A Seismic Analysis of Structural History of Makad Field, Onshore Niger Delta and Its Implications for Petroleum Occurrence

Ayoola W. Fagbenro[1], Timothy Y. Woma[2]

[1, 2]Federal University, Wukari, Department of Pure and Applied Physics,
P.M.B. 2010, Kastna- Ala Road, Wukari, Taraba State, Nigeria

Abstract: ***This study builds structural frame work for Makad field of deltaic Agbada formation under the Niger Delta by relating strata discontinuities observed in a 3D seismic volume to vertical changes observed in well logs of the field. In order to examine how structural deformation above mobile shale influences patterns of deposition, trap geometry, and their implications for petroleum accumulation, a comprehensive interpretation of a suite of 3D seismic data acquired over Makad field was carried out manually. Three sand tops namely AA-1, AA-7 and AA-L in the field were selected for interpretation based on good petrophysical parameters. The wells penetrated into the downthrown side of the major structural-building fault in the study area. The mapped horizon surfaces and fault were exported to base map and contoured, to generate fault plane maps and structure maps for the interpreted horizon. The trapping mechanism is fault assisted. The results of this study show that field conceptual development plan and economic model ought to be based on detailed 3D seismic interpretation, which must include seismic analysis of the structural geometry to reduce the geologic risk of prospect.***

Keywords: seismic, structure, fault, hydrocarbon

1. Introduction

For more than a century, progress in petroleum exploration techniques has allowed us continuous discovery of new hydrocarbon fields as a new domain become open for exploration. This expansion of research area is coming to an end, and it's becoming necessary to concentrate the exploration efforts in already studied area. We must search for fields with underestimated potentials, or fields for which the complex geometry could have limited exploitation. The growing demand for hydrocarbons and declining oil and gas reserves have made reservoir characterization an important area of research in geosciences. Indeed, even a small increase in the recovery rate of oil or gas not only lengthens the life of the field but also reduces operational costs. Therefore it is essential to study the reservoir architecture and compartmentalization, as well as faults and fractures and production-induced dynamic changes. The goal of this study is to examine how structural deformations above mobile shale influences patterns of depositions, trap geometry and the implication for the petroleum accumulation

2. The Niger Delta Province

The Niger Delta is situated in the gulf of Guinea and extends throughout the Niger Delta province as defined by [1], [21]. From the Eocene to the present, the delta has prograded South West ward, forming depobelts that represent the most active parts of the delta at each stage of its development [5].

These depobelts form one of the largest regressive deltas in the world with an area of some 300,000km^2 [12], a sediment volume of 500,000km^2 [10] and a sediment thickness of over 10km in the basin depocenter [20]. The Niger Delta province contains only one identified petroleum system [12],[17]. This system is referred to as the tertiary Niger Delta (Akata-Agbada) petroleum system. The maximum extent of the system is defined by the area of the fields and contain know resources (cumulative productive 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) [23]. Currently, most of this petroleum is in fields that are onshore or on the continental shelf in water less than 200 meters deep, and occur primarily in large relatively simple structures. A few giant fields do occur in the delta, the largest contain just over 1.0 BBO [23]. Among the provinces ranked in the U.S. Geological Surveys World Energy Assessment [21], the Niger Delta province is the twelfth richest in petroleum resources, with 2.2 % of the world's discovered oil and 1.4% of the world's discovered gas [23]. Petroleum exploration is also expanding, especially in deeper water offshore. Considering oil and gas, the overall success ratio for exploration drilling is 45% [12].

