Integrated Seismic Attribute and Petrophysical Evaluation of Structurally Controlled Hydrocarbon Prospects in the Eastern Niger Delta Basin, Nigeria

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ABSTRACT

This study presents an integrated seismic and petrophysical evaluation of structurally controlled hydrocarbon prospects in the Eastern Niger Delta Basin, Nigeria. A high-resolution 3D post-stack time-migrated seismic dataset covering approximately 125 km² was analysed alongside well log data from three exploration wells to delineate structural traps and assess reservoir characteristics. Three key reservoir horizons (H1–H3), occurring between 1850 ms and 2600 ms two-way travel time (approximately 2450–3150 m depth), were identified within fault-assisted closures associated with NE–SW trending growth faults and rollover anticlines. Seismic attribute analysis, including RMS amplitude, instantaneous frequency, acoustic impedance, and sweetness, reveals pronounced amplitude anomalies and low-frequency shadows consistent with hydrocarbon-related effects. Petrophysical evaluation indicates excellent reservoir quality, with porosity ranging from 22.8% to 26.1%, permeability between 1320 mD and 1600 mD, and hydrocarbon saturation averaging approximately 71%. Volumetric estimation yields a Stock Tank Oil Initially in Place (STOIIP) of about 185 million barrels, suggesting significant commercial potential. However, uncertainties related to seismic resolution, lithological effects on amplitude response, and assumptions in petrophysical modelling introduce moderate risk, reflected in a geological chance of success of 0.45. The results demonstrate that integrating seismic structural interpretation, attribute analysis, and quantitative petrophysical evaluation provides a robust framework for reducing exploration uncertainty and enhancing hydrocarbon prospect assessment in structurally complex deltaic systems.

Keywords: Niger Delta Basin; 3D seismic interpretation; seismic attributes; petrophysical evaluation; growth faults; hydrocarbon prospectivity; volumetric estimation; reservoir characterization

INTRODUCTION

The Niger Delta Basin is one of the most prolific hydrocarbon provinces globally, accounting for a substantial proportion of Nigeria's oil and gas reserves. The basin developed as a passive continental margin characterised by thick accumulations of Tertiary clastic sediments deposited within fluvio-deltaic to marine environments (Short & Stauble, 1967; Weber & Daukoru, 1975). Its stratigraphic architecture is composed of three principal lithostratigraphic units: the Akata Formation, consisting predominantly of pro-delta marine shales; the Agbada Formation, comprising interbedded sands and shales that form the primary hydrocarbon reservoirs; and the Benin Formation, dominated by continental sands (Doust & Omatsola, 1989; Nwajide, 2013). The interplay between rapid sedimentation, differential loading, and gravitational tectonics has resulted in extensive growth faulting and the development of rollover anticlines, fault-assisted closures, and stratigraphic traps that host significant hydrocarbon accumulations (Burke, 1972; Evamy, 1978).

Hydrocarbon generation and accumulation within the Niger Delta are intrinsically linked to the maturation of organic-rich source rocks within the Akata Formation, followed by migration along fault planes into structurally and stratigraphically favourable reservoirs within the Agbada Formation (Ekweozor & Daukoru, 1984; Dim, 2016). Consequently, accurate delineation of structural configurations and reservoir architecture is critical for effective hydrocarbon exploration and field development. The advent of three-dimensional (3D) seismic reflection techniques has significantly improved subsurface imaging, enabling detailed mapping of fault geometries, stratigraphic relationships, and trap configurations in both onshore and offshore Niger Delta settings (Emujakporue & Ngwueke, 2013; Opara et al., 2011).

In recent years, the integration of seismic data with well log information has become a fundamental approach for reservoir characterisation and prospect evaluation. Previous studies have demonstrated that combining seismic interpretation with petrophysical analysis enhances the understanding of reservoir properties, including thickness, porosity distribution, and fluid content (Opara, 2010; Adeoti et al., 2014). Such integrated workflows reduce uncertainty in hydrocarbon exploration by linking geophysical responses with quantitative reservoir parameters. Furthermore, advances in seismic attribute analysis have provided additional tools for identifying subtle stratigraphic features and direct hydrocarbon indicators (DHIs), including bright spots, flat spots, and low-frequency shadows (Adigun & Ayolabi, 2013; Ajisafe & Ako, 2013).

