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Petrophysical Appraisal of Sapele Deep Field, Niger Delta, Southern Nigeria

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ABSTRACT

The distal field, Sapele Deep Field, is situated in the Niger Delta's Northwestern region. The study had access to three wells (numbers 06, 17, and 18). Thirteen reservoirs were identified across the wells, and they were found at depths ranging from 2991.62 meters (9872.35 feet) to 3761.81 meters (12413.97 feet). The field is a brownfield with a total area of 16515.73 acres, and it has been producing hydrocarbon for over three decades. As a result, digital wireline well log data, including the neutron log, resistivity log, gamma-ray log, and density log, were used to carry out the reservoir petrophysical evaluation and gain a better understanding of the reservoir lithology and hydrocarbon potential. The research area's average values for the following parameters are 6.67 m (22.01 ft) of net sand thickness, 0.21 (21%), 1454.05 mD of permeability, 0.16 mD of shale volume, 0.47 (net-to-gross), and 0.48 (48%), respectively, for water saturation (Sw).

Keywords: Petrophysical evaluation, Lithology, Gamma-ray log, resistivity log, density log

1.0. Introduction

Petrophysical evaluation of reservoirs is imperative for both field development and production plans. The petrophysical framework of the Sapele Deep field was assessed by studying the distribution and dissimilarity of reservoir properties within the field. The evaluation of any petroleum reservoir, new or old, for maximum rate of production and maximum recovery of the hydrocarbons requires a thorough knowledge of reservoir lithology, fluid transport properties of reservoirs, and the fluid-rock interactions that influence the flow of the fluids. The Shale volume, Porosity, Net-to-gross, water saturation, and permeability values, derived from petrophysical analysis, are controlled basically by inherent depositional settings.

Reservoir's petrophysical study has evolved over the past 20 years, from a simple engineering evaluation to multidisciplinary teams of geologists, geophysicists, petrophysicists, and petroleum engineers working together. The integration of these various disciplines has changed our perception of the characteristics of oil and gas reservoirs. 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. These technologies are seismic-based methods for imaging features beneath the ground's surface, advances in well logging techniques, improvements in the ability to drill in deep water beyond the continental shelf, the advent of horizontal drilling, micropaleontology, biostratigraphy, to name a few.

The stratigraphy of the Niger Delta is closely related to its structure. The development of each is dependent on the interplay between sediment supply and subsidence rate. According to Iwuoma and Minapuye (2016), Adeogba et al., (2005), Aigbogun and Mujakperuo (2020), 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).

1.2. Description of Hydrocarbon Potential in the Niger Delta Region

Allen (1964), Hospers (1971), Burke et al., (1972) and Whiteman (1982), establish in detail, the history, evolution, and structural features of the Niger Delta. Stoneley (1966), examined the mega tectonic setting of the Niger Delta. The syn-sedimentary tectonics of the tertiary delta was extensively analyzed by Evamy et al., (1978).

According to Lehner and De Ruiter (1977), the tectonic framework of the continental margin in the Niger Delta is controlled by Cretaceous fracture zones expressed as trenches and ridges in the deep Atlantic. The fracture zone ridges divide the margin into individual basins and in Nigeria, form the boundary faults of the Cretaceous Benue-Abakaliki trough, which cuts extreme into the West African shield. The trough represents a failed arm of a rift triple junction associated with the opening of the South Atlantic. In this region, rifting started in the Late Jurassic and persisted into the Middle Cretaceous. Asseez (1976), reviewed the stratigraphy, sedimentation, and structures of the Niger Delta. Merki (1972), described the structural geology of the Tertiary Niger Delta, which is on the overlap sequence that is deformed by syn-sedimentary faulting and folding. Ekweozor and Daukoru (1984, 1994), presented a detailed report on the petroleum geology and stratigraphy of the Niger Delta showing the relationship between depositional patterns, structures and stratigraphy and their influence on the oil generation in the Niger Delta basin.

Weber and Daukoru (1975), Doust and Omatsola (1990), Reijers et al., (1997), Nton and Adebambo (2009), Nton and Adesina (2009), gave a detailed explanation on the tectonic, stratigraphy, depositional environment, petrophysics, sedimentology and hydrocarbon potential of the Niger Delta. The Niger Delta, on the passive western margin of Africa, has long been recognized as a classic example of continental-margin structural collapse under sediment loading (Khalivov and Kerimov, 1983; Morley, 1992; Morley et al., 1998; Rensbergen et al., 1999; Edwards, 2000; Rensbergen and Morley, 2000).

According to Kulke (1995), Ekweozor et al., (1984), the Niger Delta Province contains only one identified petroleum system, known as the Tertiary Niger Delta (Akata–Agbada) Petroleum System. This field, which is not a single gigantic field, is composed of thousands of individual reservoirs, most of which are sandstone strata, trapped within oil-rich shale strata. Oil and gas fields are abundant but are not outsized.

According to Hooper et al., (2002), the modern Niger Delta has distinctive basin ward variations in structural style that define.

(1) an inner extensional zone of listric growth faults beneath the outer shelf.
(2) a translational zone of diapirs and shale ridges beneath the upper slope.
(3) an outer compressional zone of imbricate toe-thrust structures beneath the lower slope.

These areas of contrasting structural style are linked on a regional scale by slow gravity collapse of this thick deltaic prism (Damuth, 1994).

Although broad regional relationships between patterns of deposition and deformation caused by structural collapse within the inner extensional zone of the Niger Delta have been proposed (Knox and Omatsola, 1989), details of high-frequency sequence development within this setting are less well documented. Most recent stratigraphic studies of the Niger Delta deposits based on modern three-dimensional (3-D) seismic records have focused on relationships between depositional patterns within the compressional toe of this clastic wedge along the base of the continental slope (Morgan, 2004; Adeogba et al., 2005; Corredor et al., 2005). Short and Stauble (1967), defined three formations within the 13,000 ft thick Niger Delta clastic wedge based on sand/shale ratios estimated from subsurface well logs as:

(i) basal, offshore marine, and pro-delta shale of the Akata Formation.
(ii) interbedded sandstone and shale of the dominantly deltaic Agbada formation.
(iii) the capping sandy fluvial Benin Formation.

Previous studies by Ladipo et al., (1992), and Stacher (1995) on sedimentological, biostratigraphical, and sequence-stratigraphic, revealed the combined influence of eustatic cyclicity and local tectonics. Recent studies on the offshore Niger Delta by Owayemi et al., (2006), and Magbagbeoloa et al., (2007) demonstrate that these concepts are still valid but perhaps could benefit from the stratigraphic information and the new approaches presented here. Depositional sequences as defined by Vail, (1987) and consisting of strata bounded by unconformities and their lateral equivalents are only recognized in specific sectors of the delta. In contrast, delta-wide genetic sequences as defined by Galloway (1989) and consisting of strata bounded by maximum flooding surfaces within transgressive shales are more readily identifiable in the Niger Delta. Individual sea-level cycles are reflected in the Niger Delta in various sedimentary sequences. Interferences of cycles with different periods result in mega sequences that are chronostratigraphically confined and sedimentologically characterised. Sequence stratigraphic concepts are increasingly finding new and unique applications in the regressive siliciclastic deposits of the Niger Delta.

According to Haq et al., (1988), the most useful criteria for the recognition of sequence boundaries in the acreage in the Niger Delta include truncation of underlying reflections, drape, dip discordance, or onlap of younger reflection over topography on sequence boundary, contrasts in seismic attributes across the sequence boundary and the sequence termination of faults at the sequence boundary. Pacht and Hall (1993), applied the sequence stratigraphic concept to exploration in the offshore of the Niger Delta. Stacher (1994), revised the earlier SPDC Bio and Time-Stratigraphic Scheme and put the scheme in a sequence stratigraphic framework allowing correlation with sea level curve using the Harland et al., (1992), global time scheme. Bowen et al., (1994), established an integrated geologic framework of the Niger Delta slope by applying established sequence stratigraphic concepts on the newly acquired seismic data sets of the Niger Delta, coupled with biostratigraphic data from twenty-six (26) key wells.

Over the years, delta wide framework of Cretaceous chronostratigraphic surfaces and a sequence stratigraphic chart for the Niger Delta has been produced, using biostratigraphic data obtained from several wells. Ozumba (1999), developed a sequence stratigraphic framework of the western Niger Delta, using foraminifera and wire line log data obtained from four wells drilled in the coastal and central swamp depobelts. He concluded that the late Miocene sequences were thicker than the middle Miocene sequences.