2.1 The Lithology

The tertiary section of the Niger Delta is divided into three formations, representing prograding depositional facies that are distinguished mostly on basis of sand – shale ratios. The type sections of these formations are described in [18] and summarized in [12]. The Akata Formation at the base of the delta is of marine origin and is composed of thick shale sequences,turbidites sand, and minor amount of clay and silt. The formation underlies the entire delta, and is typically overpressured. Deposition of the overlying Agbada formation, the major petroleum-bearing unit, began in the Eocene and continues into the recent. The formation consists of paralic siliciclastics over 3700 meters thick and represents the actual deltaic portion of the sequence. The Agbada Formation is overlain by the third formation, the Benin Formation, a continental latest Eocene to recent deposit of alluvial and upper coastal plain sands that are up to 2000m thick [16].

2.2 The Reservoir Rock

Petroleum in the Niger Delta is produced from sandstone and unconsolidated sands predominantly in the Agbada

Formation. [22] describes the primary Niger Delta reservoirs as Miocene paralic sandtones with 40% porosity, 2 darcys permeability, and a thickness of 100 meters. The lateral variation in reservoir thickness is strongly controlled by growth faults; the reservoir thickens towards the fault within the down thrown block [17].

2.3 The Traps and Seal

Most known traps in Niger Delta fields are structural although stratigraphic traps are not uncommon. The structural traps developed during synsedimentary deformation of the agbada paralic sequence [5], [6]. [19] describe a variety of structural trapping elements, including those associated with simplerollover structures,, clay filled channels, multiple growth faults, structures with antithetic faults, and collapsed crest structures. The primary seal rock in the Niger Delta is the interbedded shale within the Agbada Formation. The shale provides three types of seals – clay smears along faults, vertical seals and interbedded sealing units against which reservoir sands are juxtaposed due to faulting (fig.1).

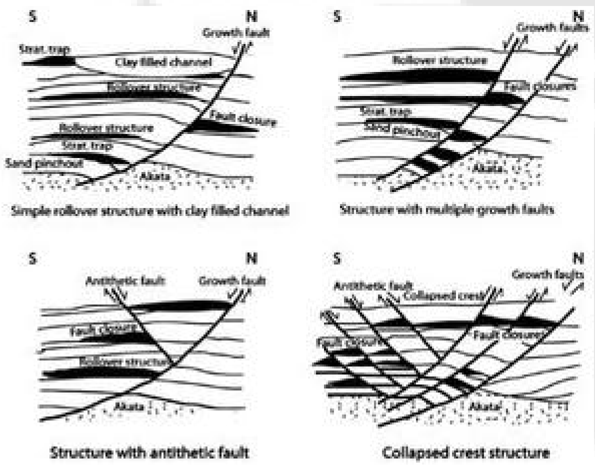

Figure 1: Common trapping configuration in Niger Delta (from [17])

2.4 The Source Rock

There has been discussion about the source rock for petroleum in the Niger Delta. Possibilities include variable contribution from the marine interbedded shale in the Agbada Formation and the marine akata shale, and cretaceous shale [5], [9], [19].

3. The Scope and Method of Study

This work focused on the interpretation of the structural history of the area from the available seismic reflection and correlated well-log data, and looked at its effect on interpreted petroleum occurrences. The method of investigation in a time line fashion is as follow:

- Work with check shot data to correlate section with well logs.
- Interpret faults and marker horizons at several depths to constrain the timing and progression of faulting in three dimensions
- Simultaneously work on petroleum interpretation and correlation from well logs.
- Correlate well-logs interpreted stratigraphic unit and horizons pick with section to place timing and offsets on faults.
- Compare results to petroleum occurrences from well picks and seismic interpretations. Does location, offsets, strike, displaced units correlate with petroleum occurrences, and if so, does this tell us something about petroleum Formation, petroleum migration, or confining hydrocarbon bearing unit.
- Identify fault bound blocks with significant petroleum and correlate with faulting history and displaced units

