Hydrocarbon Reservoir Mapping and 3d Seismic Interpretation of "Deejay" Field, Onshore Niger Delta

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Abstracts: **The 3-D seismic data interpretation and reservoir mapping of ''Deejay field'' have been carried out with the use of Schlumberger (PETREL™) software. This research work is aimed at delineating the subsurface structure and deducing the trapping system of the study area that may aid hydrocarbon accumulation.**

The research methodology involved horizon and fault interpretation to produce subsurface structural maps. Available Wireline log signatures were employed to identify hydrocarbon bearing sands and compute reservoir petrophysical parameters for hydrocarbon pore volume determination.

Two faults F_01 and F_02 (synthetic) were mapped using seismic structural attribute (variance) with fault polygon generated on the surface. Structural interpretation for inline 5533 revealed two horizons (1&2) were taken into consideration with their time and depth maps generated for the purpose of this study. The structural maps revealed fault assisted closures at the centre of the field which correspond to the crest of rollover anticlines and possibly served as the trapping medium. Three hydrocarbon bearing reservoirs - S1, S2 and S3 were delineated from three wells and the top and base of each reservoir window were mapped from the wells. Reservoirs S1, S2 and S3 have average porosity values of 30.7%, 29.8% and 29.3% respectively. All the porosity values obtained are in agreement with the established porosity values of Agbada formation of Niger Delta as it ranges from 28-32%. The obtained permeability index for the three reservoirs are rated very good. Hydrocarbon saturation values for the three wells have an average of 72.3% for S1, 83.7% for S2 and 76.7% for S3. The Petrophysical parameters from the wells show that most of the reservoirs are good targets in hydrocarbon prospecting. The result shows that the three reservoirs in the field have high hydrocarbon potential and good trapping mechanism for its productivity.

Keywords**: Hydrocarbon Reservoir, Faults, Seismic Interpretation, Petrophysical Parameters.**

I. INTRODUCTION

New petroleum resources deposits which remain the cornerstone of the economy of several nations of the world including Nigeria that could be discovered by direct observation on the surface in form of seeps and outcrop or other exposure are becoming increasingly scarce. It has become necessary to deduce the presence of buried deposits indirectly by downward projection of geological information observation observable on the surface. The enormous cost involved in exploring for this very important economic mineral has necessitated the adoption of methods which promote high level of perfection and accuracy for its detection. The true potential of the Niger Delta was not realized until seismic method was used to define structures within the delta (Doust and Omatsola, 1989).

Seismic method (acquisition, processing and interpretation) is one of the formation evaluation techniques used for examining a subsurface reservoir vis-à-vis their hydrocarbon potential in commercial quantity. Structural interpretation is an integral part of target evaluation towards oil field development.

Precise determination of reservoir thickness is best obtained on well logs, especially using the gamma ray and resistivity logs (Asquith, 2004). This is because almost all oil and gas produced today come from accumulations in the pore spaces of lithologies like sandstones, limestone or dolomites, the gamma ray log can come in handy to help in lithology identification i.e to differentiate between the reservoir rock (sand) and the embedding shale (Asquith, 2004). The resistivity log on the other hand, can be used for determining the nature of interstitial fluid i.e differentiating between (saline) water and hydrocarbon in the pore spaces of the reservoir rocks. Since these logs are recorded against depth, the hydrocarbon-bearing interval can be determined.

Also, in mapping reservoir boundaries, studies of geologic structures that can hold hydrocarbon in place must be considered. Hydrocarbons are found in geologic traps, that is, any combination of rock structure that will keep oil and gas from migrating either vertically or laterally (Wan Qin, 1995). These traps can either be structural, stratigraphic or a combination of both. Structural traps can serve to prevent both vertical and lateral migration of the connate fluid (Coffen, 1984). Examples of these include anticlines and flanks of salt domes. Stratigraphic traps include sand channels, pinchouts, unconformities and other truncations (Folami et al, 2008). According to Doust and Omatsola (1990), majority of the traps in the Niger delta are structural and to locate them, horizons are picked and faults mapped on seismic inlines and crosslines to produce the time structure map. This can reveal the structures that can serve as traps for the hydrocarbon accumulations. It is then possible to deduce the relevant petrophysical parameters from well logs for the computation of the volume of hydrocarbon in place. This research is aimed at delineating the hydrocarbon reservoir of “Deejay” field using 3D seismic structural interpretation and petrophysical analysis to evaluate the hydrocarbon potential of the study area.

