International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(Research Article)

Check for updates

Reservoir characterization using seismic and well data, freeman field, Niger delta

Ernest E. OGHOJAFOR * and Juliet EMUDIANUGHE

Federal University of Petroleum Resources, Effurun, Delta State, 330102.

International Journal of Science and Research Archive, 2025, 14(01), 157-167

Publication history: Received on 29 October 2024; revised on 10 December 2024; accepted on 12 December 2024

Article DOI: https://doi.org/10.30574/ijsra.2025.14.1.2425

Abstract

This report details the workflow for the Reservoir Freeman field, encompassing 3D seismic interpretation and the development of a 3D static model through the comprehensive integration of available data. This includes 3D seismic data, well logs, deviation data, core samples, checkshot data, and production records. The study underscores the area's petroleum potential and presents petrophysical results from four wells to enhance reservoir characterization. Seismic interpretation identified five horizons and nineteen faults, mainly antithetic and basinward-dipping. The structural framework and time maps indicate a central structural high, suggestive of hydrocarbon accumulation zones. Petrophysical analysis delineated four key hydrocarbon reservoirs (A, B, C, and D) with average thicknesses of 27.14m, 22.00m, 18.07m, and 18.15m, respectively. Reservoir porosities ranged from 0.25 to 0.35, highlighting favourable storage capacity. Permeabilities between 1993.99mD and 3640.88mD indicate well-connected pore networks. Hydrocarbon saturation (SH) varied from 0.64 to 0.76, with movable hydrocarbon indices suggesting primarily movable oil. Volumetric analysis yielded STOOIP estimates of 38,118.36 bbl/acre (A), 36,319.85 bbl/acre (B), 25,379.47 bbl/acre (C), and 18,023.39 bbl/acre (D). These findings emphasize the potential of the Reservoir Freeman field for hydrocarbon development.

Keywords: Reservoir Characterization; Seismic Interpretation; Petrophysical Analysis; 3D Seismic

1. Introduction

The primary goal of upstream petroleum businesses is to produce hydrocarbons at a sustained low cost. To maximize profitability in a competitive, high-cost environment, it is crucial to plan, delineate, and develop reservoirs properly. Reservoir characterization, as defined by Chopra and Michelena [6], involves gathering key data to accurately describe a reservoir. This process determines the volume within the trap that could hold hydrocarbons [16], as well as the accuracy of reservoir calculations, including factors like thickness and porosity [19]. Seismic data analysis plays a significant role in predicting reservoir parameters and matching seismic volume with well data, often using synthetic seismograms [17]. The scope of this study includes identifying the geological features of the sedimentary formations through the integration and interpretation of seismic and well data acquired from the Freeman field, as well as evaluating petrophysical properties such as hydrocarbon saturation (Hc_sat), porosity (Φ), water saturation (Sw), and water resistivity (Rw) to determine the volume of hydrocarbon in the identified reservoirs.

1.1. Study area

The study area falls within the Niger Delta Basin of Nigeria. The Niger Delta basin lies between latitudes 3ON and 6ON, and longitudes 5OE and 8OE, in the Gulf of Guinea in equatorial West Africa (Southern Nigeria), forming one of the world's most productive hydrocarbon provinces. Extensive details of the Niger Delta were given by Short & Stauble, [20].

* Corresponding author: Ernest E. OGHOJAFOR

Figure 1 Map of the Niger Delta region in Southern Nigeria

The Niger Delta basin is divided into mainly three lithostratigraphic units, the Akata (Paleocene to Recent), Agbada (Eocene to Recent) and the Benin (Oligocene to Recent) Formations which conform with lower pro-delta lithofacies, a middle delta front lithofacies and an upper delta top facies respectively [1, 3]. The Akata Formation, forming the base of the Niger Delta complex, consists of dark grey marine shales with occasional silty and sandy layers. Deposited in prodelta conditions, it contains less than 30% sand. The formation, up to 6500 meters thick, has deformed due to delta progradation, allowing for structural movements like up-dip extension and down-dip compression [7].

