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Petrophysical Analysis and Volumetric Estimation of Otu Field, Niger Delta Nigeria, Using 3D Seismic and Well Log Data

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Authors' contributions

This work was carried out in collaboration between all authors. Author TNO designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author EEB managed the literature searches and carried out the analysis. All authors read and approved the final manuscript.

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ABSTRACT

Petrophysical analysis and volumetric estimation was carried out using 3D seismic and well log data to evaluate the reservoir potentials of Otu Field in the Niger Delta of Nigeria. Three hydrocarbon bearing reservoirs (C10, D10 and D31) were mapped out of several identified sands. The tops of these reservoirs were tied on the seismic section using checkshots and were traced throughout the seismic volume. Faults were mapped and structure maps for the three reservoir tops were produced. For C10 reservoir mapped at the depth of about 4512 feet, gas-down-to (GDT) was picked at 4525 feet and Oil-water contact (OWC) was picked at 4592 feet. For D10 reservoir mapped at the depth of about 5337 feet, oil-water contact was picked at 5404 feet and D31 reservoir which was mapped at depth 5536 feet has oil-water contact at 5675 feet. The gross thickness of the C10 reservoir sandstone formation ranges from 45 ft to 78.5 ft. Since the reservoir was intercalated with shale, the net thickness varied between 11.5ft and 54.5ft. The gross thickness of the D10 reservoir varied between 55.5 ft and 103 ft; while the net thickness varied between 13 ft and 51 ft. The gross thickness of D31 reservoir varied between 127.5 ft and 273 ft and the net thickness varied between 11 ft and 114 ft. The petrophysical parameters obtained were

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porosity (ϕ) ranging from 0.32 to 0.34, water saturation (S_w) ranging from 0.23 to 0.29, hydrocarbon saturation (S_H) varies between 0.71 and 0.77 and net to gross (N/G) which ranges from 0.21 to 0.47. The volume of the closures (GRV) gotten from the structure maps were combined with the relevant petrophysical parameters to estimate the volume of hydrocarbon in place. The estimation of the volume of hydrocarbon revealed that C10 contains 45.98b ft^3 of gas and 95.18 million stock tank barrels of oil. The D10 and D31 reservoirs have oil with the volume estimated at 21.41 million stock tank barrels and 54.32 million stock tank barrels respectively. The study revealed that the field is prolific and the estimated volumes of hydrocarbon in the closures are satisfactory for further exploration work.

Keywords: Petrophysical; Seismic; Reservoir; Volumetric; Niger Delta.

1. INTRODUCTION

Increasing demand for oil and gas worldwide has caused an increase in exploration and development in pre-explored areas around the world such as the Niger Delta. Consequently, more detailed methods apart from structural approach are being developed which include the characterization of the hydrocarbon reservoirs. The good knowledge of some important factors which includes the character and extent of a hydrocarbon reservoir are important in quantifying the hydrocarbon in place [1]. The reservoir volumetric analysis and estimation of the volume of hydrocarbon in place are possible if the information on the thickness, pore spaces and the areal extent of the reservoir are given. Some other parameters needed are the net to gross ratio, the volume of shale and the saturation values [2].

The reservoir thickness is best determined from cut-offs which are visible on well logs, especially with the gamma ray and resistivity logs (Asquith, 2004). The density-neutron log also provides a means to estimate reservoir thickness in addition to the type of hydrocarbon present in the reservoir [1]. Identification of lithologies like sandstones is done with the help of Gamma ray log. Also Gamma ray logs can be used to identify other lithologies like limestone and dolomites if core data exist. This is because a higher percentage of oil and gas is produced from lithologies like sandstones, limestone and dolomites [3]. The resistivity log differentiates between water and hydrocarbon in the pore space of the reservoir rocks. It is used to obtain the true formation resistivity and to identify the oil-water contact [4]. Since these logs are recorded in terms of depth, the hydrocarbon bearing interval can be determined with reliability.

Accurate mapping of the lateral dimension can either be obtained from well logs, where abundantly available or direct hydrocarbon indicators [5]. To use well log to map the lateral dimension of the reservoir, gas-oil and oil-water contacts are located on structure maps [6].

When mapping reservoir boundaries, the study of subsurface structures that can hold hydrocarbon in place must be considered [7]. Hydrocarbons are found in geologic traps and these traps can either be structural, stratigraphic or a combination of both. According to Doust and Omatsola [8], majority of traps in the Niger Delta are structural. To locate these traps, faults and horizons are mapped on the section to produce the structure maps. This can reveals the structures that can serve as traps for the hydrocarbon accumulations. It is then possible to deduce the relevant petrophysical parameters of the reservoir from the well logs and the gross rock volume of the structure maps for the computation of the volume of hydrocarbon in place.