The well log data has high vertical resolution while seismic data has high horizontal resolution (Deva et al., 2018). The outlined principles and techniques in seismic/well log interpretation are relevant in oil field development for the optimization of hydrocarbon reservoir productivity.

The well log data is one-dimensional but a seismic section presents a three-dimensional area view of the earth.

II. GEOLOGY OF THE STUDY AREA

The geology of the Niger delta has been extensively discussed by several authors. The Niger Delta is situated on the Gulf of Guinea on the West Coast of Africa. It is located at the southeastern end of Nigeria, bordering the Atlantic Ocean and extends from about latitudes 4^0 to 6^0 N and longitudes 3^0 to 9^0E.The basin is bounded to east by the Calabar Flank, which is a subsurface expression of the Oban Massif. To the west, it is bounded by the Benin Basin, to the South, by the Gulf of Guinea and to the North by Older (Cretaceous) tectonic structures such as the Anambra Basin, Abakiliki Anticlinorium and Afikpo Syncline; see (Figure 2) (Hammed et al., 2017)

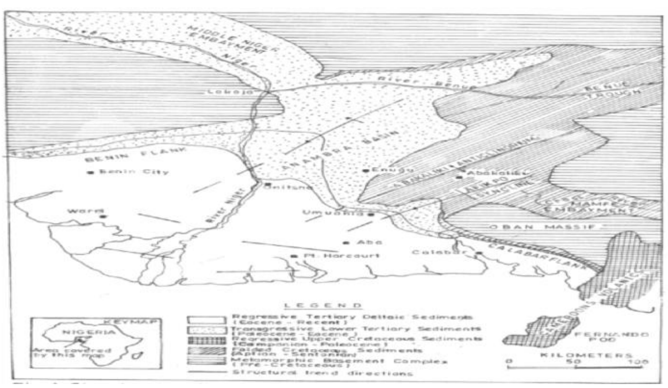

Fig.2 Structural units of Niger Delta basin (Short and Stauble 1967)

The tectonic framework of the Niger delta is related to the stresses that accompanied the separation of African and South American plates, which led to the opening of the south Atlantic. The Niger Delta is the largest delta in Africa with a sub-aerial exposure of about 75,000km2 and a clastic fill of about 9,000 to 12,000m (30,000 to 40,000ft) and terminates at different intervals by transgressive sequences. The Proto-delta developed in the Northern part of the basin during the Campanian transgression and ended with the Paleocene transgression. Formation of the modern delta began during the Eocene.

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 African basement massif. The north-eastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east south-east by the Calabar flank-a hinge line bordering the adjacent Precambrian. 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.

Sedimentary deposits in the basin have been divided into three large-scale lithostratigraphic units: (1) the basal Paleocene to Recent pro-delta facies of the Akata Formation, (2) Eocene to Recent, paralic facies of the Agbada Formation, and, (3) Oligocene-Recent, fluvial facies of the Benin Formation. These formations become progressively younger farther into the basin, recording the long-term progradation of depositional environments of the Niger Delta onto the Atlantic Ocean passive margin. (Hammed et al., 2017). The sediments were deposited in prodelta environments, with sand percentage less than 30% (Alao et al. 2013; Eze et al. 2020). The Agbada Formation consists of alternating sand and shales representing sediments of the transitional environment comprising the lower delta plain (mangrove swamps, floodplain and marsh) and the coastal barrier and fluvio marine realms. According to Obaje (2009), the sand percentage within the Agbada Formation varies from 30 to 70%, which results from the large number of depositional off lap cycles. A full cycle generally consists of thin fossiliferous transgressive marine sand, followed by an offlap sequence which commences with marine shale and continues with laminated fluvio marine sediments followed by barriers and/or fluviatile sediments terminated by another transgression cycle (Weber and Daukoru 1975; Ejedawe, 1981; as cited by Alao et al. 2013). The Benin Formation is characterized by high sand percentage (70–100%) and forms the top layer of the Niger Delta depositional sequence (Alao et al. 2013). According to Obaje (2009), the massive sands were deposited in continental environment comprising the fluvial realms (braided and meandering systems) of the upper delta plain (Nancy et al. 2018, Osisanya et al., 2021)

III. RESEARCH METHODOLOGY

This project was carried out with the use the modern method of seismic interpretation technique which was done on PETREL^{TM} workstation, a schlumberger interpretation tool for reservoir characterization and visualization of seismic models.