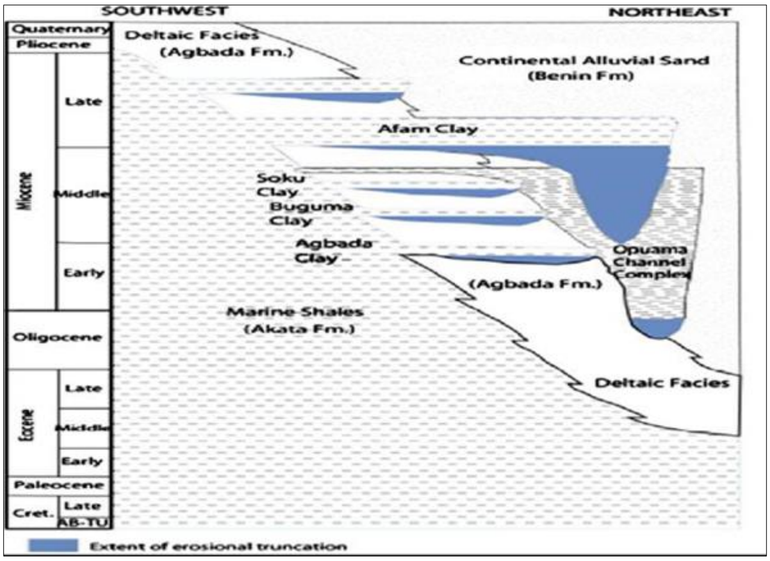

Figure 2 Stratigraphic column of the Niger Delta Basin [18]

The Agbada Formation, where most of the Niger Delta's hydrocarbon reserves are found, consists of alternating sandstone, siltstone, and shale. The sandstones vary from fine to coarse-grained, while shales become more prominent with depth. According to Avbovbo [5], thickness ranges from 9,600 to 14,000 feet, and sand content is between 30-70%, reflecting lower delta plain, coastal barrier, and fluvio-marine deposits. The formation exhibits depositional cycles, starting with transgressive sea sand and ending with off-lap sequences [8, 11]. The Benin Formation, the topmost layer of the Niger Delta depositional series, consists primarily of non-marine sands with high sand content (70-100%) and minor shale intercalations [11]. Deposited in a continental fluvial environment, it contains fine to coarse quartz grains, hematite, feldspar, plant remnants, and lignite. The formation, which thickens with depth, was laid down in alluvial or coastal plain environments and can reach up to 1,000 feet in thickness. These formations indicate a history of intricate sedimentation patterns, transitioning from tide-dominated to wave-dominated environments [6, 16].

2. Literature Review

Ibe and Oyewole [12] investigated the hydrocarbon play assessment of the X-field in the onshore Niger Delta. A variety of logs and seismic data were used. The well log data includes four wells, and three reservoirs were detected. The MH Index, water saturation, hydrocarbon saturation, porosity, and other parameters were used to evaluate the reservoir's petrophysical properties.

Hamada G.M. [11] did a study on determining hydrocarbon movability and reservoir fluid type using resistivity logs and the ratio of P-wave velocity to S-wave velocity. The study demonstrated the successful application of shallow and deep resistivity logs to monitor hydrocarbon movability by computing the HCM factor to predict hydrocarbon movability. The Vp/Vs cross is a valuable tool for evaluating the types of fluid saturation present in a reservoir (water, oil, and/or gas).

To characterize the keke field's reservoir, Edigbue and Adesuji [9] used seismic and petrophysical data. In the Keke field, two sand reservoirs were discovered and connected throughout the four wells. The fault-dependent closure of two and three faults was shown by the studied seismic data. Reservoir 1 had a net pay of 29 million dollars, a porosity of 0.28, and a gas-in-place of 14.66 million cubic feet, whereas Reservoir 2 had a net pay of 38.1 million dollars, a porosity of 0.25, and a gas-in-place of 512.4 million cubic feet.

Akaerue et al. [4] assessed the Etu field from a petrophysical standpoint. A combination of well logs and 3D seismic data is being used. From well log data between 3000 and 4500 meters, 37 reservoirs were identified, and petrophysical properties such as shale volume, porosity, permeability, formation water resistivity, bulk volume of water, and so on were computed.

3. Material and methods

The reserve estimate for hydrocarbon reservoirs involves two primary methods: petrophysical analysis of well logs and 3-D seismic interpretation. Petrophysical studies evaluate lithology, net-pay thickness, fluid contact, porosity, water saturation, and volume of shale, while seismic data offers the reservoir area. The combination of these results, interpreted both qualitatively and quantitatively, leads to reserve yield estimation.