Amigun and Bakare (2013), examined the reservoir of Danna field, Niger Delta applying 3D seismic interpretation and petrophysical analysis. They correlated five wells, defined the lithology, and established the continuity of reservoir sands as well as the general stratigraphy of the area. In their petrophysical study, they showed three sand units that are hydrocarbon-bearing reservoirs (Sand J, Sand M and Sand P) which were further evaluated using seismic interpretation. Time and depth structural maps were produced from seismic data which helped in examining the trapping subsurface structures and estimation of the prospect area of the reservoirs in acres. They computed the field’s hydrocarbon reserve using parameters like net pay, water saturation and porosity i.e., derived from well logs together with estimated prospect area as obtained from seismic interpretation. They estimated the gas reserve to be 225,997 bbl/ft3, while the oil reserve for the three reservoirs (Sand J, Sand M and Sand P) was calculated as 6,566,089.09 bbl/ft3, 14,006,716 bbl/ft3, and 42,746,580 bbl/ft3, correspondingly.

Anthony and Aurelius (2012), rummage-sale 3D seismic data and well logs to map the structure and stratigraphy in characterizing reservoir of the Z-Field, Niger Delta where identification of reservoir facies is a key challenge to plan delineation and development drilling. They identified and mapped a network of faults and four horizons, A, B, C and D. Time and depth structure maps of the top of the reservoir of interest show the hydrocarbon bearing structure is a fault-assisted anticlinal reliant structure. Gamma ray and resistivity logs in four exploratory wells were utilized to delineate formation lithologies. The target horizon C (top of sand) was picked for seismic structural mapping. They identified two major faults (F1, F2) on the time and depth structural maps and a network of other fault structures which were interpreted on the seismic sections. According to them, the quality of the reservoirs in the Z-field in the Niger Delta is moderate to good and in some distal reservoirs, they are excellent. The average porosity values are almost the same but have disparities in permeability which could be because of compaction of the older reservoirs on the proximal portion of the field (Wells A-20 and A-30).

Nyantakyi et al., (2013), incorporated seismic data with well logs to describe the subsurface structural geometry, stratigraphy and hydrocarbon trapping prospective of Delta field, offshore Niger Delta. According to them, lithologic units were identified on the logs and correlated across the wells, and the stratigraphic cross-sections produced showed a general lateral continuity of the lithologic units across the field. They mapped five sequence boundaries namely SB1, SB2, SB3, SB4 and SB5 and structure contour maps drawn for each of the sequence boundaries. As fault closures of high-quality hydrocarbon prospects were identified and delineated, stratigraphic plays such as pinch-outs, unconformities, sand lenses and channels are also assumed. They alleged, that the integration of seismic data with well logs greatly improved the extent of

accuracy of structural and stratigraphic mapping in predicting lateral and vertical variations, hydrocarbon prospects and its development in Delta Field.
Opara et al., (2011), exemplified the processes of iterative 3D seismic interpretation and structural analysis of Ossu Oil Field, Northern Depobelt, Onshore Niger Delta and displayed how 3-D seismic data acquired in the study area was used in imaging sub-surface structures. They undertook a multi-disciplinary approach which included petrophysics, seismic, and volumetric methods to achieve these goals. The interpretation was controlled by a combination of structural based geometric models with seismic and well data. They revealed a complex pattern of subsurface structures with the northern area having mainly widely spread simple rollover structures bounded by growth faults. Faulted rollover anticlines prevailed in the middle zone while the southern area is characterized by collapsed crest structures. The 7480ft sand contains non-associated oil trapped in annealment phase trap while the 4540ft sand contains associated oil. The oil in reservoir A is not in commercial quantity, whereas only about 1.7 million barrels is recoverable from the estimated 8.6 million barrels for reservoir I.

Ologe et al., (2013), delineated the complexity of faulted subsurface structural features and retaining capacity of the reservoir for hydrocarbon in a 3D seismic structural analysis of part of Aloo-Field, Southwestern Niger Delta. The 3D seismic data was analyzed, using Petrel software where horizons and fault interpretations from the seismic section were used to generate structural maps which revealed different structural styles present in the studied area. They mapped three distinct horizons. Depth structural maps generated for all surfaces of interest show subsurface features such as the geometry of the identified horizons, W-E trending growth fault and fault strata of which most of them dip to the east and fault assisted closures at the north-western-central part of the studied section. The dipping pattern of the identified faults coincides with that of the growth fault which enhances trapping mechanism for the hydrocarbon. Two principal structural trapping mechanisms presents are growth fault and rollover anticline which are synonymous with Niger Delta. According to them, the study demonstrated the importance of seismic structural interpretation in understanding the structural styles present and their retentive ability for hydrocarbon.

Adeniran (1997), studied the planktonic foraminifera from the western Niger Delta and defined six zones based on cosmopolitan planktonic foraminifera, he pointed out the lack of a unified foraminiferal zoning scheme for the Niger Delta. Okosun and Liebau (1999), confirmed the scarcity of a zonal scheme for the Niger Delta in their study of five wells in the eastern part of the Niger Delta. A study of four wells in the central and coastal swamps depobelts of the western Niger Delta by Ozumba and Amajor (1999), indicated that foraminifera were moderately rich but poorly preserved.

Obiosio (2013), studied the bolivina biostratigraphy and paleoenvironment of Tonjor-l well of the Niger Delta and documented eighteen Bolivina species reported for the first time in the Niger Delta. The stratigraphic diversity variation of the bolivinids allowed the recognition of Late Early Eocene marine transgression which correlates with global timing of Early Eocene transgression. The presence of costae and larger test suggest a deposition in a well oxygenated slope to bathyal environment.

Frankl et al., (1967), Agagu (1981), Petters (1982, 1984), Okosun et al., (1999), proposed the Danian age for the sediments of eastern Niger Delta Basin based on Globorotalia pseudobulloide, Globigerina triloculinoides, Globigerinoides daaubjergensis assemblages. Chukwu et al., (2012), carried out foraminiferal biostratigraphy and depositional environment study of Oloibiri-1 Well, in Eastern Niger Delta, Nigeria and established two zones namely: Praeorbulina glomerosa zone and Poritextularia panamensis zone.

Bassey et al., (1998), carried out sequence stratigraphy of six wells in offshore Western Niger Delta using seismic data, well log and biostratigraphic data, they established that the sediments were Late Miocene to Pleistocene and defined seven depositional sequences.
Armentrout et al., (1999), carried out high resolution sequence biostratigraphic study of Oso field in the Niger Delta and proposed three sequence stratigraphic models and data were integrated into the interpretation of the producing intervals of the Oso field:

a. Model based on biostratigraphic data and core sedimentology.
b. Model based on core sedimentology.
c. Model based on regional seismic reflection profile and well log data.

Boboye and Adeleye (2009), recognized four condensed sections based on foraminifera and nanofossil abundance and diversity patterns calibrated with chronostratigraphically important bioevents from deep offshore Niger Delta. These condensed sections were correlated with the Global chart of Haq et al., (1988).
Oluwatosin (2010), developed sequence stratigraphic model for Ningning field in the Niger Delta based on the interpretations carried out on five different wells that penetrated the various subsurface lithologies. This enabled the field-wide reconstruction of a chronostratigraphically constrained biostratigraphy of subsurface lithological sequences.
Soronnadi et al., (2013), undertook a palaeoenvironmental and sequence stratigraphic study of the D7000 sand 'Erne' field of the Niger Delta using integrated core samples, biostratigraphic data and wireline logs analyses of the D7000 sand. The environments of deposition were established as marine to estuarine settings which revealed that a period of regression was followed by a transgressive phase. Core analysis revealed the existence of ten lithofacies, which were grouped into facies association in a vertical sequence with genetic significance using primary structures and shape of wireline logs.
Santos et al., (2012), undertook an overview study of heavy oil properties and its recovery and transportation method using Pressure Volume Temperature (PVT) data. He established that, heavy oils are formed because of biodegradation and usually occur in giant shallow formations in marginal geological basins formed by non-consolidated sand.
Head et al., (2003), carried out a study on biological activity in the deep subsurface and the origin of heavy oil. He established that microbial degradation reaches optimal temperatures below 800C, promoting oil oxidation, reduction of the gas/oil ratio (GOR), and reduction of API value.
Whiteman (1982) established that the physical and chemical properties of oil in the Niger Delta are extremely unpredictable. He established that the oil within the Niger Delta has a gravity range of 16-50° API, with the lighter oils having a greenish brown colour. While Thomas (1995), stated that 56% of Niger Delta oils have an API gravity between 30° and 40°, and that oils with less than 25° API account for only 15% of the Niger Delta reserves.

