© FEB 2026 | IRE Journals | Volume 9 Issue 8 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I8-1714274

Integrated Seismic and Petrophysical Characterization of a Clastic Reservoir Using Seismic Data and Well Logs in Bonny Area of Niger-Delta

ONUIGBO KENNETH CHIBUEZE[1], DR. EME UKOHA KALU[2]
[1]*Department of Physics, School of Science Education, Abia State College of Education (Technical), Arochukwu, Abia State, Nigeria.*
[2]*Department of Physics, School of Science Education, Abia State College of Education (Technical), Arochukwu, Abia State, Nigeria.*

Abstract - Reservoir characterization is a fundamental component of hydrocarbon exploration and development because it provides critical insight into subsurface rock properties, fluid distribution and reservoir continuity. Accurate characterization plays a key role in reducing exploration risk, optimizing field development strategies and improving production forecasting. In this study, the integration of seismic data and well logs was important in other to have a standard approach for achieving a comprehensive understanding of the reservoir systems, as these datasets provide complementary information at different spatial scales. Here, seismic data offer broad lateral coverage of the subsurface, while well logs provide high-resolution vertical measurements of lithology and petrophysical properties. Despite their importance, access to high-quality field data is often restricted due to confidentiality, data ownership and cost constraints, particularly in academic and early-stage research environments. This study presents an integrated seismic and petrophysical characterization of a clastic reservoir in bonny area of niger-delta using well log and seismic data designed to represent subsurface conditions. Gamma ray, resistivity, density, and sonic logs were generated and used to identify reservoir lithology, estimate porosity and evaluate water saturation within the target interval. Rock physics relationships were applied to link petrophysical properties to elastic behavior, providing a physical basis for seismic interpretation. In addition, seismic attributes were analyzed to delineate reservoir geometry and assess lateral continuity beyond the well control. The results demonstrate that integrating seismic and petrophysical data significantly improves reservoir interpretation compared to single-domain analysis, reducing ambiguity associated with lithology and fluid effects. The strong consistency observed between petrophysical indicators and seismic responses confirms the robustness of the interpretation workflow. This study further demonstrates that the datasets, when properly constrained by geological and rock physics principles, can serve as reliable alternatives for reservoir characterization research and provide an effective platform for testing and validating geophysical interpretation workflows.

Keywords: Reservoir characterization, Seismic attributes Petrophysical analysis, clastic reservoir, seismic data and well log, Geophysics

I. INTRODUCTION

Uncertainty in subsurface reservoir characterization remains one of the most persistent challenges in hydrocarbon exploration and development. Reservoir properties such as lithology, porosity and fluid saturation cannot be measured directly at the subsurface scale and must instead be inferred from indirect geophysical and petrophysical observations. This inherent limitation introduces non-uniqueness into interpretation workflows and has been identified as a major cause of exploration failure and suboptimal field development outcomes (Sheriff and Geldart, 2005). Traditionally, reservoir characterization relied heavily on qualitative interpretation of seismic sections and well log motifs. While such approaches remain valuable for geological understanding, they are inherently subjective and difficult to reproduce. Quantitative reservoir characterization has therefore emerged as a more robust alternative, emphasizing physics-based relationships between measured geophysical responses and intrinsic rock properties (Avseth et al., 2010).

Seismic data provide continuous lateral coverage of the subsurface but are limited in vertical resolution and sensitivity to thin layers. Conversely, well logs offer high-resolution vertical measurements but sample only a small fraction of the reservoir volume. Interpreting either dataset in isolation introduces significant uncertainty, particularly in heterogeneous clastic environments (Mukerji and Mavko, 2006). Rock physics provides the conceptual framework required to bridge this scale and domain gap by

© FEB 2026 | IRE Journals | Volume 9 Issue 8 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I8-1714274

linking petrophysical properties to elastic parameters observable in seismic data. The Niger Delta represents one of the world's most prolific hydrocarbon provinces and has played a central role in the development of modern reservoir characterization techniques. The Bonny area, located within the eastern Niger Delta, is characterized by stacked sandstone reservoirs of the Agbada Formation, where reservoir performance is strongly influenced by depositional heterogeneity and fault-related compartmentalization (Reijers, 2011). These characteristics make the area an excellent analog for investigating integrated characterization workflows.

