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Mapping of Structural Traps as a Tool for Hydrocarbon Prospectivity of the K-Filed of the Niger Delta, Nigeria

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Abstract

3-D Seismic reflection Data was used in this research work to map the subsurface structural features, infer geologic information and delineate tangible prospective regions of hydrocarbon potential in the study area. The aim of this interpretation is to identify faults and pick horizons, to determine hydrocarbon trapping potential of the field and to identify and delineate possible hydrocarbon prospects in the field using the 3-D seismic volume obtained from this particular field. Faults were picked at points of major discontinuities or displacements using the Opendtect software and the four fault planes are namely; F1, F2, F3, and F4. The Fault F1 which is described as the major growth fault is dipping in the southward direction. F2 and F3 seen as the antithetic faults were dipping northwards and the fault F4 is the minor growth fault dipping in the southward direction. It is therefore suggested that large areas covered by the growth and antithetic faults are the controlling factors responsible for economic hydrocarbon accumulation as well as the high retentive capacity of the reservoirs and the hydrocarbon trapping mechanism in the studied area. Two Horizons were also mapped; H1 and H2. These horizons are interpreted to be associated with strong reflections and high amplitudes associated with moderately to low frequencies. These results indicate that the hydrocarbon boundary is close to the strong or high amplitudes and moderately to low frequency as illustrated by the seismic attributes captured from the horizons.

Keywords: *Structures; Hydrocarbon; Seismic data; Faults; Niger Delta.*

1. Introduction

There is a greater demand in energy in the present 21st century, both locally and globally like never before as the world grows in anticipation to advance her economy with a view to improving the standard of living of her citizens. This has actually placed both pressure and greater challenge to increase in energy supply.

The advancement in computational technology to evaluate the probability of hydrocarbon presence in any basin has reduced the risk factor associated with hydrocarbon exploration. In Nigeria, oil almost constitutes exclusively the revenue base for national development and as such, demands greater efforts from both the Government and the research institutions to ensure that this non-renewable resource is adequately and optimally tapped.

In view of the exploration of the huge deposits of the natural resources, particularly the hydrocarbon deposits, the study of exploration geophysics has been of great relevance to the oil and gas industry as this helps the exploration industry in identifying and delineating structural features that could serve as possible traps for the accumulation of hydrocarbons

Owing to the fact that this lucrative natural resource fondly known as the 'black gold' has become the major source of the Nigerian economy, all efforts have been intensified over the years to ensure the continuous exploration and production of this hydrocarbon deposits.

Conventional seismic interpretation implies picking and tracking laterally consistent seismic reflectors for the purpose of mapping geologic structures, stratigraphy and reservoir architecture. The ultimate goal is to detect hydrocarbon accumulations, delineate their extent, and calculate their volumes. Conventional seismic interpretation is an art that requires skill and thorough experience in geology and geophysics [1].

The seismic amplitudes, representing primarily contrasts inelastic properties between individual layers, contain information about lithology, porosity, pore-fluid type and saturation, as well as pore pressure - information that cannot be gained from conventional seismic interpretation.

Geologically, identification of structural traps in this region has become a viable tool for the determination of hydrocarbon presence and accumulation in the Niger delta region of Nigeria.

Emujakporue [2] in his research work on the Assessment of Hydrocarbon Potential in Owem Field in Niger Delta, Nigeria showed that hydrocarbon pay zones were supported by horizons that are considered to be laterally continuous and geologic structures made up of anticlinal structures and growth faults through qualitative and quantitative interpretation.

The hydrocarbon prospect and the evaluation of reservoir potential within the onshore field of the Niger delta reveals that antithetic and growth faults were responsible for the hydrocarbon entrapment within this region characterized by mapped two horizons which were proposed to be laterally continuous [3].

Of interest to us in this research paper are the horizons that are considered to be laterally continuous and the major faults that aids the accumulation of hydrocarbon in this area which has become the object of economic prospect by researchers and the team of exploration and Production Companies.

1.1. Geology of the Niger Delta

The Niger Delta is ranked among the major prolific deltaic hydrocarbon provinces in the world and is the most significant in the West African continental margin. Oil and gas in the Niger Delta are principally produced from sandstones and unconsolidated sands predominantly in the Agbada Formation. The goal of oil and gas exploration is to identify and delineate structural and stratigraphic traps suitable for economically exploitable accumulations and delineate the extent of discoveries in field appraisals and development [4].

