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Hydrocarbon Exploration of 'JM' Field' Offshore Niger Delta

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Abstract

The economy viability of JM field, Niger Delta has been subjected to controversy due to an ambiguous state of the reservoir obtained from earlier evaluation of the field. This has hitherto; put on hold the development of the identified prospects. To explore this field, knowledge of 3D seismic, well log data and structural interpretation are needed to estimate the potentiality of the reservoir zones within the JM field for possible recommendation during drilling. This research aimed at characterizing the reservoirs in the JM Field using an integrated approach. An integration of three dimensional seismic, well logs and structural and petrophysical analysis of JM Field in the Niger Delta was carried out to identify where the hydrocarbon bearing sands from the wells, post on the seismic lines. The derived Petrophysical parameters from available well logs revealed that JM field has a high prolific hydrocarbon accumulation. Based on this, more hydrocarbon prospects have been identified in the study area.

Keywords: *Hydrocarbon volume; Structural interpretation; Well logging; Reservoir characterisation; Petro-physical.*

1. Introduction

The economy viability of JM field, Niger Delta has been subjected to controversy due to the ambiguous state of the reservoir obtained from earlier evaluation of the field. This has hitherto; put on hold the development of the identified prospects. Due to the uncertainties associated with the hydrocarbon prospects in this field, the reservoir characterization was carried out in the field using 3D seismic, well log data and structural and petrophysical interpretations to estimate the potentiality of the reservoir zones within the field for possible recommendation during drilling. This intends to clear the skepticisms surrounding the field. To achieve this, meaningful interpretation of seismic data needs to be displayed in depth since the primary geophysical seismic data is recorded in time [1]. Reservoir characterization requires the integration of different types of data to define the reservoir model. What is a reservoir? A reservoir is an heterogeneous geological system with a large intrinsic complexity. Hydrocarbon saturation is directly related to storage capacity, fluid flow capacity and amount of hydrocarbon pore volume. The reservoir parameters, uncertainty, natural heterogeneity, and nonlinearity are problems related to reservoir characterization. It is difficult to quantify spatial relation of variable reservoir properties. Computer-based intelligence methods can easily handle this type of complicated problem very accurately [10-11,13].

Several researches have been carried out on reservoir characterization especially in Niger Delta Basin. These have brightened up understanding of geoscientists as regard to seismic data interpretation for petroleum exploration. Hammed *et al.* [8] applied the integrated well data (gamma ray, resistivity and neutron/density) and detailed petrophysical interpretation to estimate the potentiality of the reservoir zones within the Field. This made the recommendation during drilling a possible development. Emujakporue [5] carried out a prospect evaluation of XY field using an integration of seismic and well log interpretation. The results of the qualitative interpretation of gamma ray and resistivity logs showed that the reservoir contains hydrocarbon of appreciable thickness.

Emujakporue and Ngwueke [6] delineated and mapped hydrocarbon bearing reservoir intervals of the X field in the Niger Delta using surface seismic and well log data. Two horizons mapped out were identified at different time levels on the seismic section. The structural analysis showed that there were six synthetic and four antithetic faults in the area. The faults were responsible for hydrocarbon entrapment in the field. Hydrocarbon prospect areas were delineated in the depth structured maps produced.

Hammed *et al.* [9] applied the time-depth relationship to identify structural traps where hydrocarbon bearing sands from the wells, post on the seismic lines using an integration of three dimensional seismic, well log data and structural analysis of Igbobi field of Niger delta.

This research aimed at characterizing the reservoir in the JM Field using an integrated approach.

2. Study area and source rock identification

2.1. Study area

The study area "JM" field is located within the southern margin of offshore Niger Delta (Fig. 1). It is a prospect of a multinational oil Company in Nigeria, in one of the southern concessions.

