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Evaluation of Reservoir Property Distribution and Structural Analysis of Onshore Basin Dataset

SOFOLABO O. ADEKUNLE[1] AND IGBOR C. KINGSLEY[2]
[1](*GEOPHYSICS RESEARCH UNIT), DEPARTMENT OF PHYSICS/APPLIED GEOPHYSICS, UNIVERSITY OF PORT HARCOURT)*
[2](*GEOPHYSICS RESEARCH UNIT), DEPARTMENT OF PHYSICS/APPLIED GEOPHYSICS, UNIVERSITY OF PORT HARCOURT)*

ABSTRACT: *Evaluation of the reservoir property distribution and structural analysis of an onshore basin was performed, using dataset from an onshore Niger Delta Basin, Nigeria. This analysis was carried out utilizing well log and seismic information acquired from the field. The identified lithology in the field was found to be an alternation of sand and shale bodies interbedded together and the reservoirs are contained in the sand bodies. Petrophysical analysis was carried out on the reservoirs in the field so as to predict its possibility of hydrocarbon bearing or not. Three main reservoirs were identified and delineated in the field across the three wells used for the analysis. These reservoirs were identified by using the anomaly signature of the resistivity values observed in the well logs. The major resistivity kicks were observed in well-26 and well-30, but not too obvious in well-13, making it hard to point out the presence of hydrocarbon in this well. The available well log data of the three wells were loaded into known geophysical software, which was used to determine the following reservoir parameters such as: porosity, permeability, water saturation, hydrocarbon saturation etc., these parameters were analyzed and interpreted. Also, volumetric analysis of the field was performed to determine the reservoir thickness (dimension/geometry) and its volumetric (the volume of oil in place). The initial oil in place for reservoir 1, 2 and 3 was found to be 566bb/STB, 215bb/STB and 287bb/STB respectively, which shows the reservoirs are economical and has a commercial quantity of hydrocarbon. The result obtained shows that the field is a good hydrocarbon prospect and may contain probable commercial quantity of hydrocarbon. Also from the Petrophysical analysis of the reservoirs, it was noticed that the hydrocarbon saturation concentration of the reservoirs increased from well-13 to well-30 (increases towards the north-eastern part of the covered seismic area).*

KEYWORDS - *Structural analysis, Property distribution, Volumetric, Petrophysical analysis, Lithology, Characterization.*

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I. INTRODUCTION

Petrophysical analysis of reservoirs has become a more integrated study process considering the desire for deeper and bigger reserves especially offshore prospects. For years, several methods have been used by geologists and geophysicists to evaluate the quality of a petroleum reservoir. Reservoir evaluation and characterization has evolved for three generations—initially, it has been based only on petrophysics, follow by the use of geologic analogs maps, and most recently it has become a multidisciplinary integration processes (Alao *et al.*, 2013). Petrophysical analysis and 3-D seismic interpretation are one of the most efficient techniques and approaches that can be used to estimate reserves of any hydrocarbon bearing field in the oil and gas industries (Ameloko and Owoseni, 2015).

Hydrocarbon reservoir is simply a subsurface pool of hydrocarbon that is in porous or fractured rock formation. They are generally classified into conventional and unconventional reservoirs. In a conventional reservoir, the hydrocarbon is trapped by a cap rock that has permeability lower than that of the reservoir rocks. While in an unconventional reservoir, the rocks have a high porosity value and a permeability value low enough to keep them trapped in place which does not require a cap rock.

The reservoir rock serves as a storage where the hydrocarbon formed from the source rock is been stored and from which it can be produced. The reservoir rock could also be the source rock (where the hydrocarbon was generated) in some occasions. A rock that is a potential reservoir would have porosity and permeability in sufficient magnitude as this will help facilitate the development of the reservoir. The high porosity and permeability of the reservoir rock makes it possible for fluid to flow through the rock which is very important to facilitate the recovery of this hydrocarbon (Donev et al., 2019).

Petro-physical analysis is very essential in determining the rock properties of any reservoir. Some of these reservoir properties evaluated through petro-physical analysis include the lithology, porosity, permeability, water saturation and hydrocarbon saturation. The petro-physical properties within a reservoir across a field are important properties to be evaluated because they show how the field behaves and also ascertain the recovery rate of the hydrocarbon within. The architecture and geometry of the any given reservoir helps to determine degree of connection and compartmentalization of the reservoir, and also helps to know the structural regime present in the field (Aduomahor *et al.*, 2016)

Understanding the structure of a reservoir is necessary for a successful reservoir management which involves drilling and maintaining the wells, which produce fluids from the reservoir, transportation and processing of the produced hydrocarbon, refining the fluids and marketing them, as well as safely abandoning the reservoir when it is no longer capable of producing, and also mitigating the environmental impact of operations throughout the life cycle of the reservoir (Fanchi, 2002).

II. BACKGROUND/REVIEW

Reservoir characterization is simply an integrated process that involves studying, understanding and analyzing available data and information about the well (Lombard and Akinlua, 2009). The seismic interpretation as well as the petro-physical properties analysis is a notable approach to effective reservoir characterization. Some of the fundamental properties that govern the behavior of a reservoir are; the shale volume (V_{SH}), permeability, porosity, water saturation among others.

Understanding reservoir properties is very important as the evaluated properties are useful for well-log calibration as well as correlation of wire-line signatures, which is very essential to avoid drilling an empty well.

Edigbue *et al*., (2014) evaluated the hydrocarbon reservoir potential of Keke field in Niger Delta. Six major faults were delineated across the field using seismic structural attribute (variance). Two major sand units, S1 and S2 were evaluated to have favorable hydrocarbon saturations of 65% and 81.8% respectively. The petrophysical parameters obtained as well as the trapping mechanism of the reservoir, Keke field was shown to be favorable for hydrocarbon accumulation. While, Nande, (2012) evaluated the potential petroleum reservoirs in Shungu Shungu field in the Orange basin. Five facies types were distinguished and different rock types were identified. The targeted sandstone layers was made up of tight, fine grained sandstones that has a low porosity value which range from 3% - 6%, while some layers show porosity values that ranges between 11% - 18%. The entire study area showed a low permeability value as low as 0.1mD. The area that has high porosity value also indicated a high water saturation of about 70% - 84%. Some of the sandstones exhibits good porosity values, the shale volume as well as water saturation are low. 3D seismic and petro-physical analysis on reservoirs in Hark field, Niger delta was evaluated by Adeyemi (2018). Data were collected from 4 wells located within the reservoir. The reservoir properties obtained were the volume of shale, porosity, water saturation and permeability. The study shows an average permeability that ranges from 1108.945mD to 1767.393mD, while the effective porosity ranges from 21.4% to 23.9%. The hydrocarbon saturation discovered ranges from 69.1% to 90.5%, which indicates the presence of commercial quantity of hydrocarbon.

III. STUDY AREA

Our study area is an onshore field that is located in coastal central swampy depobelt of Niger Delta region, Nigeria. For the purpose of this research work this field will be designated as A-Field (Figure 1). The Niger Delta basin lie between Latitude 4°39'5"N and Longitude 6°37'31"E and it occupies the Gulf of Guinea continental margin in equatorial region of West Africa. This basin ranks among some of the world's most prolific petroleum-producing basins, comparable to the Mississippi, the Orionoco, the Alaska north-slope, and the Mahakam (Reijers *et al*., 1997).

