

# Structural Styles and Hydrocarbon Trapping Mechanisms Onshore and Offshore, Niger Delta

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Received on: January, 2024

Revised and Accepted on: March 2024

Published on: March 2024

## ABSTRACT

A three-dimensional (3D) seismic Data and well log Data from two oil fields (Onshore Field and Offshore Field) were obtained and analyzed with Techlog and Petrotech software in order to attempt the structural styles and Hydrocarbon trapping mechanisms onshore and offshore fields. Suites of Well logs of the two fields were interpreted and appropriate reservoir bodies were characterized. The well log petrophysical analysis revealed three reservoirs in onshore and three reservoir in offshore which cut across four (4) wells respectively. Average reservoir parameters for the onshore such as porosity 30.01% and hydrocarbon saturation 64.33% with average thickness of 26.52m while the offshore average reservoir parameters such as porosity 28% and hydrocarbon saturation 77.67% with average thickness of 10m were derived from petrophysical analysis. A total of three horizons and seven faults were mapped on the onshore seismic sections that indicated faulted anticlines, listric fault, growth fault, synthetic and antithetic fault were closely observed. While three horizons were mapped on the offshore seismic section that indicates back-to-back structures. The structural maps showed that the major structures accommodating the Hydrocarbon in both fields are fault assisted closure, four way closures and growth faults. The trapping mechanisms were identified to be fault dependent. The root-mean-square (RMS) amplitude surface maps reveal sections with bright spot anomalies. The amplitude anomalies served as direct hydrocarbon indicators (DHIs). Seismic-to-well ties shows the top of the Hydrocarbon bearing sand unit lie on top of the well on the seismic section in the field.

**Keywords:** Hydrocarbon saturation, Offshore, Onshore, Structural Styles, Trapping.

## 1.0 INTRODUCTION

Exploration and interpretation are carried out by a separate set of people within the field of study, without undermining the quality of Data and processing. Deductions are made based on the quality of the interpretation. Therefore, a detailed structural styles and trapping mechanism evaluation is relevant to predict the hydrocarbon potential oil and gas field within onshore and offshore Niger Delta. 3-D seismic interpretations are used to image subsurface structures capable of harbouring hydrocarbon (Richardson and Taioli, 2018 ; Abimbola.and ; Emujakporue ,2020). The decision to go ahead with developmental activities in oil and gas fields could largely depend on the deductions made by evaluations. The study of onshore and offshore with high-resolution images highlighting the times and depths to the tops and the bottoms of selected reservoirs are useful for thorough structural styles and trapping mechanism. The orientation and type of structural traps (anticlines and fault traps) delineated from seismic records depend on the stress fields to which they have been subjected (Hart 2000), and the underlying system of structure known as structural or tectonic style, provides a guide for interpreting ambiguous definition of Structural

Seismic Interpretation of structural features, especially where data volume are scarce (Osisanya *et al*, 2021; Adebayo,*et al* 2021). Detail structural analysis will reveal the trapping mechanism of the oil field and this will help to avoid drilling of dry hole (Aigbedion, 2023; Aigbedion and Hafiz, 2016 ; Omoja and Obiekezie 2019). The tectonic framework of the Niger Delta is related to the stress that accompanied the separation of Africa and South Atlantic (Opara *et al.*, 2013) According to Obafemi *et al.* 2020, Obasuyi *et al* 2019 Egbo and Abanum. 2020, the stratigraphic fill of the Niger Delta Basin is primarily composed of three lithostratigraphic units. These units include the lower most marine pro-delta Akata Formation, the middle shallow-marine Delta-front Agbada Formation and, the overlying youngest continental, Delta plain Benin Formation (Doust and Omatsola 1990; Adojoh *et al.* 2020 , Ogunyemi *et al* 2020 ). These three Formations extend across the whole Delta. For effective delineation of structures with significant hydrocarbon potential, subsurface configurations must be thoroughly understood (Ekanem *et al.*, 2021) . Generally, the chunk of hydrocarbons generated in the Niger Delta is derivable from sedimentary deposits in the porous pores of permeable

rocks (Kurah *et al.*, 2021; Aigbedion.2021; Aigbedion, *et al* 2024). Fluid saturation refers to how much fluids (Water, oil, or gas) are available in the pores a rock and it is very critical in determining fluid distribution in the reservoirs. NTG is the thickness of rock that can deliver hydrocarbons to the well bore at a profitable rate. These petrophysical parameters determine the best performance of any reservoir (Chongwain *et al*, 2019; Ighodaro *et al.*, 2019). Formation evaluation is consequently based

mostly on logs. Petrophysical parameters like the lithology fluid content, porosity, water saturation and hydrocarbon saturation are derived; from the well log data (Vetle , 2023 ; Aigbedion .I , 2021; Ehigiator M .O and Aigbedion I., 2010). The study is aimed at studying the structural styles and Hydrocarbon trapping mechanisms onshore and offshore Niger Delta, with the aim of getting a better understanding of the fields.

