# Reservoir Structural and Stratigraphical Evaluation of Sapele Deep Field, Niger Delta, Southern Nigeria

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**ORIGINAL RESEARCH**

**Abstract-** Throughout the course of a field's existence, the oil and gas industry has not been very good at determining and forecasting how the stratigraphical and structural makeup of reservoirs will affect fluid flow. With harder-to-find reserves and growing development costs, it is critical to have a comprehensive plan in place to identify and reduce risks and uncertainties related to the stratigraphical and structural framework of reservoirs. Improving predictive capability is therefore the main task of our day. The research area's outlined strata thickens from north to south. On the other hand, the research area's considerable fault density is revealed by the structural interpretation. There is a noticeable throw to these faults, which may provide a route for the migration and deposit of hydrocarbons. Anticlines, which are important components of the majority of the Niger Delta's massive oil fields and have the potential to have several pay horizons, are typical structural types. The two defined horizons in the research region contain Sweet Spots (Bright spots), according to the Root-Mean Square Amplitude map analysis. 3D seismic cube and well log data were used to assess the research area's reservoir structural and stratigraphical framework. The study region is located between 50 33' 42.22" E and 50 53' 54.43" N.

**Keywords-** Hydrocarbon, Stratigraphical, Structural, Sweet Spot, 3D Seismic Cube.

## 1 Introduction

Over the past twenty years, the structural and stratigraphical examination of reservoirs has changed from a straightforward technical review to the collaboration of multidisciplinary teams; petroleum engineers, geologists, geophysicists, and petrophysicists. The way these diverse fields have been integrated has altered our understanding of the properties of gas and oil reservoirs. Although these reservoirs were once thought to be relatively simple geologic features, they are actually quite complex and can be divided into architectural elements or compartments based on a variety of structural and stratigraphic features (Slatt, 1998).

A reservoir is hidden beneath the surface, therefore part of the fallacy stems from the fact that one cannot see it. Therefore, from the beginning to the end of the evaluation process, researchers should anticipate that the field will be divided and categorized, even at scales that are too small for standard subsurface technologies to detect. Accurate quantification of the reservoir geometry can be achieved by merging the several disciplines listed above. The hydrocarbon-rich Sapele Deep Field (Figure 1) is a brown field composed of highly compartmentalized reservoirs containing gas and light oil.

### 1.1 Location of the Study Area

One of Niger Delta's most productive fields, Sapele Deep field has been used for more than 30 years. An onshore field is located in the northwest (Greater Ughelli depobelt) of Niger Delta oil province, as depicted in Figure 1, with distal component of OML 41 in Figure 2. Latitude 50 53' 54.43" N and Longitude 50 33' 42.22" E contain it. Situated 50 kilometers away from Warri, Delta State, the field spans 291 square kilometers.

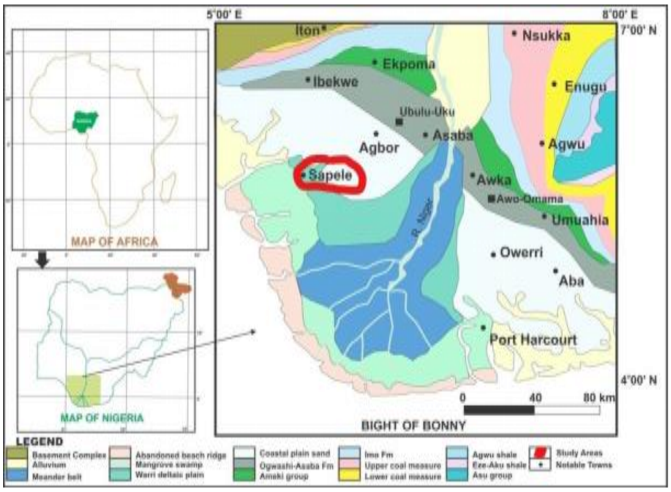


Fig. 1: Geological Map of the Niger Delta Basin showing the Study Area (Oyebanjo et al., 2018).

