PROSPECT IDENTIFICATION USING SEISMIC ATTRIBUTES FOR AN OFFSHORE NIGER DELTA BASIN X FIELD

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(Received 26th February 2025; revised 28th May 2025; accepted 05th June 2025)

Abstract. The offshore Niger Delta Basin "X" field presents significant opportunities for hydrocarbon prospecting; however, effective reservoir characterization remains challenging. This study addresses this challenge by employing a robust combination of seismic attributes, including amplitude, Root Mean Square (RMS) amplitude, variance edge, phase, frequency, and reflector continuity. Utilizing advanced seismic data processing and visualization techniques, the research aims to accurately map structural features, faults, horizons, and potential hydrocarbon traps within the "X" field. The integrated seismic attribute approach enables precise identification of prospective zones by enhancing fault delineation and improving reservoir characterization. The application of the structural smooth attribute significantly increases seismic resolution, allowing for the clear visualization of fault lines and reservoir boundaries, while the variance edge attribute proves instrumental in delineating fault trends and identifying potential trapping mechanisms. Additionally, the construction of 3D fault models using amplitude attributes enhances the interpretation of subsurface features, offering critical insights for targeted well placement. The results reveal two principal faults that align with the reservoir zones, indicating promising areas for detailed hydrocarbon exploration. The findings demonstrate that deploying a multi-attribute seismic analysis provides a cost-effective and reliable method for improving exploration accuracy, optimizing resource allocation, and supporting decision-making in offshore hydrocarbon development.
Keywords: *seismic attributes, reservoir characterization, fault mapping, hydrocarbon prospecting, offshore exploration*

Introduction

The oil and gas industry's search and exploration efforts have significantly grown due to the widespread demand for hydrocarbons since the 20th century. This has led to increased search for oil and gas deposits in reservoir rocks in a number of petroleum sedimentary basins and systems worldwide. Porosity, permeability, water saturation, thickness, and area extent are important considerations in determining the amount of hydrocarbons that can be produced in a reservoir, according to Chopra and Marfurt (2007). Geologists and geophysicists can now visualize seismic traces in terms of their distinct, measurable components, such as frequency, amplitude, velocity, etc., as a result of their seismic attributes. Because they are essential inputs for reservoir volumetric analysis, which determines the volume of hydrocarbons present, these parameters are significant. Because drilling is a highly capital-intensive endeavor, it is therefore vital to employ technologically and financially feasible approaches to investigate hydrocarbon potential zones through thorough geophysical surveys prior to the subsequent exploration via well drilling. Therefore, it is crucial to accurately and sufficiently classify a reservoir and identify the hydrocarbon present in order to prevent any loss or waste of resources. This will assist in determining the field's hydrocarbon potential. Seismic attribute-derived information can be used to obtain such geophysical information.

According to Taner (2001), seismic attributes are the components of the seismic data that are derived from the seismic data through measurement, computation, and other techniques. Seismic attributes can be broadly divided into two categories: geometric and physical. While dip, azimuth, and discontinuity are geometrical features, physical attributes are those that are directly related to lithology, wave propagation, and other parameters. The data's amplitude or Dip attribute matches the dip of the seismic events. Dip is helpful since it makes faults easier to spot. The azimuth of the seismic feature's maximum dip direction and the amplitude of the data on the azimuth attribute match. Seismic characteristics are essentially separated into time, amplitude, frequency and attenuation. The attenuation attributes are typically unknown, whereas the time-based measurement is related to the structure, the amplitude and frequency attributes are related to stratigraphy, and the reservoir characterization (Adizua and Lenyie, 2023; Tounkara et al., 2023; Ofuyah et al., 2015; Koson et al., 2013; Subrahmanyam and Rao, 2008; Radovich and Oliveros, 1998). Although pre-stacked data is utilized to determine stacking velocity, AVO (amplitude variation with offset), and other properties, measurements are often based on stacked or migrated data. Attributes make up an open set since there are numerous methods to organize data, and they are typically not independent due to the limited number of measurement types they are based on. By quantifying the amplitude and morphological features observed in the seismic data using a series of deterministic computer calculations, one of the objectives of seismic attributes is to somehow capture this expertise (Chopra and Marfurt, 2007). Because they correlate with a physical trait of interest, attributes are useful. The main benefit of attributes is that they can occasionally make it easier to discover characteristics, connections, and trends that might otherwise go unnoticed. A single trace, a volume, or various methods can be used to measure attributes.

In order to support prospect identification for reservoir characterization goals of the offshore Niger Delta Basin "X" field, this study aims to determine the hydrocarbon prospect of an offshore "X" field using a unique set of seismic attributes mix, which includes amplitude, Root Mean Square (RMS) amplitude, variance edge, phase, frequency, and reflector continuity. The benefits of this attribute mix for locating potential zones during reservoir hydrocarbon characterization drives are demonstrated in this study. The goal of the study is to make these attribute mixes more widely known in the general geoscience community for reservoir characterization purposes.

