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Structural Seismic Interpretation of Olaj - field within the Niger Delta

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Abstract

Structural seismic interpretation is a key component of seismic interpretation workflow, as much information on reservoir architecture which is required for hydrocarbon play assessment can be obtained. This study presents the results of the integration of structural time-depth maps to define reservoir units across five (5) well for hydrocarbon play assessment of Olaj-field within the Niger Delta basin. Two reservoir windows (R1 and R2) were delineated from five wells (W-02, 04, 06, 07 and 012). The top and base of each reservoir window were delineated from the five wells using their gamma ray and resistivity log response. Well to seismic correlation was carried out with checkshot data from well-012. Structural interpretation for inline 6975 revealed about eight (8) faults labelled (F1, F2, F16, F8, F10, F18, F17 and F6) were mapped. It was observed that about five (5) faults (F1, F10, F18, F17 and F6) were identified as synthetic faults and dip basinwards towards the southern while about three (3) antithetic faults (F2, F16 and F8) were observed which dips landwards in the western direction. These are characteristics of growth faulting within the Niger Delta basin. Structural interpretation revealed a highly faulted reservoir system which depicts the tectonic setting of the Niger Delta.

Keywords: *Seismic section, Structural interpretation, Faults, Structural maps and Well log.*

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I. Introduction

Structural seismic interpretation is usually carried out in a bid to construct a geological model of subsurface structures suitable for hydrocarbon accumulation in a given region (Barde *et al.* 2000). Structural analysis of seismic sections is carried out mainly to locate structural traps holding hydrocarbon in place (Mike et al., 2003). This is done by studying the reflections on the basis of their amplitudes, and identifying structures suitable for hydrocarbon accumulation with the aim of producing structural time-depth maps of the studied horizons. However, integration of seismic data with other data types is necessary for proper interpretation of 3D seismic data (Hart *et al.* 1997). Therefore, integrating seismic and well data gives better results than either in isolation because both the areal coverage of seismic data and the accuracy of the well data can be tied together to give a direct correlation between seismic facies type and lithology, and this forms the basis of integrating both data.

The seismic reflection method ever since its discovery in the late 1920s, has and still remains one of the most effective tools in the search for hydrocarbons. Reflections are due to contrast in acoustic impedance in the subsurface caused by difference in physical properties of rocks which can be density and compressional wave velocity and can be explained in terms of lithology, porosity and pore fill (Karbalaali *et al.* 2013; Hansen *et al.* 2008; and Ukaigwe 2000; as cited by Eze *et al.* 2019).

Meanwhile, the principal objective of a 3D seismic survey is to delineate structures, exact definition of subsurface stratigraphy and rock physical properties which aid in mapping of geological structures suitable for hydrocarbon accumulation and will keep oil and gas from migrating either vertically or laterally (Eshimokhai and Akhirevbulu 2012). However, many structures that provide excellent traps do not contain oil and gas in economic quantities (Telford *et al*. 1976). And due to the high cost of drilling, effort is made to derive from the seismic data as much information as possible about the nature of the rocks and subsurface structures in an effort to form an opinion about the probability of encountering hydrocarbon in economic quantities in the structures delineated from the seismic records. Reflections are often identified with bedding planes based on correlations with observations in boreholes, velocity information, synthetic seismograms or previous history of the area (Telford *et al*. 1976).

The orientation and type of structural traps (anticlines and fault traps) delineated from seismic records depend on the stress fields to which they have been subjected (Hart 2000), and the underlying system of structure known as structural or tectonic style, provides a guide for interpreting ambiguous definition of structural features, especially where data volume are scarce. As such, the interpreter needs to be able to bridge the gap between the geologic information that is available for an area and the seismic data.

The aim of this study is to carry out structural seismic interpretation of Olaj field within the Niger Delta. The objectives of the study is to structurally interpret the 3-D seismic data for Olaj Field, to delineate the geologic features / structures inferred from acquired seismic data for the field and to produce 3-Dimensional structural models of the reservoirs showing the well positions with the intent of resolving the ambiguities associated with geologic complex formation within the study area.

II. Geologic Setting

The field under study is “OLAJ” field, which is an onshore field found within the Niger Delta. The Niger Delta is the largest delta in Africa with a sub-aerial exposure of about 75,000 km^2 and clastic fill of about 9000–12,000 m (30,000–40,000ft) and terminates at different intervals by trangressive sequence (Short and Stauble 1967). The onshore Niger Delta is situated on the Gulf of Guinea on the West coast of Africa and the portion of the province is delineated by the geology of Southern Nigeria and Southwestern Cameroon. The northern boundary is the Benin flank, an east–north-east trending hinge line south of the West African basement massif. It is also defined by outcrops of the Cretaceous on the Abakaliki high and further east–south-east by calaber flank, a hinge line bordering the adjacent Precambrian.