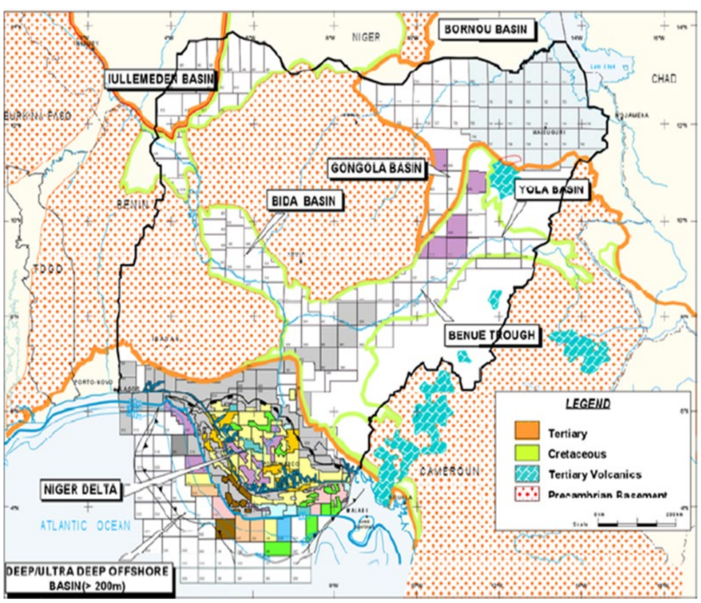

Fig 1. Geological map of Nigeria showing the Niger Delta Basin [8].

The Niger Delta, situated at the apex of the Gulf of Guinea on the west coast of Africa, covers an area of about 75 000 km^2 as shown in Figure 1. The Basement tectonics of the Niger delta related to crucial divergence and translation during the late Jurassic and Cretaceous continental rifting probably determined the original site of the main rivers that controlled the early development of the Delta. The Cenozoic development of the delta is also believed to have taken place under approximate isostatic equilibrium. The main depocenter is thought to have been at the triple junction between the continental and oceanic crust where the delta reached a main zone of crustal instability [6].

The Delta's sediments show an upward transition from marine pro-delta shales (Akata Formation) through a paralic interval (Agbada Formation) to a continental sequence (Benin Formation) as shown in Figure 2. These three sedimentary environments, typical of most deltaic environments, extend across the whole delta and ranges in age from early tertiary to recent [7].

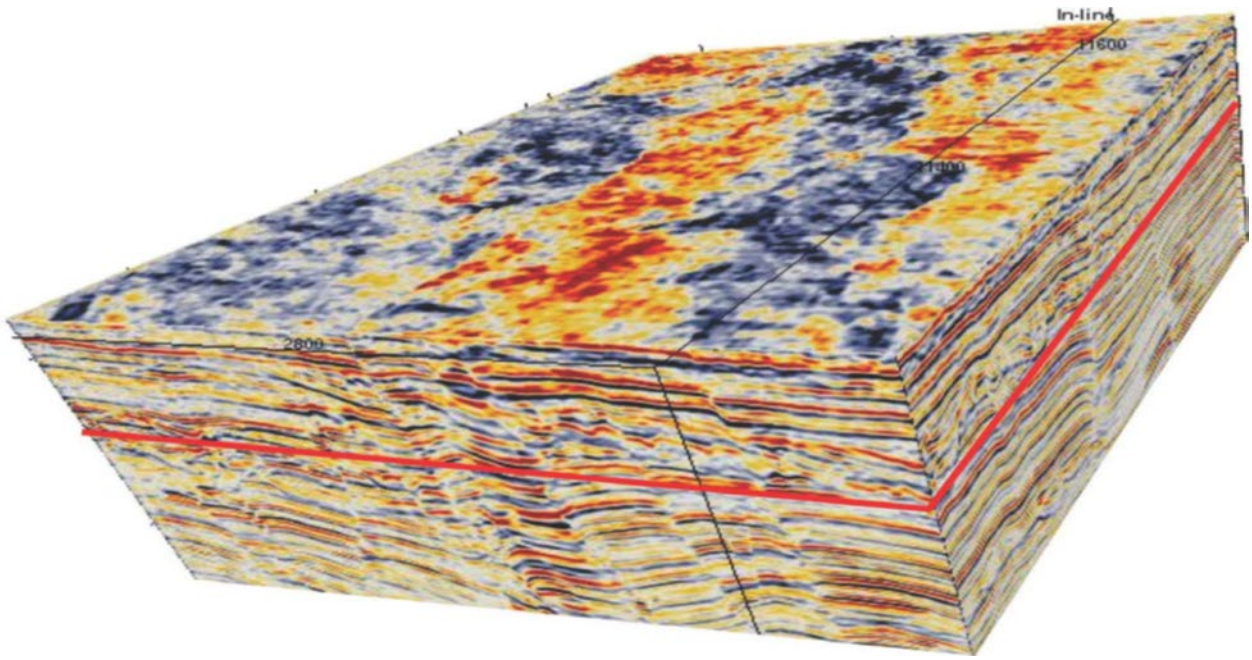

Fig 2. Perspective view of the 3D seismic volume used for this study. The red outline indicates the location of time slices extracted from the data.