Outline of the geological settings of the Niger delta basin

Sediments in the central part of the Niger Delta basin are known to reach a maximum thickness of 9000-12000 meters. The works of Edwards and Santogrossi (1990), Weber and Daukoru (1975), Weber (1971) as well as Short and Stauble (1967), provide a thorough explanation of the sedimentary facies units. The units are the continental environment, transitional environment, and marine environment, which are based on the predominant environmental influences. The Benin Formation, Agbada Formation, and Akata Formation are the three rock stratigraphic subdivisions. The Niger Delta basin's stratigraphic settings are depicted in *Figure 1*, with the Akata, Agbada, and Benin formations located from bottom to top, respectively.

eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v6i2.240

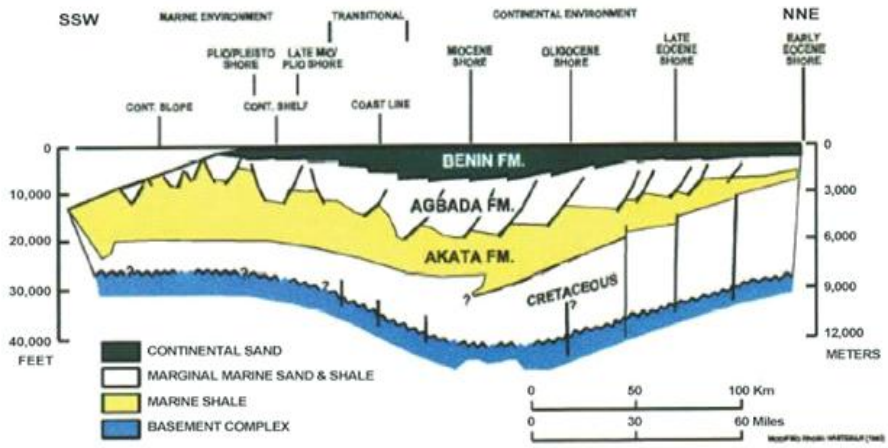

Figure 1. *Stratigraphy of the Niger Delta basin showing the three major stratigraphic units. Source: Weber and Daukoru (1975)*

The Akata Formation is about 3390 meters in total depth. Near the top, especially where it meets the Agbada Formation above, are thin sandstone lenses. This Eocene to Recent formation is thought to have been deposited in front of an advancing delta. The formation is usually over-pressured and lies beneath the entire delta. Particularly in the higher portion, the formation is composed of homogenous dark grey shale. In certain places, the higher portion, where it grades into the Agbada Formation above, is silty or sandy. Drilling activities have not penetrated the base of Akata as it is highly compacted and over pressured. The deltaic component of the sequence, which was deposited at the boundary between the lower deltaic plain and the marine of the continental shelf, is represented by the overlying Agbada Formation, a sequence of alternating sandstones and shale that is roughly 3700 meters thick. It is composed of a lower shale unit that is thicker than the top sandy unit and an upper, mostly sandy unit with some shale intercalation. In the Niger Delta Basin, the sands make up the primary reservoirs, while the shales serve as reservoir seals and are hence crucial. The Benin Formation consists of up to 2000 m thick continental alluvial and coastal plain sand deposits from the Eocene to the Recent Period. Although the Eocene to Recent is generally recognized, dating is difficult since the sediments comprise deposits from the upper deltaic plain and have no faunal material. With more than 90% sandstone, it has been referred to as the coastal plain sand. It is sub-angular to well-rounded, coarse-grained, gravelly, locally fine-grained, poorly sorted, and contains wood pieces and lignite streaks.

Materials and Methods

The data set used in the study included well head and deviation path data, well logs, check shot data, seismic data and visualization tools and software for data processing and analysis. The study employed the use of well and seismic data visualization tools to interpret the seismic data acquired from the offshore “X” field. The data were first quality checked to understand the units, the X and Y coordinates and the overall nature of the data, etc. The seismic data were imported into the software to produce variable inline and cross line sections of the seismic data showing different reflectors for which the seismic reflector attributes mix were then applied so that profound modeling of these structural features could be achieved with informed precision in line with their geophysical properties. The workflow for the study is described by *Figure 2*.

eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v6i2.240

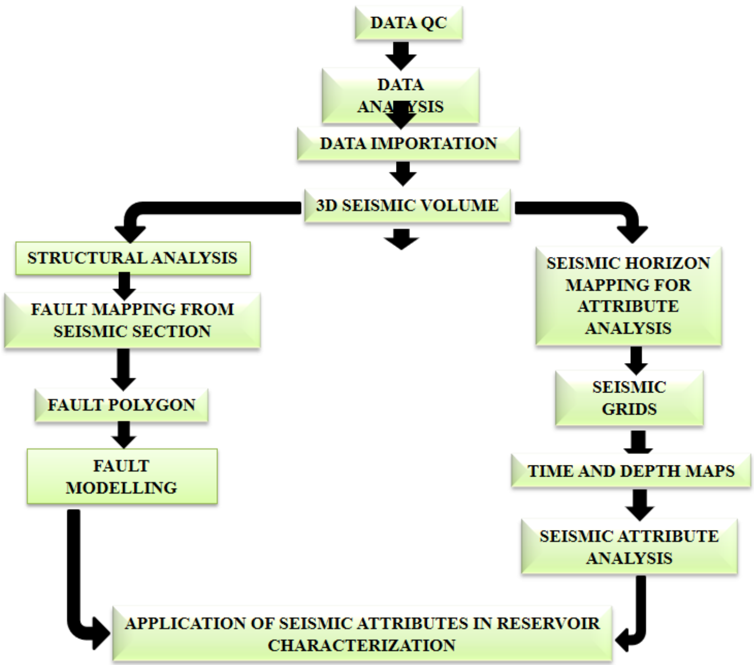

Figure 2. *A workflow showing the progressive steps taking in the interpretation processes and how it enhanced reservoir characterization in the offshore "X" field.*

Results and Discussion

Interpreted seismic section of the X field

Figure 3 shows a mapped seismic reservoir from top (A) to bottom (B) on inline 5982. The precision of the mapping was precise with the well control as physical parameters measured from both seismic data and well log data along that portion of seismic volume matched perfectly. Two faults on both sides of the well control are visible. Although, the fault to the left seem to be more pronounced than the one by the right side of the well control.

eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v6i2.240

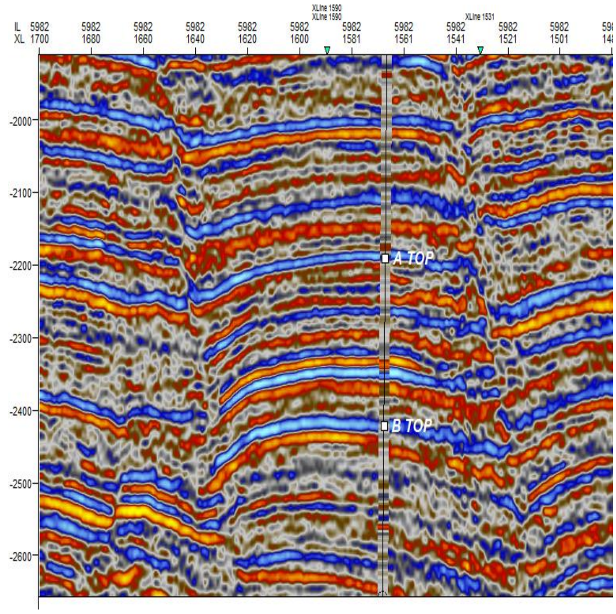

Figure 3. *Well tops of mapped reservoir A and B on Inline 5982 in the presence of well control to validate the mapping.*

Enhanced seismic resolution by application of the structural smooth attribute

Figure 4 shows the same mapped seismic inline 5982 in its original vintage form before attribute application (left panel) while the right panel shows the same seismic inline after application of structural smooth attribute (right panel). On careful examination of both panels, it is observed that the resolution of the seismic data has tremendously improved as features like faults became clearly defined and made very visible unlike in the original vintage form of the inline. Again, other hidden features associated with identifying prospective hydrocarbon bearing horizons and possible target reservoirs had better resolution and could be visibly seen. The structural smooth attribute has therefore aided in proper identification of structures such as fault and horizons and has also illuminated the potential hydrocarbon reservoirs.

eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v6i2.240

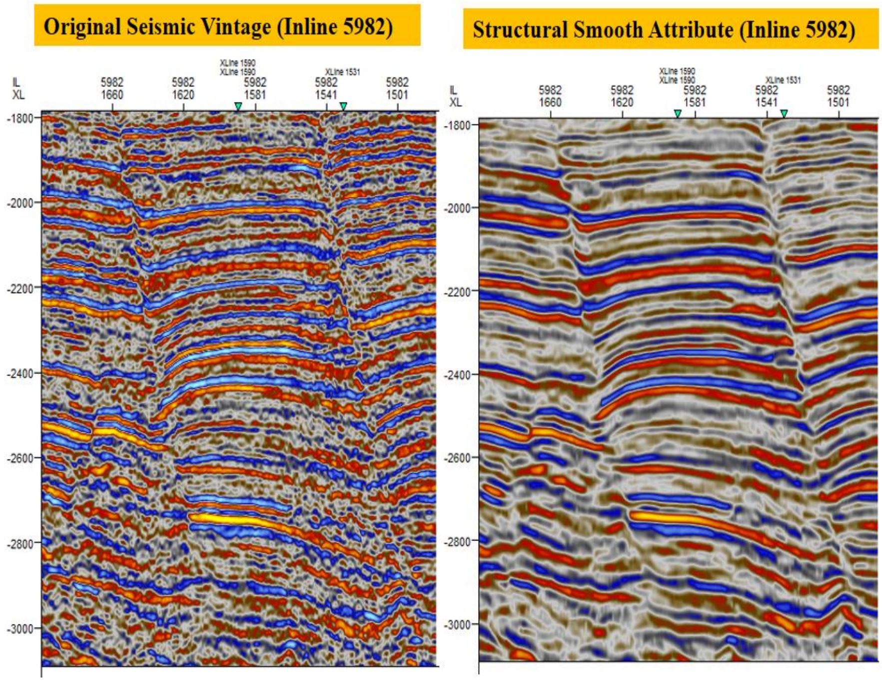

Figure 4. *Improved seismic resolution seen on structural smoothing attribute used for fault and horizon picking.*

Fault mapping from the structural smooth attribute seismically enhanced inline

Figure 5 shows the same imaged seismic inline 5982 in its structural smooth attribute seismically enhanced formed showing six (6) mapped faults (F1, F2, F3, F4, F5 and F6). The fault impressions were not clearly visible and their lateral extends couldn’t be ascertained on the vintage seismic panel. This clearly indicates that the structural smooth attribute in addition to improving seismic resolution also boosts the identification and interpretation of faults as has been demonstrated here.

eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v6i2.240

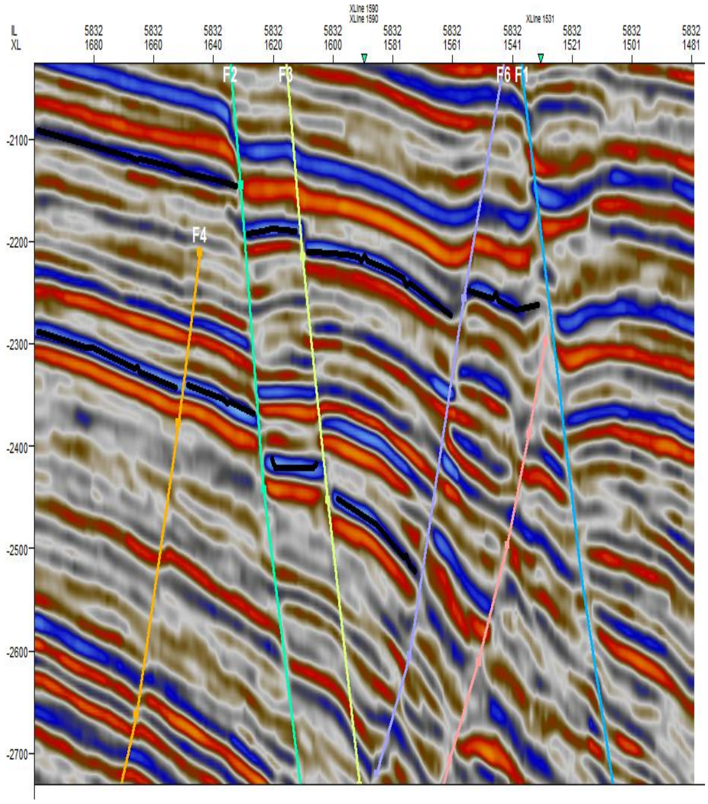

Figure 5. *Fault interpretation on structural smooth attribute on Inline 5832.*

Variance edge attribute application and analysis

The variance edge attribute was applied along a depth slice and it was useful in defining fault trends and structures. These faults were subsequently modeled along planes of their possible structural displacements as shown in *Figure 6*. These faults are conceived to be trapping mechanism for hydrocarbon pore fluids within the sandstone reservoirs in the offshore field. The Variance Edge Model for reservoir characterization is shown in *Figure 7*.

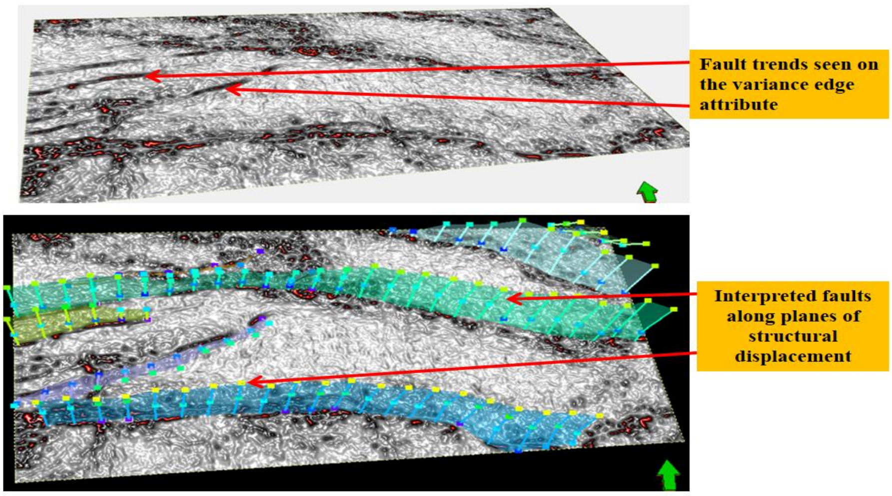

Figure 6. *Variance edge attribute along a depth (Z) line showing the fault traces as trapping mechanism for hydrocarbon pore fluids within the reservoir sand.*