Key steps in this process include:

- **Data QC/Upload:** Data is loaded into Petrel software, ensuring it is correctly formatted for reservoir modelling and petrophysical evaluation.
- **Well Logs Display/Correlation:** Well logs are displayed to verify their relevance. Gamma-ray logs from four wells are correlated to ensure consistency.
- **Synthetic Seismogram:** Using checkshot data, sonic, and density logs, a synthetic seismogram is created to link seismic data with well data. The well tops and bases are matched to seismic events.
- **Petrophysical Parameter Calculation:** Petrophysical parameters are calculated to determine the wells' hydrocarbon production potential, fluid types, and fluid mobility for well activity recommendations.
- **Structural Mapping:** Horizons (layer boundaries) are identified based on reflection patterns in seismic sections. Where well control is unavailable, seismic reflections guide mapping. Time-to-depth conversion yields a depth structure map.
- **Volumetric Analysis:** Reservoir coverage is calculated using depth structural maps, and the area is determined by gridding and computing the square length of the grids. This process ensures a comprehensive understanding of the reservoir's structure and capacity for hydrocarbon production reservoir. The stock tank oil originally in place (STOOIP) can be calculated using the calculation below:

$$\text{STOOIP} = \frac{7758 \times h \times \emptyset \times (1 - S_w)}{B_{oi}} \text{ bbl/acre}\ldots\ldots\ldots(1)$$

Where B_{oi} = 1.2bbl/STB

4. Results

4.1. Seismic-to-well tie

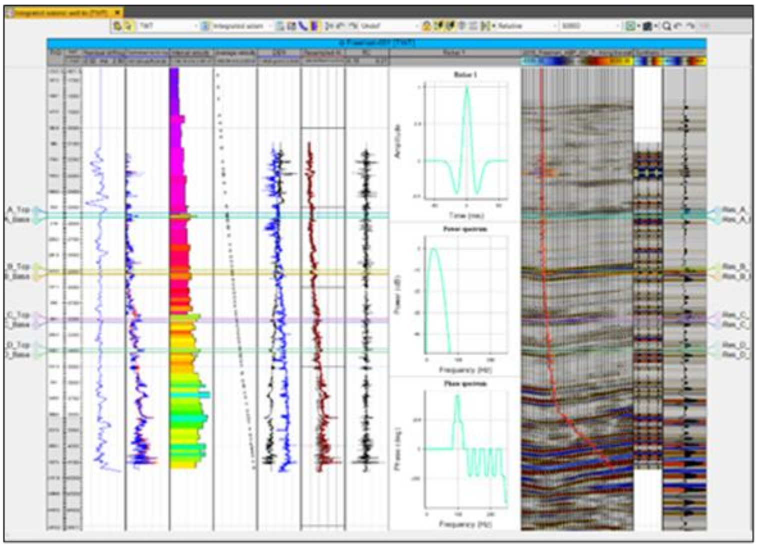

Figure 3 Seismic-to-well tie for Freeman-001

The seismic-to-well tie results for four wells in the Freeman field reveal a strong correlation between well log data and seismic reflection data.

- **Freeman-001 (Figure 3)**: The synthetic seismogram shows that all four reservoirs identified from the well-log data align with high-amplitude seismic events.
- **Freeman-003-ST1 (Figure 4)**: Two reservoirs (C and D) correlate with high amplitude events on the seismic section.
- **Freeman-004-ST1 (Figure 5)**: Three reservoirs (B, C, and D) from the well log data match high amplitude seismic reflections.
- **Freeman-005 (Figure 6)**: The only identified reservoir (C) aligns with a high amplitude seismic event.

In all cases, the synthetic seismograms show a consistent correlation between the wells and seismic reflections

