3d Seismic Structural Interpretation of a Part of Aloo-Field, Southwestern Niger Delta, Nigeria

Ologe Oluwatoyin[1], Ola-Buraimo A. Olatunji[2], BankoleShereef A[3]

[1-3](Department of Chemical and Geological Sciences, College of Natural Sciences,
Al-Hikmah University, Ilorin, Nigeria.)

Abstract: *Complexity of faulted subsurface configuration causing erroneous deductions in absence of well articulated interpretation approach led to a well refined 3D seismic data of part of ALOO-Field located in offshore southwestern Niger Delta. This study was aimed towards determining its subsurface structural features and retentive capacity of the reservoir for hydrocarbon. The methods employed include analysis of 3D seismic data using Petrel software; horizons and fault deductions from the seismic sectionwere used to generate structural maps which revealed different structural styles present in the studied area.*

Three distinct horizons were mapped. Depth structural maps generated for all surfaces of interest show subsurface features such as the geometry of the identified horizons, W-E trending growth fault, fault echelonsof which most of them dip to the east and fault assisted closures at the north-western-central part of the studied section. The dipping pattern of the identified faults coincides with that of the growth fault which enhances trapping mechanism for the hydrocarbon. Two principal structural trapping mechanisms present are growth fault and rollover anticline which are synonymous with Niger Delta. The study has demonstrated the importance of seismic structural interpretation in understanding the structural styles present and their retentive ability for hydrocarbon.

Keywords-*Fault echelons,Growth faults, Rollover anticline, Seismic Sections, and Structural styles.*

I. Introduction

Niger Delta Basin is one of the most prolific oil producing basins in theworld. It is associated with complex structural features which if not well understood may hinder maximum exploitation of hydrocarbon.Therefore, it is imperative to understand detailedstructural relationships between fault networks and stratigraphic stacking patterns of the area for future fielddevelopment. The use of 3D seismic data to interpret oilproducing fields is very important in assessing field development.

ALOO- field is located in the offshore Southwestern Niger Delta within longitudes 5.5^0E and 5.6^0E and latitudes of 5.0^0N and 5.1^0N. It is a prospect in one of the Southwestern concessions belonging to an active oil company in Nigeria. It covers an area of approximately $41km^2$. The location map of the area is shown in Fig. 1. The studyarea exhibits one of the classical examples of oil producing fields in Niger Delta with fault related problems in relation to hydrocarbon reservoir. Sometimesthe estimate of reserves may even be dependent on structural interpretation when fluid contacts located on depthstructure maps are needed as inputs in volumetric analysis [1].

The study is aimed at imaging in detail, the subsurface structures associated with new reservoirs and their retentive capacity for hydrocarbon.Majority of the traps in the Niger Delta are structurally related [2], even though stratigraphic and combined structural and stratigraphic traps are not uncommon. Therefore, our focus in this study is directedtowards mapping the structural traps available and evaluating the retentive capacity of these reservoirs.

The enormous cost of exploring for petroleum makes it necessary to maintain a high level of precision in interpreting its subsurface structures. The main objective of seismic interpretation is drilling to find oil and gas.This is achieved through array of seismic profiles in order to generate coherent geologic information for optimum hydrocarbon exploration and exploitation.