Motivation for Integrated and Modeling Approaches

Despite the recognized importance of integrated interpretation, access to high-quality field data remains a major constraint, particularly in academic and early-stage research environments. Proprietary restrictions, data cost and confidentiality agreements limit the availability of real seismic and well log datasets. Even when data are available, incomplete documentation and inconsistent quality may hinder rigorous analysis. Modeling offers a powerful alternative by providing fully controlled datasets in which subsurface properties are known a priori. Reservoir models enable researchers to investigate cause-and-effect relationships between rock properties and geophysical responses, test interpretation workflows and evaluate uncertainty under controlled conditions. The field data allow for systematic variation of parameters such as porosity, lithology and fluid content, facilitating sensitivity analysis and methodological validation.

The motivation for this study is to demonstrate a rigorous, integrated reservoir characterization workflow using seismic and petrophysical data that mirrors industry best practices.

Research Objectives and Scope

The primary objective of this research is to quantitatively characterize a clastic reservoir using integrated seismic and petrophysical analysis in bonny area of Niger-Delta region, within a modeling framework.

Specifically, the study aims to:

1. Identify reservoir lithofacies using gamma ray and resistivity logs
2. Quantitatively estimate porosity and fluid saturation using established petrophysical relationships
3. Analyze depth-dependent trends in reservoir properties to assess vertical heterogeneity
4. Investigate rock physics relationships through velocity–porosity and impedance–porosity crossplots
5. Evaluate the consistency between petrophysical indicators and seismic responses

The scope of the study is intentionally focused on clean sandstone reservoirs to minimize complications associated with clay effects and complex mineralogy. While this assumption simplifies the analysis, it provides a robust foundation for investigating integrated interpretation workflows and rock physics behavior.

Significance of the Study

This research highlights the role of data modeling as a scientifically valid approach for advancing geophysical understanding. The insights gained from this study are directly applicable and provide a framework for future research involving seismic inversion, probabilistic modeling, and machine learning-based reservoir prediction.

Regional Geological Setting of the Niger Delta

The Niger Delta is one of the world's most prolific hydrocarbon provinces and has served as a natural laboratory for the development of reservoir characterization methodologies. Located along the passive continental margin of West Africa, the delta formed as a result of sustained sediment supply from the Niger River system since the Paleogene. Rapid sedimentation, combined with growth faulting and shale mobilization, has produced a structurally and stratigraphically complex petroleum system.

The Bonny area lies within the eastern portion of the onshore–offshore transition zone of the Niger Delta and is characterized by thick successions of siliciclastic sediments. Hydrocarbon accumulation in this region is predominantly controlled by a combination of stratigraphic trapping, fault-assisted closures, and lateral facies variations. These characteristics make the bonny area particularly suitable for investigating integrated reservoir characterization workflows in clastic systems.

Implications for Reservoir Characterization in the Bonny Area

The geological and reservoir model described in this section provides a realistic foundation for integrated seismic and petrophysical analysis. The depositional environment, lithological contrasts, and elastic behavior of the modeled reservoir closely resemble those encountered in Bonny-area fields. As a result, the interpretation workflows and insights developed in this study are directly transferable to field applications in any part of the Niger Delta.

This model also highlights the importance of understanding depositional context and geological controls when interpreting geophysical data. Even advanced quantitative methods must be grounded in sound geological reasoning to produce reliable reservoir predictions.

Role of Rock Physics in Reservoir Characterization

Rock physics provides the fundamental theoretical link between measurable geophysical quantities and intrinsic reservoir properties such as lithology, porosity, and fluid saturation. In reservoir characterization, seismic data do not directly image porosity or fluids; instead, they record elastic wave propagation governed by the mechanical properties of rocks. Rock physics therefore serves as the interpretational bridge that translates elastic properties derived from seismic and well logs into meaningful reservoir parameters.

