



Research article

Asserting the pertinence of the interdependent use of seismic images and wireline logs in the evaluation of selected reservoirs in the Osland field, offshore Niger Delta, Nigeria



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ARTICLE INFO

Keywords:

Petroleum engineering
Geophysics
Geology
High-resolution imaging
Well to seismic tie
Pay thickness
Drainage area
Developmental wells
Uncertainty reduction

ABSTRACT

This study presents a correct time and depth correlations with enhanced velocity analysis, based on two reservoir horizons mapped across two wells (Osl-1 and Osl-2). It involves the use of high-resolution images to delineate the complex geological structures associated with Reservoir A-horizon (R-A_h) and Reservoir B-horizon (R-B_h) based on 3-D seismic sections and wireline logs. It focuses on showcasing magnified images of the well to seismic tie (W-S_T), to enhance appropriate times and depths posting to aid correct determination of the pay thicknesses (P_t), drainage areas (A_d) and the mapping of other probable areas within the hydrocarbon field. The idea is to magnify the points of interest at very close intervals (≤2 feet) to enable the mapping of the actual positions and times of events within the reservoirs. The aim is to enhance better results and confidence in the interpretation, as such, reduce the uncertainty regarding hydrocarbon viability and volume estimation. R-A_h is tracking below 9550 feet and 2.460 s in Osl-1. It is below 9510 feet at 2.450 s in Osl-2. Similarly, R-B_h is tracking below 10550 feet at 2.655 s in Osl-1 and below 10520 feet at 2.650 s in Osl-2. R-A_h is about 70 feet (21.34 m) thick across Ols-1 and Osl-2 while R-B_h is 70 feet (21.34 m) thick and 100 feet (30.48 m) in Osl-1 and Osl-2 respectively. In total, A_d is 172 acres (69.6 × 104 m²) for R-A_h and 206 acres (83.4 × 104 m²) for R-B_h while the P_t is 140 feet (42.67 m) for R-A_h and 170 feet (51.82 m) for R-B_h. Possible wellbore positions to aid future developmental activities could be within the south-east, south-west and north-west directions of Osl-1 and Osl-2. The field is viable with regards to hydrocarbon availability, and the use of high-resolution images has aided accurate evaluation of P_t and A_d, hence, increased the confidence in the results of the interpretation.

1. Introduction

Hydrocarbon exploration and production usually commence with data acquisition, either on the onshore or offshore; and it involves lots of risk and uncertainties (Suslick et al., 2009). In any case, risk and uncertainty management habits are advisable in the whole process involving hydrocarbon exploration. Every instrument in use (equipment, technical knowledge and proper planning) contributes to the quality of the data acquired. The quality of interpretation and presentation of data is also very significant to the success of any exploration activity. Data interpretations includes the use of wireline logs to correlate zones suitable for hydrocarbon accumulation, identify productive zones, determine depth and thickness of zones, distinguish between gas, oil, and water in a reservoir and to estimate hydrocarbon reserves (Asquith and Krygowski, 2004; Tiab and Donaldson, 2012; Richardson and Taioli, 2019). 3-D

seismic interpretations are used to image subsurface structures capable of harbouring hydrocarbon (Hamed, and Kurt, 2008; Richardson and Taioli, 2018).

Usually, several hydrocarbon wells are correlated at a time, and the use of the results of the reservoirs with the complete set of log signatures for predicting similar parameters in others that may not have them is not uncommon. This approach may be inaccurate due to the inhomogeneity of the physical properties of one reservoir to another. As such, it could lead to incorrect evaluations of the required parameters, especially in volume estimations. Therefore this study shows high-resolution images based on the individual reservoirs and presents dilated figures to enable closer interpretation of the study location, hence, boosting the confidence in the results. Magnification of points at very close intervals could enhance the determination of the actual reservoir tops and bottoms. It could also help to eliminate units within the reservoirs with shale

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<https://doi.org/10.1016/j.heliyon.2020.e05320>

Received 19 June 2019; Received in revised form 21 March 2020; Accepted 19 October 2020

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intercalations to enable more accurate estimation of the pay thickness (P_t) and drainage area (A_d). As such, errors that could lead to the over-estimation/underestimation of hydrocarbon volumes are minimized. P_t and A_d are necessary inputs for the estimation of the recoverable and volumes in places of hydrocarbon (Bateman and Fessler, 1990; Asquith and Krygowski, 2004; Richardson and Taioli, 2017). Most often, geophysical data acquisition 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 evaluation is relevant to predict the hydrocarbon potential of Osland oil and gas field within the Niger Delta. The decision to go ahead with developmental activities in oil and gas fields could largely depend on the deductions made by evaluations such as presented in this study. High-resolution images highlighting the times and depths to the tops and the bottoms of selected reservoirs are useful for thorough evaluation of pay zones, trap types and drainage areas (A_d). These parameters are significant to the prediction of possible points recommendable for sitting developmental wells within the study location.

3-D seismic data comprises a set of numerous closely spaced seismic lines that provide a high spatially sampled measure reflectivity and

typical receiver line spacing could range from 300m (1000 feet) to over 600m (2000 feet) (Coffeen, 1986; Tom, 2002; Keary et al., 2002; Schlumberger Oilfield Glossary, 2018). The original seismic lines are called the in-lines, and the lines displayed perpendicular to them are called cross-lines. A range of these lines was engaged in this evaluation. Each of these seismic lines depicts a seismic section. Seismic data with wireline logs have been used in several ways for locating and evaluating the geometry of structures that harbour hydrocarbon. According to Wang (1995), a geologic trap is a combination of rock structures that hold hydrocarbon in place and can prevent the lateral or vertical escape of oil and gas to the surface. These hydrocarbon traps are categorized as either stratigraphic (i.e. unconformity, reef, or pinch out), structural (i.e. folded or faulted) or a combination of structural and stratigraphic traps (Lines and Newrick, 2004). Lines and Newrick (2004) defined a stratigraphic trap as a hydrocarbon trap caused by lithologic changes. In this case, a reservoir unit is encased within impermeable units or is thinned out against a seal. Structural traps, on the other hand, are caused by folding, faulting or other deformities. This study projects the geologic trap (structural style) that is associated with the hydrocarbon potential and enabled the estimation of the total value of the drainage area (A_d) within

