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SEISMIC ATTRIBUTE ANALYSIS FOR HYDROCARBON PROSPECTING IN THE AGBADA FORMATION OF 'ZEE' FIELD, NIGER DELTA BASIN

***Olawale Johnson Allo and Toba Sheriffdeen Ogundimu**

Department of Geosciences, University of Lagos, Lagos, Nigeria

*Corresponding authors’ email: allobioje@gmail.com

ABSTRACT

The unconsolidated sandstone reservoirs of the Tertiary Nigeria Delta basin are prone to anomalous high amplitude seismic reflections from both hydrocarbon and non-hydrocarbon sources. In order to identify anomalous zone due to hydrocarbon presence, seismic attribute analysis was used to investigate the reservoirs and to detect Direct Hydrocarbon Indicators (DHIs) due to hydrocarbon saturation in the ‘Zee’ field reservoirs. The 3D seismic, well logs and checkshot data were used for structural interpretation which helped to identify the sandstone and hydrocarbon bearing reservoirs. Faults planes and horizon were mapped to highlight the structural geometry and reservoir surface detection respectively. Five different seismic attributes were used to qualitatively evaluate hydrocarbon prospect from seismic amplitudes. Seismic attributes revealed three (3) major normal growth faults across the field while two (2) reservoirs (shallow seated reservoir A and deep reservoir B) showed zones that contain hydrocarbon anomalies. Seismic amplitude responses and fault styles from the reservoir tops reveal structurally controlled fault dependent closure across the field. High seismic amplitude anomalies from RMS, Average Energy and Maximum Magnitude attributes significantly characterize the drilled parts of the field. This implies that the high amplitude anomaly is a DHIs in ‘Zee’ Field. Moreover, apart from the already producing zone in the field's central area, two (2) more areas marked X and Y situated on anticlinal structure at the North East corner of the field has similar high amplitude responses (bright spots). It suggests new hydrocarbon prospects that should further be investigated for more hydrocarbon discoveries.

Keywords: 3D-Seismic, Attributes, Hydrocarbon, Prospects, RMS, Closure

INTRODUCTION

Seismic attributes are mathematical descriptions of seismic data which are obtained from measurements and computations of seismic amplitude responses. It is used to extract hidden information from seismic data. All information gained from seismic data, whether by direct measurements or logical or experience-based reasoning, is referred to as seismic characteristics (Taner, 2001). Seismic attributes are derived from the basic seismic data of time, amplitude, frequency, and attenuation, which are also used to classify them (Brown, 2004). Sheriff (1992) described it as a measurement based on seismic data such as envelope, instantaneous phase, instantaneous frequency, polarity, dip, and dip azimuth, and so on. It’s worth noting that attribute interpretation complements traditional structural interpretation, and the discriminating features of the attributes set can be scrutinized for their applicability to a specific prospect’s problem.

Oil and gas are mostly generated in the Niger Delta Basin from accumulations in the pore spaces of reservoir rocks, primarily from sandstones and unconsolidated sands from the Agbada formation (Doust and Omatsola, 1990). The Niger Delta basin is one of the world’s most prolific oil producing basins. It is associated with complicated structural properties that, if not fully understood, could obstruct maximum hydrocarbon exploitation. The primary goal of oil and gas exploitation is to identify and define structural and stratigraphic traps that are suitable for economically exploitable hydrocarbon accumulations. Hydrocarbon reservoirs are found in geological traps with porous rock formation that may store and produce oil and gas when penetrated by wells while also preventing the hydrocarbon from escaping vertically or laterally (Qin, 1995). These structural and stratigraphic traps could be very subtle, making accurate mapping challenging. However, advances in 3D seismic reflection techniques and borehole geophysics have made it possible to map such structural and stratigraphic configurations with great precision and dependability, lowering the risk factor associated with hydrocarbon exploration (Aizebeokhai and Olayinka, 2011; Oyedele and Ogagarue, 2013; Obiekezie, 2014). Seismic attribute analysis being an integral part of 3D seismic reflection interpretation is one of these advancements (Chopra and Marfurt, 2007; Subrahmanyam and Rao, 2008).

The most common method of interpreting seismic data for the purpose of mapping geological structures, subsurface stratigraphy, and reservoir architecture has been traditional seismic stratigraphic interpretation. The geometrical expression of seismic reflections is quantitatively traced in time, with little or no attention paid to the intrinsic seismic amplitude changes (Avseth et al., 2005; Simm and Bacon, 2014). However, since the advent of the 3D seismic revolution, amplitudes have become an important aspect of seismic interpretation, allowing more useful geological data to be detected as seismic characteristics (i.e., phase, amplitude, instantaneous frequency, etc.). Any measure of seismic data that helps us better visualize or quantify characteristics of interpretative interest is referred to as a seismic attribute (Brown, 2004). Seismic attribute is a powerful tool for enhancing hydrocarbon exploration accuracy, as well as development interpretation and projection. Seismic attribute analysis examines minute differences in the qualities of certain reflections to determine rock qualities, such as fluid content (Taner et al., 1977; Munyithya et al., 2020)

Seismic attributes allow for the speedy and more accurate creation of various geological models. They are used to describe and quantify the content of seismic data. It appears to change the subjective and experienced-based interpretation process into something more objective and less timeconsuming. Several attributes should be connected to validate the end results of the feature of interest for effective seismic attribute studies. The amplitude content of seismic data efficiently gives physical information about the subsurface, such as acoustic impedance, reflection coefficients, velocities, and absorption effects, which offer structural and stratigraphic features or serves as direct hydrocarbon indicators (DHIs) (Taner, 2001; Barnes, 2001). Nwaezeapu et al. (2018) explained that the use of seismic attribute analysis is a faster and more reliable way of creating different geological model and quantifies a characteristics content of the seismic data. The seismic attribute analysis provides reasonable information about lead identification and structural framework towards proper delineation of bright seismic reflection. Zorasi (2019) integrated 3D structural analysis and seismic attribute analyses to evaluate the subsurface structures and hydrocarbon trapping potential in a Niger Delta field. It was revealed that the hydrocarbon structures are fault assisted anticlinal structures, the root mean square (RMS) amplitude attribute was then used to identify bright spots and this bright spot show anticlinal structures which means the field is prolific and contains economic hydrocarbon accumulation.

Seismic attribute study was integrated with pore-fill characterization of reservoir in a Niger Delta field (Arthur et al., 2023). This study investigated possible relationships between some seismic attributes and reservoir fluid types so as to establishing a model for reservoir pore-fill interpretation using seismic attribute analysis. The study of Oladele et al. (2024) investigated how the variation in reservoir fluid saturation influences seismic attributes and impact the characteristics of time-lapsed (4-D) seismic response due to the effects of production. The well-based rock physics modelling result helped to determine the seismic signatures of the reservoir and P-waves seismic amplitude becomes negative with water saturation. Conceptual integration of seismic attributes and well log data to improve pore pressure prediction accuracy with the use of machine learning techniques was studied by Ogbu et al. (2024). This study revealed that the combined seismic attributes and well log data enables a better understanding of subsurface conditions.

Many 2D and 3D seismic data with varying parameters and resolution have been recorded in the Niger delta. This seismic data may show misleading or provide an erroneous portrayal of abnormally high amplitude signals that are not always direct hydrocarbon indicators (DHIs). In this study, seismic attributes technology was applied in “Z” field to investigate the subsurface structure in order to identify hydrocarbon prospects, utilizing seismic attributes such as Root Mean Square (RMS), Average Energy and Maximum Magnitude as direct hydrocarbon indicators (DHIs). This study helps to forecast and identify potential hydrocarbon bearing reservoirs and delineate the structural style. within the field. It helps to reduce cost in hydrocarbon exploration by identifying likely hydrocarbon prospects before drilling operation begin.

Basic Principles

Root Mean Square (RSM) Attributes

This attribute computes the square root of the sum of squared amplitudes divided by the number of samples within a specified seismic window. Though, RSM is sensitive to noise, it measures the reflectivity so as to map direct hydrocarbon indicators in a zone of interest.

Maximum Magnitude

Maximum magnitude that calculates the maximum value of the absolute value of the amplitudes within a window range. This maps the strongest direct hydrocarbon indicator within a time/depth zone of interest.

Average Magnitude

This is also a post-stack attribute like RSM and Maximum magnitude which estimate the average value of the absolute value of the amplitudes within a window. This is used to map the strongest direct hydrocarbon indication inside a zone of interest (Koson et al., 2014).

Location and Geology of the Study Area

The study area is located in the offshore region of the Niger Delta basin (Figure 1), the survey area spans about 179.5 square kilometers.

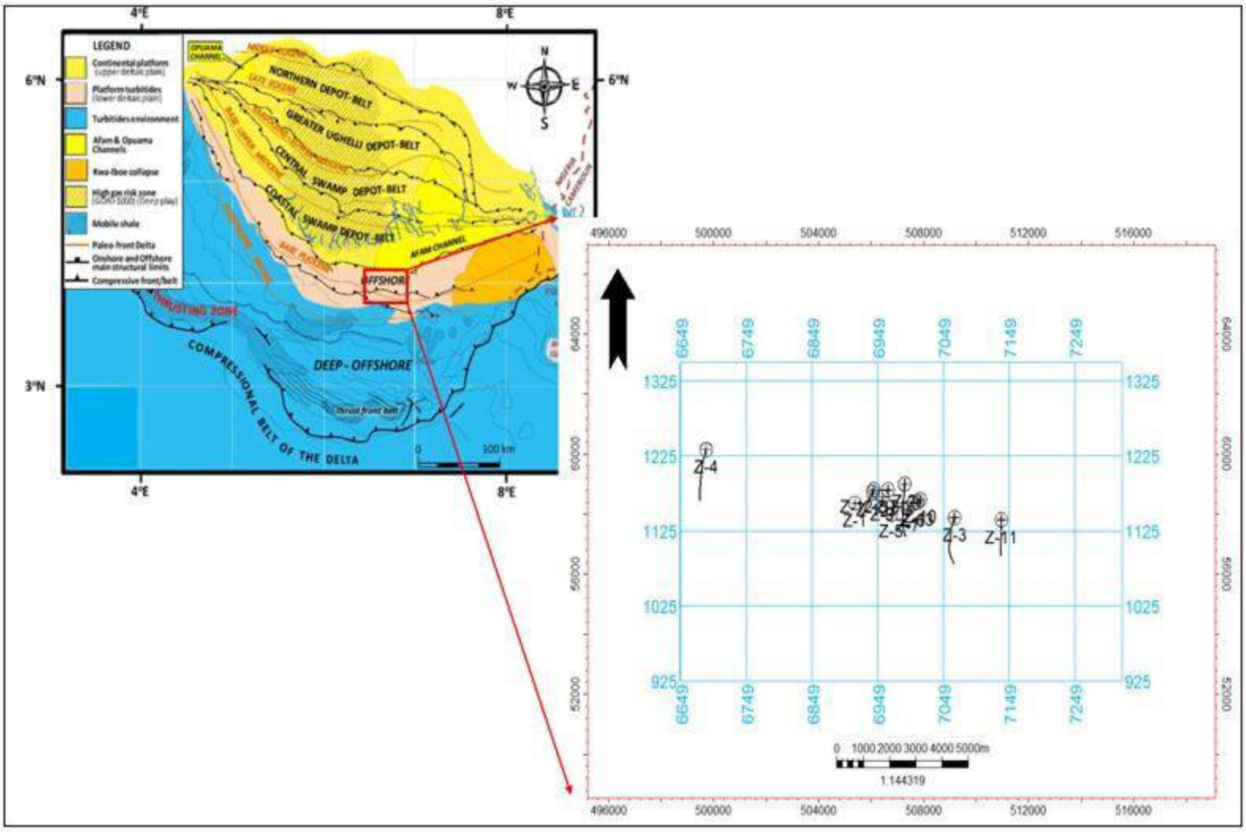


Figure 1: Geologic map of the Niger Delta showing depobelts and structural element (Obaje, 2017), and the study area highlighted in red box. Insert is the seismic survey base map