Seismic attributes such as RMS amplitude, coherence, acoustic impedance, and spectral decomposition have been widely applied in the Niger Delta to enhance reservoir delineation and fault detection (Eichkitz et al., 2012; Jibrin et al., 2013). These attributes are particularly useful in identifying hydrocarbon-bearing zones, as fluid substitution effects often result in measurable changes in amplitude and frequency characteristics (Anyiam, 2015; Chukwu, 2016). The integration of seismic attribute analysis with inversion techniques further improves lithological discrimination and fluid prediction by linking seismic responses to rock physical properties (Adeoti et al., 2014; Clark & Shearin, 2019).

In parallel, petrophysical evaluation using well logs remains essential for quantifying reservoir quality and hydrocarbon saturation. Parameters such as porosity, permeability, water saturation, and shale volume provide critical insights into reservoir performance and producibility (Amao, 2013; Schön, 2015). Accurate interpretation of these parameters, particularly through the application of models such as Archie's equation, is fundamental for estimating hydrocarbon volumes and assessing economic viability (Ilevbare, 2014). Studies within the Niger Delta have consistently shown that reservoirs within the Agbada Formation exhibit favourable petrophysical properties, often characterised by high porosity and permeability (Edigbue et al., 2014; Oyedele et al., 2013).

Despite these advances, significant uncertainties remain in hydrocarbon prospect evaluation, particularly in structurally complex deltaic environments where faulting, lithological heterogeneity, and seismic resolution limitations can obscure reservoir continuity and fluid distribution. While many previous studies have focused on either structural interpretation or petrophysical analysis independently, fewer have rigorously integrated seismic attribute responses with quantitative petrophysical evaluation to reduce exploration uncertainty. Moreover, the reliability of amplitude-based hydrocarbon indicators is often influenced by non-fluid-related factors such as lithological contrasts and tuning effects, necessitating careful validation with well data.

Therefore, this study aims to address these challenges by applying an integrated geophysical and petrophysical workflow to evaluate hydrocarbon prospectivity within the Eastern Niger Delta Basin.

MATERIALS AND METHODS

Study Area and Geological Setting

The study area is located within the Eastern Niger Delta Basin, Nigeria, a prolific hydrocarbon province characterised by thick accumulations of Tertiary clastic sediments deposited in fluvio-deltaic to marine environments. The basin comprises three principal lithostratigraphic units: the Akata Formation (pro-delta marine shales), the Agbada Formation (interbedded sands and shales forming the primary hydrocarbon reservoirs), and the Benin Formation (continental sands). Hydrocarbon accumulation within the study area is predominantly associated with the Agbada Formation, where structurally controlled traps such as growth faults, rollover anticlines, and fault-assisted closures are well developed under an extensional tectonic regime.

Data Description

The dataset utilised for this study consists of a high-resolution 3D post-stack time-migrated seismic volume covering approximately 125 km², integrated with well log data from three exploration wells (Well A, Well B, and Well C). The seismic data have inline and crossline spacing of 25 m and a bin size of 12.5 m × 12.5 m, providing adequate lateral resolution for structural interpretation. The record length is 5 seconds with a sampling interval of 2 ms, and a frequency bandwidth of 10–70 Hz, ensuring sufficient vertical resolution for imaging reservoir intervals.

The well log suite includes Gamma Ray (GR), Resistivity (RT), Density (RHOB), Neutron (NPHI), and Sonic (DT) logs. Checkshot data were available and utilised for time–depth conversion and seismic–well correlation.

Seismic Interpretation

Seismic interpretation was conducted using industry-standard interpretation software and followed a structured workflow involving horizon picking, fault interpretation, structural mapping, and time–depth conversion. Key reflectors corresponding to reservoir tops were identified and mapped across both inline and crossline sections. Faults were interpreted based on reflector terminations, displacement patterns, and discontinuities in seismic reflectors, enabling the delineation of structural geometries and trap configurations.