II. Geological Setting Of The Study Area

The Niger-Delta forms one of the world's major hydrocarbon provinces, and it is situated on the Gulf of Guineaon the west coast of Central Africa (Southern part of Nigeria). It covers an area between longitude 4 – 9°E andlatitude 4-9° N (Fig. 1). It is composed of an overall regressive clastic sequence, which reaches a maximum thickness of about 12km [3].
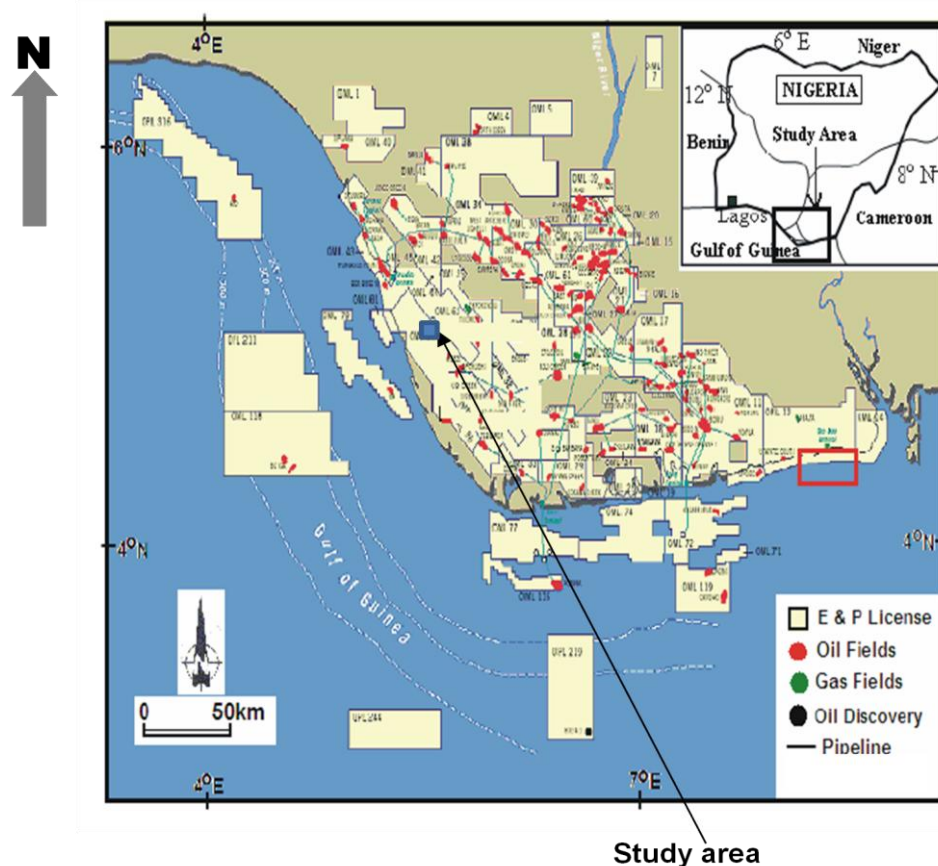
Figure 1: Location map of Niger Delta showing the study area and the inset of map of Nigeria.

2.1 Lithostratigraphy

The Niger-Delta consists of three broad formations [4]. The oldest formation in Niger Delta is the Akata Formation characterised by dominance of hemipelagicshales. The Akata Formation is overlain by Agbada Formation which consists of paralic sequence of sandstones and shales intercalation. The sandstone to shale ratio tends to decrease with depth. The youngest facie is the continental sediments known as Benin Formation. It overlies the Agbada Formation. It consists predominantly fresh water bearing continental mudstones, poorly sorted sandstoneand gravels(Fig. 2).

2.2 Hydrocarbon Source Rock

Several works have been carried out on the evaluation of the source rocks of Niger Delta which include; [2, 5-8]. A school of thought believes that most of the hydrocarbon generated in Niger Delta were derived from both Akata and Agbada Formations [2,6,7,9-13].The Akata shale is present in large volumes beneath theAgbada Formation and is at least volumetrically sufficient to generate enough oil for a world class oil province.

2.2.1 Reservoir Rock

Petroleum in the Niger Delta is produced from sandstone and unconsolidated sands predominantly in theAgbada Formation. Characteristics of the reservoirs in the Agbada Formation are controlled by depositionalenvironment and by depth of burial. Known reservoir rocks are Eocene to Pliocene in age, and are often stacked,ranging in thickness from less than 15 meters to 45 meters [3]. The thickerreservoirs represent composite bodies of stacked channels [2]. Based on reservoir geometry and quality, different reservoir types present are point bars of distributary channels and coastal barrier barsintermittently cut by sand-filled channels [14]. The primary reservoirs in Niger Deltadated Miocene age weredescribed to be paralic sandstones with about 40% porosity, 2 darcypermeability, and with a thickness of 100 meters [2]. The lateral variationin reservoir thickness is strongly controlled by growth fault while the reservoir thickens towards the fault within thedown-thrown block [9].