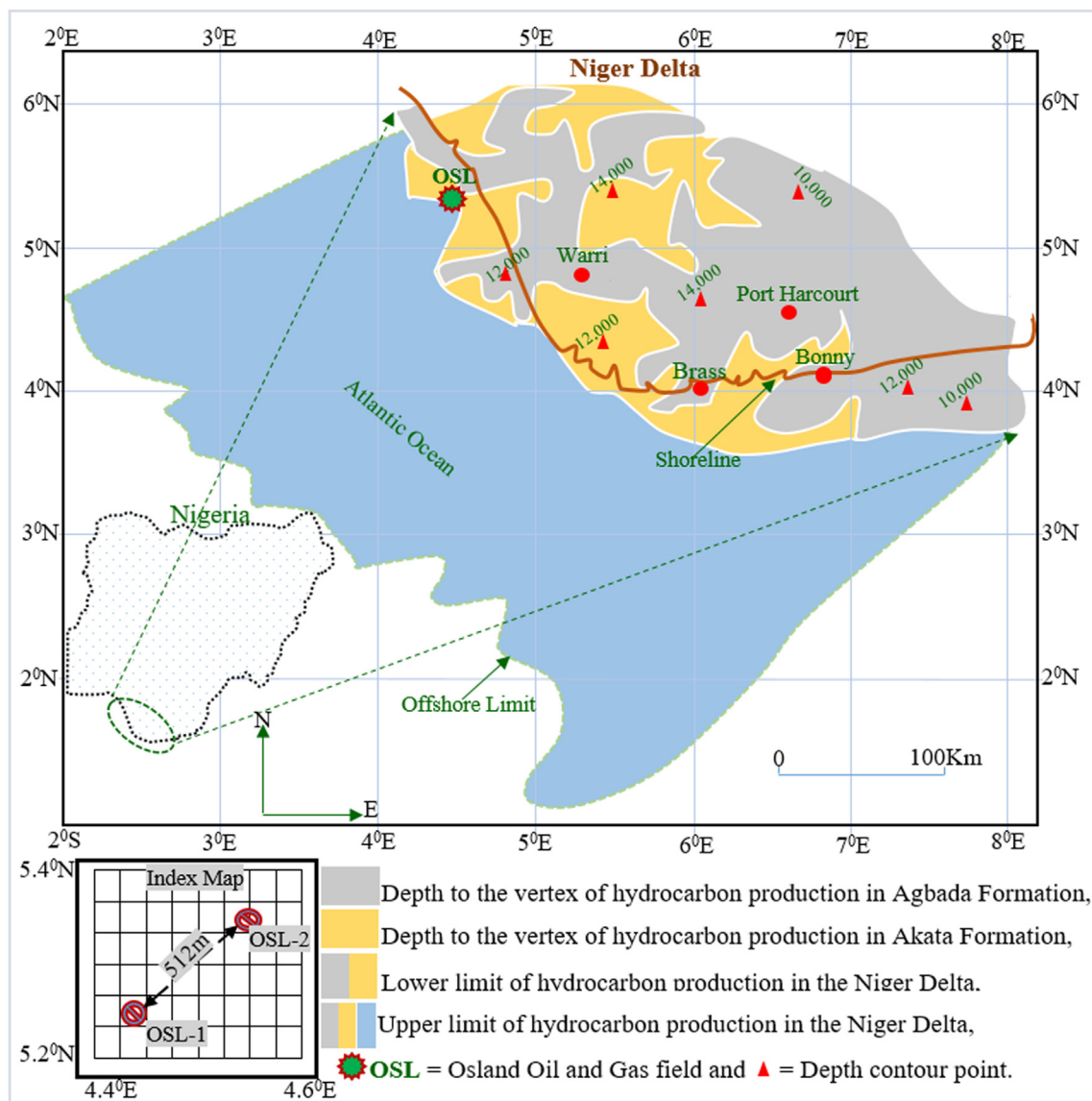


Figure 1. Niger Delta map showing study location with upper and lower limits of hydrocarbon production.

Osland oil and gas field. As such, all the delineated drainage areas are faults dependent.

Geological/geophysical concepts are indeed uncertain concerning reservoir seals, structures, availability of hydrocarbon and other physical parameters. However, this study has enabled a closer evaluation of the study location to improve the quality of the results.

2. Petroleum geology

The study area is located within the offshore continental margin, south-west Niger Delta. It occupies an area enclosed by the geographical grids of latitude 5.2°N and 5.4°N and longitude 4.4°E and 4.6°E (Figure 1). The yield of 5,100 barrels of oil per day was a success by Shell-British Petroleum in 1958, but there was a relapse due to the Biafra-Nigeria war, production increased afterwards.

Three lithostratigraphic units; Benin, Agbada and Akata Formations exist in the Niger Delta (Ejedawe, 1981; Doust and Omatsola, 1990; Reijers, 2011; Richardson and Taioli, 2019). Source rocks are sedimentary rocks that are normally very rich in organic content and are generating or have the tendency to generate petroleum (Tissot and Welte, 1984; Akinlua et al., 2016). The consensus is that the most effective source rock, in the Niger Delta sequence is the marine shale of the Akata Formation and the shale interbedded with the paralic sandstones of the Agbada Formation and that they have both yielded oil and gas. The undiscovered resources of the Tertiary Niger Delta (Akata-Agbada) Petroleum System is estimated at 40.5 billion barrels of oil and 133 trillion cubic feet of gas (Michael and Ronald, 2006).