The tectonic framework of the Niger Delta is related to the stress that accompanied the separation of Africa and South Atlantic (Opara *et al.,* 2013). The stratigraphy of Niger Delta is complicated by the syn-depositional collapse of the clastic wedge as shale of the Akata Formation mobilized under the load of prograding deltaic Agbada and fluvial Benin Formation deposits. Three major depositional cycles have been identified within the Niger Delta; the first two involve mainly marine deposition that began with a major Paleocene marine transgression. The second of these two cycles started in late Paleocene to Eocene time, which reflects the progradation of a true delta with an arcuate wave and tide-dominated coastline. These sediments range in age from Eocene in the north to Quaternary in the south (Doust and Omatsola 1990; Opara *et al.*, 2013). Deposits of the last depositional cycle have been divided into a series of depobelts, also called depocentres or megasequences separated by major syn-sedimentary fault zones. These cycles (depobelts) are 30–60 km wide, prograde south-westward 250 km over the oceanic crust into the Gulf of Guinea and are defined by syn-sedimentary faulting that occurred in response to variable rates of subsidence and sediment supply (Doust and Omatsola 1990). A depobelt therefore forms the structurally and depositionally most active portion of the dalta at each stage of its development. In the Niger Delta basin, 9000–12,000 m is the thickness range of clastic sediments that was formed due to flap of complex regression of the delta sedimentary structure (Etu-Efeotor 1997; Nwankwo *et al.,* 2014).

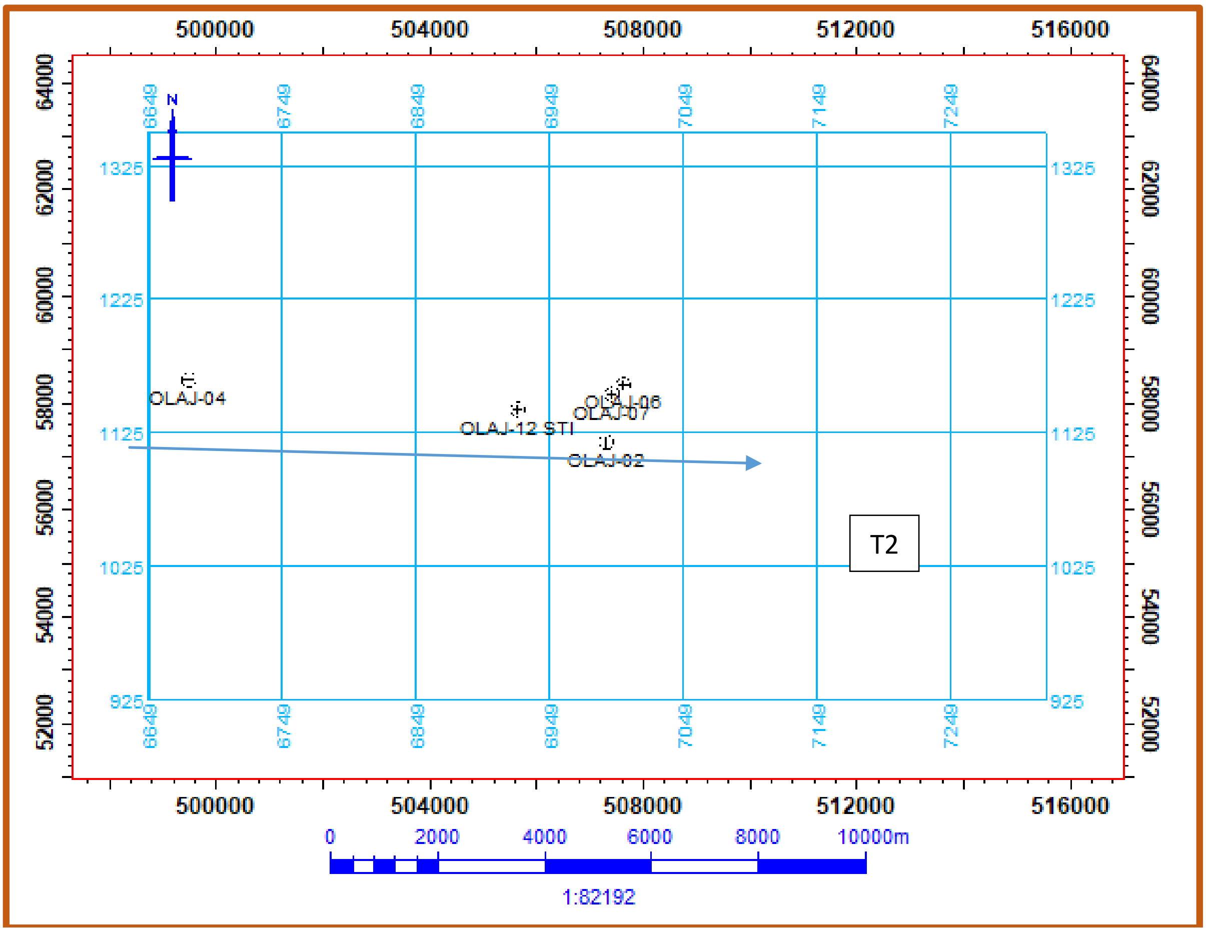

Figure 1: Base map of OLAJ field showing the seismic grid lines and various well locations (OLAJ -02, 04, 06, 07 and 012).

