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Optimizing Hydrocarbon Recovery through Seismic-Attribute Analysis in Onshore Niger Delta Fields: A Case Study of XYZ Field

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Abstract

The geology of the Niger Delta comprises fault blocks supporting immense hydrocarbon reserves, which require standard exploration methods. This research is concerned with the recovery of hydrocarbons in the XYZ field through seismic attribute (SA) analysis. Attributes such as the amplitude, frequency, and phase analysis of the seismic waves make up SA analysis which serve as coherent indications of the subsurface conditions as well as prospects for hydrocarbon emergence. In this way, benefiting from the suite of software tools, this research interprets seismic data and evaluates petrophysical properties based on incorporated 3D seismic data set and well logs. These are synthetic and antithetic faults and significant growth faults in a southwest-to-northeast orientation. Both the horizon mapping and generation of time and depth surface maps validated the types of used velocities. This proved to have good reservoir thickness, as well as porosity and permeability, which would signify considerable potential for hydrocarbons. Relative acoustic reflectance, predominantly RMS amplitude, contributed significantly to the formulation of hydrocarbon-bearing zones. The findings of the study map the hydrocarbon potential, and besides, offer volumetric estimations of Reservoir A at 240 million STB and Reservoir B at 470 million STB. The findings of this study clearly show that; for hydrocarbon exploration and production in the Niger Delta, advanced seismic attribute analysis is a critical factor.

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Introduction

Known throughout the world for its enormous energy potential, the Niger Delta is important geologically because of its intricate sedimentary structures, faulted and folded layers, and diverse reservoir properties. Because of these characteristics, oil and gas exploration and development are complicated, making it a useful case study for cutting-edge exploration methods. Located onshore in the Niger Delta the XYZ field provides the best example of these geological complexities. One of the main techniques used in this study is seismic attribute (SA) analysis which uses features like amplitude frequency phase and continuity to extract quantitative data from seismic waves and describe subsurface properties (Brown 2001). The following seismic characteristics provide information about subsurface conditions: phase can reveal structural deformations frequency reveals stratigraphic features and amplitude highlights changes in rock properties or fluid content. This approach provides a deeper comprehension of the subsurface that traditional methods might overlook. Understanding reservoir heterogeneities spotting traps and locating hydrocarbon reservoirs are all made easier with SA analysis (Avseth et al. 2010 for example. The study also examines the function of secondary faults that accompany major fault systems known as synthetic and antithetic faults. Antithetic faults dip in the opposite direction from the main fault whereas synthetic faults dip in the same direction. Because they produce fluid migration pathways and structural traps these fault systems are important in the accumulation of hydrocarbons. By applying SA analysis to the XYZ field this study seeks to maximize hydrocarbon recovery demonstrating the methods value in addressing the geological difficulties facing the Niger Delta (Taner et al. (1994). According to McQuillin et al. SA analysis is a powerful tool for releasing hydrocarbon reserves enhancing our understanding of seismic data and speeding up hydrocarbon recovery in the Niger Delta. 1984).

Study Area

XYZ field is an onshore field located in ND, the coordinate together with the precise location is concealed following guidelines provided by the Department of Petroleum Resources in line with practices in the oil sector. Figure 1 depicts a base map of the location, which provides a thorough description of the wells in the survey area.

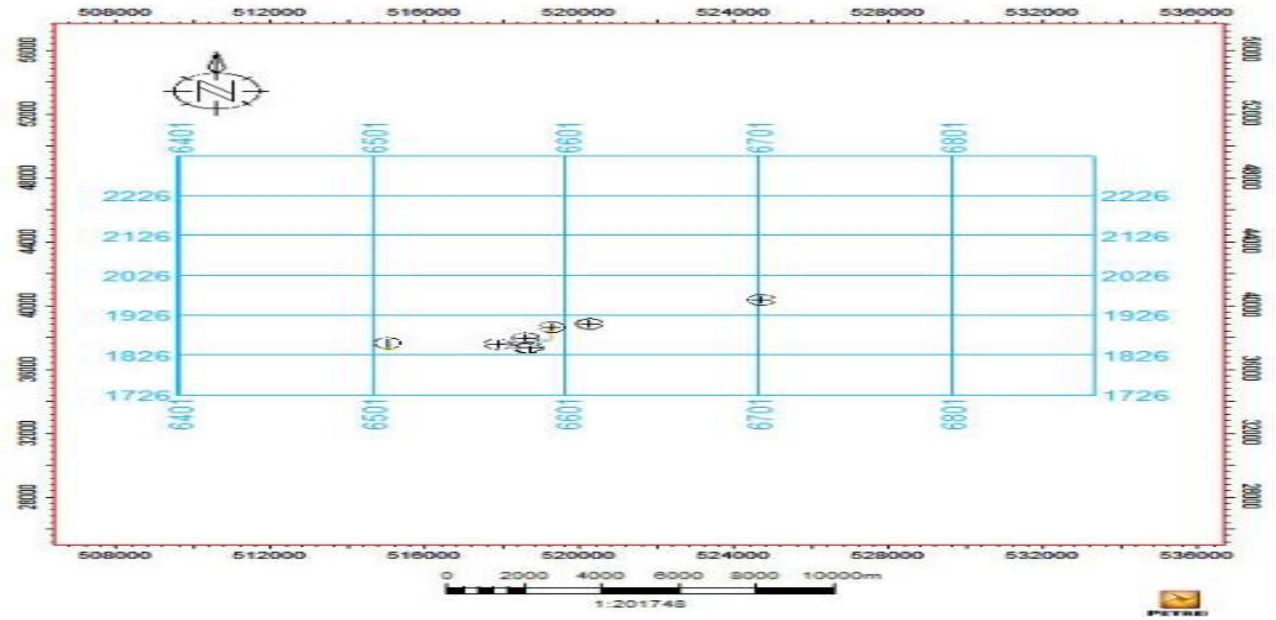

Figure 1: Base map of the study location

Materials and Methods

Data Gathering

This study utilized various forms of data crucial for analyzing the hydrocarbon prospects of the XYZ field in the Niger Delta. Key datasets include:

3D seismic data: A pre-stack 3D volume, depth-migrated, covering an area of 354 square kilometres, aiding in structural interpretation and reservoir delineation.

Well Logs: Composite well logs that include resistivity gamma ray neutron density and sonic logs offering information on fluid content lithology and petrophysical characteristics.

Additional Logs: These include resistivity logs sonic logs neutron-density logs gamma-ray logs and well deviation surveys which provide comprehensive details on reservoir properties and well pathways.