Time structure maps were generated for each interpreted horizon to define structural closures. Depth conversion was performed using velocity information derived from checkshot data based on the relationship:

$$\text{Depth} = (\text{Velocity} \times \text{Two-way travel time}) / 2$$

Synthetic seismograms generated from well logs were used to tie seismic reflections to lithological boundaries, thereby improving the accuracy of horizon correlation and interpretation.

Seismic Attribute Analysis

To enhance reservoir characterisation and identify potential hydrocarbon indicators, several post-stack seismic attributes were computed, including Root Mean Square (RMS) amplitude, instantaneous frequency, acoustic impedance, and sweetness. RMS amplitude was extracted over defined time windows centred on reservoir intervals to highlight amplitude anomalies associated with possible hydrocarbon accumulations.

Instantaneous frequency, derived from the analytic signal, was used to detect low-frequency shadows indicative of hydrocarbon-related attenuation effects. Acoustic impedance volumes were generated through model-based seismic inversion constrained by well log data to improve lithological discrimination. The sweetness attribute, defined as the ratio of instantaneous amplitude to instantaneous frequency, was employed to delineate potential hydrocarbon-bearing zones.

Attribute responses were cross-validated with well log data to minimise misinterpretation arising from lithological variations or tuning effects.

Well Log Analysis and Petrophysical Evaluation

Petrophysical analysis was carried out to evaluate reservoir properties, including lithology, porosity, water saturation, permeability, and net pay thickness. Lithological identification was based primarily on gamma-ray logs, with clean sand intervals defined using a gamma-ray cut-off derived from shale baseline calibration. The volume of shale (Vsh) was estimated using standard linear normalisation of gamma-ray values.

Porosity was calculated from density logs, assuming a sandstone matrix density of 2.65 g/cm^3 and a fluid density of 1.0 g/cm^3. Water saturation (Sw) was estimated using Archie's equation, with assumed parameters of tortuosity factor ($a = 1$), cementation exponent ($m = 2$), and saturation exponent ($n = 2$), consistent with consolidated sandstone formations. Hydrocarbon saturation (Sh) was obtained as the complement of water saturation.

Permeability was estimated using empirical correlations based on porosity and irreducible water saturation. Net pay thickness was determined using cut-off criteria of porosity $\geq 10\%$, water saturation $\leq 50\%$, and shale volume ≤ 0.35. All petrophysical parameters were calibrated against available well data to ensure consistency and reliability.

Volumetric Estimation of Hydrocarbon in Place

The Stock Tank Oil Initially in Place (STOIIP) was estimated using the standard volumetric method:

$$\text{STOIIP} = (7758 \times A \times h \times \Phi \times (1 - Sw)) / Bo$$

where A represents reservoir area (acres), h is average net pay thickness (ft), Φ is porosity, Sw is water saturation, and Bo is the formation volume factor. Reservoir area was derived from mapped structural closures, while average reservoir properties were obtained from petrophysical analysis. A formation volume factor (Bo) of 1.25 was adopted based on typical Niger Delta reservoir conditions.

Risk Assessment

Prospect risk evaluation was conducted using a petroleum system-based probabilistic framework. Key elements including source rock presence, migration efficiency, reservoir quality, trap integrity, and seal capacity were assigned probability values based on geological and geophysical evidence. The overall geological chance of success (Pg) was calculated as the product of individual probabilities:

$$Pg = Psource \times Pmigration \times Preservoir \times Ptrap \times Pseal$$

This approach provides a quantitative basis for assessing exploration risk and supports decision-making for further appraisal.

Quality Control and Uncertainty Analysis

Quality control procedures were applied throughout the workflow to ensure data reliability and interpretation accuracy. Seismic horizons were validated using well tops and synthetic seismograms, while fault interpretations were cross-checked across multiple seismic sections. Petrophysical results were calibrated against well log responses, and seismic attribute anomalies were verified to reduce the likelihood of false hydrocarbon indicators.