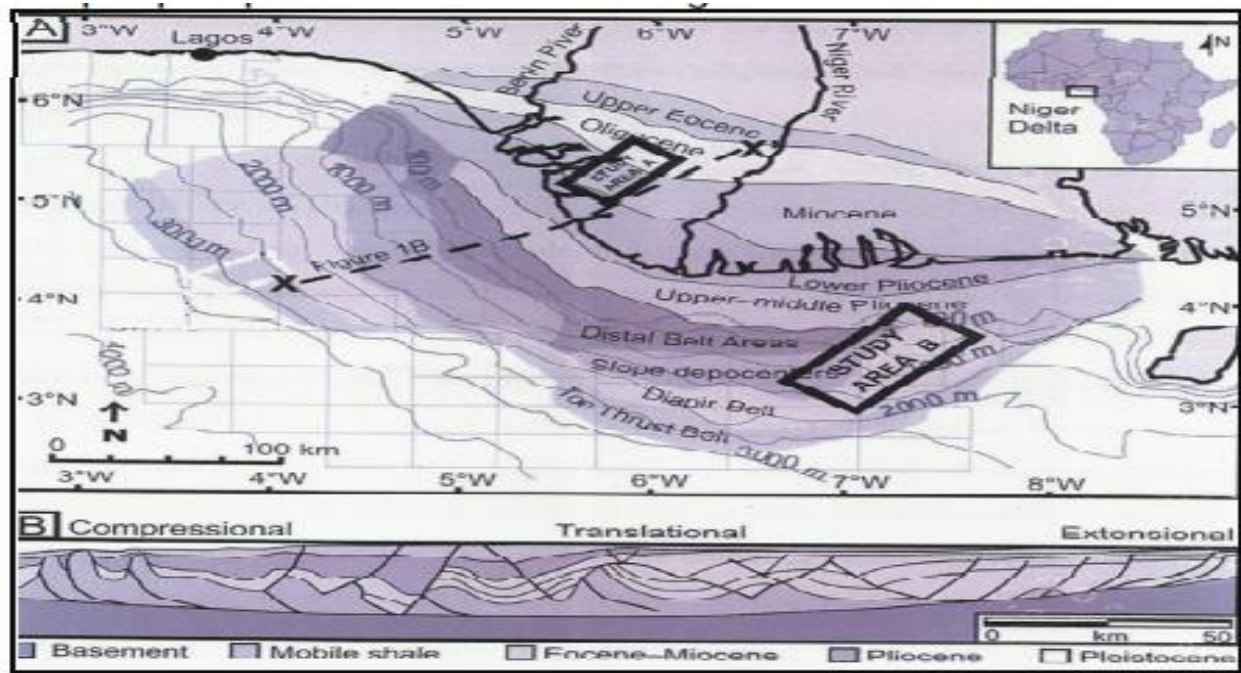


Figure 1. Map of the Niger Delta showing the Study Area (Hooper *et al.* 2002.)

### 1.1 Location of the Study Area

It is located in the Southern part of Nigeria between the Longitude 4° - 9° East and Latitude 4° - 6° North (fig1) . It is situated on the West African continental margin at the apex of the Gulf of Guinea, which formed the site of a triple junction during continental break-up in the Cretaceous (Doust and Omatsola, 1990; Bright and Egbo 2020 ).

### 2.0 Materials and Methods

The materials used for the structural styles and hydrocarbon trapping mechanisms of the onshore and offshore are Techlog and Petrotech software, gamma, resistivity, density and neutron logs. seismic sections.

The Techlog platform enables you to perform both basic and advanced interpretation on all wellbore Data types, including your own petrophysical workflow to generate meaningful quick-look interpretations based on local expertise and the application of industry standard

methods for lithology, porosity, saturation, permeability. All common Data formats are easily loaded through a powerful drag-and-drop interface into the Techlog platform. You can quickly create a log view to visualize, validate and correct data for environmental and signal noise effects. while all the seismic Data were loaded on Petrol Tech software workstation. The Study were performed using Petrol Tech 3 Dimensional (3D) Seismic interpretation modules. The cross- line (strike) and the in-line (dip) and the above mentioned data were provided by Nigerian Petroleum Development Company.