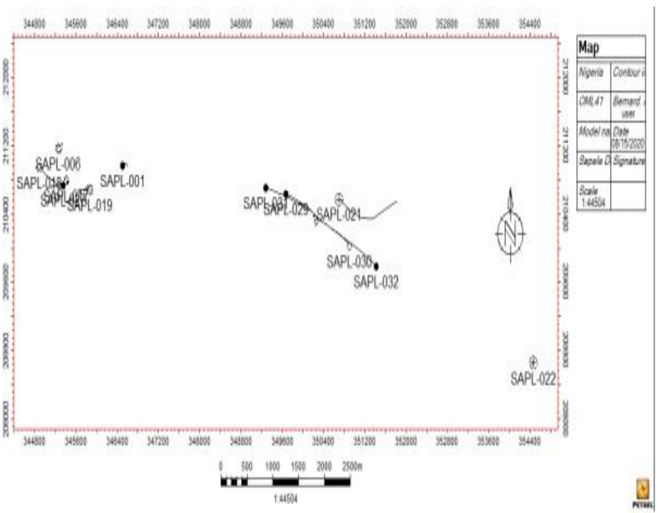


Fig. 2: Base map of oil wells in the study area (Using Petrel®2016).

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**Section F-** GENERAL SCIENCES, ENGINEERING AND TECHNOLOGY
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### 1.2 Structure and Stratigraphy of the Niger Delta

Plans for field development and production must take reservoir evaluation into consideration. Any petroleum reservoir, whether new or old, must be evaluated for maximum rate of production and maximum recovery of hydrocarbons. This requires a thorough understanding of the reservoir's lithology, fluid transport properties, Net-to-gross, water saturation, and permeability values, which are primarily determined by the reservoir's inherent depositional settings (Airen and Mujakperuo, 2023a).

Numerous synsedimentary faults and folds with an East-West trend bisect the Niger Delta complex. The differential loading of the underlying under-compacted Akata shales is what caused these structures, which are associated with growth faults. Along the top of the over-pressured Akata shale sequence, the growth faults flatten into a master detachment plane with depth. Listric normal faults account for the majority of the faults; nevertheless, Reijers et al. (1997) list antithetic, flank, crustal, and counter-regional faults are among the other types. The structure of the Niger Delta is intimately linked to its stratigraphy. The way that sediment supply and subsidence rate interact determines how each will evolve (Figures 3 and 4). The current Niger Delta is divided into three subsurface stratigraphic units, according to Knox and Omatsola (1989). Mainly composed of marine clays (Akata Formation), paralic sediments (Agbada Formation), and continental sands (Benin Formation), the delta series is topped by these layers.

A 3D seismic structural analysis of a portion of Aloo-Field, in the Southwest Niger Delta, by Ologe et al. (2013), identified the hydrocarbon reservoir's holding capacity as well as the intricacy of faulted subsurface structural characteristics. Several structural styles that are present in the examined area were revealed by creating structural maps utilizing the fault interpretations and horizons from the seismic part of the Petrel software, which was utilized to analyze the 3D seismic data. Three different horizons were mapped. Subsurface features such as the geometry of the identified horizons, the W-E trending growth fault, the fault strata, most of which dip eastward, and fault-assisted closures at the north-western-central portion of the studied section are displayed on depth structural maps that have been generated for all surfaces of interest. The growing fault's dipping pattern matches that of the indicated faults, strengthening the hydrocarbon's ability to be trapped (Aigbedion et al, 2018).

The growth fault and rollover anticline, which are associated with the Niger Delta, are the two main structural trapping processes that are now in place. This illustrates the significance of seismic structural interpretation in comprehending the existing structural types and their hydrocarbon-retentiveness (Airen and Mujakperuo, 2023b). Adeniran (1997) noted the absence of a single foraminiferal zoning scheme for the Niger Delta after studying the planktonic foraminifera from the western Niger Delta and defining six zones based on cosmopolitan planktonic foraminifera. In their 1999 investigation of five wells in the eastern Niger Delta, Okosun and Liebau verified the lack of a zonal strategy for the region. Foraminifera were found to be reasonably rich but poorly preserved in four wells studied by Ozumba and Amajor (1999) in the central and coastal swamp depobelts of the western Niger Delta.