Ejedawe et al. (1984), suggested that the Agbada shale sources the oil while the Akata shale sources the gas. On the other hand, Doust and Omatsola (1990) suggested that the Agbada and Akata Formations are both source rocks and that the Agbada Formation should be producing more. 34.5 billion barrels of recoverable oil and 93.8 trillion cubic feet of recoverable gas have been discovered in the Niger Delta (Michele et al., 1999). This indicates that the undiscovered volumes in places in the Niger Delta are more than the discovered volumes. The faults, rollover and collapsed structures observed within the studied reservoirs in Osland Oil and Gas Field are exemplary of the Niger Delta. These structures are possible aftermaths of the continental breakup and rifting of the African and South American plates (Weber and Daukoru, 1975; Genik, 1993; Stacher, 1995; Byami et al., 2016).

Rifting in the Niger Delta started from Late Jurassic to late Cretaceous, thereafter, gravity tectonism took over as a major force and influenced other structural changes (Lehner and De Ruiter, 1977; Genik 1993; Michele et al., 1999; Michael and Ronald, 2006). Structural

deformation commences when the potential of gravity is good enough to overcome the overburden internal strength and resistance to slip along the basal detachment (Rowan et al., 2004). The resultant movement brings about vertical and/or lateral displacement and influences rock deformation, such that different structures are produced. diapirs, rollover anticlines, collapsed crests and faults are closely associated with this gravity tectonics (Doust and Omatsola, 1990; Stacher, 1995; Brownfield, 2016). Some faults are synthetic and cut across the field while others are antithetic, but are terminated right on top of other faults (Figure 2). Freddy et al. (2005) also confirmed that the structures are exemplary of an extensional rift system with faults juxtaposing against each other. Niger Delta basin is characterized by diapiric shale that provides the trap (seal and cap rock) in the region (Doust and Omatsola, 1990).

The shale also provides three sealing mechanisms; clay smear along faults, interbedded sealing units against which reservoir sands are juxtaposed due to faulting and vertical seals (Doust and Omatsola, 1990; Tuttle et al., 1999; Freddy et al., 2005). Hydrocarbons are held in places in the Niger Delta because of the enormous structural traps. These traps exist due to the availability of closely distributed faults as seen in Osland Oil and Gas Field.

The production of petroleum in the Niger Delta is associated with the unconsolidated reservoir sands largely in the Agbada Formation. These reservoir sands are controlled by the depth of burial and by the depositional environment and they are Eocene to Pliocene in age (Michele et al., 1999). Furthermore, the reservoirs are normally stacked up and are vary in thicknesses and the thicker reservoirs are most likely to represent composite bodies of stacked channels (Evamy et al., 1978; Doust and Omatsola, 1990). Similarly, Kulke (1995) describes the significant reservoir types as point bars of distributary channels and coastal barrier bars intermittently cut by sand-filled channels, considering the quality and geometry of the reservoir. The Niger Delta reservoirs are described as Miocene paralic sandstones with significant flow units and thicknesses (Edwards and Santogrossi, 1990; Richardson and Taioli, 2017). It is also suggested that potential reservoirs are very likely to be created by the combined effort of deep-sea channel sands, low-stand sand bodies, and proximal turbidites (Beka and Oti, 1995). Growth faults determine the lateral variation in reservoir thickness and lithofacies, as such, the reservoir thickens towards the fault within the down-thrown block (Weber and Daukoru, 1975; Smith-Rouch et al., 1996).

3. Materials and methods

3-D seismic data with integrated wireline logs consisting of Gamma-ray log (GR), Shallow Laterologs (LLS) and Deep Laterologs (LLD), Water

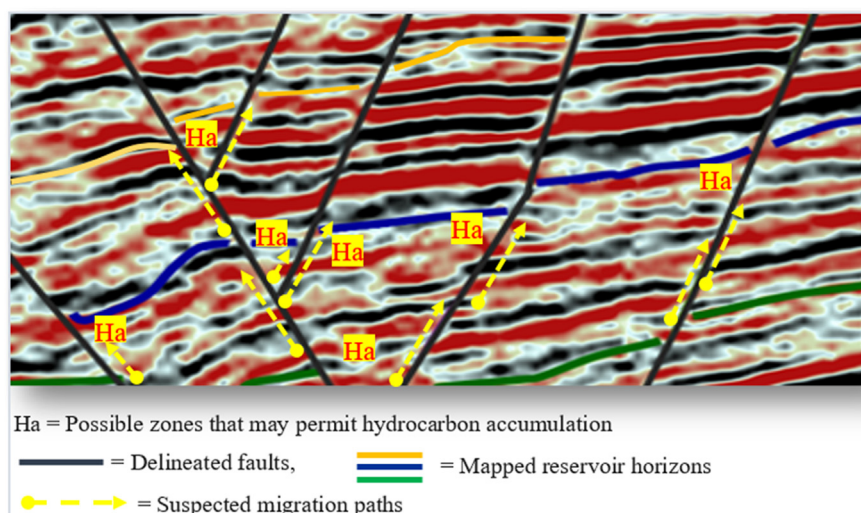


Figure 2. Influence of the structural deformation on hydrocarbon migration and accumulation within the Niger Delta Petroleum System.

Saturation log (SW) Neutron log (NPHI) and Density log (RHOB) were used for the research. The study involves high-resolution imaging with correct time/depth correlations and enhanced velocity analysis for petrophysics and seismic interpretations. The objectives include;

- The use of wireline logs to correlate zones suitable for hydrocarbon accumulation, identify productive zones,
- Generation of seismic sections to aid the mapping of faults and horizons and development of time and depth structural maps,
- Well to Seismic Tie ($W-S_T$), to evaluate the times and depths of occurrences of these reservoirs as reflected on the wireline logs data and the seismic sections
- Magnification of points of interest at very close intervals to aid thorough evaluation of Pay Thicknesses (P_t), Drainage Areas (A_d) and other points within the field for the siting of developmental wells.

3.1. Logs

The GR was used for litho-units identification and as such, the potential reservoir sands were differentiated from the shale units. In Osl-1, LLS and LLD were combined to delineate portions within the reservoirs that are hydrocarbon saturated based on the resistivity responses within the zones of interest. Osl-1 has SW, NPHI and RHOB, and they are used to confirm the presence of hydrocarbons. In Osl-2, LLD alone was used for the identification of hydrocarbon-bearing sands.