This study tries using 3D seismic reflection data obtained in Otu field in the Niger delta Nigeria to delineate the lithologies and identify the hydrocarbon bearing reservoir in the field, to locate structural traps by mapping the faults and horizons and making the structure maps to determine the Gross Rock volume (GRV). Then using the well log data obtained to compute the relevant petrophysical parameters of the target reservoirs with the aim of estimating the volume of hydrocarbon in the field.

1.1 Geology of the Study Area

Otu Field is an onshore field located in the Western part of the Niger Delta Area of Nigeria. It lies between latitudes 5° N and 6° N and longitudes 5° E and 6° E. The field covers approximately 720 km^2 and is characterised by NW-SE trending growth faults and associated rollover anticlines which is consistent with the regional structural settings of the Niger Delta.

The Niger Delta, situated on the continental margin of the Gulf of Guinea covers an area of about 75000 km^2 [9]. It is located in the Southern part of Nigeria between latitudes 3°and 6°N and longitudes 4° and 9° E (Fig. 1) and is composed of an overall regressive clastic sequence that reaches a maximum thickness of 9000 to 12000 m [10]. The Niger Delta Basin to date is the most prolific and economic sedimentary basin in Nigeria by virtue of the size of petroleum accumulations, discovered and produced as well as the spatial distribution of the petroleum resources to the Onshore, Continental shelf through deepwater terrains [11]. From the Eocene to the present, the delta has prograded south-westward, forming depobelts that represent the most active portion of the delta at each stage of its development [8].

The Niger Delta Province contains only one identified petroleum system referred to as the Tertiary Niger Delta (Akata –Agbada) Petroleum System [12,13]. The Tertiary section of the Niger Delta is divided into three formations, the Akata, Agbada and Benin formations [14].

The Akata formation is of marine origin and lies at the base of the Niger Delta sequence. It is composed of thick shale sequences (potential source rock) and also of turbidity sand (potential reservoirs in deep water) with minor amounts of clay and silt [15,16,17]. It began in the Palaeocene through the Recent and is estimated that the formation is up to 7,000 m (22,966 ft) thick [8]. The formation underlies the entire delta, and is typically over pressured. Agbada Formation is the major oil and gas reservoir of the delta and began in the Eocene continuing into the Recent. It is the transition zone and consist of intercalation of sand and shale (paralic silica clastics) with over 3700 meter thick and represent the deltaic portion of the Niger Delta sequence [18,19]. The Agbada Formation is overlain by the third formation, the Benin Formation, a continental latest Eocene to Recent deposit of alluvial and upper coastal plain sands that are up to 2000 m thick [19,20]. It is deposited in upper coastal plain environments following a southward shift of deltaic deposition into new depobelt. It traps non-commercial quantities of hydrocarbon and has sand percentage of over 8% [15].