The Niger Delta is located on the west coast of central Africa, in the Gulf Guinea (Figure 2). It built out into the Atlantic Ocean during the tertiary near the mouth of the Niger-Benue River system, a catchment region that includes over a million square kilometers of mostly savannah-covered lowlands. The Delta is one of the world's largest, with a subaerial area of roughly 75,000 km^2 and a length of more than 300km from Apex to outlet (Figure 2). It is thought that the regressive wedge of elastic sediments that is made up of has a maximum thickness of approximately 12 km (Doust and Omatsola, 1990). After the emergence of the south Atlantic Ocean between the Africans and South American continents, marine sediments began to accumulate in the basin in Albian period. True Delta formation, on the other hand, did not begin until the late Paleocene/Eocene, when sediments began to build out beyond troughs between basement horst blocks on the delta's northern border. The delta plain has steadily prograde southward onto oceanic rock, assuming a convex-to-the-sea morphology (Doust and Omatsola, 1990).

The relationship between rates of sediment supply and subsidence has shaped the delta's structure and strata throughout its geological history. Eustatic sea-level changes and climatic fluctuations in the hinterland have had a significant impact on sedimentation rate. Initial basement morphology and differential sediment loading on unstable shale have largely controlled subsidence. Syn-sedimentary and post-sedimentary normal faults, the most major of which may be tracked over long distances along strike, have a significant impact on the delta sequence. The resulting fault trends are closely tied to the sedimentation pattern and run more or less parallel to the delta front's paleogeographic position at each stage of its evolution (Doust and Omatsola, 1990; Nwajide, 2013).

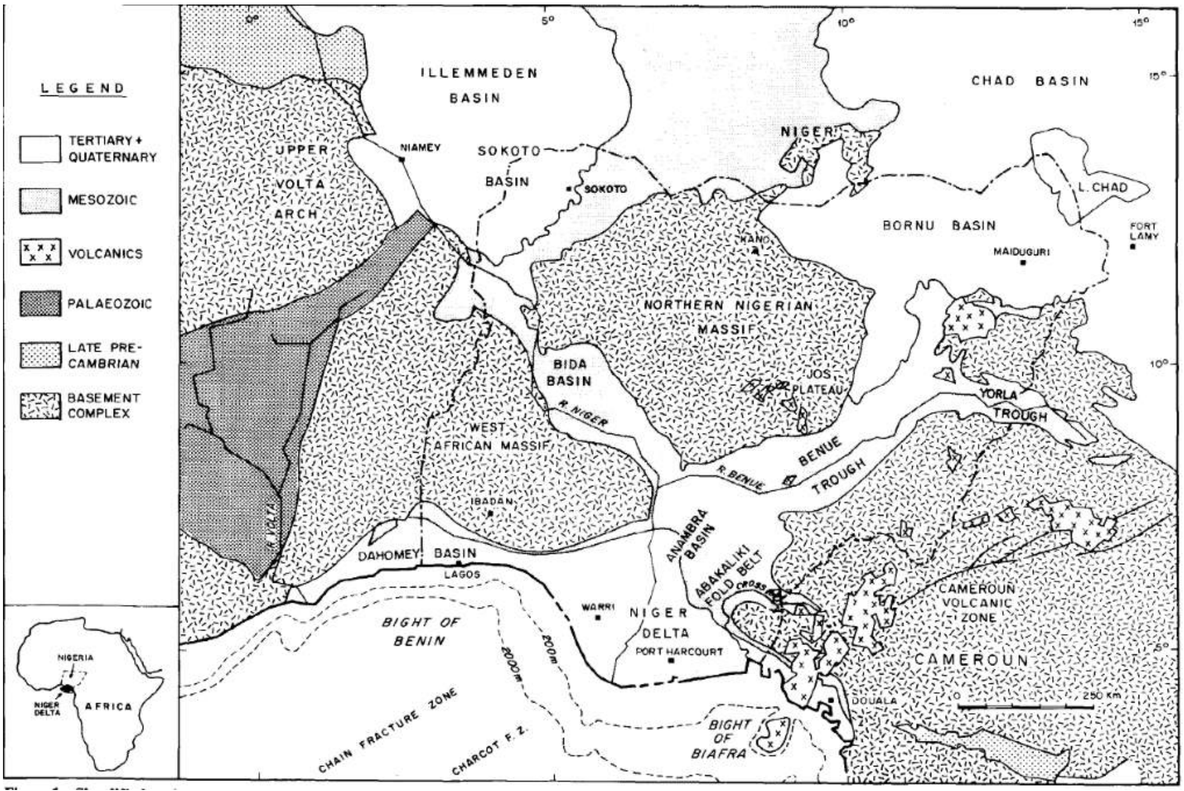


Figure 2: Simplified map of Nigeria and surrounding area showing main drainage into the Gulf of Guinea (Doust and Omatsola, 1990). (Modified from Whiteman, 1982)

MATERIALS AND METHODS

The data used for this study includes wireline logs (Gamma ray, Sonic, Density, Resistivity, and Neutron logs) from fourteen (14) wells in the field, check shot data, and the field's 3D seismic volume (179.5 km^2) were employed in the study. Petrel is the software utilized for the interpretation of the data. Well log analysis/formation evaluation and seismic data interpretation were integrated in this study.

'Zee' field seismic volume was loaded according to the byte locations while the well header information was extracted for correct positioning and loading of the well logs. Quality control by checking through Inlines and Crosslines across the entire field for data quality determination was done. Well logs diagnostic effects of the different log signatures were inspected with respect to the lithology encountered. The seismic data quality is said to be good (Figure 3a) because the peak frequency of the filtered amplitude spectrum (-120 to 120) peaked around zero as also discussed by Jason (2013)

The logs were all loaded and the sand and shale patterns were detected using the gamma log signatures. The resistivity log was used to identify sand with high resistivity values, and the neutron/density log was utilized to locate hydrocarbon bearing zones. Well to seismic tie connects subsurface depth measurements made at a wellbore with seismic data measured in time using check-shot data. The well is linked to seismic data by creating a synthetic seismogram. The time-depth relation was fine-tuned by bulk shifting.

This area of study was heavily faulted during deposition due to tectonic and sediment instability. All minor and major faults in the area have been mapped. Seismic attributes such as the variance attribute, were utilized to enhance the seismic data structurally in order to map the subtle faults. Horizons of interest were used to create the reservoir surfaces and time maps. The depth map was created from the time map using a suitable velocity model derived from the check-shot data.

In this study, various 3D seismic attributes were used to improve seismic data interpretation. Root mean square (RMS), average energy, and maximum magnitude attribute maps was created to qualitatively evaluate the hydrocarbon prospect of the research area. In addition, variance edge, structural smoothening and median filter were used for fault and reflection termination mapping, respectively. The methodology adopted is illustrated in the workflow in Figure 3b.

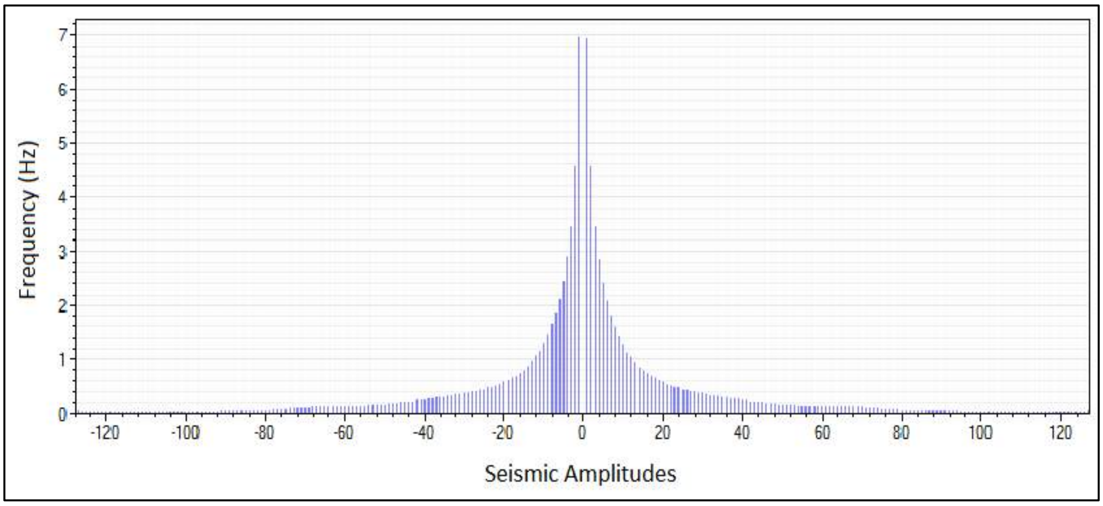


Figure 3(a): Seismic amplitude histogram showing zero peak frequency distribution

