Petroleum & Coal
ISSN 1337-7027

Available online at www.vurup.sk/petroleum-coal
Petroleum & Coal 57(6) 619-628, 2015

SEISMIC ATTRIBUTES ANALYSIS FOR RESERVOIR CHARACTERIZATION; OFFSHORE NIGER DELTA

K. David Oyeyemi* and A. Phillips Aizebeokhai

Applied Geophysics unit, College of Science and Technology, Covenant University, Nigeria

Received September 6, 2015, Accepted December 21, 2015

Abstract

In this paper we have described some commonly utilized seismic attributes that are of complementary value to the information acquire through traditional methods of seismic interpretation. Seismic attributes extraction and analyses have proven to offer new information and insights into structural and stratigraphic mapping interpretations. They further assist greatly in delineation of hydrocarbon leads and prospects which subsequently help to reduce exploration and development risk.

Keywords: Seismic attributes; Reservoir characterization; Structural mapping; Niger-Delta; Hydrocarbon prospects.

1. Introduction

A seismic attribute is any measure of seismic data that helps us better visualize or quantify features of interpretation interest. It could be described as powerful aid to improve accuracy of interpretations and predictions in hydrocarbon exploration and development. Seismic attributes allow the geoscientists to interpret faults and channels, recognize depositional environments, and unravel structural deformation history more rapidly. They are also useful in checking the quality of seismic data for artifacts delineation, seismic facies mapping, prospects identification, risk analysis and reservoir characterization. Combining information from adjacent seismic samples and traces using a physical model (such as dip and azimuth, waveform similarity, or frequency content), seismic attributes often organize features into displays that provide enhanced images for either a human interpreter or for modern geostatistical or neural-network computer analysis. While seismic attributes are sensitive to lateral changes in geology, they are however also quite sensitive to lateral changes in noise.

Seismic attributes fall into two broad categories – those that quantify the morphological component of seismic data and those that quantify the reflectivity component of seismic data. The morphological attributes are applied to extract information on reflector dip, azimuth, and terminations, which can in turn be related to faults, channels, fractures, diapirs, and carbonate buildups. The reflectivity attributes extract information on reflector amplitude, waveform, and variation with illumination angle, which can in turn be related to lithology, reservoir thickness, and the presence of hydrocarbons. While in the reconnaissance mode, 3D seismic attributes could be applied to rapidly delineate structural features and depositional environments. Whereas in reservoir characterization mode, 3D seismic attributes are calibrated against real and simulated well data to evaluate hydrocarbon accumulations and reservoir compartmentalization.

Taner *et al.* [1] presented a comprehensive classification of attributes into two categories, gomerical and physical. The geometrical attributes have the capacity to enhance the visibility of the geometrical characteristics of seismic events and are sensitive to lateral changes in dip, azimuth, continuity, similarity, curvature and energy. These are used in fault or structural interpretation and stratigraphic interpretation [1-4]. However, the physical attributes enhance the physical parameters of the subsurface relating to the lithology and stratigraphy for lithological classification and reservoir characterization. They include amplitude, phase, and frequency of seismic events. The magnitude of trace envelope is proportional to the acoustic impedance contrast; frequencies relate to bed thickness, wave scattering and absorption. Instantaneous and average velocities are directly related to rock properties.

2. Location and geology of the study area

The Niger Delta occurs at the southern end of Nigeria bordering the Atlantic Ocean extending from about Longitude 3° - 9° E and from Latitude 4° 30ˈ - 5° 20ˈN (Figure 1). It is bounded in the east, west and south by the Calabar Flank, Benin Flank and the Gulf of Guinea respectively. Niger Delta is bounded in the north by older (Cretaceous) tectonic elements among which are the Anambra Basin, Abakaliki uplift and Afikpo syncline. Weber [5] suggested that the basin which facilitated and controlled the formation of the present Niger Delta was developed by rift faulting during the Precambrian. Benin and Calabar Hinge lines are the Deep seated faults associated with the rifting controlled formation of the delta. The building of the Niger Delta over the edge of the African continent began in the middle-late Eocene [6]. Evidence from the geophysical investigations indicates that the Oligocene and younger sediments progressively toward the continental shelf and that they average 26000 feet (7924 m). The accumulation of these sediments was rather fast and hence gravitational movements within them became pronounced, resulting in contemporaneous faulting with deposition (growth faults).

2.1 Structural setting

Structurally, Niger Delta has been described in terms of three linked gravity systems of updip extension dominated by extensional growth faults and a downdip thrust related fold dominated compressional systems with a transitional shale diapir controlled system intermediate between them (Figure 2). A major detachment zone within the Akata Formation links the extensional province across the mud diapir zone to the contractional fold-thrust belts in the lower slope [7-11]. These three tier systems have been subdivided into five major structural provinces or zones based on structural styles from seismic and high resolution bathymetry data.