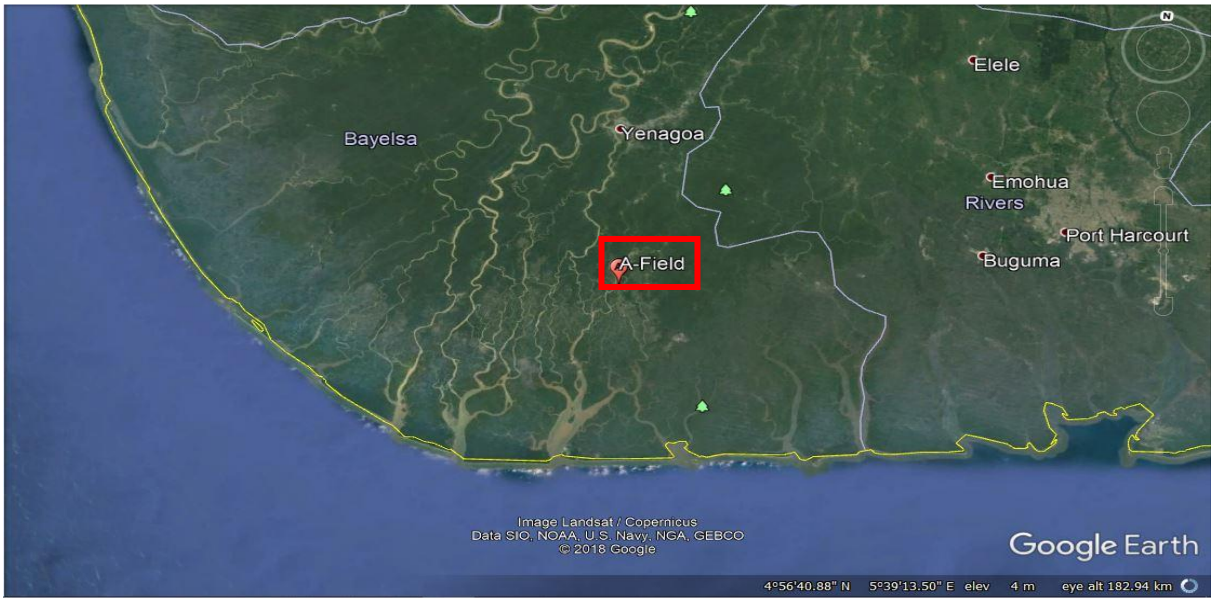

Figure 1: A map showing the location of the A-Field, Central Swamp Depobelt, Onshore Niger Delta (Source: Google Earth 2020).

IV. NIGER DELTA GEOLOGY

The Niger Delta basin is a complex basin that is located in the Niger Delta and the Gulf of Guinea, with access to Equatorial Guinea, Cameroon, and Sao-Tome. The basin is said to be of high economic value, as it is one of the major producers of oil world-wide. The Niger Delta province is ranked in twelfth position among world's richest producers of petroleum resources, as it has over 2.2% and 1.4% of the world's discovered oil and gas respectively (Petroconsultants, Inc. 1996a). The Niger Delta basin is made up of three major stratigraphic units and they have different geologic features (Unuevho, 2018). These units or geological formations are; the Akata, Agbada and Benin formation (Figure 2). These three litho-stratigraphic units are strongly diachronous (Evamy *et al.*, 1978). They can also be classified into three litho-stratigraphic units: (1) the Paleocene to present pro-delta facies of the Akata Formation, (2) The Eocene to the present, paralic facies of the rich Agbada Formation, and (3) Oligocene to the present fluvial facies of the Benin-Formation (Evamy *et al.*, 1978; Whiteman, 1982).

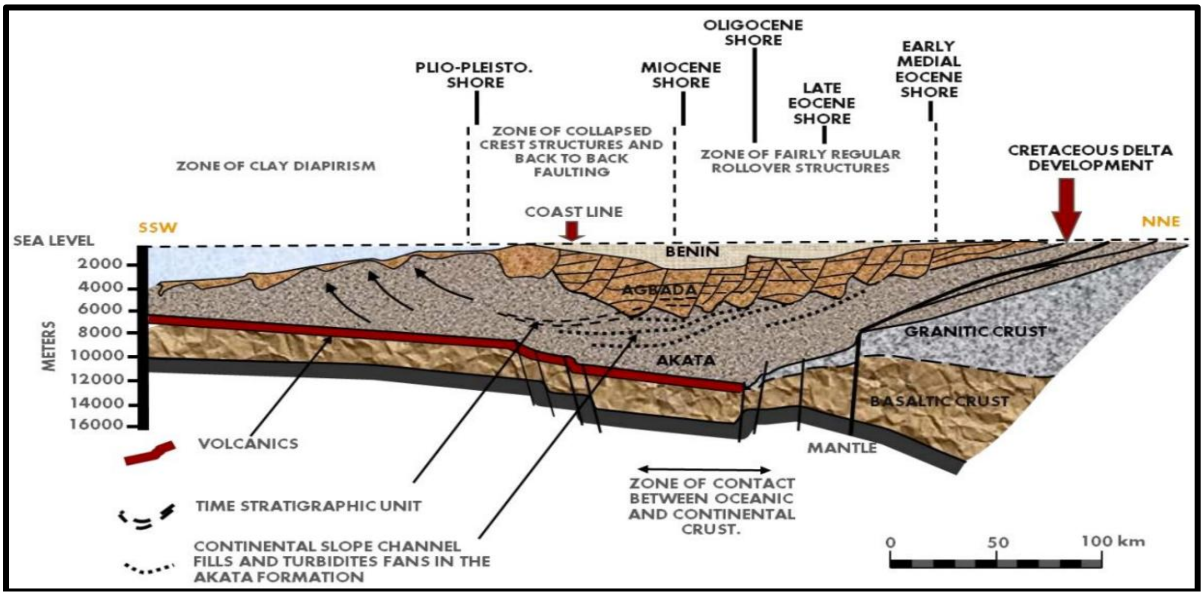

Figure 2: Schematic Dip Sections of the Niger Delta structure and trap (Weber and Daukoru, 1975)

V. METHODOLOGY

Two major data sets were used for this study, which are the well log data (LAS format) and 3D Seismic data (SEG-Y format). Three wells, namely Well-13, Well-26 and Well-30 (Table 1) were used for the analysis, with three hydrocarbon bearing reservoirs identified using the gamma ray (GR) log and the resistivity log, which were then correlated together across the wells; Petro-physical analysis was performed followed by seismic interpretation of the field for properties distribution of the field. A workflow of the various steps and stages for our study is shown in Figure 2. The porosity logs (Neutron and Density Logs) were used to identify the presence of possible hydrocarbon in these sand bodies (reservoirs). The different steps shown in Figure 2 were used to perform the petrophysical analysis and evaluated the properties. The following parameters were evaluated using the relevant equations, namely: Shale Volume (V_{sh}), Porosity, permeability, Net to Gross, water saturation and hydrocarbon saturation, while structural analysis was used for prospect identification and volumetric.