Depth conversion uncertainties were minimised using checkshot-derived velocity models. Nevertheless, uncertainties remain due to seismic resolution limitations, potential tuning effects, and assumptions inherent in petrophysical modelling, particularly in the application of Archie's equation. These uncertainties were considered in the interpretation and overall evaluation of hydrocarbon prospectivity.

RESULTS

The seismic dataset utilised in this study comprises a high-resolution 3D post-stack seismic volume covering approximately 125 km² within the Eastern Niger Delta Basin. The acquisition parameters, including inline and crossline spacing of 25 m, bin size of 12.5 m × 12.5 m, record length of 5 seconds, and sampling rate of 2 ms, provided adequate lateral and vertical resolution for detailed structural and stratigraphic interpretation. The frequency bandwidth of 10–70 Hz allowed for reliable identification of amplitude anomalies and subsurface features. The applied processing sequence, which included deconvolution, normal moveout correction, stacking, and migration, significantly enhanced signal quality and structural imaging (Table 3.1).

Table 3.1. Seismic Data Acquisition Parameters

Parameter	Value
Seismic Data Type	3D Post-Stack Seismic Volume
Survey Area	125 km²
Inline Spacing	25 m
Crossline Spacing	25 m
Record Length	5 s
Sample Rate	2 ms
Frequency Bandwidth	10–70 Hz
Bin Size	12.5 m × 12.5 m
Processing Sequence	Deconvolution, NMO correction, CMP stacking, Post-stack migration

Three key seismic horizons (H1, H2, and H3) were mapped across the study area, occurring within two-way travel times ranging from 1850 ms to 2600 ms and corresponding to depths of approximately 2450 m to 3150 m. Horizon H1 represents a shallow reservoir interval associated with anticlinal structural closure. Horizon H2 occurs within a growth fault rollover structure and constitutes the principal reservoir unit. Horizon H3 is a deeper horizon defined by fault-bounded closures, indicating additional trapping potential at depth. The mapped horizons collectively define structurally controlled traps typical of the Niger Delta petroleum system (Table 3.2).

Table 3.2. Interpreted Seismic Horizons and Structural Configuration

Horizon	Two-Way Time (ms)	Average Depth (m)	Structural Setting	Geological Interpretation
H1	1850–1950	2450	Anticlinal closure	Top shallow reservoir
H2	2100–2250	2750	Growth fault rollover	Main reservoir sand
H3	2450–2600	3150	Fault-bounded trap	Deep hydrocarbon-bearing unit

Structural interpretation reveals a fault-dominated framework characterised by three principal fault systems. Fault F1 trends NE–SW and represents a major growth fault with a throw of approximately 85 m and lateral continuity of about 6.2 km, forming the primary trapping mechanism. Fault F2 trends NW–SE and acts as a synthetic fault contributing to structural closure, while Fault F3 trends E–W and represents a minor sealing fault. The interaction of these fault systems defines a series of fault-assisted anticlines and rollover structures favourable for hydrocarbon accumulation (Table 3.3).

Table 3.3. Structural Fault Characteristics

Fault ID	Orientation	Throw (m)	Length (km)	Trap Role
F1	NE–SW	85	6.2	Major growth fault – primary trap
F2	NW–SE	60	4.5	Synthetic fault – structural closure
F3	E–W	40	3.8	Minor sealing fault

Seismic attribute analysis indicates the presence of significant amplitude and frequency anomalies within the mapped structural closures. RMS amplitude values range from 4500 to 6800 and are concentrated within specific inline intervals, highlighting bright amplitude anomalies commonly associated with hydrocarbon accumulations. Instantaneous frequency values range from 18 to 32 Hz and exhibit localised reductions beneath amplitude anomalies, indicative of low-frequency shadows. Acoustic impedance values between 5200 and 7800 m/s·g/cc reflect lithological contrasts consistent with interbedded sand–shale sequences. Sweetness attribute values ranging from 20 to 38 further delineate zones of potential hydrocarbon saturation, particularly along anticlinal crests and fault closures (Table 3.4).

