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# Seismic Attributes Analysis as a Precursor to Hydrocarbon Indicators: A Case Study of "Ok" Field, Niger Delta

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**Abstract**

Seismic data volume was employed to gain more insights into the complexities of the hydrocarbon hosting units within and outside the vicinity of well control in the OK-field Niger Delta to overcome wrong deductions from complexly faulted subsurface configuration for the oilfield exploration programme. The methodology involved integration of well log with seismic data, seismic structural analysis and seismic attributes analysis. Horizons and fault interpretations were carried out to produce subsurface attribute maps. Lithologic panels derived from well log data showed that the study area is characterized by sand-shale interbedding. Two hydrocarbon bearing reservoirs were delineated within the study interval, namely: $R_1$ and $R_2$. Well to seismic tie revealed that these horizons tied direct hydrocarbon indicators (bright spots) on the vertical sections. Structural interpretation revealed that "OK" field is characterized by a rollover anticline, with a closed trapping mechanism for the D series and fault/dip trapping mechanism in the E series. The conclusion of the study was that the highly prospective areas are where bright spots were observed, while areas with dim spots are less prospective. The study has shown the ability of instantaneous amplitude as a requisite in prospect identification and reservoir prediction.

**Keywords:** reservoirs, fault, hydrocarbon, seismic, amplitudes, structures.

## Introduction

A seismic attribute is a quantitative measure of a seismic characteristic of interest (Adewoye et al. 2015). It a powerful tool to improve accuracy of interpretations and predictions in hydrocarbon exploration and development. It is therefore possible to use seismic attribute to map geological features such as faults. Petroleum resources remain vital to the economy of numerous nations of the world, but the enormous costs of exploration make it necessary to maintain a high level of precision in interpretations. At the exploration stage, the petroleum geoscientist wants to establish the four necessary ingredients that are associated with petroleum: the source rock, trap, seal, and reservoir (Asquith 2004). In some places around the world, the geoscientist may also need to know if the purpose of the drilling is to find oil or gas, since the values of the two can be quite different. Structural interpretations and seismic attributes analysis is an important aspect of the development programme of a field. Seismic attributes allow the geoscientists to interpret faults and channels, recognize depositional environments, and unravel structural deformation history more rapidly. It has diverse applications in many areas of 3-D seismic interpretation, among which include: helping to effectively analyse controlling influences on reservoir geometry, position and hydrocarbon migration pathways (Ologe 2016). The objective of seismic interpretation is to generate a coherent geologic account from an array of seismic profiles. This involves tracing continuous reflectors across 2-D grids of seismic lines or throughout 3-D data volumes. The lines of data acquisition will then form the basis of the geologic interpretations.

Interestingly, the Niger Delta is one of the world's major hydrocarbon provinces, with proven ultimate recoverable reserves of approximately 26 billion barrels (26 bbl) of oil and an under evaluated, but vast gas resource base (Ekweozor and Okoye 1980). Nigeria has an abundance of excellent seismic reflection profiles both onshore and offshore. Exploration of this valuable resource can provide bases for realistic earth science education in universities and the oil industry in Nigeria. Structural interpretation can form the basis of locating the traps for the hydrocarbon pool (Short and Stauble 1967). On the other hand, seismic attributes need to be integrated in some interpretations as they can be used as tools for predicting reservoir geometry and possibly displaying lateral changes in thickness including fluid contacts (Steiner and Lockhart 1988). Today, various methods have been developed for their applications to broader hydrocarbon explorations and development decision making (Brown 2004). Drilling results in the study area indicated that the presence of seismic anomalies does not always guarantee successful production of hydrocarbons. Improved methodologies are therefore needed to discriminate between true hydrocarbon indicators and non-indicators by imaging the detail subsurface structure with a view to delineate new hydrocarbon zones that might be hidden in structural traps for the development programme of the field. The study will also on the overall objective provide better and detailed understanding of the subsurface geologic structure in the area for future reference purpose.

