exponent which is 2 for sands.

The water saturation S_w for the uninvaded zone was determined using the Archie equation:

$S_w^2 = \frac{F*R_w}{R_t}$ [15] (6)

Also,

$F = \frac{R_0}{R_w}$ (7)

Therefore,

$$S_w^2 = \frac{R_o * R_w}{R_w * R_t} \quad (8)$$

$$S_w = \sqrt{\frac{R_o}{R_t}} \quad (9)$$

S_w = water saturation of the uninvaded zone
R_o = Resistivity of formation at 100% water saturation
R_t = True resistivity of the formation.
F = formation factor

Hydrocarbon saturation S_h is given as

$$S_h = (100 - S_w)\% \quad (10)$$

$$S_h = 1 - S_w \quad (11)$$

Permeability and Irreducible Water Saturation

Permeability is related to porosity but not always dependent on it. It is controlled by the connected passages of the pores space (pore throats) [16]. It is measured in darcies or millidarcies. The permeability, K was calculated from the equation:

$$K = \left[\frac{250 * \emptyset^3}{S_{wirr}}\right]^2 \quad (12)$$

Where S_{wirr} = Irreducible water saturation

Irreducible water saturation is also known as critical water saturation which defines the maximum water saturation that a formation with a given permeability and porosity can retain without producing water.

$$S_{wirr} = \sqrt{\frac{F}{2000}} \quad (13)$$

Where F = formation factor and

$$F = \frac{0.81}{\emptyset^2} \quad (14)$$

Net/Gross Reservoir Thickness

The gross reservoir thickness H was determined by looking at tops and bases of the reservoir sands across the well. The net thickness which is the thickness of the reservoir was determined by defining basis for non-reservoir and reservoir sands using the gamma ray log. Hence, net reservoir thickness was obtained for all the reservoirs in the well thus:

$$h = H - h_{shale} \quad (15)$$

Net/Gross = h/H

Where H = Gross reservoir thickness, h = Net reservoir thickness and h_{shale} = Shale thickness

Results and Discussion

This section focuses on the presentation of a detailed result of petrophysical characterization within the study area.

Petrophysical Study

The petrophysical study was necessary to provide a comprehensive delineation of the reservoir in the study area and also to derive petrophysical properties using the well logs. These properties include, porosities, permeabilities, saturations (hydrocarbons and water saturations) net-to-gross reservoir thickness etc. The well logs used for the analysis include calliper, gamma ray, resistivity, density, P-wave for Akos-001, Akos-002, Akos-004, Akos-007, Akos-008, Akos-009, Akos-010 and Akos- 012 STI. The top and base of the identified reservoir of interest are presented in Table 1.

Three reservoirs (1, 2 and 3) were delineated for the studied wells. The curves of the various calculated petrophysical properties (gamma ray index, resistivity. Net-to-gross NTG, volume of shale, total/effective porosity, water saturation and permeability for eight wells are shown in Figures 1 to 8. After the wells were delineated, petrophysical properties were evaluated on each of the reservoirs.

Figure 9 shows the litho-stratigraphic correlation which provides information relating to various strata of the field of study.

Table 1: Reservoirs of Interest for Akos-001, 002, 004, 007, 008, 009, 010 and 012 ST1

Wells	Reservoir Name	Top MD (ft)	Base MD (ft)	Thickness (ft)
Akos-001	Sand 1	6113	6555	442
	Sand 2	6989	7801	812
	Sand 3	9713	10397	684
Akos-002	Sand 1	6277	6827	550
	Sand 2	7113	7667	554
	Sand 3	9411	10010	599
Akos-004	Sand 1	5309	6101	792
	Sand 2	7052	7525	473
	Sand 3	8266	9009	743
Akos-007	Sand 1	6352	7200	848
	Sand 2	7250	7808	558
	Sand 3	9390	9912	522
Akos-008	Sand 1	6428	7113	685
	Sand 2	7157	8740	1583
	Sand 3	10516	11022	506
Akos-009	Sand 1	6452	7223	771
	Sand 2	7257	7830	573
	Sand 3	9353	9754	401
Akos-010	Sand 1	6413	7040	627
	Sand 2	7194	7738	544
	Sand 3	9473	9813	340
Akos-012 St1	Sand 1	6402	7054	652
	Sand 2	7152	7752	600
	Sand 3	9308	9851	543