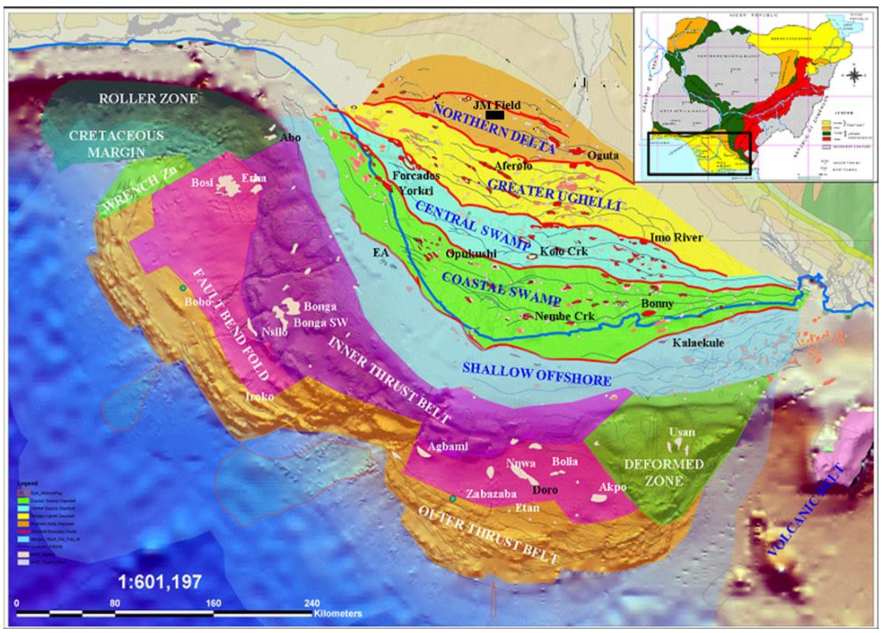

Figure 1. Map showing study area location and the Niger Delta megastructural framework (modified from Oluwajana *et al.* [14])

The Niger Delta region is situated in southern Nigeria between longitude 3^0 and 9^0 E and latitude 4^0 and 6^0 N. It occupies an area limited by Benin flank, the Anambra basin, the Calabar flank and the present coast line. It extends to the east-west direction from southwest Cameroon to Okitipupa ridge. Its apex is at the south east of the gulf of Guinea and in the north by older cretaceous tectonics elements such as the Anambra basin, Abakaliki uplift and also the Afikpo syncline. The tertiary Niger Delta covers an area of about 75,000 square kilometers and is composed of an overall regressive clastic sequence which reaches a maximum thickness of 12,0000m [7]. From the Eocene to the present, the delta has protruded southwest ward, forming depobelts that represent the most active portion of the delta at each stage of its development [2]. These depobelts from one of the largest regressive deltas in the world has an area of some 300,000 km^2, a sediment volume of 500,000 km ^{3} and a sediment thickness of over 10 km in the basin depocenter. The Niger Delta province contains only one identified petroleum system which is referred to as the tertiary Niger Delta (Akata-Agbada) petroleum system [4].

2.2. Source rock identification

The source of the oil in the Niger delta is probably the shale of Akata formation. Hydrocarbon generated in the Akata formation probably migrated up-dip through growth faults to accumulate in shallow reservoir of the Agbada formation. Many geochemical analysts believe that oil was generated from the shale of the Agbada formation. Most of the oil which is presently being produced comes from strata of miocenepliocene age. The oil field map of the Niger delta shows important faults, depobelt boundaries, and basement trends [3].

The Agbada formation has intervals that contain organic contents sufficient to be considered good source rock [12]. The intervals, however, rarely reach thickness sufficient to produce world-class oil province and are immature in various parts of the delta. The Akata shale is present in large volumes beneath the Agbada formation and is at least volumetrically sufficient to generate enough oil for world class oil providence such as the Niger Delta Base on organic-matter contents. Evamy [7] proposed that both the marine shale (Akata Formation) and shale intercalated with paralic sandstone (lower Agbada formation) were the source of the rock for the Niger Delta oil.

3. Methodology

3.1. Materials used for the study

The materials used for this study are:
(i) Field base map: it was used to identify the spatial location in the field which subsequently aid the map generation.
(ii) seismic data in SEGY-format with check shot data and well log data
(iii) a workstation with installed Petrel software 2015 version

3.2. Well Log Data

3.2.1. Loading of seismic data

Seismic data were imported into petrel in a ZGY-Y format. In order to visualize seismic data, general intersections have to be imported into the seismic data folder. Cropped volumes were inserted into the seismic data folder. A cropped volume was stored as a folder under the seismic data folder. The cropped seismic volume data were realized so that seismic section can be generated. The seismic data were properly viewed in a 3-D window and interpretation was carried out on the interpretation window plane.

3.2.2. Identification of lithology and delineation of reservoirs

In identifying lithology and delineation of reservoirs, gamma ray log was used. The lithology was identified by defining the sand and shale. The lithology is composed of intercalated of sand and shale units. The wells were correlated across the entire 'JM' field.

3.3. Determination of reservoir properties

This is a numerical estimation of reservoir properties, which involves calculation of reservoir parameters such as gross thickness, net thickness, and volume of shale, porosity, water saturation and hydrocarbon saturation with standard equations. The standard equations are discussed below;

3.3.1. Gross thickness and net thickness

This was carried out with the combination of depth log and gamma ray log or self potential log. Gross thickness is the total thickness of rock in the interval of thickness of a zone between two geological horizons or markers (i.e. sand-shale). This is obtained by subtracting depth of reservoir top from depth of reservoir base and it is expressed mathematically below:
Gross thickness = Reservoir base – Reservoir top (ft or m)
Net thickness is a thickness of reservoir sand within gross thickness.