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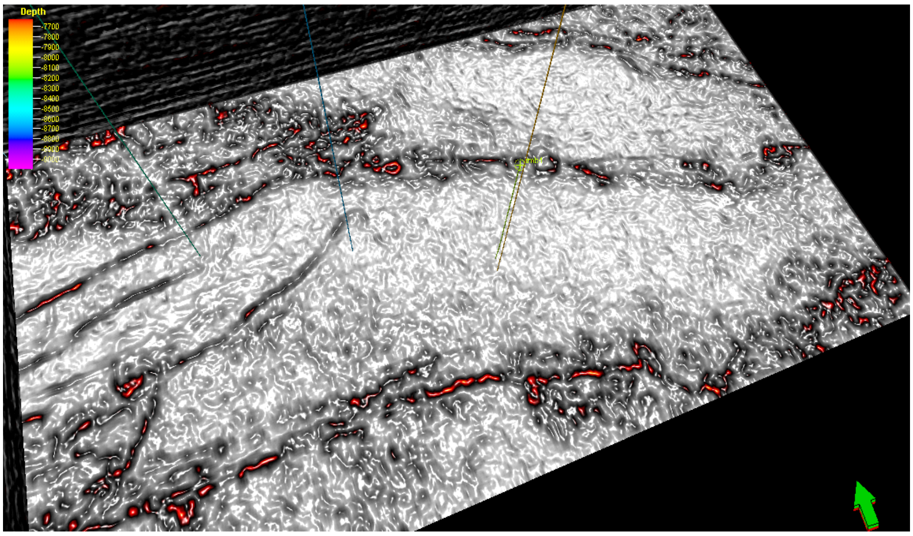

Figure 7. *Variance edge attribute model for reservoir characterization.*

Fault modeling to enhance prospect identification and characterization

Using our visualization tools, and guided by our results from the applications of the structural smooth and variance edge attributes, we built a 3D model of fault sticks formed from mapped structural faults along planes of weak bonding within the reservoir rocks as shown in *Figure 8*. This would enhance prospect identification and reservoir characterization goals of the field most especially as it pertains to the right placement of wells.

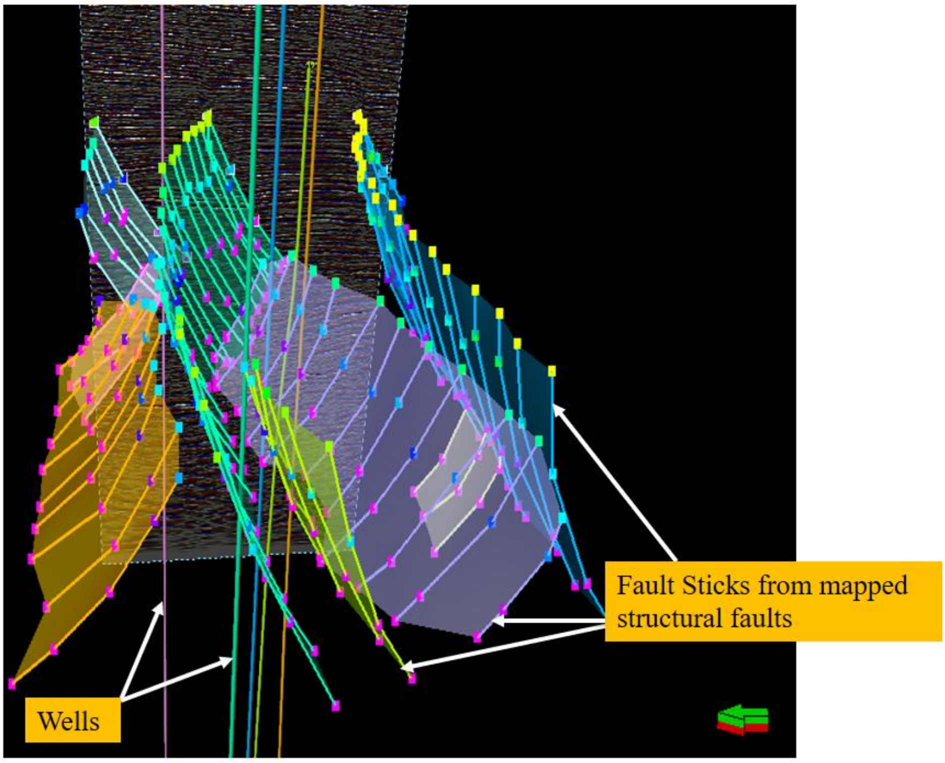

Figure 8. *A 3D model of fault sticks formed from mapped structural faults along planes of weak bonding within the reservoir rocks.*

eISSN: 2716-6341
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Seismic attribute analysis targeted at defining the nature of reflectors