Identification of the Akata–Agbada system is the only single petroleum system known and it is called Tertiary Niger (Kulke 1995; Nwankwo *et al.*, 2014).

The geology, stratigraphy and structure of the Niger Delta basin have been greatly studied by several workers (Short and Stauble 1967; Weber et al., 1975; Avbovbo 1978; Evamy *et al.*, 1978; Owoyemi and Wills 2006; Bilotti and Shaw 2005). The areal extent of the delta is about 75,000 km^2 with a clastic fill of about 12,000 m (Nwankwo *et al.*, 2014). The world energy assessment of United States (US) geological surveys ranked the Niger Delta basin as the 12th most prolific petroleum system with 2.2% of the world's oil and 1.4% of gas (Klett *et al.*, 1997; Nwankwo *et al.*, 2014).

The Niger Delta basin is made up of three formations: (1) Benin, (2) Agbada and (3) Akata Formations (Short and Stauble 1967; Nwankwo *et al.*, 2014). The shallowest is the Benin Formation and it is made up of freshwater-bearing continental sands and gravels. Agbada Formation is the next on the sequence, underlying the Benin Formation; it consists of sand and shale intercalation with a thickness of about 3700 km. This forms a better representation of the actual deltic sequence and is the hydrocarbon reservoir unit of the sequence (Nwankwo *et al.*, 2014). The final on the sequence is the Akata Formation with 7000 m thickness range; it is made up of shales, clays and silts. This formation is of turbidite origin (Short and Stauble 1967; Nwankwo *et al.*, 2014).

III. Materials And Methods

3.1 Materials

In this study, 3D Seismic data (in SEG-Y format), well log data from about five wells and check shot data was used. The data set was provided by Shell Petroleum Development Company (SPDC) Port Harcourt.

3.2 Method

The first step in this study was to pick the reservoir intervals from well logs. The reservoir intervals were picked using a combination of gamma ray and resistivity log signatures across the five wells. Lithologic units are delineated in vertical succession by distinct surfaces which represent changes in lithologic character. Two reservoir intervals (marked R1 and R2) were picked at top and base. Well-to-seismic tie seeks to import wells information into the seismic. Checkshot data from well-012 was used.

Fault mapping was done by picking fault segments on vertical seismic sections and correlating them across from line to line (Peter and Amandeep 2013). Faults were identified on inline (dip lines) 6975 of the seismic section by selecting points where the seismic events are truncated or at points of discontinuity. Following this was the picking of horizons. Two reservoir horizons were picked for reservoirs R1 and R2 at different two way time's. Time structural maps were produced for horizons 'R1 & R2'; by plotting reflection times observed on inline 6975 for these horizons against shot point position on a map. However, since subsurface structures occur at depths, the time horizons maps were converted to depth to produce depth contour maps. Structural models were generated showing well positions and faults superimposed together.

IV. Results And Discussion

Figure 2 shows the reservoir intervals R1 and R2 at top and base delineated for the five wells, which were correlated to determine the lateral extent of the reservoir sand across the wells in the field. It was also observed that structural dip increased downward and decreases upward (extensive faulting was observed within the Agbada formation). This was so because faults and other structures tend to decrease upward (Benin formation) towards the surface (Etu-Efeotor, 1997). Figure 4 shows result of well-to-seismic correlation using a synthetic seismogram, with well-012 as control well. The figure also shows the zero phase wavelet which was convolved with density and sonic log from well-012 to generate the synthetic seismogram. Two horizons were picked on inline 6975 of the seismic section as shown in figure 5a. Eight (8) faults were interpreted on inline 6975 and labelled as (F1, F2, F16, F8, F10, F18, F17 and F6) in figure 5b. It was observed that the eight faults cut across reservoirs 'R1' and 'R2' and are therefore major faults.

About five (5) faults in figure 5b (F1, F10, F18, F17 and F6) were identified as synthetic faults as they dip basinwards towards the southern while about three (3) antithetic faults (F2, F16 and F8) were identified in figure 5b which dips landwards in the western direction. There are characteristic of growth faulting within the Niger Delta basin. In figure 5b, it was observed that the hanging wall block due to reverse drag or rollover anticline slided over faults F8 and F10, thereby creating subsidence where sediments can be deposited. Therefore, faults F8 and F10 create a rollover structure which cut across the reservoirs and invaluably responsible for trapping of hydrocarbon in the field.