3.3.2. Volume of shale

The data obtained from gamma ray log was used to achieve this. The volume of shale V_{sh} was mathematically computed from the following relationships using the I_{GR};

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

where: GR_{max} is gamma ray maximum (shaly sand); GR_{min} is gamma ray minimum from clean sand; GR_{log} is gamma ray log (shaly-sand).

Volume of shale (V_{sh}) $v_{sh} = 0.083(2^{3.7 I_{GR}} - 1)$ (2)

where: V_{sh} is the volume of shale; I_{GR} is the gamma ray index.

3.3.4. Porosity

This was carried out using sonic log. The porosity is a measure of the amount of internal space that is capable of holding fluid. It is expressed in percentage (%). The mathematical expression for the calculation of porosity using sonic log is shown below;

$$\emptyset_{sonic} = \left(\frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}\right) \quad (3)$$

where: φ_{sonic}= sonic-derived porosity; Δt_{ma} = interval transit time of matrix; Δt_{log} = interval transit time of formation; Δt_f = interval transit time of the fluid in the well bore (fresh mud = 189µs/ft, salt mud = 185µs/ft). The sonic log only records matrix porosity rather than fracture or secondary porosity.

3.3.5. Water saturation

This was carried out for each reservoir using Archie (1942) formula.

$$F = \frac{R_o}{R_w} \quad (4)$$

Making R_o the subject of relation from the equation above, we get;

$$S_w^n = \frac{F.R_w}{R_t} \quad (5)$$

Replacing R_o, for $F.R_w$, we get;

$$S_{w^2} = \frac{R_o}{R_t} \quad (6)$$

where: Sw = Water saturation; F = Formation Factor; R_w = Formation water resistivity at formation temperature; R_o = Resistivity of formation at 100% water saturation; R_t = True formation resistivity; n: Saturation exponent. This is usually 2.

3.3.6. Hydrocarbon saturation

Hydrocarbon saturation was calculated using the equations (7) or (8);

$S_h = 1 - S_w$ (7), or

$S_h = S_w - 100\ (\%)$ (8)

where: S_h is hydrocarbon saturation.

3.4. 3-D seismic interpretations

A 3-D data volume is suitable for derivation of the 3-D subsurface geological model. Due to the completeness of data within that volume, 3D seismic data set revealed more information compared to the 2-D seismic data set. Although more information leads to less uncertainty in deriving the geological model, interpretation of abundant data can be exhausting. The use of an interactive interpretation work station is a common way to deal with large 3-D data volumes. Moreover, an interactive environment is versatile in viewing the 3-D data volume. For example, we can examine vertical sections in inline, cross line, or any arbitrary direction, as well as horizontal sections, namely, time slices. An interactive environment also can provide the capability to improve interpretation. For example, horizon flattening, correlation of marker horizons across faults, and some image processing tools to enhance certain features within the data volume can be implemented.

3.5.1. Seismic structural interpretation

Using the 3-D seismic data volume, faults interpretation was checked quality wise using the 3D window. Identified faults were assigned name, color-coded. Two key seismic horizons were tied to the seismic section. Quality such as continuity, even strength, amplitude and coherency were used as guides. These analyses prompted the interpretation of the seismic horizons. About six faults were picked through the field. The maps generated are time-structure and depth-structure. Since seismic data are recorded in time and it is imperative to have this time domain data in the reflection of the subsurface, which is depth.

3.5.2. Seismic structural maps

Structural interpretation was undertaken to identify and assign faults found in the 3-D seismic volume. Time and depth structure maps were used to produce two horizons where normal growth faults were identified. Structural closures were identified as rollover and displayed on the time/depth structure maps and suggested probable hydrocarbon accumulation at the upthrow side of the fault.

3.6. Petrophysical interpretation

The petrophysical data were interpreted using the interactive petrophysical software known as Petrel Schlumberger. These conventional logs were used as supplementary method for getting some information about lithology, porosity, fluid types and possible digenetic processes. The conventional logs include; the gamma ray log (GR), neutron porosity log, density log, Acoustic log, resistivity (medium, deep and micro resistivity) logs and Pef-log. The GR log was used as a base for shale volume calculations.

4. Discussion

4.1. Lithology interpretation

The lithology of the reservoirs studied (Figure 2) depicts the depth of the hydrocarbon in the range of 10500-11300ft. It indicates the identification of sand (yellow) and shale (grey) in the GR log. The LLD9 log indicates the possibility of porosity in the sand which means there is a potential for hydrocarbon reservoir. Also the RHOB log (density log), revealed the point where there is high porosity and low porosity. The base of the Formation has been indicated on the well log based on its gamma ray log characteristics which indicates sequence of sand.