The Niger Delta is said to be formed at the site of a rift triple junction related to the opening of the southern Atlantic starting in the Late Jurassic and continuing into the Cretaceous [7].

The Geophysicists and Geologists have shown that the Niger Delta Basin has spectacularly maintained a thick sedimentary apron and salient petroleum geological features favourable for petroleum generation, expulsion and trapping from the Onshore through the Continental Shelf and to the deep-water terrains.

The production of oil and gas is from accumulation in the pore spaces of reservoir rocks usually sandstone, limestone and dolomite. The formation is characterized by alternating sandstone and shale units varying in thickness from 100ft to 1500ft [5,9]. The sand in this formation is mainly hydrocarbon reservoir with shale providing lateral and vertical seal.

Petroleum in Niger Delta is produced from sandstone and unconsolidated sands predominantly in the Agbada Formation [10]. Most known traps in Niger Delta fields are structural although stratigraphic traps are not uncommon. The structural traps developed during sedimentary deformation of the Agbada paralic sequence. A variety of structural trapping elements exists, including those associated with simple rollover structures; clay filled channels, structures with multiple growth faults, structures with antithetic faults, and collapsed crest structures [11].

The onshore portion of the Niger Delta province is delineated by the geology of southern Nigeria and southwestern Cameroon. The northern boundary is the Benin flank, an east-northeast trending hinge line south of the West Africa basement massif [12]. The northeastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east-south-east by the Calabar flank, a hinge line bordering the adjacent Precambrian. The Tertiary section of the Niger Delta is divided into three formations, representing prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios. These are Akata, Agbada and Benin Formations [5].

2. Materials and method

The interpretation of the 3-D seismic volume was carried out using an interpretation software called 'Opendtect 4.3.0 version'. Opendtect version 4.3.0 is a C++ programme which is designed as an open source seismic interpretation programmed software used in interpreting structural features of the earth's subsurface from the 3-D seismic volume. The Opendtect software was used in picking and delineating faults and mapping of horizons with some associated attributes based on their seismic responses on the seismic section.

Accurate interpretation of geophysical data — in particular, reflection seismic data is one of the most important elements of a successful oil and gas exploration program. Seismic interpretation is a critical step in evaluating the subsurface. Interpretation turns the large investments in seismic data acquisition and processing into tangible value.

3-D Seismic reflection data was used in this research work to map the subsurface structural features, infer geologic information and delineate tangible prospective regions of hydrocarbon potential in the study area.

The data used in this study consist of a 3-D volume of seismic reflection data as shown in Figure 3 having a large number of Inlines and Crosslines. The procedures adopted for the structural interpretation of 3-D seismic sections were carefully done with consideration of the objectives of study.