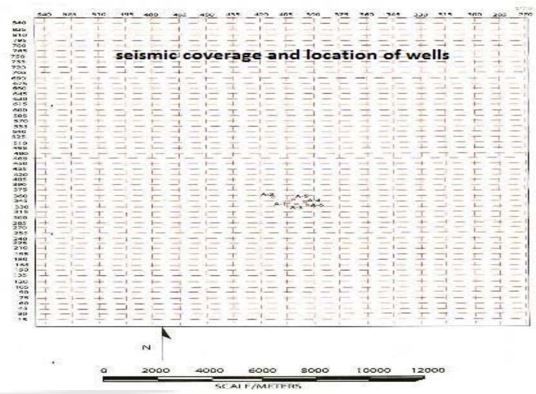

Figure 2: Seismic coverage showing locations of wells

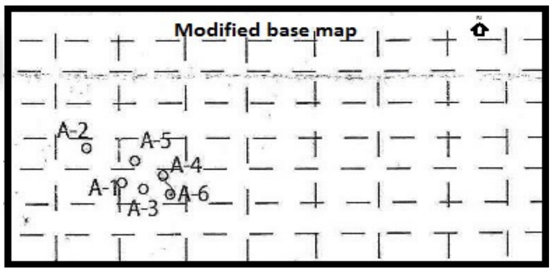

Figure 3: Modified base map

4. The Seismic Record of Makad Field

The seismic volume that spans Makad field is characterized by a series of nearly parallel reflections from stratal layers offset by listric normal fault (figure 5 and 6). Reflections within the upper 0.8ms two way travel time of this record are low amplitude, parallel, and discontinuous. Based on regional studies [5], and the uniformly blocky, low value gamma-ray patterns observed within the few well logs from Makad field through this interval, these reflect from sandy strata of the fluvial Benin Formation. This study focuses on the prominent reflections within 0.8ms to 2.10 ms two way time, inferred from regional studies to be from the Agbada Formation. Seismic reflections become discontinuous and locally transparent below about 2.00 two way time.

Deeply buried transparent intervals, for most part below the interval address here, are inferred to be fractured over-pressured shales of the basal Agbada or Akata Formations [14]. Upward extensions of these more transparent seismic facie into footwall blocks directly adjacent to major faults suggest shallower hydraulic fracturing. The top of the mobile shale reflects the overall geometry of the major trap forming structures in the field, and also indicates upward mobilization of shale under areas where overlying sediment loads were tectonically displaced basin ward along the major faults [5], [15].

Parallel reflections in upper parts of sequences, which can incrementally thicken but generally do not change abruptly in character across faults, suggest that these strata were deposited after most structurally generated irregularities had filled and accumulating sediment maintained a relatively smooth longitudinal depositional profile. Variation in the thickness of strata between successive intra-sequence surfaces thus reflect amount of growth strata that accumulated on downthrown fault blocks. Thickness changes between seismic reflections in older sequences are more strongly influenced by structural deformation with layers clearly thickening on downthrown blocks directly adjacent to fault.