4.2. Well Log correlation for reservoir characterization

The well correlation panel comprises wells JM-02 and JM-03. Figure 2 signifies the correlation panel for the two hydrocarbon reservoir A (RES A) and reservoir B (RES B) delineated from the well logs and analyzed. It is oriented from northwest to southeast (NW to SE). The general stratigraphy is composed of intercalating sand and shale layers. The reservoirs, designated as RES A and RES B, were located within a depth range of 9550– 11225 ft across the well JM-03 and JM-02. RES A is located at average depth of 9800.59 ft on the JM-03 and 10055 ft on the well JM-02 and has average thickness of 233ft. It extends across all the wells with maximum thickness in well JM-03. RES B is located at the average depth of 10300ft on the JM-03 and 11259ft on the JM-02 and has average thickness of 128ft. This reservoir extends across all the wells with maximum thickness in the hydrocarbon reservoirs thinning eastwardly and the tops of the reservoir are undulating across the wells. These type of reservoirs delineated are blanket-like reservoirs.

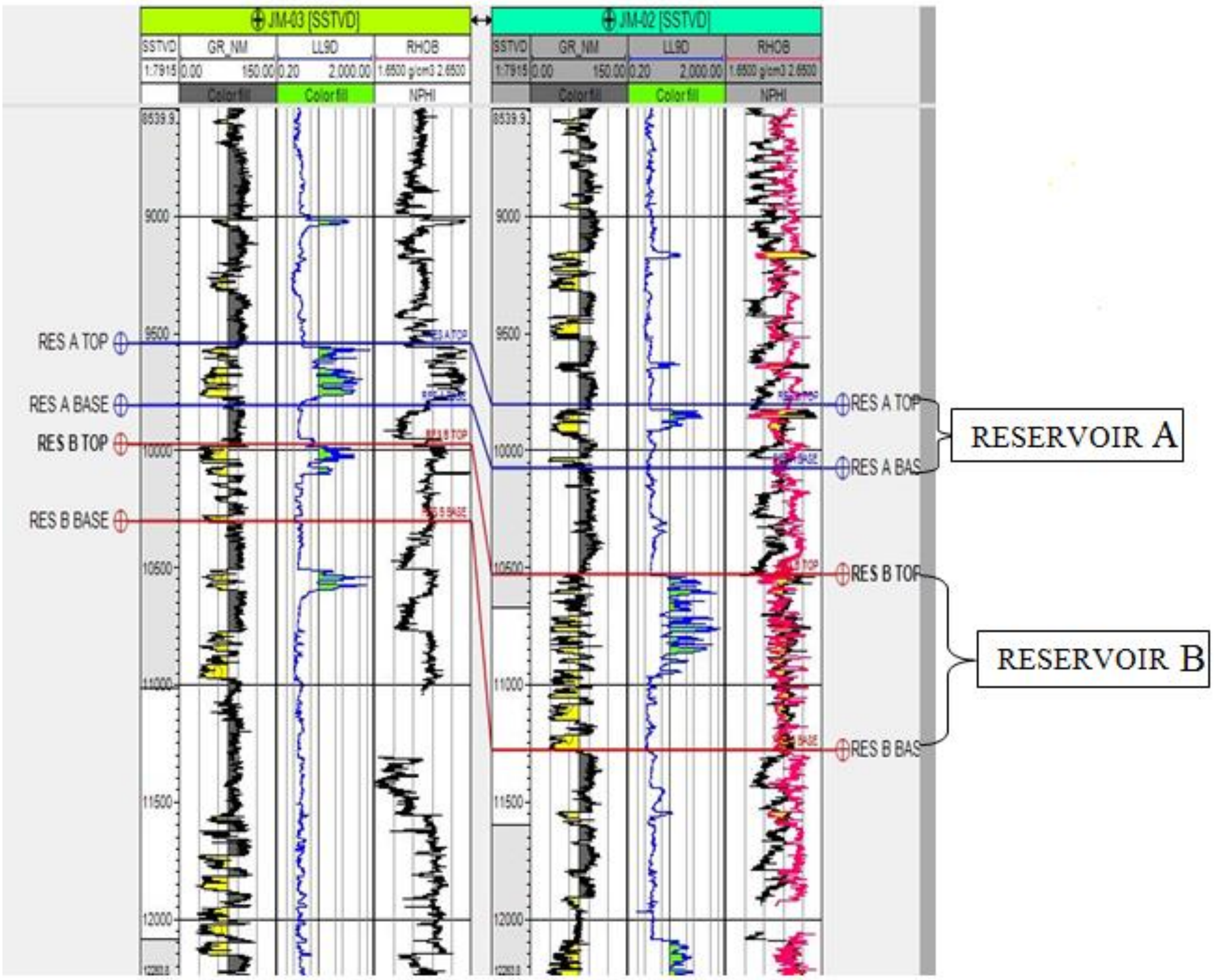

Figure 2. Lithostratigraphic well correlation of reservoirs A and B

4.3. Petrophysical analysis

The petrophysical properties of well JM-02, 03, 07 and 09 were evaluated. The computed Petrophysical properties for the reservoirs are shown in the Table 1. These parameters were calculated using standard equations.