**Location and Geological Setting of the Study Area**

"OK" field is located in the offshore southwestern Niger Delta. It is a prospect in one of the southwestern concessions belonging to an active oil company in Nigeria. It covers an area of approximately 41 $km^2$. The location map of the area is shown in Figure 1. The Niger Delta forms one of the world's major hydrocarbon provinces, and it is situated on the Gulf of Guinea on the west coast of central Africa (southern part of Nigeria). It covers an area between longitude 4–9º E and Latitude 4-9º N (Figure 1). It is composed of an overall regressive clastic sequence, which reaches a maximum thickness of about 12 km (Evamy et al. 1978). The Niger Delta consists of three broad formations (Short and Stauble 1967). These are the continental top facies (Benin formation) which is the shallowest part of the sequence and consists predominantly of fresh water bearing continental sands and gravels, Agbada formation which underlies the Benin Formation and consists primarily of sand and shale and it is of fluviomarine origin (it is also the hydrocarbon window) and the Akata formation. The lithofacies of the Akata formation is composed of shales, clays and silts at the base of the known Delta sequence. They contain a few streaks of sand, possibly of turbidite origin.

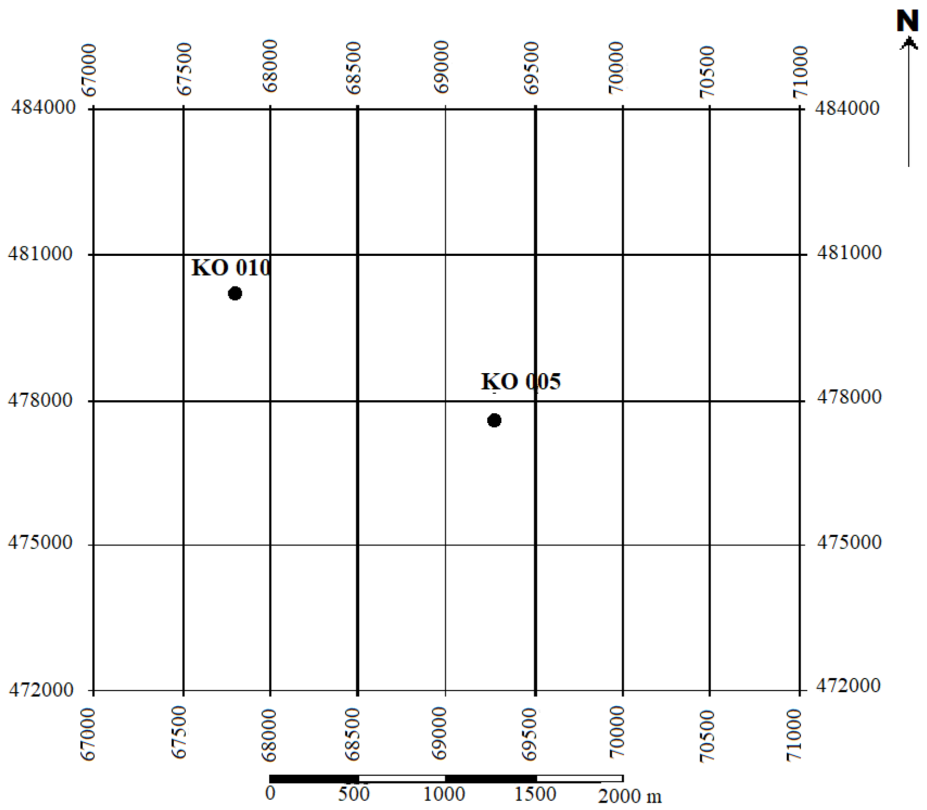


**Figure 1:** Base map of OK-field, Niger Delta showing well locations.

Characteristics of the reservoirs in the Agbada Formation are controlled by depositional environment and by depth of burial. Petroleum in the Niger Delta is produced from sandstone and unconsolidated sands predominantly in the Agbada Formation. Most known traps in Niger Delta fields are structural although stratigraphic traps are not uncommon (Doust and Omatsola 1990). The structural traps developed during synsedimentary deformation of the Agbada paralic sequence increases from the north (earlier formed depobelts) to the south (later formed depobelts) in response to increasing instability of the under-compacted, over-pressured shale (Evamy et al. 1978, Stacher 1995). The primary seal rock in the Niger Delta is the interbedded shale within the Agbada Formation.