2.2.2 Traps and Seals

Most known traps in Niger Delta fields are structural although stratigraphic traps are not uncommon [2]. Thestructural traps were developed during synsedimentary deformation of the Agbadaparalic sequence [3,11].Structural complexity 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. [2]described a variety ofstructural trapping elements, including those associated with simple rollover structures; sand filled channels,multiple growth faults, antithetic faults, and collapsed crest structures.The primary seal in the Niger Delta is the interbedded shale within the Agbada Formation. The shaleprovides three types of seals; clay smears along faults, interbedded sealing units against which reservoir sandsare juxtaposed due to faulting, and vertical seals [2].
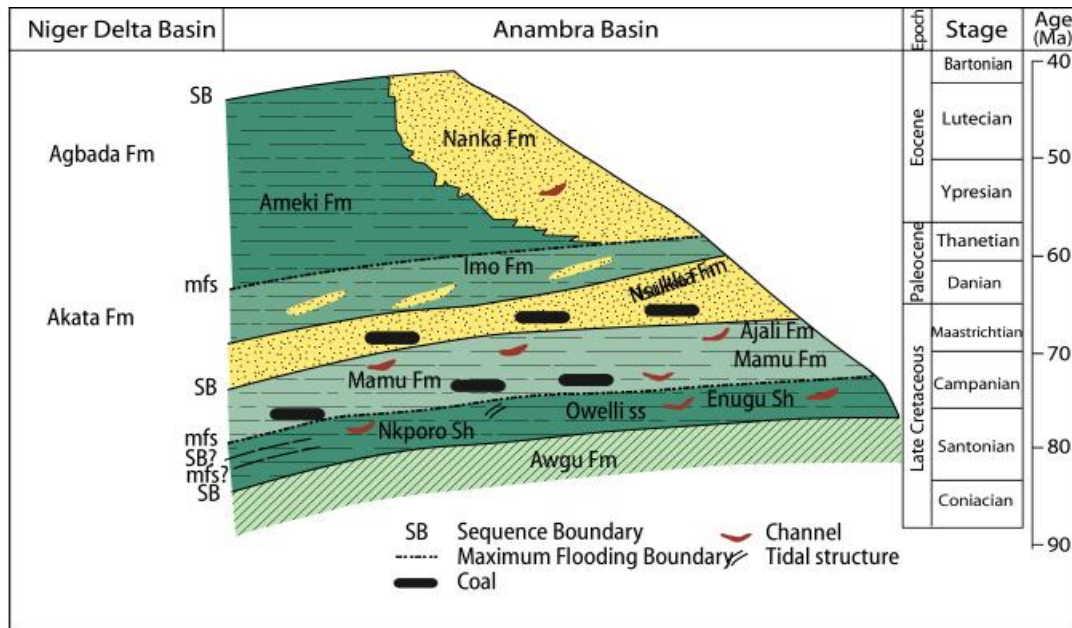

Figure 2: Lithostratigraphic units of Niger Delta and its contemporaneous sedimentary units in the adjacent Anambra Basin [15].

III.   Methodology

The research methodology involved interpretation of 3D-seismic data. This technique was carried out using PETREL software. The seismic data were checked for quality to prevent interpretation pitfalls. The seismic section was then calibrated based on horizons of interest. Horizons were tracked manually, faults were then identified and marked on the section. Interpretation procedure of the main structural framework can be summarized as follows:

1) Identification of main seismic reflectors from the 3D seismic.

2) Manual picking of horizons at this spot on inlines and crosslines whereby a combination of volume auto tracking and interpolation were then used to infill the analysis.

3) Identification of faults networks on the seismic section was also mapped out.

