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Evaluation of Petrophysical Properties of the Sapele Shallow Field, Niger Delta Area, Southern Nigeria

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ABSTRACT: Petrophysical properties are used to characterize a reservoir. Hence, this study evaluates petrophysical properties of the Sapele shallow field in the Niger Delta Area of Southern Nigeria with the aid of log data such as gamma-ray, density, neutron, and resistivity. Quantitative properties including shale volume, porosity, permeability, Irreducible water saturation, formation factor, water saturation, and hydrocarbon saturation were carried out using the well logs. One oil-bearing reservoir was identified across the field. Computed petrophysical parameters across the reservoir provided average porosity ranging from 0.30 to 0.36, permeability values range from 2707.9 to 3721.9 milli Darcy (mD) and the average hydrocarbon saturations are 0.51, 0.42, 0.47, 0.46, 0.47, and 0.49 for well 21, 22, 29, 30, 31, and 32 respectively. The field covers an area extent of 17137.18 acres.

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Keywords: hydrocarbon saturation; irreducible water saturation; porosity; permeability

The petrophysical properties can be proper indicators to identify oil and gas reservoirs, since the pore fluids have significant effects on the wave response (Rupeng et al., 2021). The oil and gas industry is a technology-driven industry, our ability to locate and extract hydrocarbons from beneath the ground surface is tied directly to the evolution of technologies, concepts, and interpretative sciences such as rock physics which is the science of measuring rock properties and establishing the relationship between these properties. Petrophysics is a viable tool for the discovery and evaluation of hydrocarbon-bearing layers. One of the fundamental properties of a reservoir rock is porosity. However, for a rock to be an effective reservoir, it must have good pore interconnectivity. The main physical parameters needed to evaluate a reservoir are porosity, hydrocarbon saturation, permeable bed thickness, permeability, etc. These parameters may be derived from electrical, nuclear, and acoustic logs, which can be translated to qualitative information on the depth/thickness of productive intervals, to distinguish between oil, gas, and water in a reservoir. Hence, the objective of this paper this study is to evaluate the petrophysical properties of the Sapele shallow field in the Niger Delta Area of Southern Nigeria is paper.

MATERIALS AND METHOD

Location of the Study Area: Sapele shallow is the proximal portion of the Sapele field in OML 41, located in the Greater Ughelli Depobelt, Northwestern part of the Niger Delta (Figure 1).

Stratigraphy of the Niger Delta: According to Frankl and Cordy (1967), Short and Stauble (1967), Weber and Daukoru (1975), Avbovbo (1978), Knox and Omatsola (1989), and Tuttle *et al.*, (1999), the modern Niger Delta is made up of three subsurface stratigraphic units. The delta sequence is mainly a succession of marine clays (Akata Formation) overlain by paralic sediments (Agbada Formation) which were finally capped by continental sands (Benin Formation). Stratigraphy of the Niger Delta is

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complicated by the Syndepositional collapse of the clastic wedge as shale of the Akata Formation mobilized under a load of prograding deltaic Agbada and fluvial Benin Formation deposits.