Archie developed his famous equation with in clay free reservoirs to calculate, from well log parameters, the water saturation ( $S_w$ ) of the uninvasion zone in a formation next to a borehole. The Archie equation can be expressed as follows:

$$R_t = R_w \phi^{-m} S_w^{-n} \quad (1.1)$$

Where  $R_t$  = true resistivity of the Formation, corrected for invasion, borehole, thin bed, and other effects.

$R_w$  = Formation water resistivity at Formation temperature,

$S_w$  = water saturation of the uninvaded zone  
 $\Phi$  = Porosity,

$n$  = saturation exponent, which varies from 1.8 to 4.0 but normally is 2.0;

$m$  = cementation exponent, which varies from 1.7 to 3.0 but normally is 1.8 in the Niger Delta;

The Simandoux equation is one of the most popular and successful equation in common use which include shale correction for the saturation calculation. It requires inputs to shale volume. In general the equation can be written as

$$S_w = \frac{C.R_w}{\Phi^2} \left[ \sqrt{\left(\frac{V_{sh}}{R_{sh}}\right)^2 + \frac{5\Phi^2}{R_w R_t}} - \frac{V_{sh}}{R_{sh}} \right] \quad (1.2)$$

where  $S_w$  = water saturation  
 $R_{sh}$  = resistivity of shale  
 $V_{sh}$  = volume of shale  
 $R_w$  = resistivity of formation waters  
 $R_t$  = true formation resistivity  
 $\Phi$  = Porosity  
 $n$  = saturation exponent  
 $C$  is set for 0.40 for sand and 0.45 for carbonate  
 Volume of Shale was derived from the gamma ray log first by determining the gamma ray index IGR [18]

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1.3)$$

where,  $GR_{log}$  = GR reading of Formation,  $GR_{min}$  = minimum GR reading (clean sand or carbonates),  $GR_{max}$  = maximum GR (shale base line value).

For the purpose of this research work, Lavrionov 1969) equation was used to determined the volume of shale for tertiary rocks.

$$V_{sh} = 0.083(2^{3.71GR} - 1.0) \quad (1.4)$$

Porosity  $\Phi$  was calculated from density porosity log using the equation:

$$\Phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad (1.5)$$

where,  $\rho_{ma}$  = matrix density = 2.65g/cc for sandstone (reference),  $\rho_b$  = bulk density which is taken to be 1 for gas and 0.87 for oil (reference).

The BVW in a reservoir is simply the product of the Water saturation ( $S_w$ ) and the porosity ( $\Phi$ ) as given in equation below

$$BVW = S_w \Phi \quad (1.6)$$

**3.0 RESULTS**

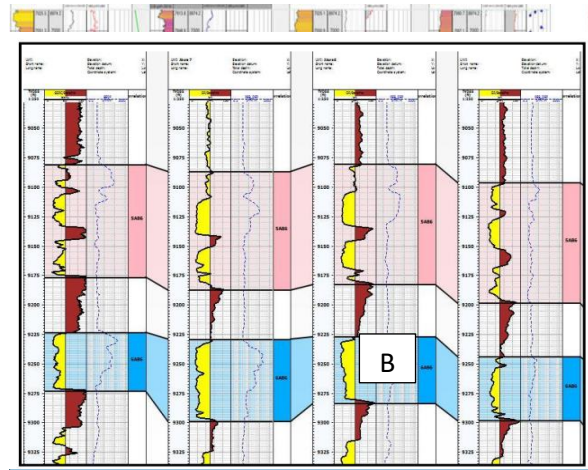


Fig 2 C,reted Well Log Cor D ion (Onshore)  
 Fig 3. Interpreted Well Log Correlation (Offshore)

**Table1: Petrophysical Results (Onshore)**

Reservoir F		Porosity	Vsh%	Sw%	Sh	BVW	Swirr%
well	Thickn ess (m)	( $\Phi$ %)			(%)		
A	11.28	33	15	15	85	0.042	6.0
B	60.0	27	09	95	05	0.27	6.0
C	9.14	30	12	28	72	0.096	5.5
D	19.0	29	05	20	80	0.048	6.0