Table 1. Computed petrophysical parameters of reservoir A across the Four Wells

Petrophysical parameters/Wells	JM-03	JM-02	JM-07	JM-09
Top (ft)	9553	9823	8796	9155
Base (ft)	9786	9951	8898	9248
Gross (ft)	233	128	102	93
Net (ft)	157	107	93	28
NTG (%)	67	84	91	30
I_{GR}	0.46	0.31	0.35	0.60
V_{SH}(%)	19	11	13	31
Φ^D(%)	22	28	27	33
F	20.66	12.76	13.72	9.18
S_{wirr} (%)	0.11	0.08	0.09	0.07
R_t(Ω-m)	80.37	22.55	38.58	6.83
S_w(%)	12	23	21	40
S_h (%)	88	77	79	60

Table 2. Computed petrophysical parameters of reservoir B across the Four Wells

Petrophysical parameters/Wells	JM-03	JM-02	JM-07	JM-09
Top (ft)	9983	10532	9394	9410
Base (ft)	10312	11055	9704	9732
Gross (ft)	329	532	310	322
Net (ft)	185	366	184	217
NTG (%)	56	69	59	67
I_{GR}	0.49	0.28	0.31	0.47
V_{SH}(%)	21	9	11	20
Φ^D(%)	26	27	25	28
F	14.79	13.72	16.00	12.76
S_{wirr} (%)	0.10	0.09	0.12	0.08
R_t(Ω-m)	16.14	69.48	67.67	41.45
S_W(%)	27	13	16	17
S_h (%)	73	87	84	83

The petrophysical analysis (as shown in Table 1 and 2) revealed that all the four (4) reservoirs in the field are of good quality. Four hydrocarbon bearing sand reservoirs named JM 2, 3, 7, and 9 were identified with the aid of gamma ray signature and resistivity log response. Four (4) petrophysical properties namely: water saturation (S_w); hydrocarbon saturation (S_h); porosity (Φ); volume of shale (V_{sh}) were computed from the reservoirs (Table 1 and 2). The Detailed results showed the average petrophysical values of the reservoirs in each well; JM-02, JM_03, JM-07 and JM-09. The effective porosity, water saturation and hydrocarbon saturation for JM-02 could not be determined due to non availability of Neutron logs. In this case, fluid contact of the different fluids present in the reservoir could not be evaluated. The Petrophysical parameters from available well logs revealed that the field has high prolific hydrocarbon accumulation. Two prospects have been identified in the field.

4.4. Seismic structural interpretation

The interpreted seismic section of the study location was generated (Figure 3). Faults were mapped out on the seismic sections. F_1, F_2, F_3, F_4, F_5, F_6, F_7, F_8, F_9, F_{10}, F_{11}, F_{12}, F_{13}, F_{14}, and F_{15}. The fault, F_8, which could be observed through the north-west direction served as the antithetic fault that has high potential for hydrocarbon trap. The horizons indicate where the hydrocarbon could be observed.