The data used in this study includes digital suites of well logs, checkshot data, inlines and crosslines of 3-D seismic sections and base map of the study area, all of which are imported into the interactive workstation. Horizons were also tracked on these reflections, on both inlines and crosslines across the field to produce the time structure (isochron) maps.

The relevant wireline log signatures were employed to identify hydrocarbon-bearing reservoirs and computation of reservoir petrophysical parameters like porosity, permeability, water saturation, net reservoir thickness, gross reservoir thickness and the ratio of net to gross thickness. These logs include: gamma ray log (lithology identification), density and neutron log (delineating fluid contacts), resistivity and sonic log.

According to Brown (2004), mapping the lateral boundary of the reservoir can be done (with the interactive workstation) by extracting and mapping amplitudes of direct hydrocarbon indicators like bright spots on the seismic sections.

The volume of hydrocarbon-in-place (hydrocarbon pore volume, HCPV) is calculated using Aly (1989):

$$HCPV = V\,\Phi N/G\,(1-Sw) \text{ where}$$

V = Volume of hydrocarbon; which equals the product of reservoir area extent (A) and its thickness (t). The thickness of the reservoir was obtained by taking average values from well log (gamma ray, neutron and density logs) signatures.

Φ = Average effective porosity obtained from the density log.

S_W = Average water saturation values from water saturation log.

N/G = ratio of net-to-gross thickness of the reservoir as obtained from the gamma ray logs.

$S_{h\,=}$ hydrocarbon saturation, $1-S_{W=}\ S_h$ (Amigu et al., 2003)

Porosity Percentage	Qualitative Interpretation	Permeability Values	Qualitative Interpretation
0 – 5	Negligible	< 10-5	Poor to Fair
5 – 10	Poor	15-50	Moderate
15 – 20	Good	50-250	Good
20 – 25	Very good	250-1000	Very good
Over 30	Excellent	>1000	Excellent

Table 3.1: Qualitative Interpretation of Porosity and Permeability Respectively (Rider, 1996)

IV. PRESENTATION OF RESULTS

The 3 D seismic data volume and the well log data were analysed for hydrocarbon reservoir mapping of "Deejay" field. The base map of the study area showing the spatial location of the three wells in the grinded line is showed in Figure 4.1. Structural interpretation of inline 5533 on the seismic section showed two horizon 1 and 2 and two major faults F-01 and F-02 which cut across the horizons. The faults dip in the south direction and trend in north-east to south-west direction, while fault F_02 is not continuous across the section. (Figure 4.2). This technique show the way fault obeyed horizons. The horizons used were derived from 3-D seeded

auto tracking before converting to surfaces. Variance attribute was used to confirm the orientation of the faults (figure 4.3). These surfaces showed visible faults before mapping. The faults were mapped on the surfaces using the fault polygon technique. The horizons were mapped and represent the interphase where there is a distinct acoustic impedance contrast in the reflection between the reservoir sand and the overlying shale found at different time interval.

4. 1 Time Structure Maps

The Time Structural Maps (Figure 4.4 and 4.5) show the two-way-travel time of the mapped horizons and highlight the geometry of the reflectors. It ranges from 1150ms to 2030ms. Examination of these maps shows the presence of structures (growth fault and anticline) that can possibly harbour hydrocarbon in the study area. An anticlinal structure could be observed about the central portion of the study area which is close to major fault F_01.