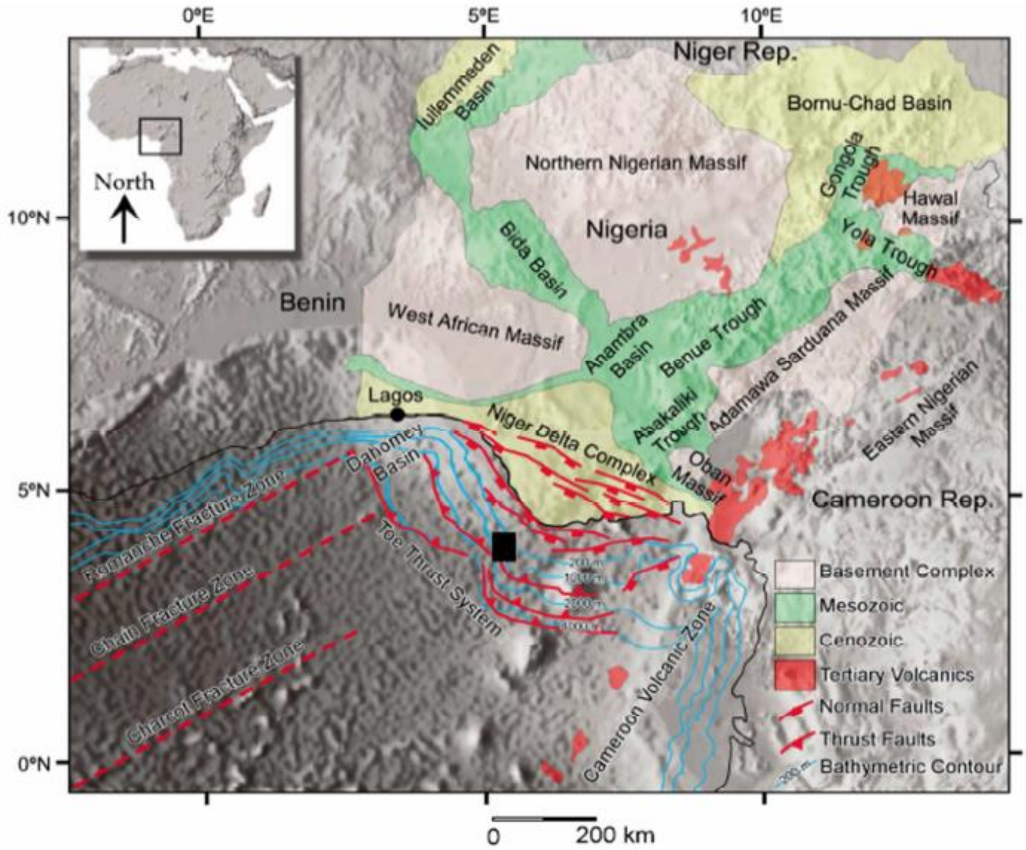

Figure 1 Map of Niger Delta showing the location of the study area

The zones include (i) extensional province (ii) mud diapir zone (iii) inner fold and thrust belts (iv) transitional detachment fold zone, and (v) outer fold and thrust belt zone. The deformation across these structural zones is still active today, resulting in the pronounced bathymetric expression of structures that are not buried by recent sediments as illustrated on figure 2. The predominant structural features within Niger Delta include Normal faults, growth faults and roll over anticlines.

Many growth faults are crescent shaped, both in cross section and in plan view, with the concave side toward the down thrown block. Due to this form, the down thrown block tends to rotate along an axis roughly parallel to the fault. If sufficient movement takes place along such a curved fault plane an elongate anticline forms in front of the fault termed roll over structures. Such anticlines within Niger Delta are small ranging up to 6437 to 8047 metres across the long axes and 3219 to 4828 metres along the short axes. These may be cut by either minor growth faults or antithetic compensatory faults. Subsurface structural evidence so far available suggest that the growth fault trends die out laterally, and are replaced by long, comparatively unbroken flanks. Drilling along growth fault trends also has further demonstrated a tendency for the expended section open the down thrown sides of the growth faults to thin towards the end of the growth fault trends.