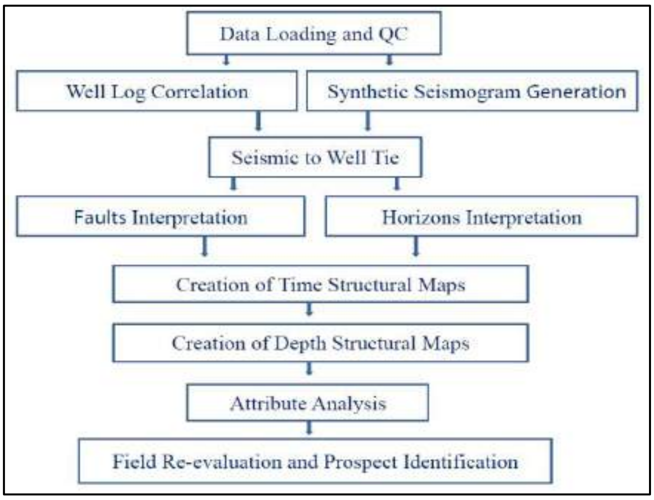
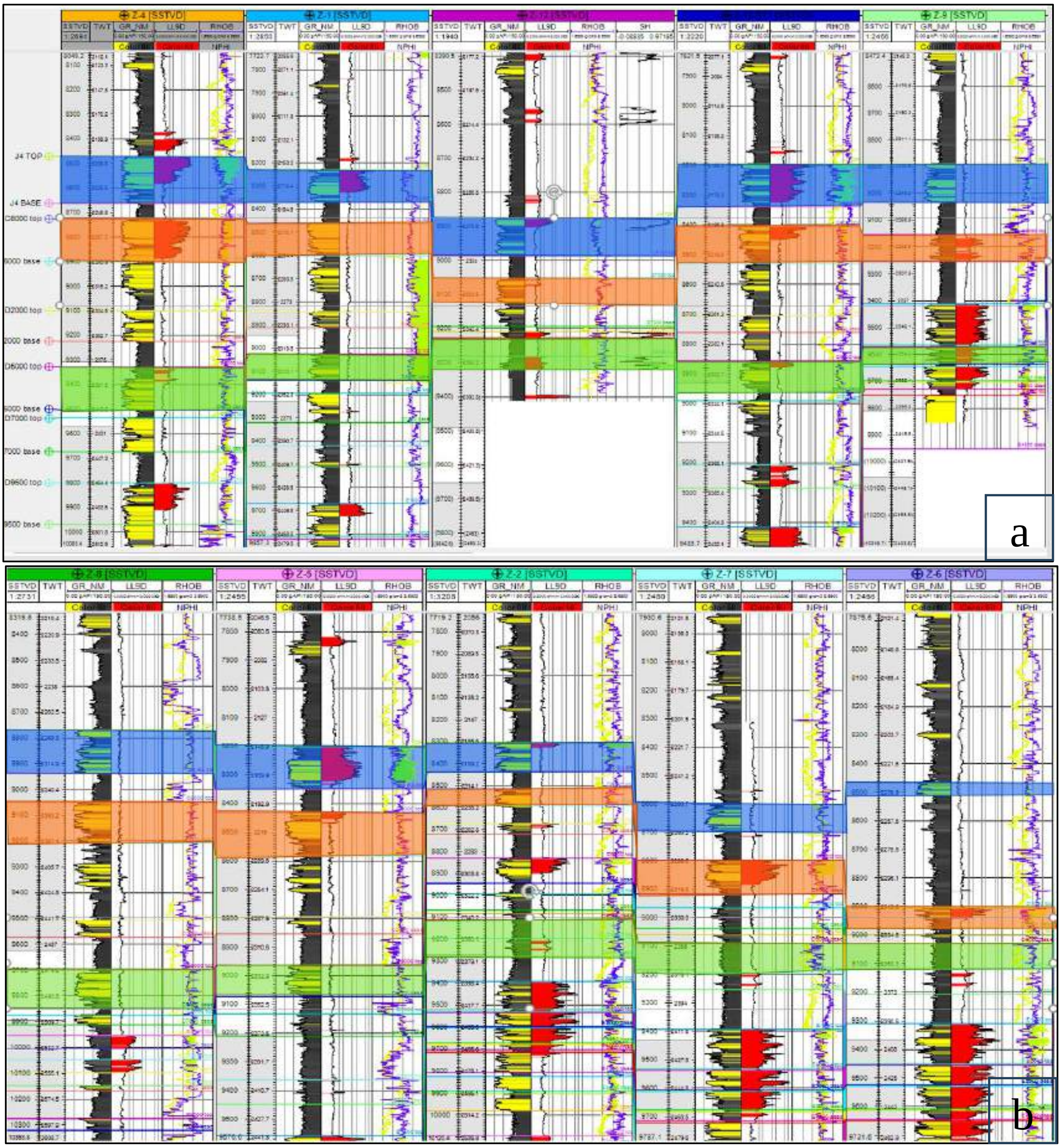


Figure 3(b): Workflow chart used in the study

RESULTS AND DISCUSSION

Well Log Interpretation

Figure 4 depicts the identified three (3) reservoir intervals based on well log interpretation. The wells were arranged from based on direction of sediment deposits. Figure 4 illustrates the correlation of all wells. Three Reservoirs A, B and C contain thick sand reservoir zones with high resistivity values, suggesting the presence of hydrocarbon are of interest to this study. Other reservoirs that were identified are not laterally extensive.


Z-4 [SSTVD]
Z-1 [SSTVD]
Z-9 [SSTVD]
SSTVD
TWT
GR_NM
LLSD
RHOB
NPHI
SH
J4 TOP
J4 BASE
C8000 top
8000 base
D2000 top
2000 base
D6000 top
6000 base
D7000 top
7000 base
D9500 top
9500 base
a
Z-5 [SSTVD]
Z-2 [SSTVD]
Z-7 [SSTVD]
Z-6 [SSTVD]
b

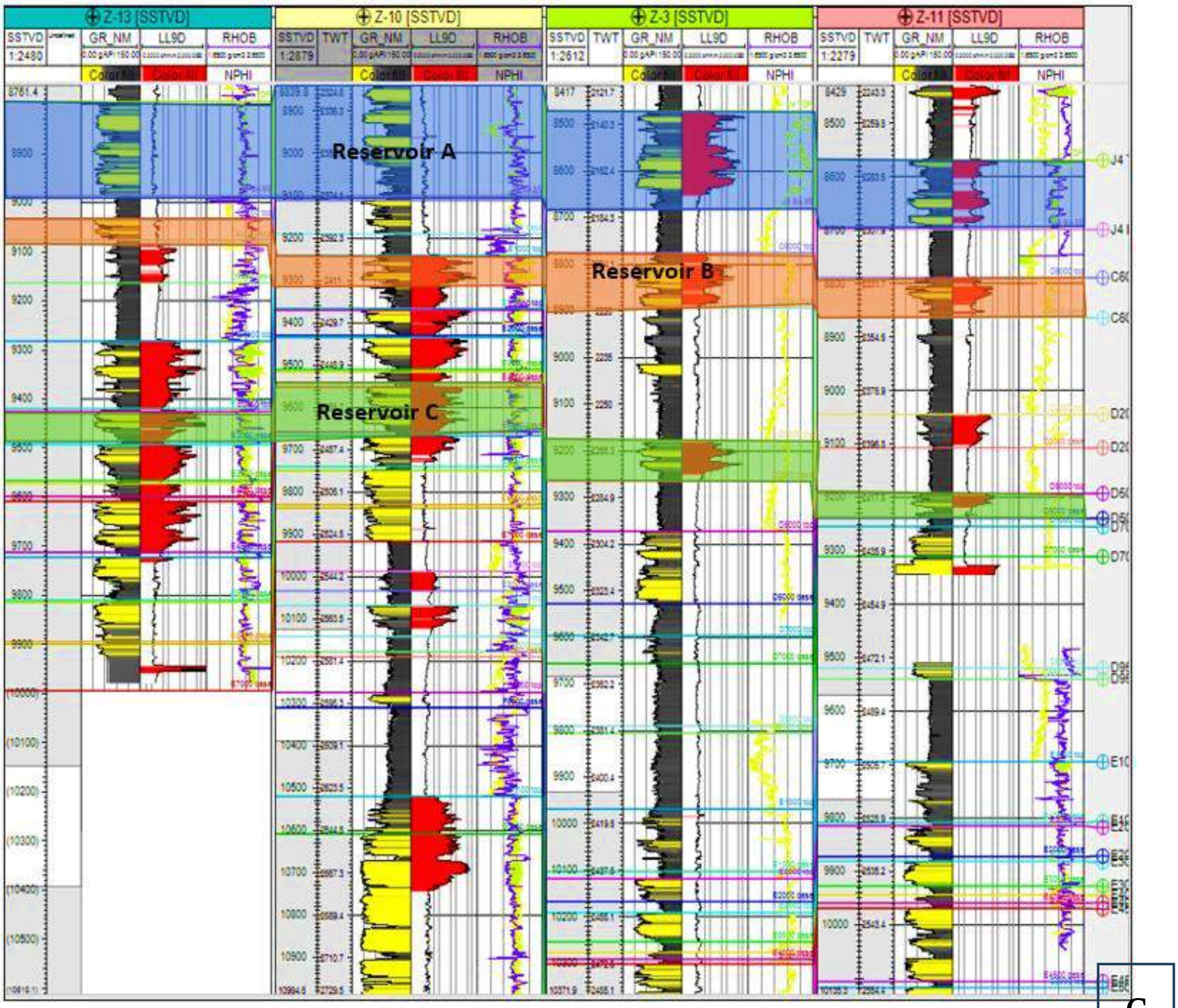


Figure 4: Well correlation panels (a, b and c) of all the wells. (a) Z4, Z10, Z12, Z12st, Z9 (b) Z8, Z5, Z2, Z7, Z7 and (c) Z13, Z10, Z3 and Z11

Well to Seismic Tie

Constant velocity function technique (Figure 5a) was used to model the velocity relationship of the 'Zee' field reservoirs. It reveals the relation between the depth, 'y' in (ft) and time 'x' in (ms) of which produced this $y = 4.10x - 875$ relation. It indicates a steady velocity variation in time, a consequence of linear relationship between time and depth in the study area. The synthetic seismogram shown in Figure 5b created along well Z-4, shows the correlation between well and the seismic data. Seismic volume revealed mixed-placed wavelets, which influenced the mapping of structures and horizons. The zero-phase wavelet allows for simple identification of stratigraphic sequences of continuous reflections and improved fault characterization. Well data and synthetic seismogram displayed good correlation. Mixed wavelets with reduced correlation between well and seismic amplitudes are consequence of the heterogeneity of the detected layers.

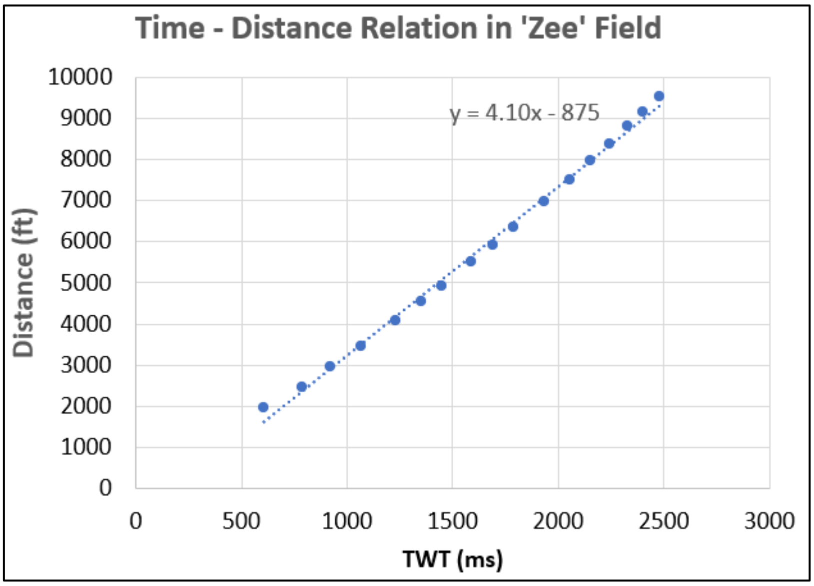


Figure 5(a): Time versus Distance relationship plot with trendline from the 'Zee' Field reservoirs

