

Integrated Reservoir Characterization and Volumetric Re-evaluation of the 'WOFEM' Field Onshore Niger-Delta for Field Review

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Abstract: As campaign is ongoing and efforts are put in place to increase the Nigeria total oil production rate above 1.75 million BOPD, it is expedient to carry out the petrophysical re-evaluation of some of the fields in order to understand the reservoir behaviour and possibly optimize production. In this work, all the hydrocarbon bearing reservoirs were mapped and correlated across the three (3) wells and the petrophysics were evaluated accordingly. This work reveals that there is decrease in the Net to Gross (NTG), porosity and the water saturation (Sw) with increase in depth. The decrease in the NTG of this field may be due to the frequent intercalation of the shale. The closer we approach the Akata Formation the more shaly the sand becomes. We can infer that the decrease in the porosity with increase in depth in this field is due to compaction as a result of the load of the overburden. The anomalies in the trend may likely be the resultant effect of the mud in the invasion zones. The NTG ranges between 0.43 and 0.98, Porosity ranges between 0.17 and 0.28 and the Sw ranges between 0.12 and 0.40. Three (3) reservoirs were selected for volumetric re-evaluation based on their NTG and porosity values. The B3 reservoir at the depth of 8243ft has the lowest volume Stock Tank Oil Initially in Place (STOIIP) with about 14.31MMBO while the C1 reservoir had the highest volume with a STOIIP of about 14.71MMBO.

Keywords: Reservoir characterization, Niger-Delta Basin, oil and gas, STOIIP, Petrophysical parameters

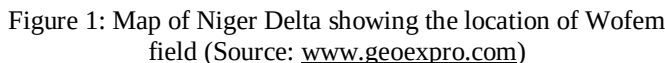
I. Introduction

The increase in the global energy demand has placed both pressure and greater challenge to increase energy supply. The advancement in computational technology to evaluate the probability of hydrocarbon presence in any basin has reduced the risk factor associated with hydrocarbon exploration. In Nigeria, oil almost constitutes exclusively the revenue base for national development and as such it demands greater efforts from both the government and the research institutions to ensure that this non-renewable resource is adequately and optimally tapped. As campaign is ongoing and efforts are put in place to increase the Nigeria total oil production rate above 1.75 million BOPD (NUPRC), it is expedient to carry out the petrophysical re-evaluation of some of the fields and understand the reservoir behaviour.

The Niger Delta Province contains only one identified petroleum system (Kulke, 1995; Ekweozor and Daukoru, 1994). The Agbada Formation is characterized by alternating sand and shale units varying in thickness from 100ft to 1500ft. (Doust and Omatsola, 1990). The sand in this Formation is mainly hydrocarbon reservoir with shale providing lateral and vertical seal. Recent works on the reservoir characterization of some fields in Niger-Delta include that of Obiora et al (2016), Olaleye et al (2021) and Lawson and Balogun (2023). Obiora et al (2016), in his work on Royal onshore field revealed that the average porosity values in the field ranges from 0.18 and 0.24. Other various works such as sequence stratigraphy, structural analysis and hydrocarbon prospects etc. have also been carried out in different parts of the Niger Delta by various workers. Nyantakyi et al. (2013) carried out the structures and hydrocarbon prospects in EMI field using integrated subsurface interpretation techniques and identified six (6) counter regional faults and delineated four (4) horizons. These counter regional faults were trending west-east and dipping south-east and that the faults were sealing on the up-thrown side of the fault where most of the hydrocarbon accumulation could be trapped. The work done by Oresajo et al. (2015) on sequence stratigraphy and structural analysis of EMI field using integrated subsurface interpretation techniques revealed three (3) major depositional sequence and that the transgressive sands and the highstand sands constitute good (potential) reservoir while the corresponding shales form seals for the potential traps in the field. The work done by Olowokere (2009) on 3D Seismic Evaluation and Opportunity Identification in some parts of the Niger Delta reveal that most structures consist of tilted fault blocks both in a foot wall and hanging wall setting, some of them in collapsed crests. Very few four way dip closures were identified and those that do exist show limited areal extent. Olowokere et al. (2011) carried out the Porosity and Lithology Prediction in Eve Field, Niger Delta using Compaction Curves and Rock Physics Models (CCRPM) and observed that the Plots of sonic porosity against depth show great dispersion in porosity values while plotting porosity values against depth for different lithologies produced well-defined porosity trends. This shows decrease in porosity with depth.