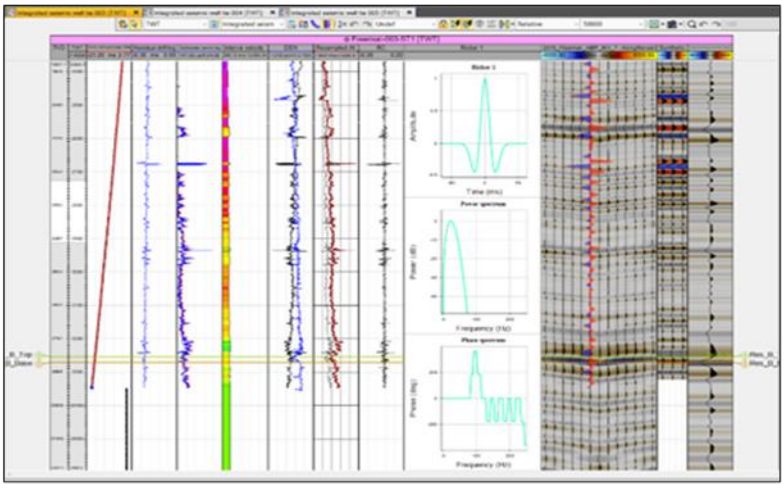

Figure 4 Seismic-to-well tie for Freeman-003-ST1

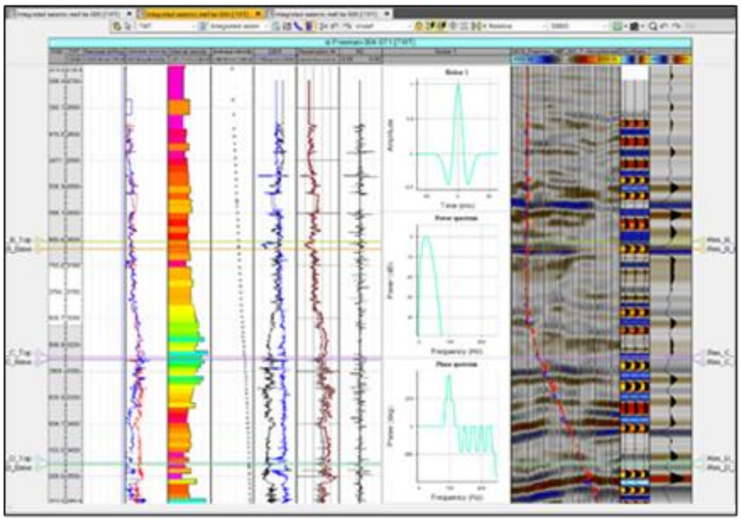

Figure 5 Seismic-to-well tie for Freeman-004-ST1

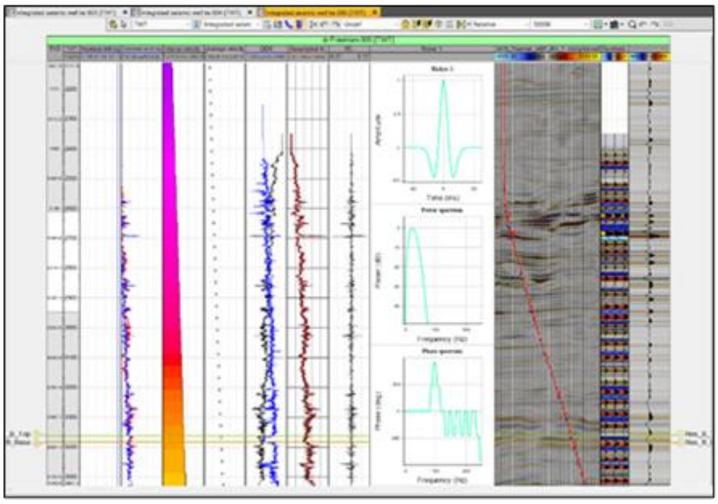

Figure 6 Seismic-to-well tie for Freeman-005

4.2. Correlation of the Reservoir Sands

Fig. 7 presents the correlation of the reservoir sands across the wells in the Freeman field. The correlation was done from the top to the bottom of the well logs. Gamma-ray (GR) logs are the main logs used for correlation because they exhibit patterns that are easier to spot between wells and provide a dependable means for correlation [14]. The Deep Resistivity logs were used to identify the sands with good hydrocarbon potential.

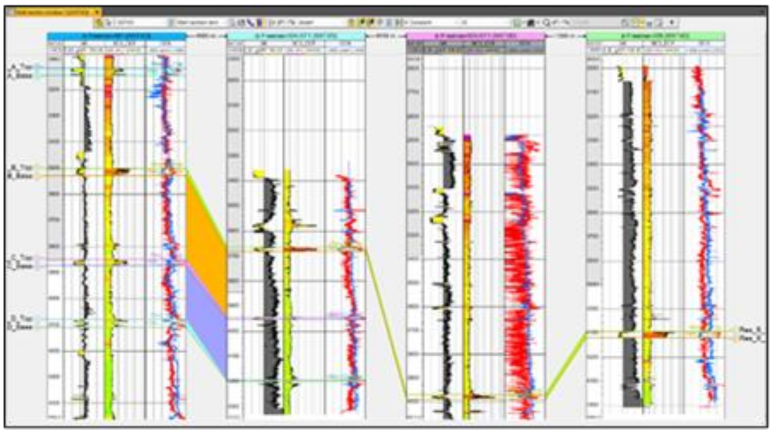

Figure 7 Correlation of the reservoir sands

4.3. Structural Interpretation

Seismic sections are cross-sectional views of the subsurface created from seismic data. They are essential for interpreting geological structures, including faults and horizons. The horizons and the associated faults were mapped using the seismic continuity (matching the well sand tops) and discontinuity respectively.