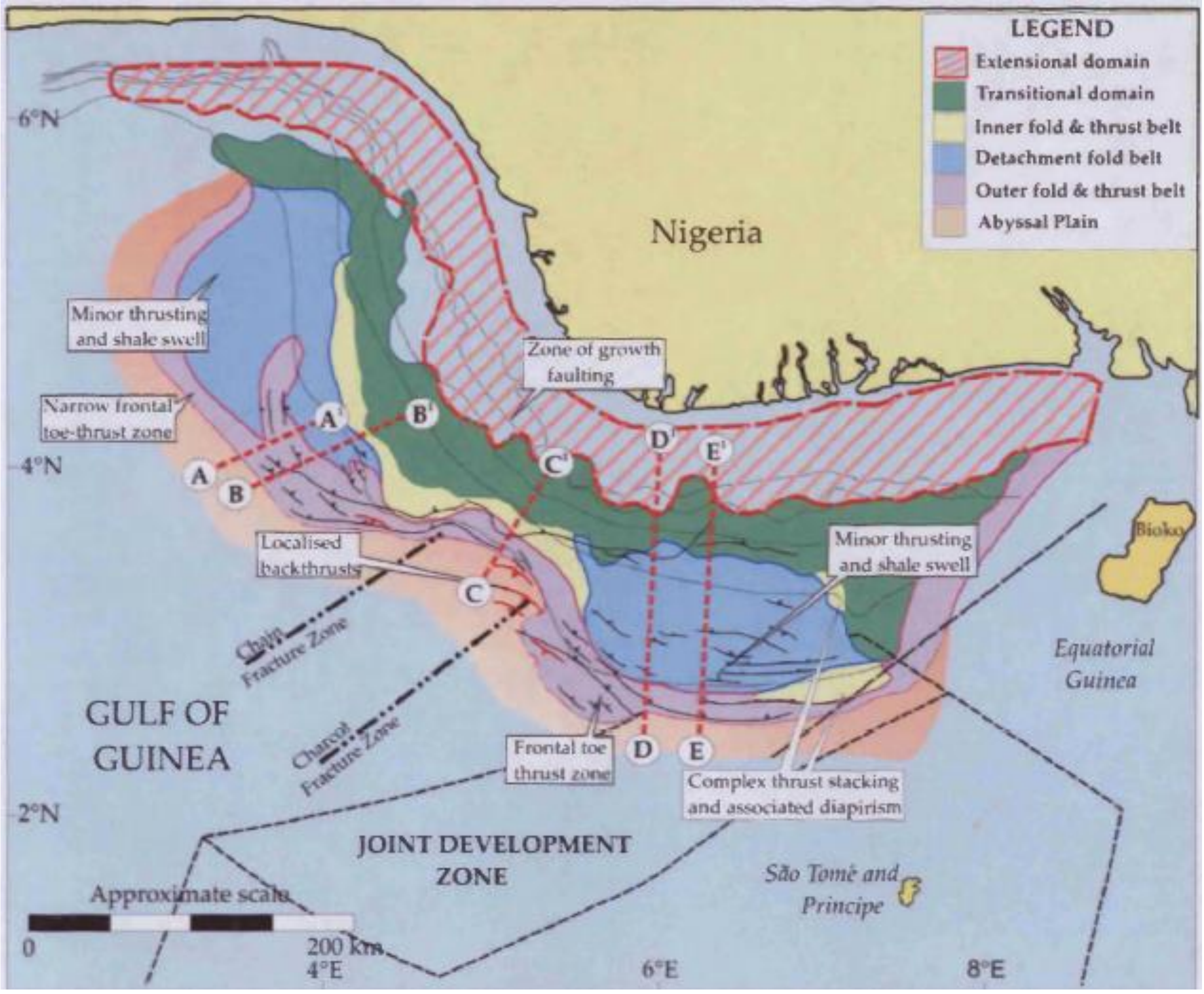

Figure 2 Map of the Niger Delta showing the distribution of the main structural styles [12]

2.2 Depositional setting and stratigraphy

Based on the premise that both oceanic currents and tectonic activities have remained relatively constant from Eocene to recent, Weber [5] characterized five physiographic provinces in the modern Niger Delta. They are Holomarine, Transition, Barrier Bars, Tidal coastal plain and Floodplains zones. Holomarine zone is predominantly clay deposit with depth ranging from the outer shelf to 100 feet (30.48 m). Transition zone of barrier foot or fluvio marine sedimentation consists typically laminated clays, silts and fine sands in waters 10 to 100 feet (3.05-30.48 m). Barrier Bars which occurs along the coastal belt and consisting fine-medium grained sand at depth ranging up to 30 feet (9.2 m). Inter-fingering of these bars with barrier foot sediments swamps, beach ridges and sand splits are common. River mouth bars occurs in front of tidal channels. Tidal coastal plain includes tidal flats and swamps. It extends behind barrier bars. The sediments within this zone vary from medium to coarse clayey and peaty deposits in swam and lagoons. Floodplains consist of deposits which are predominantly medium to coarse grained point-bar sands and clayey backswamps deposits.

Niger Delta started its growth during the Paleocene. The delta sequence consists mainly marine clays overlain paralic sediments which were finally capped by continental gravels and sands. Short and Stauble, [13] divided the tertiary deltaic complex into three major lithofacies units based on the dominant environmental influence which continental, transitional and marine environments. The sediments from these environments in the Niger Delta are stratigraphically superimposed. The base of the stratigraphic sequence is represented by massive marine shales. The middle part of the sequence is represented by the interbedded shallow marine and fluvial sands, silts and clays which are typical of a paralic setting. This sequence is capped by a section of massive continental sands. These three depositional lithofacies are Akata, Agbada and Benin Formations respectively. They make up an overall regressive clastic sequence of about 37 000 to 39 000 feet (11278 – 11887) thick [7].

2.3 Petroleum system

The identified petroleum system within the Niger Delta province is the Tertiary Niger Delta (Akata-Agbada) petroleum system [14-16]. The rocks within the petroleum system are from Paleocene to Recent in age. The minimum extent of the petroleum system is defined by the areal extent of fields and contains known resources (cumulative production plus proved reserves) of 34.5 billion barrels of oil (BBO) and 93.8 trillion cubic feet of gas (TCFG) (14.9 billion barrels of oil equivalent, BBOE) [17]. The marine shale facies of the upper Akata Formation is the primary source rock with possible contribution from the interbedded marine shale of the lowermost Agbada Formation. Reservoirs for the discovered petroleum are the sandstones and unconsolidated sands predominantly in the Agbada Formation. These reservoirs are characteristically controlled by depositional environment and depth of burial. Known reservoir rocks within Agbada Formation are Eocene to Pliocene in age, and are often stacked, ranging in thickness from less than 15 meters to 10% having greater than 45 meters thickness [7]. Kulke, [15] based on the geometry and qualities recognized the most important reservoir types as point bars of distributary channels and coastal barrier bars intermittently cut by sand-filled channels. Miocene paralic sandstones with as Miocene paralic sandstones with 40% porosity, 2 Darcys permeability, and a thickness of 100 meters have been described as the primary Niger Delta reservoirs [18]. Growth faults strongly control the lateral variation in reservoir thickness within the Agbada Formation thereby thicken the reservoirs towards the fault within the down-thrown block [19].

Common traps in the Niger Delta province are structural although stratigraphic traps are not uncommon. The structural trapping elements include those associated with simple rollover structures, clay filled channels, structures with multiple growth faults, structures with antithetic faults, and collapsed crest structures. These traps developed during sysedimentary deformation of the Agbada paralic sequence [7,20], they increases from the earlier formed depobelts in the North to the later formed depobelts in the South, responding to increasing instability of the under-compacted, over-pressured shale. On the flanks of the delta, stratigraphic traps are likely as important as structural traps [21]. In this region, pockets of sandstone occur between diapiric structures. Towards the delta toe (base of distal slope), this alternating sequence of sandstone and shale gradually grades to essentially sandstone. The interbedded shale within the Agbada Formation form the primary seal rock in the Niger Delta. Doust and Omatsola, [8] recognized the shale as providing three types of seals; clay smears along faults, interbedded sealing units against which reservoir sands are juxtaposed due to faulting, and vertical seals. Major erosional events of early to middle Miocene age on the flanks of the Delta formed canyons that are now clay-filled. These clays form the top seals for some important offshore fields within Niger Delta.

3. Seismic database and methodology

The SEG-Y format 3D seismic dataset consist of inlines 5800-6200 and crosslines 1480-1700, with line spacing of 25 meters covering a total area of about 72.8 km^2. Horizons are usually picked based on the prospective zones identified from petrophysical analysis of well logs. Tops and Bases of these horizons were mapped and correlated across the available wells as shown in Figure 3. The correlation was done using gamma-ray and resistivity logs. Three horizons were mapped and correlated. The tops and bases of these horizons were tied to the seismic section to aid the construction of time surface maps and generate subsequently depth maps using the available checkshot data (Figure 4).