This work aims to characterize the ‘Wofem’ field by evaluating its petrophysical parameters and base on that determine the stock tank oil initially in place volume of selected reservoir using seismic data and composite well logs (which include the Gamma Ray, Resistivity, Caliper, Sonic and Neutron Density logs) data.

Geologic setting: Wofem Field is located in the Greater Ughelli onshore depobelt of the Niger Delta basin and lies within latitude 5° - 6° N and longitude 5°15' - 5°34'E. The Niger Delta, situated at the apex of the Gulf of Guinea on the west coast of Africa, and it covers an area of about 75 000 km² (Fig. 1) (Nyantakyi *et al.* 2013).



The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and southwestern Cameroon. The northern boundary is the Benin flank: an east-northeast trending hinge line south of the West Africa basement massif. The northeastern boundary is defined by the outcrops of the Cretaceous Abakaliki High and further east-south-east by the Calabar flank: a hinge line bordering the adjacent Precambrian basement complex. The offshore boundary of the province is defined by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey basin (the eastern-most West African transform-fault passive margin) to the west, and the two kilometer sediment thickness contour or the 4000-meter bathymetric contour in areas where sediment thickness is greater than two kilometers to the south and southwest (Fig. 2). The province covers 300,000 km² and includes the geologic extent of the Tertiary Niger Delta (Akata-Agbada) Petroleum System.



Dataset

Well log and 3D seismic data were provided for this study. The well log data provided include; gamma ray, spontaneous potential, resistivity, caliper, neutron, density, sonic, deviation data, and checkshot data. Three (3) wells have been drilled; WOFEM-01 with total depth of 13251.47ftSS, WOFEM-02 with depth of 10976.70ftSS and WOFEM-03 with depth of 11005.39ftSS. Two (2) were vertical wells and one (1) is a deviated well with deviated data. All the wells has gamma ray log, resistivity log, neutron log, density log and sonic log; only WOFEM-01 has spontaneous potential log and a checkshot data but no caliper log; only WOFEM-02 has a deviation (figure 3). The 3D seismic data has 614 inlines and 590 crosslines with time range from 0 – 5600ms. The whole seismic data covers a total area of 64.7955sq.km. From about 0 – 1000ms the quality of the seismic was fair, it was good from about 1000ms–2600ms and at time greater than 2600ms the seismic was poor (Fig. 3).

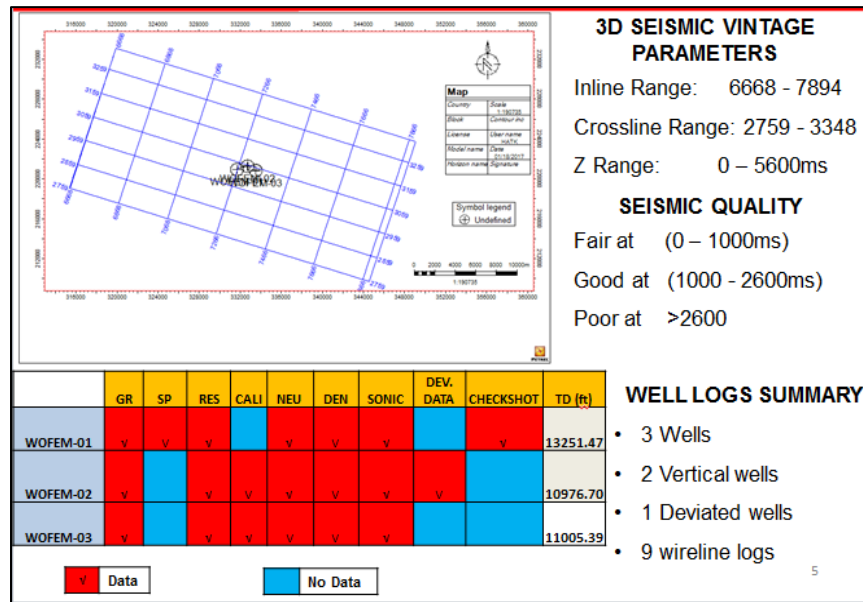


Figure 3: The summary of the data set

II. Methodology and interpretation

Methodology: Well log data with higher-vertical resolution with respect to that of seismic data, but of very shallow lateral penetration provided petrophysical parameters in the rock formations adjacent to the borehole. The Post Stack Time Migrated 3-D seismic data were used to delineate geophysical structure evidenced by continuous lateral reflection events. Surface seismic data with high-lateral resolution, but of low vertical- resolution, provided acoustic impedance data. Amplitude variation of the same reflections was interpreted in terms of lateral and vertical changes in petrophysical properties and lithologies for reservoir characterization.