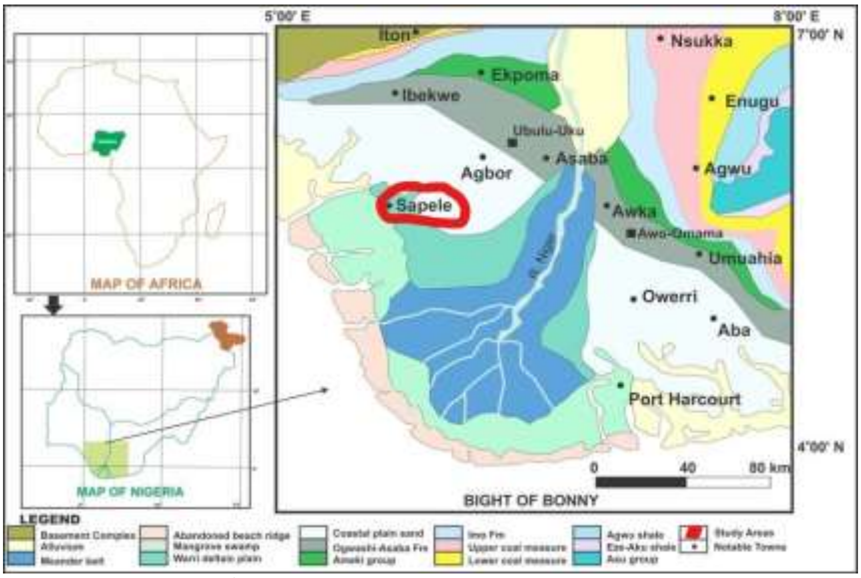

Fig 1: Geological Map of the Niger Delta Basin showing the Study Area (Oyebanjo *et al.*, 2018).

Measurement and Evaluation: Digital wireline well logs data from six wells across the field was used in carrying out this study these subsurface data belong to Seplat Petroleum Development Company PLC (Seplat Energy PLC) and were released under the approval of the Department of Petroleum Resources (DPR), Nigeria. Petrel®2016 (Schlumberger software) was used in the interpretation of the data. The log types used for quantitative analysis in this study are gamma-ray, resistivity, sonic, density, and neutron logs. Although, the neutron log was absent in well 21.

Petrophysical Evaluation: Some petrophysical parameters used in the field reservoir petrophysical evaluation are:

Shale Volume: Reservoirs are mostly associated with shale content and from the gamma ray logs, shale volume can be determined from gamma ray index due to the high radioactive material that exist in shale. Gamma ray log reading will increase as the shale content in the formation increases compared to other formation like carbonate or sandstone.

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \qquad (1)$$

Where, I_{GR} = gamma ray index; GR_{log} = gamma ray reading of formation from log; GR_{min} = minimum gamma ray (clean sand); GR_{max} = maximum gamma ray (shale);

$$V_{sh} = 0.083 \times (2^{3.7 \times I_{GR}} - 1) \qquad (2)$$

Where, V_{sh} = volume of shale

Porosity: Percentage of pore volume or void space, or that volume within rock that can contain fluids, is porosity. Porosity values will differ based on the type of formations, grain orientations and other factors.

$$\Phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad (3)$$

$$\Phi_{eff} = (1 - V_{sh}) \times \Phi \qquad (4)$$

Where: Φ = porosity; ρ_{ma} = matrix density; ρ_b= formation bulk density; ρ_f = density of the fluid saturating the rock immediately surrounding; Φ_{eff} = effective Porosity

Permeability: In addition to being porous, a reservoir rock must have the ability to allow petroleum fluids to flow through its interconnected pores. The rock's ability to conduct fluids is termed permeability.

$$K = 307 + 26552\ \Phi^2 - 3450(\Phi S_{wirr})^2 \quad (5)$$

Where: K =Permeability; S_{wirr}= Irreducible water saturation.

RESULTS AND DISCUSSION

Reservoir Petrophysical Evaluation of Well 21: This well is made up of only one reservoir (Reservoir A). As denoted in figure 2, reservoir was delineated with well tops at depth of 1418.80 m (4682.14 ft) as top of reservoir and at 2152.30 m (7102.72 ft) as the base.

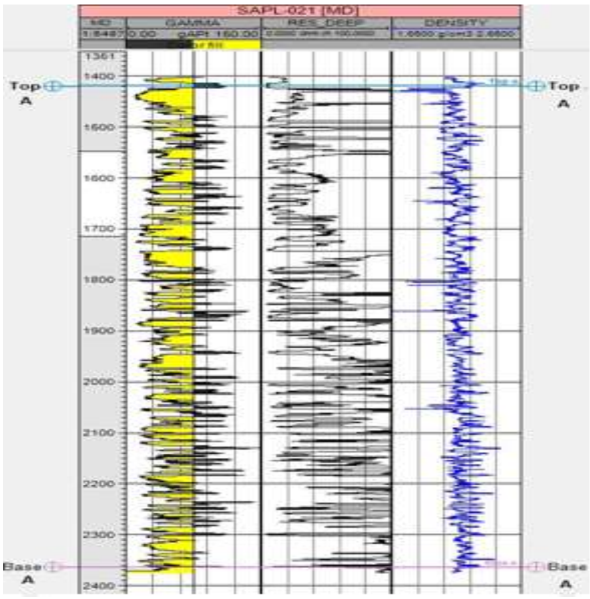

Fig 2: Well Log Signature of Well 21 (Using Petrel®2016).