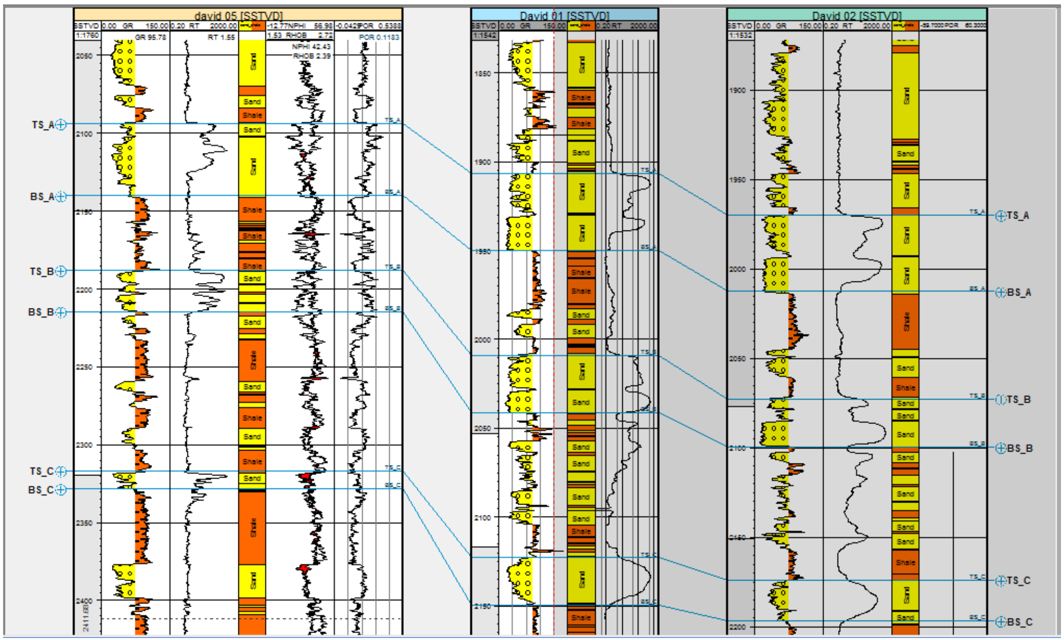

Figure 3 Correlation panel within the well section window.

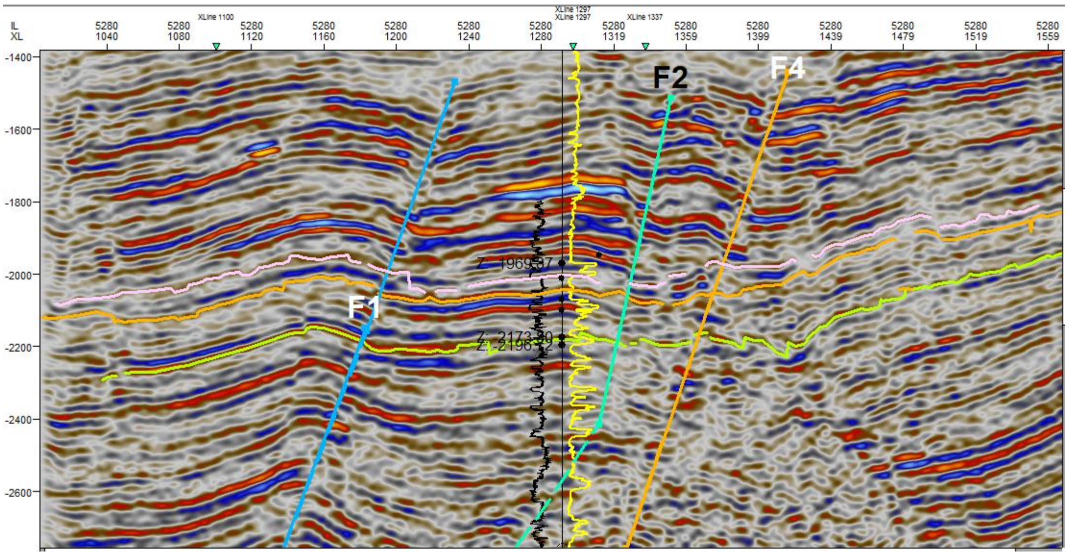

Figure 4 Well-to-seismic tie

A series of volume seismic attributes such as variance edge and sweetness attributes visualized in Schlumberger's Petrel® software interface were run on the available 3D seismic volume data to investigate potential structural and stratigraphic controls within the study area. Similarly, surface attributes including interval average arithmetic, acoustic amplitude, lower loop area and interval mean were run on the horizon surfaces to generate the attributes maps and gain full understanding of the target features in terms of porosity, permeability and direct hydrocarbon indicators (DHI) for hydrocarbon exploration in the study area.

4. Results and observation

The prime motivation for using seismic reflection data to characterize the reservoirs comes from its ability to provide useful relationship between the seismic reflection data and physical properties. The results of running the volume attributes such as sweetness, variance edge, RMS amplitude and relative acoustic impedance on the 3D seismic data from the study area alongside with the mapped horizons and faults are presented in figure 5. The significant effects of the acoustic amplitude, lower loop and interval mean attributes on the mapped horizons surfaces are also presented (Figures 6-9).