This method provides processing steps which bring the two sets of measurements to common physical base and to a common time/depth domain.

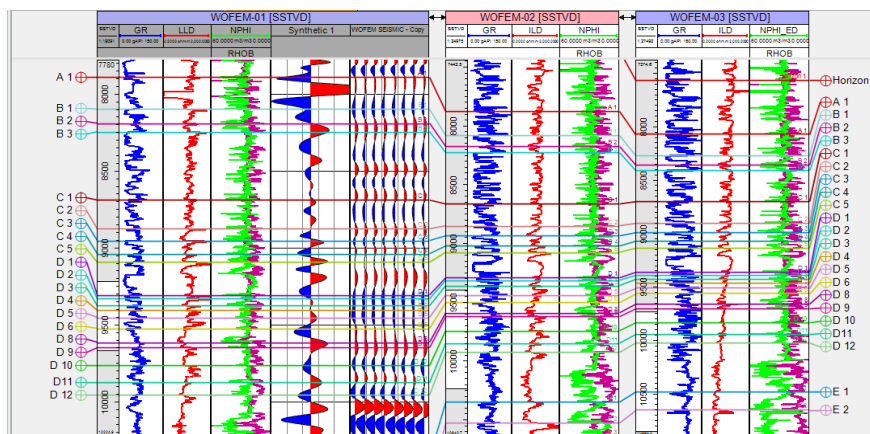


Fig. 4. Well correlation panel across 3 wells

The first step involved delineating the reservoir sands and saturating fluids in terms of standard petrophysical parameters (well log interpretation). This step aided in the interpretation of vertical - resolution of the field. The interpretation and correlation of different lithologies from the well logs were carefully carried out, noting and picking areas of sand and shale development from gamma ray and resistivity logs (Fig. 4). The depth boundaries of such compartments were transformed into time domain to provide reference markers to the seismic data. Subsequently, seismic time horizons were tied to the markers and laterally followed across the complete seismic cube to reconstruct the local structural traps and stratigraphic embedding. Petrophysical parameters were also determined from the logs. The porosity (ϕ) was derived from the sonic log using the Wyllie et al. (1958) equation and the water saturation (S_w) was derived using the Archie (1942) equation.

$$\phi_s = \frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_{fl} - \Delta t_{ma}} \quad (i)$$

Where:

ϕ_s = sonic porosity

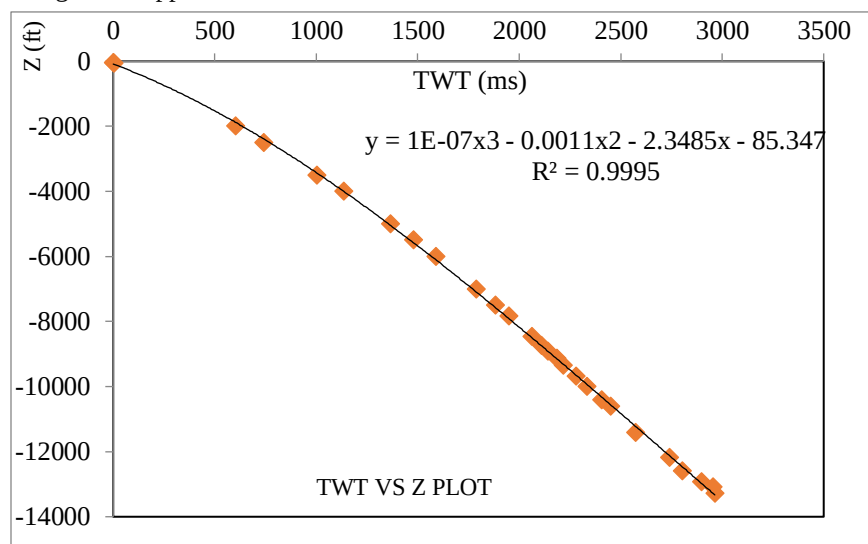
Δt_{ma} = matrix interval transit time

Δt_{log} = interval transit time of the formation (from the sonic log)