4.2 Depth Structure Maps

Figure 4.6 and 4.7 show the depth structural maps of horizon one and two. The depth structural maps reflect the subsurface structural pattern of the study field. There is a perfect similarity between this map and that of the time map which perfectly reveals the velocity information of the study area. The depth contour varies from 1300ft to 1600ft with corresponding high and faults as depicted by the time structural maps.

4.3 Closures

The major fault on the field which is a synthetic fault trends to give an evidence for the structural closures formed around this area. Fault F_01 and fault F_02 can be considered to form a good trapping mechanism for hydrocarbon accumulation (Figure 4.6 and 4.7).

There are two different closures present in the structural base map; the fault dependent closure at the north-west flank and four-way closure at the north–east central part of the study area. This is a structural high. Areas with such geologic features are good for locating wells.

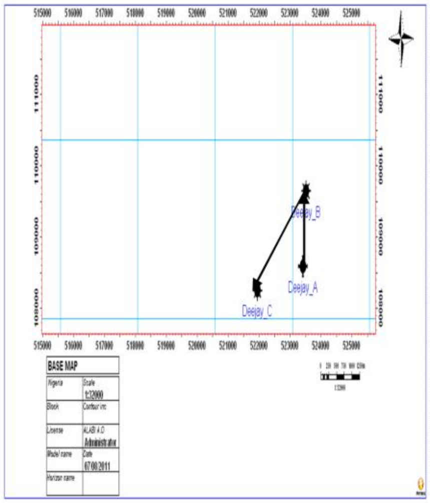

Figure 4.1 Base map of the study area showing the spatial locations of the three wells relative to one another.

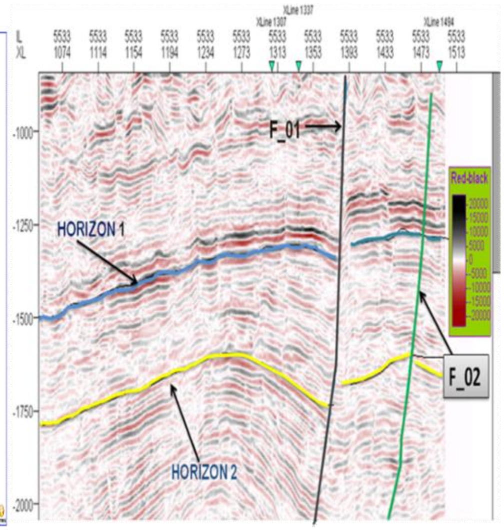

Figure 4.2: Typical seismic section (Inline 5533), showing Horizons and Faults.

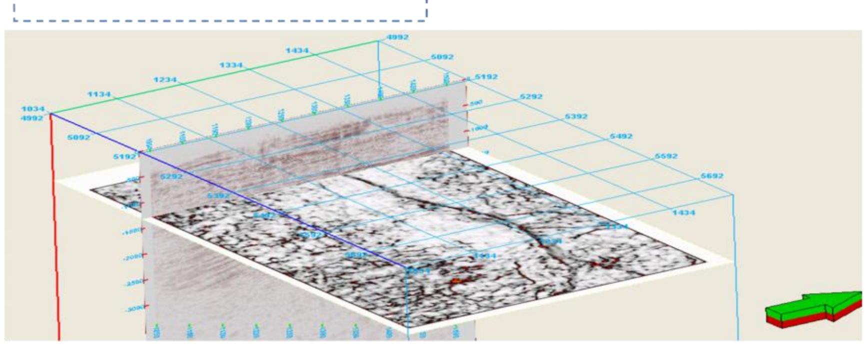

Figure 4.3 Variance Time slice at 1305ms showing orientation of the faults

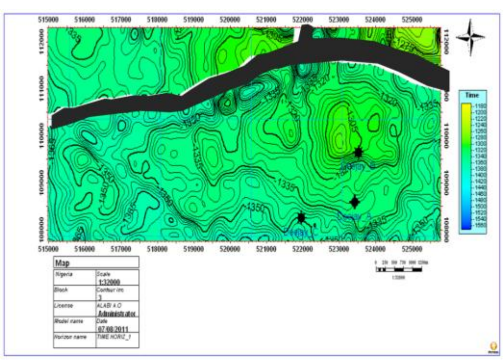

Figure 4.4: Time structural map of Horizon one.