3.2. Seismic

Qualitative hydrocarbon reservoirs evaluation is done with seismic sections and structural maps. In this study, faults and horizon delineation (Figure 3) was fundamental and was carried out with distinct attention to the abrupt endings of reflections, up-throw with relative down-throw, abrupt changes in dip directions, distortion/displacement of reflections and disappearance of reflection below suspected faults lines. These points were carefully looked out for because the field is characterised by multiple faults with collapsed and rollover structures. Two consistent horizons [Reservoir A-horizon ($R-A_h$) and Reservoir B-horizon ($R-B_h$)] were picked respectively on both inlines and crosslines. The timing was done by reading reflection time on the horizon picked at intervals. The values for the time obtained were, therefore, posted at appropriate points on the seismic situation maps. The tops and bottoms of the selected horizons were timed at every change in reflection. It represents the arrival time of the reflection from the sea level. Faults were posted to their

corresponding location on the depth structure map. Before contouring, the horizon times were gridded, smoothened and converted to depth grids.

Grids were generated in different colours, each representing a delineated horizon and aided the production of the time and depth contour maps. Times to depths (T-D) conversion was carried out with the use of check shot survey data. T-D conversion involves the changing of the acoustic wave travel time to the actual depth, based on the acoustic velocity of the subsurface medium. This conversion permitted to produce depth and thickness maps of subsurface layers interpreted on seismic reflection data. These maps are essential in hydrocarbon exploration to aid the estimation of the recoverable volumes of hydrocarbons.

3.3. Well to seismic tie ($W-S_T$)

Check shot data of Osl-1 and Osl-2 was used for the conversion of seismic travel time values to depth and to tie well logs to seismic sections within the evaluated reservoirs. Usually, check shot includes direct measurement of the travel time from an energy source at the surface down to various depths within the reservoir of interest.

3.4. Pay thickness (P_t) and drainage area (A_d)

The mapping of the P_t is based on the deflections of Shallow Laterolog (LLS), Deep Laterolog (LLD) and Gamma-ray log (GR). Maximum Resistivity logs (LLS and LLD) with a corresponding minimum GR signifies the presence of a hydrocarbon-bearing unit within the reservoir. Magnification of points at intervals of less than 2 feet within each of the reservoirs, enabled high-resolution at the tops and bottoms of Pt. As such, it showed the exact tops and bottoms of the hydrocarbon-bearing units and aided to eliminate portions with shale intercalations within each of the reservoirs, to avoid incorrect estimations of the actual P_t . In the same vein, the magnification of the reservoirs horizons at close intervals permitted to accurately outlined the A_d with the aid of the planimetry tool in the Kingdom suit software.

4. Results

Figure 4 shows the first well (Osl-1) tied to the seismic to aid the production of the time and depth structure map. The two horizons were consistent on the reservoir sand. The thickness of the portion occupied by the hydrocarbon below the Reservoir A-horizon ($R-A_h$) is about 70ft. (9550ft. to 9620ft.) and timed between 2.46 and 2.48 s. Below the Reservoir B-horizon ($R-B_h$), the thickness of the hydrocarbon column is about 70ft. (10530ft. to 10600ft.) and timed between 2.65 and 2.67 s.

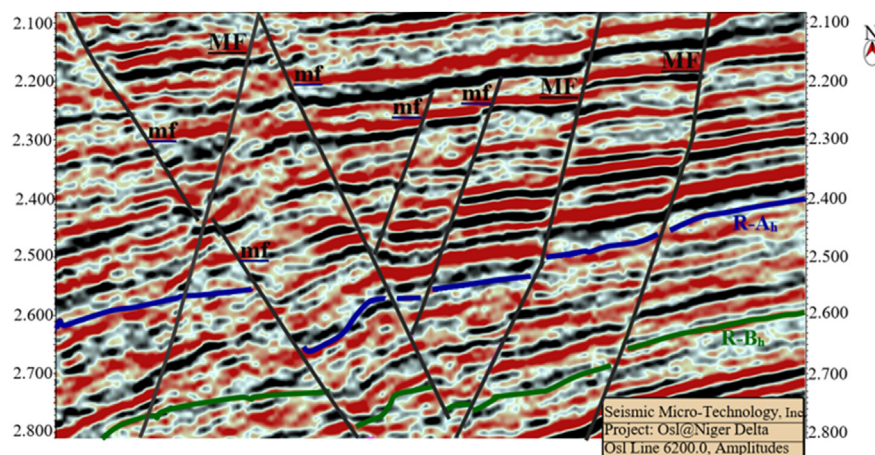


Figure 3. Inline 6200 Showing Structure with Multiple Growth Faults, Collapsed Structures, Structural Traps and Selected Horizons (Osland Oil and Gas Field). MF = Major Fault, mf = Minor Fault, $R-A_h$ = Reservoir A-horizon, and $R-B_h$ = Reservoir B-horizon.