Software Tools: The software tools that were used were Microsoft Excel for data analysis and visualization and Schlumberger Petrel 2016 for data management.

Methodology

The research workflow was meticulously designed to ensure comprehensive analysis. The steps are as follows:

Data Preparation and Quality Control: Imported well headers, deviation surveys, and log data into petrel, conducted comprehensive data quality assessment, performed data normalization and error checking, Verified coordinate systems and datum corrections

Seismic Data Processing: Applied noise reduction techniques, performed seismic trace editing, conducted amplitude preservation processing, Generated variance time slices for improved structural interpretation, Seismic-Well Integration:

Performed detailed seismic-to-well tie analysis, used synthetic seismogram generation, calibrated seismic data with well log information, Established robust correlation between seismic and well data

Structural Interpretation: Mapped structural and stratigraphic features, Identified and characterized fault systems,Generated horizon maps, Created time surface representations of reservoir boundaries

Time-Depth Conversion

Developed velocity models using: Sonic log information, Seismic interval velocity analysis, Applied standard time-to-depth conversion techniques, Incorporated iterative refinement to minimize conversion errors

Seismic Attribute Analysis:

Extracted and analyzed multiple seismic attributes: Focused on: Amplitude variations, Frequency characteristics

Phase coherence, Instantaneous attributes

Petrophysical Evaluation: Calculated reservoir properties using standard empirical relationships

Determined: Total porosity, Effective porosity, Permeability, Net-to-gross ratio, Volume of shale, Water saturation

Hydrocarbon Volume Estimation:

Applied probabilistic volumetric calculations: Using statistical methods to estimate the range of possible hydrocarbon volumes. Incorporated uncertainty analysis: Evaluating the uncertainties in reservoir parameters like area, thickness, porosity, and recovery factor.

Utilized Monte Carlo simulation techniques for robust volume estimation: For robust volume estimation, multiple iterations were run to account for variability in the input parameters, Data Validation and Uncertainty Assessment, Implemented cross-validation techniques, Conducted sensitivity analyses, Evaluated potential sources of interpretation uncertainty

Applied statistical methods to quantify interpretation reliability

This methodology ensures a rigorous and systematic approach to hydrocarbon prospect evaluation in the XYZ field, leveraging advanced geophysical interpretation techniques and state-of-the-art software tools.

Results and Interpretation

Well Correlation

From the logs provided, two reservoirs of interest were picked and the reservoir sands were correlated across the seven available wells (Figure 2). These reservoir sands were correlated considering the gamma-ray logs and resistivity because gamma-ray logs deal with natural radioactivity so, it can determine where there is shale and sand. The resistivity log helps in identifying the fluid content in the geologic formation.

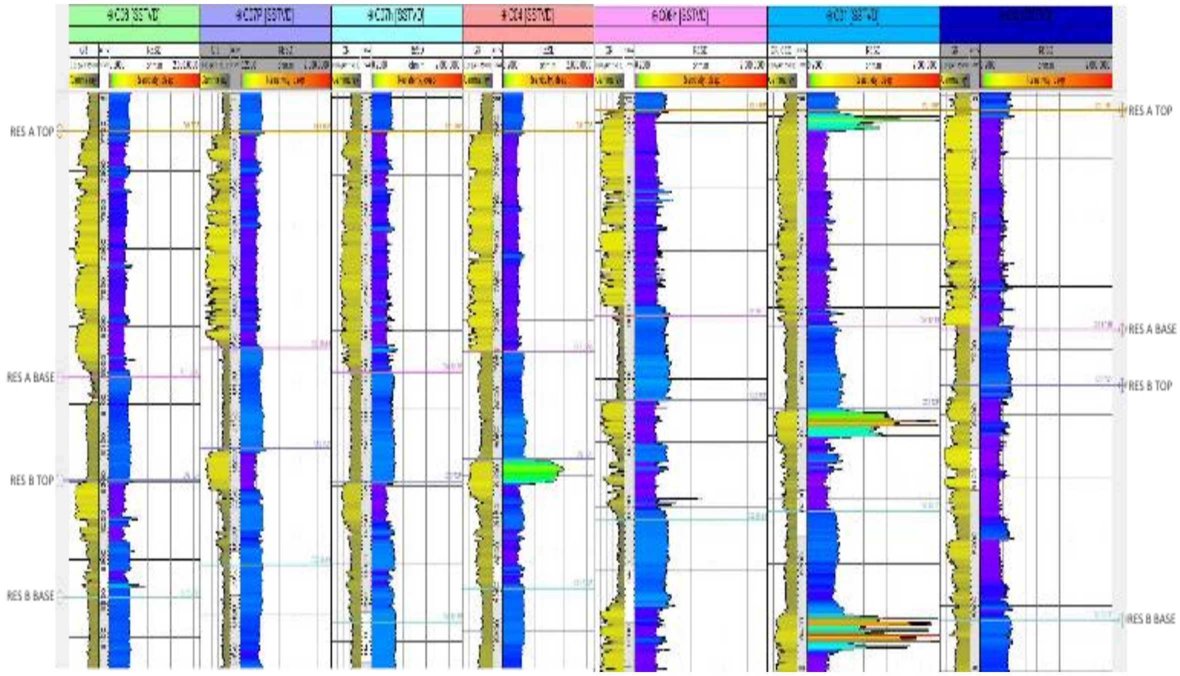

Figure 2: Well correlation across seven wells.

Petrophysical Evaluation

From the log (Figure 3), the average thickness of reservoir A is 324.07ft which is very thick enough to accumulate a large volume of HC. The average total porosity is 0.34 while the porosity that is effective for the reservoir is 0.29 and this is said to be a good porosity for HC. The average Sw, NTG & shale volumes are 0.77, 0.78 and 0.63 respectively. The permeability of reservoir A is 1887mD. (Table 1) shows a detailed explanation of the values of petrophysical parameters for reservoir A. In reservoir B, the log explained that the average reservoir thickness is 210.34ft and it is considered thick enough to host Hydrocarbon. Poro T is 0.32 while the Poro E that can allow the flow of HC is 0.27. the permeability for this reservoir is 1531.11mD and this is said to be a good permeability for easy transmissivity of fluid. The average Sw for reservoir B is 0.69, Vsh is 0.56 and NTG is 0.71 accordingly. (Table 2) A plot of averaged petrophysical parameters was plotted for reservoirs A and B (Figure 4) and also plotted for averaged permeability for reservoirs A and B (Figure 5). Then a comparison was made for all the petrophysical parameters for reservoirs A and B as seen in Figures 6 and 7 respectively.