Δt_{fl} = fluid interval transit time

Oil water contact (OWC) was determined based on the resistivity response and neutron - density logs cross plot. The second step involved the application of seismic, structural and stratigraphic interpretation techniques, after tying the log markers (well tops) to the seismic time section. This method involves fault interpretation (i.e. the identification of prominent features such as major and minor faults), and the delineation / mapping of continuous seismic reflection events (i.e. horizon interpretation).

To integrate the two sets of the measurements, velocity model was built with a check shots of the control well and stacking velocity of the area for the conversion of Time-Depth using third-order polynomial function with Microsoft Excel software (Fig. 5). The model was used to convert time structure map to the depth map of the selected horizons and the fault traces were posted to the structural maps produced using Petrel application.



Interpretation: All the hydrocarbon bearing reservoirs were mapped across the three wells making a total of twenty-three (23) reservoirs: 4 A and B series, 5C series, 12D series, and 2E series. Petrophysical parameters (NTG, ϕ , k , S_w) was derived from the density log, and the water saturation S_w , was derived using Archie's (1942) equation.

(ii)

Where:

S_w = water saturation of the uninvaded zone

a = tortuosity factor

R_t = true formation resistivity

m = cementation exponent

R_w = resistivity of formation water at formation temperature

n = saturation exponent

Φ = porosity

Three horizons; B3, C1 and D12 were mapped through all the seismic sections. Eleven faults were identified in the field; four (4) major faults and seven (7) minor faults which were identified mainly on abrupt termination of reflection events and interpreted on the inlines. These faults were trending west-east and dipping southwest. Fault traces at all levels was consistent. The horizons were then tied at their intersection points in order to ensure consistency in all the lines of intersections and in all the seismic sections which covered the entire survey area. The horizons mapped were laterally continuous on the seismic records and formed a closed loop along the tie lines. All the structural closures in the region are faults dependent mainly three-way closure (Fig. 6). These closures were identified as good traps for hydrocarbon.

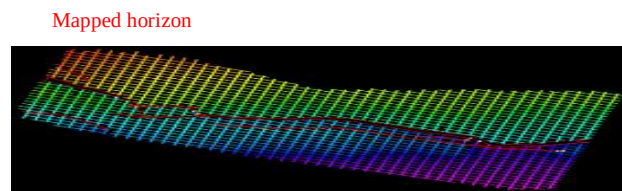
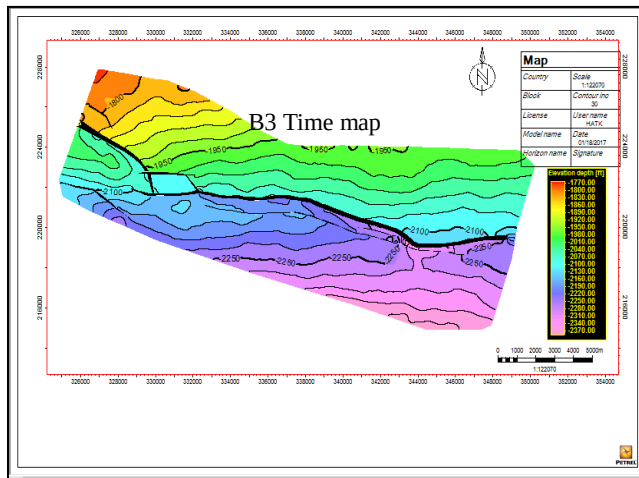