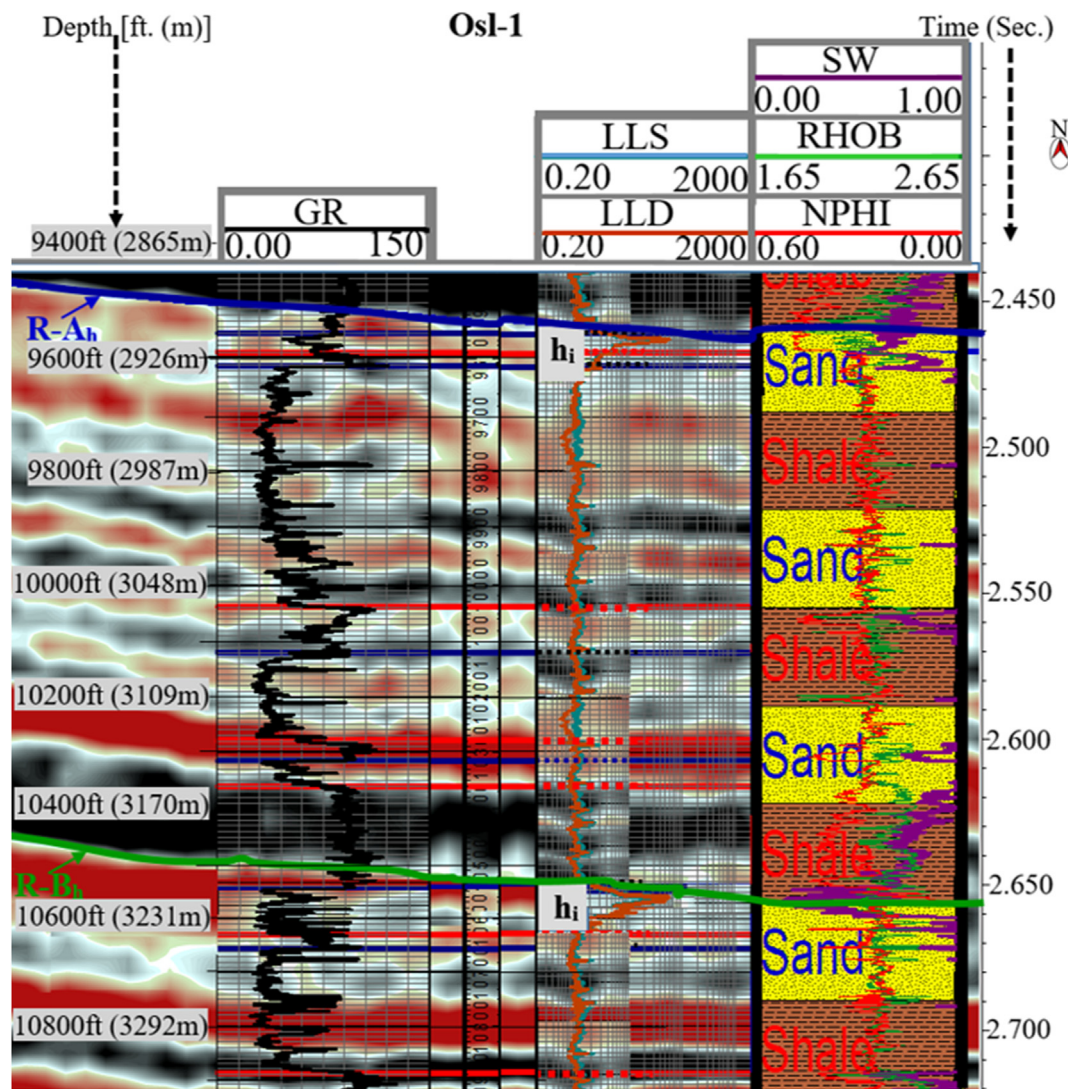


Figure 4. Well to Seismic Tie (W-S-T) of Osl-1. GR = Gamma ray log, LLD = Deep laterolog, LLS = Shallow laterolog, NPHI = Neutron Porosity log, ROHB = Density tool, and SW = Water Saturation Log. R-A_h = Reservoir A-horizon, R-B_h = Reservoir B-horizon and h_i = Hydrocarbon Indication.

Figure 5 shows the first well (Osl-2). The thickness of the portion occupied by the hydrocarbon below Reservoir A-horizon (R-A_h) is about 100ft. (9510ft. to 9610ft.) and timed between 2.45 and 2.48 s. Below the Reservoir B-horizon (R-B_h), the thickness of the hydrocarbon zone is 70ft. (10520ft. to 10590ft.) and timed between 2.65 and 2.67 s.

The structural maps (contoured in time and depth) of the two selected horizons show the two-way travel time of the seismic wave, the geometry of the reflector, probable areas considering structural highs, depths of occurrence and faults orientation. These maps reflect the geologic information, such as anticline with their respective syncline and the geometry of the faults as they relate to migration and accumulation of hydrocarbon.

Each of the depth structure maps shows the delineated drainage areas (A_{d-1}, A_{d-2} and A_{d-3}). The depths of occurrences of these zones on the seismic images correspond to the wireline logs. The structural map of Reservoir A-horizon (R-A_h) (Figure 6) reveals a travel time tracking between 2.097 and 2.704 s. The portions outlined as hydrocarbon saturated track between 2.45 and 2.50 s, it corresponds to the results of the W-ST. R-A_h (Figure 7) reveals a depth between 7770 feet and 10764 feet. The thicknesses of the portions delineated as hydrocarbon saturated is between 9450 feet and 9700 feet, and it corresponds to the results of the wireline logs.

Similarly, the structural map of Reservoir B-horizon (R-B_h) (Figure 8) reveals a travel time tracking between 2.223 and 2.995 s. The portions outlined as hydrocarbon saturated track between 2.65 and 2.70 s. R-A_h (Figure 9) reveals a depth between 8359 feet and 12299 feet.

The thicknesses of the portions delineated as hydrocarbon saturated in both wells is between 10450 feet and 10610 feet. and the respective values of the drainage areas (A_{d-1}, A_{d-2} and A_{d-3}) are 94.204 acres ($38 \times 10^4 \text{ m}^2$), 24.320 acres ($1 \times 10^4 \text{ m}^2$) and 87.863 acres ($36 \times 10^4 \text{ m}^2$) (Table 1).