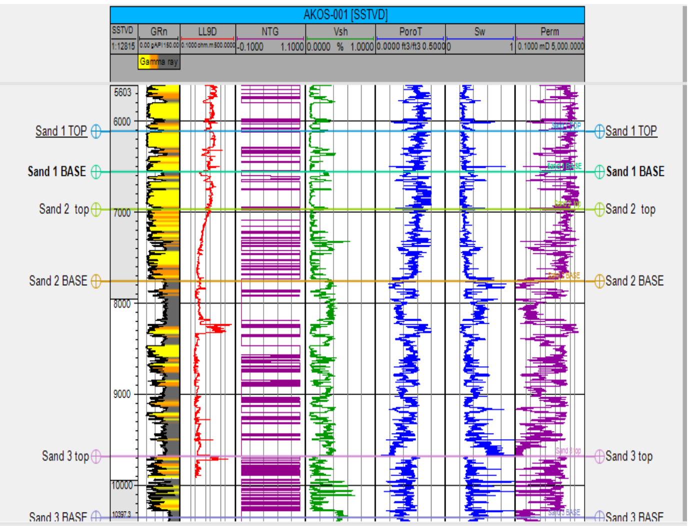

Figure 1: Akos-001 Log Curves of the Calculated Petrophysical Properties

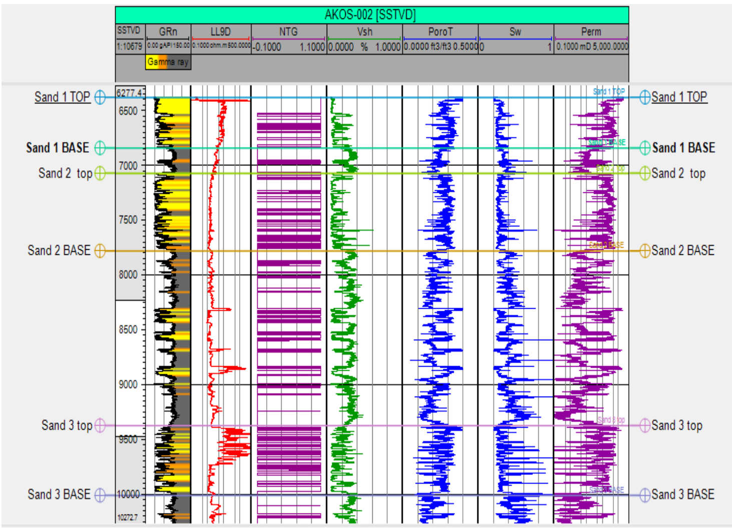

Figure 2: Akos-002 Log Curves of the Calculated Petrophysical Properties

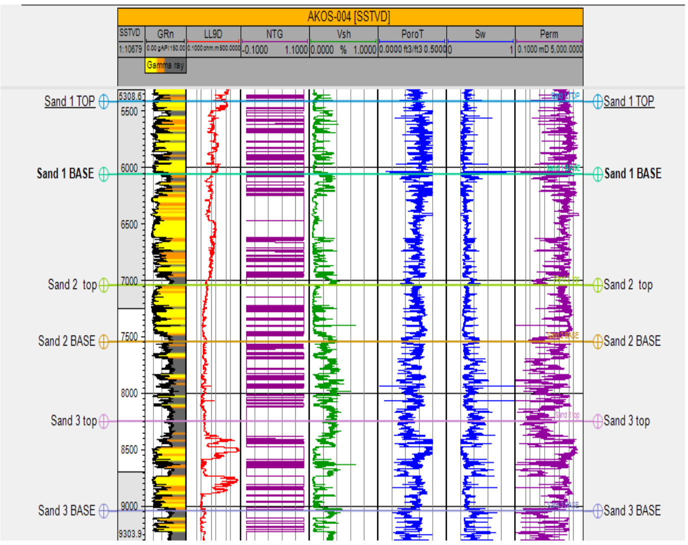

Figure 3: Akos-001 Log Curves of the Calculated Petrophysical Properties

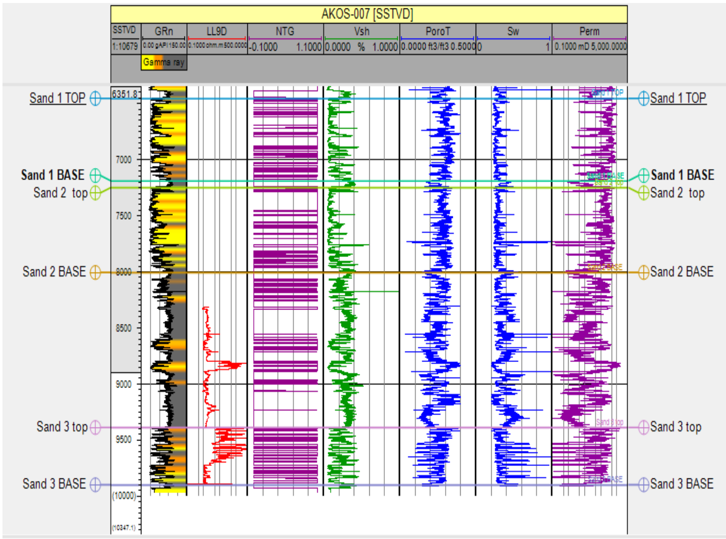

Figure 4: Akos-002 Log Curves of the Calculated Petrophysical Properties