Obiosio (2013) examined the paleoenvironment and bolivina biostratigraphy of the Tonjor-l well in the Niger Delta, documenting eighteen species of bolivina that had never been previously described there. The identification of the Late Early Eocene maritime transgression, which aligns with the global chronology of the Early Eocene transgression, was made possible by the stratigraphic diversity variation of the bolivinids. Larger test and the presence of costae indicate a deposition in a well-oxygenated slope to bathyal environment.

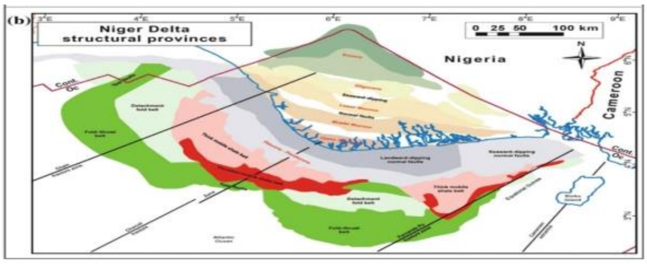


Fig. 3: Regional structural provinces map of the Niger Delta showing the Fractured Zones (Wiener et al., 2010).

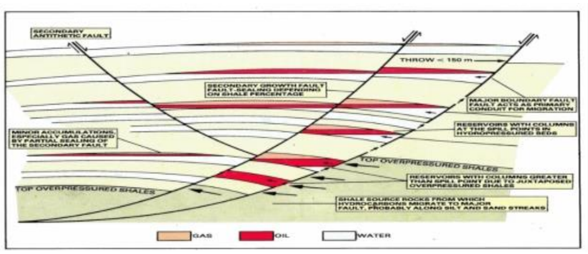


Fig. 4: Generalized sequence stratigraphic model for the Niger Delta showing the relation of source migration pathways and hydrocarbon traps related to growth faults (Wiener et al., 2010).

## 2 Materials and Methods

The suite of subsurface data, which comprises 3D seismic cube and well logs data supplied across the field, was utilized in the research endeavor. The Department of Petroleum Resources (DPR), Ministry of Petroleum, Nigeria, approved the publication of these subsurface data, which are owned by Seplat Petroleum Development Company PLC.

### 2.1 Operational Seismic Analysis

To prepare the Petrel®2016 workstation for interpretation, the 3D seismic volume and well data were methodically loaded. Subsequently, the 3D volume underwent structural smooth and trace automated gain control (AGC) volume attribute operations before realization. These were carried out to enhance weak events for better interpretability, reduce boosted noise, and extend the continuity of the seismic reflectors.

### 2.2 Fault Interpretation

Interpretation of geological faults was carried out on every tenth crossline and inline. Where the fault pattern was not visible on the inline or trace (cross line), arbitrary lines were drawn. The seismic lines' major and minor

 

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discontinuities were located and selected. These are the defects that are major and minor, respectively. At the representative levels, the problems were found on the traces, in-lines, and time slices. These found errors were given names, categorized by color, and evaluated.

### 2.3 Well To Seismic Tie
For well 01 (Figure 5), a synthetic seismogram with a sonic log was created, and this was utilized to link seismic to well data. Since there are numerous wells in the mature field, an arbitrary line was drawn inside the seismic data to calibrate the seismic to well data. The outcomes from both approaches were the same.

### 2.4 Horizon Definition
After connecting seismic data to well data, each time horizon was chosen based on how it related to the synthetic seismogram on the seismic section. For interpretation, the peak amplitude of the horizon was traced continuously. A depositional surface connected to a particular occurrence was described as a continuous reflection pattern. Every tenth in-line and every fifth cross-line, horizon monitoring was performed. For every fifth in-line and every tenth in-line, a denser grid was adjusted. Over the whole seismic volume, this mapping and digitization was completed.