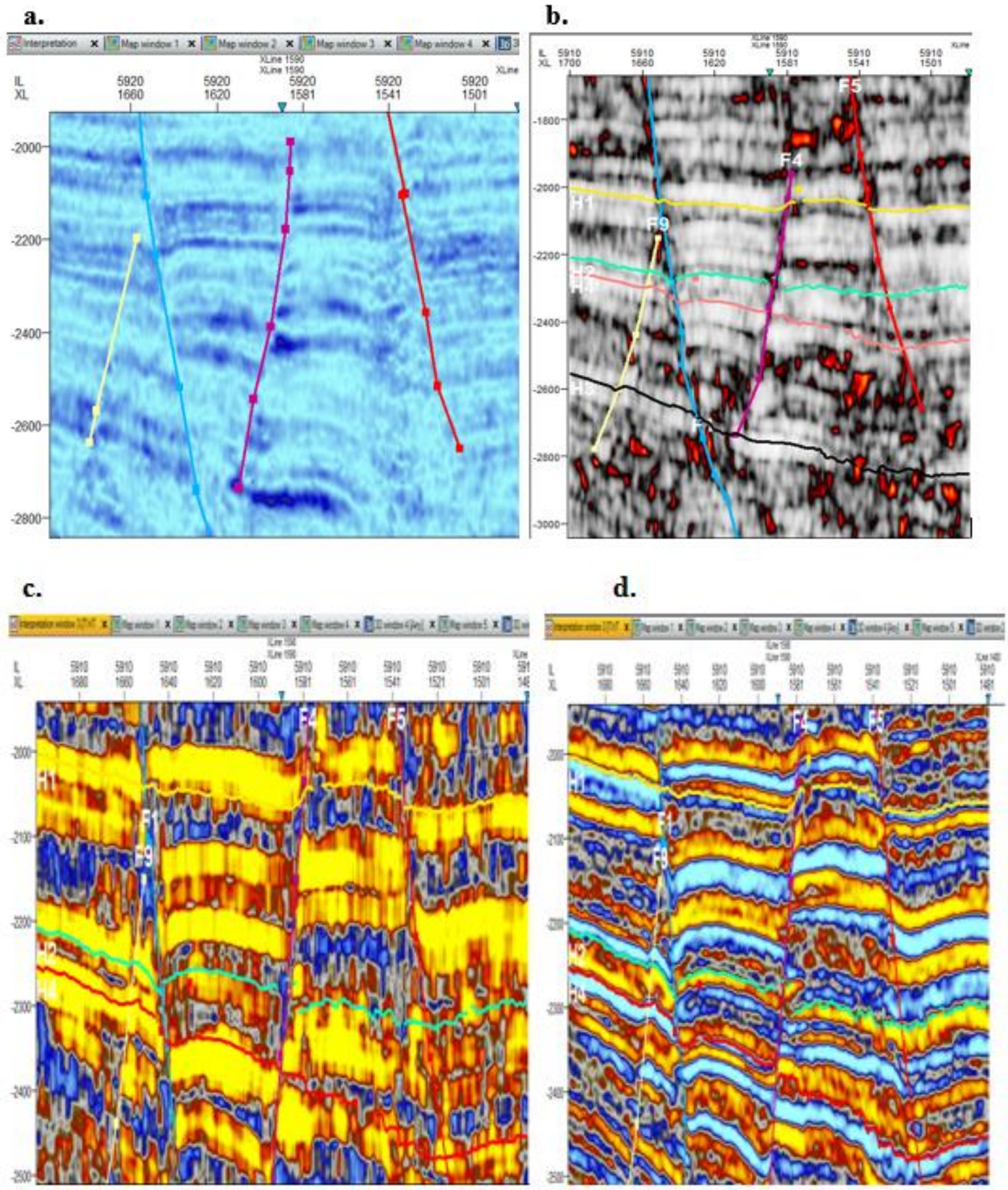

Figure 5 Volume attributes with Picked horizons and faults (a) Sweetness attribute (b) Variance edge attribute (c) RMS amplitude attribute (d) Relative accoustic impedance attribute