The Gamma ray log was a useful tool in determining the lithology at depth, which was considered before selecting the reservoir with high sand thickness, the resistivity log shows a high kick which could represent the presence of hydrocarbon in the reservoir. The hydrocarbon type present in the reservoir could not be determine with the conventional neutron-density log due to the absence of neutron log. The delineated reservoir has a gross thickness of 733.5 m (2420.58 ft), net productive sand thickness of 656.36 m (2165.99 ft), an average porosity value of 0.30 (30%), an average permeability value of 2707.9 mD and water saturation of 0.49 (49%) as shown in table 1.

Reservoir Petrophysical Evaluation of Well 22: Reservoir "A" of well 22 was delineated with well tops at a depth of 738.75 m (2437.88 ft) as reservoir top and the base at 1833.20 m (6049.56 ft).

Table 1: Petrophysical values of Reservoir "A" of Well 21

Start MD (M)	Vsh	Net Sand (M)	Φ	EffΦ	K(mD)	F	Swirr	Sw	Sh
1418.8	0.21	111.83	0.32	0.26	3017.6	8.49	0.07	0.63	0.37
1586.2	0.22	110.39	0.31	0.25	2847.3	9.05	0.07	0.59	0.41
1744.4	0.19	134.86	0.31	0.26	2814.5	9.13	0.07	0.49	0.51
1928.8	0.27	147.22	0.29	0.22	2478.8	11.04	0.07	0.40	0.60
2152.3	0.21	152.06	0.28	0.23	2381.2	11.33	0.08	0.32	0.68
Average									
1766.1	**0.22**	**131.27**	**0.30**	**0.24**	**2707.9**	**9.8**	**0.07**	**0.49**	**0.51**

Reservoir gross thickness: 2152.3m – 1418.8m = 733.5 m (2420.55 ft)
Net-to-Gross ratio: ∑Net sand)/Gross thickness = 656.36/733.5 = 0.8

The lithology of the formation is sand dominated with little shale intercalation which was delineated with the aid of the gamma ray log. As shown from the neutron-density combination, reservoir "A" is a single-phase (oil) reservoir with no visible balloon shape neutron density separation (Figure 3). The reservoir is made up of five zones and has a gross thickness of 1094.45 m (3611.68 ft), net Productive Sand thickness of 847.99 m (2798.37 ft), an average porosity value of 0.33 (33%), an average permeability value of 3302 mD, an average shale volume of 0.16 and water saturation of 0.58 (58%) as shown in table 2.

Reservoir Petrophysical Evaluation of Well 29: Reservoir "A" in well 29 was delineated at a top depth of 763.38 m (2519.15 ft) and base of 2200.00 m (7260.00 ft). The Gamma-ray log was applied in deciphering the lithology of the formation before delineating the reservoir with high sand thickness together with high resistivity signature that indicates hydrocarbon presence in the reservoirs. The reservoir is a single-phase (oil) reservoir with no visible balloon shape neutron-density separation (Figure 4).

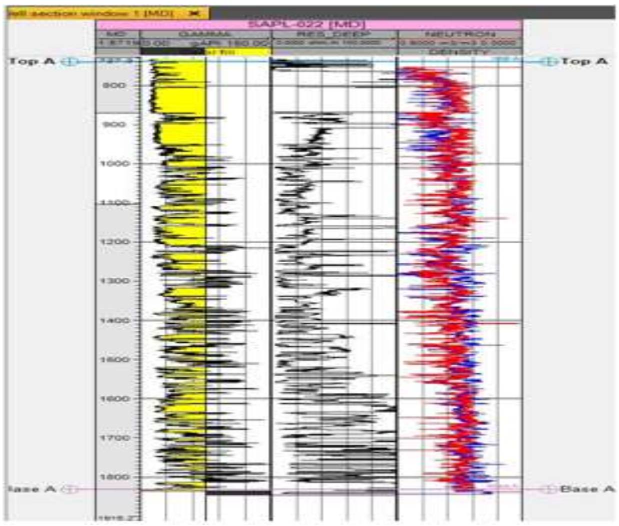

Fig 3: Well Log Signature of Well 22 (Using Petrel®2016).