2.0 Methodology

2.1 Study Area
Sapele field is an onshore field of OML 41, located in the Northwestern part (Greater Ughelli depobelt) of the Niger Delta oil province (Figures 1 and 2). It lies within Latitude 50 53’ 54.43” N and Longitude 50 33’ 42.22” E. Figure 1: Base map of oil wells in the study area

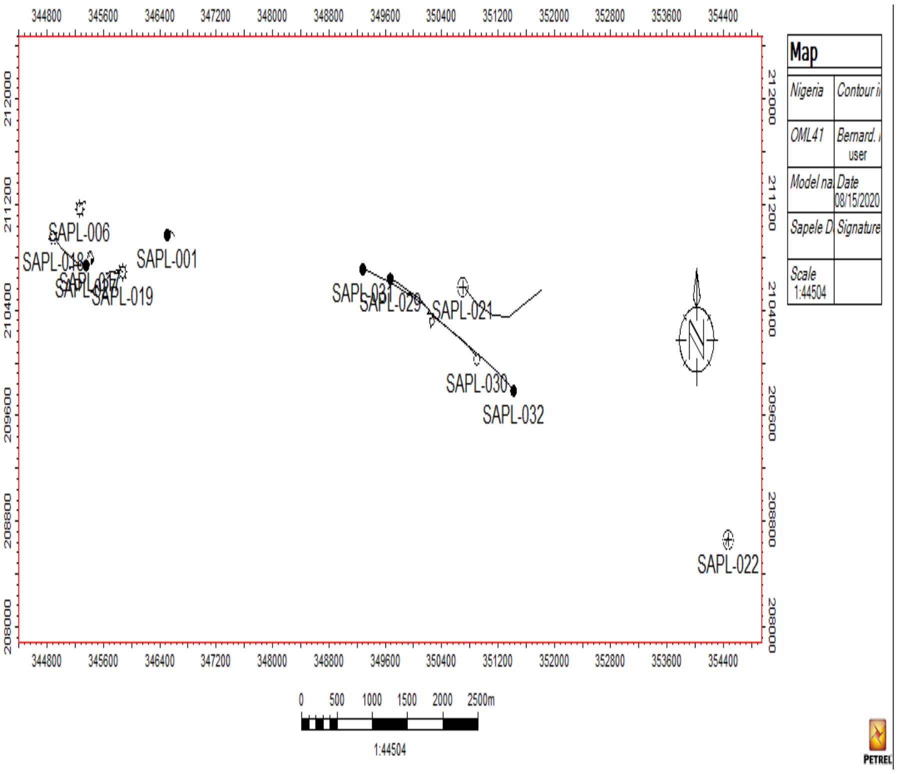

Figure 1: Base map of oil wells in the study area

2.2. Location of the Study Area

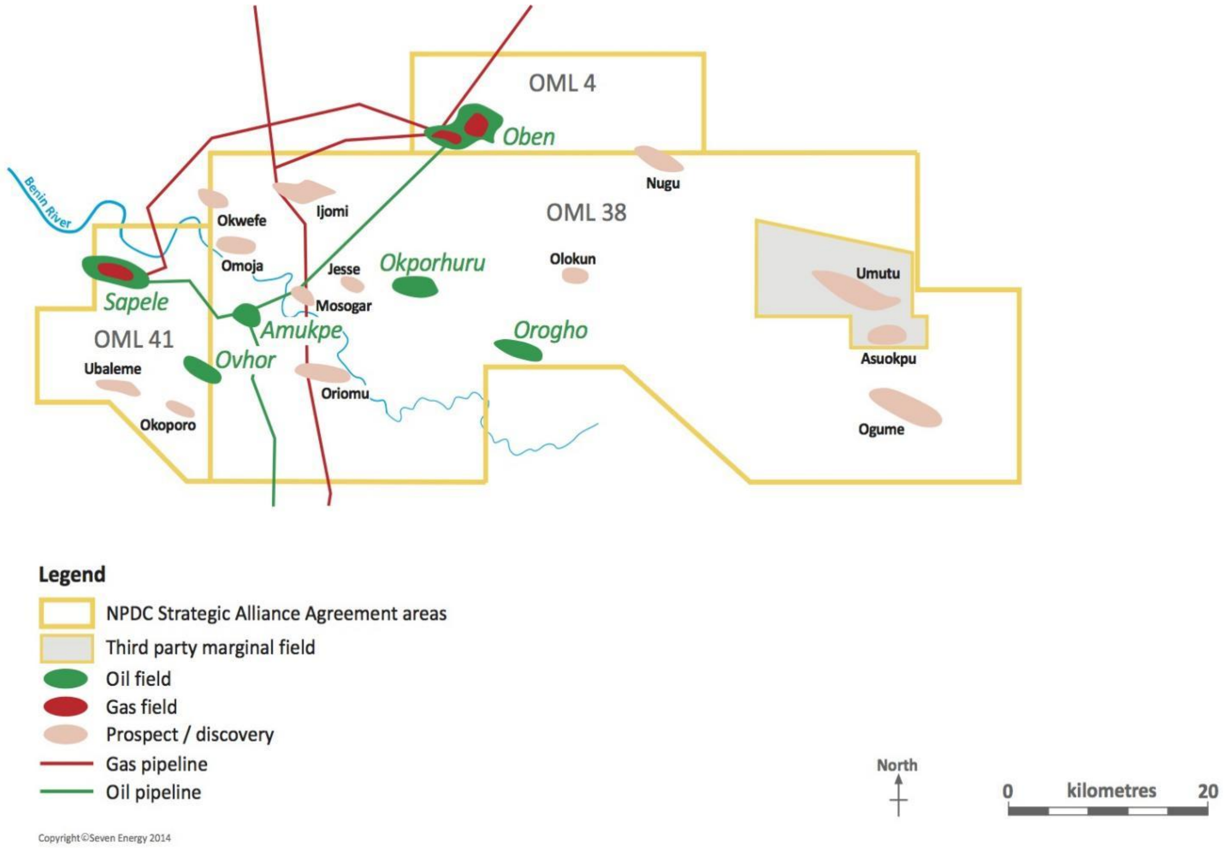

Figure 2: Location Map of Seplat Various OMLs (Seplat, 2014)

2.3 Materials and Methods

The materials used in carrying out this study are a suit of subsurface well logs data from three wells provided across the field. 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 well log data.

The data is of good quality and were drilled with water-based mud. The log types used for quantitative analysis in this study are gamma-ray, resistivity, sonic, density, and neutron logs. The formula used in calculating the petrophysical parameters is shown in Table 1.

The materials used while carrying out this research work are a suit of subsurface data which includes, 3D seismic cube, twelve well logs data provided across the fields, biostratigraphy data, and a pressure volume temperature data. These subsurface data belong to Seplat Petroleum Development Company PLC and was released under the approval of the Department of Petroleum Resources (DPR), Nigeria.

Table 1. Formulae Used to Compute for Petrophysical Parameters in Sapele Deep Field

S/N	Author(s)	Formula	Petrophysical parameters
1	Larionov, 1969	$V_{sh} = 0.083 \times (2^{3.7 \times I_{GR}} - 1)$	**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.
2	Owolabi *et al.*, 1994	$\Phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$	**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.
3	Owolabi *et al.*, 1994	Sw = $\frac{0.082}{\Phi\_Den}$	**Water Saturation**: This is the percentage or ratio of water present in a reservoir rock.
4	Owolabi *et al.*, 1994	$F = \Phi_D \frac{0.62}{2.15}$	**Formation Factor:** The ratio of the resistivity of a rock filled with water (Ro) to the resistivity of that water (Rw).
5	Owolabi *et al.*, 1994	$S_{wirr} = \sqrt{\frac{F}{200}}$	**Irreducible Water Saturation:** Irreducible water saturation (critical water saturation) defines the maximum water saturation that a formation with a given permeability and porosity can retain without producing water.
6	Owolabi *et al.*, 1994	$K = 307 + 26552\ \Phi^2 - 3450(\Phi S_{wirr})^2$	**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.
7	Owolabi *et al.*, 1994	$S_h = (1 - S_w)$	**Hydrocarbon Saturation**: This is the percentage or ratio of hydrocarbon present in a reservoir rock.
8	Owolabi *et al.*, 1994	NTG = $\frac{\sum Net\ Sand\ thickness}{Gross\ Sand\ thickness}$	**Net-to-Gross Ratio**: This is a measure of the thickness of the productive (Net) reservoir sands within the total (Gross) reservoir thickness.