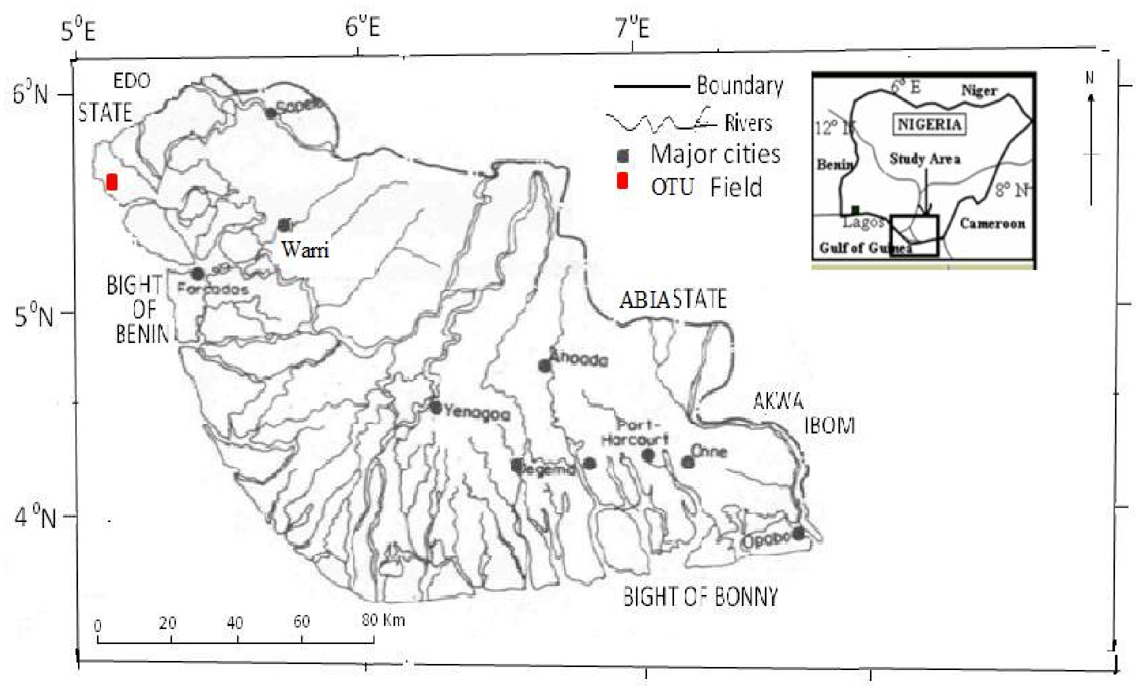

Fig. 1. Location map of the study area (Otu field) in the Niger Delta, Nigeria

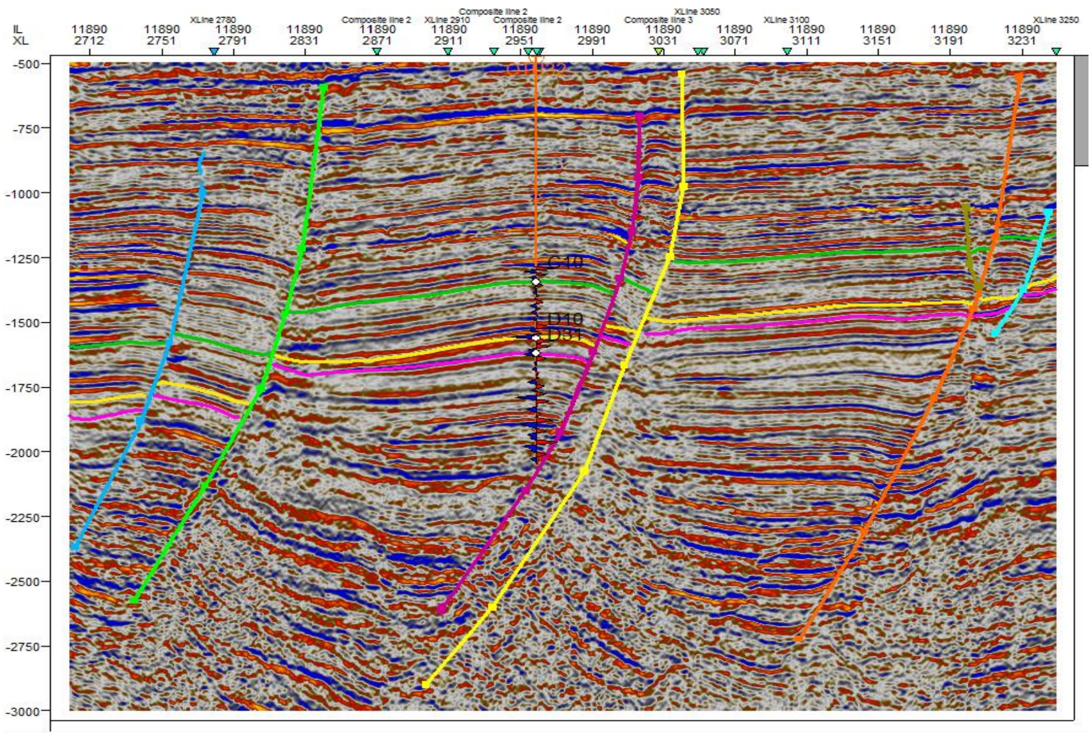

Fig. 2. Seismic Inline showing fault sticks, synthetic seismogram and horizons interpreted

2. METHODOLOGY

The data used for this study was provided by Shell Petroleum Development Company (SPDC), Nigeria. The data include 3D seismic volume in segy format, composite well logs comprising of gamma ray (GR), deep resistivity (R_D), neutron (NEU), density (FDC) and sonic (BHC) as well as checkshots data. Gamma ray log was used to delineate the lithology (sand and shale). The deep resistivity log was used to differentiate between water and hydrocarbon in the pores of the delineated sand reservoirs. Neutron and density logs were combined to identify type of fluid (oil and gas) in the formation as well as picking the fluid contacts. A log correlation connecting the wells across the area was carried out to determine the lateral continuity or discontinuity of the facies and this helped in reservoir distribution prediction. Faults were picked throughout the seismic data. The synthetic seismogram was generated using sonic and density logs as well as checkshots. The synthetic seismogram was used for seismic to well tie and it aided in mapping the delineated hydrocarbon bearing reservoirs on the seismic data (Fig. 2). The delineated reservoir interpreted as horizons on the seismic section (Fig. 2) were used to generate the time structure maps. The time structure was converted to depth maps with the aid of the checkshots. The maps helped to delineate the structures favourable for hydrocarbon accumulation in the field and in locating the hydrocarbon closures.