**Materials and Methods**

The data used in the research were digital and they include the following:

I. Suites of well logs from two wells in the field-These include gamma ray log, density porosity log, neutron log and resistivity log. Gamma ray log was used in lithologic identification.
II. 3-D Seismic volume in SEG-Y format. This is the representation of the seismic data in form of a seismic volume.
III. Base map of the study area.

3-D seismic data (SEG-Y) is a collection of seismic reflection records that traverses the study area. Inlines and crosslines of seismic sections (vertical slices through the volume) were generated (with the interactive workstation, *Petrel*$^{TM}$) from the 3-D seismic data. Well data were tied to the seismic data after the mapped horizon was digitized, and this was done with the aid of synthetic seismogram. The reflections that matched the depth to top of the hydrocarbon zones on the well logs were noted. The top of hydrocarbon bearing sands tied with horizon picked on the seismic section.

**Theoretical framework of seismic reflection**

Seismic exploration is a geophysical method that involves imaging the sub surface using artificially generated sound waves. Surface receiving devices, or geophones are used to detect the seismic energy that originates from a seismic source (e.g. small dynamite explosion), travels down into the earth and gets partially reflected back to the surface at geological boundaries. The seismic records obtained from the field survey inevitably contain reflected events (signals) from subsurface rocks and also contains several types of unwanted noise. During data processing (deconvolution, stacking and migration), many unwanted effects are removed or reduced to a barest minimum. Seismic reflection interpretation involves structural analysis and seismic sequence analysis, and is the process of tracking significant geological boundaries (e.g. target coal seams) and producing two-way time (TWT) horizon surfaces. These TWT surfaces, together with the seismic volume itself, can be used to derive a number of secondary seismic attributes (i.e. TWT gradient, seismic amplitude, instantaneous frequency), to yield high-definition structural maps, locate stratigraphic anomalies, and provide detailed fault information.

**Results and Discussion**

Two hydrocarbon-bearing reservoirs were identified from the wells log analyses, namely Reservoir $R_2$ and $R_1$. Four different types of logs were used. They include the gamma ray log, density porosity log, neutron log and resistivity logs. Log values were read on well sections. Figure 2 shows Reservoir $R_1$ top revealed on well OK 010 at the depth of 3244.7 m. This was correlated in well OK005 at the depth of 3246.3 m. Reservoir $R_2$ was observed on well OK 010 at the depth of 3507 m and its top was correlated in well OK 005 (Figure 2) at the depth of 3538.5 m. The determination of hydrocarbons and water contacts was done with the aid of neutron-density porosity log overlay. This was also used to differentiate among gas, oil and water in the reservoir. Gas effect is created by gas in the pores. It causes the density porosity log to record high porosity and causes the neutron log to record too low porosity values. The neutron log records low porosity values because the hydrogen index which the neutron log measures is lower in gas zones. The cross-over point where an increase in density porosity (DPHI) occurs along with a decrease in neutron porosity gives the gas-oil contact (Asquith 2004). In order to determine the oil-water contact, the separation between the neutron and density curves were studied. They close up because neutron porosity increases (hydrogen index which the neutron log measures is assumed to increase in oil) and density porosity decreases. Again cross over points are witnessed and they define the oil-water contact.

**Well to seismic match and direct hydrocarbon indicator**

Seed picks of horizons were made on a grid of inlines and crosslines that covered the entire field in order to generate structure maps. Horizons are usually picked based on the prospective zones identified from well logs. Tops and bases of these horizons were mapped and correlated across the available wells as shown in Figure 2. The correlation was done using gamma-ray and resistivity logs. Three horizons (D7.5, E4.0 and E4.2) were mapped and correlated.