Table 1: The different logs available from the wells for petrophysical analysis

	LOG TYPES					
WELL NAME	**CALIPER (inches)**	**GAMMA RAY (gapi))**	**RESISTIVITY (ohm-m)**	**SONIC (us/ft)**	**DENSITY (G/C^3)**	**NEUTRON (ft^3/ft^3)**
WELL 13	N	A	A	A	A	A
WELL 26	A	A	A	A	A	N
WELL 30	A	A	A	A	A	N

LEGEND: A – Available, N – Not Available

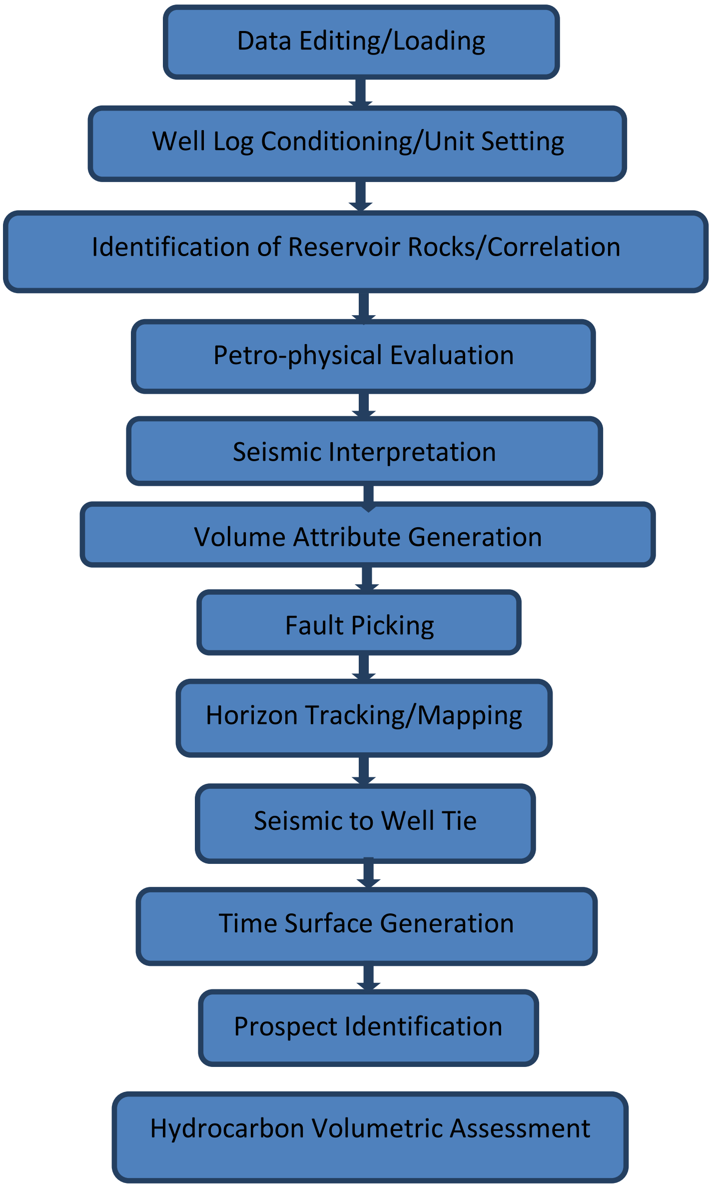

Figure 2: Flowchart of the Study

VI. RESULTS AND DISCUSSION

6.1. RESULTS

The reservoir identified are shown in Figure 3, which cut across the three wells used for the analysis, the calculated petrophysical properties and volumetric for the three reservoir respectively are tabulated in Table 2 – 4. Seismic interpretation gave an idea of the hydrocarbon trapping system and the mapped horizon of the reservoir (Figure 4, 5 and 6). Some of the processes carried and results obtained in seismic interpretation of the field includes; picking of faults, generating seismogram used for the seismic to well tie, horizon picking and volumetric analysis respectively. The time surfaces of the three reservoirs generated are shown in Figures 7, 8 and 9 respectively, while depth surface maps generated in 3D is shown in Figure 10. The combined surface maps of the time and depth is shown in Figure 11, while Figure 12 shows the mapped faults identified on the 3D seismic data. The well section showing the evaluated Petro-physical properties of the Reservoirs is shown in Figure 13, while the calculated volumetric for each of the reservoir are shown in Figure 14, 15 and 16 respectively.

6.2. STRUCTURAL ANALYSIS

Structural analysis of A-Field shows that the hydrocarbon in the field is trapped by growth faults, which is a common trapping mechanism generally observed in Niger delta. The Petrophysical analysis showed that the hydrocarbon saturation increased from well-13 to well-30 (towards the North-eastern portion of the covered seismic area). The contour numbers on the time map indicates different depths across the field. The hydrocarbon prospect area is enclosed within the fault, which is a rollover anticline.

The surface maps represented in Figure 8 to Figure 11 shows the different depths at which the three reservoirs are located. The legend to the left of the map presents the color codes that depict different depths. Red color from the map indicates regions with the shallowest depth while purple color indicates regions with the deepest depth.

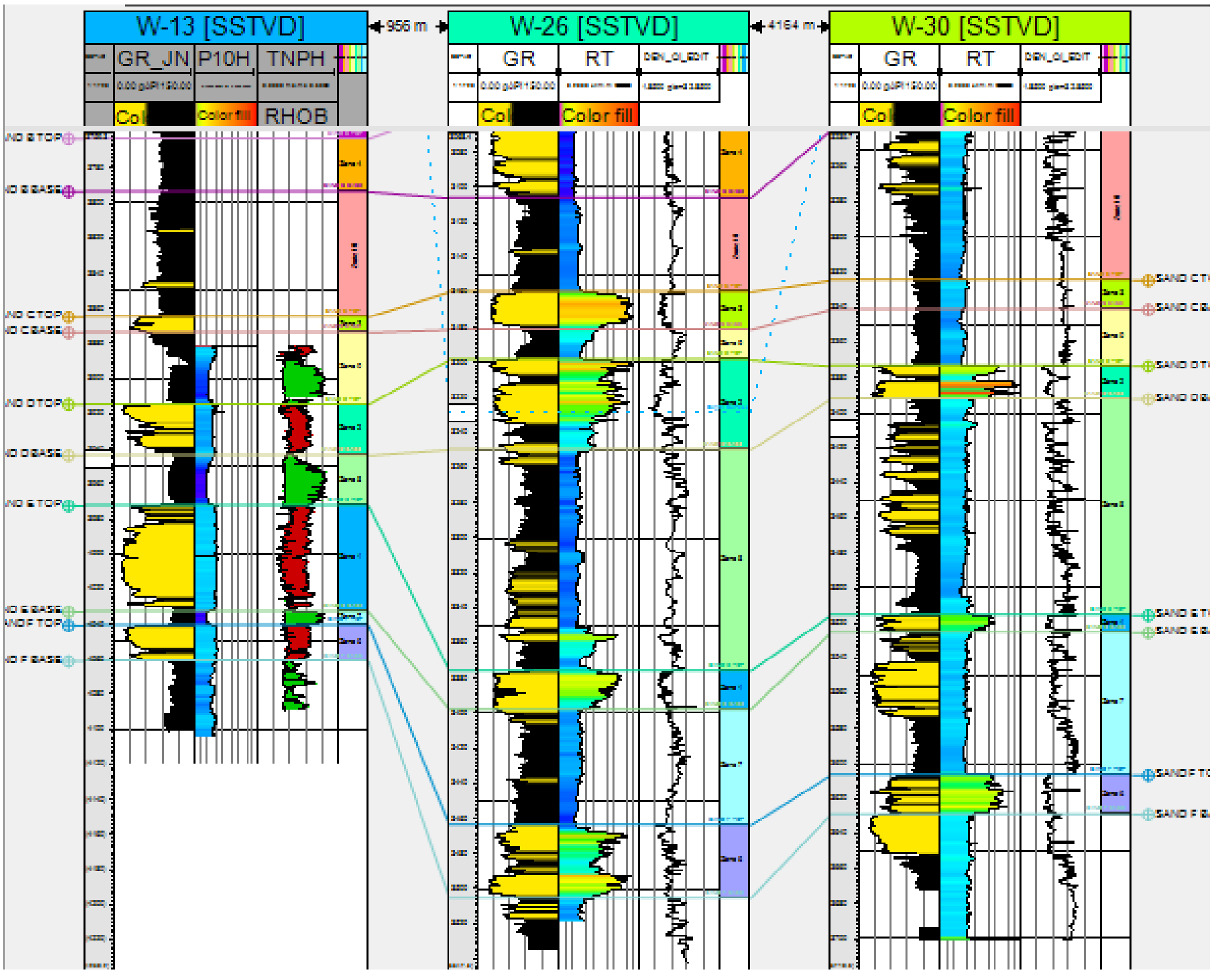

Figure 3: Correlation of the reservoirs in the three wells within the Field.