In order to estimate the volume of hydrocarbon in place, the volumes of the closures were determined and petrophysical evaluation of the reservoirs parameters was carried out. The petrophysical evaluation of the logs was performed using Fugro Jason Powerlog, a Petrophysical evaluation software. Porosity (Φ), the parameter that tells us what fraction of the reservoir volume is pore space – where the fluids are located was generated from density log using Equation (1) [21]:

$$\Phi_d = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}} \quad (1)$$

Where

ρ_{ma} = matrix density
ρ_b = density log represents bulk density of the formation
ρ_{fl} = density of the fluid in the formation

Water saturation (S_w), Volume fraction of porosity filled with interstitial water was computed using Equation (2) [22]:

$$S_w = \left(\frac{aR_w}{PHI^m R_t}\right)^{1/n} \quad (2)$$

Where

a = formation factor coefficient
m = cementation exponent
n = saturation exponent
R_w = water resistivity (Ohm)

R_t = True formation resistivity (Ohm)
PHI = Porosity (dec)

From the water saturation values, the values of the hydrocarbon saturation (S_H) were computed using Equation (3) [22]:

$$S_H = 1 - S_W \quad (3)$$

Net to Gross ratio (N/G) of the reservoirs, percentage of the target interval that is truly reservoir quality i.e. layers from which hydrocarbons can be can produced was also determined using Equation (4).

$$N/G = \frac{\sum(\text{Net Int})}{\sum(\text{Gross Int})} \quad (4)$$

Where Net Int. is the interval of the net pay section of the reservoir. Gross Int. is the interval of the entire reservoir.

The averages of the parameters from the net pay section of the reservoirs were used.

From the depth maps of the surfaces, GRV (Gross Rock Volume) of the prospect was determined. The volume of the hydrocarbon in place was calculated using the simple volumetric equation.

$$STOIIP = \frac{0.1781 * GRV * N/G * \Phi * (1 - S_W)}{B_o} \quad (5)$$

$$GIIP = \frac{GRV * N/G * \Phi * (1 - S_W)}{B_g} \quad (6)$$

Where

STOIIP is the Stock Tank Oil Initially In Place
GIIP is the Gas Initially In Place
GRV is the Gross Rock Volume
N/G is the net to gross
Φ is the porosity,
S_W is the water saturation
B_O is the oil formation volume factor
B_g is the gas formation volume factor

3. RESULTS AND DISCUSSION

A log correlation connecting the wells across the area is shown in Fig. 3 where the entire formations were considered and a good agreement was observed of their continuity within the extent of the well location as this was carried out in strike direction. From the gamma ray log, the interval coloured yellow is sand, while the interval coloured ash is shale. The reservoirs consist of intercalation of sand and shale. It was observed that the reservoirs have more shale content in the North-western region and this shale volume reduces towards the South-eastern region.

From the structure maps produced, structural highs are stretched over the field in the Northeast while structural lows were observed in the Southwest direction. The petroleum trapping systems are fault assisted closures and rollover anticlines this observation is in agreement with [23,24]. The C10 reservoir is an oil/gas reservoir with GDT at 4525 ft and OWC at 4592 ft. Fig. 4 shows depth structure map of C10 with two major faults and other subsidiary faults as well as hydrocarbon contacts and the wells. The D10 reservoir is an oil reservoir with OWC at 5404 ft. Fig. 5 shows depth structure map of D10 with two major faults and other subsidiary faults as well as OWC and the wells. The D31 reservoir is an oil reservoir with OWC at 5675 ft. Fig. 6 shows depth structure map of D31 with two major faults and other subsidiary faults with OWC and the wells. The volumes of the closure (GRV) were determined with the aid of petrel software. These closures are shown on the depth structure maps of the reservoirs.

The green colour in the structure maps indicates the presence of gas in the closure while the red colour indicates the presence of oil.

The petrophysical parameters such as porosity (ϕ), water saturation (S_W), hydrocarbon saturation (S_H) and net/gross (N/G) of the reservoirs have been carefully analysed in order to determine the hydrocarbon potential and economic viability of the field. Some of these parameters are shown in Table 1, 2 and 3.