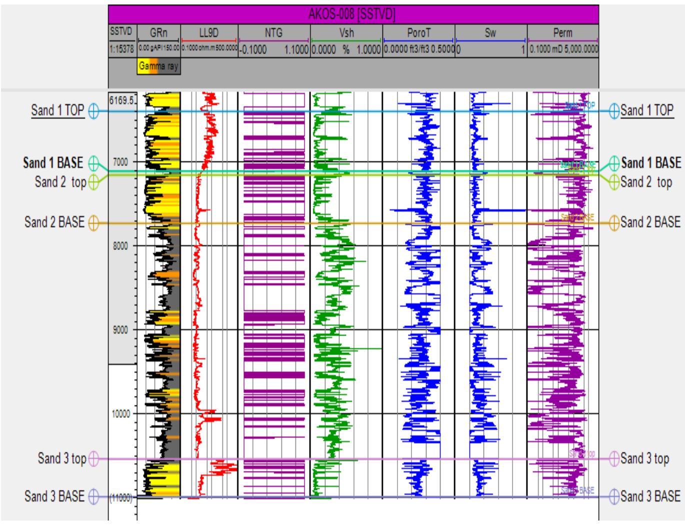

Figure 5: Akos-001 Log Curves of the Calculated Petrophysical Properties

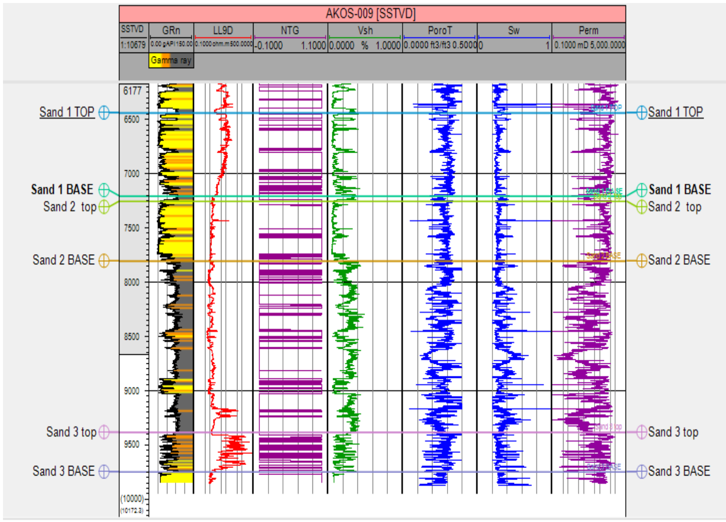

Figure 6: Akos-002 Log Curves of the Calculated Petrophysical Properties

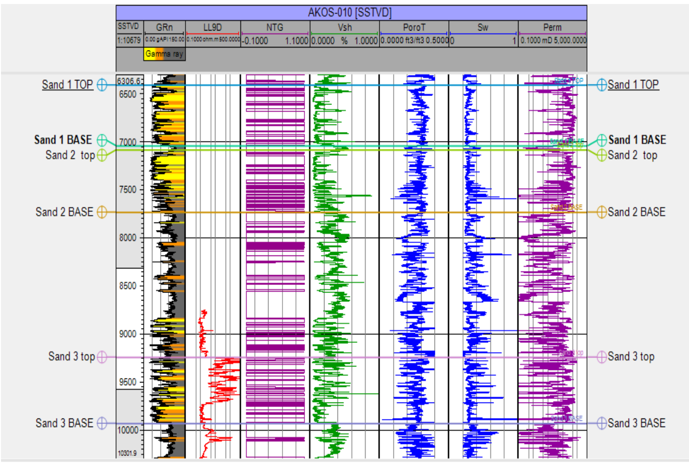

Figure 7: Akos-001 Log Curves of the Calculated Petrophysical Properties

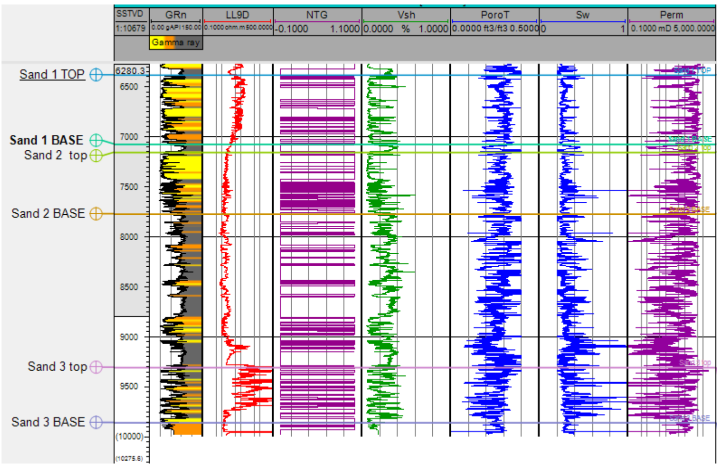

Figure 8: Akos-002 Log Curves of the Calculated Petrophysical Properties