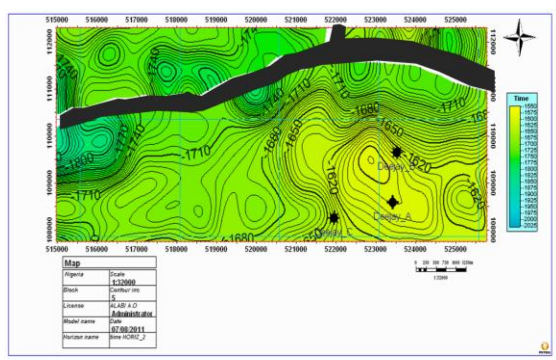

Figure 4.5: Time structural map of Horizon two

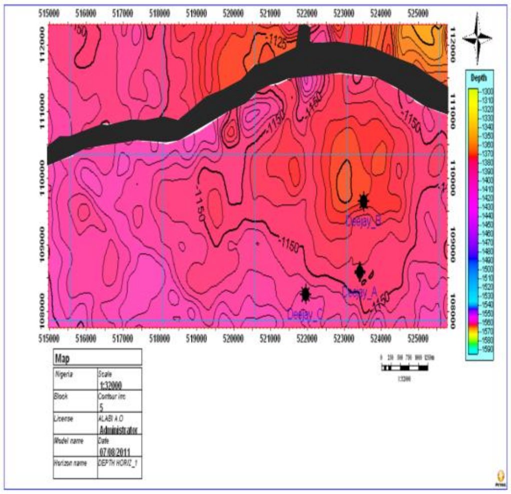

Figure 4.6: Depth Structure Map of Horizon one

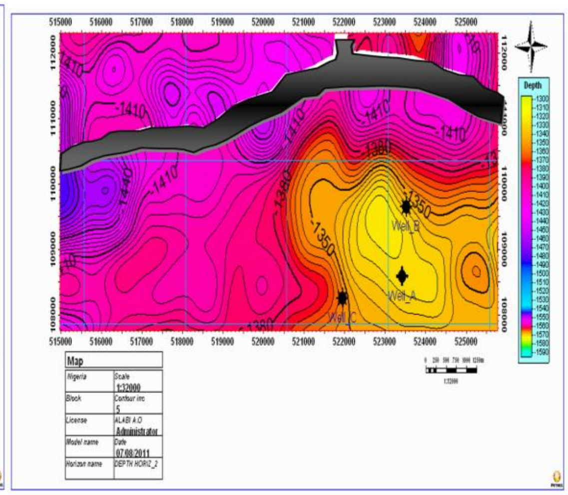

Figure 4.7: Depth Structure Map of Horizon two

4.3 RESULTS FROM WELL LOGS

Preliminary study on the well logs revealed hydrocarbon-bearing reservoirs of which three were mapped - S1, S2 and S3 - within depth interval of 5300ft (1617m) and 7156,ft (2181m). The petrophysical results derived from the available logs can be seen in Table 4.1

4.4 Correlation Of Lithologic Units

The correlated sections of the wells reservoirs in ''Deejay field'' are shown in figure 4.8 – 4.10 showing the lithologies of each well. The reservoirs windows (SA, SB and SC) delineated from well logs were correlated from top to base across well A, B and C using gamma ray and resistivity logs. Reservoir SA has a thickness of 75m (1728-1803m) on well A. Also a thickness of 50m (1616-1666m) on well B and a thickness of 190m (1152-1342m) on well C. Moreso, reservoir SB has a thickness of 60m (1814-1874m) on well A and a thickness of 85m (1706-1791m) on well B while a thickness of 93m (1359-1452m) on well C. Reservoir SC has a thickness of 70m (2112-2182m) on well A, while a thickness of 200m (1811-2011m) on well B and a thickness of 420m (1483-1903m on well C. The correlation sections of the wells in the field were done considering the spatial locations of the wells in the field. The general stratigraphy shows that the lithology consists of sand shale intercalation which is typical of the stratigraphy of Niger Delta, specifically the Agbada formation that actually covers the zone of investigation. Also correlated stratigraphic units showed a variation in thickness from well to another. This could probably suggest nonconformity in the rate of sediments deposition and compaction. The correlated section also show a variation in gross and net sand thicknesses which confirmed the fact that hydrocarbon reservoirs are restricted to sand units and not shale units.