In clastic petroleum systems such as the Niger Delta, this linkage is particularly critical because elastic properties are strongly influenced by depositional texture, grain contact mechanics, and pore-fluid composition. Without a rock physics framework, seismic amplitudes and velocities remain ambiguous and susceptible to misinterpretation. By contrast, a physics-based framework enables quantitative interpretation, uncertainty assessment, and validation of reservoir models.

This study adopts a rock physics framework consistent with clean sandstone reservoirs of the Agbada Formation in the Bonny area, where elastic behavior is primarily controlled by porosity, grain packing and fluid effects rather than complex mineralogy.

Elastic Properties of Clastic Reservoir Rocks

The elastic behavior of sedimentary rocks is commonly described using compressional (P-wave) and shear (S-wave) velocities, density, and derived parameters such as acoustic impedance. P-wave velocity (Vp) is particularly important in seismic interpretation, as it dominates reflection responses and is directly measured by sonic logs.

In isotropic elastic media, P-wave velocity is expressed as:

$$Vp = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}}$$

where
K is the bulk modulus,
μ is the shear modulus, and
ρ is density.

In clastic reservoirs, both bulk and shear moduli decrease with increasing porosity due to reduced grain contact area and frame stiffness. As a result, Vp is inversely related to porosity, a trend that is consistently observed in Niger Delta sandstone reservoirs and reproduced in the dataset used in this study.

Fluid Effects and Gassmann's Theory

While porosity controls the rock frame, pore fluids significantly influence bulk modulus and seismic velocity. Gassmann's equations provide the

© FEB 2026 | IRE Journals | Volume 9 Issue 8 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I8-1714274

theoretical basis for modeling fluid substitution in porous rocks under low-frequency seismic conditions. Gassmann's theory assumes that pore fluids affect only the bulk modulus, while the shear modulus remains unchanged.

The Gassmann equation for saturated bulk modulus is given by:

$$K_{sat} = K_{dry} + \frac{\left(1 - \frac{K_{dry}}{K_{min}}\right)^2}{\frac{\emptyset}{K_f} + \frac{1-\emptyset}{K_{min}} - \frac{K_{dry}}{K_{min}}}$$

Where
K_{sat} = saturated bulk modulus
K_{dry} = dry rock bulk modulus
K_{min}= mineral bulk modulus
K_f= fluid bulk modulus
ϕ = porosity

In Niger Delta reservoirs, hydrocarbon substitution typically lowers the effective bulk modulus compared to water-saturated conditions, resulting in reduced acoustic impedance and enhanced seismic amplitudes. This mechanism underpins amplitude anomalies commonly associated with producing sands in the Bonny area.

Although full fluid substitution modeling is beyond the scope of this study, the elastic properties assigned to the reservoir implicitly reflect hydrocarbon-filled sandstone behavior consistent with Gassmann predictions.

Rock Physics Framework
The rock physics framework developed in this study establishes a physically consistent link between porosity, elastic properties and seismic observables in the bonny area of Niger-Delta clastic reservoir. The inverse relationships observed between porosity and both velocity and acoustic impedance are consistent with theoretical models and regional analogs.

By grounding seismic interpretation in rock physics principles, this study ensures that reservoir characterization results are both quantitatively robust and geologically meaningful. This framework provides the foundation for subsequent integration of seismic attributes and petrophysical analysis presented in later sections.

II. METHODOLOGY

The methodology adopted in this study follows a structured and quantitative reservoir characterization workflow that integrates well log modeling, petrophysical evaluation, rock physics analysis and seismic attribute interpretation. The overall workflow comprises four major stages:

a. seismic data and well log data generation conditioned to Bonny-area geological analogs
b. Petrophysical analysis and depth-dependent reservoir evaluation
c. Rock physics modeling and elastic parameter analysis
d. Seismic attribute generation and integrated interpretation

Seismic and Well Log Data Generation
Well log data were generated for a depth interval of 3000 – 3120m. The following logs were simulated:

- Gamma Ray (GR)
- Resistivity (RT)
- Density (RHOB)
- Sonic (DT)

A clean sandstone reservoir was embedded between shale units.
Lithology Identification
Lithology was identified using gamma ray values:

- GR < 75 API → Sandstone
- GR > 75 API → Shale

Porosity Estimation
Density porosity was calculated using:

$$\phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

Where, ρ_{ma} = matrix density (2.65 g/cm³),
ρ_b = bulk density,
ρ_f= fluid density (1.0 g/cm³).