A contouring interval of 20 m was used while the minimum and maximum contours were 2615m to 3185m, 2926m to 3749m, and 2956m to 3932 m for horizons D7.5, E1.0 and E4.2 respectively. Structural maps were generated and integrated for interpretation. Structural contour maps generated were employed in monitoring reservoir distribution and identification of hydrocarbon prospect away from the known productive zones. Horizon and fault interpretation were then carried out.

IV. Results And Discussions

The 3D seismic data was interpreted on an interactive workstation. The three key horizons (E4.2, E1.0 and D7.5) were interpreted and mapped using their seismic continuities. The continuities of the fault segments and their assignment were rigorously checked on the seismic sections (Fig. 3).
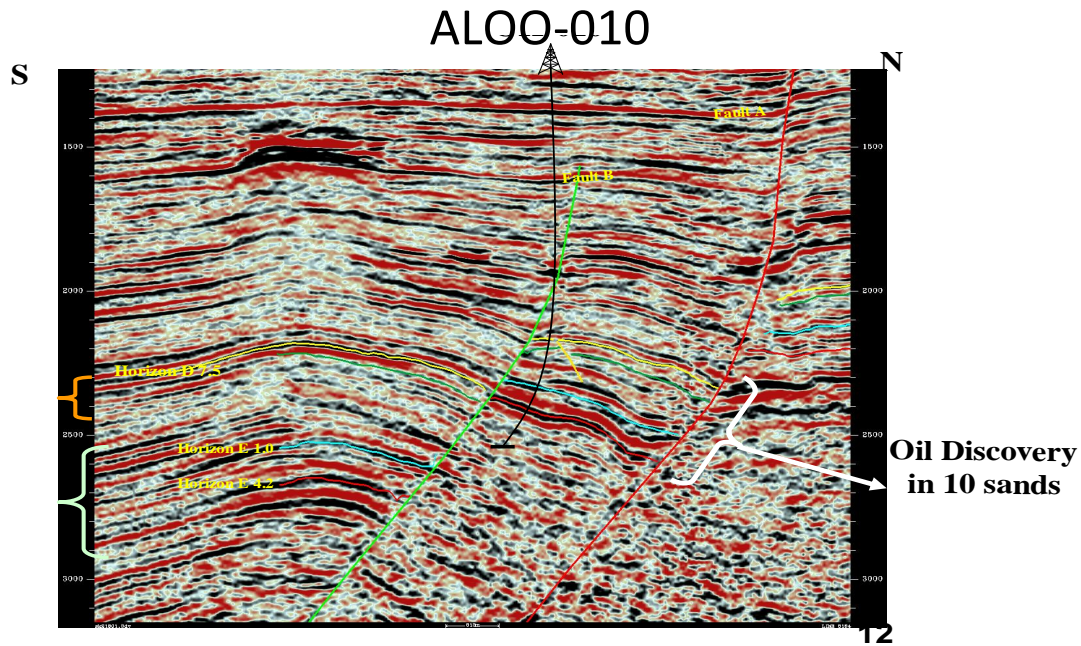
Figure 3: Seismic section showing the picked horizons and the associated fault.

Three horizons of different characteristics were mapped as follows:
• Horizon E1.0 is characterized by low-to-high or variable amplitude reflections, with poor-to-low continuity. In some places, it is disturbed by some truncations which are more of fault related than lithologic heterogeneity.
• Horizon D7.5 was characterized by high amplitude moderate-to-good continuity reflections, mostly appearing parallel-to- sub parallel.
• Horizon E4.2 was characterized by high amplitude with moderate-to-good continuity reflections, mostly disturbed by some truncations.