3.0 Results and Discussion

3.1. Petrophysical Summary of Well 06 Reservoirs

The data presented in Table 2, indicates that well 06 reservoirs on average, have a gross thickness of 47.47 m (156.65 ft), shale volume of 0.15, net sand thickness of 6.94 m (22.90 ft), porosity of 0.20, permeability of 1416.23 mD and a water saturation of 0.47 (47%). using Seplat shale volume cut-off of 0.35 and water saturation cut-off of 0.60 for Sapele deep, it means the reservoirs in well 06 are prolific reservoirs except for reservoir "H" whose Sw is 0.90.
Well 06 penetrated seven reservoirs (B, C, D, E, F, G and H) out of the thirteen reservoirs present in the field (Figures 2a and 2b) and it is made up of three single-phase oil reservoirs, and four phase double-phase (Gas/Oil) reservoirs.

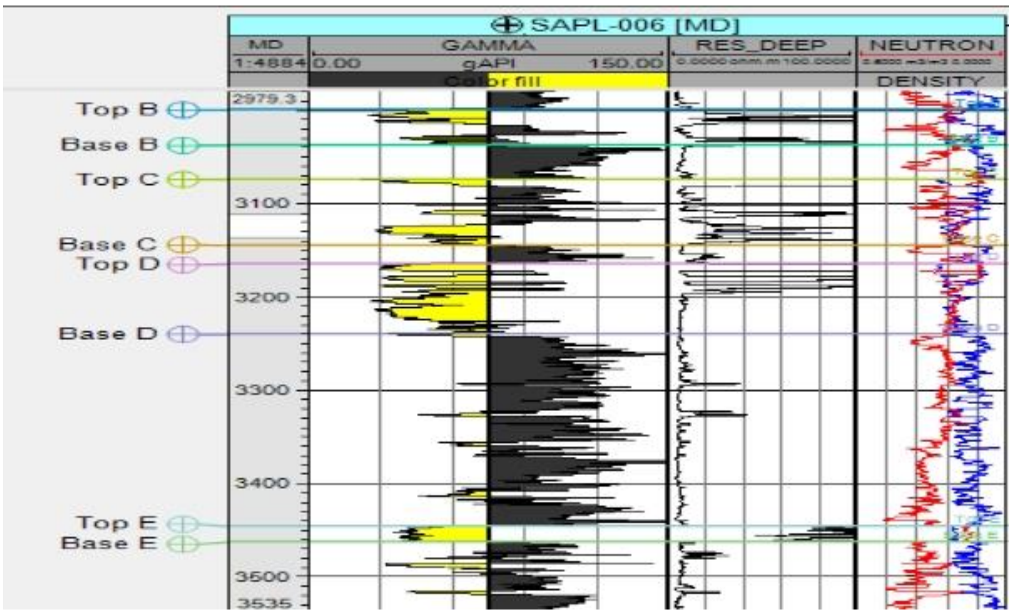

Figure 2a: Well log signature of well 06 from 2979.3 m to 3535 m (Using Petrel®2016)

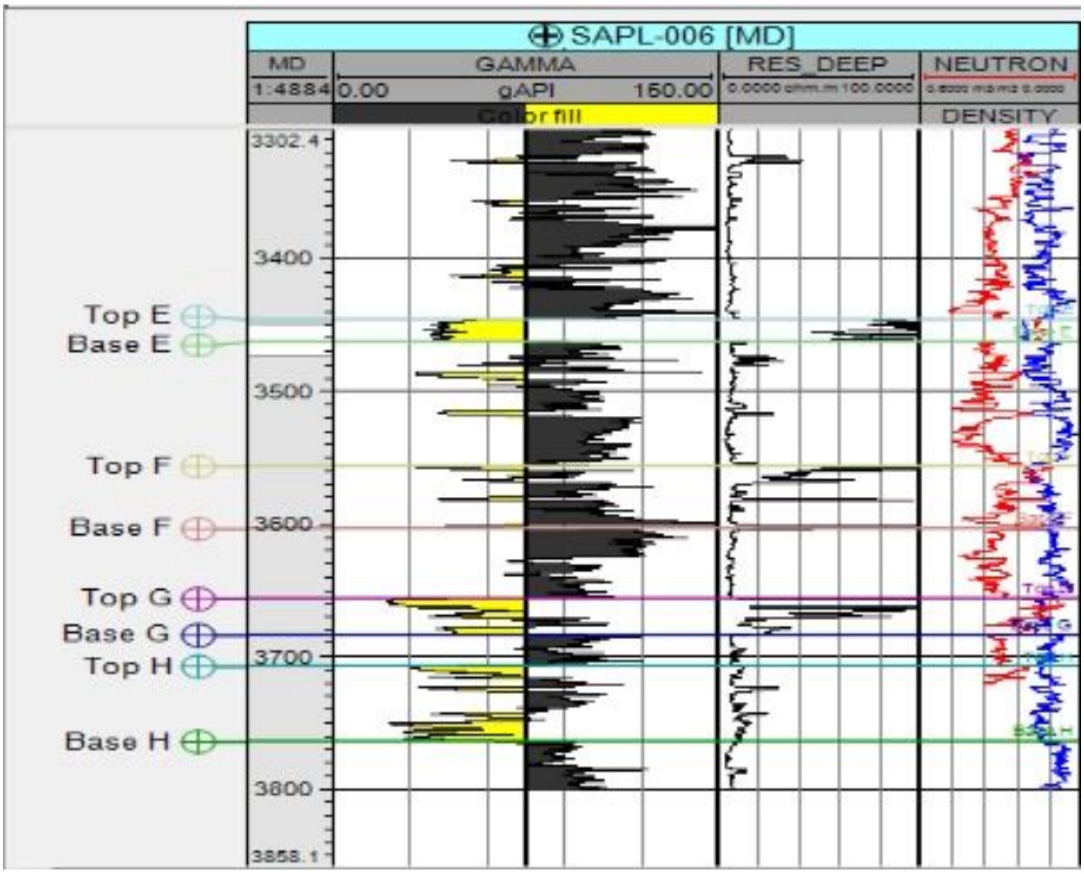

Figure 2b: Well log signature of well 06 from 3302.4 m to 3800 m (Using Petrel®2016)

Table 2: Petrophysical Summary of Well 06

Reservoirs	Thickness (m)	Vsh	Net Sand (m)	Φ	EffΦ	K(mD)	F	NTG	Swirr	Sw	Sh
B	37.32	0.11	9.250	0.22	0.20	1605.60	18.47	0.50	0.10	0.40	0.60
C	70.67	0.08	5.346	0.24	0.22	1836.27	14.76	0.38	0.09	0.40	0.60
D	75.43	0.27	5.520	0.23	0.18	1720.13	21.98	0.44	0.10	0.50	0.50
E	18.00	0.06	16.060	0.22	0.20	1552.00	17.26	0.89	0.09	0.30	0.70
F	47.65	0.20	1.630	0.19	0.16	1305.26	21.79	0.17	0.10	0.40	0.60
G	28.00	0.10	8.790	0.17	0.16	1038.15	30.16	0.63	0.12	0.40	0.60
H	55.24	0.25	2.040	0.15	0.12	856.22	46.82	0.07	0.15	0.90	0.10
Average	**47.47**	**0.15**	**6.940**	**0.20**	**0.18**	**1416.23**	**24.46**	**0.44**	**0.11**	**0.47**	**0.53**

Φ = Porosity, EffΦ = Effective Porosity, F = Formation Factor, NTG = Net to Gross Ratio, Swirr = Irreducible Water Saturation, Sw = Water Saturation, S_h=Hydrocarbon Saturation.

3.2. Reservoir Petrophysical Evaluation of Well 17

This well intercepted eight reservoirs (B, C, D, E, F, G, H, and I) out of the thirteen reservoir sand present in the field (Figures 3a and 3b) and ranges in depth from 2967.2 (9791.76) m to 3630 m (11979 ft). Well 17 is made up of three single-phase gas reservoirs, three single-phase oil reservoirs, and two double-phase reservoirs (Gas/Oil).