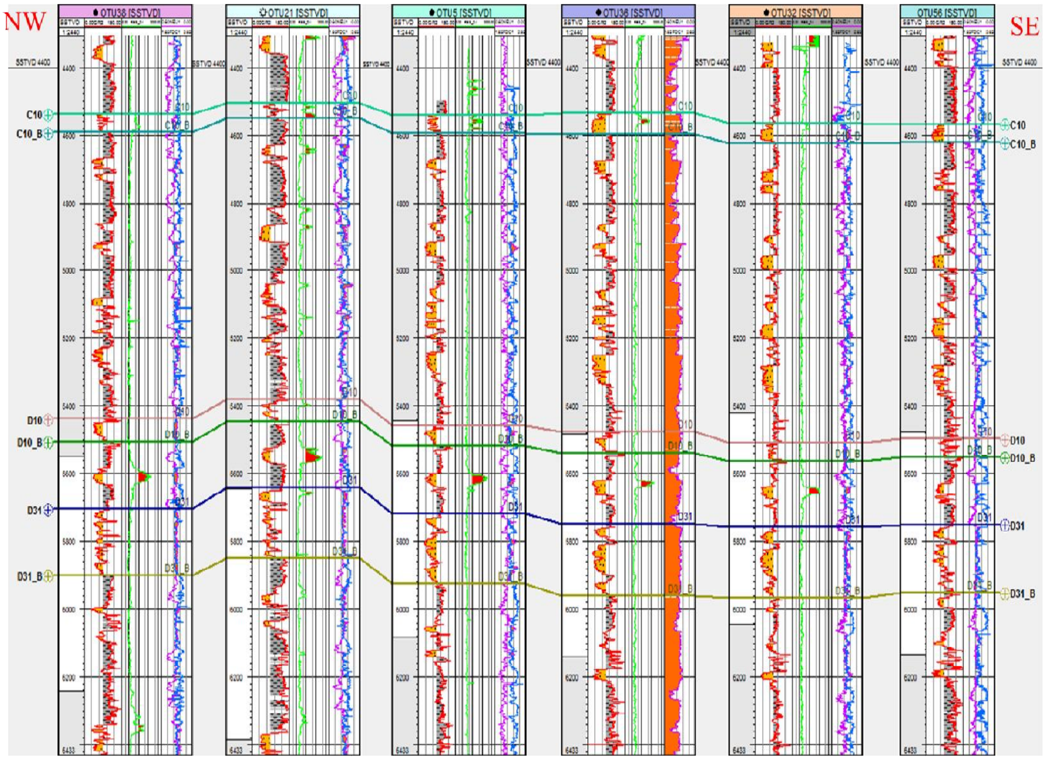

Fig. 3a. Well correlation panel in strike direction

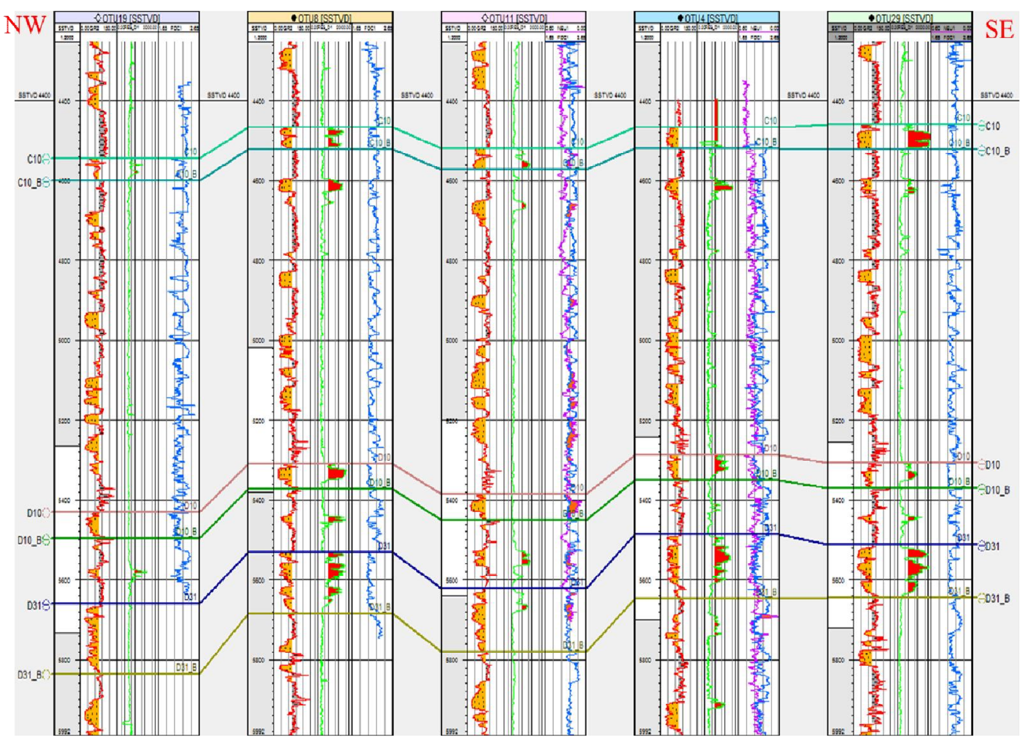

Fig. 3b. Well correlation panel contd

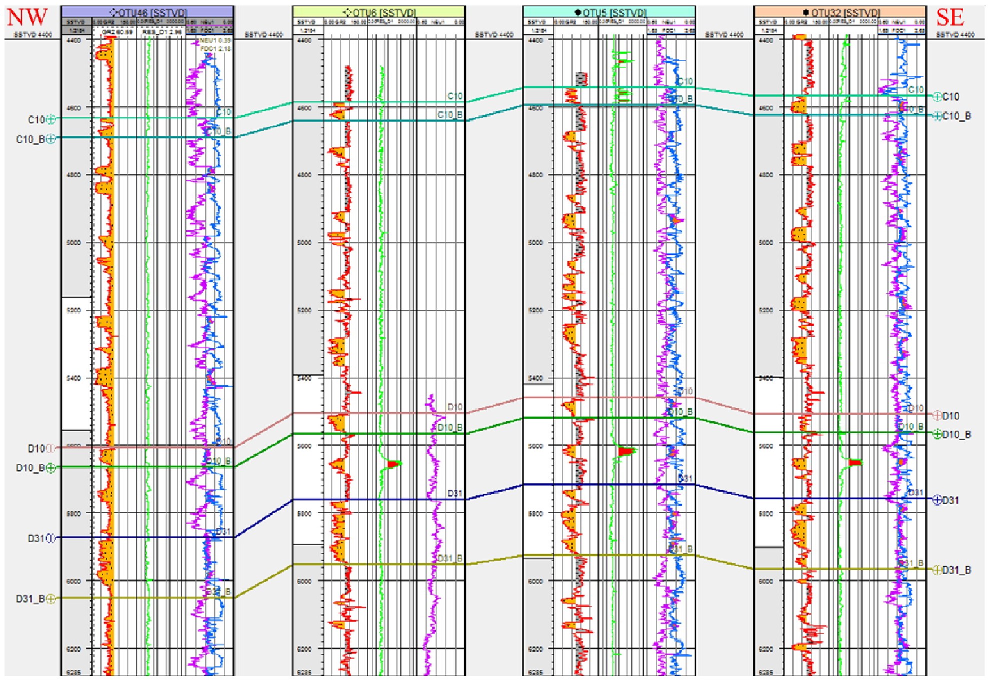

Fig. 3c. Well correlation panel contd

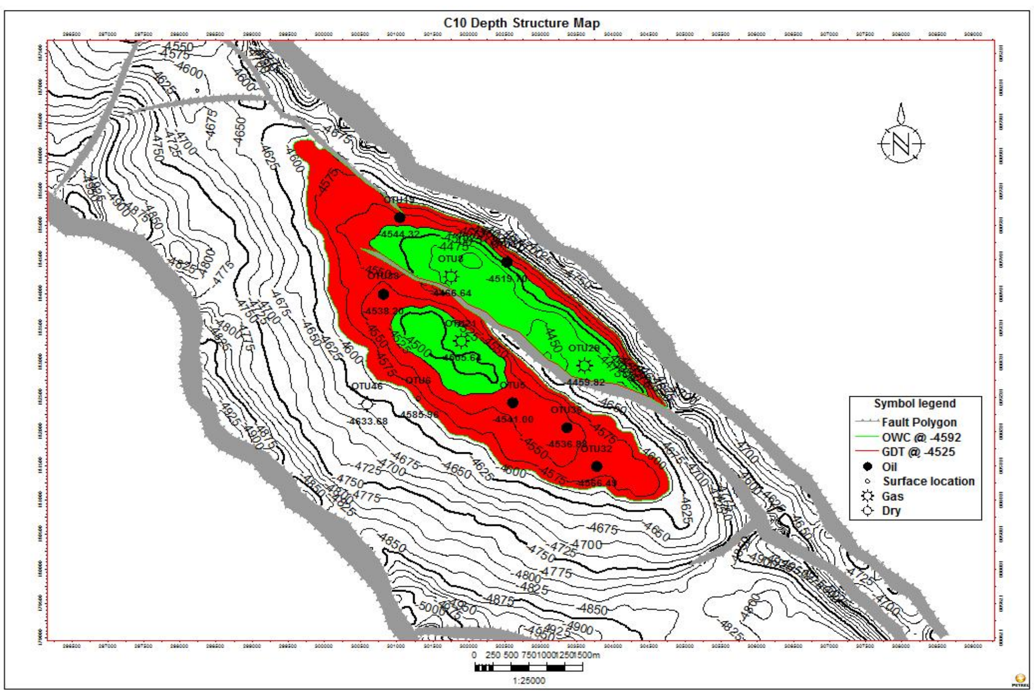

Fig. 4. C10 depth structure map showing the wells tops and hydrocarbon contacts

The analysis revealed that the reservoirs are good quality reservoir sands with average porosities ranging from 0.32 – 0.34, average water saturation ranging from 0.23 – 0.29 and hydrocarbon saturation averaging between 0.71 – 0.77. The net/gross of the reservoir is between 0.21 – 0.47. The averages of these parameters are summarized in Table 4.

These averages were use as input together with the gross rock volume (GRV) in estimating the volume of hydrocarbon in place.

The volumes of hydrocarbon in place for the three reservoirs were estimated as follows. C10 reservoir has a STOIIP of 95.18 mbl and GIIP of 45.98 ft^3 while D10 and D31 have a STOIIP of 21.41mbl and 54.32 mbl respectively. The details of the GRV and the estimated volumes of hydrocarbon are shown in Table 5.