**Reservoir W**

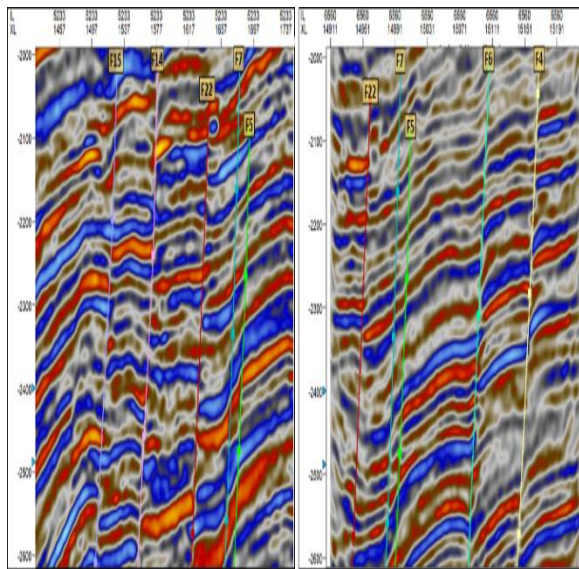
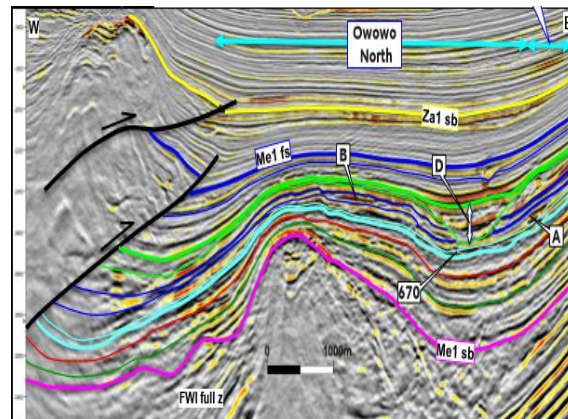
well	Thickn ess (m)	Porosity ( $\Phi$ %)	Vsh%	Sw%	Sh (%)	BVW	Swirr%
A	29.57	30	35	10	90	0.057	6.0
B	28.96	28	09	95	05	0.266	6.0
C	27.43	26	20	15	85	0.070	6.0
D	15.24	32	32	80	20	0.262	6.0

**Reservoir N**

well	Thickn ess (m)	Porosity ( $\Phi$ %)	Vsh%	Sw%	Sh (%)	BVW	Swirr%
A	31.4	29	18	15	85	0.0540	6.0
B	29.57	25	14	30	70	0.0928	6.0
C	22.86	29	08	06	94	0.0162	7.0
D	34.45	30	05	100	00	0.304	7.0

**Table 2: Petrolphysical Results (offshore)**

Reservoir	GR (API)	Interval (m)	Gross Thickness (m)	Bulk Density (g/cc)	Porosity ( $\Phi$ %)	Water Saturation (%)	Hydrocar bon Saturatio n (%)
A	47	2922-2929	7	2.18	28	22	78
B	22	2942-2950	8	2.22	26	25	75
C	18	2966-2977	11	2.30	21	20	80