The seismicdata analysis revealed presence of growth faults labelled A and B on the seismic section (Fig. 3). Bothfaults A and B are the major structure building faults, which correspond to the growth fault in the area.Fault population is characterized by mostly east-west trending normal faults that are dipping towards the south-west, parallel to the main boundary faults (A and B).In the north, fault population is characterized mostly by north-south trend normal faults. This is in response to the main boundary fault to the west of the ALOO-fieldwhich trends north-southdirection.The identified growth faults (A and B) are significantly responsible for trapping of hydrocarbon. 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 that are witnessed from one horizon to another.The vertical displacements of the growth faults show that the amount of throw on both sides of the faults are small and varied from line to line in the seismic survey but increases in the northern part of the field for all the horizons considered (Fig. 4).
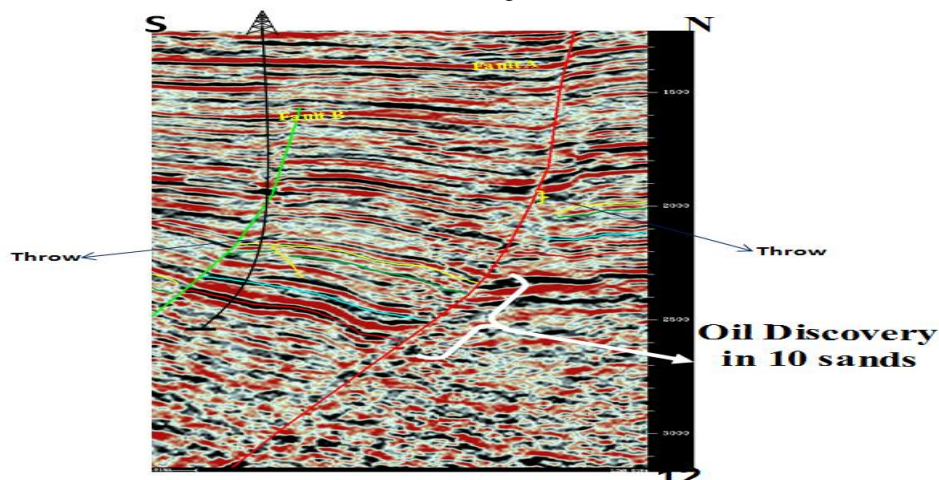

Figure 4: Seismic section showing the various degree of throw increasing from south to north.