Results Description:

- **Fault Identification**: Interpreted and mapped several faults, distinguishing between normal, reverse, and strike-slip faults.
- **Horizon Delineation**: Delineated key seismic horizons, correlating them with geological formations.
- **Cross-sectional Views**: Provided multiple seismic sections showing the continuity and displacement of horizons across fault planes.
- **Amplitude Variations**: Analysed amplitude variations to identify potential hydrocarbon-bearing zones and lithological changes.

Figures 8 and 9 show the horizons and some faults in the field that were identified from the seismic data interpretation, while Figure 8 gives the structural framework of the field. The structural morphology of the subsurface is a combination of antithetic and growth faults which are commonly found in the Niger Delta Basin.

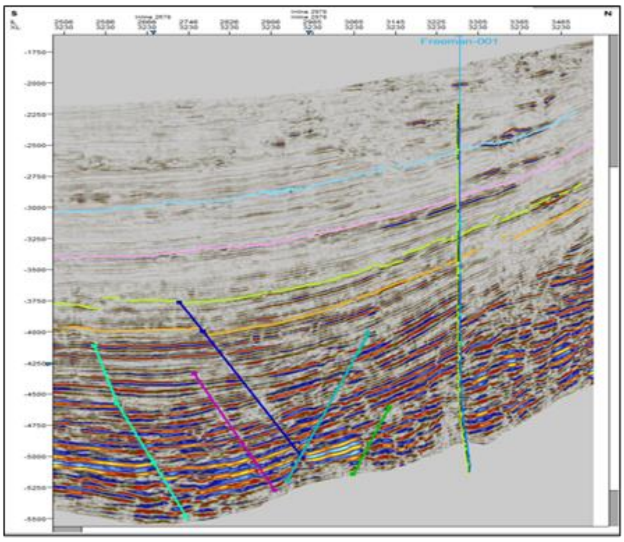

Figure 8 The seismic section shows major faults and the horizons at inline 2978

Figure 10 is the faults structural framework of the study area. It describes the overall arrangement and characteristics of faults within the study area, crucial for understanding the tectonic history and potential hydrocarbon traps. It is a comprehensive fault network model, illustrating the orientation, length, and connectivity of faults. The faults were classified faults into 6 major and 13 minor categories, providing insights into their relative significance and impact on reservoir properties.

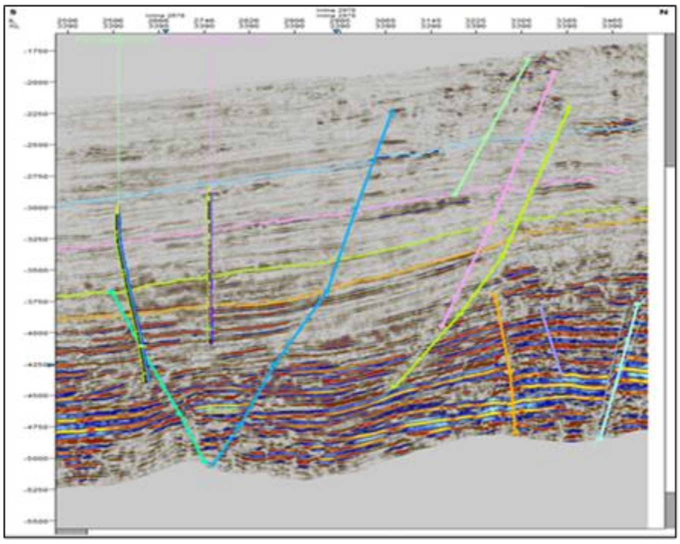

Figure 9 The seismic section shows major faults and the horizons at inline 2878.