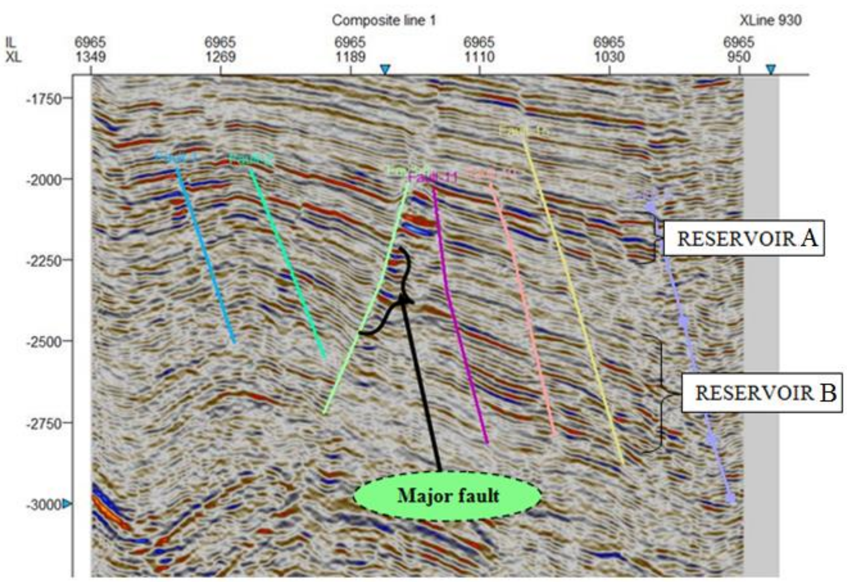

Figure 3. Some of the faults mapped showing on inline 6965

4.5. Seismic-to Well Tie

The results obtained from the integration of the time-depth conversion and well log depth generated a synthetic seismogram that can be used to determine the depth at which hydrocarbon can be found. The plot of time-depth conversion and the synthetic seismogram obtained in Figures 4 and 5 respectively delineated the depth at which hydrocarbon can be explored in the seismic well tie in the JM-09 well in the inline between 1161.00-1181.00ft. The synthetic model took into account the tied synthetic log of the JM-09 well.