Depth structural map of horizon E1.0 is presented in Fig. 5. The contoured map has values ranging from 2926.12m in the north to 3749.1m in the southeast. Structural highs are observed at northwest-centre of the field. This is represented by closedstructure between the interval of 3334.6m to 3317.5m as can be seen on the map (Fig. 5). This area forms a good trapping system thereby increasing retentive capacity for hydrocarbon.Factors such as; low throw index, increased convex curvature, grouting, wedging and excellent shale seal for the hydrocarbon trapping in the area are responsible for the excellent retentive capacity. The oil-gas contact (OGC) is delineated at depth of 3221.8m and the oil-water contact (OWC) is established at depth of 3243.1m (Fig. 5). Structural highs can also be seen in the north but no hydrocarbon accumulation has been linked to it due to the presence of crestal fault that could lead to secondary migration of hydrocarbon into another reservoir. Fig. 6 is the depth structural map for horizon D7.5. The contoured interval value ranges from 2615.2m in the north to 3185.2m in the east. Structural highs were observed in the northwestern part of the horizon where gas has been identified. The structural highs serve as good traps for the hydrocarbon accumulation. The oil-water contact (OWC) is located at depth ofabout 2706.7m. In the northwestern section between the contour interval of 1859.3m and 2651.8m, closed structureswere seen. Since the contour values in the northwestern section for this interval are very low compared to the adjacent contours, thus, the area is suggested to be structurally high. The closedstructures represent anticlinal forms that can serve as good hydrocarbon traps.In Fig. 7, the depth structural map for horizon E4.2 is presented. The contoured map value ranges from 2956.6m in the east to 3932m in the north. Structural highs were observed in the northwestern part of the field where gas has been identified. The structural highsrepresentgood trapping system for the hydrocarbon in the analyzed horizon. The gas-oil contact (GOC) has been traced out to the depth of 3386.4m. Also, in the northwestern sector between the contour intervalof 3078.5m and 3901.5m closed structureswere noticed. Since the contour values are very low compared to the adjacent contours, this area has also been zoned as a structural high. The closed structuresindicate anticlinal structures. These structuresalso serve as good trapping mechanism for hydrocarbon accumulation found within. The oil-water contact (OWC) is situated at depth 3394m.The structure in the northern part of the field covers an area of about 9.5 km^2 while the one at the centre of the field spans an area of about 10.19km^2. These structures can serve as good traps for the hydrocarbon reservoirs because they can impede both vertical and lateral migration of fluids, with the embedded shale serving as the seal. The extensive lateral area covered by the structural highs combined with fairly thick reservoirs mapped could suggest occurrence of economic accumulation of hydrocarbon.
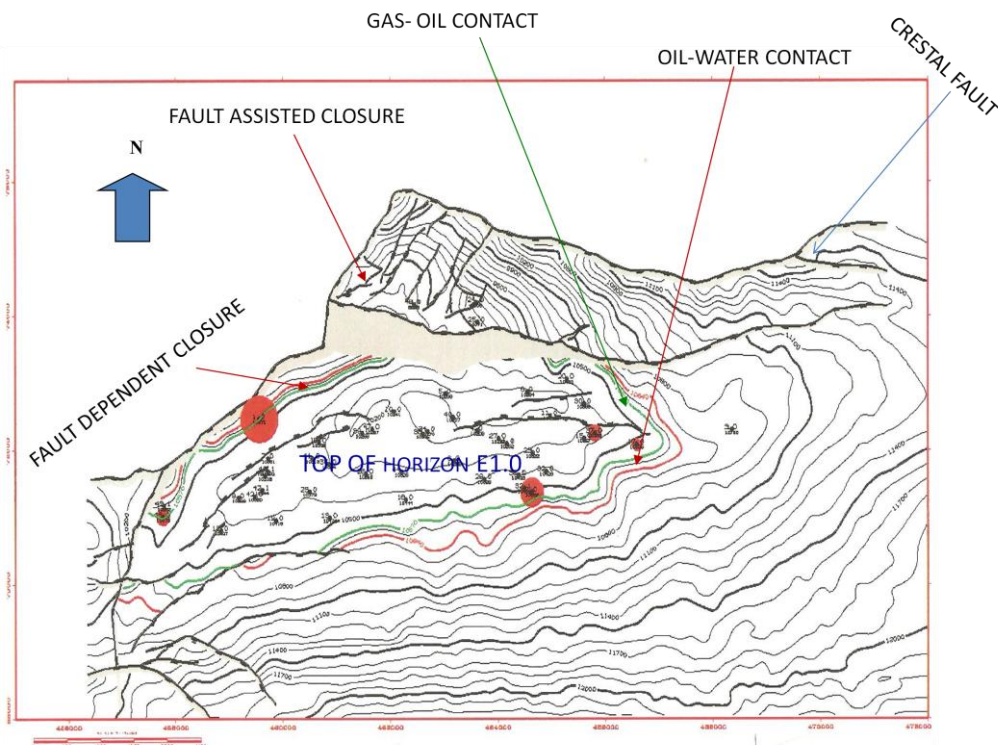