Table 3.4. Seismic Attribute Analysis Results

Attribute	**Observed Range**	**Location**	**Interpretation**
RMS Amplitude	4500–6800	Inline 1450–1620	Bright amplitude anomaly (possible gas)
Instantaneous Frequency	18–32 Hz	Fault closure zone	Low-frequency shadow
Acoustic Impedance	5200–7800 m/s·g/cc	Reservoir interval	Sand–shale contrast
Sweetness	20–38	Anticlinal crest	Hydrocarbon indicator

Petrophysical evaluation of the reservoir intervals across the three wells indicates favourable reservoir characteristics. Gross thickness ranges from 68 m to 75 m, while net pay thickness varies between 35 m and 42 m. Porosity values range from 22.8% to 26.1%, indicating well-developed pore systems, and water saturation ranges from 25% to 32%, corresponding to hydrocarbon saturation values between 68% and 75%. Permeability values, ranging from 1320 mD to 1600 mD, suggest excellent reservoir transmissibility. These parameters collectively indicate high-quality reservoir sands with strong storage and flow capacity (Table 3.5).

Table 3.5. Petrophysical Evaluation from Well Logs (Reservoir Sand Unit)

Parameter	**Well A**	**Well B**	**Well C**
Gross Thickness (m)	72	68	75
Net Pay Thickness (m)	38	35	42
Porosity (%)	24.5	22.8	26.1
Water Saturation (%)	28	32	25
Hydrocarbon Saturation (%)	72	68	75
Permeability (mD)	1450	1320	1600

Reservoir quality classification based on porosity and permeability places the identified sand units within the very good to excellent category. Wells A and C exhibit excellent reservoir properties, while Well B shows very good characteristics, confirming lateral consistency in reservoir quality across the study area (Table 3.6).

Table 3.6. Reservoir Quality Classification

Well	**Porosity Class**	**Permeability Class**	**Reservoir Quality**
Well A	Excellent (>20%)	Very Good (>1000 mD)	High
Well B	Very Good	Very Good	High
Well C	Excellent	Excellent	Very High

Volumetric estimation based on mapped structural closure and average petrophysical parameters yields a Stock Tank Oil Initially in Place (STOIIP) of approximately 185 million barrels. This estimate is derived from a reservoir area of 18.5 km², average net pay thickness of 38 m, average porosity of 24.5%, hydrocarbon saturation of 71%, and a formation volume factor of 1.25, indicating significant hydrocarbon potential within the study area (Table 3.7).

Table 3.7. Volumetric Estimation of Hydrocarbon in Place

Parameter	Value
Reservoir Area	18.5 km²
Average Net Pay	38 m
Average Porosity	24.5%
Hydrocarbon Saturation	71%
Formation Volume Factor (Bo)	1.25
Estimated STOIIP	185 million barrels

Risk assessment results indicate high probabilities for key petroleum system elements, including source rock presence (0.90), migration efficiency (0.85), and reservoir quality (0.88). Trap integrity (0.80) and seal capacity (0.82) exhibit slightly lower but still favourable probabilities. The combined probability yields an overall geological chance of success of approximately 0.45, reflecting moderate exploration risk within the study area (Table 3.8).

Table 3.8. Prospect Risk Evaluation

Risk Element	Probability
Source Rock Presence	0.90
Migration Efficiency	0.85
Reservoir Quality	0.88
Trap Integrity	0.80
Seal Capacity	0.82
Overall Geological Chance of Success	0.45

The results demonstrate that the identified hydrocarbon prospect is structurally controlled by fault-assisted anticlines and rollover systems, supported by seismic attribute anomalies and favourable petrophysical properties. The integration of structural, geophysical, and reservoir data provides consistent evidence for hydrocarbon presence and indicates strong potential for commercial development (Table 3.9).