Figure 3: Cross section of Petrophysics

Table 1: Results of Petrophysics for Reservoir A

WELL NAME	TOP (ft)	BASE (ft)	THICKNESS	PORO T	PORO E	PERM (mD)	Sw	VSH	NTG
C01	7653.2	7895.12	241.92	0.25	0.21	1896	0.65	0.21	0.74
C02	7896.22	8236.23	340.01	0.39	0.31	2354	0.57	0.65	0.62
C04	8326.59	8659.24	332.65	0.37	0.29	1563	0.98	0.87	0.86
C06	7966.65	8206.11	239.46	0.29	0.26	1850	0.87	0.52	0.69
C07	8568.21	8965.47	397.26	0.36	0.34	1692	0.91	0.69	0.85
C08	7539.51	7932.64	393.13	0.35	0.31	1965	0.64	0.83	0.88
AVERAGE			324.07	0.34	0.29	1887	0.77	0.63	0.78

Table 2: Results of Petrophysics for Reservoir B

WELL NAME	TOP (ft)	BASE (ft)	THICKNESS	PORO T	PORO E	PERM (mD)	Sw	VSH	NTG
C01	8136.32	8308.34	172.02	0.39	0.32	1689.21	0.58	0.32	0.68
C02	8156.76	8369.06	212.3	0.26	0.21	1895.33	0.67	0.56	0.85
C04	8479.65	8643.45	163.8	0.34	0.3	1624.03	0.72	0.38	0.63
C06	9289.99	9468.33	178.34	0.23	0.19	1382.51	0.61	0.68	0.59
C07	8639.2	8895.77	256.57	0.39	0.34	1012.35	0.87	0.81	0.73
C08	9011.32	9288.39	277.07	0.28	0.23	1583.2	0.67	0.63	0.78
AVERAGE			210.34	0.32	0.27	1531.11	0.69	0.56	0.71

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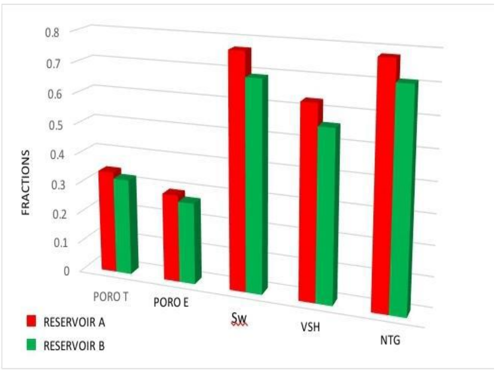


Figure 4: Plot of averaged petrophysical parameters for the two reservoirs

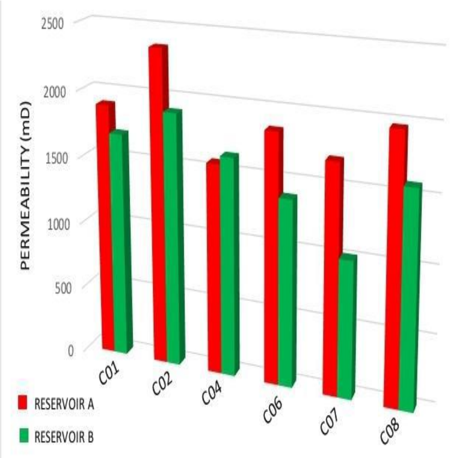


Figure 5: Plot of averaged permeability for the two reservoirs

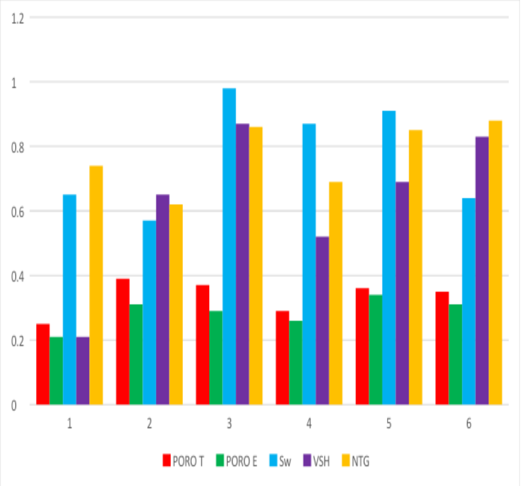


Figure 6: Compared petrophysical properties for reservoir A

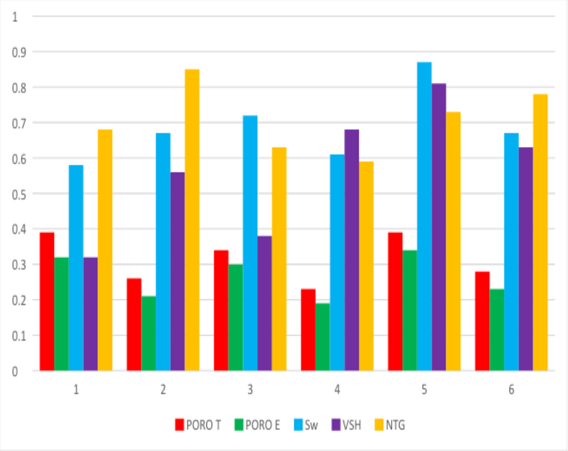


Figure 7: Compared petrophysical properties for reservoir B

Result of Volume Calculations

Table 3 gives detailed information on the volume of Hydrocarbons that is calculated with the Petrel software. For reservoir A, the volume of HC is 240 million Stock Tank barrels while for reservoir B, we have 470 million Stock Tank barrels. From the results, we advise that the well should be developed going on the volume of Hydrocarbon calculated, we were able to get a good reservoir that is economically viable can recover the cost incurred and also generate profit.

Table 3: Volumetric Calculation

PETROPHYSICAL PARAMETERS	RESERVOIR A	RESERVOIR B
RESERVOIR THICKNESS (ft)	324.07	210.34
POROSITY$_{effective}$	0.29	0.27
WATER SATURATION	0.77	0.69
NET-TO-GROSS	0.78	0.71
PORE VOLUME (10^6 RB)	956	1370
BULK VOLUME (10^6 ft^3)	18716	37689
NET VOLUME (10^6 ft^3)	16862	29861
OIL FVF Bo (RB/STB)	1.5	1.5
RECOVERY FACTOR OIL	1	1
STOIIP (10^6 STB)	240	470
RECOVERABLE OIL (10^6 STB)	240	470

Results of Seismic Interpretation

Fault Interpretations

Faults were interpreted across the entire seismic inline with a 10-spacing increment. Initial identification was conducted using the variance time slice (Figure 8). The analysis revealed synthetic and antithetic faults, alongside a major growth fault trending southwest to northeast (Figure 9). These interpreted faults are also displayed on a variance time slice (Figure 10).