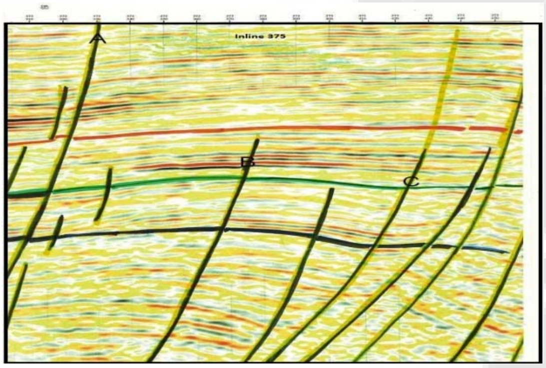

Figure 4: Inline 375 from Makad field

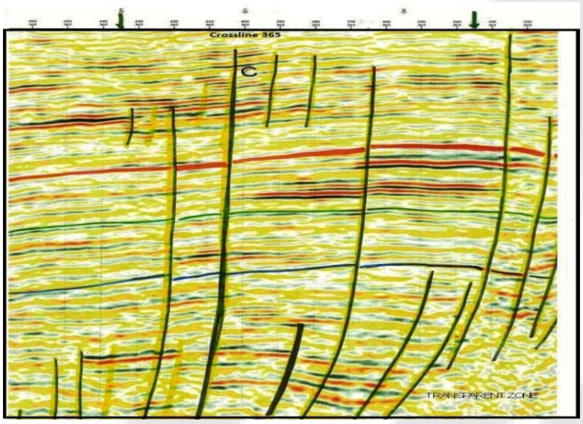

Figure 5: Crossline 365 from Makad field

4.1. Structural deformation and growth strata

Major faults are defined by abrupt dislocation of reflection patterns. Three major faults (labeled A, B and C) and associated rollover anticlines on down thrown blocks dominate structure within the central part of the seismic volume. Abundant smaller faults, associated with less reflection displacement in cross section, generally strike sub-parallel to adjacent major faults trend (fig. 4 and 5).

Successively younger reflectors can be significantly less offset across faults, demonstrating syndepositional displacement. Growth strata are also indicated by intervals between reflections that thicken away from anticline crests. The average offset of successive reflections across faults becomes progressively less upsection, suggesting that rates of fault movement decreased overtime.

4.2. Well logs of Makad field

Wells of Makad field penetrate only part of the area documented by the seismic record. They provide critical information for interpreting lithic variations associated with changes in seismic facies, incision depth of sequence boundaries, incision depth of hydrocarbon and depositional patterns across major faults. Responses from SP and Gamma ray logs were interpreted in terms of the lithology penetrated by the wells. The responses showed that the area of interest which is Agbada Formation is characterized by alternation of shale and sand. The correlation panel (fig. 6) shows that the horizons are continuous and exhibit a little variation across the wells. The variation in the percentage of shale in the sand across the wells caused by upsection due to minor faults, defines the quality of the reservoir.

The Gamma ray density and Neutron porosity crossover plot from the well logs were used to interpret the occurrence of hydrocarbon in the sandstone of the Agbada Formation. Well A_4 and A_6 penetrated series of sandstone with appreciate amount of hydrocarbon. Three sand tops namely sand AA-1, AA-7 and AA-L were selected as good interpretation candidates based on good petrophysical parameters and presence of hydrocarbon.

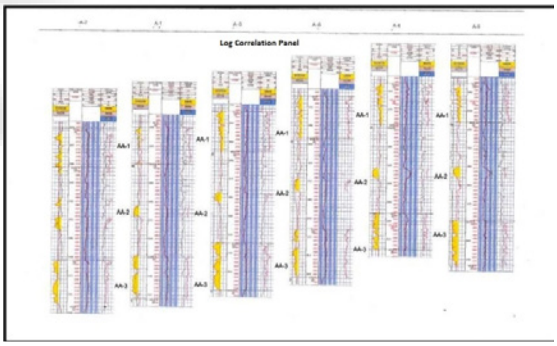

Figure 6: Wells correlation panel from Makad field

4.3. Fault plane map of Makad field

Fault plane maps were constructed for the three major faults found in this area (fig. 7 and 8). Fault B and C have northwest – southwest strike trend and listric basin-ward dip to the southwest (fig. 7). Fault A has northeast – southwest strike trend and basin-ward dip to the southwest (fig. 8). These help to define the location of the faults in horizontal and vertical dimensions and to reconstruct structural history of Makad field, where faults serve as the boundary limit of hydrocarbon reservoir.