The petrophysical parameters of interest are gross thickness (ft), net thickness (ft), net to gross, average porosity (ϕ), permeability, water saturation and hydrocarbon saturation. The petrophysical parameter showed that the reservoir S1(Table 4.1) has an average net to gross of 97%, average effective porosity of 31% and average water saturation of 27.67%. The low average water saturation implies hydrocarbon saturation in the reservoir. The effective porosity ranges from 28 to 32%. Permeability index ranges from 440 to 660mD and hydrocarbon saturation ranges from 70 to 84% across the wells. The porosity and permeability index derived from reservoir S1 is rated very good according to Rider (1996). More so, reservoir S2 has an average net to gross of 91%, average effective porosity of 30% and average water saturation of 16.30% which is lower compared to reservoir S1. The effective porosity ranges from 28 to 30%, permeability index ranges from 690 to 781mD and hydrocarbon saturation values ranges from 79 to 87% across the wells. In analogy with reservoir S1, the porosity and permeability values obtained for reservoir S2 is also rated very good according to Rider (1996). This connotes high connectivity potential of the reservoirs. Lastly, reservoir S3 has an average net to gross of 85%, average porosity of 29% and average water saturation of 23.3%. permeability values ranges from 800 to 945 Md and hydrocarbon saturation from 64 to 86% across the wells. similar to reservoir S1and S2, the porosity and permeability value obtained for reservoir S3 is rated very good based on Rider (1996) criteria. The effective porosity values obtained for the three reservoir (S1, S2 and S3) validate the established porosity range of 28 to 32 % in the Niger delta.