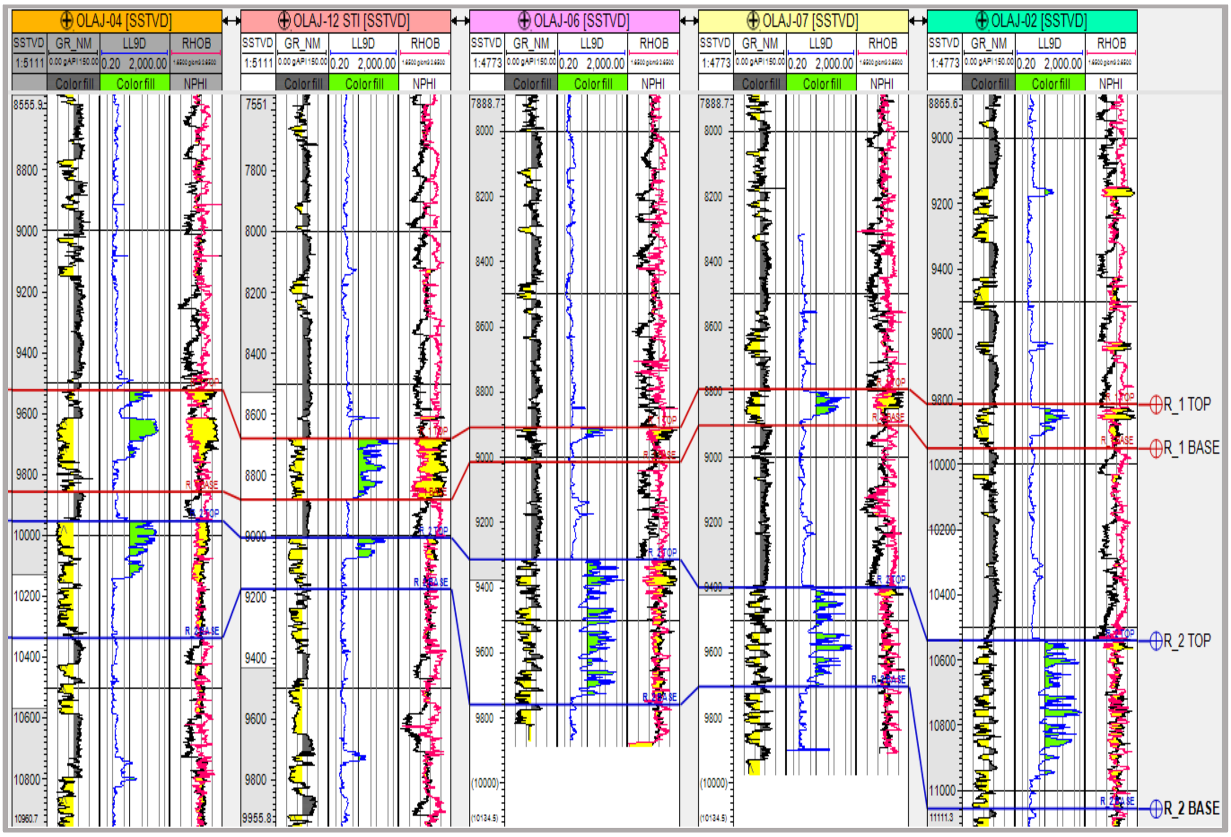

Figure 2: Well correlation for the five wells, showing the top and base of the reservoir intervals R1 and R2 delineated for each well.