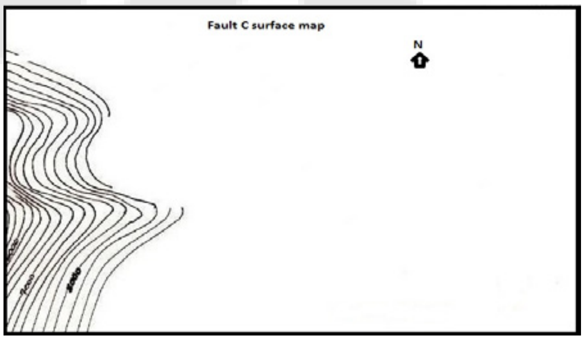

Figure 7: Fault plane map (fault C)

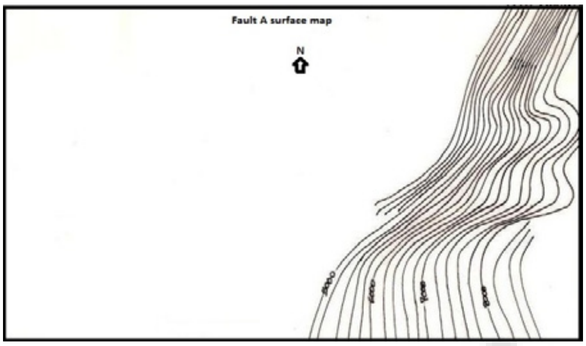

Figure 8: Fault plane map (fault A)

4.4. Structure map of Makad field

Mapped horizons surfaces were exported to the base map. With fault plane maps, depth structure maps were generated for the top of the three picked horizons (fig. 9 and 10). The area has structural complexity that increases from northeast to the southwest in response to increasing instability of the under compacted, over pressure shale.

The structure map of horizon AA-7 (fig. 9) shows the top of 5700 feet sand. This area covered by the Makad field is probable underlain by crest of a rollover anticlines faulted at eastern and western portion of the field. The structural trap for the hydrocarbon is a fault dip closure, that is, rollover anticline and growth fault caused by rapid sedimentation onto under compacted mud's, which causes instability and slumping which produces the growth fault.

The structure map of horizon AA-L (fig. 10) shows another kind of structural traps influenced by fault B and C, the traps can be referred to as combined dip foot, hanging wall closure. The trapping mechanism for hydrocarbon in Makad field is fault assisted as the traps are up dip fault closure against the downthrown side. The interbedded shale in the makad field is the primary seal rock. The shale provides interbedded sealing unit against which reservoir sands are juxtaposed due to faulting.

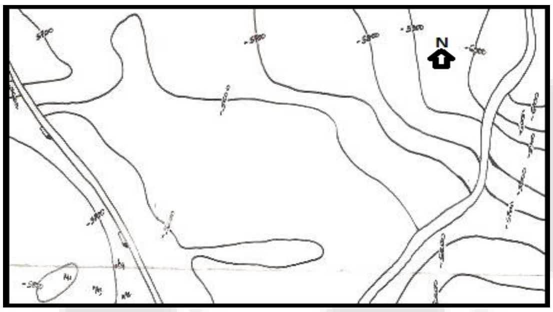

Figure 9: Structure map (horizon AA- 7)

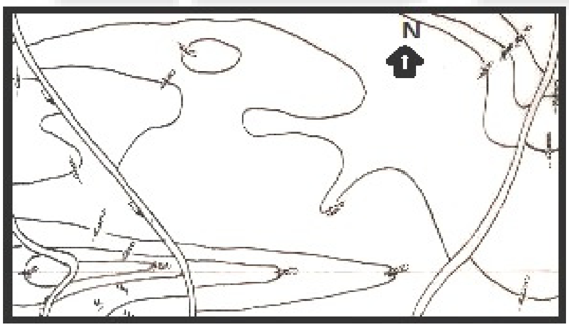

Figure 10: Structure Map (horizon AA-L)

5. Conclusion

This paper present workflow aimed at building structural frame work for Makad field directly from the seismic data and well logs. The integration of seismic data and well logs proved to be useful and valid tool in structural mapping. From the well log analysis, three major horizons were identified. The result of the qualitative interpretation of the gamma ray and resistivity logs showed that the three horizons contain appreciable amount of hydrocarbon.