Reflectors were grouped into two: (1) High continuity reflectors as shown in *Figure 9* which were most probably formed due to continuous strata deposited in widespread and uniform environments such as in marine conditions and settings.; (2) Low continuity reflectors as shown in *Figure 10* which were equally formed by sediments deposited with variable energy such as in fluvial settings by fluvial currents. Most of the identified high continuity reflectors were also of high amplitude contents as seen from *Figure 11*. These were majorly characterized by inter-bedded lithology with high and low energy and by extension a high impedance contrast. In the same vein, most low continuity reflectors were of low amplitude as seen *Figure 12*, formed most probably by disrupted depositions in low energy settings with typical low impedance contrast with adjoining beds. *Figure 13* gives a segregation of the frequency content of the reflectors, showing zones of high and low frequencies. *Figure 14* shows seismic attributes in Phase used for horizon interpretation on inline 5580 from the offshore "X" field.

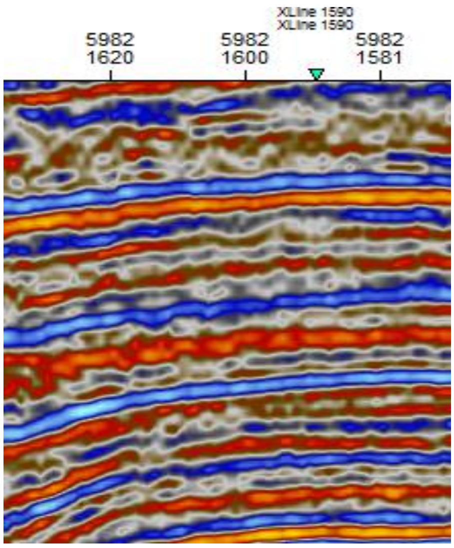

Figure 9. *High continuity reflectors formed due to continuous strata deposition in uniform environments such as in marine conditions and settings.*

eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v6i2.240

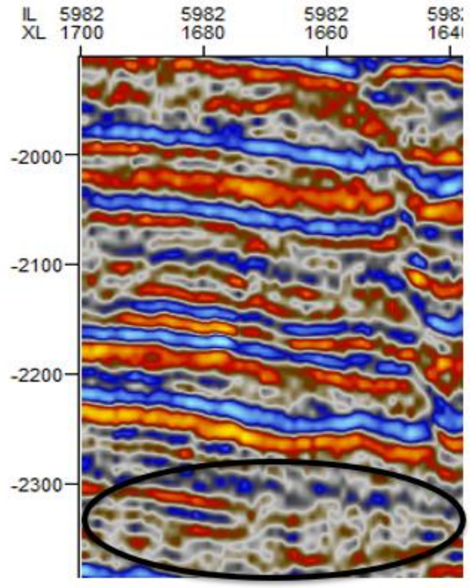

Figure 10. *Low continuity reflectors (in black embossed circle) formed due to sediment deposition with variable energy, for instance deposition associated with fluvial currents in fluvial settings.*

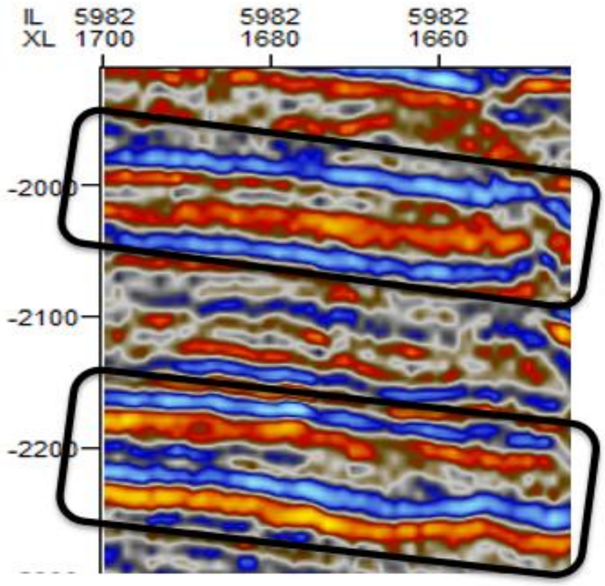

Figure 11. *High amplitude reflectors (in black embossed circle) formed due to inter-bedded lithology with high and low energy resulting in a high impedance contrast during interpretation.*

eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v6i2.240

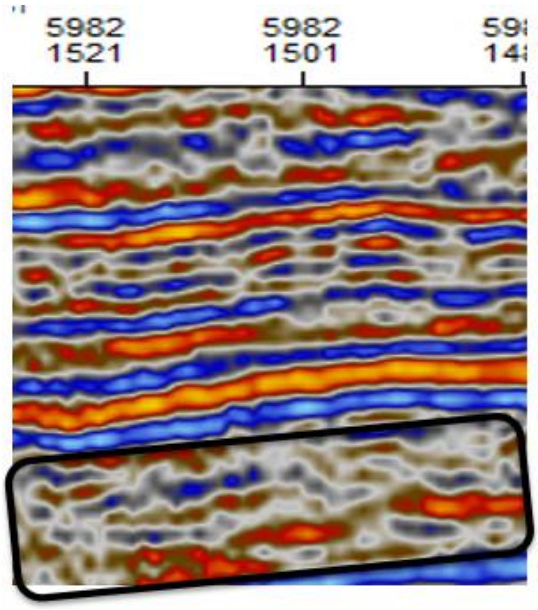

Figure 12. *Low amplitude reflectors (in black embossed circle) formed due to uniform lithology and energy, low impedance contrast.*

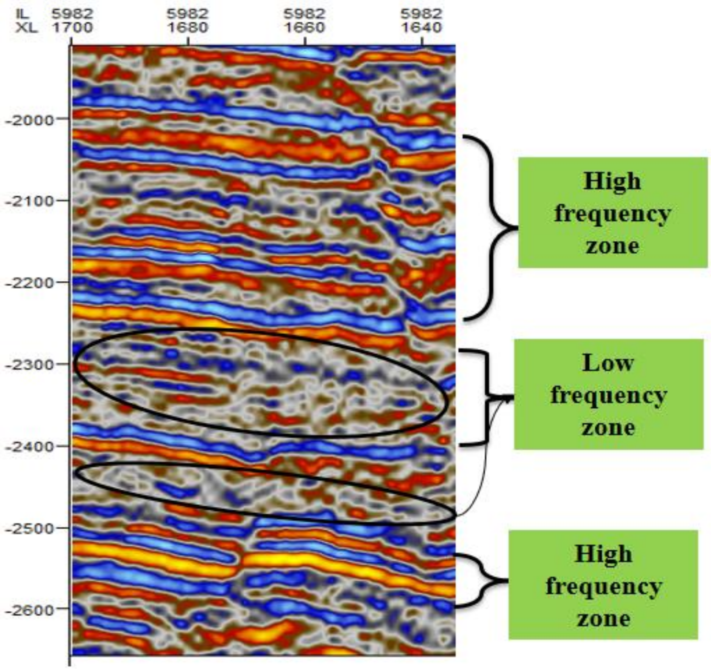

Figure 13. *High and low frequencies formed due to inter-bedded lithology with thicker, continuous and thinner, discontinuous beds.*

eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v6i2.240

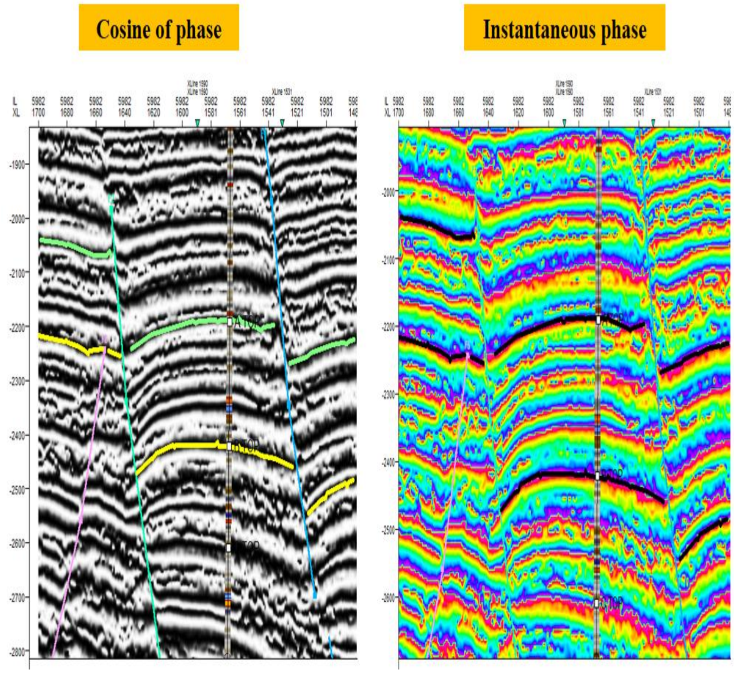

Figure 14. *Seismic attributes in Phase used for horizon interpretation on inline 5580.*

Amplitude structural model

Based on the fault modeling which was performed based on the variance edge attribute outcomes, we built a 3D model of fault and reservoir structures by the amplitude attributes. We equally deployed the Root Mean Square (RMS) amplitude attribute to validate structural faults and reservoir zones as shown in *Figure 15* and *Figure 16*.