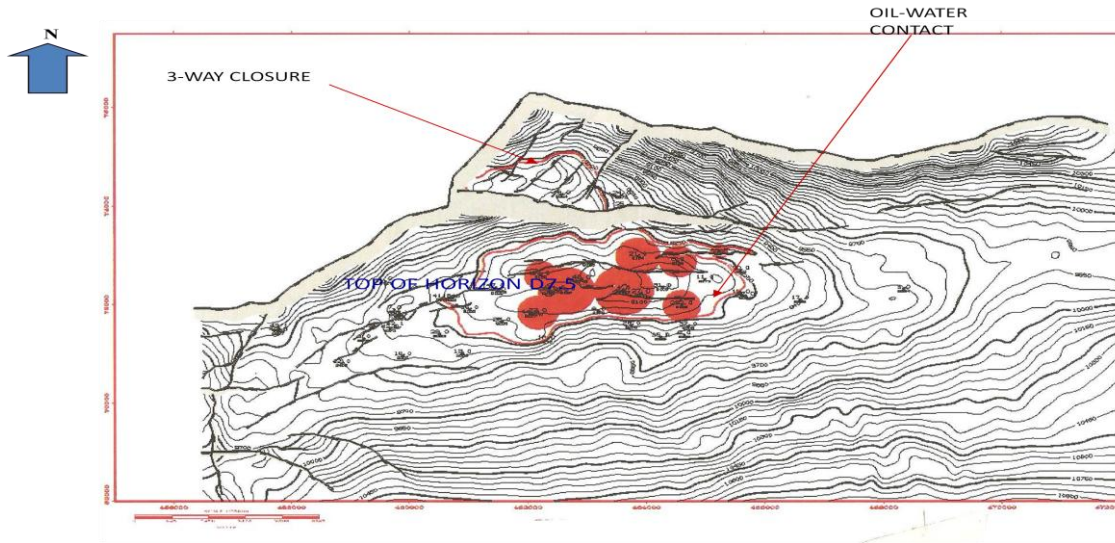Figure 5: Depth structural map of horizon E 1.0
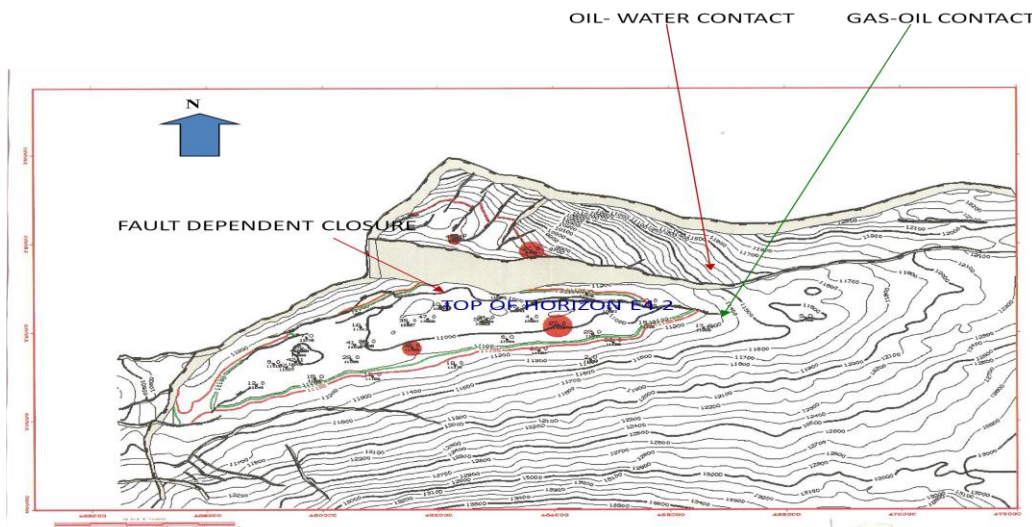
Figure 6: Depth structural map of horizon D 7.5.

Figure 7: Depth structural map of horizon E 4.2.

V.   Conclusion

3D seismic structural interpretation was carried out on part of Aloo-Oil Field through the analysis of threeselectedhorizonswhich include; EI.0, E4.2 and D7.5. Main structural features of the area are growth faults, anticlinal structures, rollover anticlines and crestal faults. The growth faults trend W-E and dip towards the east, while the northern part is defined by fault population trending N-S which are responsible for high retentive capacity of the reservoirs and the hydrocarbon trapping mechanism in the studied area. Both gas and oil are present in the area. Gas-Oil contact(GOC) and Oil –Water contact(OWC) were established for horizons E1.0 and E4.2; while only Oil-Water contact(OWC) was delineated at horizon D7.5.