### 2.5 Time And Depth Map
When understanding variations in thickness between interpreted horizons, time interval maps are frequently employed. For this investigation, the time interval map was created by contouring the values obtained from calculating the variations in time (often two-way time) between two occurrences at each shot point. On the other hand, a velocity gradient map was multiplied by a one-way time map to create the depth maps. Because of this, the times on a two-way map were cut in half before this computation. All that is needed to create a simple depth map is to multiply the one-way time by the velocity at each location where velocity data is available, then contour the results. Gridding the time and velocity maps and multiplying the time by the velocity at each grid point yields a significantly better result. By interpolating values across locations where data are available, both grids can be created. The products were contoured once time and velocity at each grid point were multiplied. For this investigation, the Schlumberger Petrel was utilized to perform the gridding approach.

### 2.6 Root-Mean Square Amplitude
The hydrocarbon prospects of the research area were ascertained using the Root-Mean-Square (RMS) amplitude, a post-stack amplitude attribute map. It served as an instantaneous direct hydrocarbon indicator (DHI) and improved the hydrocarbon bright spots. RMS values are typically larger when there are more differences in acoustic impedance, which are linked to variations in stacking lithology.

## 3 Results and Discussion
### 3.1 Well to Seismic Integration
Calibrated as well-tops along well-track and presented against seismic data are the regional stratigraphic markers, Maximum Flooding Surfaces, and Sequence Boundaries (MFSs and SBs), identified from well-log sequence stratigraphy. This allowed the markers/surfaces to be linked to seismic events (Figure 6). Seismic evidence was evaluated and used to limit their choices, including geometry and reflection terminations. Not all of the picks in the well-log sequence stratigraphic panel, though, had sufficient seismic tying throughout the study region.

Because certain extremely ancient MFS and SB were not picked in all of the wells—particularly in the wells farther out in the study region where they did not penetrate older units—it was challenging to map and tie these older markers across faults. Similarly, it was challenging to map extremely young MFS and SB throughout the whole research region since they are located within the chaotic and discontinuous reflections. These markers were extrapolated and mapped throughout the study region using pattern recognition and fundamental stratigraphic and structural geology concepts.

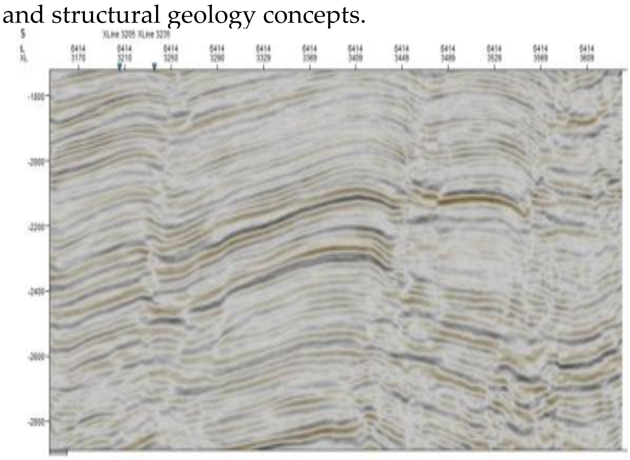

Fig. 5: Seismic Section of the Study Area (Using Petrel®2016)

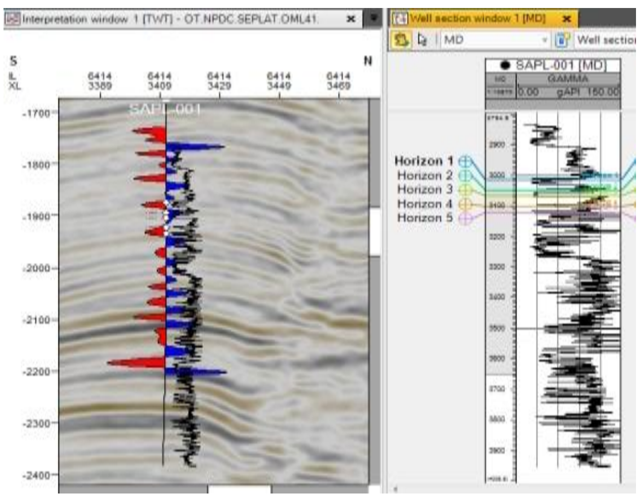


Fig. 6: Well to Seismic integration of Sapele deep well 01 (Using Petrel®2016)

### 3.2 Fault Interpretation
Reflection discontinuities and patterns observed and interpreted as faults are shown on the seismic volume and semblance map (Figure 7). With the use of interactive 3-D windows, these fault sticks were manually interpreted. This was especially significant and beneficial in the deepest portions of the seismic section, where tracing the continuity of a fault becomes more difficult due to a



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decline in data quality. While some faults, particularly the shorter ones, were linear, the majority of the interpreted sticks were large listric faults. The majority of the bordering regional (down-to-basin) faults are concave basinward and listric in origin. The majority of them are synthetic, and their dip direction matches that of the local stratigraphic package.