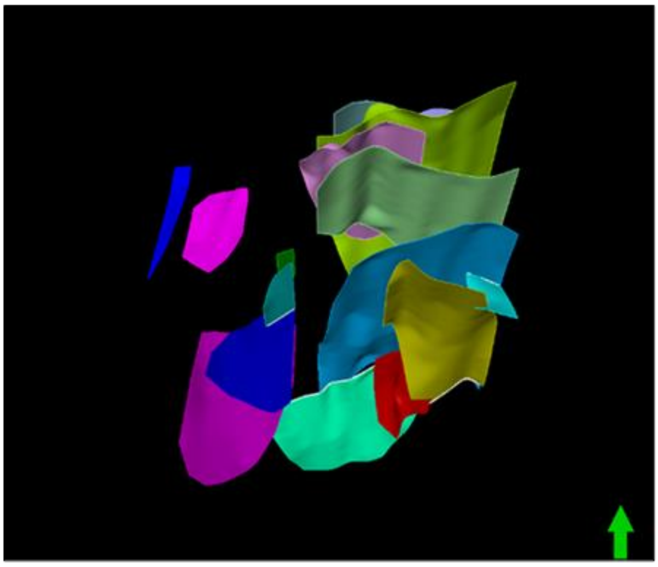

Figure 10 Fault structural framework of the Freeman field

4.4. Time Structural Map

The time structural maps for reservoirs A, B, C, and D (Figures 11–14) display the subsurface geometry and distribution of key horizons based on the two-way travel time (TWT) of seismic waves. Each map highlights an anticlinal structural framework with time differences marking structural highs and lows.

- **Reservoir A (Figure 11)**: The anticlinal structure has a TWT range from 1600ms in the central area to 2600ms on the fringes.
- **Reservoir B (Figure 12)**: This anticline has a TWT range from 2100ms in the Northern/Central regions to 3050ms at the edges, with a steep gradient in the northeast and northwest, and gentler slopes in the south.
- **Reservoir C (Figure 13)**: The TWT range is from 2450ms in the Northern/Central regions to 3550ms on the fringes, with a steep gradient in the northwest and gentler slopes to the southeast.

- **Reservoir D (Figure 14)**: The TWT range is from 2700ms in the Northern/Central regions to 3700ms on the edges, showing a steep gradient in the northwest and gentler slopes in the southeast.

These maps help identify the structural features and spatial distribution of geological formations in the time domain.