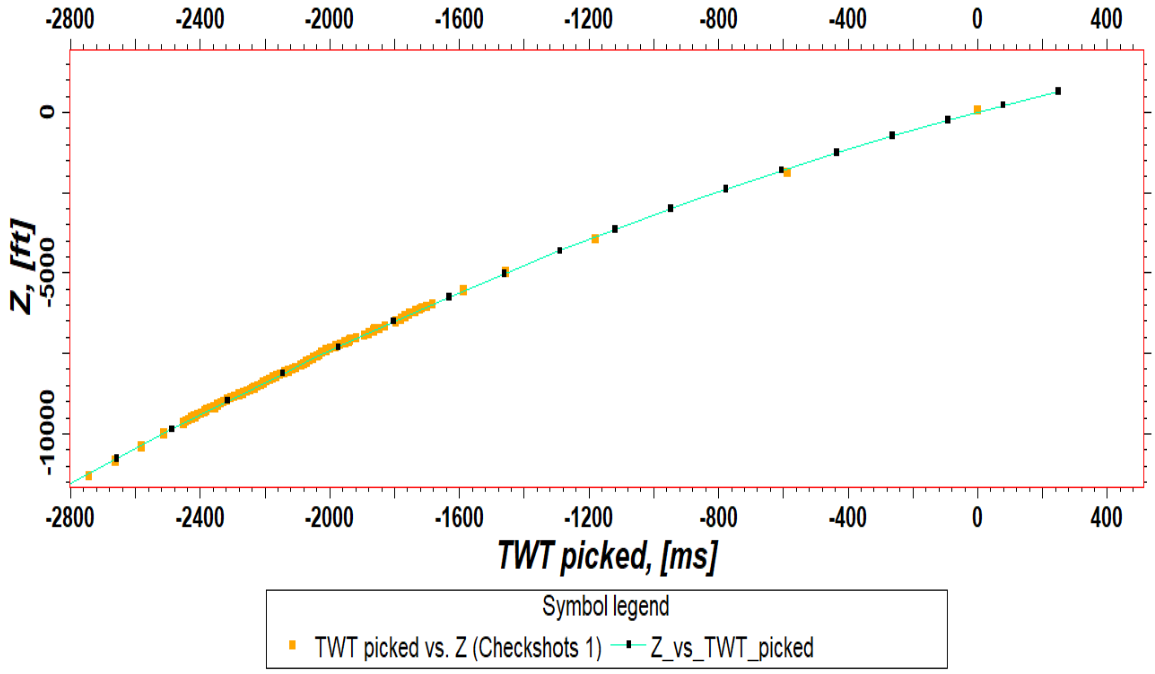

Figure 3: Time depth curve for well-012.

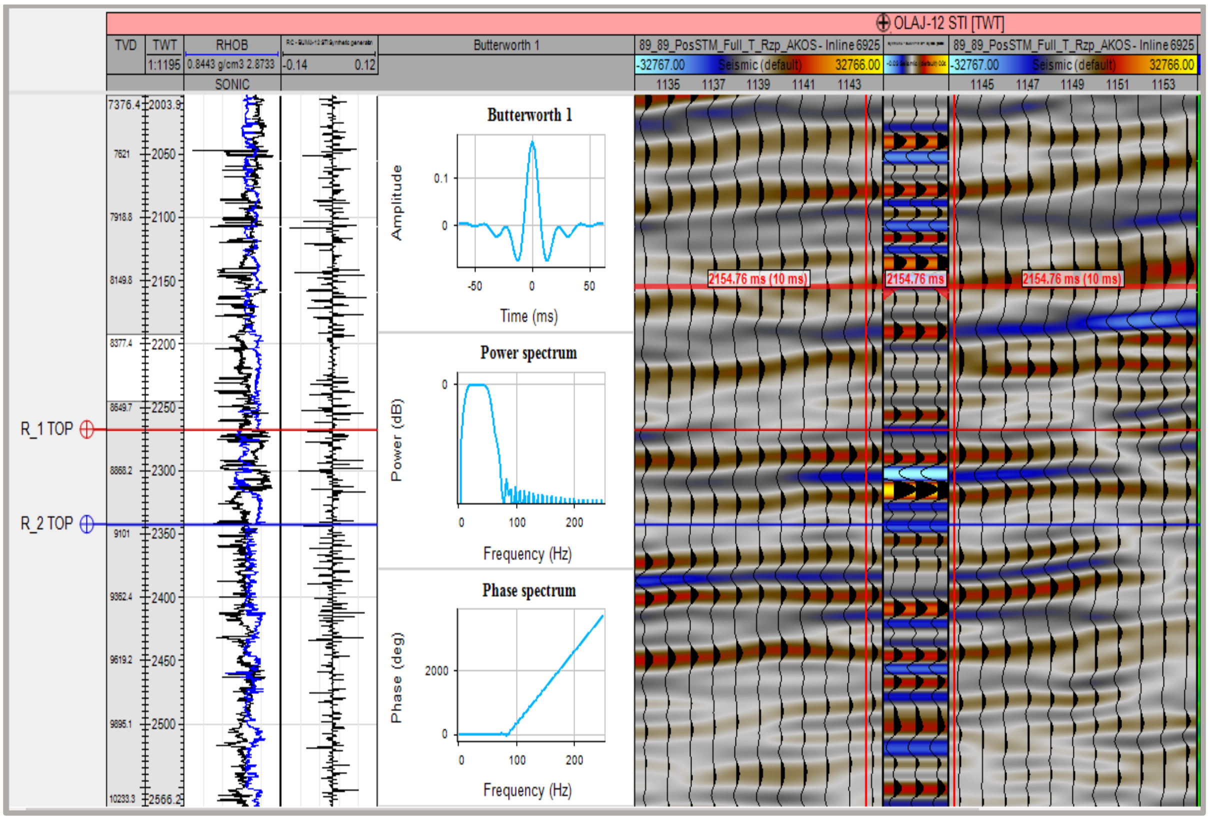

Figure 4: Seismic-to-well tie using synthetic seismogram.