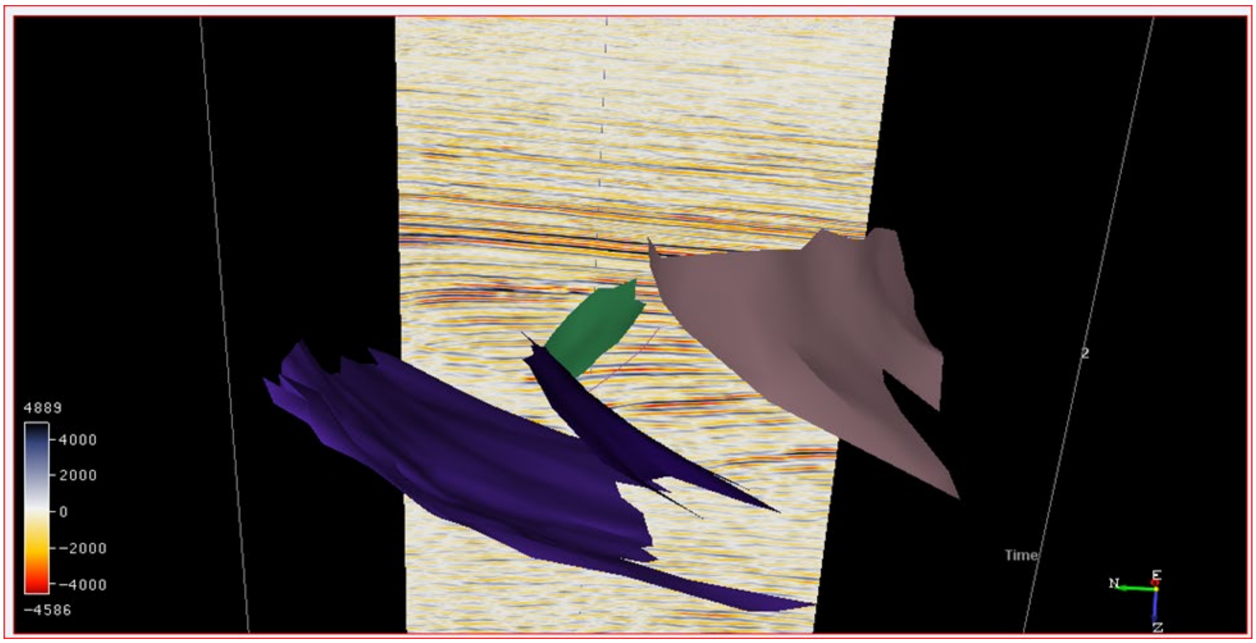

Fig 3. A 3-D view of fault display on the seismic section.

2.1. Fault picking

Faults which are displacements of rocks are easily identified and picked on the inlines (dip lines) of the seismic section by selecting/ clicking across points where the events truncate at points of discontinuity. Faults are fractural discontinuities in geologic arrangement associated with displacements. The faults picked were digitized from time surfaces on the 3-D window as shown in Figure 3 and Figure 4.

Faults were tracked at the various points of displacement or discontinuities using the Opendtect software. There were both growth faults and the antithetic faults in which some were dipping south and others dipping north. Identification of faults on the seismic section was based on changes in pattern of events across the faults which includes Reflection discontinuity at the fault plane, Vertical displacement of reflection events, Abrupt termination of events and Overlapping of reflections [13-15].

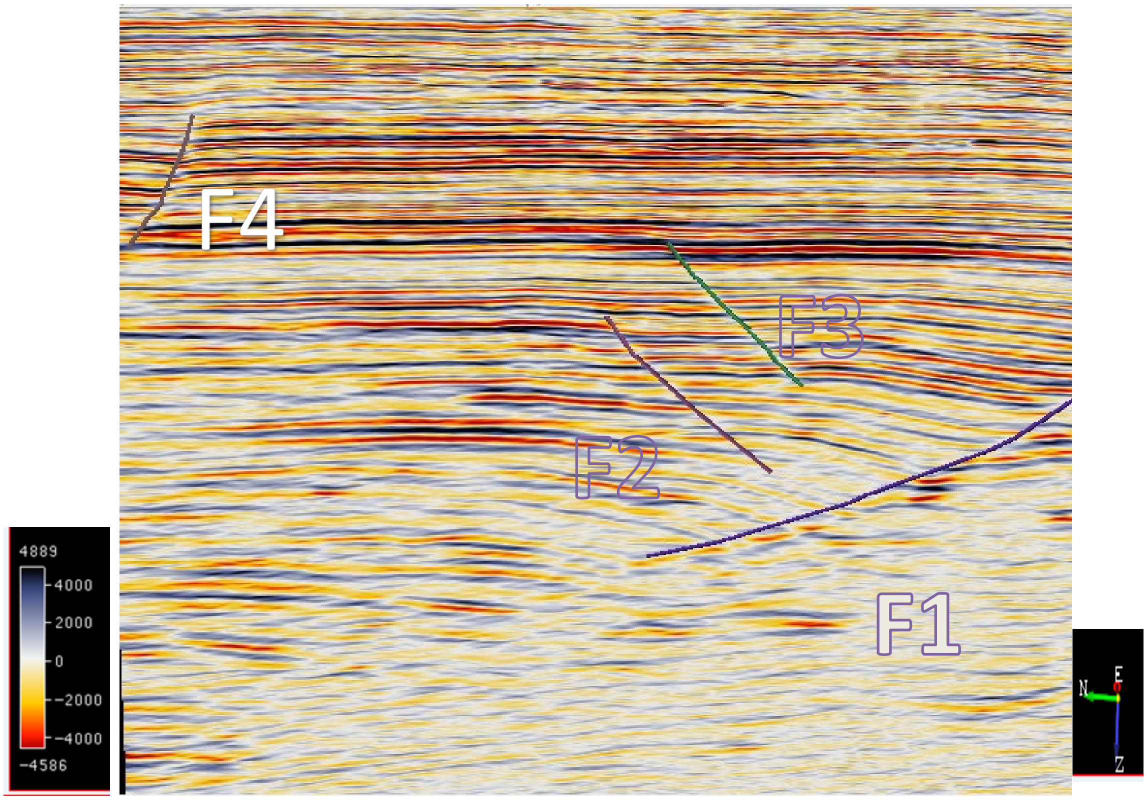

Fig 4. The four faults labelled on 11750 inline on the seismic section.

