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RESEARCH ARTICLE OPEN ACCESS

Evaluation of Fault Compartmentalization of "XAS" Reservoir, Onshore Niger Delta

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Abstract

The potential that the faults in the XAS reservoir might possibly result in compartmentalization was evaluated. The hypothesis is that unexpected compartmentalization issues due to false negatives and false positives, can infringe on earlier supply arrangement and can thwart production schemes and reserves that are booked from the field, booking of reserves is tight and highly regulated by government authorities. Data were obtained that consists well logs, 3D seismic volume for the XAS field. Petrel version 2014 was used for modelling, the structural model unravel that the reservoir has three faulted compartments. The petrophysical properties of the fault zone which comprised the fault zone permeability, the shale gouge ratio, the fault thickness were observed to fall short of the conditions for constraint of fluid flow across faults in the reservoirs. Thus, the faults are non-sealing but suggested to be barriers or/ baffles.

Keywords: **compartmentalization, barriers, baffles, faults, reservoir, seals**.

1.0 INTRODUCTION.

Faults play a significant role in the creation of hydrocarbon traps. The risks associated with fault-controlled prospects and production from faulted fields are appreciated by understanding the processes and contributing factors to the sealing of faults.

Reservoir compartmentalization is the segregation of hydrocarbon accumulations into individual fluid or pressure compartments; it has also been defined as the existence of petroleum accumulations in discrete individual compartments in the reservoir (Jolley et al., 2010). The basic seal types that can sustain compartmentalization are static and dynamic seals.

Static seals can prevent fluid flow over geological time frame while dynamic seals can prevent fluid flow during production time scale. Examples of dynamic seals are baffles and barriers (Jolley et al., 2010). Faulted compartmentalization has been one of the attributes that determine the plumbing and orientation of reservoirs (Ainsworth, 2006). The integrity of faulted compartmentalization has been attributed to the clay content of the faults, where Shale-Gouge ratio or Clay smear potential, or shale smear potential had been used as a tool for evaluating and ranking seals and had also been used as a proxy for clay content evaluation (Jolley et al., 2010). The sealing fault potential had been depended on the clay content or shale gouge ratio.

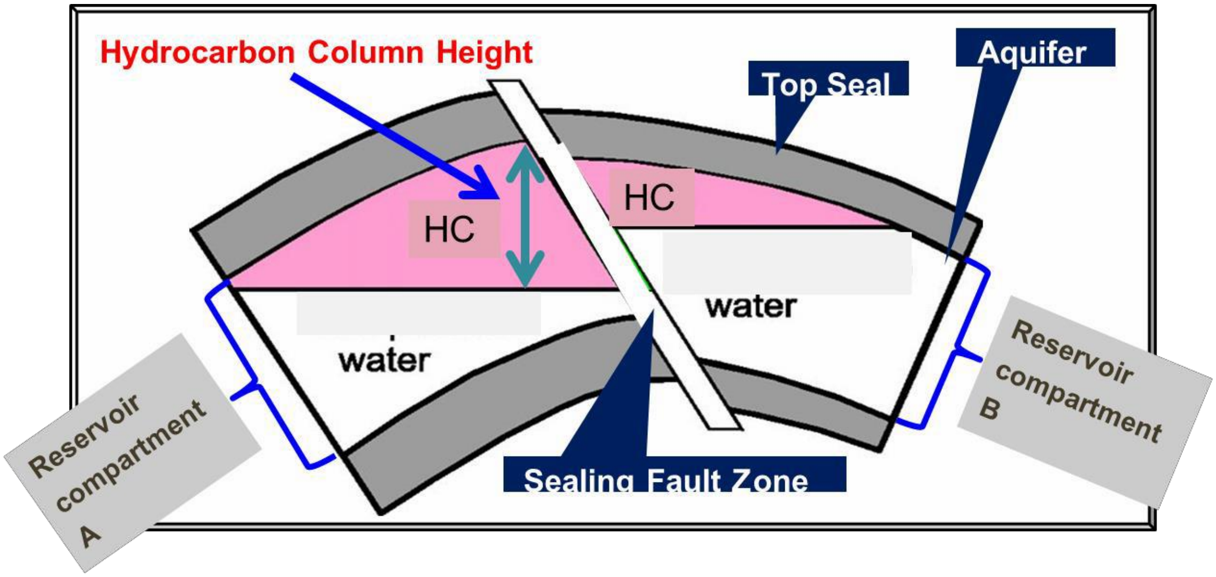

Figure 1**:** Diagram showing Hydrocarbon Column Height (Modified after Bretan *et al*, 2003)

Weber *et al.* (1978) experimentally proved clay gouge to be an effective seal to water flow. It has been observed in open cast mines in an unconsolidated Tertiary deltaic sequence that the clay gouge zone gradually thins away from the clay source bed, the thickest clay gouges observed were about 0.5 m (Weber *et al.* 1978).