5. Discussion

This study has shown a correct time/depth correlation and enhanced velocity analysis for seismic processing in the evaluated wells. It presents the high-resolution imaging in Osl-1 and Osl-2 and complex geological structures associated with the reservoirs. The results of this evaluation further confirm the viability of the hydrocarbon reservoirs. The enhanced images of the wireline logs and structural maps provided clear pictures, showcasing the details of the reservoirs' conditions. The orientation of the faults aids the structural traps within the field. Two major (MF₁ and MF₂) and five minor (mf_a, mf_b, mf_c, mf_d, and mf_e) faults are within the study area, with the former cutting across the entire field while most of the later are within the western portion. These faults are in closed

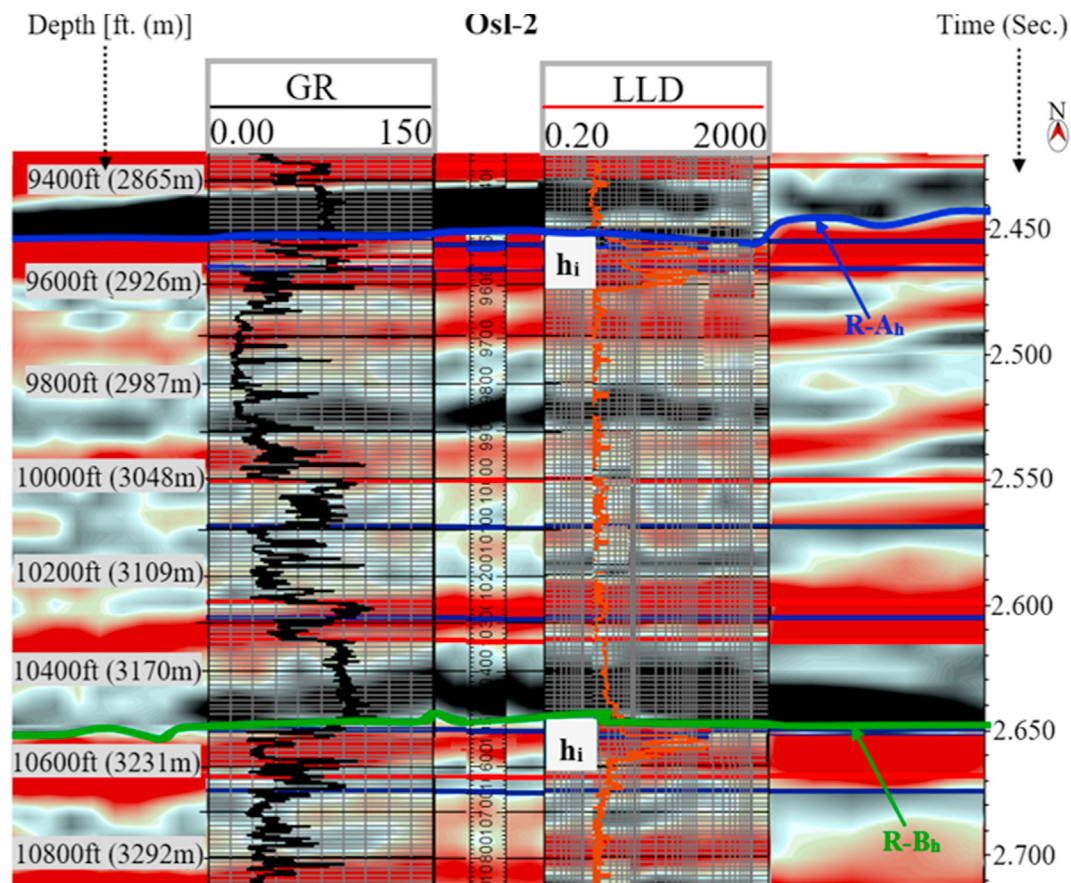


Figure 5. Well to Seismic Tie (W-S_T) of Osl-2. GR = Gamma-ray log, LLD = Deep laterolog, R-A_h = Reservoir horizon A. R-B_h = Reservoir horizon B and h_i = Hydrocarbon Indication.