2.2. Horizon mapping

A horizon is a reflecting surface that appears on seismic sections and is recognized as coherent reflection event. It is the interface between two different rock layers. It is associated with continuous and reliable reflection on the sections that appear over a large area.

In this research work, two horizons were picked using the Opendtect software namely H1 and H2 and with some attributes analysis which includes amplitudes and frequency attributes as shown in Figure 8 to Figure 11.

3. Results

The Table 1 shows the interpreted faults in terms of their dip direction and fault type, and seismic attributes observed on the different labeled horizons on the seismic sections having F1, F2, F3 and F4.

Table 1. Interpreted fault types, their dip direction and their fault types.

Faults	Fault direction	Fault type
F1	South	Major growth fault
F2	North	Antithetic fault
F3	North	Antithetic fault
F4	South	Minor growth fault

4. Discussion

The seismic section has been found to contain some structural features from interpretational analysis. These structures include some faults and horizons with their associated seismic attributes captured from the Opendtect software which are found to have indications of hydrocarbon trapping capacities as illustrated by Figure 2 to Figure 5 and Figure 8 to Figure 11.

During the interpretation, a number of faults were identified and mapped but four faults of interests is displayed on Table 1. The faults F1 is a major growth fault dipping in the southward direction and we have the faults F2 and F3 described as the antithetic faults dipping in the northward direction and F4 dips in the south direction and is noted as the minor growth fault.

From Fig 4-Fig 6, two Horizons H1 and H2 were majorly identified based on their reflection patterns. H1 tends to be continuous with parallel – sub-parallel configuration, with strong reflection strength, uniform frequency and medium-high amplitude. This Horizon H1 is interpreted as massive sand body with shale intercalations deposited in a low energy deltaic plain of the Niger Delta. The moderate to strong reflection and medium- high amplitude with low uniform frequency distribution could indicate sharp sand-shale boundaries and their alternating successions.

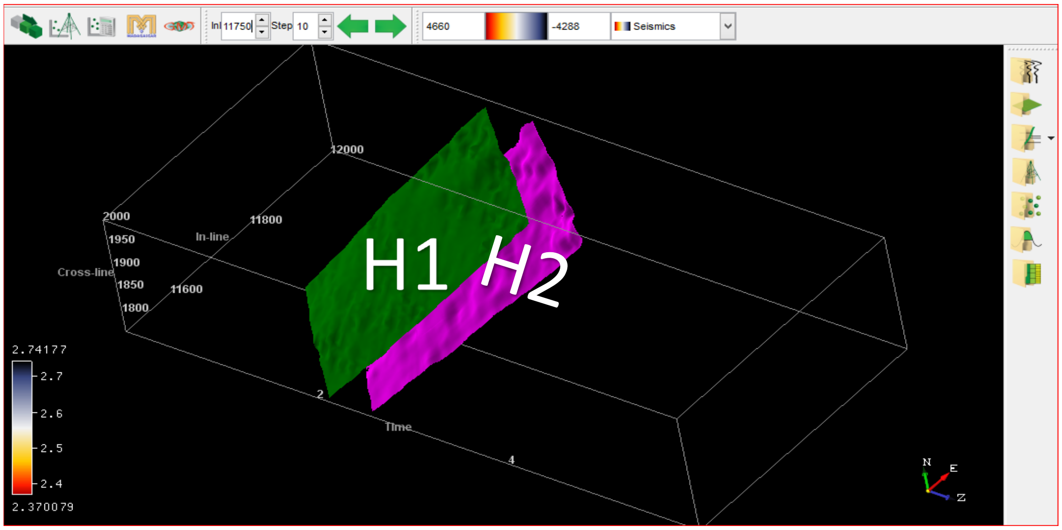

Fig 5. A 3-D view of the horizon display.