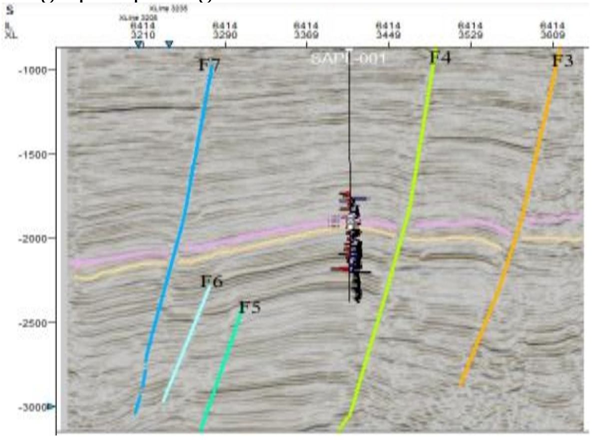


Fig. 7: Fault mapping of Sapele Deep Field (Using Petrel®2016).

### 3.3 Horizon Interpretation

Based on their strong seismic-to-well correlation and seismic continuity, the tops and bottoms of two important horizons from the corresponding fields were interpreted and mapped. For every horizon, contour maps of the structures were created. Figure 8 illustrates that sand units were associated with high amplitude reflection events, whereas shale units were associated with low amplitude reflection events.

Iteratively, horizontal picks were made in both in-line and cross-line directions, with misties fixed. Where reflection quality and features are strong, lines are selected at bigger intervals; in places where reflection quality is relatively low and chaotic and discontinuous, lines are selected at closer intervals to minimize mismatches to an acceptable level. Horizons 2 and 4, respectively, are the two horizons that were traced across the dip and strike portions. According to interpretation, these stratigraphic surfaces often thicken from the north to the south (basinward).

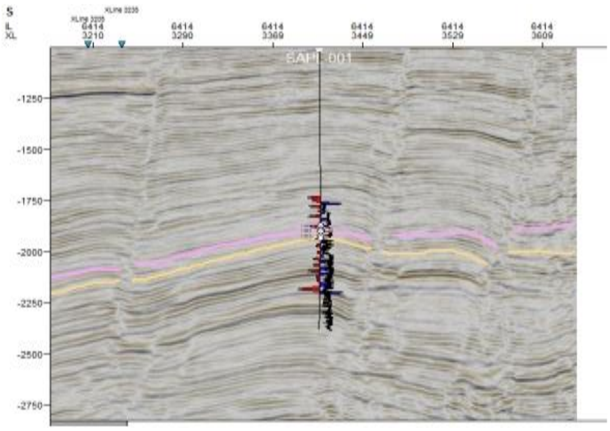


Fig. 8: Horizon Mapping of Sapele Deep (Using Petrel®2016).

### 3.4 Geologic Modelling

This stage involves creating a three-dimensional framework of the faults and horizons by modeling the interpreted fault horizons. Mapped/picked faults and horizon lines were used to construct seed grids. To create a structural and stratigraphic framework, as well as horizon maps of certain regional markers, this was gridded using the relevant module in the software interface. Moreover, boundary polygons were drawn on these horizon lines and fault sticks to produce structural top maps. In a three-dimensional window, Figures 9 and 10 depict the fault and horizon framework.