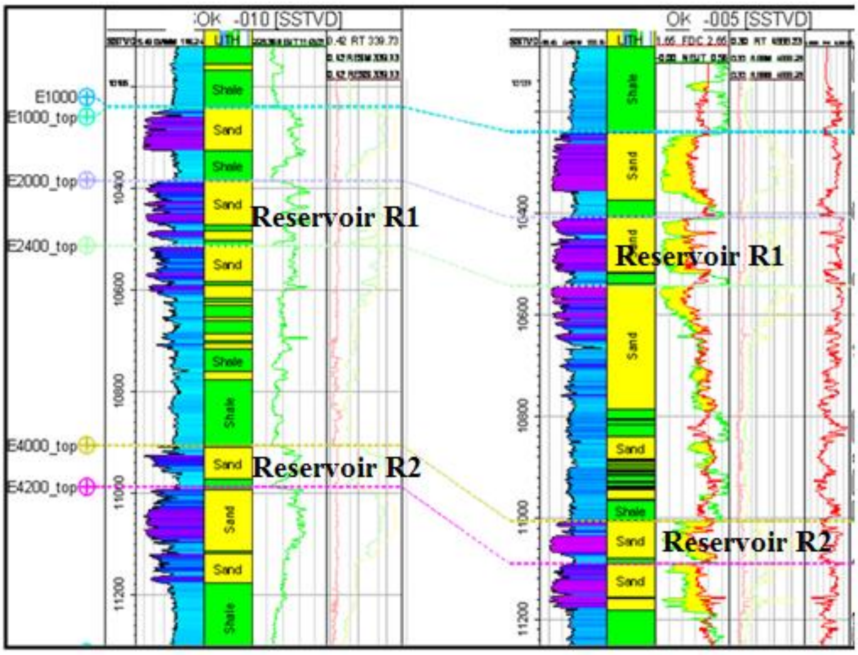


**Figure 2:** Well log section showing the reservoirs delineated and correlated across OK-010 and OK-005 wells.

The tops and bases of these horizons were tied to the seismic section (Figure 5) to aid the construction of necessary attributes map. Figure 3 and Figure 4 are synthetic seismograms generated for well to seismic matches of horizons D 7.5, E 1.0 and E 4.2. The synthetic seismograms show that the well ties with the seismic marker previously identified. In Figures 3 and 4, the tops were tied to a moderately black strong reflector labelled horizons E 1.0, E 4.2 and D 7.5. The synthetic seismograms indicated that the tops of the reservoir sands in the area are represented on the seismic volume by maximum amplitude reflections. The well to seismic match provides the basis for horizon identification and interpretation in the fluid. There is a good well synthetic match particularly with zero phased data. Most synthetic seismograms also show a reflection coinciding with the oil water contact at most of the matched wells. Since each horizon represents reflections, which are recorded in time, it is possible to post these two-way travel times on the base map and then contour them. This was done with the interactive workstation. The possibility of traps can increase with the detection of faults within the field because faults can serve as lateral barriers to the escape of hydrocarbon. Faults interpretations were enhanced using Dip attribute. Dip attribute is a time derived horizon attribute that converts a volume of seismic continuity (the normal reflections) into a volume of discontinuity, (Brown 2004). Spatial difference or edges in the seismic volume are made more noticeable so that faults can easily be seen as lineation or dark bands (Coffen 1998).