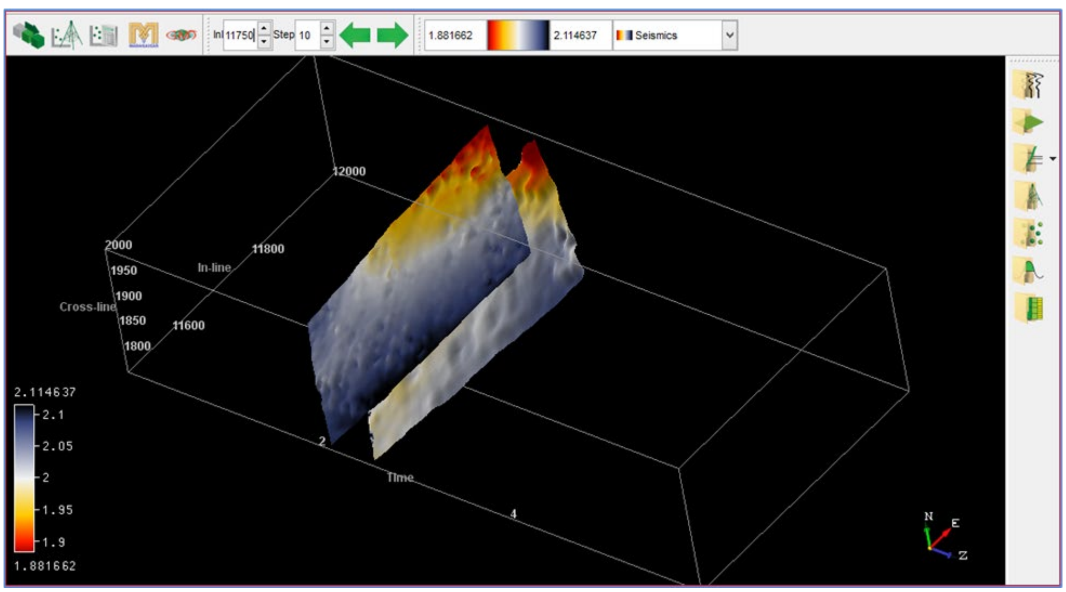

Fig 6. A 3-D view of the horizons display showing the depth characteristics.

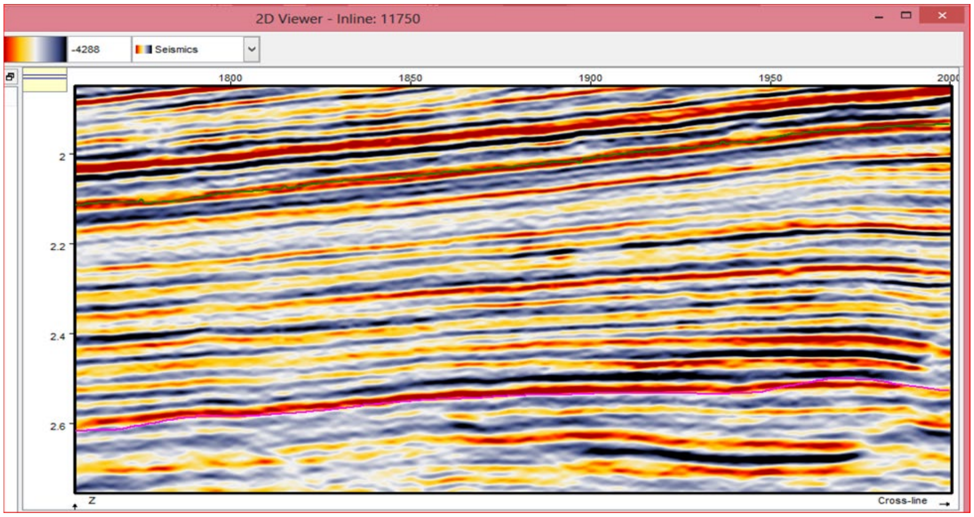

Fig 7. A 3-D display of two Horizons on inline 11750 (H1 represented by the green colour that passes through the horizon and H2 represented by the magenta colour that passes through the horizon).