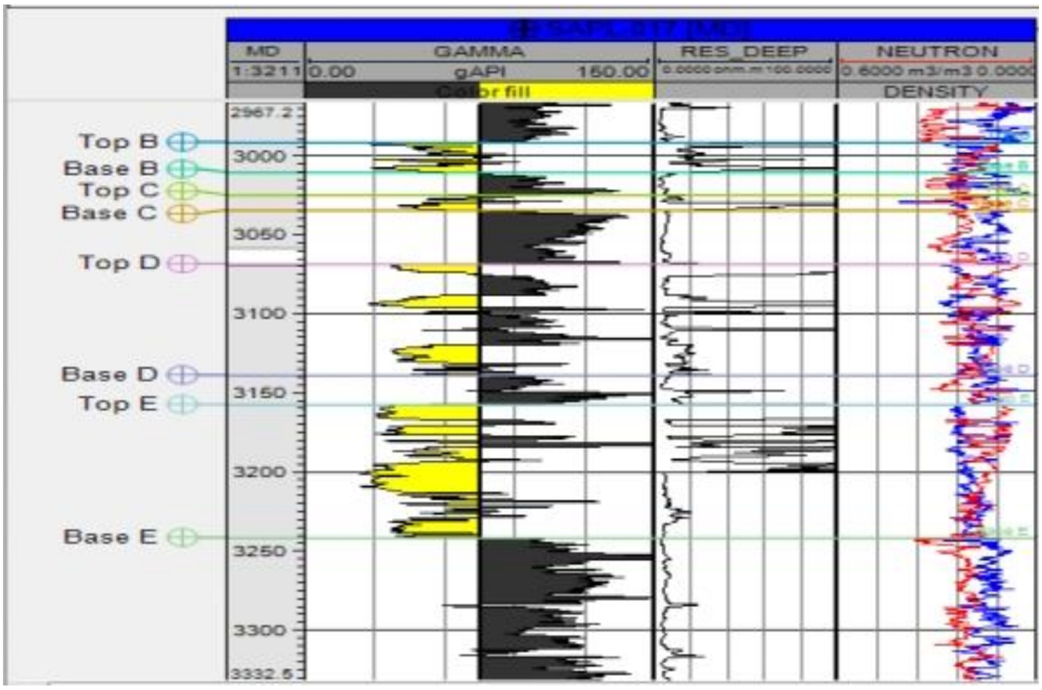

Figure 3a: Well log signature of well 17 from 2967.2 m to 3332.5 m (Using Petrel®2016)

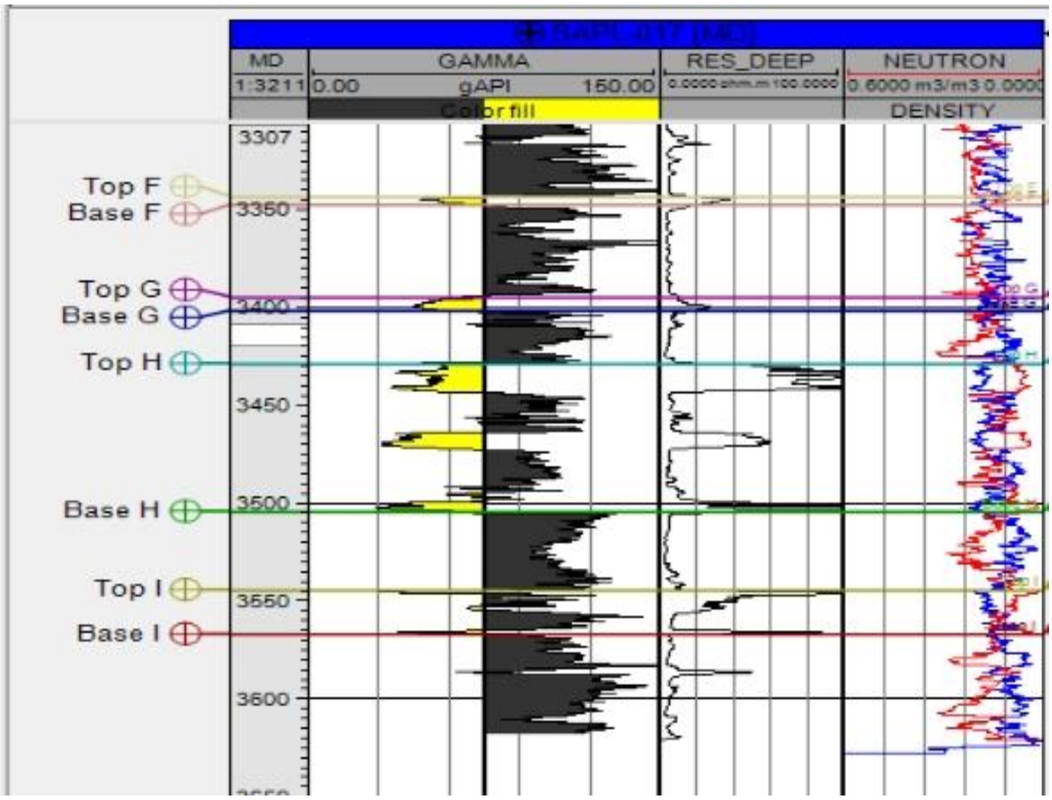

Figure 3b: Well log signature of well 17 from 3307 m to 3630 m (Using Petrel®2016)

3.3. Petrophysical Summary of Well 17 Reservoirs

The cumulative petrophysical summary as shown in Table 3, indicates that well 17 reservoirs on average, has a gross thickness of 36.30 m (119.79 ft), shale volume of 0.13, net sand thickness of 6.36 m (20.99 ft), porosity of 0.21, permeability of 1479.46 mD and a water saturation of 0.47 (47%). However, using Seplat shale volume cut-off of 0.35 and water saturation cut-off of 0.60 for Sapele deep, it means the reservoirs in well 17 are very good with sound petrophysical properties except reservoir “G” which has water saturation of 0.68 that is far above the cut-off.

Table 3: Petrophysical Summary of Well 17 reservoirs

Reservoirs	Thickness (m)	Vsh	Net Sand (m)	Φ	EffΦ	K(mD)	F	Swirr	Sw	Sh
B	2991.620	0.15	13.39	0.20	0.18	1393.540	31.86	0.13	0.53	0.47
C	3025.000	0.20	6.32	0.24	0.19	1866.900	15.52	0.09	0.60	0.41
D	3101.130	0.12	4.96	0.23	0.21	1740.150	16.29	0.09	0.40	0.58
E	3187.740	0.08	7.44	0.24	0.22	1796.770	14.92	0.09	0.31	0.69
F	3343.210	0.14	2.99	0.19	0.17	1313.134	21.94	0.10	0.51	0.49
G	3394.710	0.11	5.58	0.19	0.17	1219.227	24.15	0.11	0.68	0.32
H	3465.360	0.11	8.90	0.19	0.18	1309.578	22.69	0.11	0.43	0.57
I	3555.895	0.13	1.32	0.18	0.16	1196.420	26.90	0.11	0.31	0.69
Average	**3258.000**	**0.10**	**6.40**	**0.20**	**0.20**	**1479.000**	**21.80**	**0.10**	**0**	**0.50**

3.4. Reservoir Petrophysical Evaluation of Well 18

As indicated in figures 4a and 4b, well 18 penetrated the thirteen reservoirs (B, C, D, E, F, G, H, I, J, K, L, M, and N) present in the field and ranges in depth from 3001 (9,903.30) m to 3720 m (12,276 ft). Reservoirs in this well are all single-phase reservoirs, the first reservoir is a single-phase oil reservoir, while the remaining twelve reservoirs are single phase gas reservoirs.