Fig. 6 (a) The structural time map of the B3 reservoir

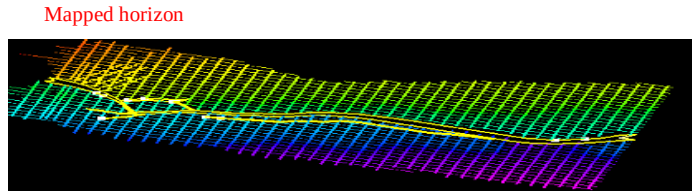
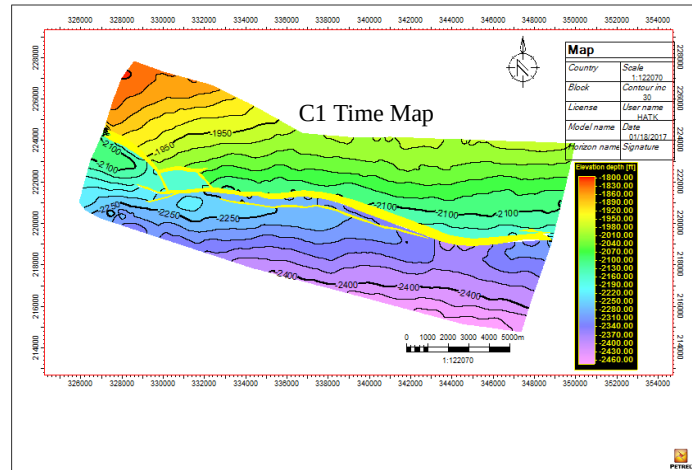


Fig. 6 (b) The structural time map of the C1 reservoir

Table 1: The result of the petrophysical parameters of the twenty-three reservoirs

Reservoirs	Depth	Gross (ft)	Net (ft)	NTG	Poro	Perm.	Sw
A1	7891	18	17.6	0.98	0.28	208.57	0.38
B1	8094	57	51.9	0.91	0.26	229.57	0.29
B2	8190	18	15.7	0.87	0.24	97.50	0.35
B3	8246	96.2	81.8	0.85	0.24	97.50	0.35
C1	8687	117.4	74.9	0.64	0.22	44.29	0.4
C2	8874	31.8	23.5	0.74	0.24	132.71	0.3
C3	8953	34.2	33.2	0.97	0.24	109.68	0.33
C4	9038	26.4	23.8	0.9	0.23	64.07	0.38
C5	9091	31.9	28.4	0.89	0.23	209.80	0.21
D1	9306	19.5	18.6	0.95	0.22	361.54	0.14
D2	9328	20.3	16.6	0.82	0.24	829.44	0.12
D3	9375	20.1	15.9	0.79	0.17	9.43	0.4
D4	9406	38.3	31.4	0.82	0.21	110.75	0.22
D5	9452	55.6	28	0.5	0.2	54.87	0.27

D6	9523	56.2	50.2	0.89	0.22	34.99	0.45
D8	9615	21	9	0.43	0.21	317.18	0.13
D9	9647	63.2	36.1	0.57	0.2	47.56	0.29
D10	9763	92.2	53.6	0.58	0.21	148.49	0.19
D11	9872	21	9.1	0.44	0.17	11.64	0.36
D12	9956	114.9	97.7	0.85	0.2	32.65	0.35
E1	10360	51.2	38.3	0.75	0.21	31.89	0.41