Table 2: Petro-Physical Properties in Reservoir 1

PROPERTIES	WELL 13	WELL 16	WELL 30
Shale Volume (V_{sh}) (%)	14%	14%	14%
Effective Porosity (%) - PoroE	21%	24%	22%
Permeability (md)	1799	2914	2050
Water Saturation (%) - S_w	90%	30%	19%
Hydrocarbon Saturation (%) - S_H	10%	70%	81%
Net to Gross (N/G)	0.8819	0.9409	0.8785

Table 3: Petro-Physical Properties in Reservoir 2

PROPERTIES	**WELL 13**	**WELL 16**	**WELL 30**
Shale Volume (V_{sh}) (%)	10%	9%	12%
Effective Porosity (%) - PoroE	22%	26%	28%
Permeability (md)	1947	2896	2066
Water Saturation (%) - S_w	75%	25%	20%
Hydrocarbon Saturation (%) - S_H	25%	75%	80%
Net to Gross (N/G)	0.8982	0.9662	0.8579

Table 4: Petro-Physical Properties in Reservoir 3

PROPERTIES	**WELL 13**	**WELL 16**	**WELL 30**
Shale Volume (V_{sh}) (%)	10%	13%	15%
Effective Porosity (%) - PoroE	23%	23%	23%
Permeability (md)	1973	1216	1618
Water Saturation (%) - S_w	75%	30%	16%
Hydrocarbon Saturation (%) - S_H	25%	70%	84%
Net to Gross (N/G)	0.9349	0.9341	0.9365

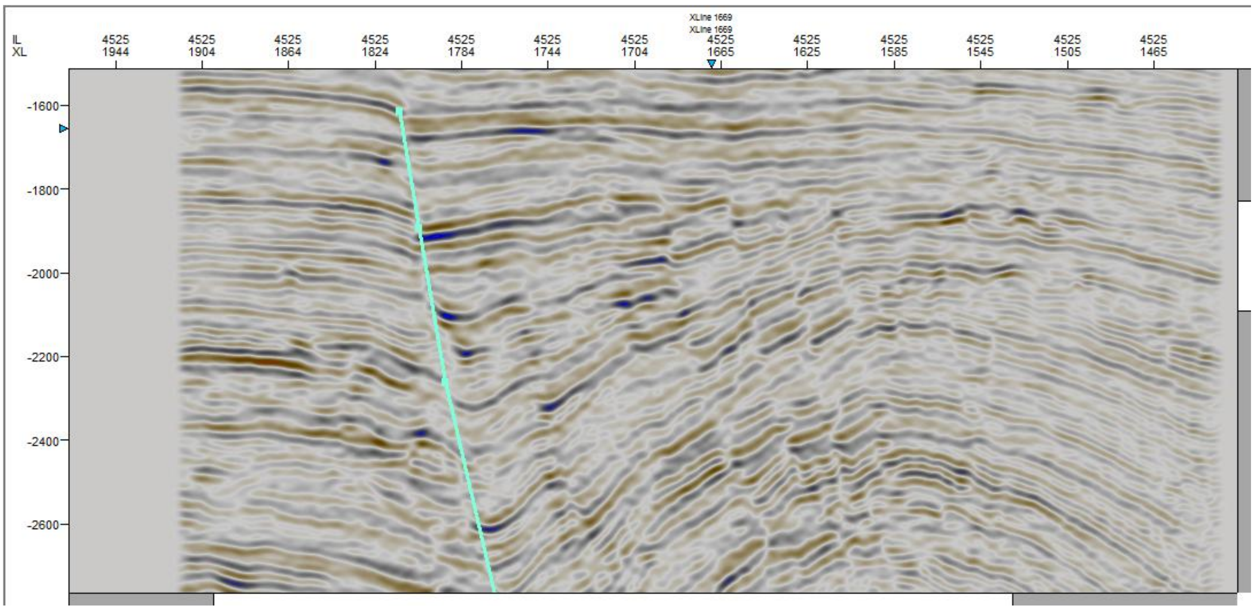

Figure 4: The fault mapped on the inline 4525 and X-line 1465 – 1944 of our seismic section showing the anticlinal fault structure.