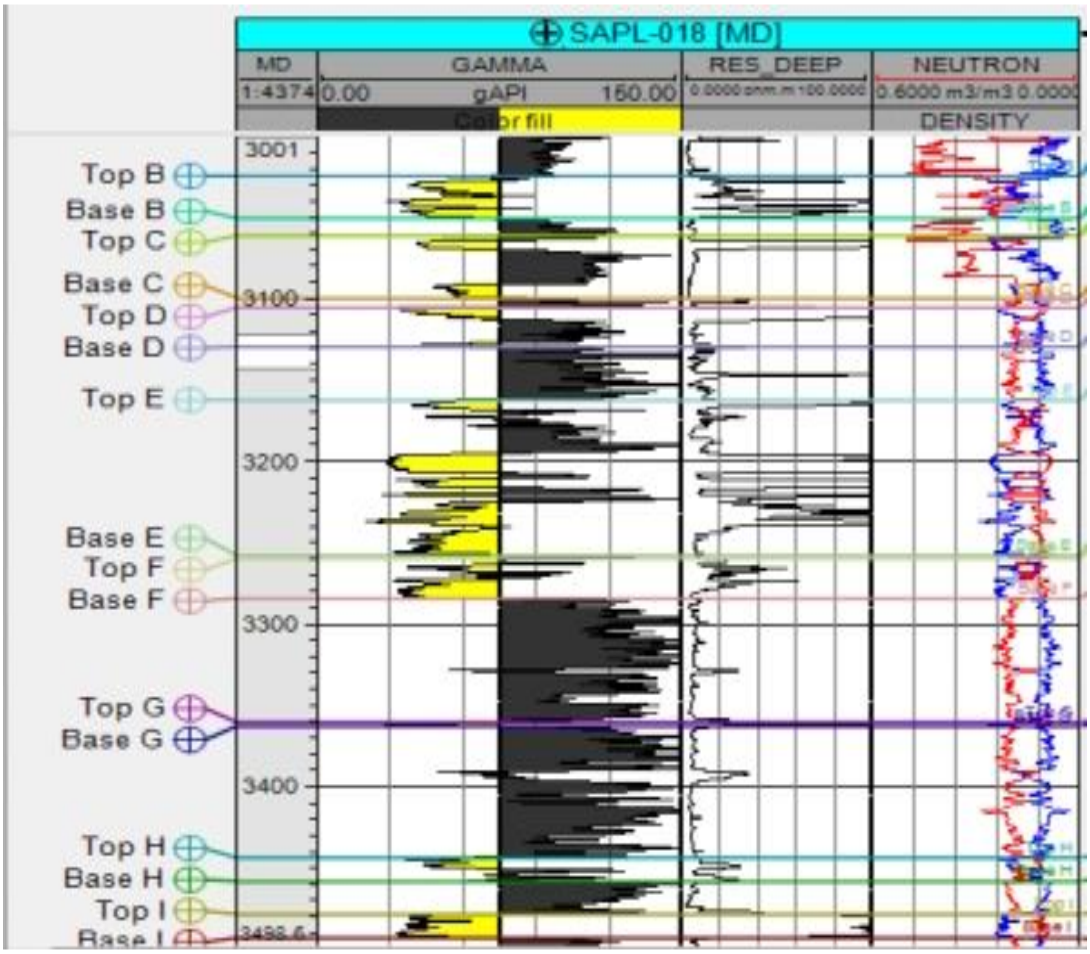

Figure 4a: Well log signature of well 18 from 3001 m to 3498.6 m (Using Petrel®2016)

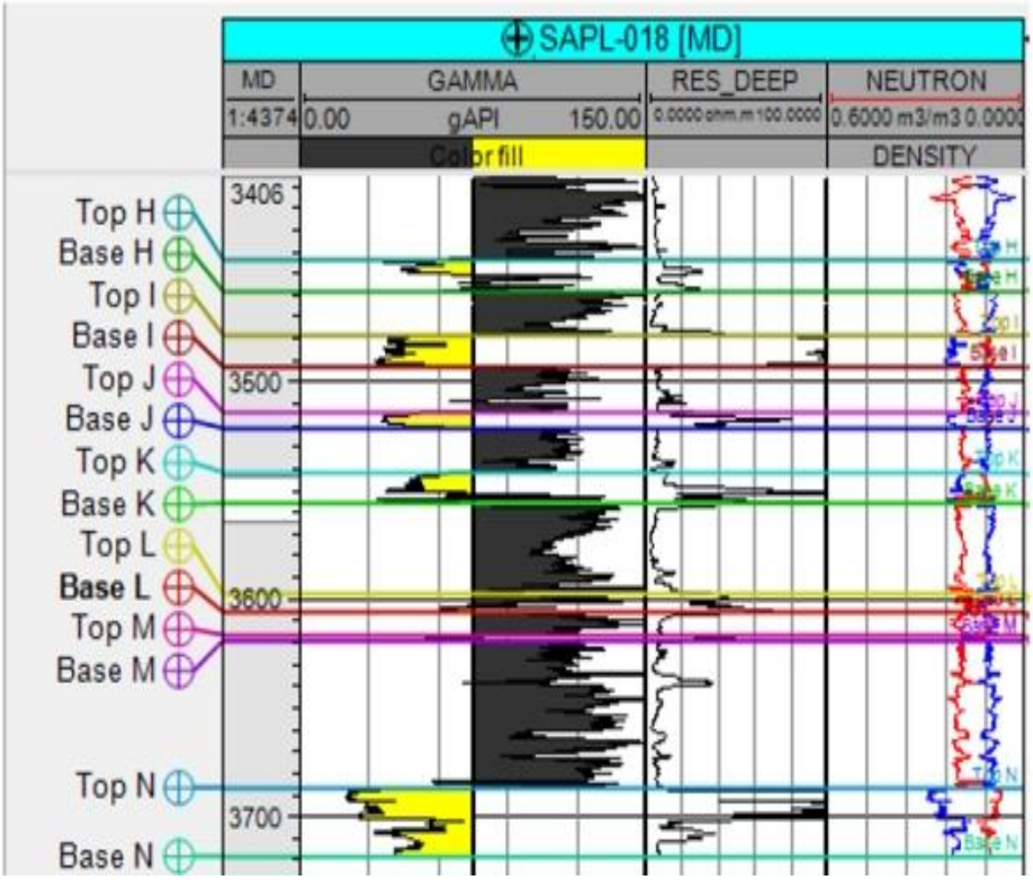

Figure 4b: Well log signature of well 18 from 3406 m to 3720m (Using Petrel®2016)

3.5. Petrophysical Summary of Well 18 Reservoirs

The amassed petrophysical data of all well 18 reservoirs (Table 4), stipulates that the reservoirs on average, has a gross thickness of 23.43 m (77.32 ft), net sand thickness of 6.67 m (22.01 ft), shale volume of 0.15, porosity of 0.21, permeability of 1466.46 mD, a water saturation of 0.49 (49%) and a net to gross ratio of 0.44.

Table 4: Petrophysical Summary of Well 18 reservoirs

Reservoirs	Thickness (m)	Vsh	Net Sand (m)	Φ	EffΦ	K(mD)	F	NTG	Swirr	Sw	Sh
B	25.52	0.12	19.29	0.22	0.19	1537.19	21.88	0.76	0.10	0.51	0.49
C	38.48	0.27	5.59	0.23	0.19	1766.02	24.47	0.15	0.11	0.61	0.39
D	23.94	0.09	3.91	0.21	0.19	1508.27	18.55	0.33	0.10	0.40	0.60
E	95.41	0.19	5.71	0.22	0.19	1587.88	21.35	0.36	0.10	0.34	0.66
F	24.73	0.16	14.84	0.21	0.18	1437.18	21.63	0.56	0.10	0.68	0.32
G	2.99	0.23	1.13	0.17	0.13	1108.54	27.28	0.37	0.12	0.50	0.50
H	14.55	0.09	6.24	0.21	0.19	1496.69	18.27	0.43	0.10	0.73	0.27
I	14.95	0.06	12.77	0.23	0.22	1678.61	15.89	0.85	0.09	0.25	0.75
J	7.38	0.06	6.26	0.23	0.21	1660.53	16.35	0.85	0.09	0.49	0.51
K	14.15	0.24	1.94	0.19	0.16	1308.81	24.91	0.14	0.11	0.59	0.41
L	8.37	0.20	0.75	0.18	0.14	1146.87	25.64	0.09	0.11	0.33	0.67
M	2.60	0.22	0.45	0.18	0.14	1131.8	26.49	0.05	0.12	0.44	0.56
N	31.50	0.08	7.80	0.23	0.21	1695.56	17.01	0.74	0.09	0.52	0.48
J	7.38	0.06	6.26	0.23	0.21	1660.53	16.35	0.85	0.09	0.49	0.51
K	14.15	0.24	1.94	0.19	0.16	1308.81	24.91	0.14	0.11	0.59	0.41
Average	**23.43**	**0.15**	**6.67**	**0.21**	**0.18**	**1466.46**	**21.52**	**0.44**	**0.10**	**0.49**	**0.51**

3.6. Cumulative Petrophysical Summary of Sapele Deep

The cumulative petrophysical parameters presented in Table 5 reveal that Sapele deep field on average, has a gross thickness of 309.05m (1019.86 ft), net sand thickness of 6.67 m (22.01 ft), porosity value of 0.21 (21%), permeability of 1454.05 mD, shale volume of 0.16, net-to-gross value of 0.47 and water saturation (Sw) of 0.48 (48%). Thus, we can infer that Sapele deep reservoirs possess very good to excellent petrophysical properties.