**Fig.4 Interpreted Seismic Section Onshore Field****Fig.5. Interpreted Seismic Section Offshore field.**

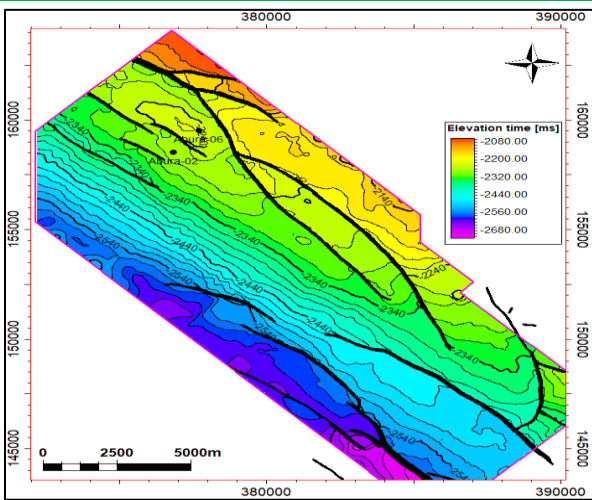


Fig 6a

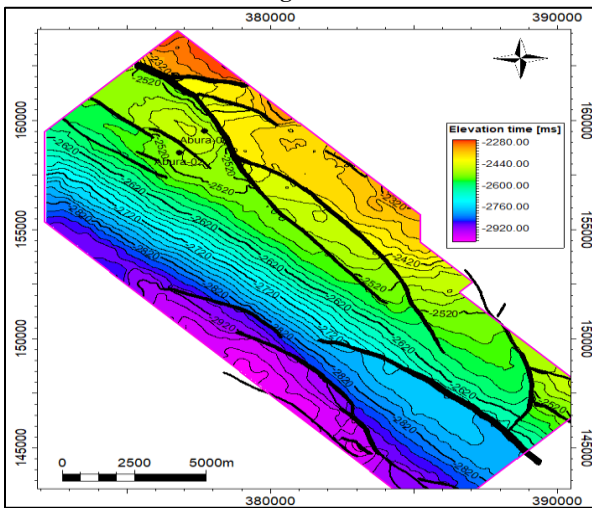


Fig 6b

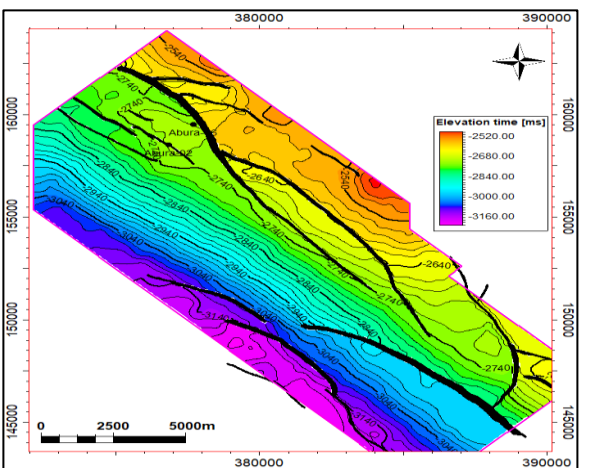


Fig 6c

Fig. 6a-c. Reservoir Top Time Structure map showing Onshore fault

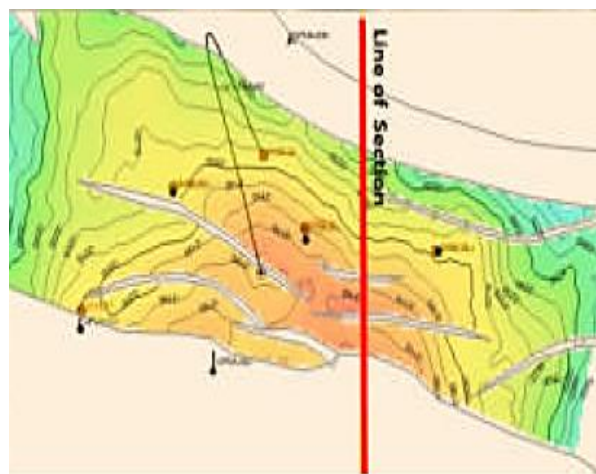