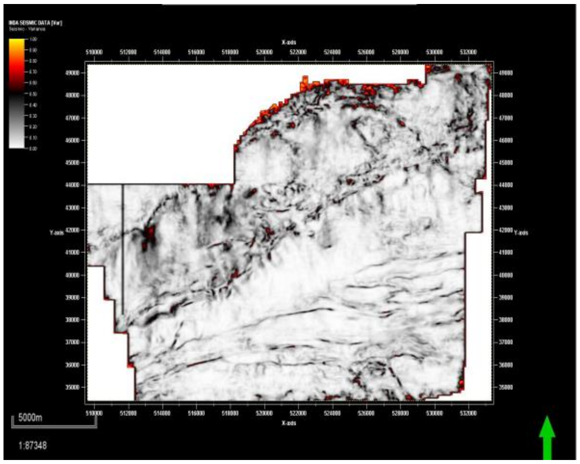


Figure 8: Variance time slice on the 2D window displaying the faults clearly

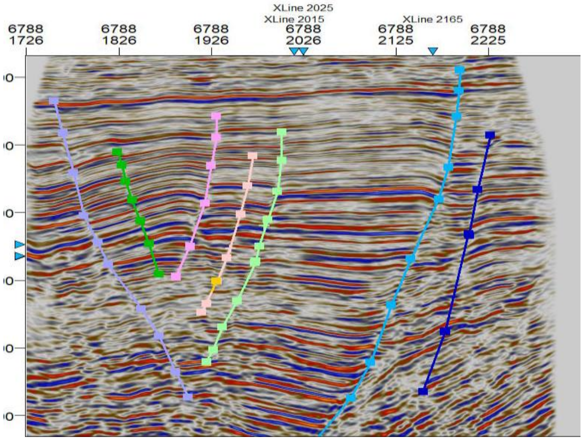


Figure 9: Interpreted Faults in the seismic section

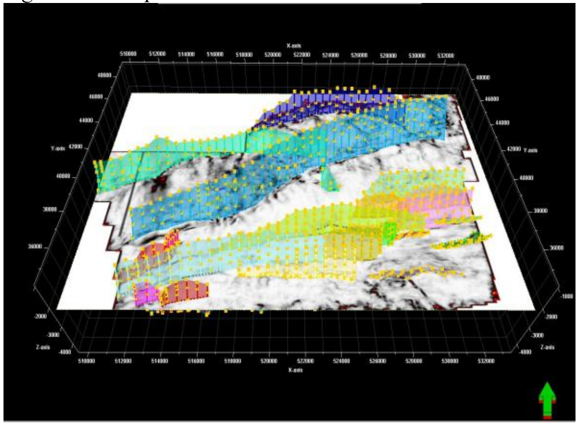


Figure 10: Interpreted faults on variance time slice

Seismic Horizon

Reservoir tops were mapped according to horizon mapping rules, starting from the middle and extending to the edges. This process, conducted in 10-spacing increments, produced a time seed grid (Figures 11 and 12) which was auto-tracked to fill unmapped points (Figures 13 and 14).