Table 5: Cumulative Average Petrophysical Values of Sapele Deep

Wells	Gross Thickness (m)	Vsh	Net Sand (m)	Φ	EffΦ	K(mD)	F	NTG	Swirr	Sw	Sh
06	332.21	0.15	6.94	0.2	0.18	1416.233	24.46	0.44	0.11	0.47	0.53
17	290.38	0.13	6.36	0.2	0.19	1479.460	21.80	0.53	0.10	0.47	0.50
18	304.57	0.15	6.67	0.2	0.18	1466.460	21.50	0.44	0.10	0.49	0.50
Average	**309.05**	**0.14**	**6.66**	**0.2**	**0.18**	**1454.050**	**22.59**	**0.47**	**0.10**	**0.48**	**0.52**

4.0. Conclusions

From logs evaluations, prolific sands were encountered at depth range of 2999.53 m (9898.45 ft) – 3761.55 m (12413.12 ft) and the delineated lithology are mainly sand and shale formations, with occasional sand-shale intercalation. The field delineated reservoirs are made up of single-phase gas reservoirs, single-phase oil reservoirs, and double-phase (Gas/Oil) reservoirs.

Using Seplat shale volume cut-off of 0.35 and water saturation cut-off of 0.60, all reservoirs in the well are very good with average shale volume and average water saturation value lesser than the set-up cut-off except well 06 reservoir “H” (Table 2), well 17 reservoir “G” (Table 3), well 18 reservoir “F” and “H” (Table 4) whose water saturation is over 0.60.

Conclusively, from the evaluated petrophysical parameters (Table 5), we can say that Sapele shallow is a viable hydrocarbon field with great exploration/exploitation prospects.

References

Adeniran, B. V., (1997). Quantitative Neogene planktic foraminiferal biostratigraphy of Western Niger Delta, Nigeria. Nigerian Association of Petroleum Explorationists Bulletin. 12 (10) pp. 54-59.

Adeogba, A. A., McHargue, T. R., and Graham, S. A., (2005). Transient fan architecture and depositional controls from near-surface 3-D seismic data Niger Delta continental slope. American Association of Petroleum Geologists Bulletin, 89 pp. 627–638.

Agagu, O. K., (1981). Effect of overpressure in petroleum accumulation in the Niger subsurface. American Association of Petroleum Geologists Bulletin, 70 pp. 50-75.

Aigbogun C. O. and Mujakperuo B. J. O. (2020). Reservoir Characterization of an Onshore X-Field, Niger Delta, Southern Nigeria, Using Well Logs Data. International Journal of Science Invention Today (www.ijsit.com), 9 (1), January-February 2020.

Allen, J. R. L., (1964). The Nigerian continental margin; bottom sediments, submarine morphology and geological evolution. Marine Geology, 1, pp. 289–332.

Amigun, J. O., and Bakare, N. O., (2013). Reservoir Evaluation of Danna Field Niger Delta using Petrophysical Analysis and 3D Seismic Interpretation. Petroleum and Coal, 55(2), pp. 119-127.

Anthony, A. A, and Aurelius O. O., (2012). Reservoir Characterization and Structural Interpretation of Seismic Profile: A Case Study of Z-Field, Niger Delta, Nigeria. Petroleum and Coal 55 (1), pp. 37-43.

Armentrout, J. M., Feam, B., Rodgers, K., Root, S., Lyle, W. D., Hedrick, D. C., Bloch, R. B., Snedden, J. W., and Nwankwo, B., (1999). High resolution sequence biostratigraphy of a lowstand prograding deltaic wedge: Oso field (Late Miocene), Nigeria. In: Jones, R.W., and Simmons, M.D., (eds.) Biostratigraphy in production and development geology. Geological society, London, Special Bulletin. 152, pp. 259-290

Asseez, L. O., (1976). Review of stratigraphic sedimentation and structure of the Niger Delta In Kogbe, C.A., (ed.) Geology of Nigeria Rock in View: pp. 311-324.

Bassey, C. E., and Ojesina, O. A., (1998). Sequence stratigraphic interpretation of E – Block in western offshore Niger Delta, Nigeria. Global Journal of Pure and Applied Sciences.5, pp. 227 – 233.

Boboye, E. A. and Adeleye, A.M., (2009). High resolution biostratigraphy of Early Pliocene to Late Miocene calcareous Nannoplankton and foraminifera, deep offshore, Niger Delta, Nigeria. European Journal of Scientific Research, 34: 308 - 325

Burke, K. C., Dessauvage, T. F. J., and Whiteman, A. J., (1972). Geological History of the Benue Valley, and adjacent areas. In African Geology, T.F.J. Dessauvagie and A.J. Whiteman ed., pp. 187-205.

Chukwu, J. N., Okosun, E. A., and Alkali, Y. B., (2012). Foraminiferal Biostratigraphy and Depositional Environment of Oloibiri-1 Well, Eastern Niger Delta, Nigeria Journal of Geography and Geology; 4 (4): 114 - 122

Corredor, F., Shaw, J. H., and Billoti, F., (2005). Structural styles in the deep-water fold and thrust belts of the Niger Delta. American Association of Petroleum Geologists Bulletin, 89, 753–780.

Damuth, J. E., (1994). Neogene gravity tectonics and depositional processes on the deep Niger Delta continental margin. Marine and Petroleum Geology, 11, 320–346.

Doust, H., and Omatsola, E., (1990). Niger Delta, in, Edwards, J. D., and Santogrossi, P.A., eds., Divergent/passive Margin Basins, AAPG Memoir 48: Tulsa, American Association of Petroleum Geologists, p. 239-248.

Edwards, M. B., (2000). Origin and significance of retrograde failed shelf margins; Tertiary northern Gulf Coast Basin. Transactions of the Gulf Coast Association, 50, 81–93.

Ekweozor, C. M., and Daukoru, E. M., (1984). Petroleum source bed evaluation of Tertiary Niger Delta--reply: American Association of Petroleum Geologists Bulletin, v. 68, p. 390-394.

Ekweozor, C. M., and Daukoru, E. M., (1994). Northern delta depobelt portion of the Akata-Agbada(!) petroleum system, Niger Delta, Nigeria, in, Magoon, L.B., and Dow, W.G., eds., The Petroleum System--From Source to Trap, AAPG Memoir 60: Tulsa, American Association of Petroleum Geologists, p. 599-614.

Evamy, B. D., Haremboure, J., Kamerling, P., Knaap, W. A., Molloy, F. A., and Rowlands, P. H., (1978). Hydrocarbon habitat of Tertiary Niger Delta. American Association of Petroleum Geologists Bulletin, 62, 1–39.

Frankl, E. J., and Cordy, E. A., (1967). The Niger Delta oil province: Recent developments onshore and offshore. In Proceedings of the Seventh world petroleum congress (Vol. 2, pp. 195–209). Mexico.

Galloway, W. E., (1989). Genetic stratigraphic sequences in basin analysis; I, Architecture, and genesis of flooding-surface bounded depositional units. American Association of Petroleum Geologists Bulletin, 73, 125–142.

Haq, B. U., Hardenbol, J., and Vail, P. R., (1988). Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. In C. K. Wilgus et al., (Eds.), Sea-level changes: An integrated approach (Vol. 42, pp. 71–108). Society of Economic Paleontologists and Mineralogists, Special Publication.

Harland, W. B., Scott, R. A., Aukland, K. A., and Snape, I., (1992). The Ny Friesland Orogen, Spitsbergen. Geological Magazine, 129, 679–707.

Head, I. M., Jones, D. M. and Larter, S. R., (2003). Biological activity in the deep subsurface and the origin of heavy oil. Nature, 426, 344-352.

Hooper, R. J., Fitzsimmons, R. J., Grant, N., and Vendeville, B. C., (2002). The role of deformation in controlling depositional patterns in the south-central Niger Delta, west Africa. Journal of Structural Geology, 24, 847–859.

Hospers, J., (1971). The Geology of the Niger delta area. Great Britain Institute of Geological science report, 70 (16): 121 -142.

Iwuoma J. O and Minapuye I. O. (2016). Structural Interpretation and Hydrocarbon Potential of Obua Field, Niger Delta, Southern Nigeria. International Journal of Science Invention Today (www.ijsit.com), 5 (2), March-April 2016.

Khalivov, N. Y., and Kerimov, A. A., (1983). Origin of mud volcanism and diapirism. International Geological Review, 25, 877–881.

Knox, G. J., and Omatsola, E. M., (1989). Development of the Cenozoic Niger delta in terms of the "Escalator Regression" model and impact on hydrocarbon distribution. In Proceedings of the KNGMG Symposium on Coastal Lowlands, Geology and Geotechnology, 1987 pp. 181–202.