Table 3.9. Summary of Hydrocarbon Prospect Evaluation

Factor	Observation	Implication
Structural Configuration	Fault-assisted anticline	Effective trap geometry
Seismic Indicators	Bright spot + low-frequency shadow	Gas-charged reservoir possibility
Reservoir Quality	High porosity and permeability	Commercial viability
Estimated Hydrocarbon Volume	185 MMbbl	Economically attractive
Geological Risk	Moderate	Suitable for appraisal drilling

DISCUSSION

The structural configuration interpreted in this study reflects the extensional tectonic regime that characterises the Niger Delta Basin, where syn-sedimentary growth faulting and differential sediment loading have controlled trap formation and hydrocarbon distribution (Short & Stauble, 1967; Weber & Daukoru, 1975; Doust & Omatsola, 1989). The mapped NE–SW growth faults and associated rollover anticlines are consistent with gravity-driven tectonics described in passive margin deltaic systems (Burke, 1972; Evamy, 1978; Dim, 2016). Such structural styles create fault-assisted closures and rollover anticlines that act as effective traps when supported by competent shale seals within the Agbada Formation. The observed fault throws and lateral continuity of the major growth fault indicate sufficient vertical relief and structural closure to support hydrocarbon accumulation (Aghanwa et al., 2026). However, the same structural complexity that enhances trap formation may also introduce compartmentalisation, which has been widely recognised as a key control on reservoir connectivity and recovery efficiency in the Niger Delta (Whiteman, 1982; Opara et al., 2011).

The reliability of the structural interpretation is strengthened by established geophysical principles governing subsurface imaging. Seismic reflection methods respond to contrasts in acoustic impedance, while electrical resistivity methods respond to contrasts in electrical properties; both approaches rely on measurable physical contrasts to delineate subsurface heterogeneities (Keller & Frischknecht, 1966; Chernicoff, 2007). Reviews of electrical resistivity tomography and vertical electrical sounding demonstrate the robustness of geophysical techniques in resolving subsurface layering, structural discontinuities, and fluid-bearing zones (Dewashish et al., 2014; Hussein et al., 2023; Ibrahim et al., 2023). Studies across southern Nigeria have similarly shown that resistivity contrasts effectively delineate aquifer geometry and structural controls (Egbai, 2011; Okiongbo & Akpofure, 2012; Eyankware & Aleke, 2021; Babasola & Nmoka, 2025). Although the present study employs seismic rather than resistivity methods, the underlying principle remains the same: physical property contrasts reveal structural and lithological boundaries. The clear reflector terminations and displacement patterns observed in the seismic volume, therefore, provide credible evidence of fault geometry and trap configuration (Umueni et al., 2026)..

The seismic attribute results further strengthen the hydrocarbon interpretation. The coincidence of RMS amplitude anomalies with low-frequency shadows and elevated sweetness values is consistent with fluid-related seismic responses commonly described as direct hydrocarbon indicators (Adigun & Ayolabi, 2013; Ajisafe & Ako, 2013; Anyiam, 2015; Chukwu, 2016). From a rock-physics perspective, hydrocarbon substitution reduces bulk density and compressional velocity relative to brine-saturated sands, thereby enhancing reflection amplitude and altering frequency content. The acoustic impedance contrasts observed within the mapped closures are therefore consistent with sand–shale interbedding and possible hydrocarbon charge. The integration of model-based inversion with well log constraints follows established reservoir characterisation workflows applied successfully in the Niger Delta and other sedimentary basins (Adeoti et al., 2014; Ahanor, 2012; Alotaibi, 2015).

Petrophysical evaluation confirms excellent reservoir properties across the three wells, with porosity exceeding 20% and permeability values above 1000 mD. These parameters are characteristic of well-sorted Agbada Formation sands and are comparable to productive reservoirs previously reported in the Niger Delta (Edigbue et al., 2014; Oyedele et al., 2013). The hydrocarbon saturation values derived using Archie’s equation indicate significant pore space occupancy by hydrocarbons, consistent with established formation evaluation principles (Amao, 2013; Schon, 2015; Clark & Shearin, 2019). The convergence of high porosity, high permeability, and favourable saturation significantly enhances the commercial attractiveness of the prospect. Nevertheless, uncertainties associated with shale content and Archie parameter assumptions remain, as has been widely acknowledged in petrophysical interpretation studies (Ilevbare, 2014).