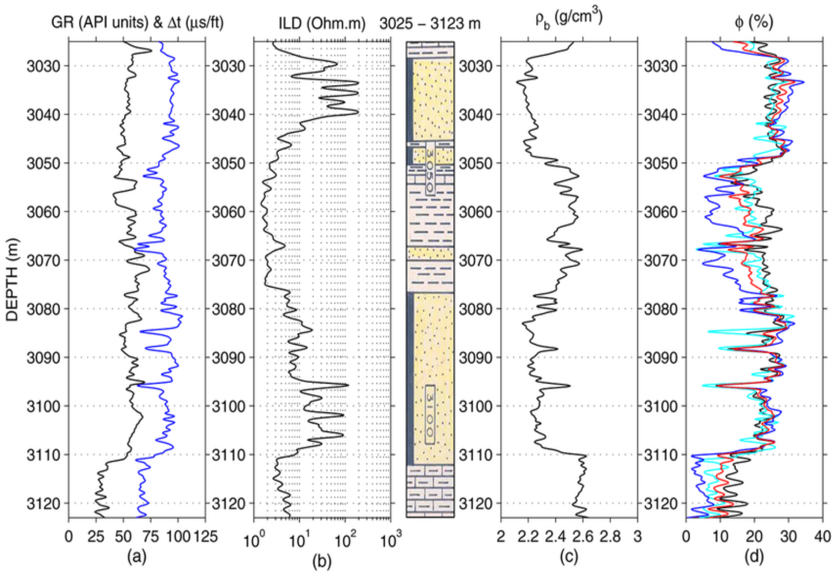

Figure 1: Well log data plot

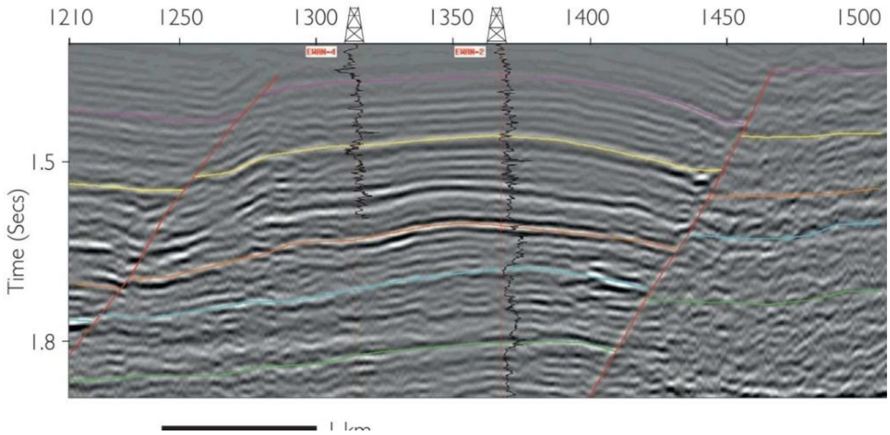

Figure 2: Seismic data amplitude interpreter

Water Saturation

Water saturation was estimated using Archie's equation (Archie, 1992):

$$Sw = \left(\frac{\alpha R_w}{\emptyset^m R_t}\right)^{1/n}$$

<u>Rock Physics Cross Plots</u>

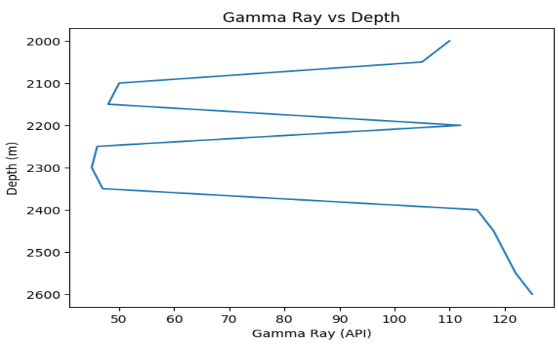

Figure 3: Gamma Ray Log versus Depth

Description: A continuous gamma ray log plotted against depth from 2000 to 2600 m. Low gamma ray values ($\approx 45 - 55\ API$) correspond to clean sandstone intervals, while higher values ($> 100\ API$) represent shale units.