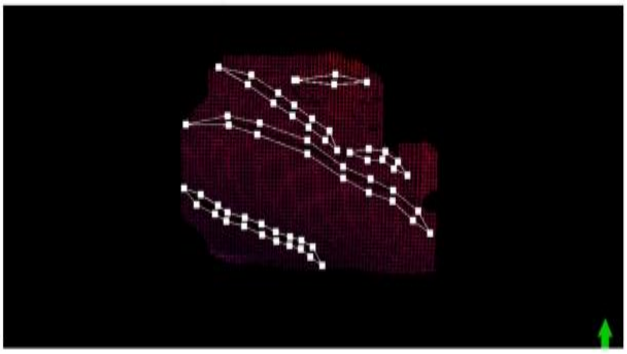

Fig. 9: Structural model of Sapele deep horizon 2 (Using Petrel®2016)

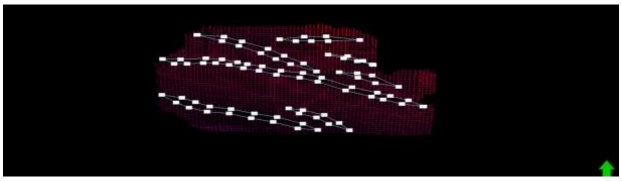

Fig. 10: Structural model of Sapele deep horizon 4 (Using Petrel®2016).

### 3.6 Time–Depth (T–Z) Conversion

Time–depth conversion was done using the checkshot data of the field. The 1D polynomial function plot (from T-Z relationships) generated was based on Petrel's depth conversion and Microsoft excel workflows. The polynomial equation indicates that R2 coefficient is high (approximately = 1.0) thus giving a high confidence that the time–depth relationship is correlatable (Figure 11).

$$\text{Two}-\text{Way Travel Time (TWT) vs Z (Checkshot)}$$
$$Y = -1E - 0.6x2 + 0.2222x + 253.28$$
$$R2 = 0.9951$$

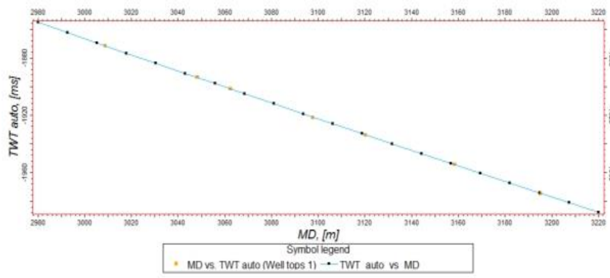


Fig. 11: Time-Depth (T-Z) curve generated from checkshot data (Using Petrel®2016).

### 3.7 Time Structure and Depth Maps

Geological features that could be the subject of an exploration are typically shown on structure maps. The time structure at the top of this horizon shows moderate to high structure trends from northwest to southeast, which is caused by the effect major fault, according to analysis of the contoured time structure map for the study area. The top of this formation has a low structure in terms of time structure on the northwest side of the fields. There are a few small faults on the study area's eastern and western sides. When the depth and time-generated maps are compared, they show the same structures. Growth faults and rollover anticlines are the main features that accommodate hydrocarbons, according to these maps (Figures 12, 13, 14, and 15).

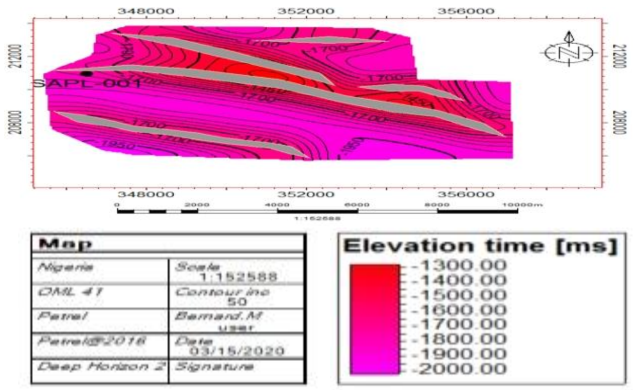


Fig. 12: Time Structural Map of Sapele Deep Horizon 2 (Using Petrel®2016).