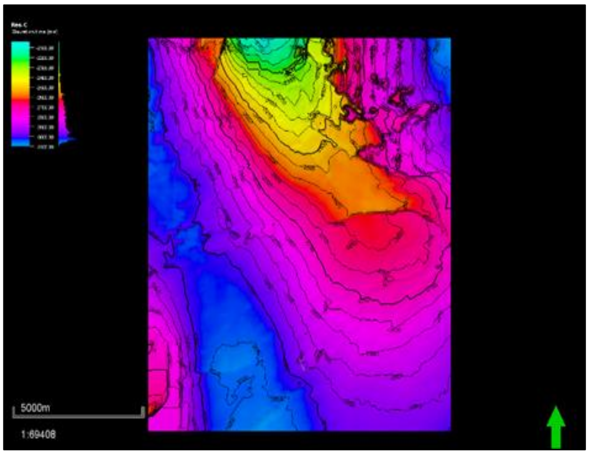

Figure 11 Time structural map of Res. A

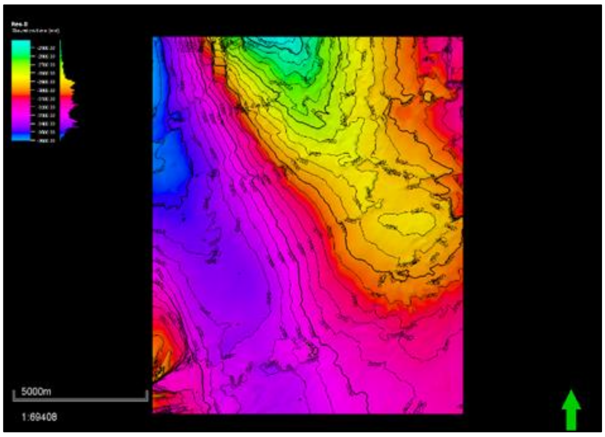

Figure 12 Time structural map of Res. B

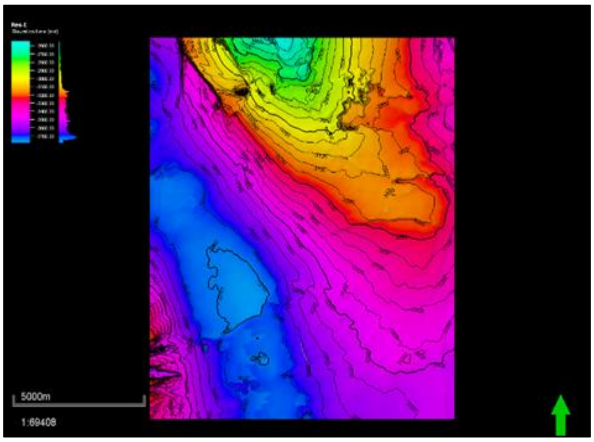

Figure 13 Time structural map of Res. C

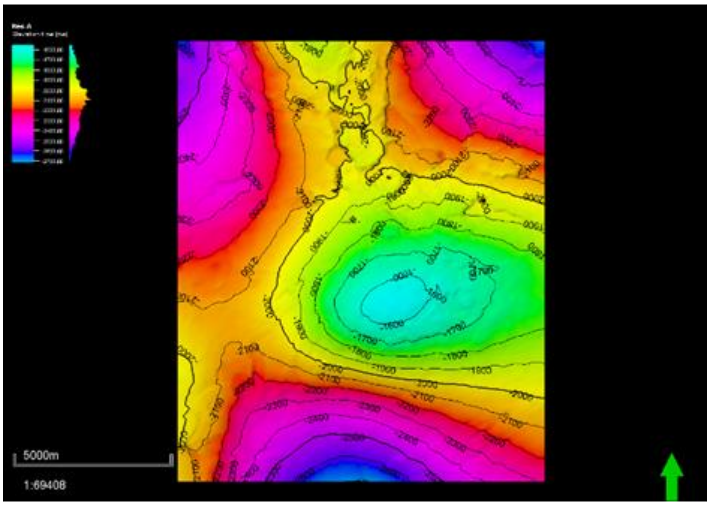

Figure 14 Time structural map of Res. D

Table 1 Volumetric analysis results for the 4 reservoirs

Reservoir	**A**	**B**	**C**	**D**
Thickness (m)	27.14	22	18.07	18.15
Porosity	0.31	0.35	0.31	0.25
SH	0.73	0.76	0.73	0.64
Permeability	2810.25	3549.4	3640.88	1993.99
STOOIP (bbl/acre)	38118.36	36319.85	25379.47	18023.39

5. Discussion

In the seismic data analysis, four (4) horizons and nineteen (19) faults were identified. The faults were mostly antithetic and dipped basinwards. The morphology of the reservoirs, fault structural framework, as well as the time structural maps of the reservoirs, were also generated, with the structural high located at the centre and indicative of the potential accumulation of hydrocarbon. From the petrophysical analysis of the well data, four (4) sand bodies identified as potential hydrocarbon reservoirs (A, B, C, and D) were delineated and correlated across four (4) wells (Freeman-001, Freeman-003-ST1, Freeman-004-ST1 and Freeman-005). The sonic log was calibrated using the checkshot (time-depth-relation) data, and the wells were tied to the seismic data.

From the well data, the thicknesses of the reservoirs were estimated with average thicknesses of 27.14m, 22.00m, 18.07m and 18.15m for reservoirs A, B, C, and D respectively. The average porosities across the wells were also calculated across the reservoirs and the values were found to be 0.31, 0.35, 0.31 and 0.25 for reservoirs A, B, C, and D respectively, indicating that the formations have good porosities and as such are capable of accommodating hydrocarbons. The permeabilities of the reservoirs ranged from 1993.99mD to 3640.88mD indicating that the formation pore spaces are well connected. The mean hydrocarbon saturation ranged from 0.64 in Reservoir D to 0.76 in reservoir B. The Movable Hydrocarbon Indices (0.32 - 0.48) revealed that hydrocarbons are majorly oil and are moveable during invasion and this is in agreement with the formations tendencies to accommodate and transmit hydrocarbon (good porosity and permeability values). Volumetric analysis of the reservoirs gave STOOIP values of 38,118.36bbl/acre for Reservoir A, 36,319.85bbl/acre for Reservoir B, 25,379.47bbl/acre for Reservoir C and 18,023.39bbl/acre for reservoir D.

6. Conclusion

The Freeman field in the Niger Delta was assessed for hydrocarbon potential using seismic and well data, identifying 19 faults and four reservoirs. Reservoirs showed good porosity, permeability, and movable oil, confirmed by MHI values. Volumetric analysis estimated hydrocarbon reserves using the STOOIP formula.