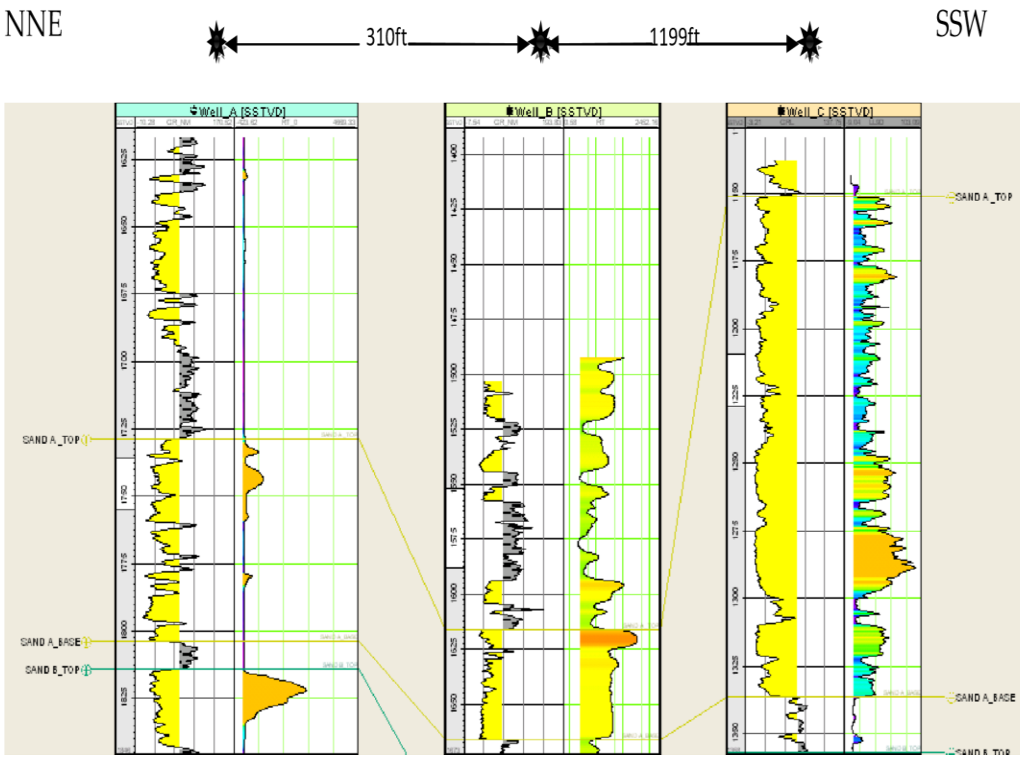

Figure 4.8 showing reservoir sand A top and base

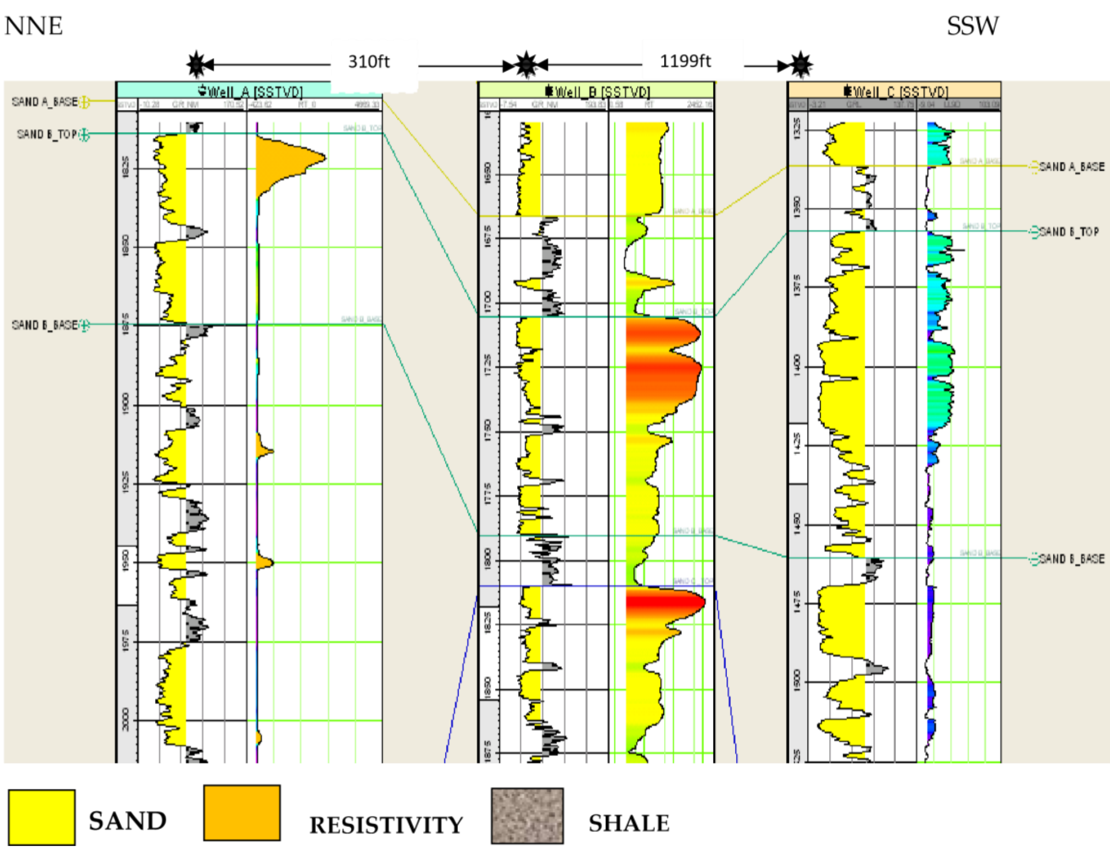

Figure 4.9 showing the reservoir sand B top and base.