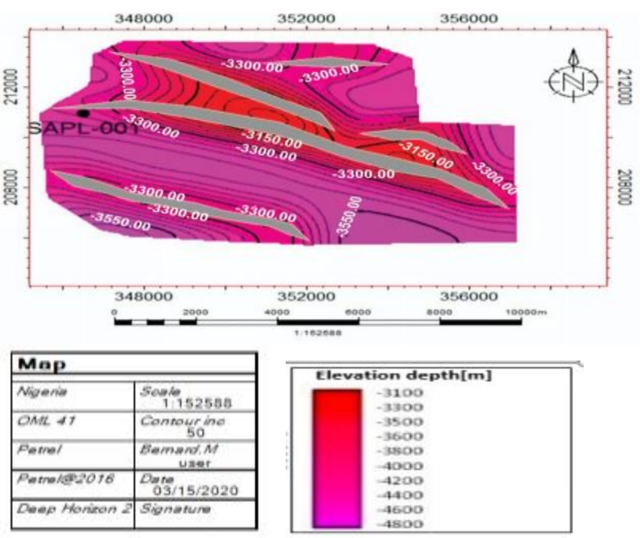


Fig. 13: Depth Structural Map of Sapele Deep Horizon 2 (Using Petrel®2016).

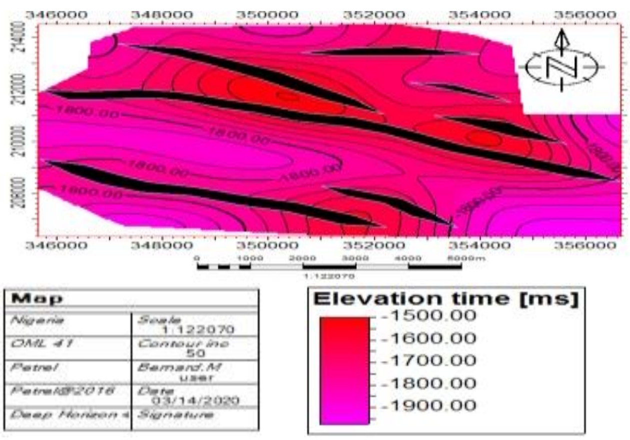


Fig. 14: Time Structural Map of Sapele Deep Horizon 4 (Using Petrel®2016).

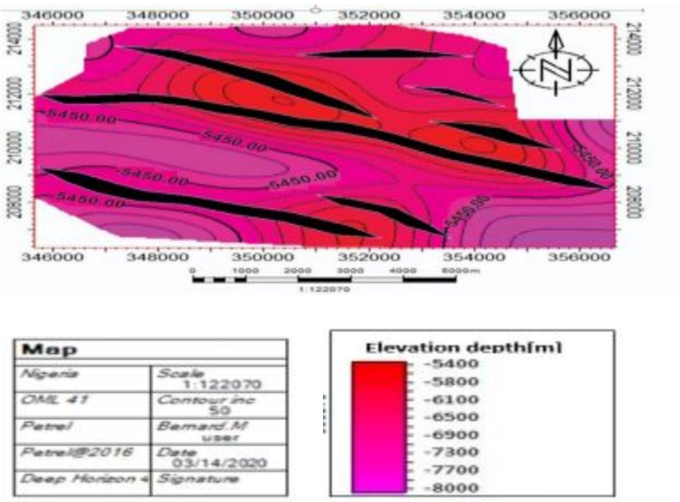


Fig. 15: Depth Structural Map of Sapele Deep Horizon 4 (Using Petrel®2016).

Identification and classification of entrapment structures were made easier by fault and horizon interpretations in the study area. The field has more E-W trending regional faults, rollover anticlines, and collapsed crest structures, according to studies done on the fault network and important horizons. Dependent on the faults are the closures. Simple faulty rollover, back-to-back constructions, and regional hanging wall closure are also found. According to the seismic interpretations, the fault structures disappear at lower elevations. However the E-W trending faulting is more pronounced at the shallow and intermediate intervals, with collapsed crest structures predominating. This indicates that the study area has a complex subsurface structure.

### 3.8 Root-Mean Square Amplitude Analysis

The research region's amplitude maps display the area covered by the bright spots, often known as "sweet spots," of different seismic properties that were calculated from the horizons. After several subjectively bright areas were found, the well-log data of interest and seismic amplitude were correlated. Because of the hydrocarbons that may be present in the indicated sands, the exceptionally strong reflections (bright spots) that have been seen are indicative of reservoir rocks (Figures 16 and 17).