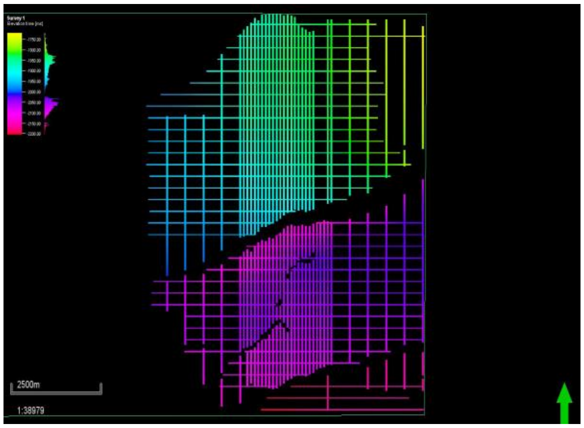


Figure 11: Seed grid for Reservoir A

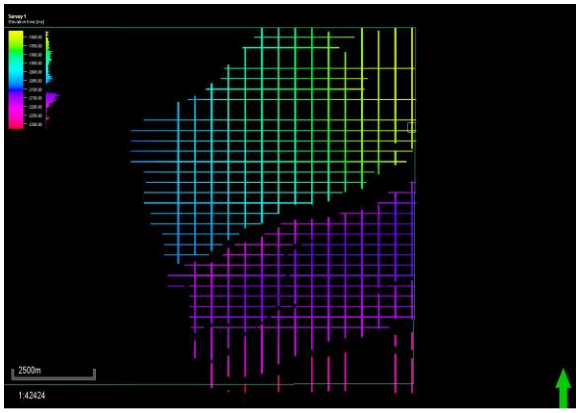


Figure 12: Seed grid for reservoir B

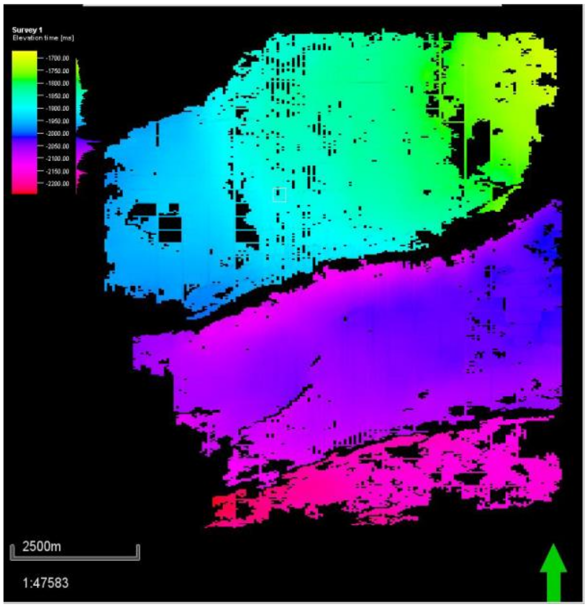


Figure 13: Auto tracked seed grid for reservoir A

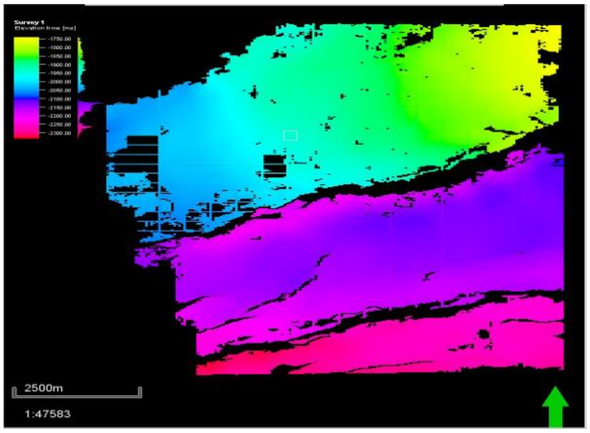


Figure 14: Auto-tracked seed grid for reservoir B

Time Surface Maps

The auto-tracked seed grids were used to generate time surface maps, which depict the reservoir tops during seismic data acquisition. Fault polygons from the fault interpretation were also included to show fault locations on these maps (Figures 15 and 16).

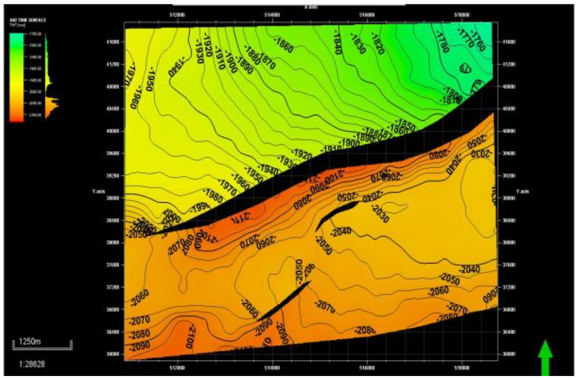


Figure 15: Time surface map for reservoir A

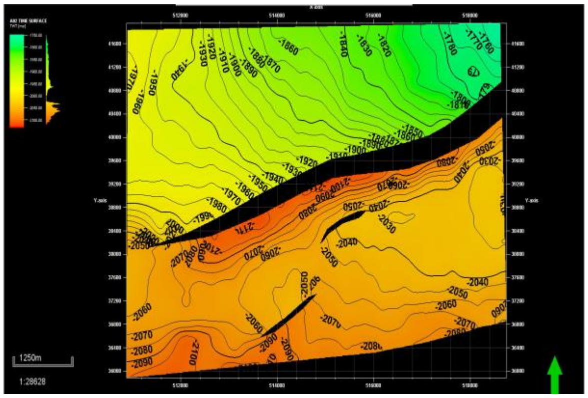


Figure 16: Time surface map for reservoir B

Velocity Model

A model was developed to convert the time surface map to a depth surface map using a third-order non-linear polynomial function, producing a straight-line curve (Figure 17).

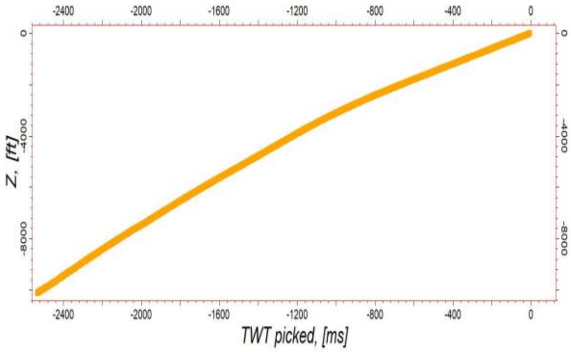


Figure 17: Plot of Z (ft) against TWT (ms)

Depth Surface Map

The depth surface map represents the true elevation of reservoir tops. Generated using the velocity model and time surface map, these maps confirm the accuracy of the velocity model, showing depth ranges for reservoir sand A (-5643 ft to -7895 ft) and B (-63742 ft to -8769 ft) (Figures 18 and 19).

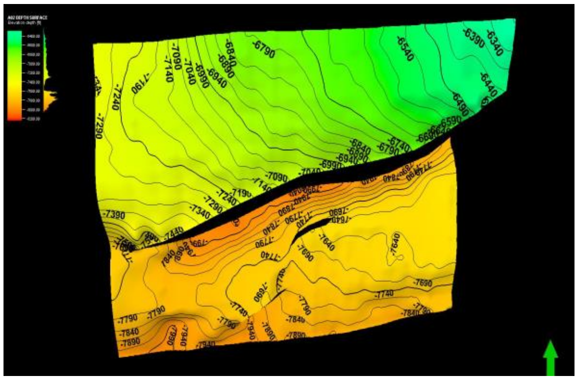


Figure 18: Reservoir A depth-surface map

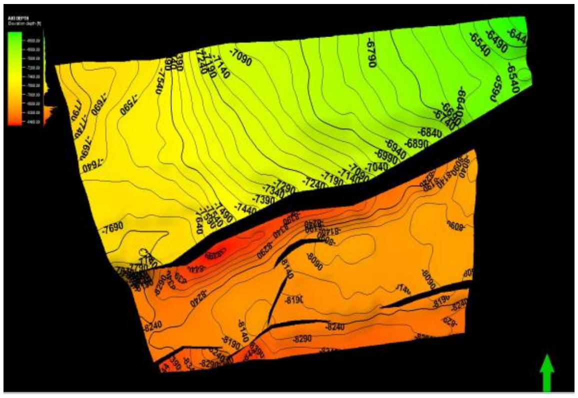


Figure 19: Reservoir B depth-surface map

Seismic Attributes

Various attributes were analyzed as indicators for hydrocarbon (HC) accumulation in the XYZ field, including maximum amplitude, average energy, average envelope, mean amplitude, and root mean square (RMS) amplitude. High RMS amplitude values, coupled with low acoustic impedance, were interpreted as indicators of hydrocarbon-saturated sands. These were further validated by well log data showing high porosity above 20% and permeability (>150 mD) (Figures 20 and 21). RMS amplitude, showing high-amplitude anomalies, effectively indicates HC presence, while blue and purple colours suggest little or no HC. The average envelope (Figures 22 and 23) corroborates RMS amplitude findings. Although average energy (Figures 24 and 25) is not a direct HC indicator, it complements other attributes. Mean amplitude inversely validates previous results, showing HC accumulation in blue to purple zones (Figures 26 and 27).