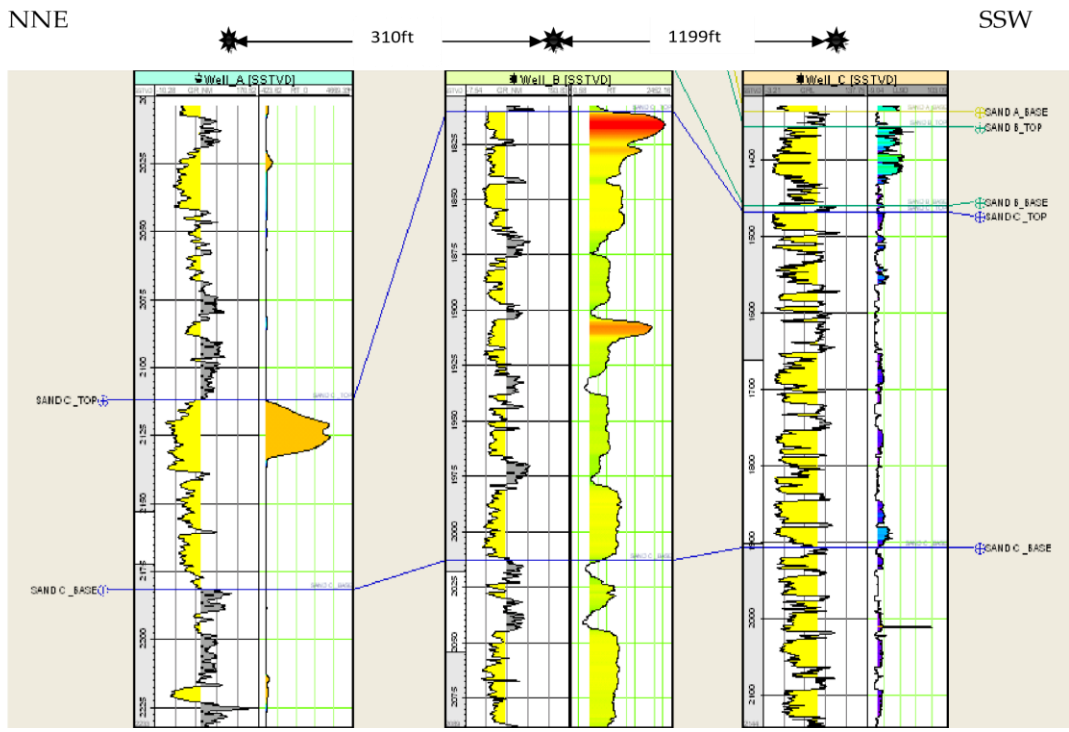

Figure 4.10 showing reservoir sand C top and base.

Deejay wells	Interval	Top MD (ft)	Bottom MD (ft)	Gross Thickness (ft)	Net Thick-ness (ft)	Net to Gross %	Effective porosity (Φ) %	K (mD)	S_H (Sh)%	Water saturation (Sw)%
DJ_A	S1	5671.4	5917.6	246.2	229.2	93	28	546	73	27
	S2	5951.5	6152.9	201.4	182.25	90	30	720	87	13
	S3	6928.9	7156.9	228	211.52	93	28	800	64	36
DJ_B	S1	5305.6	5466.7	161.1	157.34	98	32	440	74	26
	S2	5594.1	5720.4	295.3	250	85	28	690	79	21
	S3	5933.6	6604.1	670.5	513.16	77	30	945	86	14
DJ_C	S1	3776.4	4384.7	608.3	600.39	99	32	660	70	30
	S2	4452.2	4791.7	339.5	332.18	99	30	781	85	15
	S3	5418.3	6246.9	828.6	700.36	85	30	896	80	20

Table 4.1 derived petrophysical parameters.

V. CONCLUSION

The delineation and mapping of the hydrocarbon bearing reservoirs of "Deejee field" from the seismic section and well logs within the depth interval of 3776ft and 7156ft have been carried out. The time depth structural maps for the three reservoirs indicate a structural high fault dependent closure which are good for locating wells. The structural pattern observed in the field is made up of major and minor faults which are the characteristic of Niger delta basin. The fault system observed within the wells enhanced the effective porosity which also aid the high permeability index (k > 100 Md) obtained in the study area. The petrophysical parameters estimated from reservoir S1, S2 and S3 show that the reservoirs have high connectivity and hydrocarbon potential. From this research, it has been established that the trapping mechanism in the study field are fault assisted, fault dependent and rollover anticline. The results show that all the reservoirs within the study area have good hydrocarbon potential. The closures could be seen from the fault geometry and this would serve as guide for the positioning of subsequent wells which would reduce the amount to be invested during the oil field development.

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