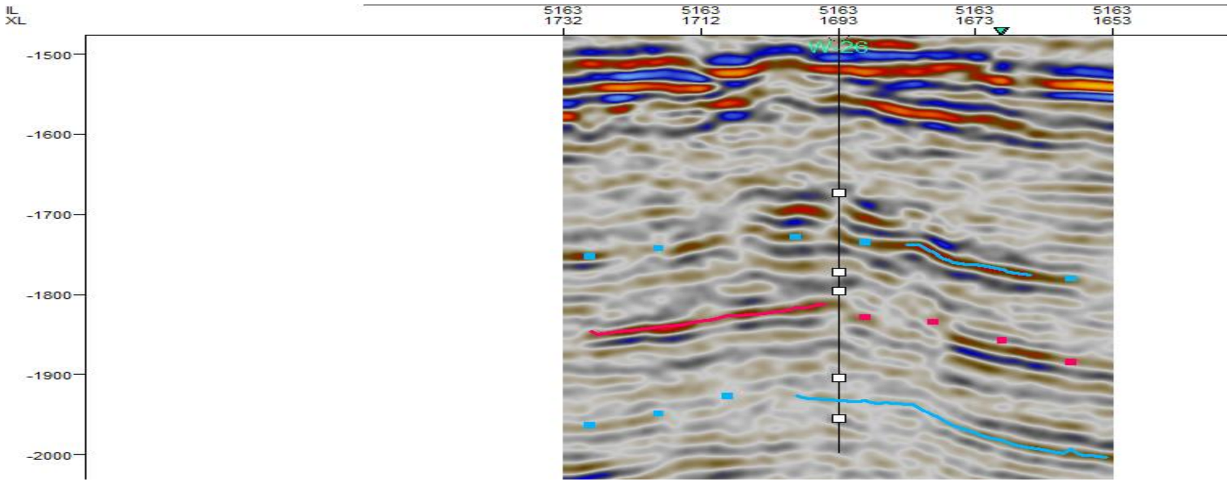

Figure 5: **The horizons mapped on the intersection window along inline 5163cm**

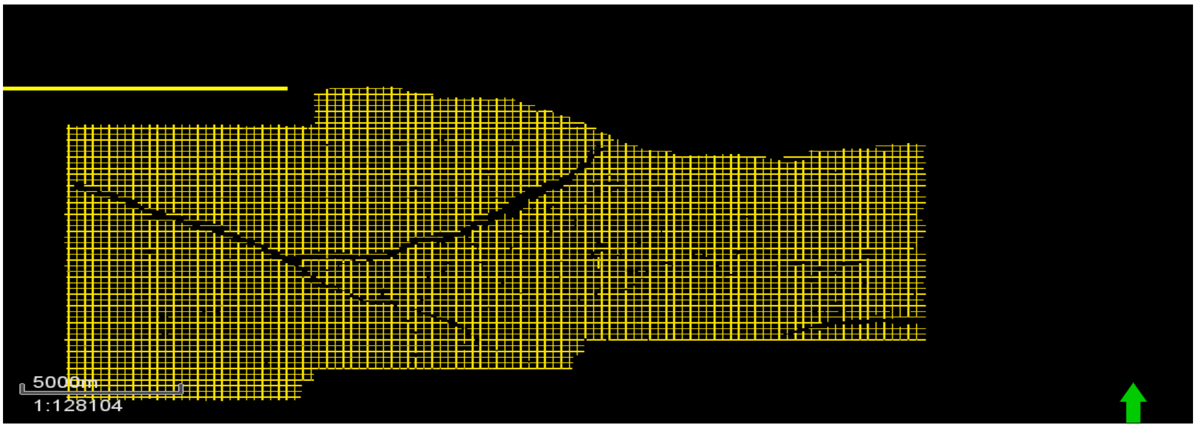

Figure 6: Horizons mapping in 2-D window

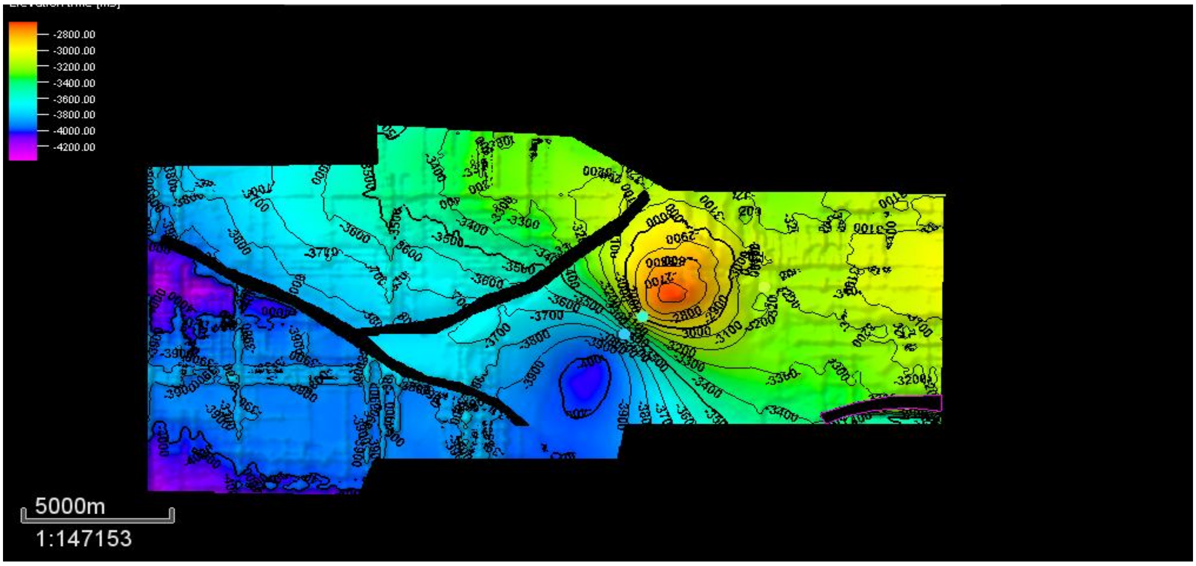

Figure 7: **Time surface map of reservoir 1**

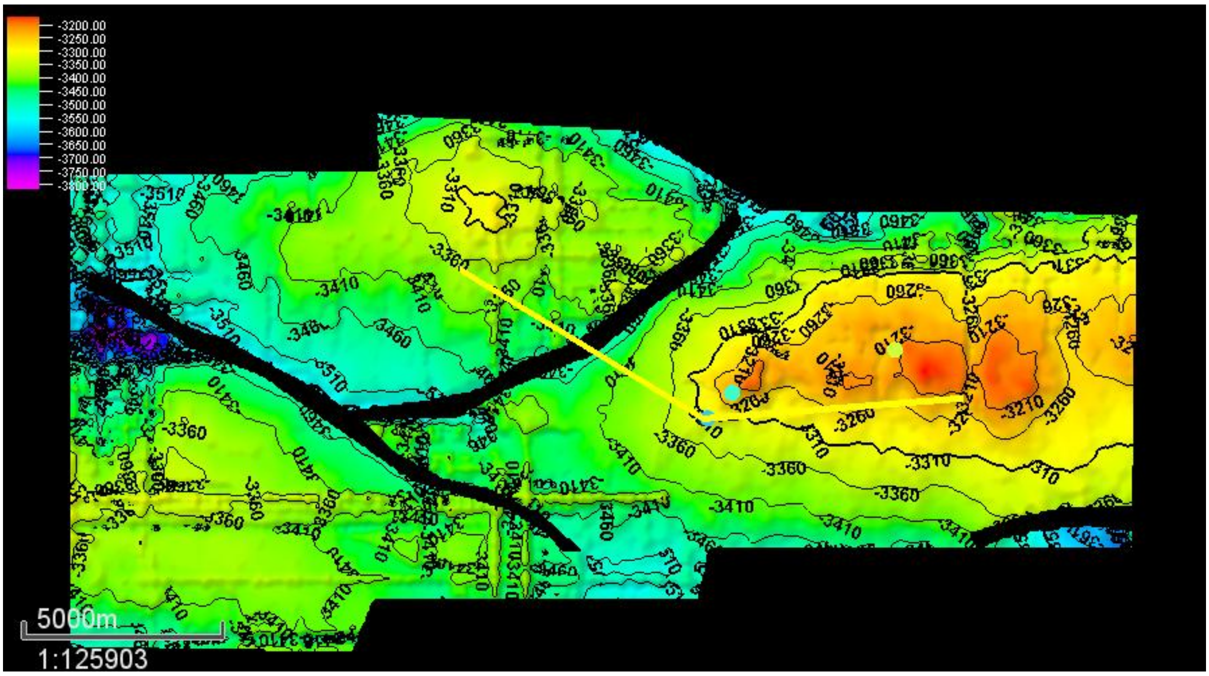

Figure 8: **Time surface map of reservoir 2**

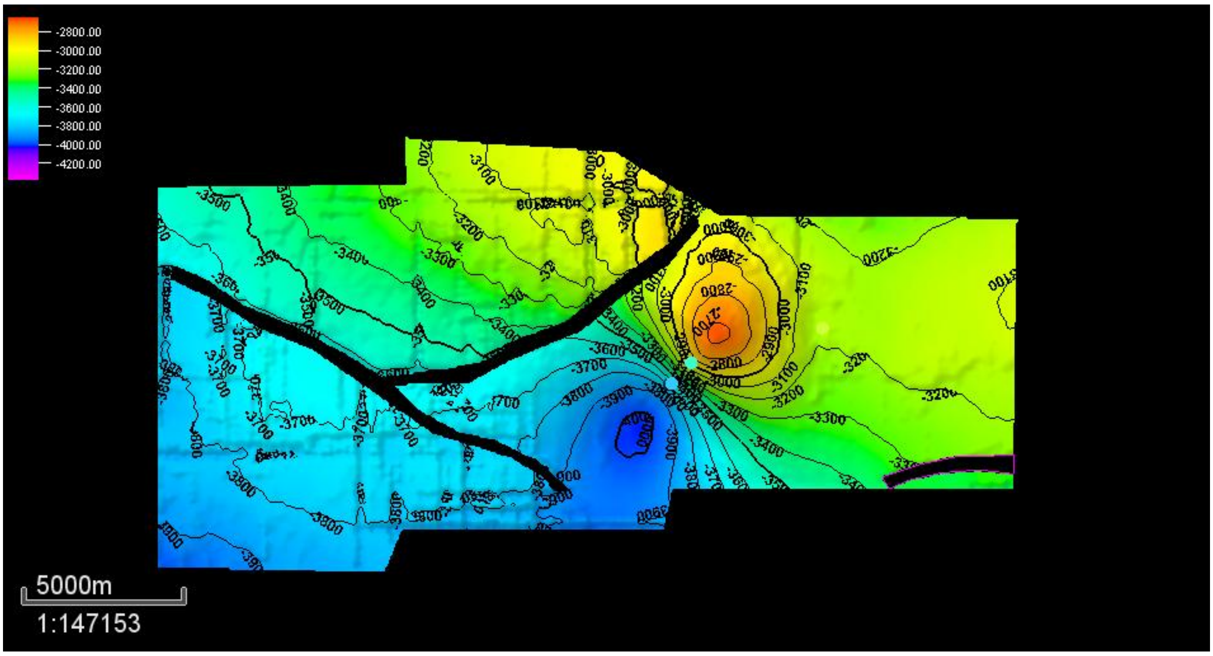

Figure 9: **Time surface map of reservoir 3**

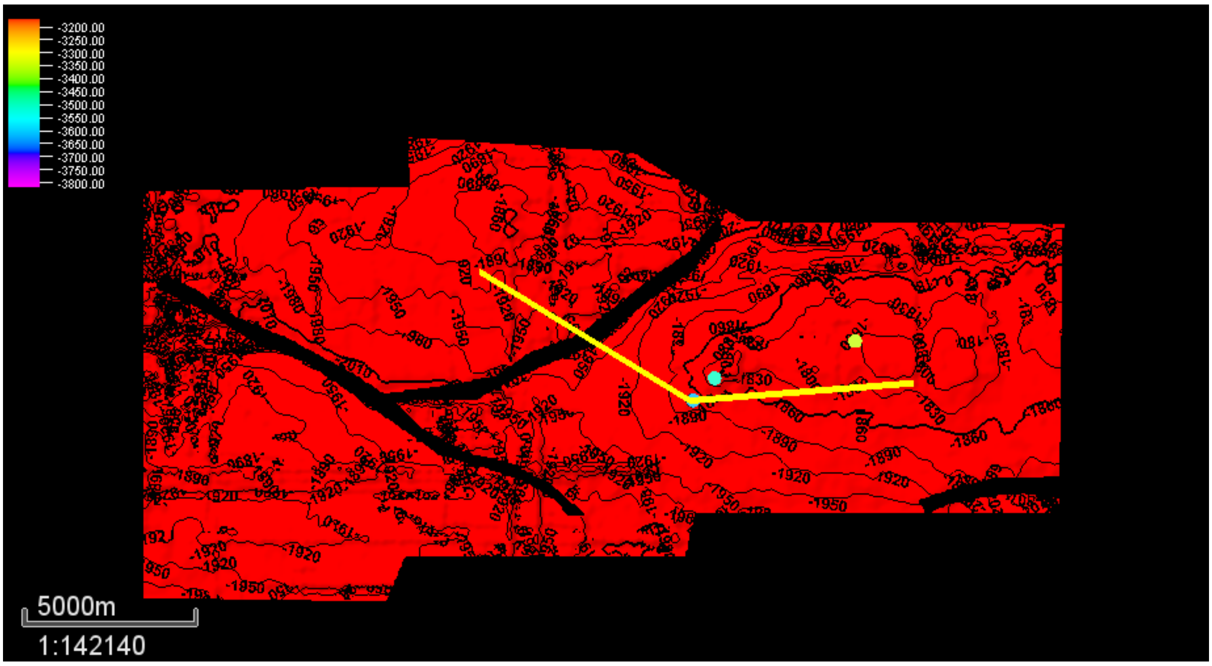

Figure 10: Depth Surface map of the reservoir

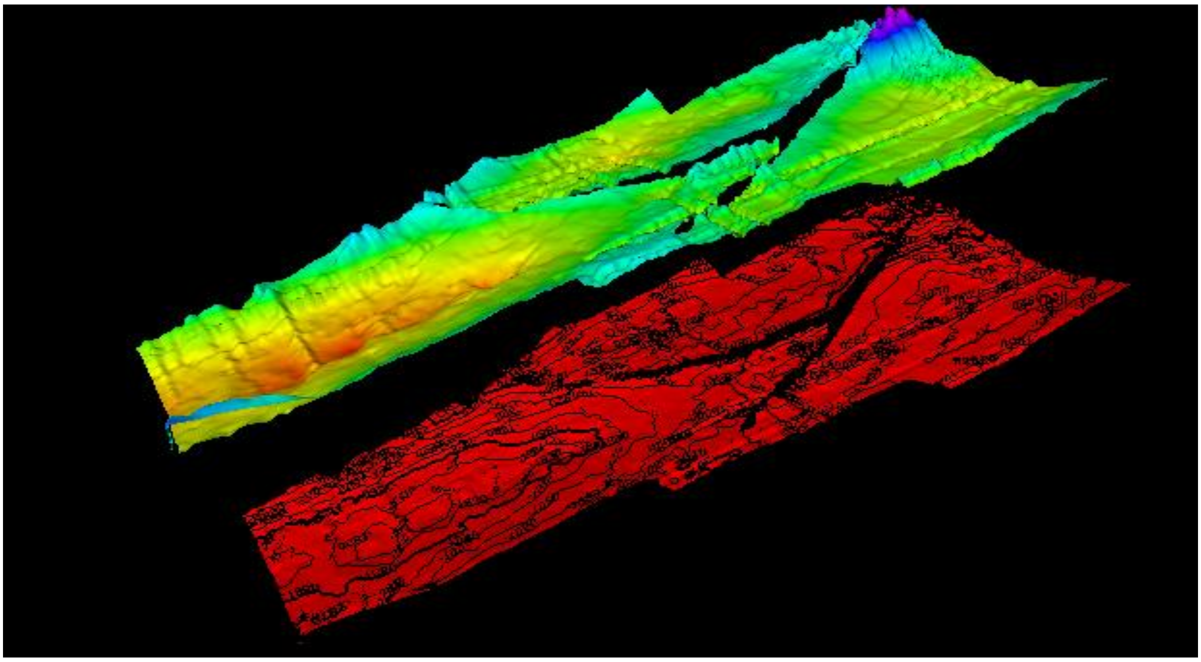

Figure 11: The combined Time and Depth Surface Maps

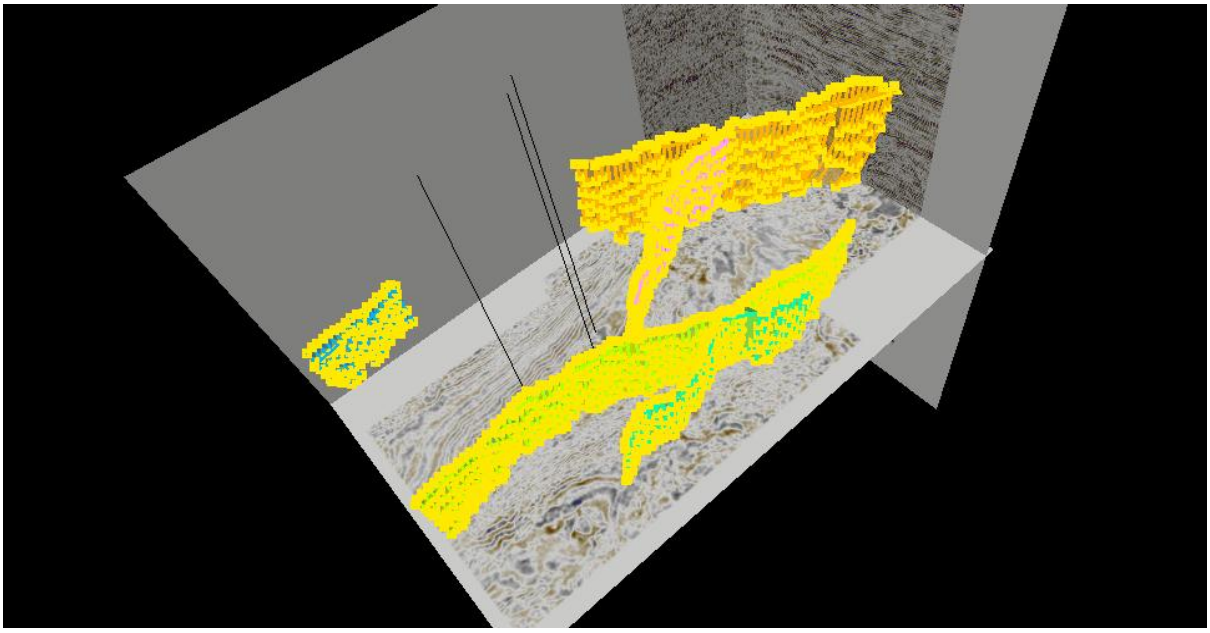

Figure 12: Faults displayed on seismic in 3D window