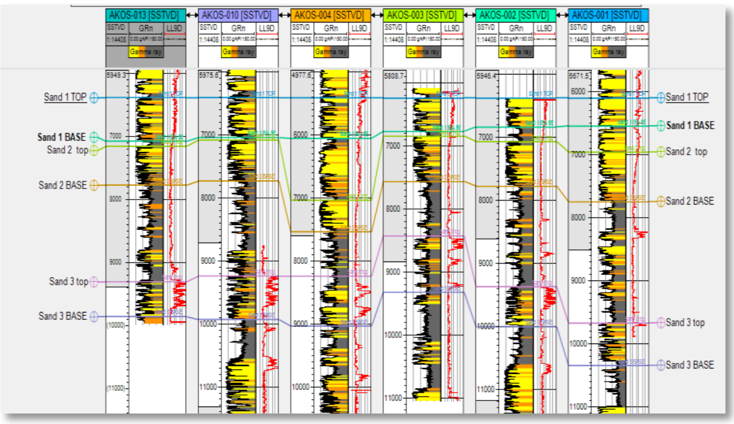

Figure 9: Lithologic Correlation showing Delineated Reservoirs at various depth

Average Petrophysical Properties

After computation of various petrophysical parameters from the well logs to characterize the hydrocarbon reservoirs in the formation of interest which are associated to hydrocarbons within the formation, the averages of the estimated results for each reservoir were obtained and presented in Table 2.