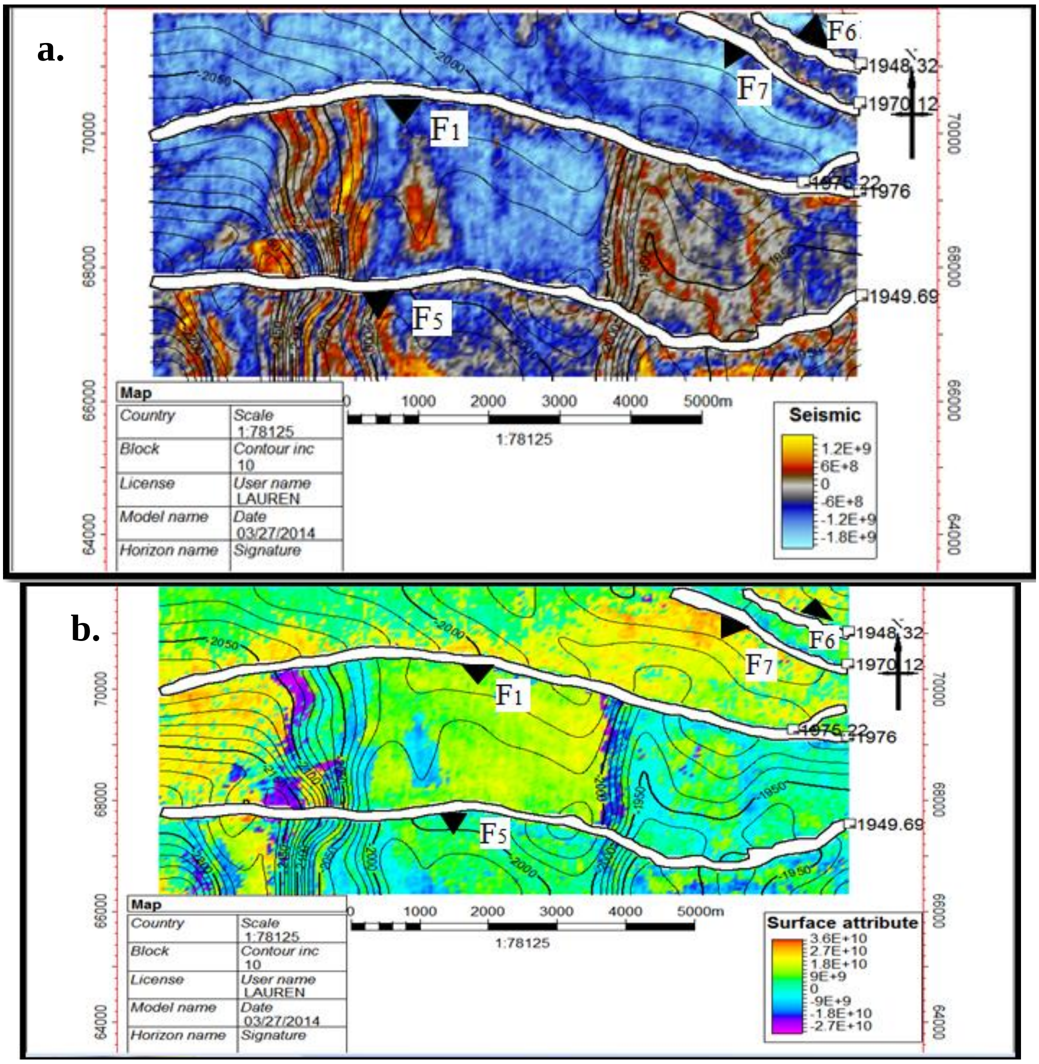

Figure 6 (a) Acoustic amplitude surface attribute for H1 (b) Lower loop area surface attribute for H1