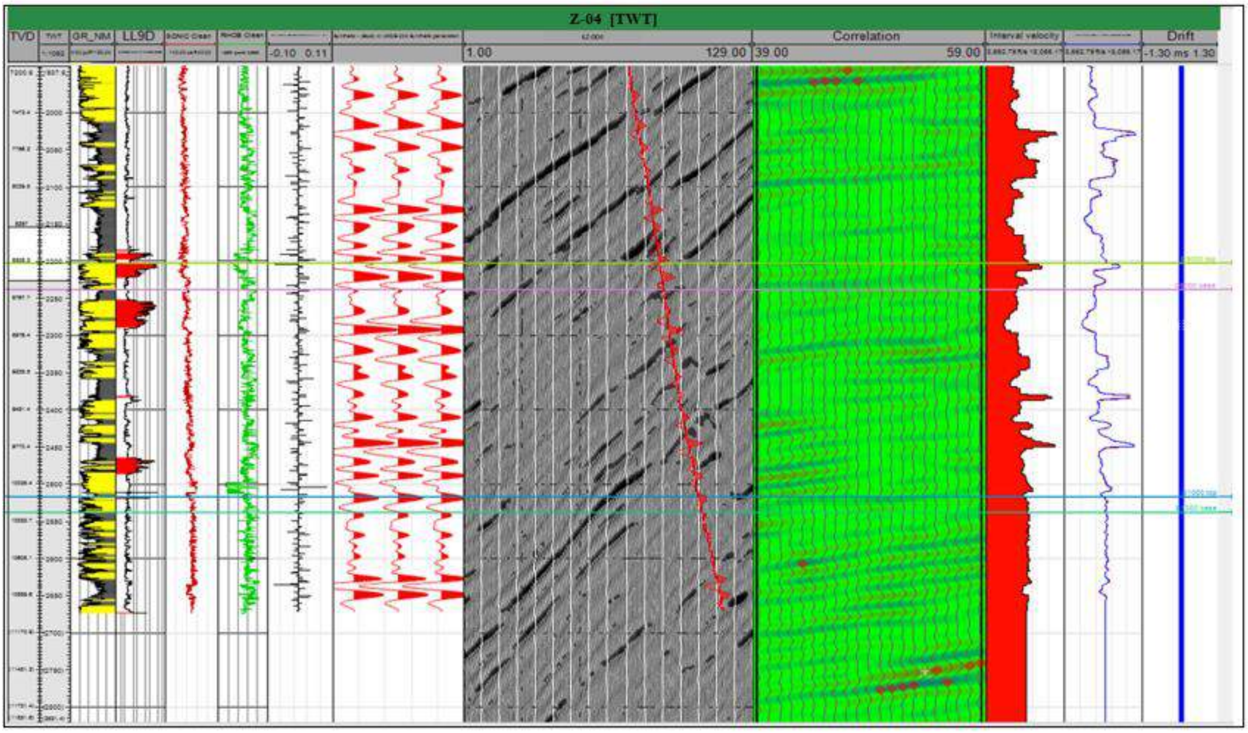


Figure 5(b): Well to seismic tie to indicate the well tops on the seismic section

Fault and Horizon Analyses

As illustrated in Figure 6 to Figure 8, the Z-field is characterized by three large normal growth faults as identified as A, B, and C, that run the length of the field with smaller antithetic faults. Multiple growth faults, antithetic or counter fault structures are all found in Z-Field typical of the faulting system in the Niger Delta Basin (Doust and Omatsola, 1990). The drilled wells in this study were located within large fault blocks, indicating that these significant faults operate as a hydrocarbon trap. In Figures 6 (a and b) and 7 (a and b), median filter and variance edge attribute helped to locate faults that were not evident in the original seismic section.

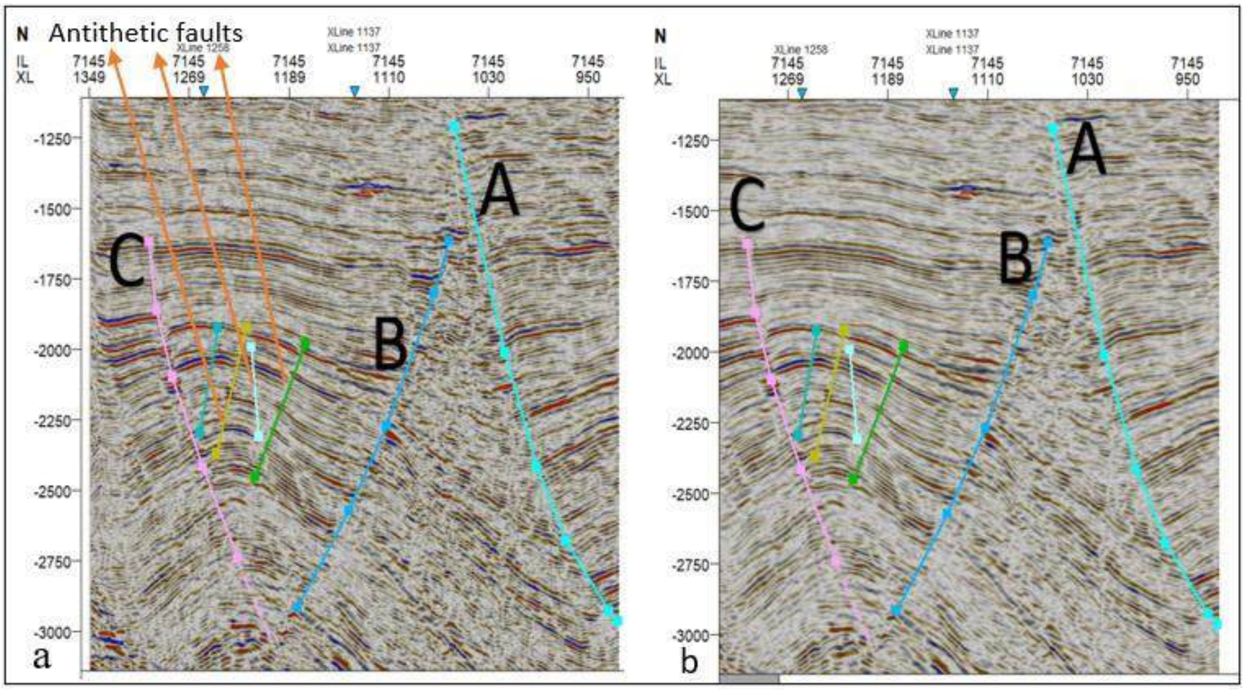


Figure 6: (a) Shows fault identified on inline 6965 in the original seismic section, (b) shows fault identified on inline 6965 using the median filter attribute

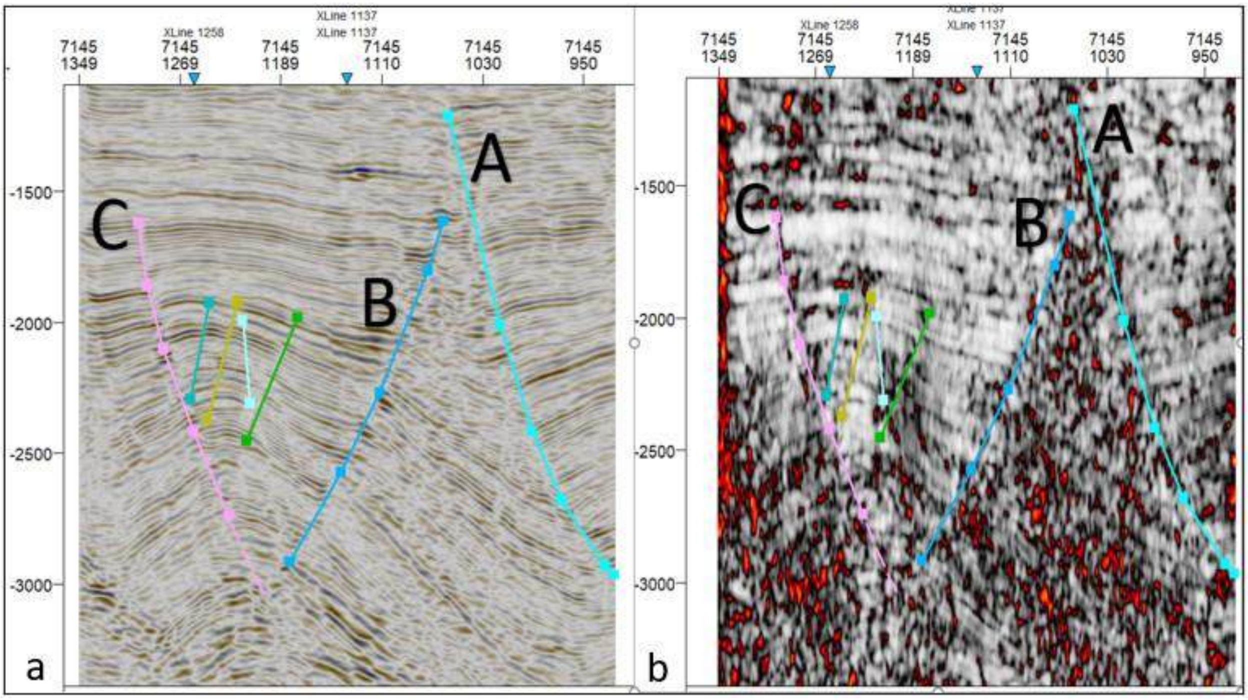


Figure 7: (a) Shows fault identified on inline 6965 using the structural smoothening attribute, (b) shows fault identified on inline 6965 using the variance attribute.

Synthetic seismogram that linked seismic data to well data helped to identify reservoir tops. Three horizons were mapped along the seismic section due to high amplitude strength and field wide consistency at or near sand tops. The mapped horizons are shown in Figure 8, these mark the tops of Sand Reservoirs A, B and C. However, analysis of Reservoir C is discontinued due to its proximity to the highly shale Akata formation and its small area coverage.