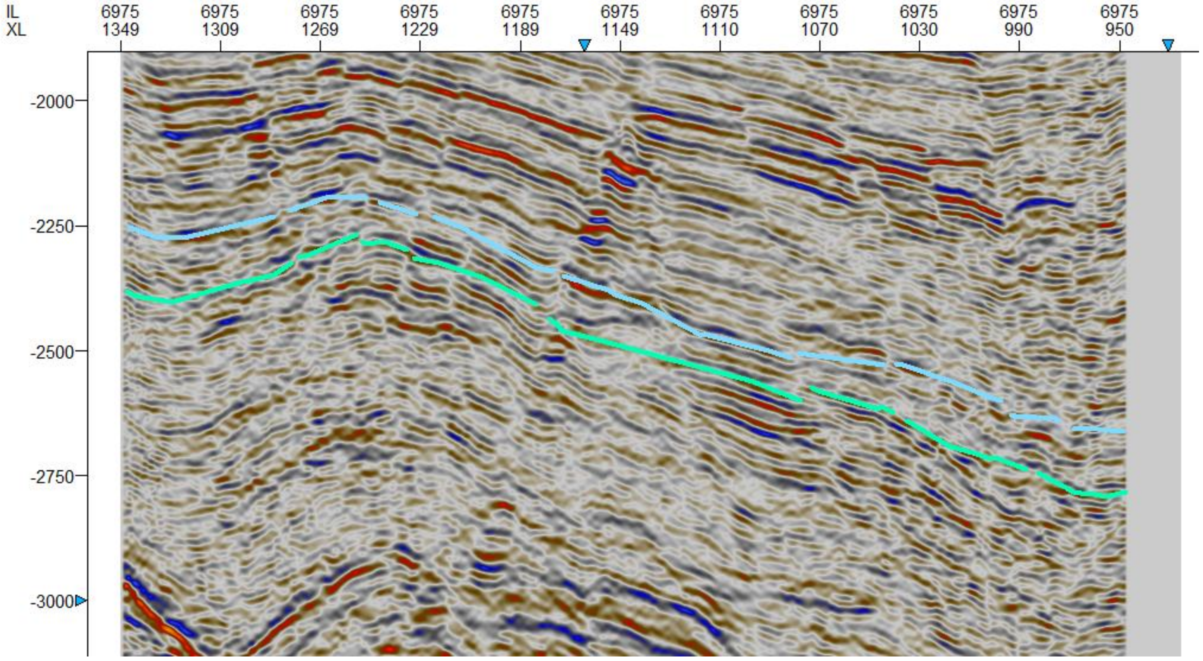

Figure 5a: Interpreted Seismic section for Inline 6975 showing the mapped horizons.

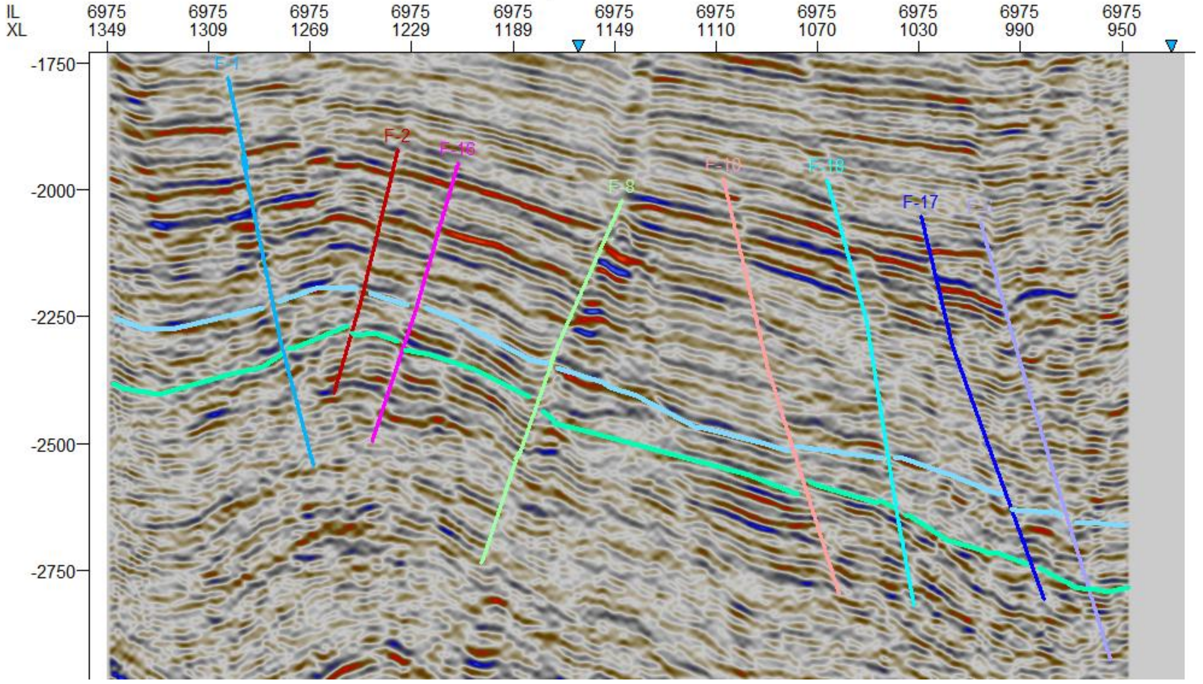

Figure 5b: Interpreted Seismic section for Inline 6975 showing the mapped horizons and faults.