Fig 7a

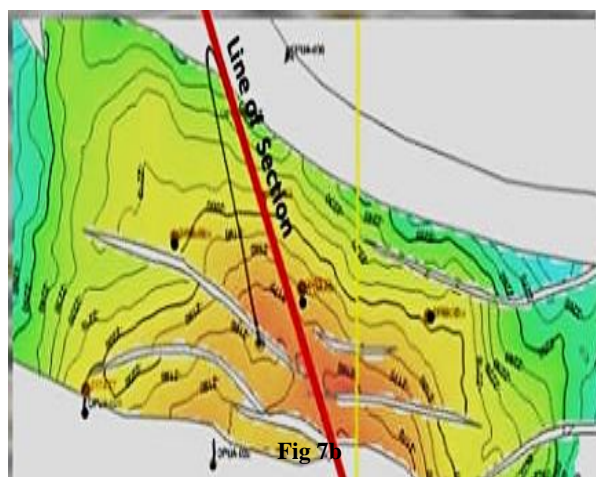


Fig 7b

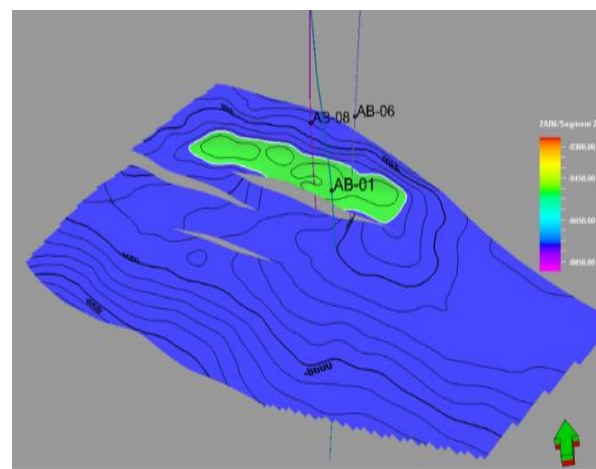


Fig 7.a-c Depth Structural Map Showing faults onshore

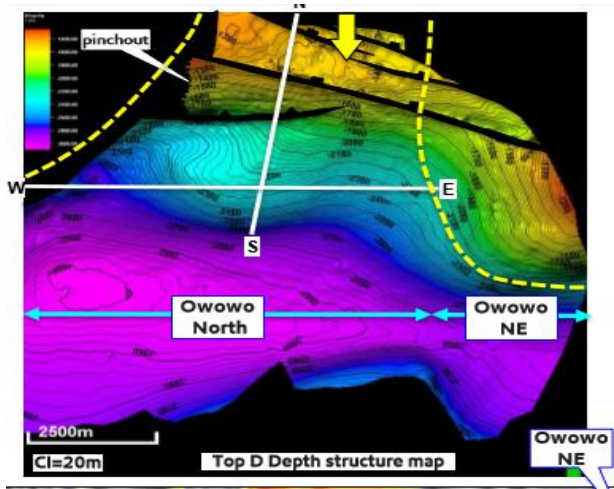


Fig. 8 a Top D Depth structure map

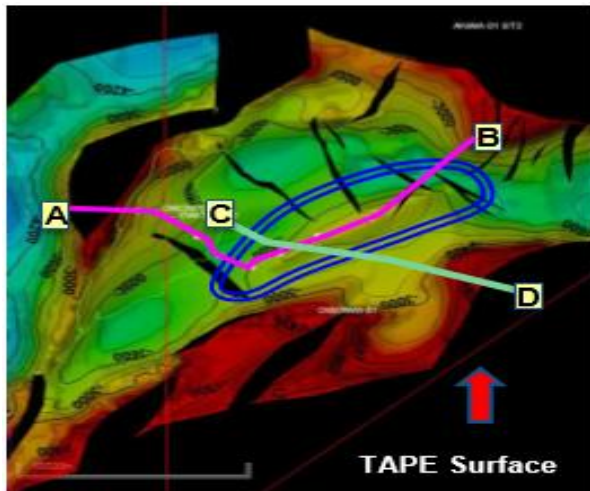


Fig.8b Depth Structural Map showing Potentially four closure to combination trap.