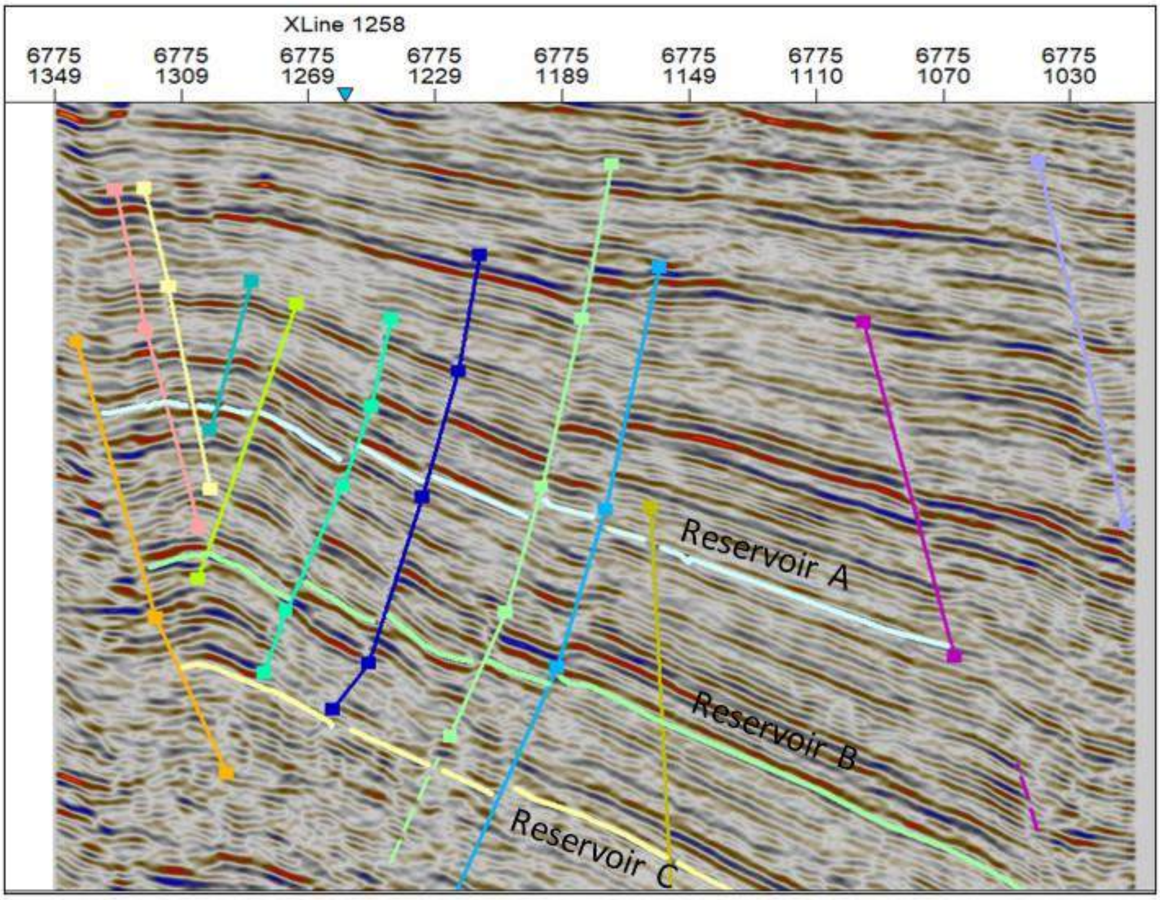


Figure 8: The three horizons of Reservoirs A (blue), B (green) and C (yellow)

Depth Structure Map
The structural maps in time and depth are remarkably comparable, just as illustrated in Figures 9 and 10. This suggests that the horizon interpretation is reliable. The faults segregated the field into numerous blocks, and these faults and fault blocks produced closures (traps) for hydrocarbon accumulation as revealed by the structural maps. These traps were the focus of the wells drilled in the field.

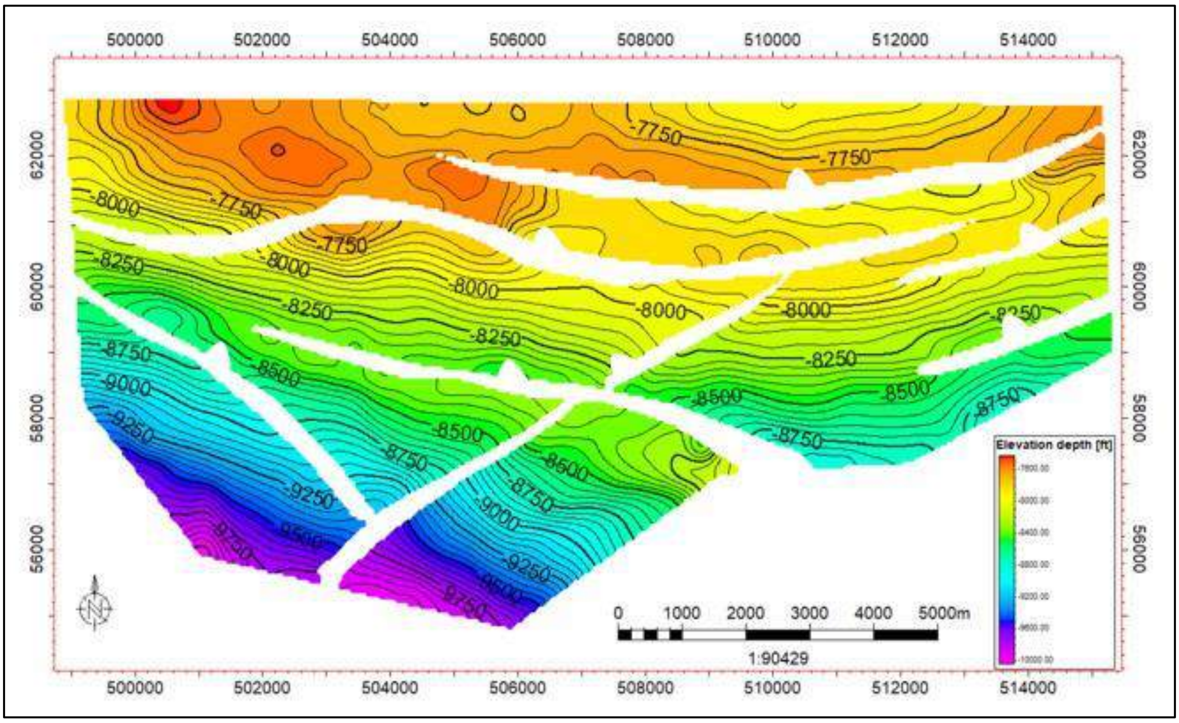


Figure 9: Depth structural map for the mapped Reservoir A horizon

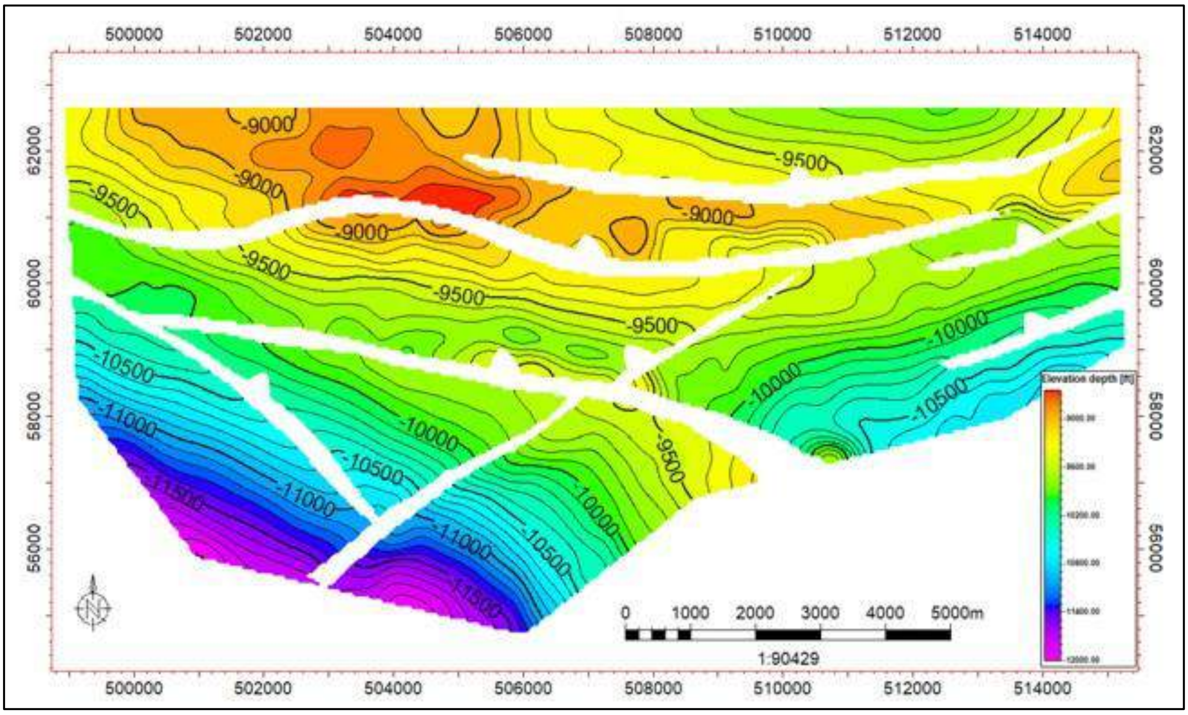


Figure 10: Depth structural map for the mapped Reservoir B horizon

Seismic Attribute analysis

The fault closures are characterized by high amplitude as observed from the seismic amplitude attribute maps. The large amplitudes recorded on the horizons, which mark the top of reservoirs, shows the existence of hydrocarbon within the mapped reservoirs and confirms the well log analysis results. Strong amplitude anomalies were observed in the central section of the field, especially at the Reservoirs A and B (Figures 11 and 13). The detected rollover anticline structure in the field correlates to the center region of the field where large amplitude anomalies were recorded. Strong amplitude anomalies are structurally controlled, as evidenced by their occurrence near faults on structural top maps. Bright spot anomalies are suggestive of hydrocarbon occurrence, according to seismic amplitude characteristics analysis. Bright spot anomalies were found in the three amplitude attributes maps developed for reservoir tops A and B shown in Figures 11 and 13 which are probably connected with facies and/or fluid content (Raef *et al*., 2016). Furthermore, these anomalies can be detected on structural highs, implying that prospects are in line with regional structural highs.

The RMS maps of Reservoirs A and B (Figures 11 and 13) reveal seismic amplitude variation due to lithology heterogeneity and fluid effects. Sandstone rich and hydrocarbon saturated areas are indicative of high amplitude and shale dominating area shows low seismic amplitudes as revealed in the histogram in Figure 12. The histogram distribution of scaled amplitudes versus frequency of occurrence, N of the RMS attribute from the high amplitude drilled area (blue) and low amplitude area (pink) of Reservoir A. These observations are supported by Avseth et al. (2005) and Emujakporue and Enyenihi (2020) and Allo et al. (2022). The RMS attribute for the Reservoir A and B indicates high amplitudes in the areas that have already been drilled, as well as in the areas identified as X and Y which have not been explored. Since the RMS seismic amplitude responses of the drilled region and the area that has not been drilled are similar, the areas X and Y are considered a prospective area of interest for future exploration activity.

Furthermore, the Envelope attribute map (Figure 14 and 15), which also delineate lithology confirms that the area of the reservoir that were identified as X and Y by the RMS map due to high amplitude are hydrocarbon prospects. Envelope attribute map shows high amplitude in the same region which supports that the region is a sand zone and hydrocarbon prospect that can be subjected for more study.

The Average Energy (Figure 16 and 17), maximum magnitude (Figure 18 and 19), average magnitude (Figure 20 and 21), and standard deviation attribute (Figure 22 and 23) further illustrate the presence of fluid hydrocarbon fluid in these reservoirs. These four attributes all exhibit bright spots (high amplitude regions) in the undrilled zone prospect labelled X and Y.

The seismic attribute amplitude map shown in the prospect area marked X and Y suggest the presence of hydrocarbon since the amplitudes in the area is similar to the amplitudes in proven area (drilled). Also, hydrocarbon presence in the reservoirs is supported by fault closures which serves as a trap for hydrocarbon accumulation. The identified areas marked as X and Y are considered as possible prospect for hydrocarbon exploration.