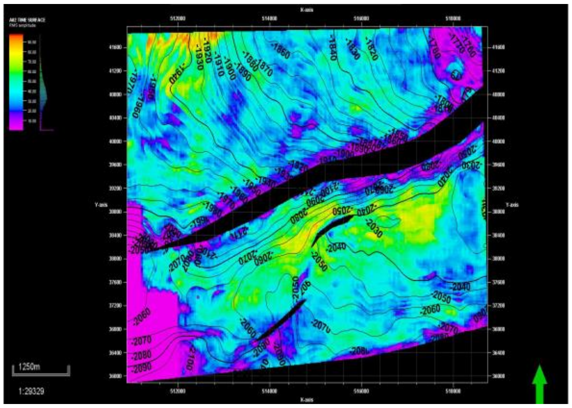


Figure 20: Reservoir A RMS Amplitude

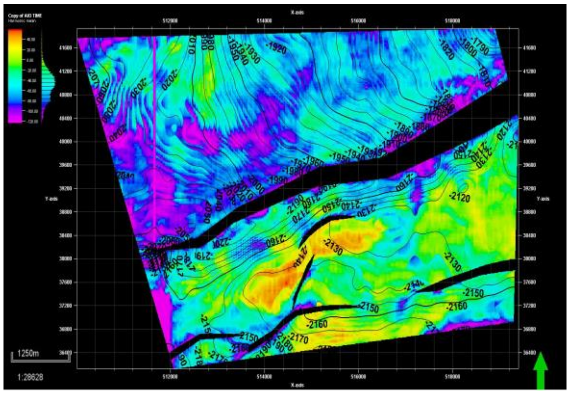


Figure 21: Reservoir B RMS Amplitude

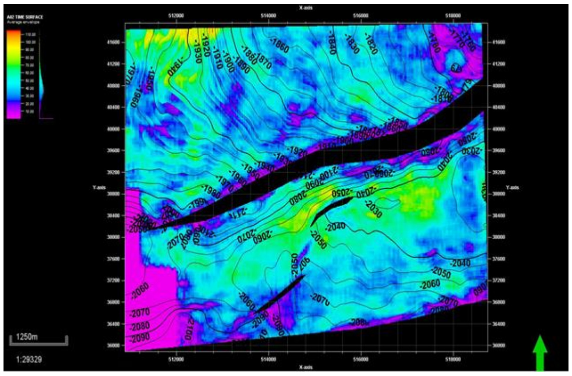


Figure 22: Average Envelop for Reservoir

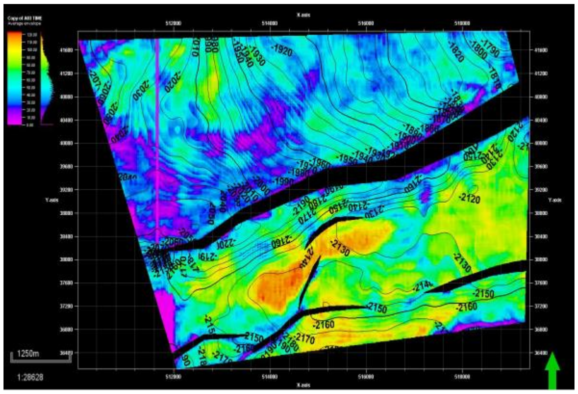


Figure 23: Average Envelop for Reservoir B

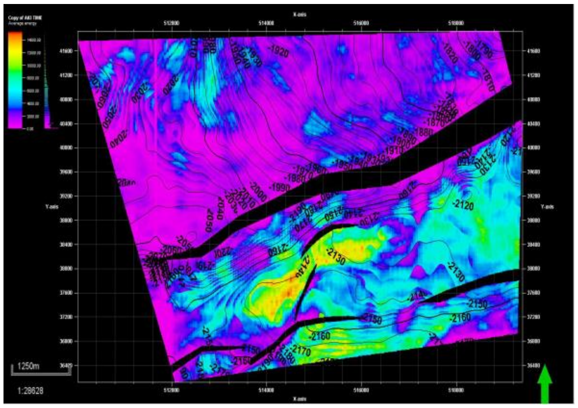


Figure 24: Average Energy for Reservoir A

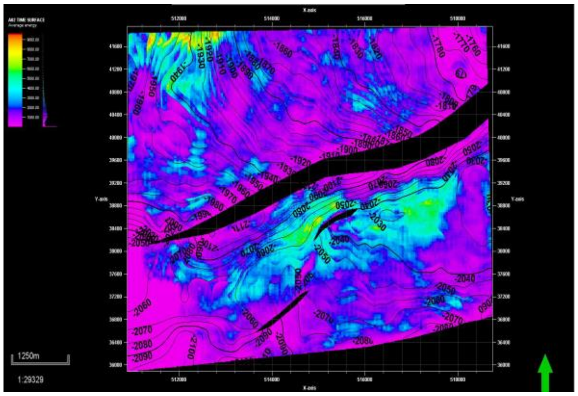


Figure 25: Average Energy for Reservoir B

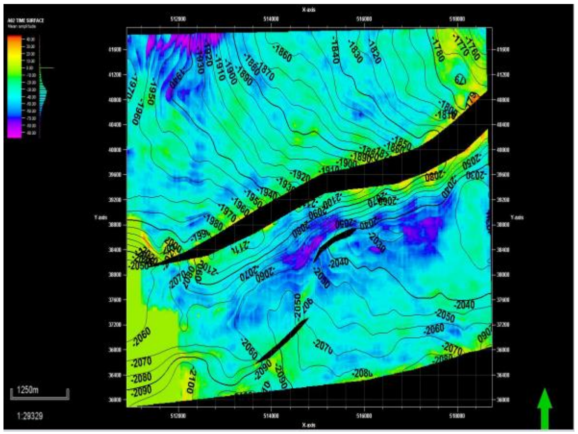
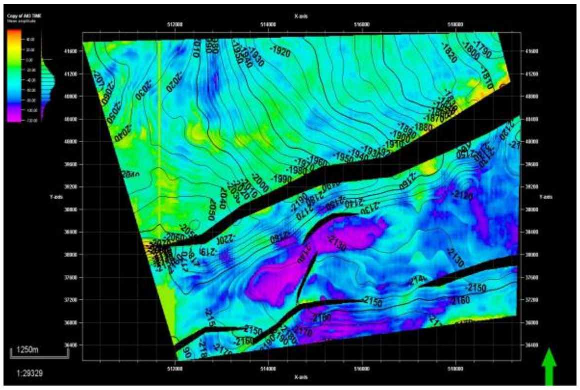


Figure 26: Mean Amplitude for Reservoir A



Prospect Evaluation

Comparing all seismic attributes, RMS amplitude is the most reliable for direct HC indication. Other attributes support RMS findings. High RMS amplitude values specifically indicated hydrocarbon-bearing zones due to their correlation with high porosity and permeability in well log data. Areas marked 'K' indicate prospects, while 'A' denotes leads requiring further study. The structural pattern, with the major fault enclosing HC, confirms the prospect areas (Figures 28 and 29).