As a result of the research's conclusion, it is recommended that hydrocarbon exploitation take place within the Freeman field in the Niger Delta based on analytics and interpretation of the seismic and petrophysical data obtained from the field. To corroborate the test results, core drilling can be done. NMR-log can also be used to measure the density of the hydrocarbon in place, which can indicate its quality rather than relying on the computed MHI values.

Compliance with ethical standards

Acknowledgments

I acknowledge the Editor-in-chief and the Reviewers for their selfless services in improving this research work.

Disclosure of conflict of interest

I declare that there is no conflict of interest.

References

[1] Aigbedion, I. & Aigbedion, H.O. (2011) Hydrocarbon Volumetric Analysis using Seismic and Borehole data over Umoro field, Niger Delta-Nigeria. International Journal of Geoscience 2, pp. 179 -183.

[2] Aigbedion, I., & Ilukhor, O. M. (2017). Reservoir Characterization in 'O' Field in the Niger Delta using.

[3] Ajaegwu, N.E., Odoh, B.I., Akpunonu, E.O., Odiadi, I.I. & Anakwuba E.K. (2012) Late Miocene to Early Pliocene Palynostratigraphy and Paleoenvironments of ANE-1 well, Eastern Niger Delta, Nigeria. Journal of Mining and Geology 48 (1), pp. 31-43.

[4] Akaerue et al. (2018) assessed the Etu field from a petrophysical standpoint. A combination of well logs and 3D seismic data is being used.

[5] Avbovbo, A. A., (1978). Tertiary lithostratigraphy of Niger Delta. American Association of Petroleum Geologists, Volume 62, pp. 295-300.

[6] Burke, K. (1972). Longshore drift, submarine canyons, and submarine fans in development of Niger Delta. American Association of Petroleum Geologists, 56, 1975-1983.

[7] Chopra, S. & Michelna, R.J. (2011). Introduction to Reservoir Characterization Special edition of The Leading Edge, pp. 35-37.

[8] Doust, H., & Omatsola, E. (1990). Stratigraphy of the Niger Delta. In J. Edwards, & P. Santagrossi, Divergent/Passive Margi Basins (pp. 239-248). Tulsa: American Association of Petroleum Geologists.

[9] Edigbue, Paul, Komolafe, Akinola, Adesida, A, Itamuko, O. (2014). Hydrocarbon reservoir characterization of "Keke" field, Niger Delta using 3D seismic and petrophysical data. Am. J. of Sci. and Ind. Res. 2. 73-80. 10.5251/ajsir.2014.5.2.73.80.

[10] Ejedawe, J. (2012) Nigeria's potential waiting to be trapped. AAPG Explore 33(5).

[11] Hamada G.M. (2013) did a study on determining hydrocarbon movability and reservoir fluid type using resistivity logs and the ratio of P-wave velocity to S-wave velocity.

[12] Ibe, A.A., Oyewole, T.E. Hydrocarbon play assessment of X-field in an Onshore Niger Delta, Nigeria. J Petrol Explor Prod Technol 9, 61–74 (2019). https://doi.org/10.1007/s13202-018-0497-5

[13] Obaje, N.G. (2009) Geology and mineral resources of Nigeria, vol 120. Springer, New York.

[14] Ogbe, M. O. (2015) A Paper presented at NAPPS Delta State Educational Conference.

[15] Ologe, O. (2016). Reservoir Evaluation of “T-X” Field (Onshore, Niger Delta) From Well Log Petrophysical Analysis. Bayero Journal of Pure and Applied Sciences, 9(2): 132 – 140.

[16] Reijers, T., Petters, S., & Nwajide, C. (1997). The Niger Delta Basin. In R. Selley (Ed.), African Basins--Sedimentary Basin of the World 3 (pp. 151-172). Amsterdam: Elsevier Science.

[17] Schlumberger, C. (1989). Log Interpretation Principle/Applications. Houston, Texas.

[18] Shannon, P. M., & N., N. (1989). Petroleum Basin Studies. London: Graham and Trotman Limited.

[19] Sheriff, R. E. (2002). Encyclopedia Dictionary of Applied Geophysics. Society of Exploration

[20] Short, K.C. & Stauble, A.J. (1967) Outline of Geology of Niger Delta. AAPG Bulletin, 51, 761-779.