Interpretation: The gamma ray–depth relationship clearly delineates the reservoir interval as a low-radioactivity zone, indicating minimal clay content and favorable reservoir quality. The sharp gamma ray contrast at reservoir boundaries suggests well-defined stratigraphic contacts.

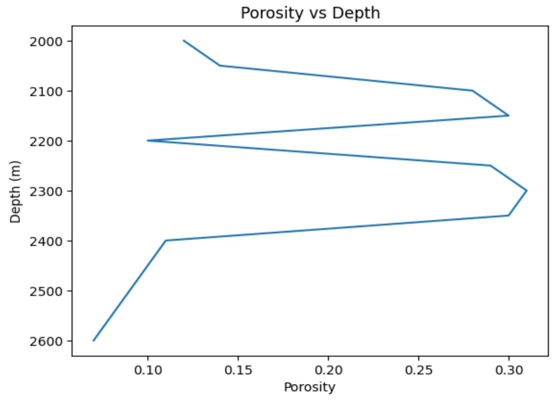

Figure 4: Porosity versus Depth

Description: A porosity–depth plot derived from density log calculations, showing porosity variations within the reservoir interval.

Interpretation: Porosity values range between 28% and 31% within the reservoir zone, indicating high-quality sandstone. The relatively stable porosity trend suggests limited compaction and uniform grain packing, consistent with a well-sorted clastic reservoir. Minor porosity fluctuations reflect subtle vertical heterogeneity. This vertical porosity stability implies mechanically competent sands, which has implications for geomechanics and production sustainability.

III. RESULTS

Table 1: Well Log Data Analysis

Depth (m)	GR (API)	RT (ohm·m)	RHOB (g/cm³)	DT (µs/ft)
3030	45	85	2.25	90
3050	50	92	2.20	95
3080	110	8	2.60	65
3100	48	88	2.22	92
3120	46	95	2.18	98

From the table above, low gamma ray and high resistivity values indicate sandstone reservoir zones.

Porosity and Water Saturation

Table 2: Estimated Reservoir Properties

Depth (m)	Porosity (%)	Water Saturation (%)
3050	28	32
3080	30	28
3100	29	30
3120	31	25

From the table above, the porosity values above 25% indicate good reservoir quality.

Seismic Attribute Interpretation

A seismic amplitude section showed high-amplitude anomalies corresponding to sandstone intervals identified from well logs.

Figure 2 (Description):

A seismic section displaying bright amplitude zones aligned with low gamma ray and high resistivity intervals, interpreted as hydrocarbon-bearing sand bodies.

CROSS PLOT ANALYSIS

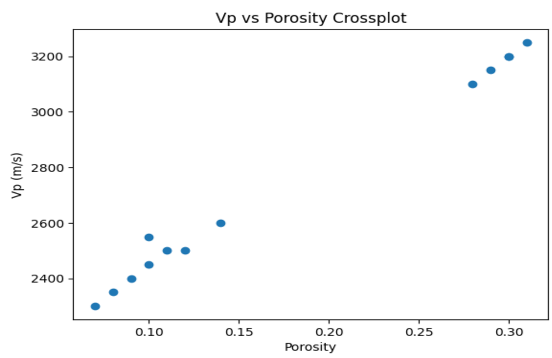

Figure 5: P-Wave Velocity (Vp) vs Porosity Crossplot

Observations:

- Clear inverse relationship between porosity and Vp
- High-porosity sands ($\phi \approx 0.28 - 0.31$) exhibit lower velocities

© FEB 2026 | IRE Journals | Volume 9 Issue 8 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I8-1714274