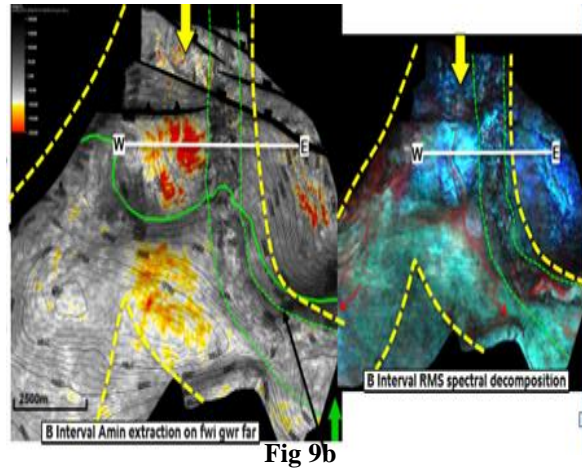


Fig 9b

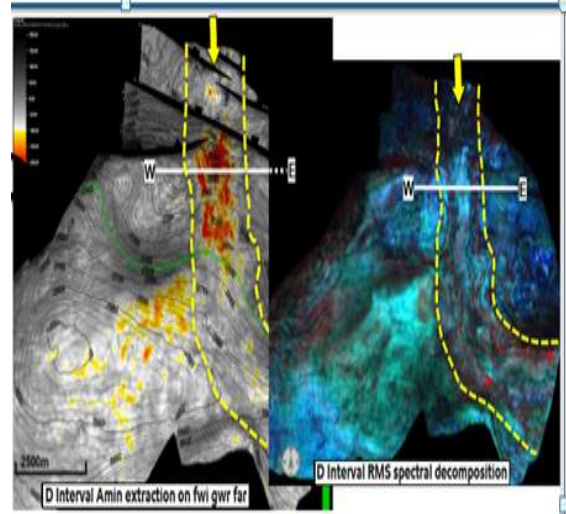


Fig 9c

Fig.9.a-c FWI and RMS structural maps

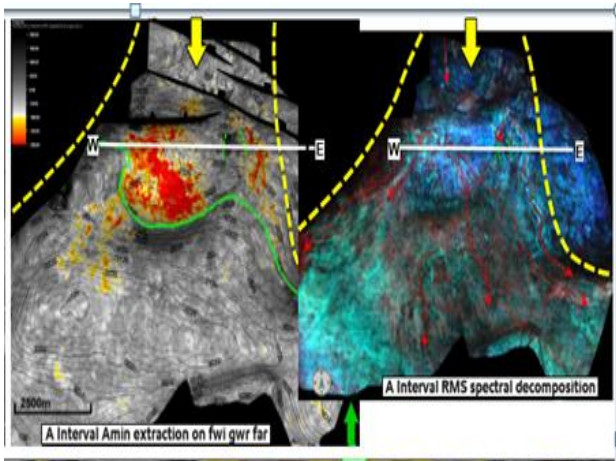
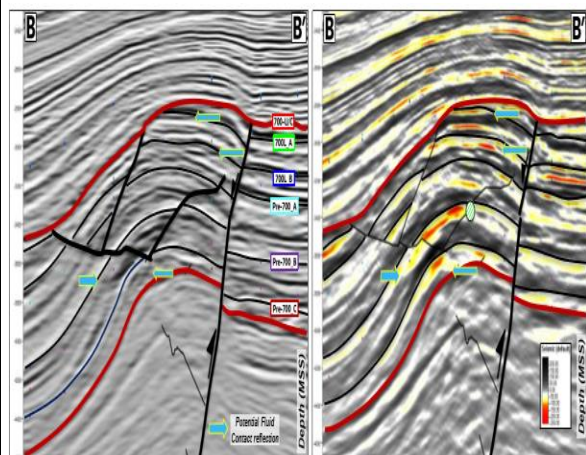
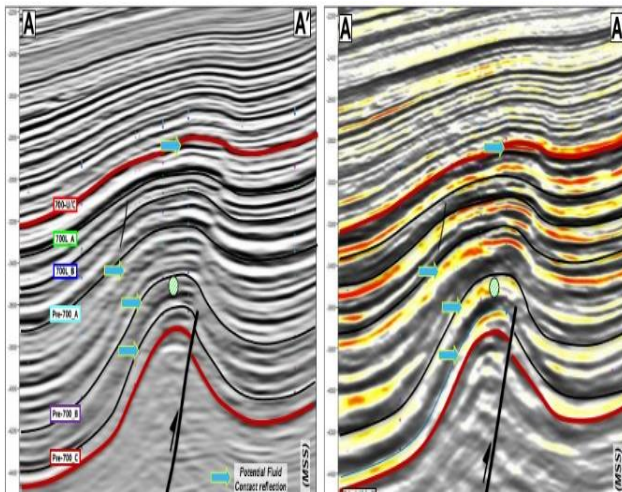
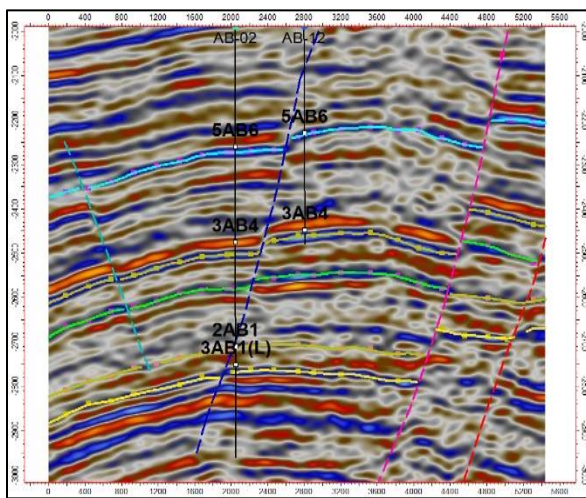