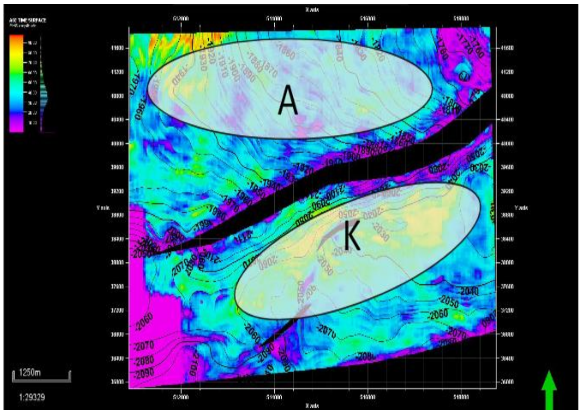


Figure 27: Mean Amplitude for Reservoir B

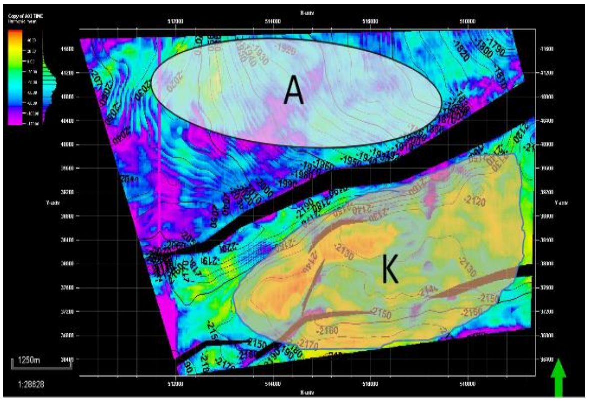


Figure 28: Prospect and lead for Reservoir A

Discussion

This study was carried out at the XYZ field, located in the onshore area of the Niger Delta, to evaluate hydrocarbon exploration and production prospects. The primary method for assessing the subsurface and defining favorable zones for hydrocarbon trapping was seismic attribute analysis (SA). The subsurface stratigraphic variations fluid content and reservoir characteristics were highlighted by seismic characteristics like RMS amplitude frequency and phase. The inclusion of petrophysical evaluation and SA analysis for the XYZ field illustrates the importance of sophisticated geophysical methods in hydrocarbon exploration. For instance, because of its sensitivity to changes in rock and fluid characteristics RMS amplitude—a seismic attribute that represents the root-mean-square of amplitudes—is especially useful in locating reservoirs that are filled with fluid. This method enhances subsurface interpretation and facilitates field development and resource utilization decision-making. Furthermore the study highlights the relevance of synthetic and antithetic faults which play a critical role in forming structural traps that enhance hydrocarbon accumulation.

Seismic Interpretation and Fault Analysis:

In this study seismic attribute analysis was crucial to identifying the presence of hydrocarbons in the XYZ field. Several seismic sections were examined for characteristics like mean amplitude average envelope average energy and RMS amplitude. RMS amplitude which identified areas with high hydrocarbon prospects produced the most encouraging results out of all of these. An important indicator of fluid-filled reservoirs is RMS amplitude which quantifies the energy of seismic reflections. These seismic characteristics were correlated with petrophysical data to provide a comprehensive understanding of the subsurface. As a result geological features like synthetic and antithetic faults which produce structural traps and fluid migration pathways essential for the accumulation of hydrocarbons could be identified. According to the analysis SA is a crucial tool for identifying hydrocarbon reservoirs and directing exploration tactics.

Petrophysical Evaluation: The distribution of the reservoirs properties such as porosity permeability net-to-gross ratio and water saturation was made possible by the petrophysical analysis. With an effective porosity of 0. 29 an average permeability of 1887 mD and an average thickness of 324. 07 feet reservoir A showed promise for a hydrocarbon trap. Similar to this Reservoir Bs average thickness was 210–34 feet its effective porosity was 0–27 and its permeability was 1531–11 mD. . These petrophysical characteristics indicate that both reservoirs offer an ideal environment for the transportation and storage of hydrocarbons.

Seismic Attribute Analysis: The RMS amplitude, average envelope, average energy, and mean amplitude of different seismic sections were critical in recognizing the presence of hydrocarbons. RMS amplitude gave the most promising results and the area of interest, with high hydrocarbon prospects. By correlating these attributes with petrophysical data, a thorough study of the subsurface was achieved thereby proving the identified hydrocarbon prospects.

Hydrocarbon Volume Estimation: The subsequent volumetric calculations provided large hydrocarbon volume indications for both reservoirs. Volumetric estimations were calculated using the formula:

Volume = Area×Thickness×Porosity×Recovery Factor

with a porosity assumption of 29% for Reservoir A and 27% for Reservoir B, and a recovery factor of 30%. Reservoir A indicated over 240 million STB (Stock Tank Barrels) and Reservoir B 470 million STB. Such absolutes should add credence to the feasibility of developing these reservoirs as well as encourage additional investment and drilling practices.

Hydrocarbon Potential: The RMS amplitude of seismic attributes helped establish close linkages (letter 'K' on figures) between structural characteristics and probable places for HC prospects due to their inherent seismic properties. Objects in concern were defined and labeled as 'A' leads that indicated to need for more inputs.