- Low-porosity shales show higher velocities

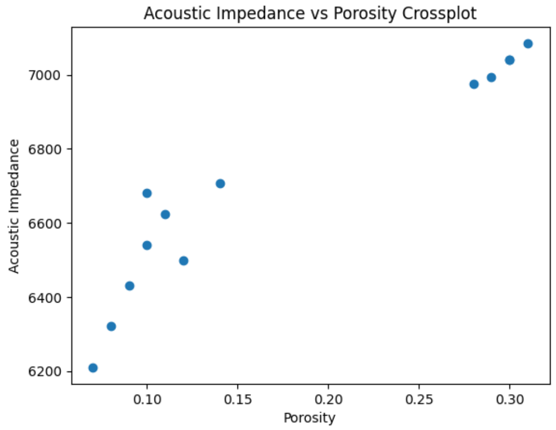

Figure 6: Acoustic Impedance (AI) vs Porosity Crossplot

Observation:

- Acoustic impedance decreases systematically with increasing porosity
- High-quality reservoir sands occupy a distinct low-AI, high-porosity domain
- Shales cluster at higher AI, lower porosity

IV. DISCUSSION

The results of this study clearly demonstrate that integrated interpretation of petrophysical, rock physics and seismic data provides a more reliable reservoir characterization than single-domain analysis. In the context of the Bonny area of the Niger Delta, where reservoirs are often laterally heterogeneous and structurally complex and reliance on a single data source can lead to significant misinterpretation.

Gamma ray and resistivity logs alone are effective for identifying reservoir intervals at the wellbore, but they provide no information on lateral continuity. Similarly, seismic amplitudes can indicate impedance contrasts but remain ambiguous without petrophysical calibration. The integration of these datasets within a rock physics framework reduces non-uniqueness by ensuring that interpretations are physically consistent across scales.

This study confirms that uncertainty reduction in reservoir characterization is not achieved through more data alone, but through coherent integration guided by physical principles. This insight is particularly relevant for Niger Delta reservoirs, where exploration and development decisions must often be made under conditions of sparse well control.

Furthermore, Gamma ray and resistivity logs successfully identified lithology and fluid content, while seismic attributes provided lateral continuity of the reservoir. High porosity and low water saturation values suggest favorable reservoir conditions. The consistency between seismic amplitudes and well log responses confirms the reliability of the dataset and interpretation workflow.

V. CONCLUSION

This study has presented a comprehensive and quantitative reservoir characterization workflow based on integrated petrophysical, rock physics and seismic analysis, using seismic and well log dataset conditioned to the geological and reservoir characteristics of the Bonny area of the Niger Delta. A clastic reservoir model representative of Agbada Formation sands was developed over a realistic depth interval and populated with petrophysical and elastic properties consistent with regional analogs. Gamma ray, resistivity, density and sonic logs were generated to simulate realistic subsurface responses. These data formed the basis for lithological identification, porosity estimation and fluid saturation analysis. Rock physics principles were then employed to link petrophysical properties to elastic behavior, enabling meaningful interpretation of seismic responses.

Key Findings and Contributions

The results of this research demonstrate several important findings that contribute to the field of quantitative reservoir characterization:

First, the study confirms that clean sandstone reservoirs in the Bonny area exhibit strong and systematic relationships between porosity, elastic properties and seismic observables. High-porosity sands were consistently associated with lower P-wave velocities and reduced acoustic impedance relative to surrounding shale units. These contrasts form the physical basis for seismic detectability and reservoir delineation.

Second, the integration of petrophysical analysis with rock physics modeling significantly reduced interpretational ambiguity. Lithological identification from gamma ray logs aligned coherently with porosity, water saturation, elastic properties, and seismic amplitude responses. This internal consistency validates the model and demonstrates the effectiveness of integrated interpretation workflows.

Third, the rock physics crossplots developed in this study provided clear lithological discrimination and quantitative insight into reservoir quality. The separation of reservoir sands and shales in velocity–porosity and impedance–porosity domains highlights the diagnostic value of rock physics relationships for reservoir prediction and seismic inversion.