The well to seismic tie revealed that the major faults are defined by abrupt dislocation of reflection patterns with younger reflector significantly less offset across faults, demonstrating syndepositional displacement. Three major faults were identified. By constraining the timing and progression of the three faults in three dimension, the location of the faults in horizontal and vertical dimensions were well define to accurately reflect area within the field that are affected by faulting

The three horizons and the three major faults were mapped for the purpose of carrying out subsurface structural interpretation. These were used in generating structure maps. From the maps, it was observed that the principal structure responsible for hydrocarbon entrapment in the field for the three horizons considered is the structural high at the eastern part of the field. These structures correspond to the crest of rollover structure in the field.

The trapping mechanism for hydrocarbon in Makad field is fault assisted. The traps as seen on the structure maps are capable of providing hydrocarbon production from number of horizons, and they can be sealed and a number of pools might be stacked, greatly enhancing the value of the field.

Information extracted from the integration of seismic and well logs data have resulted in more understanding of the structure and hydrocarbon potential of the Makad field, onshore Niger Delta. Based on the above, it is clear that a suitable integration of seismic and well data will definitely help to provide better reservoir characterizations. This result suggest the use of workstation to allow for generation and analysis of horizon attributes, useful for identifying the correct location of structures and edges like faults, understanding the throw profile behavior along faults and the true location of fault tips for volumetric and spill point analysis. This will help an interpreter to characterize the static and dynamic subsurface characteristics.

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References

[1] A. A. Adeogba, T.R. McHargue, S. A. Graham, "Transient fan architecture and depositional controls from near- surface 3-D seismic data, Niger Delta

continental slope", American Association of Petroleum Geologists, Bulletin, 89, pp. 627-643, 2005.

[2] L. F. Brown, R. G. Loucks, R.H. Trevino, U. Hammmes, "Understanding growth fault intraslope sub basin by applying sequence stratigraphic principles: examples from the south Texas Oligocene Frio formation", American Association of Petroleum Geologists, Bulletin, 88, pp.1501-1522, 2004.

[3] K. Burke, "Longshore drift, submarine canyons and submarine fans in development of Niger Delta", American Association of Petroleum Geologists, Bulletin, 56, pp.1975-1983, 1972.

[4] L. S. Cobos, "Structural Interpretation of the Monagas Foreland Thrust Belt, Eastern Venezuela" ,Adapted from extended abstract prepared for presentation at AAPG Annual Convention, Dallas, Texas, April 17-21, 2004.

[5] H. Doust, E. Omatsola, "Niger Delta", in J. D. Edwards, and P. A. Santagrosseid,(eds.), Divergent/passive margin basins, America Association of Petroleum Geologist Memoir 48, pp.239- 248, 1990.

[6] B.D. Evamy, J. Haremboure, R. Kammerling, W.A. Knaap, F.A. Molloy, P.H. Rowlands, "Hydrocarbon habitat of Tertiary Niger Delta", America Association of Petroleum Geologist, Bulletin, 62, pp. 1- 39, 1978.

[7] W.E. Galloway, "Growth faults and fault-related structures of prograding terrigenous clastic continental margins", Gulf Coast Association of Geological Societies, Transactions, 36, pp.121-128, 1986.

[8] W. E. Galloway, "Genetic stratigraphic sequences in basin analysis II: application to the northwest gulf of Mexico Cenozoic basin", America Association of Petroleum Geologists, Bulletin, 73, pp.143-154, 1989.

[9] R. C. Haack, P. Sundaraman, J. Dahl, "Niger Delta Petroleum System" in Extended Abstracts, AAPG/ABGP Hedberg Research Symposium, Petroleum System of the South Atlantic Margin, November 16-19, 1997, Riobde Janeiro, Brazil.

[10] J. Hosper, "Gravity and Structure of the Niger Delta, Nigeria, West Africa", Geol. Soc. Amer.,Bulletin 76, pp. 407 – 422, 1965.