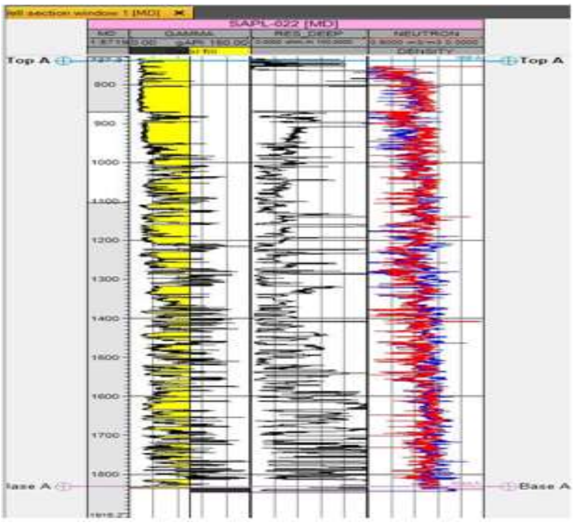

Fig 3: Well Log Signature of Well 22 (Using Petrel®2016).

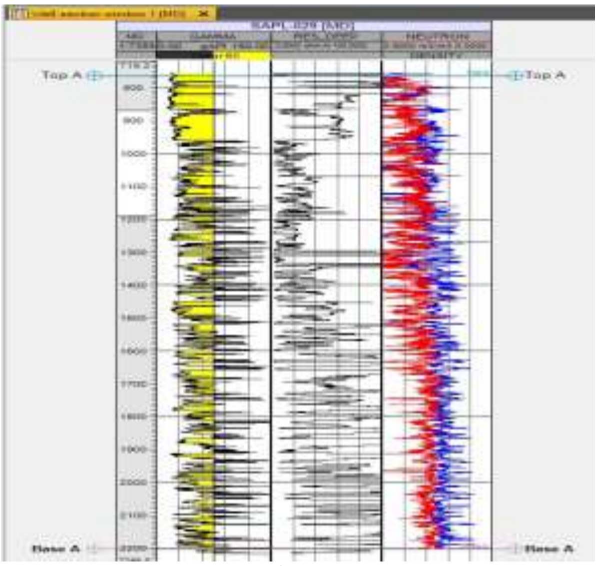

Fig 4: Well Log Signature of Well 29 (Using Petrel®2016).

The has a gross thickness of 1436.62 m (4740.85 ft), a net Productive Sand thickness of 974.28 m (3215.12 ft), an average porosity value of 0.35 (35%), an average permeability value of 3585.79 mD, an average shale volume of 0.42 and water saturation of 0.53 (53%) as shown in table 3.

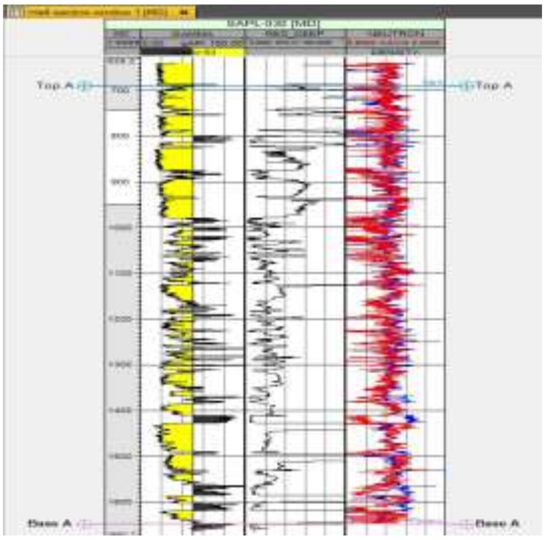

Fig 5: Well Log Signature of Well 30 (Using Petrel®2016).