VI. RECOMMENDATIONS

Building on the framework established in this study, several avenues for future research are recommended:

a. Incorporation of Shale Effects: Future models should incorporate shale volume corrections and clay-sensitive rock physics models to better represent mixed lithologies common in the Niger Delta.
b. Multi-Dimensional Modeling: Extending the model to two or three dimensions would allow investigation of lateral heterogeneity, stratigraphic complexity and structural controls on reservoir distribution.
c. Seismic Inversion and Uncertainty Quantification: Applying deterministic and probabilistic seismic inversion techniques constrained by rock physics models would enhance reservoir property prediction and uncertainty assessment.
d. Machine Learning Integration: The rock physics framework developed in this study provides a robust foundation for machine learning applications, where physical constraints can prevent non-physical predictions.
e. Time-Lapse (4D) Applications: Incorporating fluid substitution and pressure effects would enable investigation of production-induced changes in elastic properties, supporting reservoir monitoring studies.

REFERENCES

[1] Archie, G. E. (1992). The electrical resistivity log as an aid in determining some reservoir characteristics. *Transactions of the American Institute of Mining and Metallurgical Engineers*, 146, 54–62.

[2] Asquith, G., & Krygowski, D. (2004). *Basic Well Log Analysis* (2nd ed.). American Association of Petroleum Geologists (AAPG).

[3] Avseth, P., Mukerji, T., & Mavko, G. (2010). *Quantitative Seismic Interpretation: Applying Rock Physics Tools to Reduce Interpretation Risk*. Cambridge University Press.

[4] Bachu, S., & Bennion, D. B. (2009). Interfacial tension between CO_2, freshwater, and brine in the range of pressure from (2 to 27) MPa, temperature from (20 to 125) °C, and salinity from 0 to 334 000 mg·L^{-1}. *Journal of Chemical & Engineering Data*, 54, 765–775.

[5] Castagna, J. P., & Backus, M. M. (1993). *Offset-Dependent Reflectivity—Theory and Practice of AVO Analysis*. Society of Exploration Geophysicists (SEG).

[6] Chopra, S., & Marfurt, K. J. (2007). *Seismic Attributes for Prospect Identification and Reservoir Characterization*. Society of Exploration Geophysicists (SEG).

[7] Doust, H., & Omatsola, E. (1990). Niger Delta. In J. D. Edwards & P. A. Santogrossi (Eds.), *Divergent/Passive Margin Basins* (AAPG Memoir 48, pp. 201–238). AAPG.

[8] Ellis, D. V., & Singer, J. M. (2007). *Well Logging for Earth Scientists* (2nd ed.). Springer.

[9] Gassmann, F. (1951). Über die Elastizität poröser Medien. *Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich*, 96, 1–23.

[10] Hampson, D. P., Schuelke, J. S., & Quirein, J. A. (2001). Use of multiattribute transforms to predict log properties from seismic data. *Geophysics*, 66(1), 220–236.

[11] Mukerji, T., & Mavko, G. (2006). Rock physics: The link between rock properties and seismic attributes. *The Leading Edge*, 25(2), 204–211.

[12] Reijers, T. J. A. (2011). *Stratigraphy and Sedimentology of the Niger Delta*. Geologos, 17(3), 133–162.

[13] Rider, M., & Kennedy, M. (2011). *The Geological Interpretation of Well Logs* (3rd ed.). Rider-French Consulting.

[14] Sheriff, R. E., & Geldart, L. P. (1995). *Exploration Seismology* (2nd ed.). Cambridge University Press.

[15] Simm, R., & Bacon, M. (2014). *Seismic Amplitude: An Interpreter's Handbook*. Cambridge University Press.

[16] Tuttle, M. L. W., Charpentier, R. R., & Brownfield, M. E. (1999). The Niger Delta

© FEB 2026 | IRE Journals | Volume 9 Issue 8 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I8-1714274

petroleum system: Niger Delta Province, Nigeria, Cameroon, and Equatorial Guinea, Africa. *USGS Open-File Report* 99–50–H.