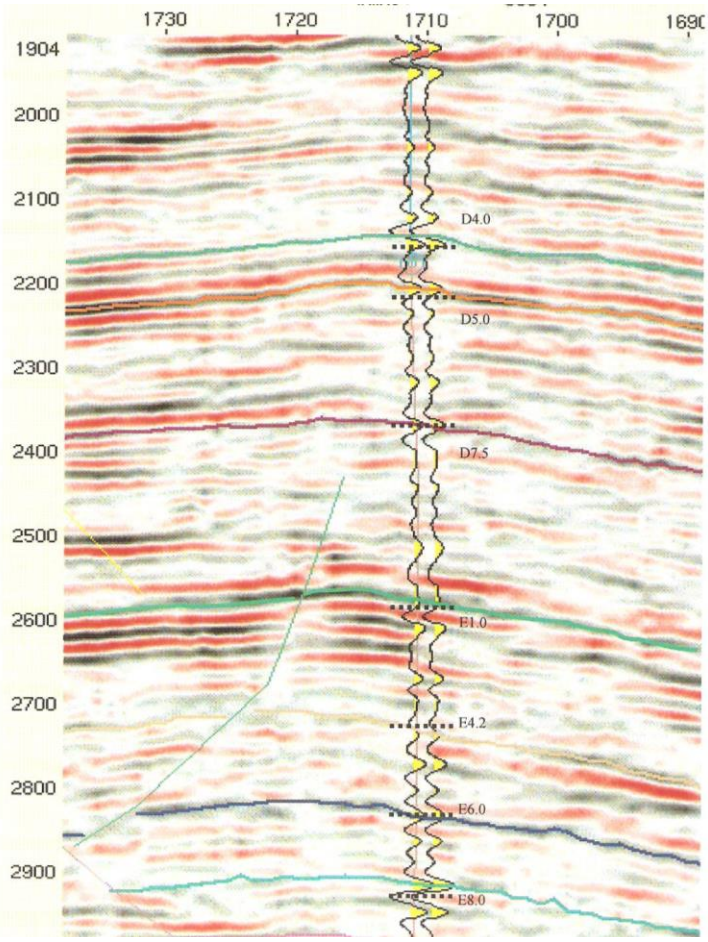


**Figure 3:** OK-010 well synthetic and seismic match (22 ms shift upward of synthetic).

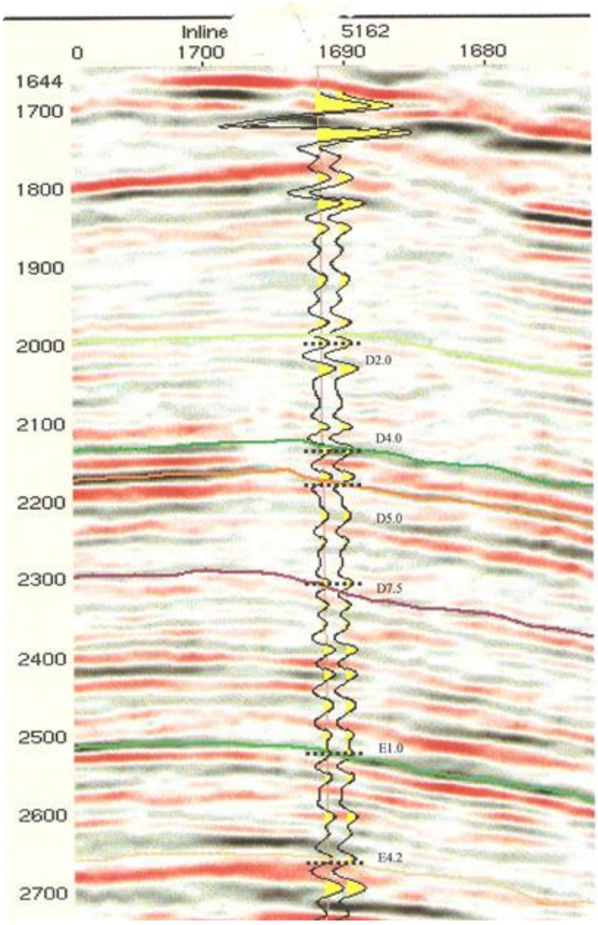


**Figure 4:** OK-005 well synthetic and seismic match (10 ms shift downward of synthetic).

**Horizon identification and interpretation**

Mapping of seismic reflectors was carried out using the *Petrel* software. As described above, the synthetic seismograms indicated that the tops of the reservoir sands in the area are represented on the seismic volume by maximum amplitude reflectors. In all, three key reflectors (horizons) were interpreted. Table 1 provides assessments on the seismic characters and the continuity of the seismic reflectors tied to existing reservoirs in the field.

**Table 1:** Assessments of seismic character

| *Levels* | *Seismic characters* | *Seismic continuity* |
|---|---|---|
| *E4.2* | Moderate positive reflector | Good continuity throughout except crestal part of field |
| *E1.0* | Strong positive reflector | Good continuity throughout |
| *D7.5* | Weak positive reflector | Poor continuity throughout |

The Table shows that E4.2 level was tied to a moderate positive reflector using well match from wells OK010 and OK005. The reflections showed good continuity throughout the field. Also E1.0 level was tied to a strong positive reflector using well match from wells OK010 and OK005. The reflections showed good continuity throughout the field. D7.5 level was tied to weak positive reflector using well match from these same wells above. The reflections showed poor continuity throughout. Figure 5 shows the picked horizons on the seismic sections (D7.5, E1.0 and E 4.2) and the faults patterns in the study area.