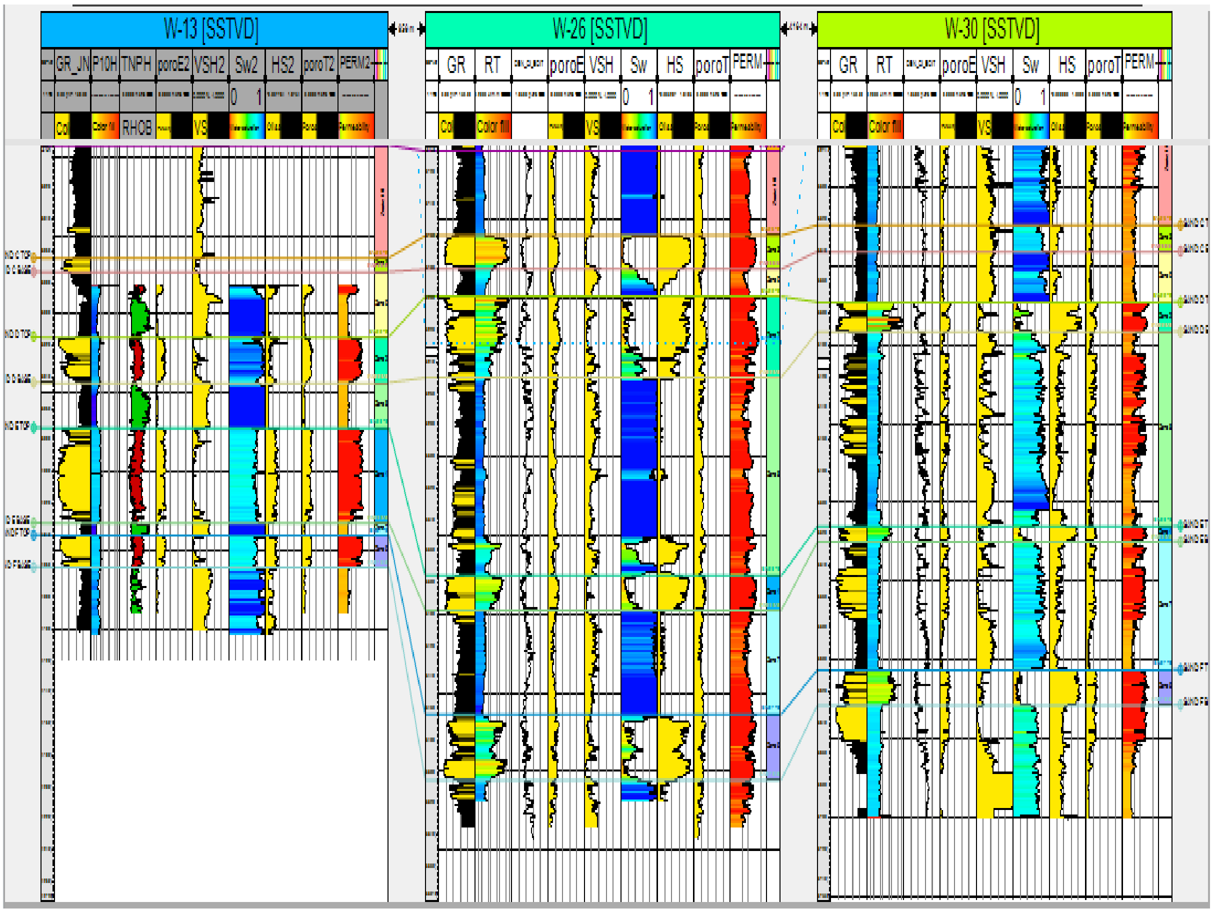

Figure 13: Well section showing the evaluated Petro-physical properties of the Reservoirs

Volumetric Evaluated for the Reservoir 1

2	User name	user							
3	Date	Friday, August 20 2021 08:41:47							
4	Project	Main project.pet							
5									
6	Input XY unit	m							
7	Input Z unit	m							
8									
9	Input data								
10	Zone(s)	Top surface	Base surface/Isochore	Net-to-gross	Porosity	Water saturation	Formation volume factor	Recovery factor	Contact
11	Zone Corrected Depth Surface	Corrected Depth Surface	-3943.00	0.9000	0.2200	0.46000	1.2700	0.2500	-3943
12									
13	Boundaries								
14	PROSPECT AREA								
15									
16	Case	HC Area[m2]	Bulk volume[m3]	Net volume[m3]	Pore volume[rm3]	HCPV[rm3]	STOIIP[sm3]	Recoverable[sm3]	
17	Reservoir1	101286801.45	6.724450e+010	6.052005e+010	1.331441e+010	7189781982	5661245740	1415311435	
18									
19	Totals all result types								
20									
21	Zones	HC Area[m2]	Bulk volume[m3]	Net volume[m3]	Pore volume[rm3]	HCPV[rm3]	STOIIP[sm3]	Recoverable[sm3]	
22	Zone Corrected Depth Surface	101286801.45	6.724450e+010	6.052005e+010	1.331441e+010	7189781982	5661245740	1415311435	
23									
24	Detailed results								
25									
26	Zones		HC Area[m2]	Bulk volume[m3]	Net volume[m3]	Pore volume[rm3]	HCPV[rm3]	STOIIP[sm3]	Recoverable[sn
27	Zone Corrected Depth Surface		101286801.45	6.724450e+010	6.052005e+010	1.331441e+010	7189781982	5661245740	14153114