Conclusion

This study has demonstrated the profound significance of integrating seismic attribute analysis into hydrocarbon exploration workflows, particularly in geologically complex regions like the Niger Delta. By systematically examining and correlating various seismic attributes, including RMS amplitude, frequency, and phase, with detailed petrophysical data, the research team has been able to delineate hydrocarbon reservoirs with a high degree of confidence. The findings underscore the critical role that structural features, such as synthetic and antithetic faults, play in hydrocarbon migration and trapping. The studys fault-bounded closures turned out to be perfect places for hydrocarbon accumulation highlighting how crucial it is to include reliable structural interpretations in the exploration process. The petroleum industry as a whole will be significantly impacted by these findings. The techniques used in this study can be used as a model for exploration efforts in other sedimentary basins with fault-block dominance around the world. Even in geologically challenging environments geoscientists can now more successfully identify and assess hydrocarbon prospects by utilizing the power of seismic attribute analysis. Additionally a thorough and open method of resource evaluation is offered by the probabilistic volumetric estimation approach which incorporates uncertainty analysis and Monte Carlo simulations. This method aids in more accurately estimating the risks and unknowns related to hydrocarbon accumulations which results in better decision-making for exploration appraisal and development operations. Looking ahead there are intriguing chances to improve this methodologys predictive power even more. By incorporating machine learning algorithms into the seismic attribute analysis workflow it may be possible to more accurately delineate complex reservoir geometries and enhance the detection of subtle hydrocarbon indicators. Time-lapse monitoring and the continuous development of 4D seismic techniques may also provide important new information about the dynamic behavior of hydrocarbon systems inside fault-controlled traps. Finally by showcasing the revolutionary potential of seismic attribute analysis in hydrocarbon exploration this study has significantly advanced the field of petroleum geoscience. The results offer a solid framework for revealing fault-block reservoirs untapped potential enabling geoscientists to make better decisions and eventually improve the recovery of priceless energy resources for the good of society.

Conflict of Interest: The authors declare no conflict of interest.

References

Adeoti, L., Adesanya, O.Y., Oyedele, K.F., Afinotan, I.P. and Adekanle, A. (2017). Lithology and fluid prediction from simultaneous seismic inversion over Sandfish field, Niger Delta, Nigeria. Geosci J 22(1):155–169. https://doi.org/10.1007/s12303-017-0018-4

Adetokunbo, P., Al-Shuhail, A.A., and Al-Dossary, S. (2016). 3D seismic edge detection using magic squares and cubes. Interpretation, 4(3), T271--T280.

Adiela, U.P., and Samuel, O. (2019). Petrophysical and Hydrocarbon Explorative Studies - A case study of Niger Delta Well, Nigeria. Research Gate, 8. 1111-1117.

Allstair, R.B. (2011). Interpretation of 3D seismic data. AAPG Mem, 42, 294–298.

Anstey, (2005). Attributes in color: the early years: Canadian Society of Exploration Geophysicists Recorder, 30, March, 12–15.

Anstey, N.A., and Anstey, N.A. (1980). Seismic exploration for sandstone reservoirs. Springer.

Anstey, N.A. (1973). The significance of color displays in the direct detection of hydrocarbons: 43rd Ann. Int Mtg Soc Expl. Geophys.

Avseth, P., Mukerji, T., and Mavko, G. (2010). Quantitative seismic interpretation: Applying the principles. Cambridge University Press.

Balch, A.H., (1971) Color Sonograms: A New dimension in Seismic data interpretation: Geophysics, 36, 1074-1098.

Barry, K.M., Shugart, T.R., (1974). Seismic hydrocarbon-indicators and models. The Sixth Annual Offshore Technology Conference, Dallas-Texas, May 6-8, 1974, v. 1, p. 659-672. https://doi.org/10.4043/2003-MS

Barnes, A.E., (2001). Seismic attributes in your facies: Canadian Society of Exploration Geophysicists Recorder. September 26:41–47

Brown, A.R. (2001). Understanding seismic attributes. Geophysics, 66, 47-48. https://doi.org/10.1190/1.1444919

Carrillat, A., T. Randen, and L. Sonneland, (2002). Seismic stratigraphic mapping of carbonate mounds using 3-D texture attributes: 64th Annual International Meeting, European Association of Geoscientists and Engineers, Z-99.

Duncan, W., P. Constance, and K.J. Marfurt, (2002). Comparison of 3-D edge detection seismic attributes to Vinton Dome, Louisiana: 72nd Annual International Meeting, SEG, Expanded Abstracts, 577–580.

Ebrom, D., (2004). The low-frequency gas shadow on seismic sections: The Leading Edge, 23, 772.

Ekweozor, C.M., and Daukoru, E.M. (1994). Northern delta depobelt portion of the Akata–Agbada petroleum system, Niger Delta, Nigeria. In L. B. Magoon & W. G. Dow (Eds.), The petroleum system—from source to trap (pp. 599–613). American Association of Petroleum Geologists Memoir 60.

Evamy, B. D., Haremboure, J., Kamerling, P., Knaap, W. A., Molloy, F. A., and Rowlands, P. H., 1978. "Hydrocarbon habitat of Tertiary Niger Delta". AAPG Bulletin. 62: 277-298.

Farfour, M., Foster, D., (2020). New AVO expression and classification using pseudo-Poisson reflectivity. SEG Technical Program Expanded Abstracts. https://doi.org/10.1190/segam2020-3425356.1

Fatti, J.L., Smith, G.C., Vail, P.J., Strauss, P.J., Levitt, P. R., (1994). Detection of gas in sandstone reservoirs using AVO analysis: A 3-D seismic case history using the Geostack technique. Geophysics 59:1362–1376

McQuillin, R., Bacon, M., and Barclay, W. (1984). Geophysical exploration for the petroleum industry. John Wiley & Sons.

Robertson, J.D., and Nogami, H.H., (1984). Complex seismic trace analysis of thin beds: Geophysics, 49, 344-352

Rubino, J.G., Velis, D.R., and Holliger, K., (2012). Permeability effects on the seismic response of gas reservoirs. Geophys J Int 189(2012):448–468. https://doi.org/10.1111/j.1365-246X.2011.05322.x

Rummerfeld, B., (1954). Reflection quality, a fourth dimension: Geophysics, 19, 684–694.

Russell, B.H, Lines L.R, and Hampson D.P (2003) Application of the radial basis function neural network to the prediction of log properties from seismic data. Explor Geophys 34(2):15–23. https ://doi.org/10.1071/EG030 15

Rutherford, S.R., and Williams, R.H., (1989). Amplitude-versus-offset variations in gas sands. Geophysics 54:680–688

Sheriff, R.E., (1974) Seismic detection of hydrocarbons—the underlying physical principles. The Sixth Annual Offshore Technology Conference, Dallas-Texas, May 6-8, 1974, v. 1, p. 637-650. https://doi.org/10.4043/2001-MS

Short, K.C. and Stauble, A.J. (1967). Outline Geology of the Niger Delta. AAPG Bull 51; 761-779.

Taner, M.T., Treitel, S., and Sheriff, R.E. (1994). Encyclopedia of geophysics. Elsevier.