Reservoir Petrophysical Evaluation of Well 30: From table 4, reservoir "A" of well 30 has a gross thickness of 957.92 m (3161.14 ft), a net Productive Sand thickness of 683.25 m (2254.73 ft), an average porosity value of 0.36 (36%), an average permeability value of 3721.86 mD, an average shale volume of 0.28 and water saturation of 0.54 (54%). The reservoir was delineated at a top depth of 690.48 m (2278.58 ft) as the top of the reservoir and base of 1648.40 m (5439.72 ft) as reveal by the well tops markers. The Gamma ray log was used in determining the lithology at that depth which was considered before picking the reservoir with high sand thickness, with a corresponding high resistivity signature that shows hydrocarbon presence in the reservoirs. With the aid of the neutron-density log, we were able to deduce that the reservoir is a single phase (oil) reservoir with no visible balloon shape neutron-density separation (Figure 5).

Table 2: Petrophysical values of Reservoir "A" of Well 22

Start MD (M)	Vsh	Net Sand (M)	Φ	EffΦ	K(mD)	F	Swirr	Sw	Sh
738.75	0.01	237.43	0.37	0.31	3902.2	4.93	0.05	0.55	0.45
984.56	0.12	124.94	0.34	0.30	3346.1	7.55	0.06	0.66	0.34
1138.91	0.17	120.67	0.36	0.31	3746.5	7.41	0.06	0.67	0.33
1302.34	0.25	183.65	0.32	0.25	2980.1	10.77	0.07	0.65	0.35
1833.20	0.26	181.3	0.29	0.23	2535.4	10.89	0.07	0.40	0.60
Average									
1199.55	**0.16**	**169.60**	**0.33**	**0.28**	**3302**	**8.31**	**0.06**	**0.58**	**0.42**

Reservoir gross thickness: 1833.20 – 738.75 = 1094.45 m (3611.68 ft)
Net-to-Gross ratio: (∑Net sand)/Gross thickness = 847.99/1094.45 = 0.77

Table 3: Petrophysical values of Reservoir "A" of Well 29

Start MD (M)	Vsh	Net Sand (M)	Φ	EffΦ	K(mD)	F	Swirr	Sw	Sh
763.38	0.11	224.93	0.44	0.40	5447.99	5.44	0.05	0.52	0.48
1034.41	0.23	159.81	0.40	0.33	4628.18	6.46	0.06	0.68	0.32
1251.15	0.42	184.96	0.33	0.22	3199.79	11.87	0.08	0.67	0.33
1545.37	0.89	185.58	0.28	0.06	2434.98	11.23	0.07	0.46	0.54
2200.00	0.44	219	0.27	0.18	2218.04	13.9	0.08	0.34	0.66
Average									
1358.86	**0.42**	**194.86**	**0.35**	**0.24**	**3585.79**	**9.78**	**0.07**	**0.53**	**0.47**

Reservoir gross thickness: 2200 m – 763.38 m = 1436.62 m (4740.85ft)
Net-to-Gross ratio: (∑Net sand)/Gross thickness = 974.28/1436.62 = 0.68

Table 4: Petrophysical values of Reservoir "A" of Well 30

Start MD (M)	Vsh	Net Sand (M)	Φ	EffΦ	K(mD)	F	Swirr	Sw	Sh
690.48	0.11	162.5	0.39	0.36	4368.71	6.58	0.06	0.38	0.62
876.16	0.17	105.03	0.38	0.32	4079.17	6.7	0.06	0.54	0.46
1011.51	0.23	112.92	0.37	0.29	3934.48	6.77	0.06	0.62	0.38
1187.06	0.49	126.93	0.33	0.19	3174.11	8.95	0.07	0.61	0.39
1648.4	0.39	175.87	0.32	0.22	3052.81	11.64	0.08	0.53	0.47
Average									
1082.72	**0.28**	**136.65**	**0.36**	**0.27**	**3721.86**	**8.13**	**0.06**	**0.54**	**0.46**

Reservoir gross thickness: 1648.4 m – 690.48m = 957.92 m (3161.14 ft)
Net-to-Gross ratio: (∑Net sand)/Gross thickness = 683.25/957.92 = 0.71

Reservoir Petrophysical Evaluation of Well 31: Reservoir "A" of well 31 has a gross thickness of 976.65 m (3222.95 ft), a net Productive Sand thickness of 612.95 m (2022.74 ft), an average porosity value of 0.32 (32%), an average permeability value of 3087.62 mD, an average shale volume of 0.47 and water saturation of 0.53 (53%) as seen in table 5. Figure 6 indicates that the reservoir was delineated at a top depth of 997.35 m (3291.26 ft) as the top of the reservoir and base of 1974 m (6514.20 ft) as revealed by the well tops markers. The reservoir is a single-phase (oil) reservoir with no visible balloon shape neutron-density separation.