Figure 14: Reservoir volumetric generated using the software

Volumetric Evaluated for the Reservoir 2

2	User name	user							
3	Date	Friday, August 20 2021 08:48:27							
4	Project	Main project.pet							
5									
6	Input XY unit	m							
7	Input Z unit	m							
8									
9	Input data								
10	Zone(s)	Top surface	Base surface/Isochore	Net-to-gross	Porosity	Water saturation	Formation volume factor	Recovery factor	Contact
11	Zone Corrected Depth Surface	Corrected Depth Surface	-3397.32	0.9100	0.2500	0.40000	1.2700	0.2500	-3397
12									
13	Boundaries								
14	PROSPECT AREA								
15									
16	Case	HC Area[m2]	Bulk volume[m3]	Net volume[m3]	Pore volume[rm3]	HCPV[rm3]	STOIIP[sm3]	Recoverable[sm3]	
17	Reservoir2	75265000.38	2.008394e+010	1.827639e+010	4569096628	2741457949	2158628339	539657085	
18									
19	Totals all result types								
20									
21	Zones	HC Area[m2]	Bulk volume[m3]	Net volume[m3]	Pore volume[rm3]	HCPV[rm3]	STOIIP[sm3]	Recoverable[sm3]	
22	Zone Corrected Depth Surface	75265000.38	2.008394e+010	1.827639e+010	4569096628	2741457949	2158628339	539657085	
23									
24	Detailed results								
25									
26	Zones		HC Area[m2]	Bulk volume[m3]	Net volume[m3]	Pore volume[rm3]	HCPV[rm3]	STOIIP[sm3]	Recoverable[sn
27	Zone Corrected Depth Surface		75265000.38	2.008394e+010	1.827639e+010	4569096628	2741457949	2158628339	539657C

Figure 15: Reservoir volumetric generated using the software

Volumetric Evaluated for the Reservoir 3

2	User name	user							
3	Date	Friday, August 20 2021 08:53:26							
4	Project	Main project.pet							
5									
6	Input XY unit	m							
7	Input Z unit	m							
8									
9	Input data								
10	Zone(s)	Top surface	Base surface/Isochore	Net-to-gross	Porosity	Water saturation	Formation volume factor	Recovery factor	Contact
11	Zone Corrected Depth Surface	Corrected Depth Surface	-3505.08	0.9300	0.2300	0.40000	1.2700	0.2500	-3505
12									
13	Boundaries								
14	PROSPECT AREA								
15									
16	Case	HC Area[m2]	Bulk volume[m3]	Net volume[m3]	Pore volume[rm3]	HCPV[rm3]	STOIIP[sm3]	Recoverable[sm3]	
17	Reservoir3	79154548.52	2.842009e+010	2.643068e+010	6079056465	3647433843	2871995195	717998799	
18									
19	Totals all result types								
20									
21	Zones	HC Area[m2]	Bulk volume[m3]	Net volume[m3]	Pore volume[rm3]	HCPV[rm3]	STOIIP[sm3]	Recoverable[sm3]	
22	Zone Corrected Depth Surface	79154548.52	2.842009e+010	2.643068e+010	6079056465	3647433843	2871995195	717998799	
23									
24	Detailed results								
25									
26	Zones		HC Area[m2]	Bulk volume[m3]	Net volume[m3]	Pore volume[rm3]	HCPV[rm3]	STOIIP[sm3]	Recoverable[sr
27	Zone Corrected Depth Surface		79154548.52	2.842009e+010	2.643068e+010	6079056465	3647433843	2871995195	717998

Figure 16: Reservoir volumetric generated using the software

6.3. DISCUSSION

6.3.1. DESCRIPTION OF RESERVOIRS

The Field composed of an alternation of sand and shale bodies interbedded together and the reservoirs are contained in the sand bodies. In this study, reservoir1, reservoir2 and reservoir3 were delineated across three wells (Well-13, Well-26 and Well-30) to ensure a proper characterization of the reservoir. Neutron and density logs are used to determine the kind of hydrocarbon that is contained in the reservoir (oil or gas), from the results of the petro-physical analysis, the three wells are productive, with Well -30 having the highest hydrocarbon saturation.

The average permeability of the three reservoirs observed across the three wells ranges from 1,216.5mD to 2,914.4mD, while the hydrocarbon saturation range from 10% to 84% (which shows field x as a good hydrocarbon prospect). The effective porosity value of the wells ranged from 21% to 28%. The result of the petro-physical analysis of the three reservoirs is shown in Table 5. When the porosity value of a reservoir is less than 12%, it depicts a tight reservoir and anything higher than 12% depicts a free siliciclastic reservoir. Also, the maximum permeability value of a tight reservoir is 1000mD. The porosity and permeability values gotten from the three reservoirs shows that it is a free siliciclastic reservoir. Also, the STOIIP and HCPV values gotten from volumetric analysis of the three reservoirs shows that the reservoirs contain commercial quantity of hydrocarbon.

Table 5: Volumetric Analysis of the Reservoirs

Petrophysical Properties	Reservoir 1	Reservoir 2	Reservoir 3
Oil water Contact (OWC)	3943	3397	3505
Formation Volume Factor (B_{oi})	1.27	1.27	1.27
Porosity	23%	76%	23%
Net to Gross	90m	90m	93m
Water Saturation (S_w)	46%	40%	40%
Bulk Volume (*$10^6$$m^3$)	67244	20083	28420
Net Volume (*$10^6$$m^3$)	60560	18276	26430
Pore Volume (*$10^6$$m^3$)	1331	4569	6079
HCPV Oil (*$10^6$$m^3$)	718	271	364
STOIIP (MMBL)	566	215	287
Hydrocarbon Area (m^2)	101286801.28	75265000.38	79154548.52

VII. CONCLUSION

From the results obtained from the petro-physical analysis, it can be seen that the lithological correlation of the three wells penetrated the field, which consists of an intercalation of sand and shale. This agrees with the generally observed lithology of Niger Delta. The three reservoirs cuts across the three wells (well-13, well-26 and well-30) and it's net to gross thickness range from 85m to 96m. The results obtained from the petro-physical analysis of reservoir shows that the reservoir is a free siliciclastic reservoir as it has porosity and permeability values higher than that of a tight reservoir. The porosity and permeability value that depicts a tight reservoir is below 12% and 1000mD respectively. The 3D seismic volume data helped in understanding the structural styles and architecture of the field. The results gotten from this study shows that the hydrocarbon trapping configuration of the field is fault assisted and rollover anticline. This result obtained shows that the wells are enclosed within the growth faults which confirm a possibility of hydrocarbon accumulation within the area. It can also be seen from the surface map that the hydrocarbon saturation concentration increases towards the north eastern region of the field. The value of hydrocarbon in place gotten for each reservoir is satisfactory.

The initial oil in place for reservoir 1, 2 and 3 was found to be 566bb/STB, 215bb/STB and 287bb/STB respectively, which shows the reservoirs are economical and has a commercial quantity of hydrocarbon. Also, looking at the balloon effect observed in the neutron and density log from figure, it can be deduced that the kind of hydrocarbon contained in the reservoir is oil. If the reservoir was gas bearing, the balloon effect would have a wider opening. The results of the petrophysical and seismic analysis show that field has good hydrocarbon potential for commercial exploitation.

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