Kulke, H., (1995). Nigeria, in, Kulke, H., ed., Regional Petroleum Geology of the World. Part II: Africa, America, Australia, and Antarctica: Berlin, Gebrüder Borntraeger, pp. 143-172.

Ladipo, K. O., Nwajide, C. S., and Akande, S. O., (1992). Cretaceous and Paleogene sequences in the Abakaliki and Anambra basins, southeastern Nigeria: A field guide. Port Harcourt: International Symposium on Geology of Deltas.

Larionov, V. V., (1969). Radiometry of boreholes (in Russian), NEDRA, Moscow.

Lehner, P., and De Ruiter, P. A. C., (1977). Structural history of Atlantic Margin of Africa: AAPG Bulletin, vol. 61, pp. 961-981.

Magbagbeola, O. A., and Willis, B. J., (2007). Sequence stratigraphy and Syndepositional deformation of the Agbada formation, Robert kiri field, Niger Delta, Nigeria. American Association of Petroleum Geologists Bulletin, 91(7), 945–958.

Merki, P. J., (1972). Structural Geology of the Cenozoic Niger delta. In: Dessauvagie, T.F.J and Whiteman, A.J(eds). African Geology, University of Ibadan press: 635-646.

Morgan, R., (2004). Structural controls on the positioning of submarine channels on the lower slopes of the Niger Delta. Geological Society (London) Memoir, 29, 45–51.

Morley, C.K., (1992). Notes on Neogene basin history of the Western Alboran Sea and its implications for the tectonic evolution of the Rif-Betic orogenic belt. Journal of African Earth Sciences, 14, 57-65. -& GUERIN, G. 1996. Comparison of gravity-driven deformation styles and behaviour associated with mobile shales and salt. Tectonics, 15, 1154-1170.

Morley, C. K., Crevello, P., and Ahmad, Z. H., (1998). Shale tectonics and deformation associated with active diapirism: The Jerudong anticline, Brunei Darussalam. Journal of the Geological Society (London), 155, 475–490.

Nton, M. E., and Adesina, A.D., (2009). Aspects of structures and depositional environment of sand bodies within Tomboy Field, offshore western Niger Delta, Nigeria., RMZ – Materials and Geoenvironment, Vol. 56, 3, 284–303

Nton, M. E., and Adebambo, B.A., (2009). Petrophysical evaluation and depositional environments of reservoir sands of X- field, offshore Niger Delta, Nigeria. Mineral Wealth 151, 7-18,

Nyantakyi, E. K., Hu, W. S., Borkloe, J. K., Qin, G., and Han, M. C., (2013). Structural and Stratigraphic Mapping of Delta Field, Agbada Formation, Offshore Niger Delta, Nigeria. American Journal of Engineering Research (AJER), 2, 11, pp-204-215.

Obiosio, E. O., (2013). Biostratigraphy and Paleoenvironment of Bolivina fauna from the Niger Delta, Nigeria. Earth Science Research. 2 (2): pp. 80 – 90.

Okosun, E. A., and Liebau, A., (1999). Foraminiferal Biostratigraphy of Eastern Niger Delta, Nigeria. Nigerian Association of Petroleum Explorationist Bulletin. 13 (2): pp. 136 - 156

Okosun, E. A., Chukwu, J. N., Ajayi, E. G., and Olatunji, O. A., (2012). Biostratigraphy, Depositional Environment and Sequence Stratigraphy of Akata Field (Akata 2, 4, 6 and 7 Wells), Eastern Niger Delta, Nigeria. International Journal of Scientific & Engineering Research3 (7): pp. 1 – 27

Ologe, O., Ola-Buraimo, A. O., and Bankole S. A., (2013). 3-D Seismic Structural Interpretation of a Part of Aloo-Field, Southwestern Niger-Delta, Nigeria. Journal of Science Research. 12: pp. 305-313.

Oluwatosin, J. R., (2010). Sequence stratigraphy study within a chronostratigraphic framework of 'Ningning field', Niger Delta. RMZ - Materials and Geo environment. 57: pp 475 – 500.

Opara, A. I., Anyiam, U. O., and Nduka, V., (2011). 3-D Seismic Interpretation and Structural Analysis of Ossu Oil Field, Northern Depobelt, Onshore Niger Delta, Nigeria. The Pacific Journal of Science and Technology; 12, (1) pp. 2-8.

Owolabi, O. O., Longjohn, T. F. and Ajienka, J. A., (1994). An empirical expression for permeability in unconsolidated sands of the eastern Niger delta. Journal of Petroleum Geology. 17 (1), pp. 111–116.

Owoyemi, A. O., and Willis, B. J., (2006). Depositional patterns across syn-depositional normal faults, Niger Delta, Nigeria. Journal of Sedimentary Research, 76 (1–2), pp. 346–363.

Ozumba, B. M., (1999). Middle to Late Miocene sequence stratigraphy of the Western Niger Delta. Nigerian Association of Petroleum Explorationist Bulletin, 13 and 14(2), pp. 176–192.

Ozumba, M. B. and Amajor, L. C., (1999). Evolutionary Relationships in some benthonic foraminifera of the Middle to Late Miocene, Niger Delta. Nigerian Association of Petroleum Explorationist Bulletin. 14 (2): pp. 157-167

Pacht, J. A., and Hall D. J., (1993). Sequence stratigraphic approach to exploration in offshore Nigeria 1, pp. 241–248. Offshore Technology Conference.

Petters, S. W., (1982). Central West African Cretaceous-Tertiary benthic foraminifera and stratigraphy: Palaeon tographia, A 179, pp. 1–104.

Petters, S. W., (1984). An ancient submarine canyon in the Oligocene-Miocene of the western Niger Delta. Sedimentology 31, pp. 805–810.

Reijers, T. J. A., Petters, S. W., and Nwajide, C. S., (1997). The Niger Delta Basin, in Selley, R.C., ed., African Basins--Sedimentary Basin of the World 3: Amsterdam, Elsevier Science, pp. 151-172.

Reijers, T. R. A., (2011). Stratigraphy and Sedimentology of the Niger Delta. Geologos. 17(3). pp 133-162. Doi:10.2478/v10118-011-008-3.

Rensbergen, P. V., and Morley, C. K., (2000). 3D seismic study of a shale expulsion syncline at the base of the Champion delta, offshore Brunei, and its implications for the early structural evolution of large delta systems. Marine and Petroleum Geology, 17, pp. 861–872.

Rensbergen, P. V., Morley, C. K., Ang, D. W., Hoan, T. Q., and Lam, N. T., (1999). Structural evolution of shale diapirs from reactive rise to mud volcanism: 3D seismic data from the Baram delta, offshore Brunei Darussalam. Journal of the Geological Society (London), 156, pp. 633–650.

Santos1 R. G., W. Loh, A. C. Bannwart, and O. V., Trevisan, (2012). An overview of heavy oil Properties and its recovery and transportation methods. Brazilian Journal of Chemical Engineering: 31, 3, pp. 571 – 590.

Short, K. C. and Stauble, A. J., (1967). Outline geology of the Niger Delta. American Association of Petroleum Geologists Bulletin51: pp. 761-779.

Soronnadi-Ononiwu, G. C., Omoboriowo, A. O., Yikareboga, Y., and Madu, V.C., (2013). Paleoenvironmental and sequence stratigraphic studies of the D7000 sand, 'Erne' field, Niger Delta, Nigeria. Greener Journal of Physical Sciences. 3: pp. 6 -18.

Stacher, P., (1994). Niger Delta hydrocarbon habitat. Nigerian Association of Petroleum Explorationists Bulletin, 9(10), pp. 67–75.

Stacher, P., (1995). Present understanding of the Niger delta hydrocarbon habitat, in Oti, M. N. and Postma, G., (eds). Geology of deltas: Rotterdam, A.A. Balkema: pp. 257-267.

Stoneley R., (1966). The Niger delta region in the light of the theory of continental drift. Geological Magazine 103. pp. 385–397.

Vail, P. R., (1987). Seismic stratigraphy interpretation using sequence stratigraphy, part 1: Seismic stratigraphy interpretation procedure. In A. W. Bally (Ed.), Atlas of seismic stratigraphy. American Association of Petroleum Geologists.

Weber, K. J., and Daukoru, E., (1975). Petroleum geology of the Niger Delta: Ninth World Petroleum congress Tokyo proceedings. (Geology), 2, pp. 209 – 221

Whiteman, A., (1982). Nigeria; Its Petroleum geology, resources and potentials, 1 and 2: London, Graham and Trotman Ltd: pp. 176-238.

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