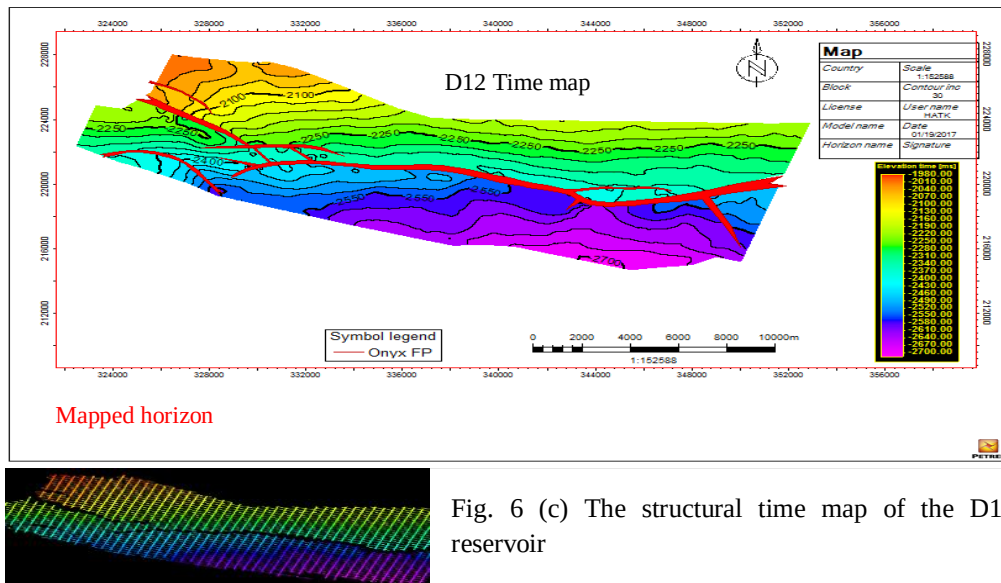


Fig. 6 (c) The structural time map of the D12 reservoir

III. Result Presentation and Discussion

The Petrophysical parameters

The porosity derived from the wells using the porosity cut off of 15% for Niger delta (Doust and Omatsola, 1990) show that the reservoirs have good sand. From all the twenty-three (23) reservoirs that were evaluated for petrophysical evaluation, the A1 reservoir has the highest net to gross (NTG) of 0.98 while the D8 reservoir has the least net to gross (NTG) of 0.43. The average NTG of the field is 0.82. The porosity of the field ranges from 0.17 to 0.28 with an average porosity of 0.22. The A1 reservoir has the highest porosity while the D3 and D11 equally have the least porosity (Table 1). Different reservoir has different water saturation, the water saturation (S_w) of these reservoir ranges from 0.12 to 0.45 (Table 1).

Generally, the result shows that there is decrease in the NTG, porosity, and water saturation with increase in depth of the reservoirs. The decrease in the NTG of the reservoir with depth may likely due to the frequent intercalation of the shale down dip. The more we approach the Akata Formation, the more shaly and dirty the sand becomes (Fig.11). The decrease in the porosity of the reservoir with depth may like due to compaction as a result of the weight of the overburden load. The anomalies observed in the trend are due to the prograding nature of the sand (Fig. 12).

In-Place Volume of Selected Reservoirs

The results from the three reservoirs (B3, C1 and D12) selected for volumetric evaluation show that Wofem-01 is optimally positioned on the crest of the structure and the Wofem-02 and Wofem-03 are towards the flank of the structure. The B3 reservoir at the depth of -8246ftSS made only one discovery with the oil water contact (OWC) at -8280ft (fig.15). The reservoir has a gross thickness of 96.2ft and net thickness of 81.8ft (Table 1).

The stock tank oil initially in place volume (STOIIP) was computed using the formula;

$$STOIIP = \frac{7758 * GRV * NTG * \phi * S_o}{Bo} \quad (ii)$$

Where;

GRV = Gross Rock Volume

NTG = Net to Gross sand

ϕ = Reservoir porosity

S_o = Oil saturation

B_o = Oil formation volume factor

But,

$$GRV = Area * Thickness \quad (iii)$$

And,

$$S_o = 1 - S_w \quad (iv)$$

The B3 reservoir has a stock tank oil initially in place (STOIIP) volume of 14.31MMBO (Table 3). The C1 reservoir at the depth of -8687ftTSS made only one discovery with the oil water contact (OWC) at -8730ft (Fig. 6b). It has a gross thickness of 117.4ft and net thickness of 74.9ft (Table 1). The C1 reservoir has a STOIIP volume of 14.71MMBO (Table 3). The D12 reservoir made two discoveries at the depth of -9956ftSS with the deepest OWC at -10015ft (Fig. 17). It has a STOIIP volume of 14.68MMBO (Table 3).

Table 2: The volumetric result of the selected reservoirs

Reservoirs	Area (Acre)	Thickness (ft)	Gross (ft)	Net (ft)	NTG	Conv. Factor	Poro	Bo	So	Sw	STOIIP(MBO)
B3	429.45149	34	96	81.6	0.85	7758	0.24	1.05	0.65	0.35	14.305302
C1	547.94233	43	117	78.8	0.64	7758	0.22	1.05	0.60	0.4	14.706783
D12	411.64279	59	115	97.7	0.85	7758	0.2	1.418	0.65	0.35	14.682782