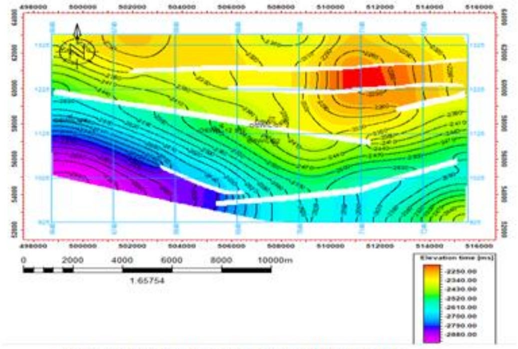

Figure 6a: R1 Top Structural time Map

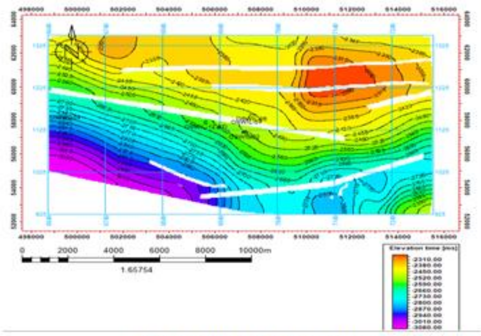

Figure 6b: R2 Top Structural time Map

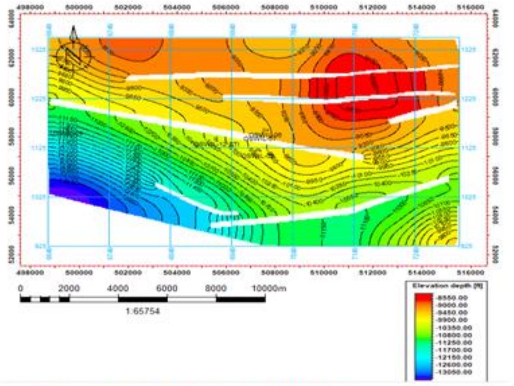

Figure 6c: R1 Top Structural depth Map

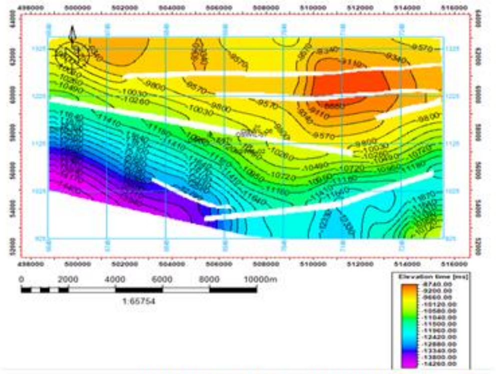

Figure 6d: R2 Top Structural depth Map

The shallowest and deepest parts of the top of horizons ‘R1’ and ‘R2’ were estimated to occur at a two way time of -2250.00ms and -2880.00ms for horizon ‘R1’ and two way time of -2310.00ms and -3080.00ms for horizon ‘R2’ on their time contour maps (figures 6a and 6b). For horizon ‘R1’, these times corresponds to depths of about 8550ft and 13,050ft respectively on the depth contour map for horizon ‘R1’ (Figure 6c). For horizon ‘R2’, it corresponded to depths of -8740ft and -14,260ft on the depth contour map for horizon ‘R2’ (Figure 6d). The depth maps for horizons ‘R1’ and ‘R2’ (figures 6c and 6d) showed the structural high closures against fault which are possible prospective zones across the study area. 3D skeletal and fault model generated for reservoirs R1 and R2 (figures 7 and 8) shows the faults cutting across the various well location on the surfaces within the 3D seismic volume.