**Fault mapping**

Fault interpretation was performed using cross section (every 4th in-line). The continuity of the fault segments and their assignment were rigorously checked on the seismic sections (Figure 5).

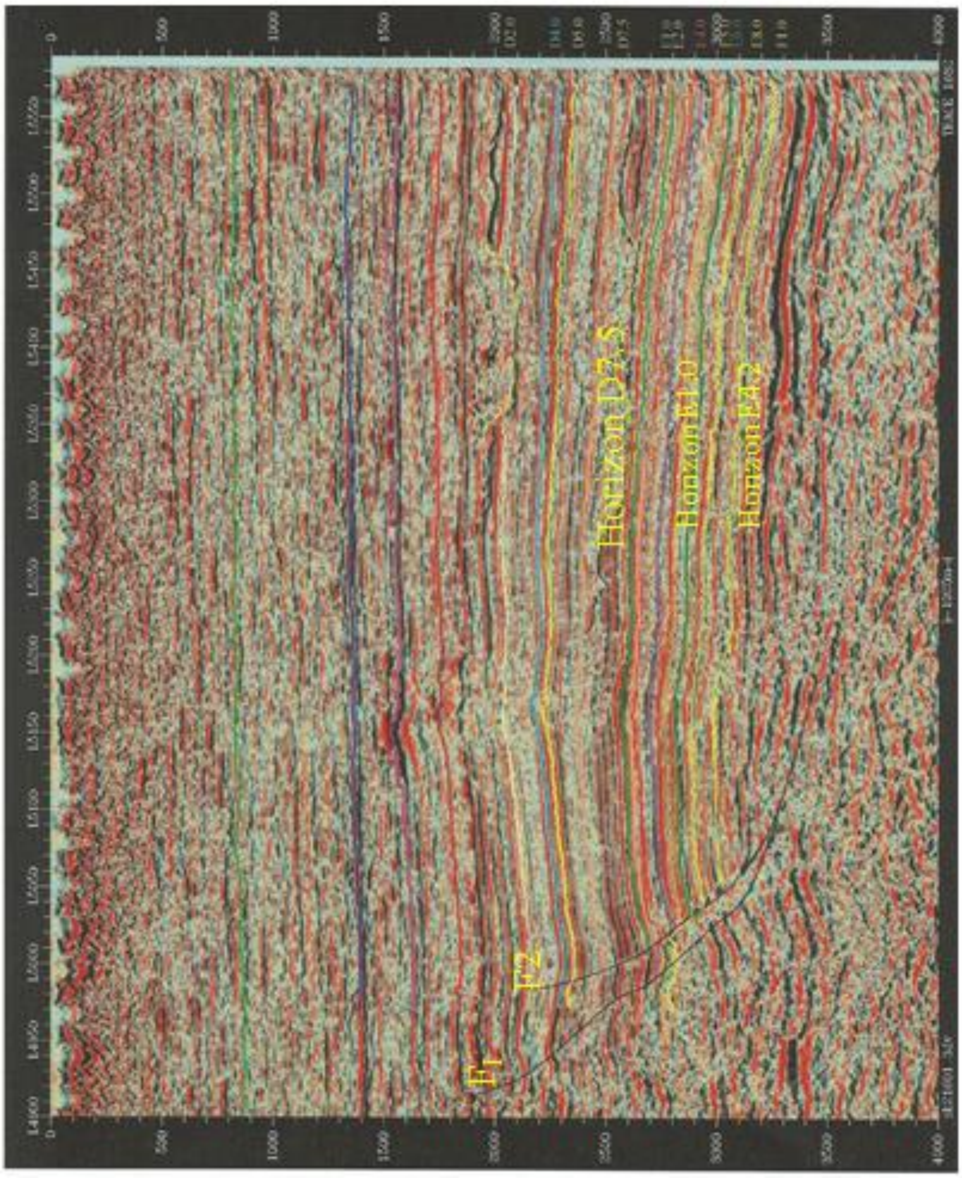


**Figure 5:** Seismic section showing the picked horizons and the fault types.

Two major faults were mapped on the seismic section shown on dip attribute time slice extracted from the seismic volume (Figure 6 and Figure 7). Fault population is characterized by mostly east-west trending normal faults that are dipping towards the south-west, parallel to the main boundary fault ($F_1$). The faults are of limited lateral extends and do not form any compartment in the field. In the North, fault population characterizes mostly North-South trends normal faults. This is in response to the main boundary fault to the west of the OK fields and also trends North-South. All the faults interpreted are done for all the horizons mapped. The faults are also significant tools in the trapping of hydrocarbon sand, especially the growth fault $F_1$ that is laterally extensive (it is a regional fault). The trapping configurations of the faults along with the embedding shale are presumed to be responsible for the creation of multiple reservoir compartments of hydrocarbon bearing formations (Olowokere 2009) that is witnessed from horizon to horizon.