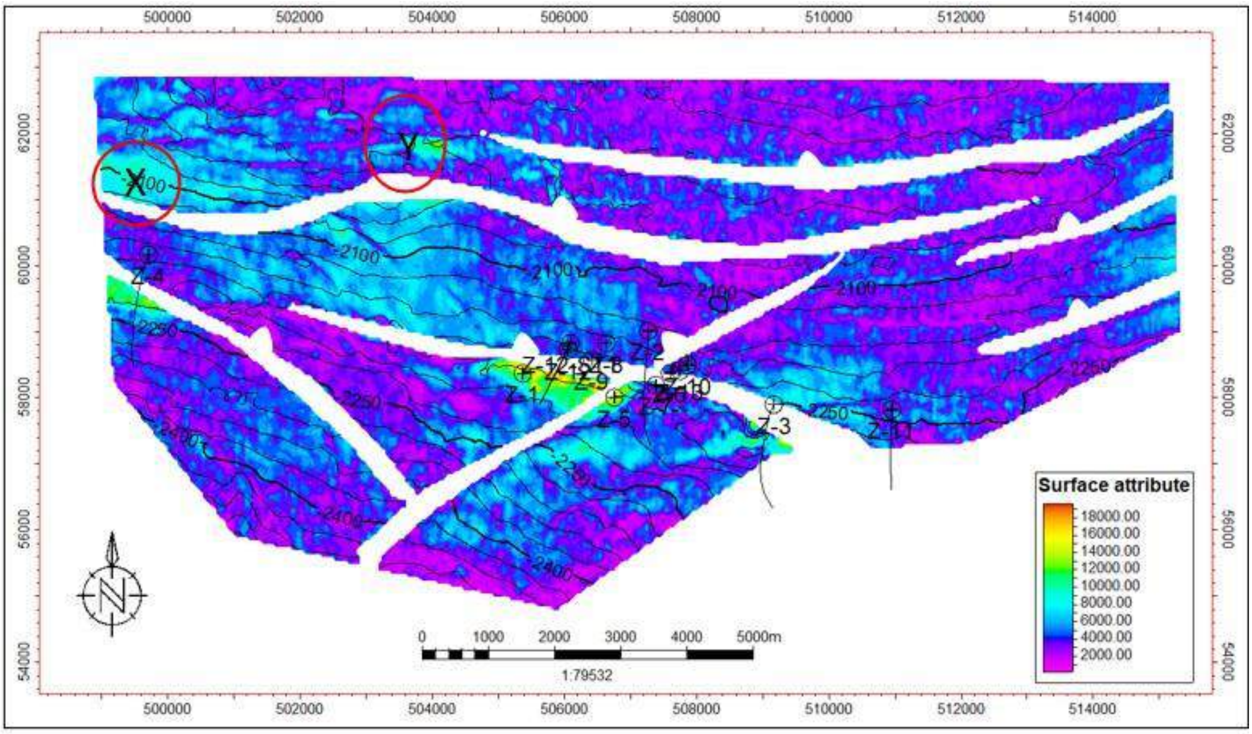


Figure 11: Root Mean Square (RMS) attribute map for Reservoir A

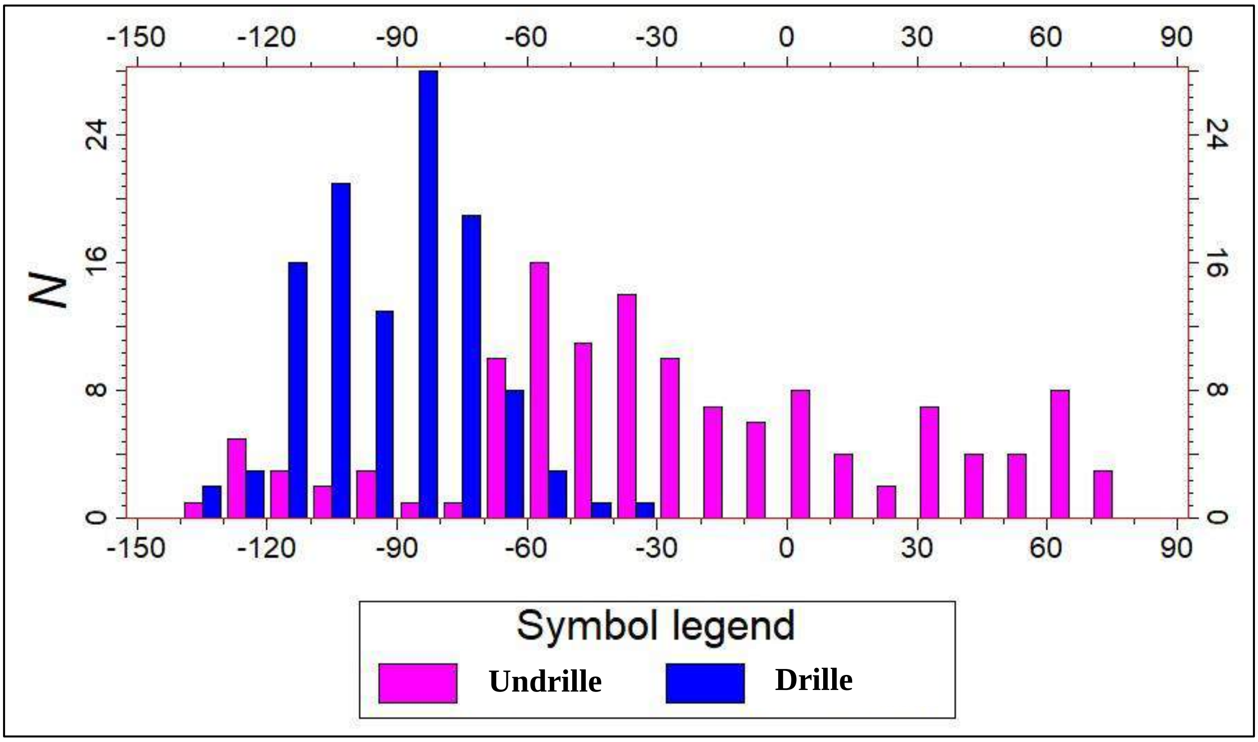


Figure 12: Seismic amplitudes at drilled section (proven) and the undrilled sections (prospect)