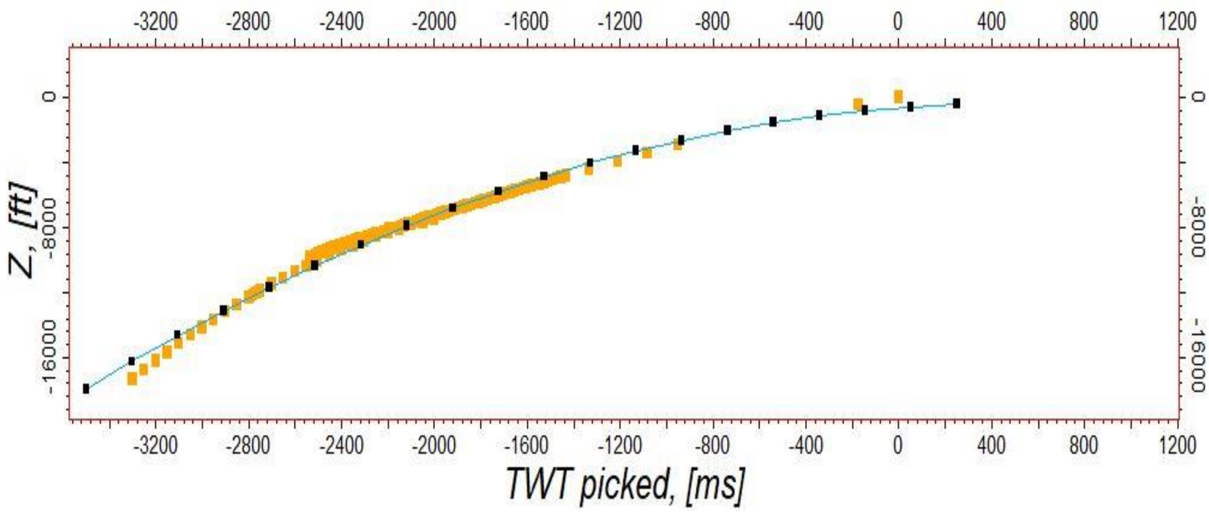

Figure 4. Time-Depth conversion Curve for JM Field

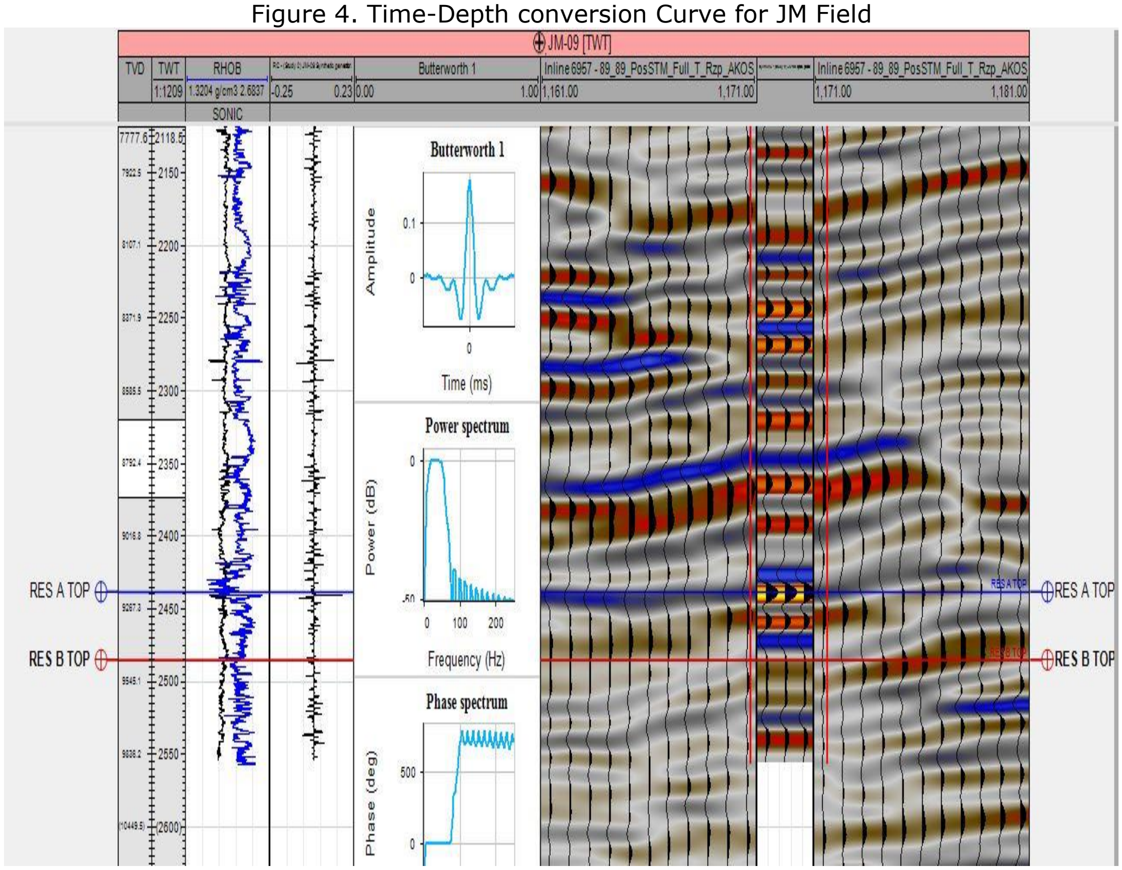

Figure 5: Seismic-to-well tie, which displays both the seismic and well log data

4.6. Time-structural map of RES A and RES B tops

The time-structural maps of reservoir, RES A and reservoir, RES B tops respectively showed that RES A top has a time range of horizon between 2960 and 2160 milliseconds and contour interval 125 milliseconds (Figure 6) and RES B top has a time range of horizon between 3060 and 2340 milliseconds and contour interval 125 milliseconds (Figure 7). They were mapped for closures or structures that possess effective trapping system suitable for hydrocarbon accumulation, development and production. It was observed that the contour patterns in the north central have hydrocarbon potentials. This signifies that the there could be further prospect of hydrocarbon exploration. It was also observed that in the RES A which has the contour lines between -10800 and -9000 and RES B which has the contour line between 2700 and 2430, there is high potential for hydrocarbon exploration. Also the well which falls on the faults JM-07 and JM-09 helps in trapping hydrocarbon contents.