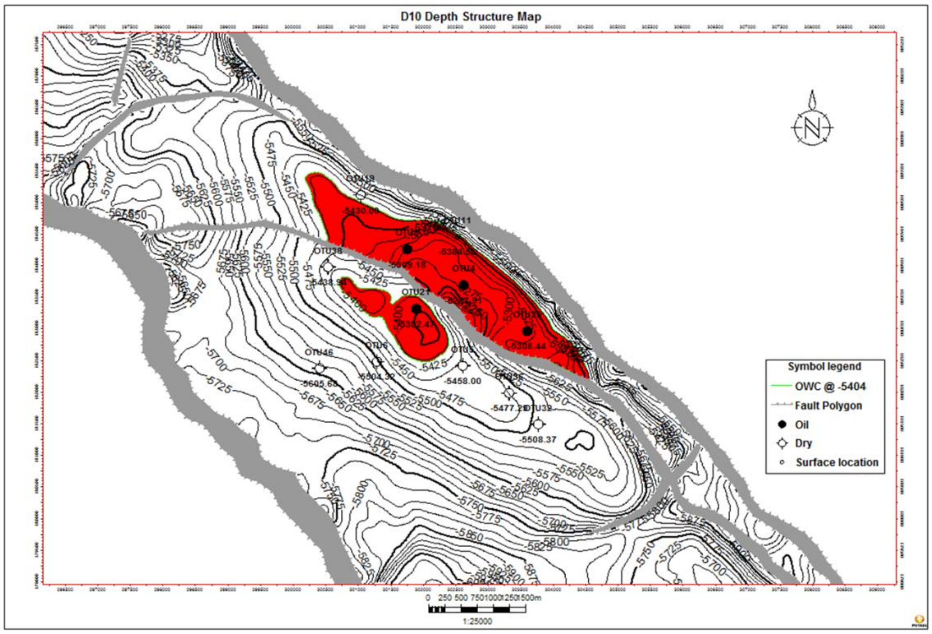

Fig. 5. D10 depth structure map with the wells tops and hydrocarbon contacts

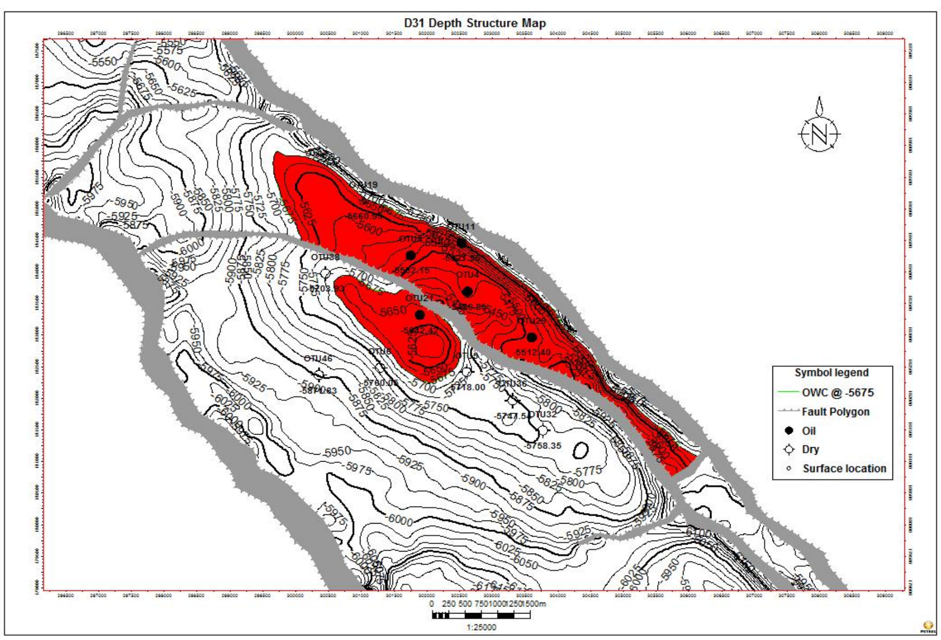

Fig. 6. D31 depth structure map with the wells tops and hydrocarbon contacts

Table 1. The petrophysical parameters for C10 reservoir

Well name	Zone name	Top res (tvd)	Bot res (tvd)	Gross interval	Net pay int (Tvd)	Avg phi (Pay)	Net*phi	Avg net sw (Pay)	Net*phi*sw
OTU5	C10	4591.5	4643.5	53	26.5	0.28	7.42	0.373	2.76766
OTU8	C10	4515	4569	56.5	43	0.347	14.921	0.227	3.387067
OTU11	C10	4570	4622	52.5	39	0.258	10.062	0.288	2.897856
OTU19	C10	4591	4647	57	17.5	0.309	5.4075	0.419	2.265743
OTU21	C10	4553.5	4597.5	45	29	0.365	10.585	0.295	3.122575
OTU29	C10	4512	4574	63.5	54.5	0.3	16.35	0.113	1.84755
OTU32	C10	4617	4673.5	57	11.5	0.359	4.1285	0.461	1.903239
OTU38	C10	5038	5116	78.5	29	0.343	9.947	0.442	4.396574
OTU46	C10	5350	5417.5	68	0	0	0	1	0
				531	250		78.821		22.58826
	Net/Gross	0.47		Ave. Por(Pay)	0.32		Ave. Sw(Pay)	0.29	