Table 5: Petrophysical values of Reservoir "A" of Well 31

Start MD (M)	Vsh	Net Sand (M)	Φ	EffΦ	K(mD)	F	Swirr	Sw	Sh
997.35	0.26	167.73	0.4	0.3	4494.27	6.53	0.06	0.66	0.34
1234.68	0.49	115.59	0.34	0.21	3377.88	10.72	0.07	0.71	0.29
1440.04	0.39	122.57	0.31	0.2	2794.83	10.15	0.07	0.55	0.45
1625.7	0.56	104.01	0.27	0.13	2271.27	12.55	0.08	0.43	0.57
1974	0.65	103.05	0.29	0.17	2499.84	13	0.08	0.3	0.7
Average									
1454.35	**0.47**	**122.59**	**0.32**	**0.2**	**3087.62**	**10.59**	**0.07**	**0.53**	**0.47**

Reservoir gross thickness: 1974 m – 997.35 m = 976.65 m (3222.95 ft)
Net-to-Gross ratio: (∑Net sand)/Gross thickness = 612.95/976.65 = 0.63

Reservoir Petrophysical Evaluation of Well 32: Reservoir "A" of well 32 as shown in figure 7, was delineated at a top depth of 672.16 m (2218.13 ft) as the top of the reservoir and base of 2480.23 m (8184.56 ft) as revealed by the well tops markers. The reservoir was delineated by defining the lithology at depth with the help of the gamma-ray log which segregates the shale and sand bodies, with a matching high resistivity signature that displays hydrocarbon presence in the reservoirs. The reservoir is a sole phase (oil) reservoir with no noticeable balloon shape neutron-density parting. The hydrocarbon reservoir has a gross thickness of 1808.07 m (5966.63 ft), a net Productive Sand thickness of 1124.94 m (3712.30 ft), an average porosity value of 0.33 (33%), an average permeability value of 3208.20 mD, an average shale volume of 0.51 and water saturation of 0.51 (51%) as seen in table 6.

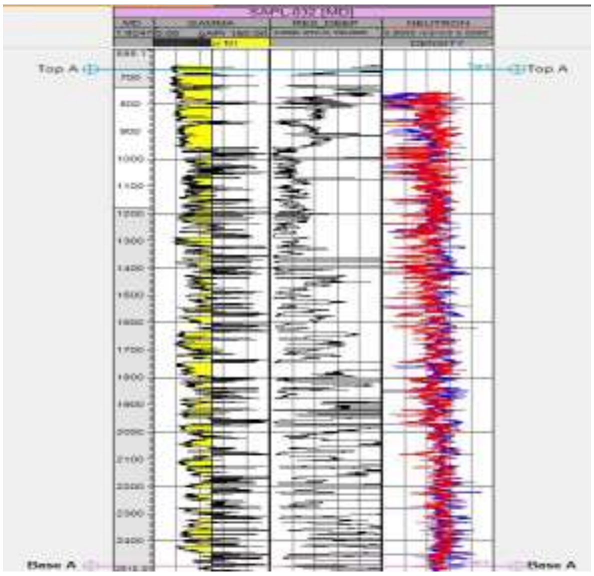

Fig 7: Well Log Signature of Well 32 (Using Petrel®2016).