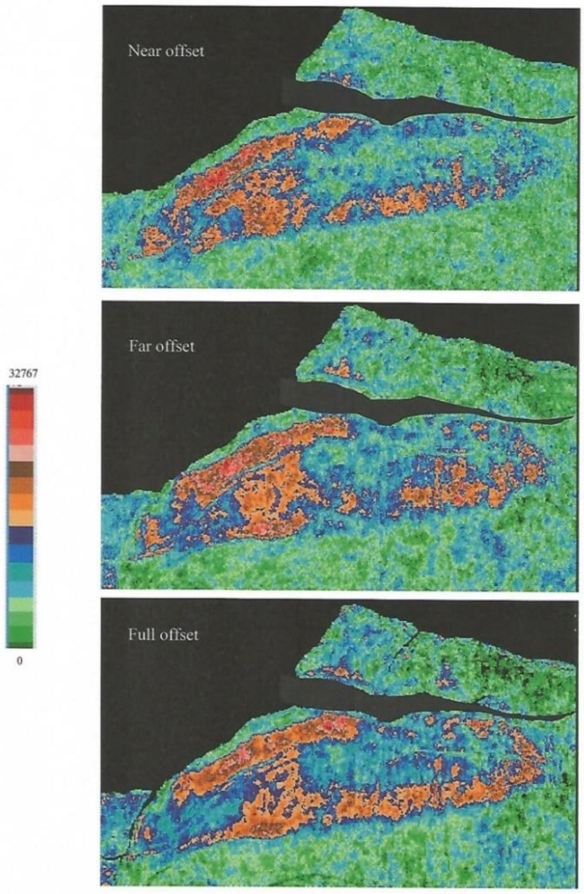


**Figure 6:** Dip attribute extracted 10 ms above E1.0 horizon showing the fault patterns.

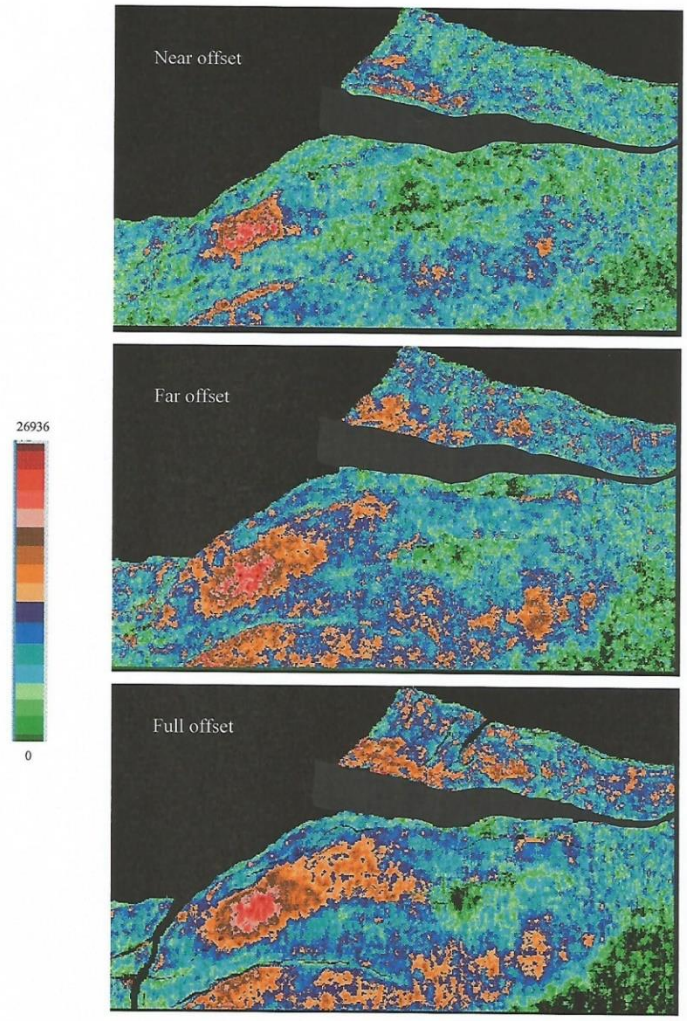


**Figure 7:** Dip attribute extracted 10 ms above E4.2 horizon showing the fault pattern.

**Conclusion**

Two hydrocarbon-producing reservoirs ($R_1$ and $R_2$) were identified. Well to seismic ties showed that hydrocarbon bearing reservoirs tied on seismic sections. Three horizons were studied and two major faults ($F_1$ and $F_2$) were mapped. This interpretation was further enhanced with Dip attribute extracted from 3-D structural interpretation. This was combined with well log analysis in the delineation of suitable traps in the reservoirs. Amplitude analysis showed both zones of bright and dim spots which corresponds to prospective and less prospective hydrocarbon accumulations. This was used in the delineation of fluid contacts. OK field is characterized by a rollover anticline, with a dip closed trapping mechanism for the D series and fault/dip trapping mechanism in the E series. More hydrocarbon production is possible with good development programmes of the field. So, the other horizons within the oil window of the reservoir rock (Agbada formation) of OK field which were not considered in the study should be mapped because the field has shown a lot of potential for oil and gas accumulation. It is recommended that careful quality control of the updated velocities using existing horizons should be performed so that the resulting velocity maps can be used for accurate depth conversion. Finally, fault seal analysis should be carried out to confirm that the suspected trapping faults are not leaking in which case they serve as conduits for hydrocarbon migrations rather than lateral barriers to hydrocarbon escape.