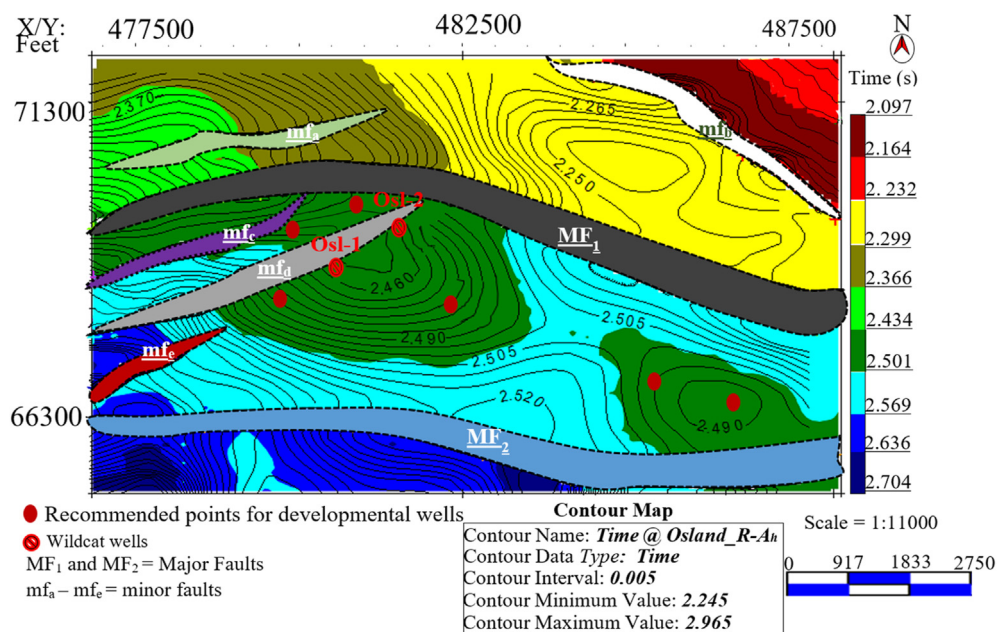
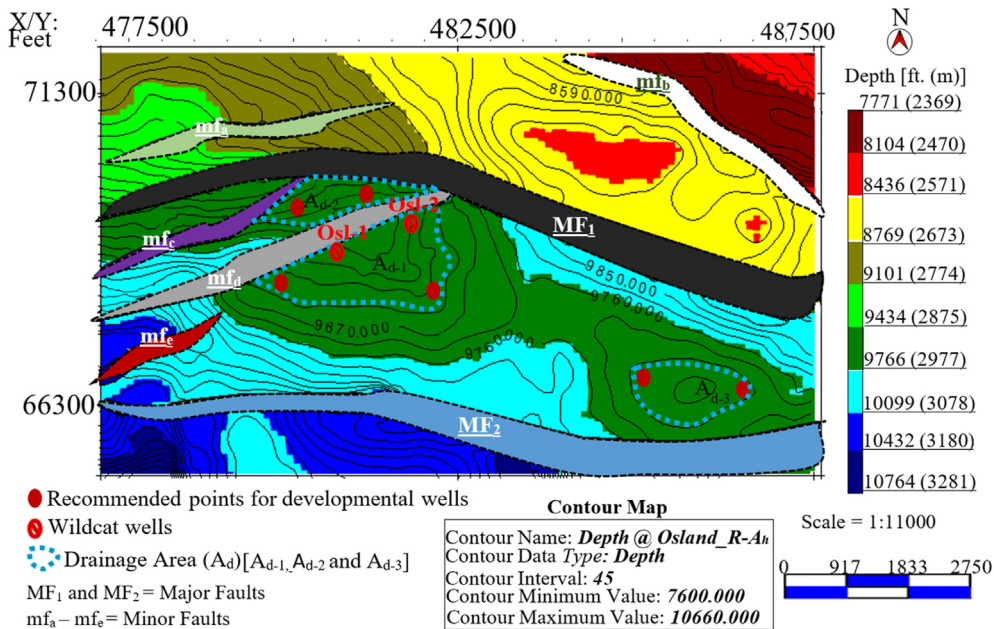
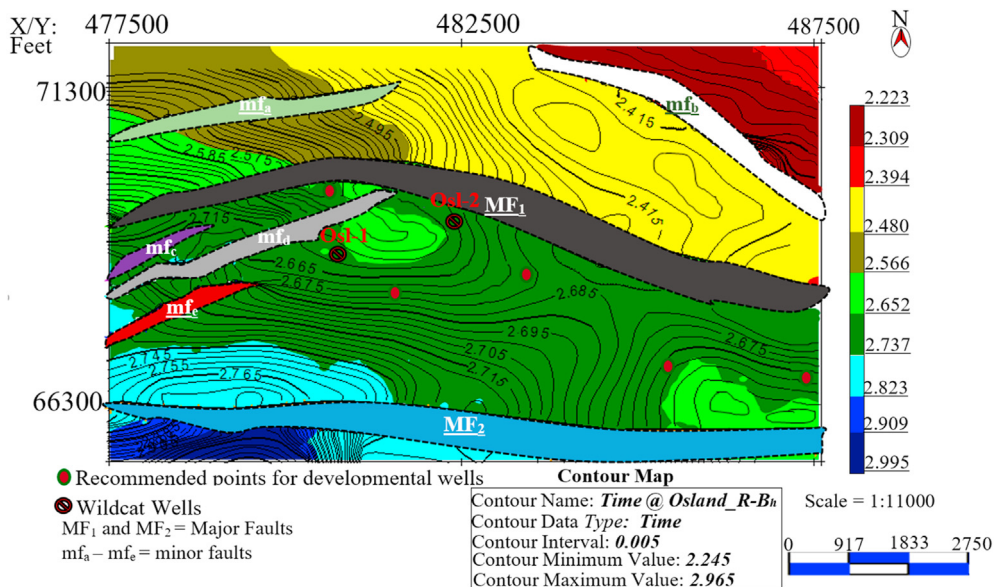


Figure 6. Time structural map of reservoir A-horizon (R-A_h).

proximity and provide the structural closure needed to trap the hydrocarbon. The shale markers and the fault seals are common in the Niger Delta. The shale markers form the basis of the predictions of most hydrocarbon seal, because of the uniqueness of biostratigraphy constituents

and they provide three types of seals; vertical seal, clay smears through faults and interbedded sealing units against which reservoir sands juxtapose due to faulting (Doust and Omatsola, 1990). The fault seals consist of main faults that display growth faults. However, whenever clay

Figure 7. Depth structural map of reservoir A-horizon (R-A_h).Figure 8. Time structural of reservoir B-horizon (R-B_h).

smears are sufficient or if reservoirs juxtapose against shale, they provide the required seals good enough as migration paths or to hold the hydrocarbons in places. The orientation of the mapped faults across the Osland oil and gas field is exemplary in these explanations.

The wildcats (Osl-1 and Osl-2) located within the central portion where the faults juxtapose, enable a better evaluation of that portion of the field. They aided to ascertain the presence of hydrocarbon, reservoir thickness and drainage area (A_d) within that portion. There is a structural high supported by MF₂ at the south-eastern area where the fault is edging out on the field. This area is indicative of a stratigraphic structure truncated on the faults, and it corresponds (by correlation) to the central portion of the field in times and depths. Therefore, delineating that portion as a pay zone may not be misleading. Based on the times and depths of occurrences, structural highs and fault assisted traps, some points within the central and south-eastern directions are good for siting development wells. Down the well, Reservoir A-horizon (R-A_h) and

Reservoir B-horizon (R-B_h) are about 70 feet. (21.34 m) each in Osl-1. In Osl-2, R-A_h is about 70 feet. (21.34 m) while R-B_h is 100 feet. (30.48 m). Across the wells, R-A_h has a total value of 171.944 acres ($67 \times 104 \text{ m}^2$) for A_d , with 80.767 acres ($33 \times 104 \text{ m}^2$), 45.110 acres ($18 \times 104 \text{ m}^2$) and 46.067 acres ($19 \times 104 \text{ m}^2$) for A_{d-1} , A_{d-2} and A_{d-3} respectively. Similarly, R-B_h has a total value of 206.387 acres ($83.5 \times 104 \text{ m}^2$) for A_d , with 94.204 acres ($38 \times 104 \text{ m}^2$), 24.320 acres ($1 \times 104 \text{ m}^2$) and 87.863 acres ($36 \times 104 \text{ m}^2$) for A_{d-1} , A_{d-2} and A_{d-3} respectively. The sum of the drainage areas ($A_{d-1} + A_{d-2} + A_{d-3}$) on R-A_h is 172 acres ($69.6 \times 104 \text{ m}^2$) and that of R-B_h is 206 acres ($83.4 \times 104 \text{ m}^2$). The dilated images show that the wireline logs are appropriately tied to the seismic sections and permitted the definition of the geometry of the reservoirs. Hence, the thorough delineation of the pay thicknesses and drainage areas via magnification of the portions of interest, at very close intervals within the reservoir has enabled more accurate results, reducing the uncertainty regarding the availability of hydrocarbon and volume estimations.