Table 2. The petrophysical parameters for D10 reservoir

Well name	Zone name	Top res (tvd)	Bot res (tvd)	Gross interval	Net Pay Int (Tvd)	Avg phi (Pay)	Net*phi	Avg net sw (Pay)	Net*phi*sw
OTU4	D10	5337	5398.5	62	51	0.323	16.473	0.242	3.986466
OTU5	D10	5508	5566.5	61.5	0	0	0	1	0
OTU8	D10	5358	5416.5	63	41	0.351	14.391	0.202	2.906982
OTU11	D10	5435	5498	67.5	0	0	0	1	0
OTU19	D10	5477.5	5541.5	67.5	0	0	0	1	0
OTU21	D10	5432.5	5490	64	13	0.381	4.953	0.436	2.159508
OTU29	D10	5361	5421	62	40	0.354	14.16	0.26	3.6816
OTU32	D10	5559	5614	55.5	0	0	0	1	0
OTU38	D10	6330	6425.5	96	0	0	0	1	0
OTU46	D10	6464	6566.5	103	0	0	0	1	0
				702	145		49.977		12.73456
	Net/gross	0.21		Ave. por(pay)	0.34		Ave. sw(pay)	0.25	

Table 3. The petrophysical parameters for D31 reservoir

Well name	Zone name	Top res (tvd)	Bot res (tvd)	Gross interval	Net pay int (Tvd)	Avg phi (Pay)	Net*phi (Pay)	Avg net sw (Pay)	Net*phi*sw
OTU4	D31	5536.5	5672	136.5	111.5	0.31	34.565	0.239	8.261035
OTU5	D31	5768	5973	206.5	0	0	0	1	0
OTU8	D31	5581	5727	152.5	107.5	0.358	38.485	0.236	9.08246
OTU11	D31	5672	5862	190.5	39	0.283	11.037	0.319	3.520803
OTU19	D31	4100	4100	174.5	0	0	0	1	0
OTU21	D31	5697.5	5895.5	207	11	0.332	3.652	0.322	1.175944
OTU29	D31	5565	5689	127.5	114	0.328	37.392	0.166	6.207072
OTU32	D31	5809	6060.5	252	0	0	0	1	0
OTU38	D31	6707	6979.5	273	0	0	0	1	0
				1720	383		125.131		28.24731
	Net/gross	0.22		Ave. por(pay)	0.33		Ave. sw(pay)	0.23	

Table 4. The Summary of the petrophysical parameters used for the volumetric

Reservoir	N/G	Φ	S_W	S_H	Contact (Feet)	Fluid type
C10	0.47	0.32	0.29	0.71	GDT@-4525/OWC@-4592	Oil & Gas
D10	0.21	0.34	0.25	0.75	OWC@-5404	Oil
D31	0.22	0.33	0.23	0.77	OWC@-5675	Oil

Table 5. Volume of hydrocarbon in place of the reservoirs

Reservoir	FLUID TYPE	GRV(ft^3)	GIIP(ft^3) / STOIIP(bl)
C10	Gas	1,718,080,000	45,980,815,719
C10	Oil	7,256,850,000	95,180,997
D10	Oil	3,255,170,000	21,410,611
D31	Oil	7,910,870,000	54,318,468

4. CONCLUSION

The petrophysical analysis and volumetric estimation of Otu Field revealed that the field is a prolific hydrocarbon zone. Three reservoirs (C10, D10 and D31) were delineated and the petrophysical parameters of these reservoirs were carefully analysed. The analysis revealed that the reservoirs are good quality reservoir sands with average porosities ranging from 0.32 – 0.34, average water saturation ranging from 0.23 – 0.29 and hydrocarbon saturation averaging between 0.71 – 0.77. The net/gross of the reservoir is between 0.21 – 0.47. The C10 reservoir contains oil and gas while D10 and D31 reservoirs are oil bearing. From the volume estimation, 95.18 mbl of oil and 45.98b ft^3 of gas was estimated in C10, while 21.41mbl and 54.32 mbl of oil was estimated for D10 and D31 respectively. The results of these study has shown that incorporation of 3D seismic data with the well logs data have given room for the generation and analysis of 3D images that show more revealing details of the geometry of the geologic features and also the area extent with which volumetric reservoir estimations can be calculated.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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