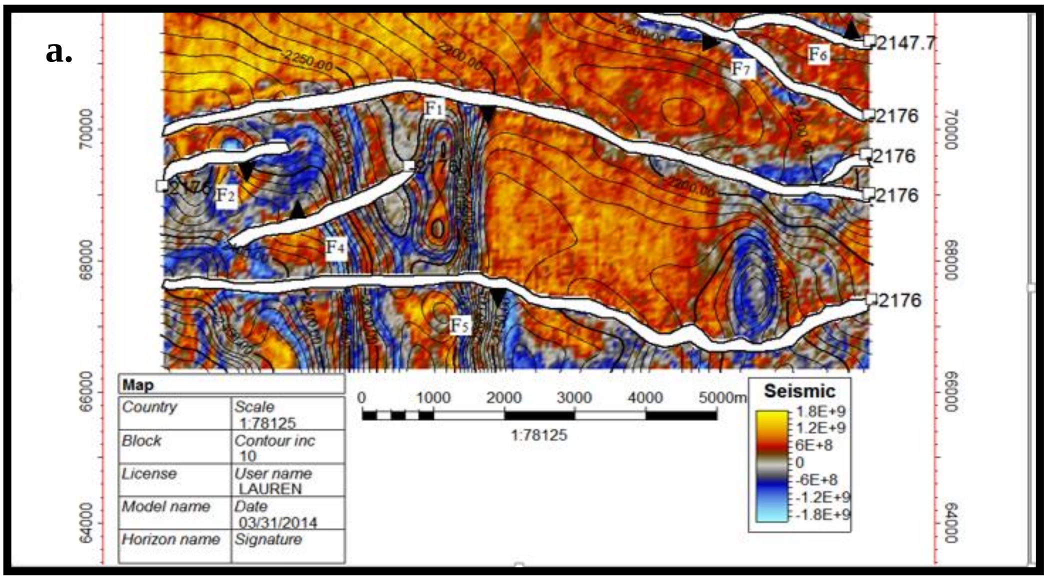

Figure 7 (a) Acoustic amplitude surface attribute for H2

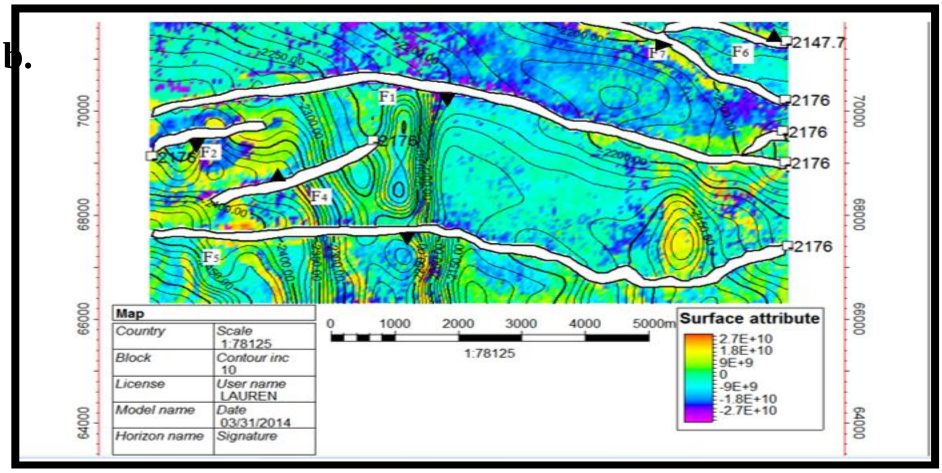

Figure 7 (b) Lower loop area surface attribute for H2

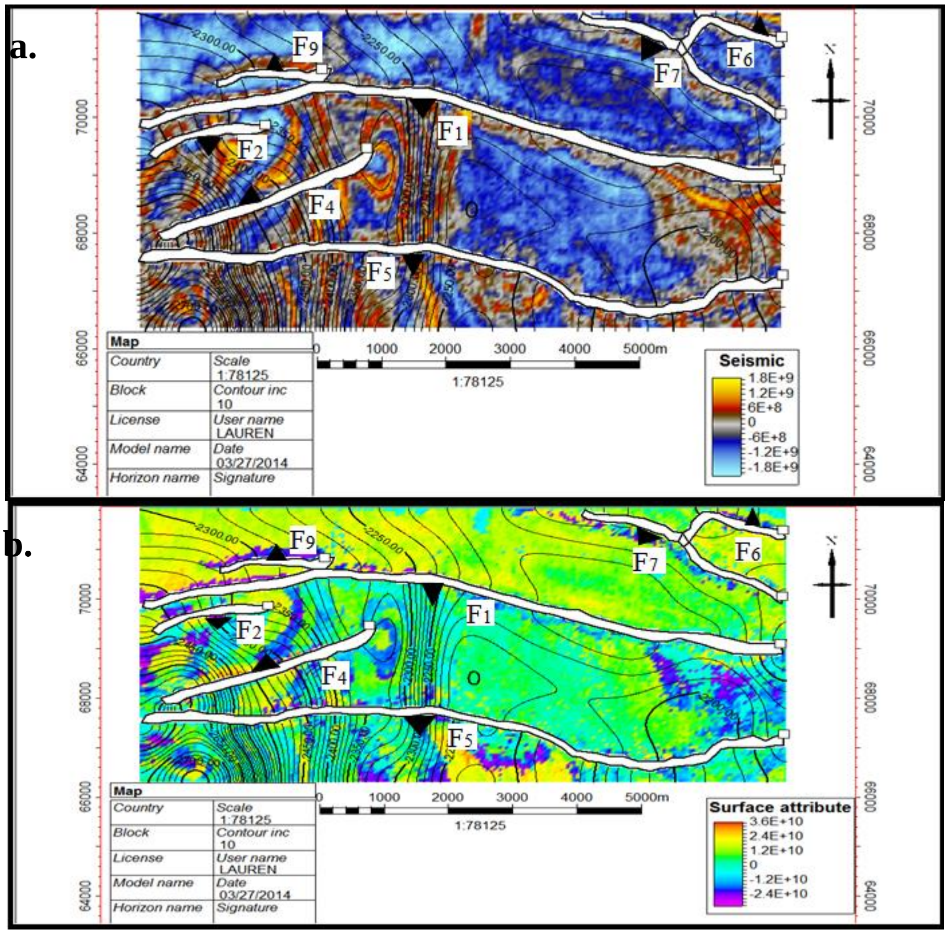

Figure 8 (a) Acoustic amplitude surface attribute of H3 (b) Lower loop area surface attribute for H3

5. Discussion

5.1. Seismic attributes analysis

The essence of running sweetness attributes on seismic volume is to identify and subsequently map sweet spots on the seismic section. Figure 5a shows high sweetness region within the seismic data indicating characteristically high amplitude and low frequency of hydrocarbon bearing sand units. Though sweetness attribute is quite effective for channel detection and characterization of gas charged bearing sand units, it is known to be less useful when the acoustic impedance contrast between shale and sand units are low, and also less effective when both lithologic units are highly inter bedded. The variance edge seismic attribute (Figure 5b) correlate well with faults and fractures within the study area. Faults signatures were enhanced through calculating the variance within the seismic data volume with an edge enhancement option, thereby enabling the mapping across discontinuities within the data. RMS amplitude attribute correlate strongly with formation porosity and/or liquid saturation (oil/water vs. gas).

The attributes were able to demonstrate the prediction of lithology and porosity within the reservoir layers by extracting seismic attributes from the 3D seismic data. Figure 5c shows bright spots across the seismic data indicating the porosity of the delineated reservoir sand units. Similarly the acoustic impedance attributes (Figure 5d), which depends significantly on the velocity, Density and seismic reflection across the interface of two acoustically different media. Likewise, the effects of running seismic attributes on mapped horizons surfaces are as shown in the figures 6-9. High acoustic amplitude can be observed predominantly SW-SE regions in all the reservoirs sand units (H1-H3). This further affirm that the identified and mapped reservoirs within the field are highly porous and permeable.

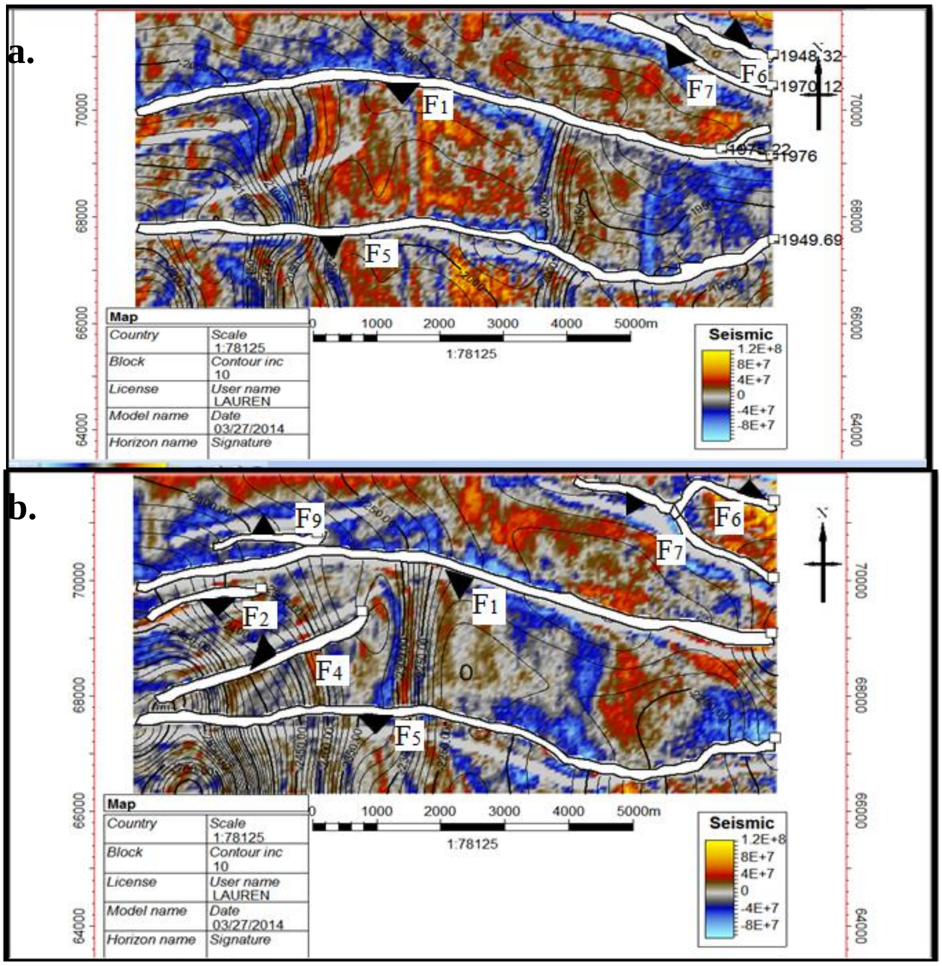

Figure 9 (a) Interval mean surface attribute between H1 and H2 (b) Interval mean attribute between H2 and H3