**References**

Adewoye O, Amigun JO and Afuwai CG 2015 Lithostratigraphic interpretation and seismic attributes analysis for reservoir characterization in some parts of Niger Delta. *Petroleum & Coal* 57(1): 76-84.

Asquith G 2004 Basic well logs analysis. AAPG methods in exploration series. *Am. Assoc. Pet. Geol.* 16: 12-135.

Brown AR 2004 Interpretation of three-dimensional seismic data. *AAPG Mem. 42 SEG Invest. Geophys.* 9: 12-89.

Coffen JA 1998 Interpreting seismic data: Penwell Publishing Company, Tulsa Oklahoma, 39-118.

Doust H and Omatsola E 1990 Niger Delta, In: Edwads JD and Santogrossi PA (Eds): Divergent/passive Margin Basins, AAPG Memoir 48, Tulsa. *Am. Assoc. Pet.\ Geol.* 239-248.

Ekweozor CM and Okoye NV 1980 Petroleum source-bed evaluation of Tertiary Niger Delta. *Am. Assoc. Petrol. Geologists Bull.* 64: 1251-1259.

Evamy BD, Haremboure J, Kamerling P, Knaap WA, Molloy FA and Rowlands PH 1978. Hydrocarbon habitat of Tertiary Niger Delta. *Am. Assoc. Pet. Geol. Bull.* 62: 1-39.

Olowokere MT 2009 Amplitude and fluid contact mapping in some parts of Niger Delta using seismic attribute analysis and inversion. *Pacific J. Sci. Technol*. 10: 721-732.

Ologe O 2016 Reservoir evaluation of “T-X” field (Onshore, Niger Delta) from well log petrophysical analysis. *Bayero J. Pure Appl. Sci.* 9(2): 132-140.

Short S and Stauble G 1967 Outline of geology of Niger Delta. *Am. Assoc. Pet. Geol. Bull.* 51: 761-779.

Stacher P 1995 Present understanding of the Niger Delta hydrocarbon habitat, In: Oti MN and Postma G (Eds), Geology of Deltas: Rotterdam, AA Balkema

Steiner W and Lockhart J 1988 Seismic classification and reservoir volume analysis of the upper Wahoo oil field: Internet archive. www.petrobjects.com/papers