Table 2: Average petrophysical properties for the Akos Field

Reservoir Name	Top ft MD	Base ft MD	NTG	Volume of Shale	Φ_T (frac)	Φ_{eff} (frac)	S_w (frac)	S_h (frac)	K (mD)
AKOS-001									
Sand 1	6113	6555	0.67	0.25	0.26	0.20	0.32	0.68	151
Sand 2	6989	7801	0.67	0.14	0.28	0.24	0.29	0.61	166
Sand 3	6113	6555	0.67	0.25	0.26	0.20	0.32	0.68	151
AKOS-002									
Sand 1	6277	6827	0.92	0.12	0.27	0.26	0.29	0.71	219
Sand 2	7113	7667	0.45	0.21	0.25	0.23	0.35	0.65	141
Sand 3	9411	10010	0.82	0.25	0.24	0.19	0.37	0.64	264
AKOS-004									
Sand 1	5309	6101	0.80	0.12	0.36	0.31	0.29	0.61	545
Sand 2	7052	7525	0.86	0.09	0.39	0.30	0.28	0.62	433
Sand 3	8266	9009	0.90	0.24	0.33	0.30	0.30	0.70	208
AKOS-007									
Sand 1	6352	7200	0.55	0.19	0.29	0.24	0.29	0.71	292
Sand 2	7250	7808	0.73	0.16	0.28	0.24	0.29	0.71	228
Sand 3	9390	9912	0.56	0.17	0.25	0.21	0.34	0.66	164
AKOS-008									
Sand 1	6428	7113	0.67	0.31	0.31	0.31	0.34	0.66	130
Sand 2	7157	8740	0.78	0.22	0.22	0.22	0.29	0.71	330
Sand 3	10516	11022	0.55	0.18	0.18	0.18	0.28	0.72	244
AKOS-009									
Sand 1	6452	7223	0.87	0.12	0.30	0.27	0.27	0.73	387
Sand 2	7257	7830	1	0.08	0.29	0.27	0.27	0.73	311
Sand 3	9353	9754	0.88	0.27	0.28	0.21	0.33	0.67	206
AKOS-010									
Sand 1	6413	7040	0.95	0.13	0.33	0.29	0.15	0.85	451
Sand 2	7194	7738	0.97	0.19	0.38	0.34	0.11	0.89	685
Sand 3	9473	9813	0.82	0.17	0.41	0.39	0.22	0.88	774
AKOS-012 ST1									
Sand 1	6413	7040	0.95	0.13	0.33	0.29	0.15	0.85	451
Sand 2	7194	7738	0.97	0.19	0.38	0.34	0.11	0.89	685
Sand 3	9473	9813	0.82	0.17	0.41	0.39	0.22	0.88	774

The Table 2 above showed the summary of the average petrophysical parameters of the wells (AKOS-001 – AKOS-012ST1). The wells were all delineated to contain three reservoirs identified as (Sand 1, Sand 2 and Sand 3) as hydrocarbon-bearing.

The petrophysical parameters calculated showed that porosity values ranges between (14 - 27%) for Akos-1, (19 - 26%) for Akos-002, (30 - 31%) for Akos-004, (21 - 24%) for Akos- 007, (18 - 31%) for Akos-008, (21 - 27%) for Akos-009 (29 - 39%) for Akos-010, (29 - 35%) for Akos-012 STI. Permeability values ranges between (151 -237) for Akos-1, (141 - 264) for Akos-002, (208 - 545) for Akos-004, (164 - 292) for Akos- 007, (130 - 330) for Akos-008, (206 - 387) for Akos-009 (451 - 774) for Akos-010, (568 - 1083) for Akos-012 STI356. Saturation values (water) ranges between (0.29– 0.43) for Akos-1, (0.29 – 0.37) for Akos-002, (0.28–0.30) for Akos-004, (0.29– 0.34) for Akos- 007, (0.28–0.34) for Akos-008, (0.27–0.33) for Akos-009 (0.11–0.22) for Akos-010, (0.13–0.19) for Akos-012 STI. Hydrocarbon saturation values also ranges between (0.57–0.68) for Akos-1, (0.64– 0.71) for Akos-002, (0.61–0.70) for Akos-004, (0.66– 0.71) for Akos- 007, (0.66–0.72) for Akos-008, (0.67–0.73) for Akos-009 (0.85–0.89) for Akos-010, (0.81–0.87) for Akos-012 STI. For the Net-to-Gross the values ranges between (0.67–0.89) for Akos-1, (0.45– 0.92) for Akos-002, (0.80–0.90) for Akos-004, (0.55– 0.73) for Akos- 007, (0.55–0.78) for Akos-008, (0.87–1.00) for Akos-009 (0.82–0.97) for Akos-010, (0.59–0.59) for Akos-012 ST1.

Conclusion

This study shows in details how various petrophysical properties (gamma ray index, resistivity, Net-to-gross NTG (pay zone), volume of shale, total/effective porosity, water saturation and permeability can be obtained in order to evaluate the field's hydrocarbon prospectivity. These properties were used to characterize the reservoir's potential of the field. Detailed petrophysical revealed that the petrophysical values obtained from the results were characteristic of the Niger Delta Formation and the reservoirs identified exhibited good qualities with Akos-004, Akos-010 and Akos-012 ST1 most outstanding. The hydrocarbon yield of the field is generally high and viable for production.

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