The intensity of the color indicates the amplitude levels; the range of reddish yellow color indicates large amplitudes, while the range of dark blue areas indicates low amplitudes. The bright glow surrounding the well locations is indicated by a high amplitude pattern that could be the result of a locally greater-than-normal velocity contrast between two layers. Similar bright patches, which are likely promising but have not yet been verified, were seen in the northern portion of the map. Ajisafe and Ako (2013) and this finding are in agreement. For the two mapped horizons from the field, amplitude maps were created to support the structural interpretation. The discrete anomalous amplitude zones align with the previously identified structural high and the areas where wells have been dug. A valuable guide for developmental well drilling in the Sapele deep field would be the distribution of low amplitudes and high amplitudes, as the amplitude map correlates with the




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structurally high locations and bright spots from seismic characteristics analysis.

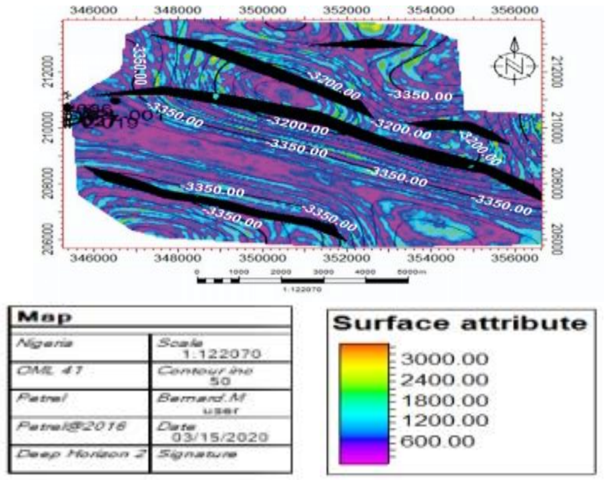


Fig. 16: Root-Mean Square Amplitude of Sapele Deep Horizon 2 (Using Petrel®2016).

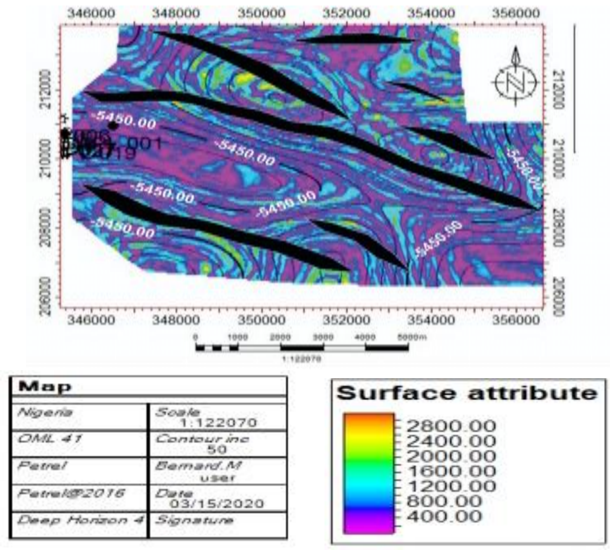


Fig. 17: Root-Mean Square Amplitude of Sapele Deep Horizon 4 (Using Petrel®2016).

## 4 CONCLUSION

The study area has a significant fault density, according to structural interpretation. There is a noticeable throw to these faults, which may provide a route for the migration and deposit of hydrocarbons. Fault interpretations that characterized the field's structural configuration revealed three main faults flowing east to west and dipping southward among numerous smaller faults. The majority of the significant faults in the field are synthetic, and they often descend to the basin as a result of progradation. The presence of a brilliant Spot (Sweet Spot) is indicated by the root-mean-square amplitude maps of two specified horizons in the study area. The possibility of undiscovered additional reservoirs in the field's core north and northeast is suggested by the bright spots on the RMS amplitude map. The studied area's structural and stratigraphic framework has generally demonstrated that there are, in fact, zones at deeper and intermediate intervals with well-developed trapping mechanisms and booming amplitudes that have not been drilled. This kind of potential hydrocarbon leads ought to undergo additional confirmation.

## ACKNOWLEDGEMENT

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