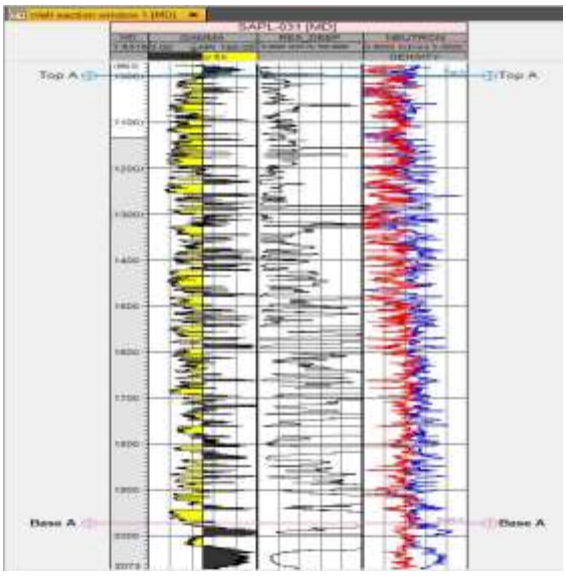

Fig 6: Well Log Signature of Well 31 (Using Petrel®2016).

Table 6: Petrophysical values of Reservoir "A" of Well 32

Start MD (M)	Vsh	Net Sand (M)	Φ	EffΦ	K(mD)	F	Swirr	Sw	Sh
672.16	0.15	261.29	0.41	0.35	4701.47	5.87	0.05	0.46	0.54
980.78	0.89	238.96	0.34	0.1	3396.52	7.94	0.06	0.72	0.28
1376.15	0.48	190.65	0.31	0.18	2883.45	9.56	0.07	0.57	0.43
1704.01	0.41	249.08	0.3	0.2	2711.06	10.07	0.07	0.44	0.56
2480.23	0.65	184.96	0.28	0.12	2348.5	12.77	0.08	0.36	0.64
Average									
1442.67	**0.51**	**224.99**	**0.33**	**0.19**	**3208.2**	**9.24**	**0.07**	**0.51**	**0.49**

Reservoir thickness: 2480.23 m – 672.16 m =1808.07 m (5966.63 ft)
Net-to-Gross ratio :(∑Net sand)/Gross thickness =1124.94 /1808.07 =0.62

Table 7: Cumulative Average Petrophysical Values of Sapele Shallow

Wells	Gross Thickness (M)	Vsh	Net Sand (M)	Φ	EffΦ	K(mD)	F	NTG	Swirr	Sw	Sh
Well 21	733.5	0.22	131	0.30	0.24	2707.9	9.8	0.89	0.07	0.49	0.51
Well 22	1094.45	0.16	170	0.33	0.28	3302	8.31	0.77	0.06	0.58	0.42
Well 29	1436.62	0.42	195	0.35	0.21	3585.8	9.78	0.68	0.07	0.53	0.47
Well 30	957.92	0.28	137	0.36	0.27	3721.9	8.13	0.71	0.06	0.54	0.46
Well 31	976.65	0.47	123	0.32	0.20	3087.6	10.6	0.63	0.07	0.53	0.47
Well 32	1808.07	0.51	225	0.33	0.19	3208.2	9.24	0.62	0.07	0.51	0.49
Average											
	1167.87	**0.34**	**163.33**	**0.33**	**0.24**	**3262.27**	**9.31**	**0.72**	**0.07**	**0.53**	**0.48**

Cumulative Petrophysical Summary of Sapele Shallow: The petrophysical properties of Sapele shallow as summarized in table 7, has an average gross thickness of 1167.87 m (3853.97 ft), an average net sand thickness of 163.33 m (538.99 ft), an average porosity value of 0.33 (33%), average permeability of 3262.27 mD, an average shale volume of 0.34, an average net-to-gross value of 0.72 (72%) and an average water saturation (Sw) of 0.53 (53%). From the above petrophysical values, we can say that the reservoir of Sapele Shallow field, is a good hydrocarbon reservoir with an excellent petrophysical value.

Conclusion: Reservoir "A" is the only delineated reservoir in Sapele shallow that was encountered at a shallow depth of 672.16 m (2218.13) – 2115.06 m (6979.70 ft) across the field. Using Seplat shale volume cut-off of 0.35 and water saturation cut-off of 0.60, reservoirs in well 21, 22, and 30 are very good with average shale volume and average water saturation value lesser than the set-up cut-off. While reservoir in well 29, 31, and 32 has shale volume that exceeds Seplat cut-off value of 0.35 which has led to a reduction in the effective porosity (Φ_{eff}) of these wells.

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