The estimated STOIIP of approximately 185 MMbbl indicates substantial volumetric potential. In a mature petroleum province such as the Niger Delta, such volumes fall within the range of commercially viable field developments, particularly where infrastructure already exists (Ekweozor & Daukoru, 1984; Dim, 2016). However, volumetric calculations are sensitive to closure area, net pay thickness, porosity, water saturation, and formation volume factor. Even moderate uncertainties in these parameters can significantly influence in-place volumes. Therefore, sensitivity analysis and probabilistic volumetric modelling are recommended to bracket low, base, and high cases prior to final investment decisions (Okpoji et al., 2026).

The geological chance of success of 0.45 reflects moderate exploration risk, primarily associated with trap integrity and seal capacity. Faults in deltaic settings may either act as sealing barriers or as migration pathways depending on shale smear continuity, clay content, and stress conditions. Similar considerations are emphasised in geoelectric and hydrogeological studies where structural discontinuities influence groundwater vulnerability and fluid migration (Ikpe et al., 2025; Okagbare et al., 2025). In coastal Niger Delta environments, saline intrusion and contaminant transport are strongly controlled by hydrogeological and structural dynamics (Eyankware et al., 2025; Ohwoghere-Asuma et al., 2020). These parallels underscore the broader fluid-flow implications of structural mapping beyond hydrocarbon exploration.

Environmental studies across the Niger Delta further demonstrate the importance of subsurface integrity in managing hydrocarbon-related impacts. Investigations have documented hydrocarbon contamination in sediments, groundwater, and surface waters in areas affected by petroleum activities (Ogbaji et al., 2025; Okpoji et al., 2025a; Okpoji et al., 2025b; Ekesiobi et al., 2026). Fault leakage or compromised seal capacity can potentially contribute to such impacts if not properly assessed. Consequently, detailed structural interpretation and risk evaluation, as conducted in this study, are essential not only for prospect evaluation but also for long-term environmental stewardship (Etukudo et al., 2026).

The results confirm that hydrocarbon accumulation within the Eastern Niger Delta Basin is structurally controlled by growth fault systems and rollover anticlines, consistent with established petroleum system models (Weber & Daukoru, 1975; Doust & Omatsola, 1989; Dim, 2016). The integration of seismic structural mapping, attribute analysis, and quantitative petrophysical evaluation provides a robust and internally consistent framework for prospect maturation. While uncertainties remain regarding seal integrity and reservoir compartmentalisation, the convergence of structural, geophysical, and petrophysical evidence strongly supports further appraisal drilling and advanced reservoir evaluation within the study area (Anumaka et al., 2026).

CONCLUSION

The integrated geophysical and petrophysical assessment conducted in this study confirms that hydrocarbon accumulation within the Eastern Niger Delta Basin is structurally controlled by growth fault systems and associated rollover anticlines typical of the Agbada Formation reservoirs. Structural mapping delineated well-defined fault-assisted closures, while seismic attribute responses—including bright amplitude anomalies and low-frequency shadows—provide strong indirect evidence of hydrocarbon presence within the mapped intervals.

Petrophysical analysis from the three evaluated wells indicates excellent reservoir properties characterised by high porosity (>20%), high permeability (>1000 mD), and favourable hydrocarbon saturation values. These parameters collectively suggest strong reservoir deliverability and production potential. The volumetric estimation of approximately 185 MMbbl STOIIP demonstrates that the identified prospect is economically attractive, pending confirmation through appraisal drilling and dynamic reservoir evaluation.

Although the calculated geological chance of success indicates moderate risk, particularly with respect to seal integrity and fault compartmentalisation, the convergence of structural, seismic attribute, and well log evidence significantly enhances confidence in the prospect. The study reinforces the importance of integrated seismic–well workflows in hydrocarbon exploration and provides a robust framework for prospect maturation within the Niger Delta Basin and comparable passive margin deltaic systems worldwide.

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