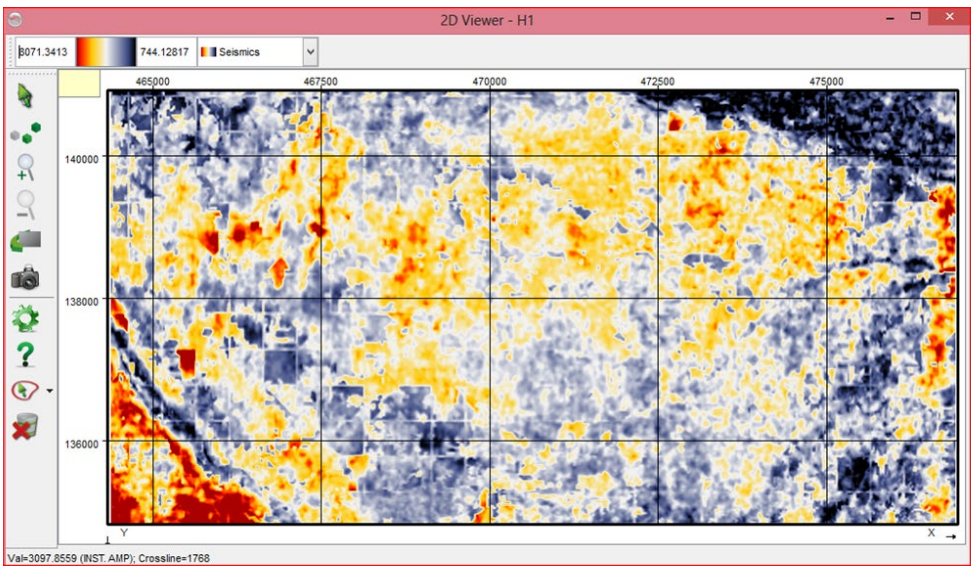

Fig 8. A display of 11750 inline amplitude attribute of Horizon 1 on the seismic section.

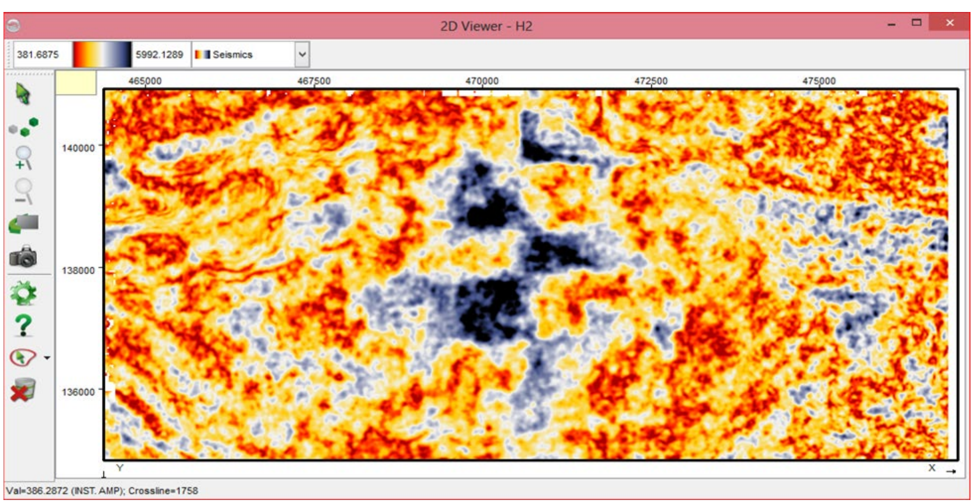

Fig 9. A display of 11750 inline amplitude attribute of Horizon 2 on the seismic section.

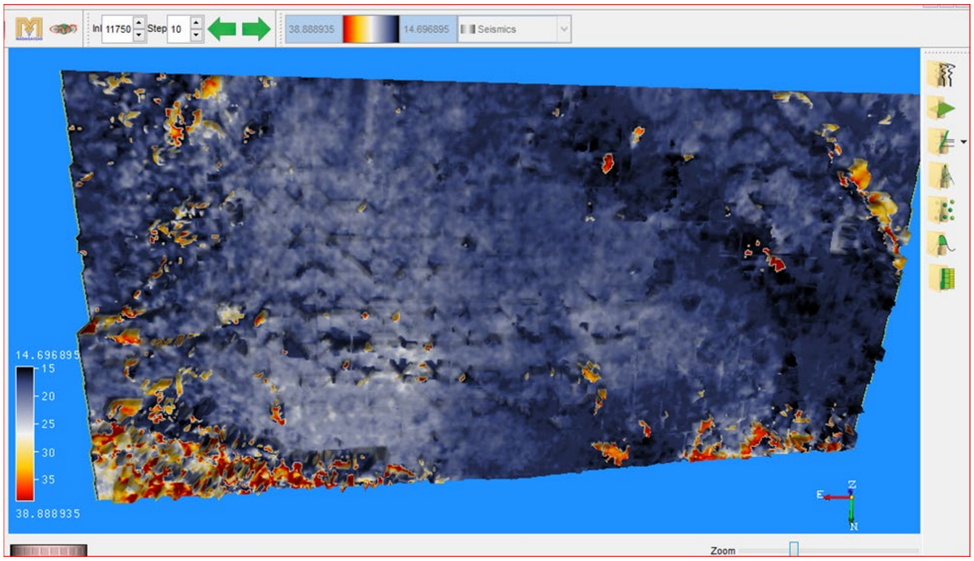

Fig 10. Frequency attribute display of horizon 1 on inline 11750.