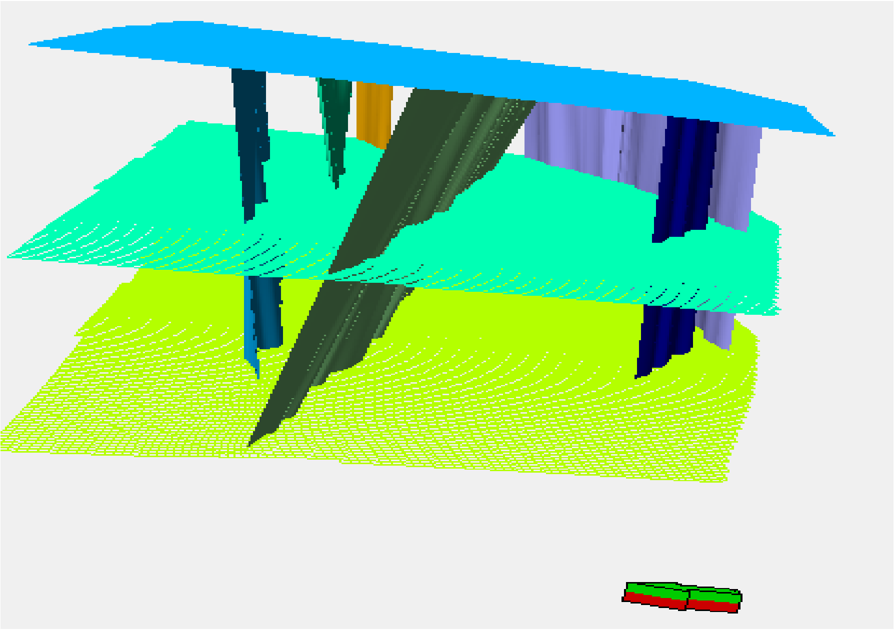

Figure 7: 3D Skeleton and fault model.

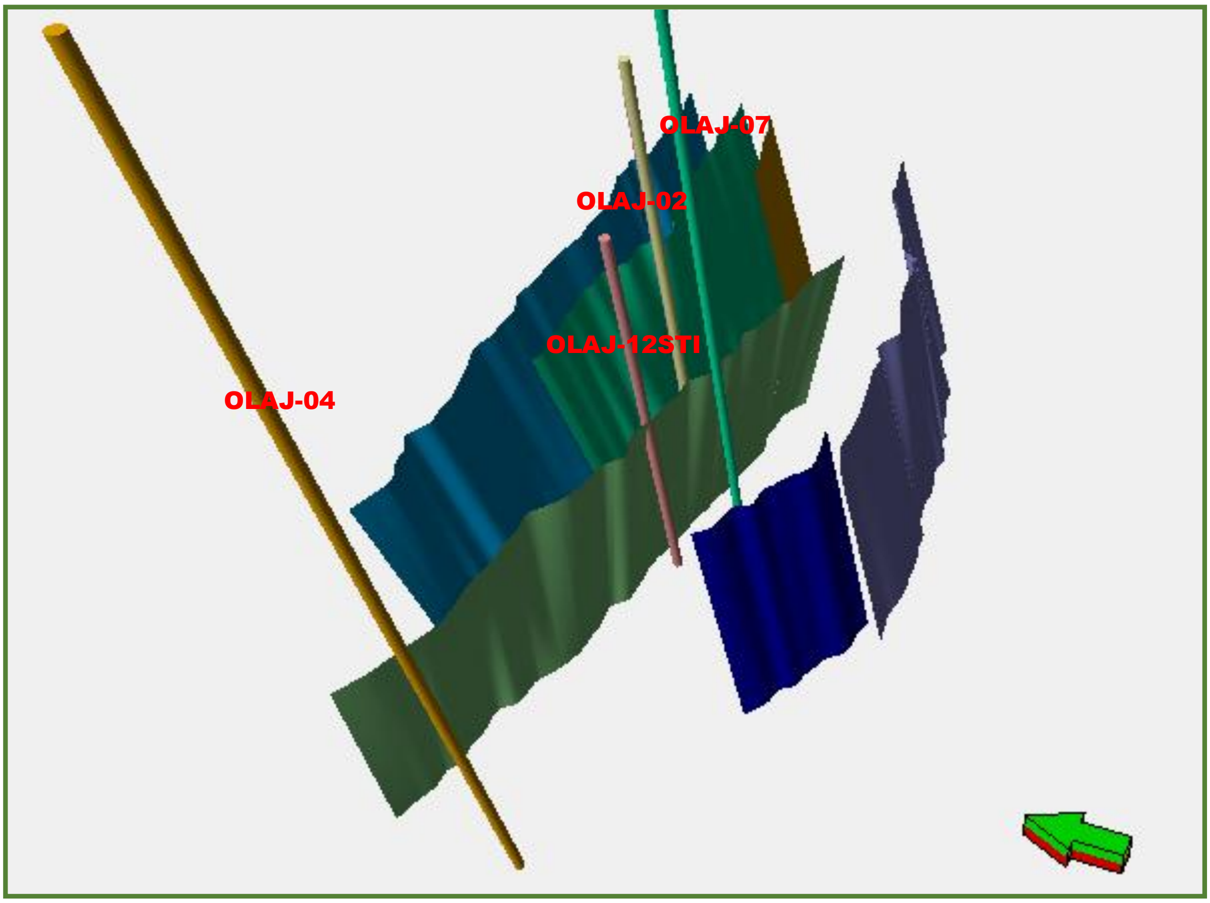

Figure 8: 3D Skeleton and fault model

V. Conclusion

This study has applied 3D seismic sections with well logs to delineate the structural style and trend of subsurface geological strcututres within the studied horizons to delineate hydrocarbon entrapment structures in the study area. Time-depth maps produced for reservoir horizons 'R1' and 'R2' delineated structural controls in the field which shows normal faulting and rollover structures as the principal structural features in the field which depicts a typical tectonic setting of the Niger Delta basin.

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