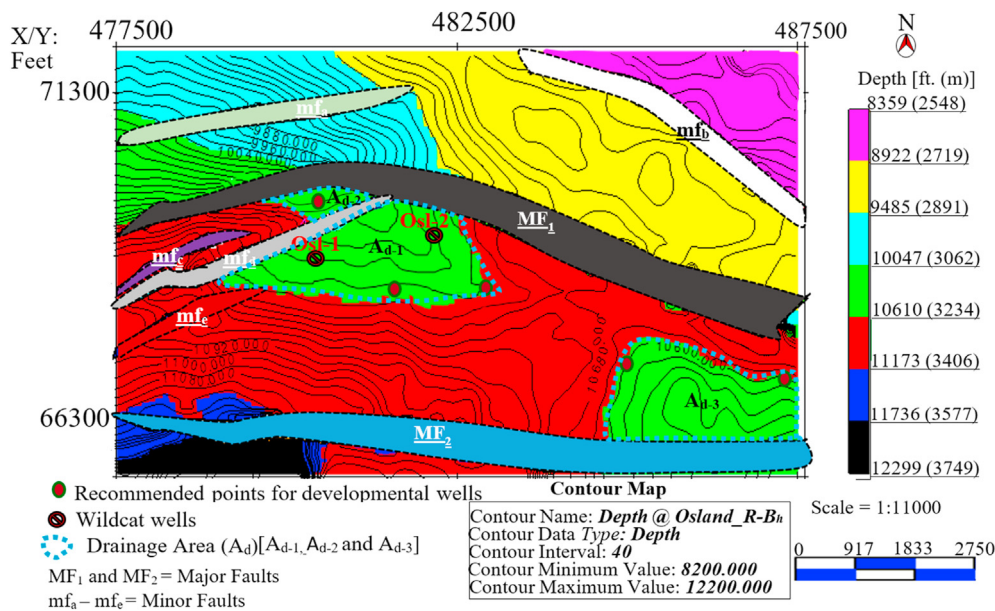


Figure 9. Depth structural of reservoir B-horizon (R-B_h).

Table 1. Showing reservoirs' thickness and drainage area.

Reservoir horizon	Thickness [Ft. (m)]		Drainage Area (A_d)		
	Osl-1	Osl-2	A_{d-1} [acre. (m ²)]	A_{d-2} [acre. (m ²)]	A_{d-3} [acre. (m ²)]
R-A _h	70 (21.34)	100 (30.48)	80.767 (33 × 10 ⁴)	45.110 (18 × 10 ⁴)	46.067 (19 × 10 ⁴)
R-B _h	70 (21.34)	70 (21.34)	94.204 (38 × 10 ⁴)	24.320 (1 × 10 ⁴)	87.863 (36 × 10 ⁴)

6. Conclusion

3-D seismic sections with wireline logs served as complementary tools to evaluate the hydrocarbon viability of Oil-1 and Oil-2 in Osland Oil and gas field within the Niger Delta, Nigeria. Reservoir A-horizon (R-A_h) and Reservoir B-horizon (R-B_h) were mapped across two wells (Osl-1 and Osl-2) and aided to determine pay thicknesses (P_t), drainage areas (A_d) and other points to site developmental wells. The magnification of the portions of interest, at very close intervals has aided a thorough evaluation of the reservoirs across the wells. The high-resolution images of the well to seismic tie (W-S_T) present enhanced figures and aided the accurate evaluation of P_t and A_d . W-S_T shows that the depth of occurrence and the travel times of seismic waves at the interface between media having different velocities/densities are the same on the wireline logs and seismic sections. The generated structural maps (based on R-A_h and R-B_h) helped in delineating A_d , while the wireline logs provided the P_t of the reservoirs. Total P_t and A_d are 310 feet. (94.5 m) and 378.331 acres (153 × 10⁴ m²) respectively for the two wells (Osl-1 and Osl-2) across the reservoirs and the values are significant. There may be little or no doubts concerning the degree of correctness of each of the A_d calculated for the delineated portions for hydrocarbon production within the field. Regardless, the reservoir thicknesses are likely not to be the same as in the wildcats within the recommended points for future hydrocarbon production. There are possibilities that the reservoirs are thicker (or otherwise) in those portions. Hence, production wells must be sited in these portions to determine the thicknesses of the hydrocarbon units within reservoir sands. The recommended points for sitting developmental wells are just points within the confines of the delineated drainage areas. As such, under field or technical conditions or based on sequence stratigraphic evaluations, engineers may decide to place the developmental wells at the appropriate positions within the mapped areas. This study has increased the confidence concerning the hydrocarbon viability of the selected reservoirs. It has minimised the

uncertainty regarding the computation of P_t , A_d and the volumes of recoverable hydrocarbons.

Declarations

Author contribution statement

A-A M. Richardson: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

F. Taioli: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Funding statement

This work was supported by The World Academy of Sciences/National Council for Scientific and Technological Development (TWA-CNPq) (3240286506) and Financier of Studies and Projects (FINEP) who sponsored the technical visit/data collection.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

Appreciation goes to God for life, and Department of Petroleum Resources (DPR) of Nigeria/Total Nigeria limited for the provision of data.

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