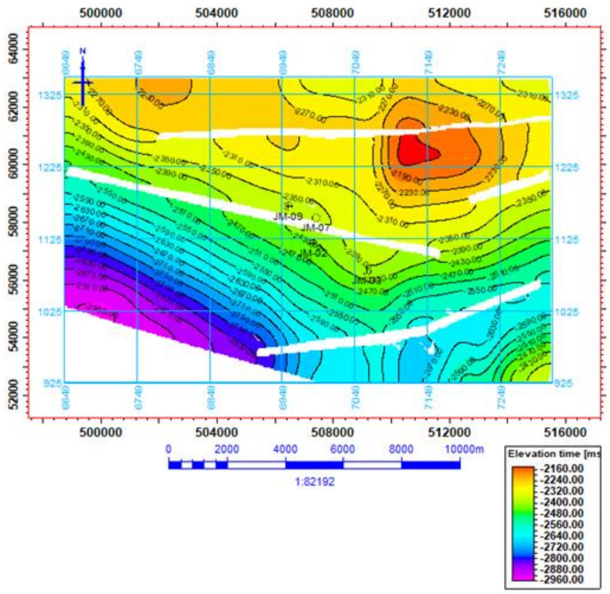

Figure 6. Time structural map of reservoir A top

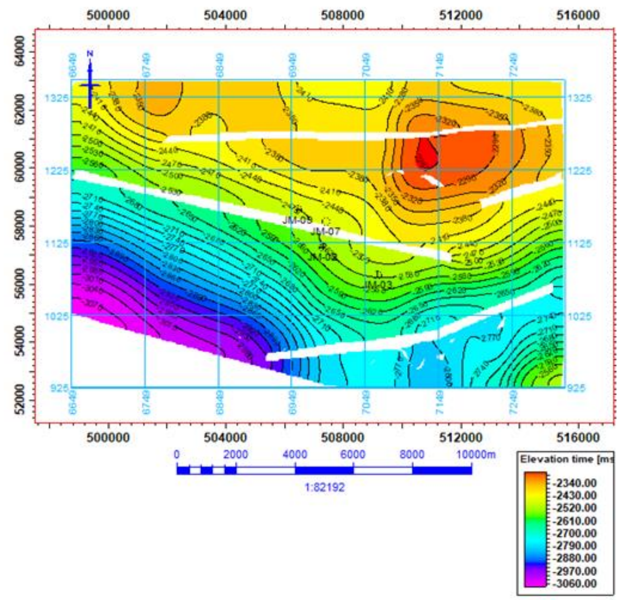

Figure 7. Time-structural map of reservoir B Top

4.7. Depth-structural map of RES A AND RES B tops

The depth-structural maps of RES A and RES B tops revealed that RES A top has a depth range between 13600 and 8260ft with contour interval of 250ft (Figure 8) and RES B has a depth range between 14250 and 9000ft with a contour interval of 250ft (Figure 9). This is an indication that the well JM-07 and JM-09 fall directly on the hydrocarbon trap. Thus, the two wells have high potential for quick hydrocarbon exploration. It also implies that the north central of the field has high potential for hydrocarbon exploration.

4.8. Identification of traps, prospects and reserve evaluation

Structural traps were observed from the closures on the Time Structural Map that is generated for each Sand Top. The contour patterns were used as fault assisted, fault dependent and anticline traps. Most closures were penetrated by wells. Therefore, the discovered prospects were easily viewed. Therefore in the contour line of the depth, RES A top map, (9750ft) in the south-east region is a possible prospect of hydrocarbon exploration in reservoirs A and B.

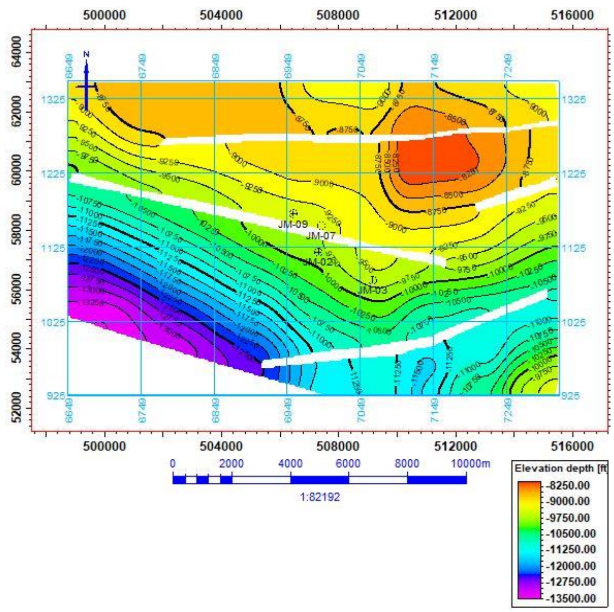

Figure 8. Depth-structural map of reservoir A Top

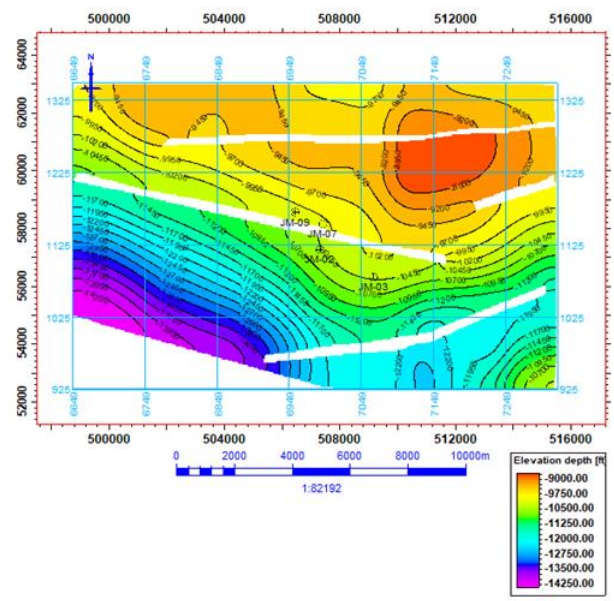

Figure 9. Depth-structural map of reservoir B Top

5. Conclusion

The derived petrophysical parameters from available well logs revealed that JM field has a high prolific hydrocarbon accumulation. Based on this, more hydrocarbon prospects have been identified in the study area. The growth faults trend W-E and dip towards the east, while the northern part is defined by fault population trending N-S which are responsible for high retentive capacity of the reservoirs and the hydrocarbon trapping mechanism in the studied area. Hydrocarbon prospect areas were delineated in the depth structural maps produced.

Finally, the information obtained from the seismic interpretation has resulted in more understanding of the structures and hydrocarbon potentials of the Northern Niger Delta depobelts. The 'JM' field is therefore recommended as a prospect for hydrocarbon exploration and should proceed to a further stage.

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