Fig 9a





**Fig 10. Interpreted stack Seismic volume showing observed hydrocarbon indicators.**



**Fig.11. Seismic to Well Ties with Interpreted Horizons**

### 3.1 DISCUSSION OF RESULTS

The Well logs were interpreted and appropriate reservoir bodies were characterized. Three hydrocarbon bearing reservoir (F, W and N) of varying thickness were identified and mapped at the depth. Four Wells (A, B, C and D) were evaluated showing some of the hydrocarbon-saturation intervals and they are bounded by fault. The logs were correlated to establish potential reservoir intervals in the block as well as the continuity of the sand bodies in the onshore field (fig.2). Across the wells in reservoir 'F', (Table1) show an average porosity value of 29.75% and volume of shale of 10.25%. In well A, C and D it has an average hydrocarbon saturation of 60.5% while well B has 95% water saturated and is considered wet zone. Across the wells in reservoir 'W' shows average porosity of 30.5% and shale value of 29%. Well A and C Shows average hydrocarbon saturation of

50.0%. The values of hydrocarbon saturation in well B and D are also low. Across the well in reservoir 'N' shows an average porosity value of 28.25% Volume of shale is 11.25%. In well A, B and C has an average of hydrocarbon saturation of 83% D show 100% water saturation is also a wet zone. The shale values in the wells are relatively high which implies that the reservoir is relatively seal and the well shows the BVW and Swirr are almost constant which suggest that the zones are homogenous.

While the Offshore well log (fig.3) show a four wells petrophysical analysis which revealed three key reservoir intervals. The reservoirs (A, B and C) lies between the depth intervals of 2922m to 2929m, 2942m to 2950m and 2966m to 2977m. From the comparison of the values of the petrophysical parameters (Table.2) the offshore porosity ranges from 21-28% which is very good for sandstone reservoir rocks and good hydrocarbon saturation ranging from 72 to 80%. It can then be said that the wells penetrated both Benin and Agbada Formations and probably the top of Akata Formation in which the fresh water sands belong to the Benin Formation and intervals that are hydrocarbon-bearing including correlated intervals belong to the Agbada Formation. The correlated images of the wireline logs and structural maps provided clear pictures showcasing the details of the reservoirs' conditions in the Onshore and offshore fields.

The seismic sections showed that three horizons and seven faults were mapped on the onshore field (fig. 4). While in the offshore field three horizons were interpreted and mapped with their respective seismic continuity (fig 5). The structural style that characterized the fields were mainly back-to-back structures, growth faults, listric fault, anticline fault, synthetic and antithetic faults. The mapped horizons in onshore and offshore field were used to generate the structural maps (fig 6,7 and 8). The maps revealed contour closures that exhibit structural trapping mechanism in the fields. It is both a four-way closure and fault assisted closures. And it provides an excellent mechanism for hydrocarbon entrapment

Full Wave Inversion and RMS maps (fig.9) were produced in order to get the sediment orientation and to highlight high amplitude zones. The fwi and RMS map of horizons A,B and D revealed sediment input fairway orientation to N-S and its orthogonal to the strike of the structure. The fair way deflected to South east by synkinematic growth of the structure in the south and the RMS show the strong amplitude anomalies in that directions. Analyses of the root-mean-square (RMS) revealed sections with bright spot anomalies. These

amplitude anomalies served as direct hydrocarbon indicators (DHIs) (fig10), the DHI observed in the stack volume seismic are lateral amplitude contrast, elevated amplitude background, fit to structure and flat spot. The observed flat events on the stacked volume was used to constrain hydrocarbon water contact elevation on depth maps along with other direct hydrocarbon indicator attributes. From well-seismic tie (fig.11) the top of the hydrocarbon bearing sand unit lie on top of the wells on the seismic section.

#### 4.0 CONCLUSION

The study of the structural style and trapping mechanism onshore and offshore Niger Delta has been studied with 3D seismic and well log data. Three hydrocarbon bearing reservoir of varying thickness were identified and mapped at the depth and three horizons and seven faults were mapped and interpreted in the onshore field while in the offshore field three horizons were interpreted and mapped with their respective seismic continuity. The structural maps illustrated that growth fault, listric fault, anticline fault, synthetic and antithetic fault are structural features in both fields. The maps revealed contour closures that exhibit structural trapping mechanism in the fields. It is both a four-way closure and fault assisted closures. And it provides an excellent mechanism for hydrocarbon entrapment. Smaller internal faults were also identified in the offshore field. Growth faults cut across the fields which serves as a trap that prevents seepage of hydrocarbon. Generally, structural framework of the fields from the comparison showed that indeed there exists a well developed structural styles and trapping mechanisms that are similar in both fields. These forms possible hydrocarbon leads that should be subjected to further revalidation.

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