The degree of fault throws tends to improve from south to north thereby increasing retentive petroleum capacity in the south than in the north. Also, closed structures are present in all the analyzed horizons whereby the associated structural highs suggest good hydrocarbon trapping system. However, crestal faults present are incapable of holding hydrocarbon which may be responsible for secondary migration in the area. Therefore, large area covered by structural highs, growth faults, rollover anticlines and fair reservoir thickness are suggested to be the controlling factors responsible for economic hydrocarbon accumulation in the studied area.

References

[1]   G. Jon, and S.Richard,Petroleum Geoscience(USA: Blackwell Publishing, 2004) 54 – 112.

[2]   H.Doust, and E.Omatsola, Niger Delta, in, Edwads, J. D., and Santogrossi, P.A.,(Eds), Divergent/passive Margin Basins, AAPG Memoir 48, *American Association of Petroleum Geologists*, Tulsa, , 1990, 239-248.

[3]   B.D.Evamy, J.Haremboure, P.Kamerling, F.A. Molloy, and P.H.Rowlands, Hydrocarbon habitat of Tertiary Niger Delta,*American Association of Petroleum Geologists Bulletin,62,*1978, 1-39.

[4]   S. Short, and G.Stauble, Outline of Geology of Niger Delta, *American Association of Petroleum Geologists Bulletin,*1967 761-768.

[5]   C. M. Ekweozor,J.I.Okogun, D.E.U.Ekong, and J.R.Maxwell,Preliminary organicgeochemical studies of samples from the Niger Delta, Nigeria, Part 1, analysis of crude oils for triterpanes,*Chemical Geology,27,*1979, 11-28.

[6]   C. M. Ekweozor, and N.V.Okoye, Petroleum source-bed evaluation of Tertiary Niger Delta,*American Association of Petroleum Geologists Bulletin, 64,* 1980, 1251-1259.

[7]   D. O.Lambert-Aikhionbare, and A.C.Ibe, Petroleum source-bed evaluation of the Tertiary Niger Delta, discussion, *American Association of Petroleum Geologists Bulletin, 68,*1984, 387-394.

[8]   R. M.Bustin, Sedimentology and characteristics of dispersed organic matter in Tertiary Niger Delta: origin of source rocks in a deltaic environment,*American Association of Petroleum Geologists Bulletin, 72,*1988, 277-298.

[9]   K. J. Weber, and E.M.Daukoru, Petroleum geology of the Niger Delta, *Proceedings of the Ninth World Petroleum Congress, Geology, 2,* London, 1975, 210-221.

[10]   J.E.Ejedawe, Patterns of incidence of oil reserves in Niger Delta Basin,*American Association of Petroleum Geologists, 65,*1979, 1574-1585.

[11]   P.Stacher, Present understanding of the Niger Delta hydrocarbon habitat, in M.N.Oti, and G.Postma, (Eds)., *Geology of Deltas*, Rotterdam, A.A. Balkema,1995.

[12]   B.R. Frost, A Cretaceous Niger Delta Petroleum System: Extended abstracts, Petroleum Systems of the South Atlantic Margin,*AAPG/ABGP Hedberg Research Symposium, November 16-19,*Rio de Janeiro, Brazil, 1997.

[13]   R.C.Haack,P.Sundararaman, andJ. Dahl, Niger Delta petroleum System: Extended abstracts,Petroleum Systems of the South Atlantic Margin, *AAPG/ABGP Hedberg Research Symposium, November 16-19,*Rio de Janeiro, Brazil. 1997.

[14]   H. Kulke, Regional petroleum geology of the world. Part II: Africa, America, Australia and Antarctica: Berlin, GebrüderBorntraeger, 1995, 143-172.

[15]   T.J.A.Reijers, S.W.Petters, and C.S.Nwajide, The Niger Delta Basin, *in*R.C.Selley, (Ed.), *African Basins--Sedimentary Basin of the World, 3*(Amsterdam: Elsevier Science,1997)151-172.