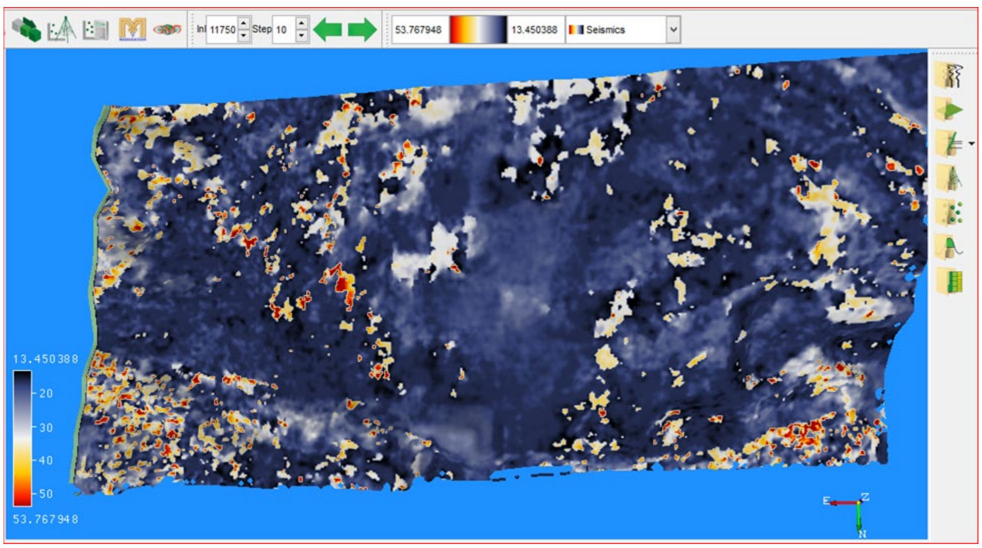

Fig 11. Frequency attribute display of horizon 2 on inline 11750.

Below the H1, is the horizon H2, which is characterized by parallel to sub- parallel reflection pattern or arrangement with a good continuity and high amplitude but with moderately low frequency distribution. The H2 has a good continuity with strong reflections. This horizon is interpreted as thick sand body with inter-bedding shale deposited in a medium-high energy deltaic front. The high amplitude and moderately low frequency distribution of H2 is interpreted as indication of alternating thick and thin lithology with relatively high fluid content. The very strong reflection strength implies high acoustic impedance contrasts of the lithology and variable hydrocarbon content within the reservoirs.

Interpretation of the results of similar works done by previous researchers in this field using similar methodology, show that the horizons are laterally continuous. The horizons mapped are all within the Agbada Formation where most of the hydrocarbon is believed to be trapped in the Niger Delta. The major structure responsible for the hydrocarbon entrapment in the field is an anticlinal structure and growth faults [2].

Recent study carried out within the same study area aimed at evaluating the productivity of a reservoir and the hydrocarbon entrapment through the analysis of trapping system within the study location showed that the study location is made of up of a highly faulted region that exhibit a typical Niger Delta tectonic setting [3].

5. Conclusion

The software Opendtect was used to interpret the seismic data. From the interpretational analysis, four faults, were identified which has a major growth fault trending south, two antithetic fault trending north and a minor growth fault having a dip direction in the southward. The growth faults may have acted as migratory paths for hydrocarbon flow from the underlying Akata Formation.

Anticlinal and fault assisted closures are regarded as good hydrocarbon prospect areas in the Niger Delta. It can be therefore suggested that the trapping potential of the field are attributed to faults, acting as fault assisted closures which have been perceived to be responsible for high retentive capacity of the reservoirs and the hydrocarbon trapping mechanism in the studied area.

The high amplitude and strong reflection strength along the margin of the faults are indication of the smearing of the faults and sealing of the reservoirs by clays or shale, thus trapping the hydrocarbons migration within the closures.

It is therefore suggested that large areas covered by the growth and antithetic faults are suggested to be the controlling factors responsible for economic hydrocarbon accumulation in this particular study area of the Niger Delta.

When a reservoir contains hydrocarbon, it often has strong reflection strength with strong or moderately-high amplitudes displayed on the seismic section which is also often associated with moderately-low frequency. The horizon H1 and H2 is associated with strong reflections and high amplitudes associated with moderately to low Frequencies.

These results indicate that the hydrocarbon boundary is close to the strong or high amplitudes and moderately to low frequency as illustrated by the seismic attributes captured from the horizon. The Frequency of the reservoir decreases in terms of the gas and oil accumulated in the reservoir and generally, the hydrocarbon layers show lower frequency than that of water layers.

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