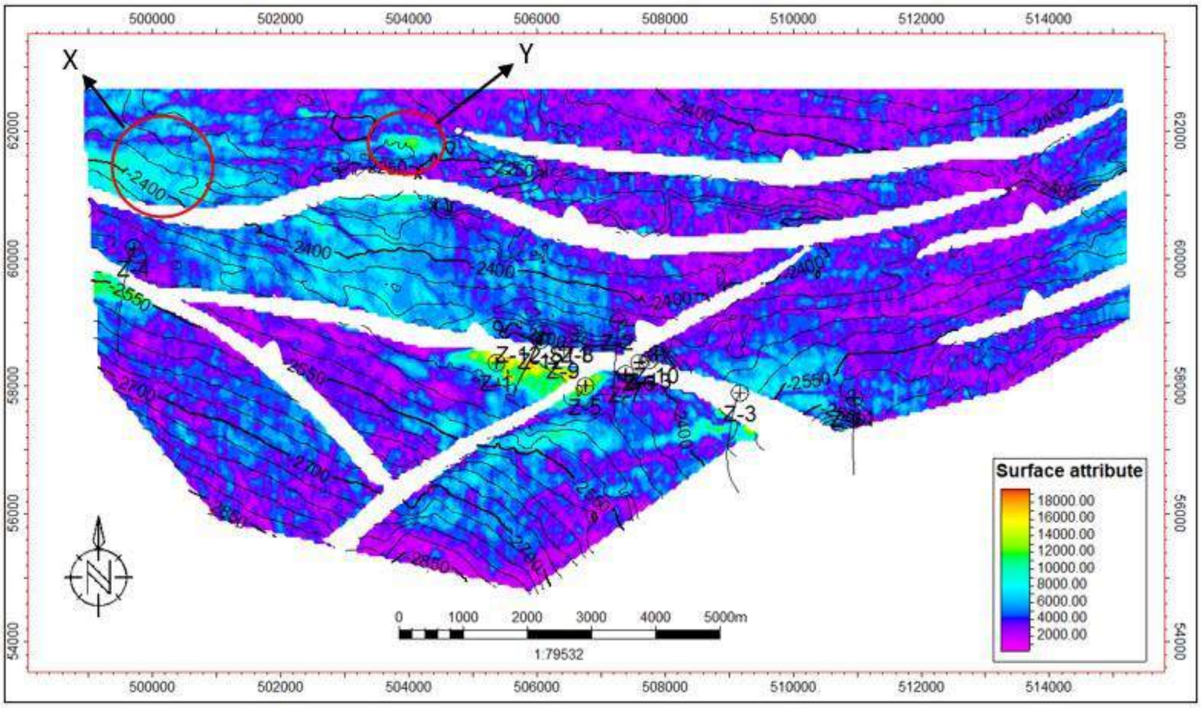


Figure 13: Root Mean Square (RMS) attribute map for Reservoir B

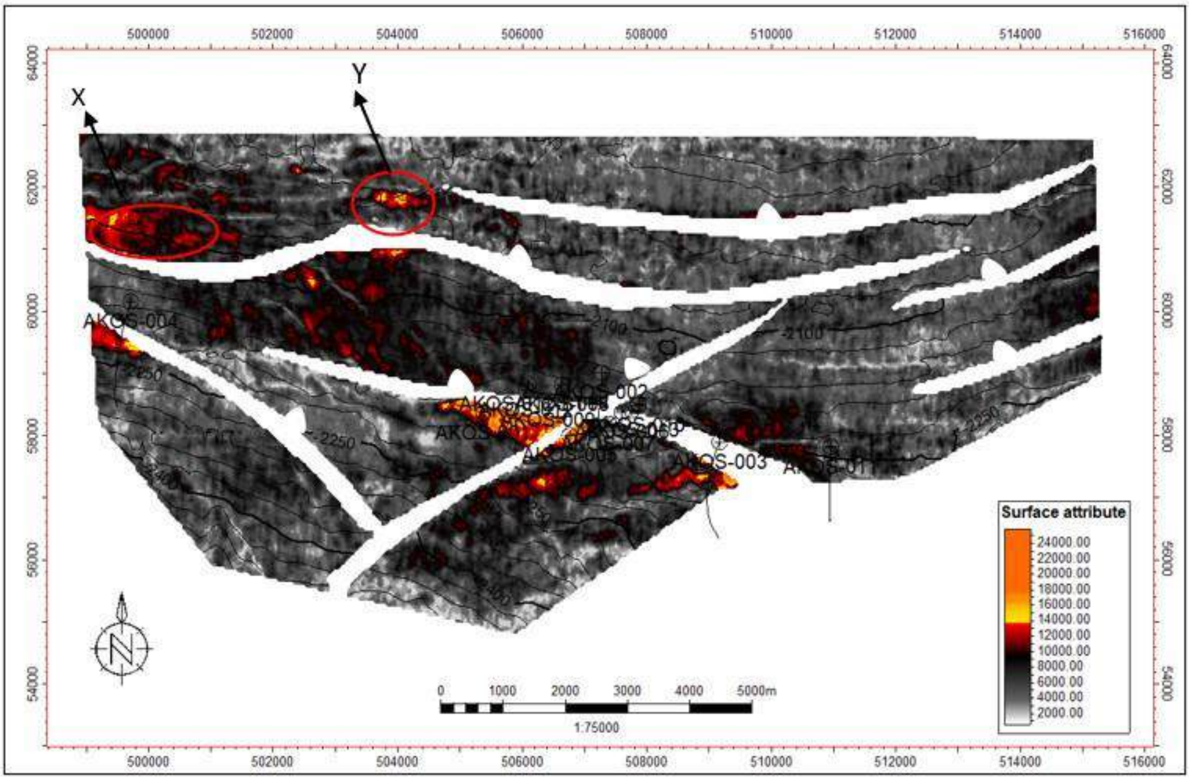


Figure 14: Envelope attribute map for Reservoir A

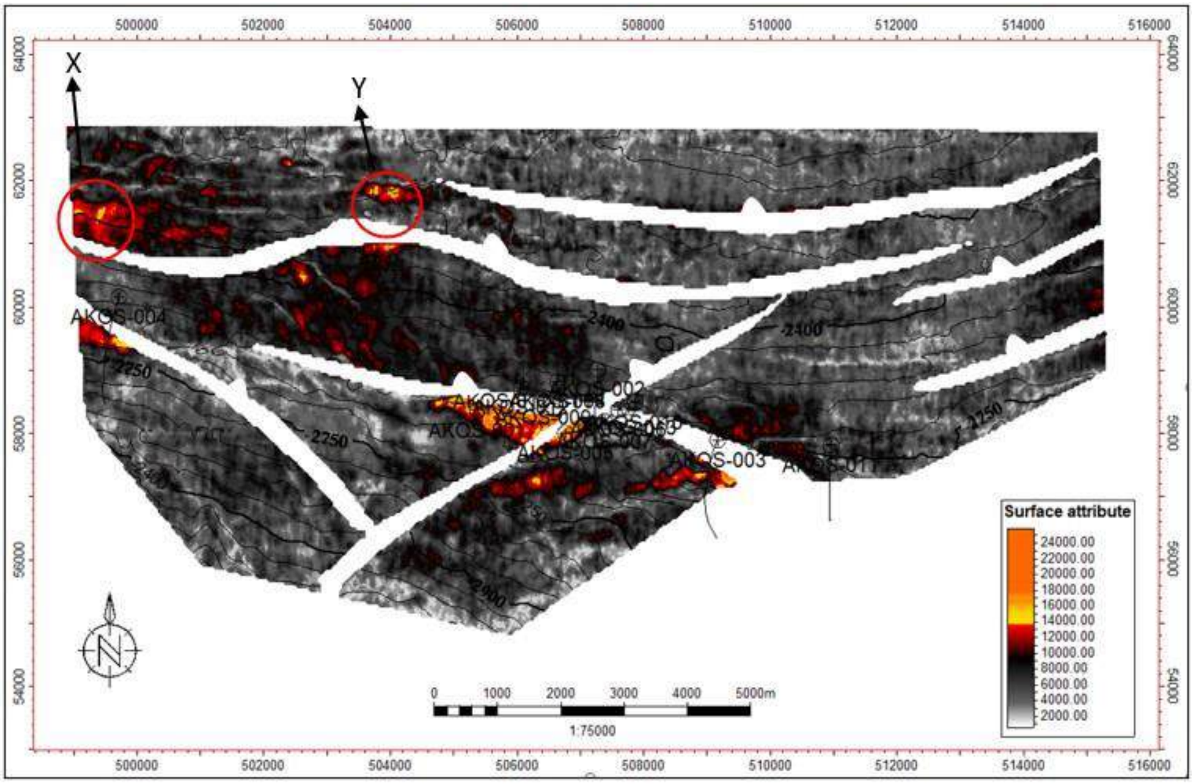


Figure 15: Envelope attribute map for Reservoir B

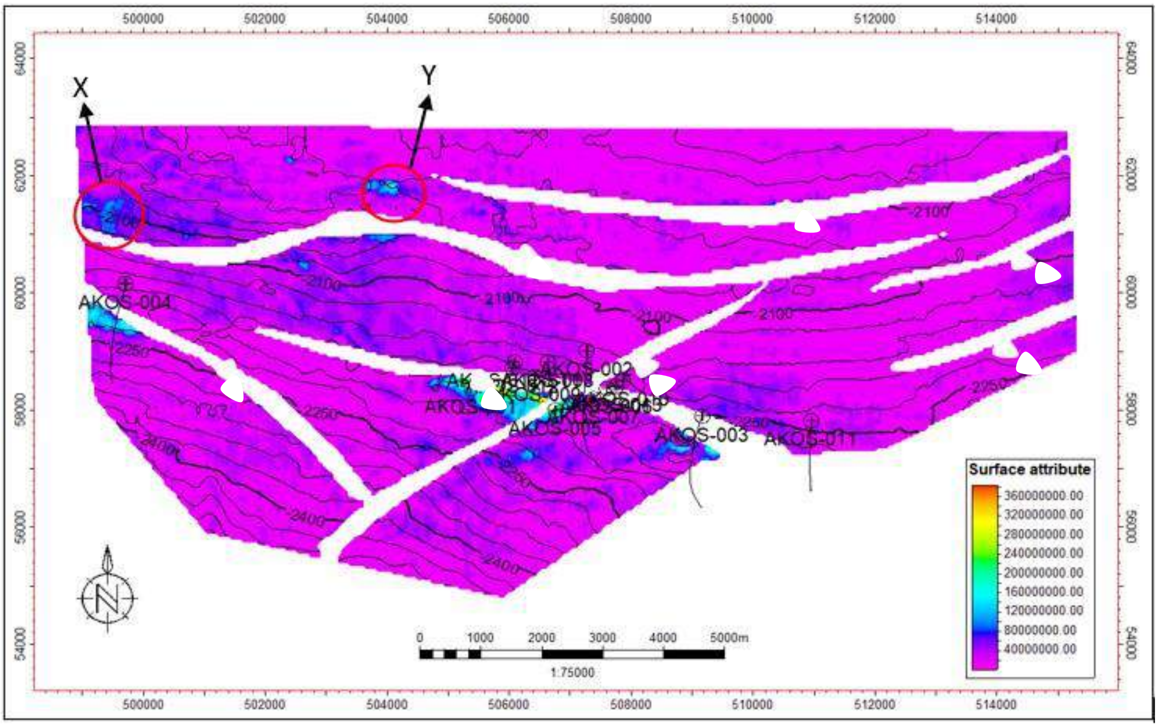


Figure 16: Average energy attribute map for Reservoir A

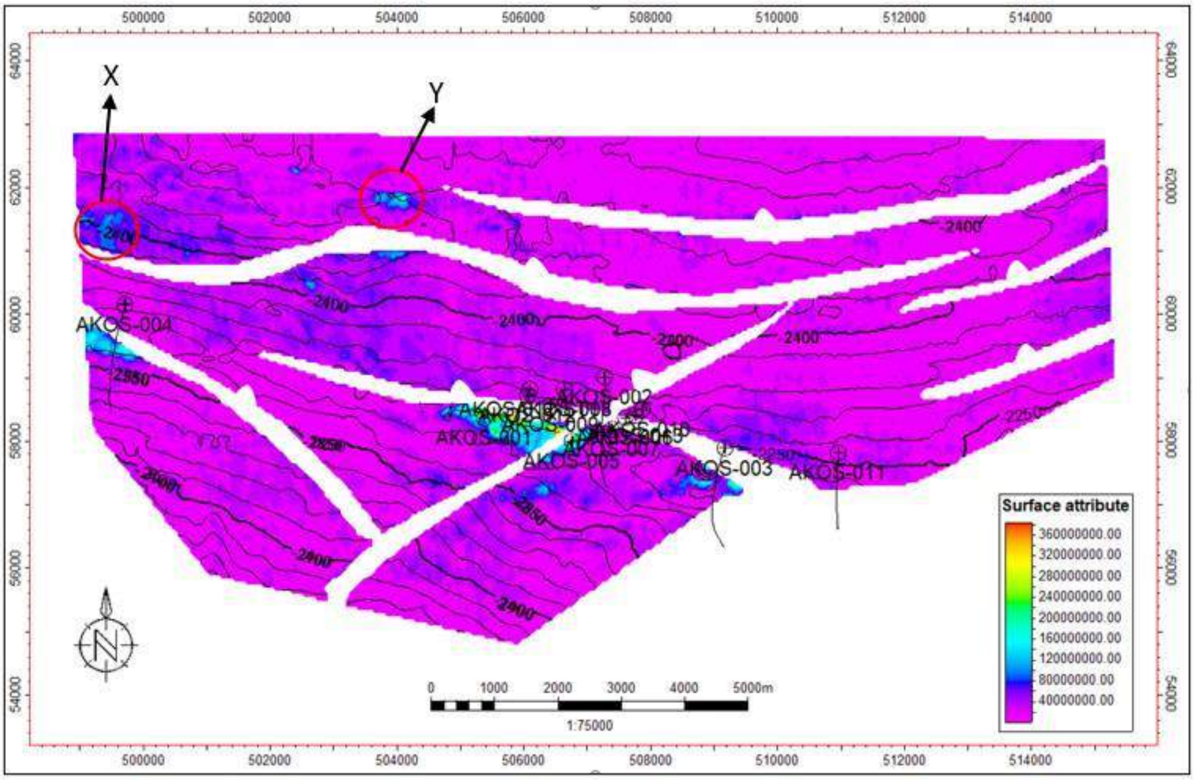


Figure 17: Average Energy attribute map for Reservoir B

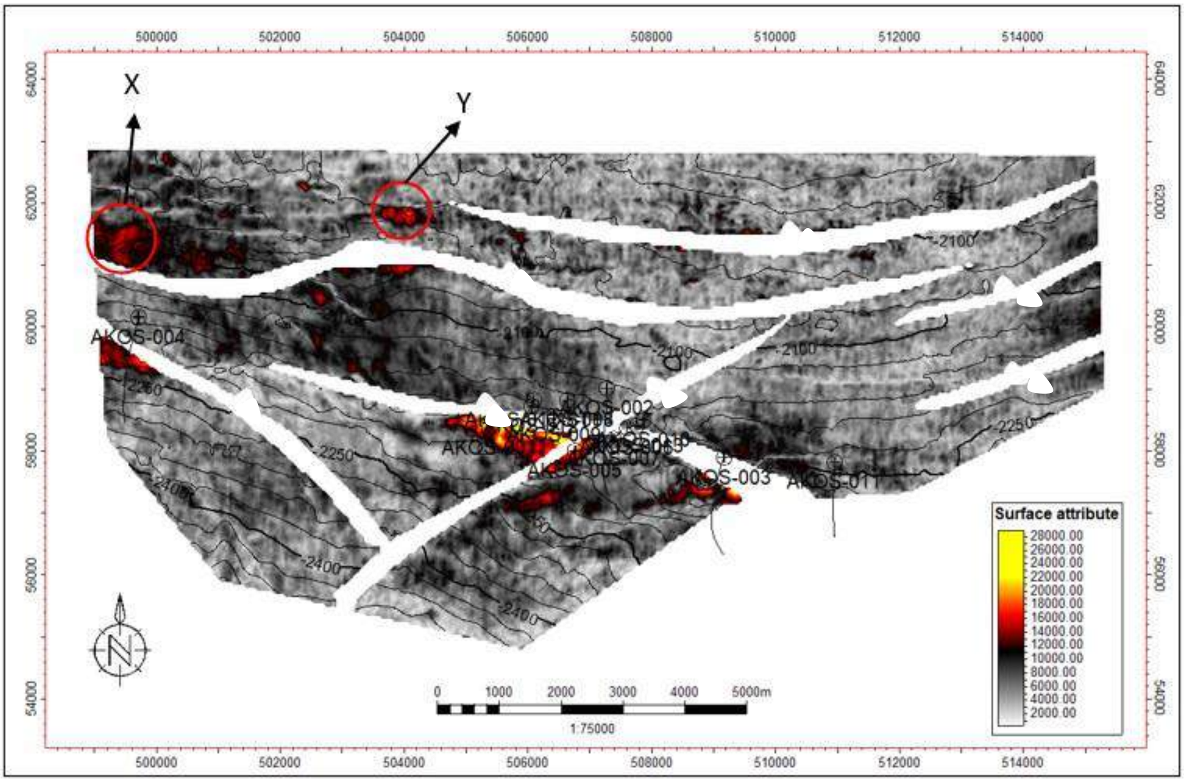


Figure 18: Maximum magnitude attribute for Reservoir A

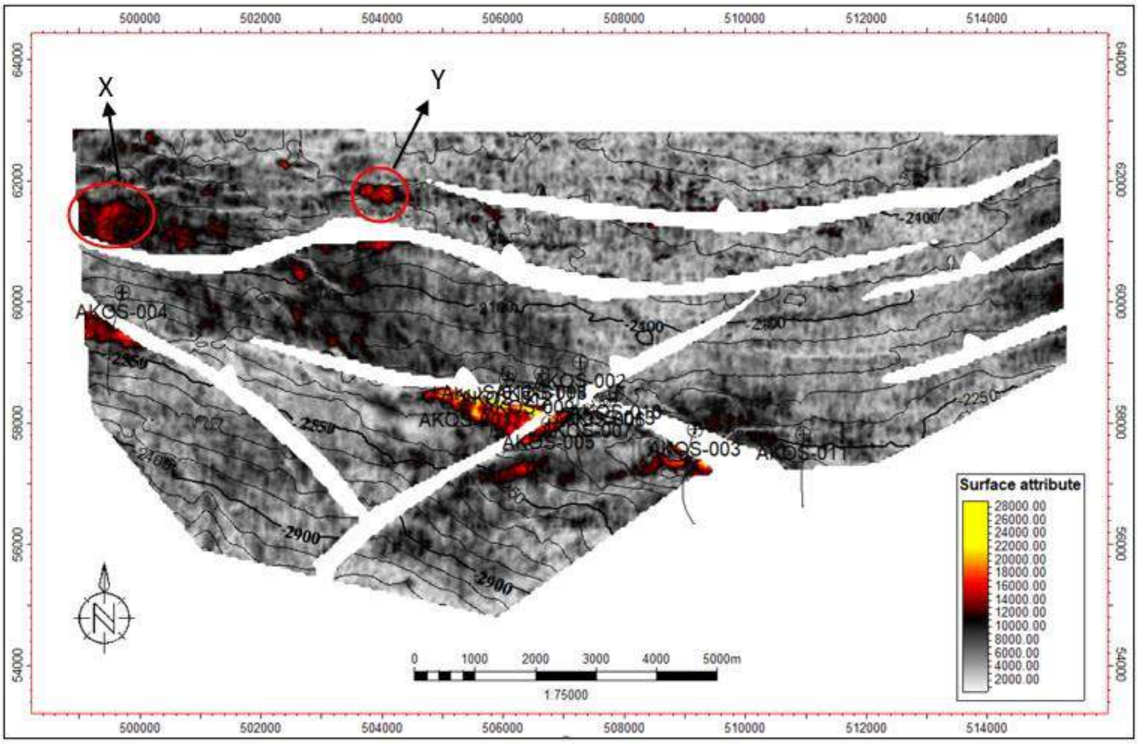


Figure 19: Maximum magnitude attribute for Reservoir B

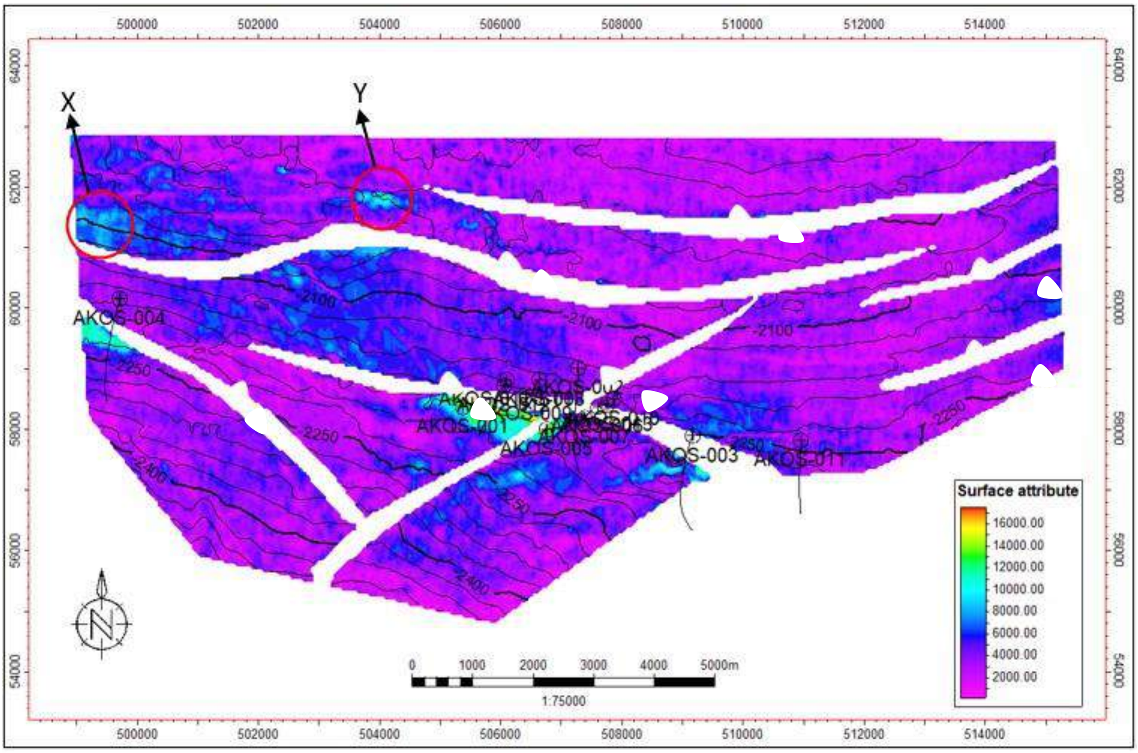


Figure 20: Average magnitude attribute for Reservoir A

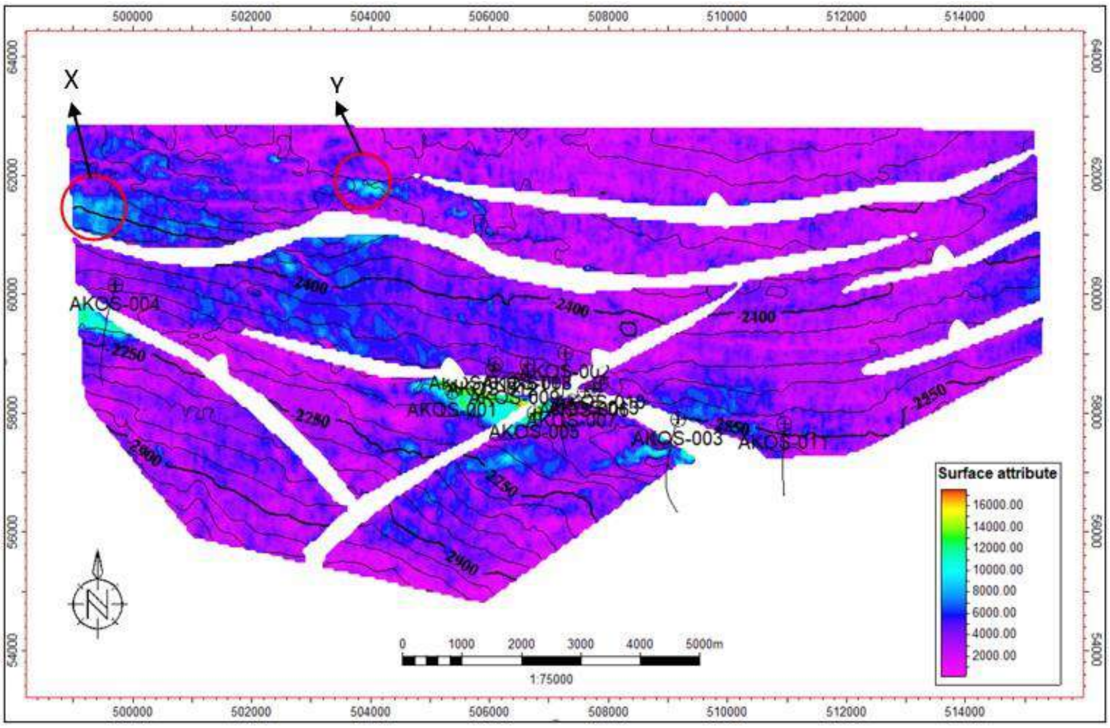


Figure 21: Average magnitude attribute for Reservoir B

CONCLUSION

This study helped to reveal other hydrocarbon potential zones away from the producing zone in the central portion of the field. More potential hydrocarbon prospects identified as X and Y in reservoir intervals of Reservoir A and Reservoir B are characterized by strong trapping features mainly faults and rollover anticlines structures which aid hydrocarbon accumulation. The reservoirs' fault dependent closures define the identified potential zones. Zones with high seismic amplitude responses support the presence of hydrocarbon in the identified undrilled areas of the reservoirs. Furthermore, the Root-Mean-Square amplitude attribute also revealed subsurface reservoir structures that supports hydrocarbon deposits in this field. This study revealed that seismic amplitude attributes such as the RMS, Envelope, Average Energy, Maximum Magnitude and Average Magnitude can provide information on the existence and distribution of hydrocarbons reservoir sand, thereby assisted to untangle prospective zones where there are no well controls in this type of field. The identified faults and hydrocarbon prospect which are not visible using the conventional seismic data can be identified by these seismic attributes for better interpretation in this type of geological field type. However, this study recommends that fault seal analysis should be carried out in this prospective zone to verify the competence of the trapping mechanism of the area.

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