[11] G.J. Knox, E.M. Omatsola, "Development of the Cenozoic Niger delta in terms of the escalator regression model and impact on hydrocarbon distribution", Dordrecht, Kluwer Academic Publishers, The Netherlands, pp.181-202, 1989

[12] H. Kulke, "Regional Petroleum geology of the world. Part II: Africa, America, Australia and Antarctica", Berlin, Gebruder Borntraeger. 143-173.,1995

[13] D. K. Larue, H. Legarre, "Flow units, connectivity, and reservoir characterization in wave dominated deltaic reservoir: Meren reservoir, Nigeria", American Association of Petroleum Geologists, Bulletin, 88, pp.303-324, 2004.

[14] R. Morgan, "Structural controls on the positioning of the submarine channels on the lower slope of the Niger Delta", in R. J. Davis, J. A. Cartwright, S.A. Steward, M. Lappin, and J. R. Underhill eds., 3-D seismic Technology: Application to the Exploration of Sedimentary Basins: Geological Society of London, Memoir 29,pp. 45-51, 2004.

[15] C. K. Morley, G. Guerin, "Comparison of gravity – driven deformation styles and behavior associated with mobile shales and salt", Tectonics, 15, pp. 1154 – 1170, 1996.

[16] J. M. Oirife, A.A. Avbovbo, "Stratigraphic and unconformity traps" in the J. M. Armentrout, K. A. Kanschatn, K. Meisling, J. J. Tsakma, L. Antrim, and D. R. McConnel, 200, Neogene turbidite systems of the Gulf of Guinea continental margin slope, offshore Nigeria,in A. H. Bouma and C. G. Stone eds., Fine Grained Turbidites Systems: American Association of Petroleum Geologist, Memoir 72, And SEPM, Special Publication 68, pp. 93-108,1982,

[17] K. J. Weber, E.M. Daukoru, "Petroleum Geology of the Niger Delta" Proceedings of the Ninth World Petroleum Congress, Geology, Applied Science Publishers, London, 1975.

[18] K. C. Short, A. J. Stauble, "Outline of the geology of Niger Delta", America Association of Petroleum Geologists Bulletin, 51, pp. 776 – 779, 1967.

[19] P. Stacher, "Present understanding of the Niger Delta hydrocarbon habitat", In M. N. Oti and G. Postmag (eds), Geology of Deltas, Rotterdam, A. A., Balkema, pp. 257- 267, 1995.

[20] A. Kaplan, C. U. Lusser, I. O. Norton, "Tectonic map of the world, Panel 10", American Association of Petroleum Geologist, Tulsa, 1994.

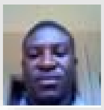
[21] T. R. Klett, T. S. Ahlbrandt, J. W. Schmoker, J. L. Dolton, "Ranking of the world's oil and gas provinces by known petroleum volumes", U.S., Geology Survey Open – file Report, pp. 97 – 463, 1997.

[22] J. D. Edwards, P. A. Santogrossi, "Summary and Conclusions, in, J. D. Edwards and P. A. Santogrossi, Divergent/Passive Margin Basins", American Association of Petroleum Geologists Memoir 48, pp. 239 – 248, 1990.

[23] Petroconsultants, "Petroleum Exploration and Production Database", Petroconsultants Inc, Houston, Texas, 1996a.

Author Profile

Ayoola W. Fagbenro received the B.Tech and M.Sc. degrees in Applied Geophysics from Federal University of Technology, Akure in 2001 and University of Ibadan, Ibadan in 2007 respectively. He is currently with Federal University, Wukari, Taraba, Nigeria



Timothy W. Woma received the B.Eng degree in Mechanical Engineering and Production and M.Sc. degree in Petrophysics from Abubakar Tafawa Balewa University, Bauchi and Heriot Watt University, Edinburgh, UK respectively. He is currently with Federal University, Wukari, Taraba, Nigeria.