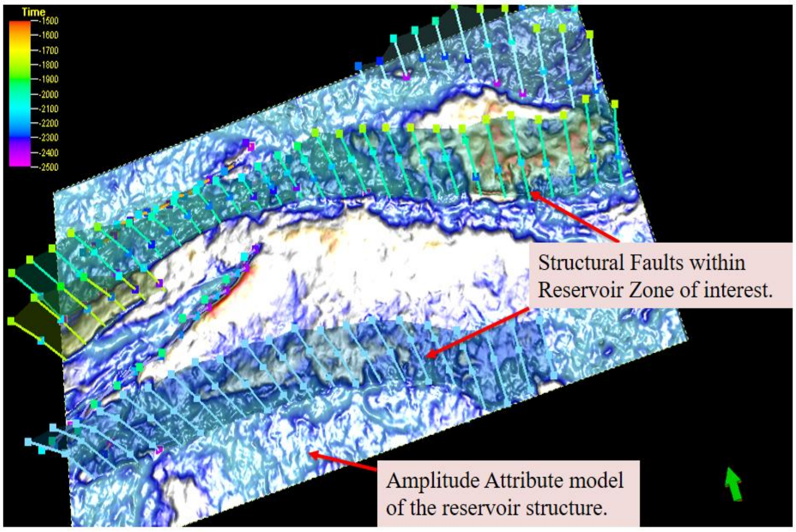

Figure 15. *A 3D model of Fault and reservoir structures defined by amplitude attribute.*

eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v6i2.240

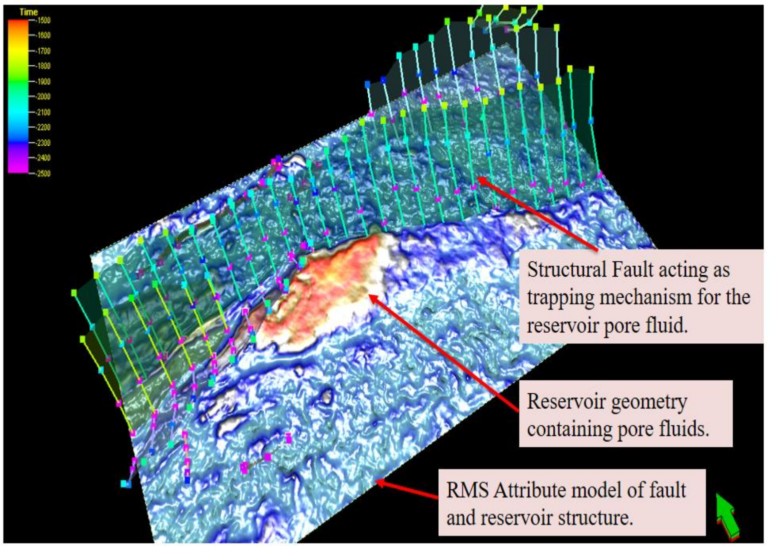

Figure 16. *A 3D model showing structural faults and reservoir zone defined by Root Mean Square (RMS) amplitude attribute.*

Conclusion

A special blend of seismic attributes mix was used in prospect identification to foster reservoir characterization goals of an offshore "X" field in the Niger Delta Basin, Nigeria. The seismic attributes mix includes the amplitude, Root Mean Square (RMS) amplitude, variance edge, phase, frequency and reflector continuity. The study mapped faults and horizon and possible trapping mechanism from the geological models derived by means of the seismic attributes mix. In conclusion, several geological models produced show that two principal faults aligned the reservoir zones and indicate prospective areas or zones of interest for detailed reservoir characterization. This study has therefore shown that deploying these seismic attributes mix could offer complementary and effective means of identifying prospects thereby enhancing reservoir characterization goals.

Acknowledgement

Our profound appreciation goes to Shell Petroleum Development Company (SPDC) for providing research data made possible via the Department of Petroleum Resources (DPR). SPDC is notably known for granting researchers and students in Nigerian Higher Institutions access to valuable research data to foster learning and research in line with Industry standards. Our affiliate Institution, the University of Port Harcourt, Rivers State, Nigeria is appreciated for providing teaching and research platforms. We appreciate the team of geologists and geophysicists that were consulted in the build up to this work. We are also grateful to the Quantum Academic Publishers, Perak, Malaysia, publishers of the Quantum Journal of Engineering, Science and Technology (QJOEST) for publication sponsorship. Authors of the resources consulted are thankfully appreciated.

Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v6i2.240