5.2. Structural styles and hydrocarbon prospects

The predominant structural features within the area are concave upward faults with downdip planes. Four major faults, four intermediate faults and two minor faults cutting through the reservoir sand units were identified and mapped on the variance edge seismic attributes. The probable hydrocarbon prospects in the field consist of the anticlinal structure and roll over structure assisted by faults. Fault closure against down to south crescentic growth fault derived from a roll over anticline, is seeing localized south eastern section of the horizon H2 (Figure 7). The intermediate faults (F_4, F_7) cutting through the horizon surfaces are predominantly synthetic and antithetic faults.

6. Conclusions

Seismic attributes within the framework of this research have been used to provide good information about the mapped reservoirs and identified structural traps towards a better delineation of hydrocarbon prospects and improved reservoir characterization. It has been further demonstrated that seismic attributes are complementary to the information derived through traditional methods of seismic interpretation. Extraction of seismic attributes from seismic data can bring to fore new information and insights into stratigraphic and structural interpretations. The deliverables from seismic attributes extraction and analysis will help greatly in reducing exploration and development risk.

References

[1] Taner MT, Schuelke, JS, O'Doherty R and Baysal E. Seismic attributes revisited: 64th Annual International Meeting, SEG, Expanded Abstracts 1994, 1104 -1106.

[2] Liner C, Li CF, Gersztenkorn A and Smythe J. 2004. SPICE: Anew general seismic attribute: 72nd Annual International Meeting, SEG, Expanded Abstracts 433-436.

[3] Chopra S and Marfurt KJ. Seismic attributes-A historical perspective. Geophysics 2006., Vol. 70, no. 5, 3SO-28SO, doi: 10.1190/1.2098670.

[4] Mirkamali MS, Keshavarz, FK and Bakhtiari, MR. Fault zone identification in the eastern part of the Persian Gulf based on combined attributes. J. Geophys. Eng 2013. Vol. 10, 11pp, doi 10.1088/1742-2132/10/1/015007.

[5] Weber KJ. Sedimentological aspects of oil fields in Niger Delta. Geologic en Mijnbouw 1971, Vol. 50, no. 1, pp. 239-248

[6] Hospers J. Gravity field and structure of the Niger Delta, Nigeria, West Africa. Geological Society of American Bulletin 1965, Vol. 76, p. 407- 422.

[7] Evamy BD, Haremboure J, Kamerling P, Knaap WA, Malloy FA. and Rowlands PH. Hydrocarbon habitat of Tertiary Niger Delta. AAPG Bulletin 1978, Vol. 62, p. 1-39.

[8] Doust H. and Omatsola ME. 1990. Niger Delta, In: JD. Edwards, PA Santogrossi (eds.), Divergent / Passive margin basin of petroleum Geologists; pp. 239-248.

[9] Damuth JE. Neogene gravity tectonics and depositional processes on the deep Niger Delta continental margin. Marine and Petroleum Geology 1994, 11: 320-346.

[10] Cohen HA and McClay KR. Niger Delta Shale tectonics. Marine and Petroleum Geology 1996; 13: 313-328.

[11] Briggs SE, Davies RJ, Cartwright JA and Morgan R. Multiple detachment levels and their control on fold styles in the compressional domain of the deepwater west Niger Delta. Basin Research 2006; 18: 435-450.

[12] Whiteman A. 1982. Nigeria: its Petroleum Geology, Resources, and Potential. Vols. 1-2 Graham and Totter, London 394 pp.

[13] Short KC, Stauble J. Outline geology of the Niger Delta. AAPG Bulletin 1967; 5: 761-779.

[14] Ekweozor CM, and Daukoru EM. Petroleum source-bed evaluation of Tertiary Niger Delta; discussion and reply, AAPG Bulletin 1984; Vol. 68, p. 387-394.

[15] Kulke H. 1995. Nigeria, In: Kulke, H., ed., Regional Petroleum Geology of the World: Part II, Africa, America, Australia and Antartica: Berlin, Gebruder, Bontraeger, pp. 143-172.

[16] Tuttle LWM, Charpentier RR and Brownfield EM. 1999. The Niger Delta Petroleum System: Niger Delta Province, Nigeria Cameroon, and Equatorial Guinea, Africa. U.S. Geological Survey Open-File Report 99-50-H, Denver, Colorado, 70 pp.

[17] Petroconsultants, 1996. Petroleum exploration and production database: Houston, Texas, Petroconsultants, Inc.

[18] Edwards JD, and Santogross PA. 1990. Summary and conclusions, in, Edwards, JD, and Santogrossi PA., eds., Divergent/passive Margin Basins, AAPG Memoir 48, pp. 239-248.

[19] Weber KJ and Daukoru EM. 1975. Petroleum geology of the Niger Delta: Proceedings of the 9th World Petroleum Congress, Vol. 2 Geology: London, Applied Science Publishers, Ltd., p. 210-221.

[20] Stacher P. 1995. Present understanding of the Niger Delta hydrocarbon habitat, in, Oti, MN, and Postma G., eds., Geology of Deltas: Rotterdam, AA Balkema, p. 257-267.

[21] Beka FT, and Ot MN. 1995. The distal offshore Niger Delta: frontier prospects of a mature petroleum province, in, Oti MN, and Postma G., eds., Geology of Deltas: Rotterdam, AA Balkema, p. 237-241.

*Corresponding author email: kdoyeyemi@yahoo.com; kehinde.oyeyemi@covenantuniversity.edu.ng