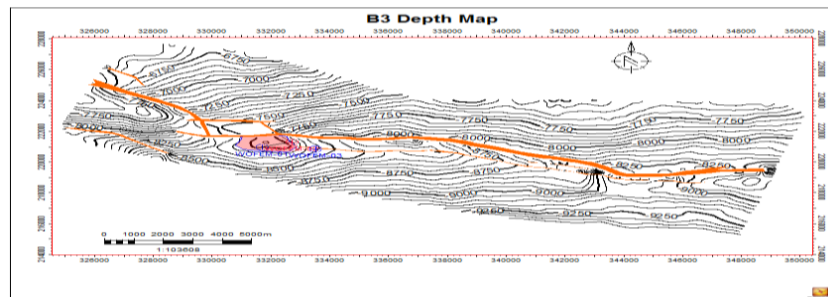


Fig. 7: B3 reservoir depth map

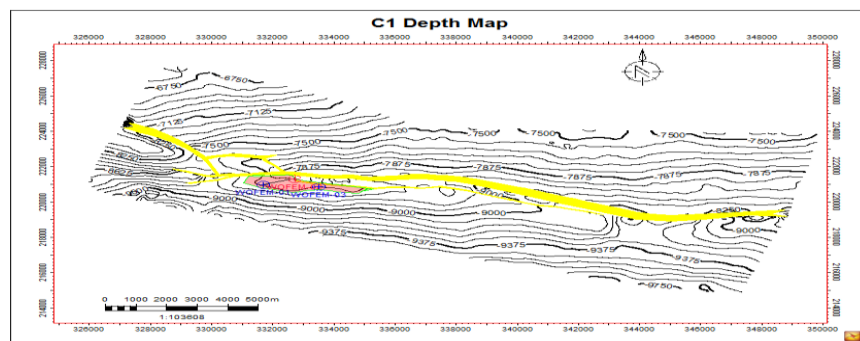


Fig. 7b: C1 reservoir depth map



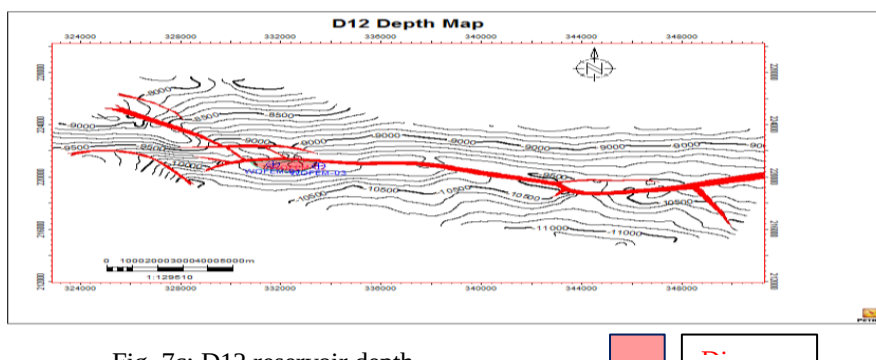


Fig. 7c: D12 reservoir depth

IV. Conclusion

From all the hydrocarbon bearing sands correlated across the three wells, it is observed that the net to gross, porosity and water saturation decreases down with depth. The net to gross of the reservoirs in the field ranges from 0.43 to 0.98 with an average of 0.82 and the porosity ranges from 0.17 to 0.28 with an average of 0.22 (which corresponds to that of Royal onshore field) while the water saturation ranges from 0.12 to 0.40. The decrease in the net to gross is as a result of the frequent intercalation of the shale. The closer we approach the Akata Formation the dirtier the sand becomes. The decrease in the porosity is as a result of the compaction due to sediment load (weight of the overburden load) and the anomalies in the trend are likely due to the overall prograding nature of the sand. The three reservoirs selected for volumetric evaluation indicate that C1 reservoir at the depth of -8687ftSS has the highest stock tank oil initially in place (STOIIP) volume with 14.71MMBO followed by the D12 reservoir at the depth of -9956ftSS with a STOIIP of about 14.68MMBO while the B3 reservoir at the depth of -8246ftSS has the least with a STOIIP volume of about 14.31MMBO. For profit maximization of the asset, other prospects should be identified and evaluated. For development planning, the shallower reservoir should be the target based on the high NTG as well as porosity and positioned up-dip between Wofem-02 and Wofem-03 or to the left of Wofem-01. Drill stem testing (DST) and other dynamic test should be carried out to ascertain the flow behavior of the reservoirs. Also, the seismic data should be re-processed to allow for better imaging of deeper prospects, faults and amplitudes.

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Conflict of Interest: The authors declare no conflict of interest

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Data Availability: The data used for this study are highly classified data and as such cannot be publicly shared due to confidentiality restrictions.