Lindsay *et al.* (1993) described outcrop studies of a Carboniferous fluvio-deltaic sequence shale smear, contrasting the description of Weber *et al.* (1978), unraveled, that the carboniferous rocks were lithified during faulting (burial depth about 2 km). Lindsay *et al.* (1993) then recognized three types of shale smear, namely: abrasion, shear, and injection.

1. Shear smears bear a strong resemblance to those described by Weber *et al.* (1978). The smears thicknesses decrease with distance from the source bed and reach a minimum in the central region between the terminations of the hanging-wall and footwall bed.
2. Abrasion smears, which are the commonest type in lithified sequences, comprise of a wafer-thin veneer that is abraded by a sandstone wall rock as it slips across shale beds. These smears tend to be thickest when they are made from thicker source layers and when the fault throw is relatively small. In larger throws, the shale veneer tends to be eroded.

3 Injection smears are a local response to volume changes during faulting. Injection smear thickness is not easily predictable.

The fault zone commonly contains a sheared mixture of the various wall rocks where a fault offset is greater than the bed thickness. Berg and Avery, (1995) stated that the capillary entry pressure or the permeability of the interface of this type of fault rocks could be two orders of magnitude greater than adjacent reservoir sands. Arch and Maltman, (1990) also stated that the alignment of clays in a shear zone introduces a strong directional permeability contrast. The likelihood of clay/shale smearing are controlled by the following factors:

1 Shear-type smears decrease in thickness with distance from the source layer,
2 Thick source beds can produce comparatively thicker clay smears,
3 Multiple source beds can give rise to a combined continuous smear. These relationships imply a possibility of a quantitative approach to clay smear prediction.
4 Abrasion-type smears decrease in thickness with increasing throw.

Watts (1987) stated that fault related seal can be grouped into two, which are the sealing faults and the juxtaposition faults. The mechanisms for sealing faults were stated as Clay smear, Cataclasis, (where grain crushing results in breakage and crushing during fault movement and reduces permeability within the fault zone due to fine grained gouge;) and Diagenetic healing, where preferential cementation along the original fault plane results in increase of capillary entry pressure and low permeability interface.

Bouvier *et al.* (1989) studied the Niger Delta Nun River field. They described a clay smear potential (CSP) as a means of estimating the likelihood of clay smearing in areas of sand-on-sand juxtaposition on faults. The clay smear potential represents the relative amount of clay that has been smeared from individual shale source beds at certain points along a fault plane.

It should be noted that none of the attributes described is entirely a measure of sealing capacity of the fault surface. They should rather be seen as estimates of the relative likelihood of clay smear being developed on the fault surface. However, Onyeagoro *et al*., (2001) and Yielding *et al*., (2010) set conditions needed for hydrocarbon fluid flow across faults as:

1. Shale Gouge Ratio (SGR) must be less than 30 %.
2. Fault thickness range must be 2-20 ft.
3. Reservoir permeability (K) ~ 1000 mD.
4. Fault zone permeability (k) greater than 1 mD.

These conditions are being applied in evaluating the integrity of fault seal in this study.

The hypothesis of this study is based on the fact that operators and investors need to be informed and also equipped with the ability to estimate and identify compartmentalized areas and areas likely to become compartmentalized within the reservoir, during production due to high potential for false negatives (compartments assumed absent due to homogeneous fluid properties, when infact, fluids would have equilibrated even in the presence of compartments), false positives (where fluid differences are interpreted as evidence of compartments, when infact, there has not been sufficient time for equilibration to occur). Unexpected compartmentalization issues can infringe on earlier arrangement and can thwart production schemes and reserves that are booked from the field, booking of reserves is tight and highly regulated by government authorities as aspect of future markets.

The objectives of the study include, effectively mapping and defining the reservoir structural top (i.e., to identify the reservoir structure and the significant faults running through it); build a fit-for- purpose static model of the reservoir to define its petrophysical attributes and perform fault analysis on relevant intra-reservoir faults to determine the possibility of hydrocarbon fluid flow across these faults.

2.0 LOCATION OF STUDY AREA

‘XAS' reservoir is one of the numerous reservoirs located in the Central Swamp Depobelt of the wave and tide-dominated Niger Delta basin in the Gulf of Guinea. The field was discovered in 1961. It lies in the seasonally flooded freshwater swamp area, some 110 Km west of Port Harcourt. The target reservoir is an oil and gas bearing reservoir with 5 wells penetration available. All the wells are concentrated at the eastern region of the reservoir.

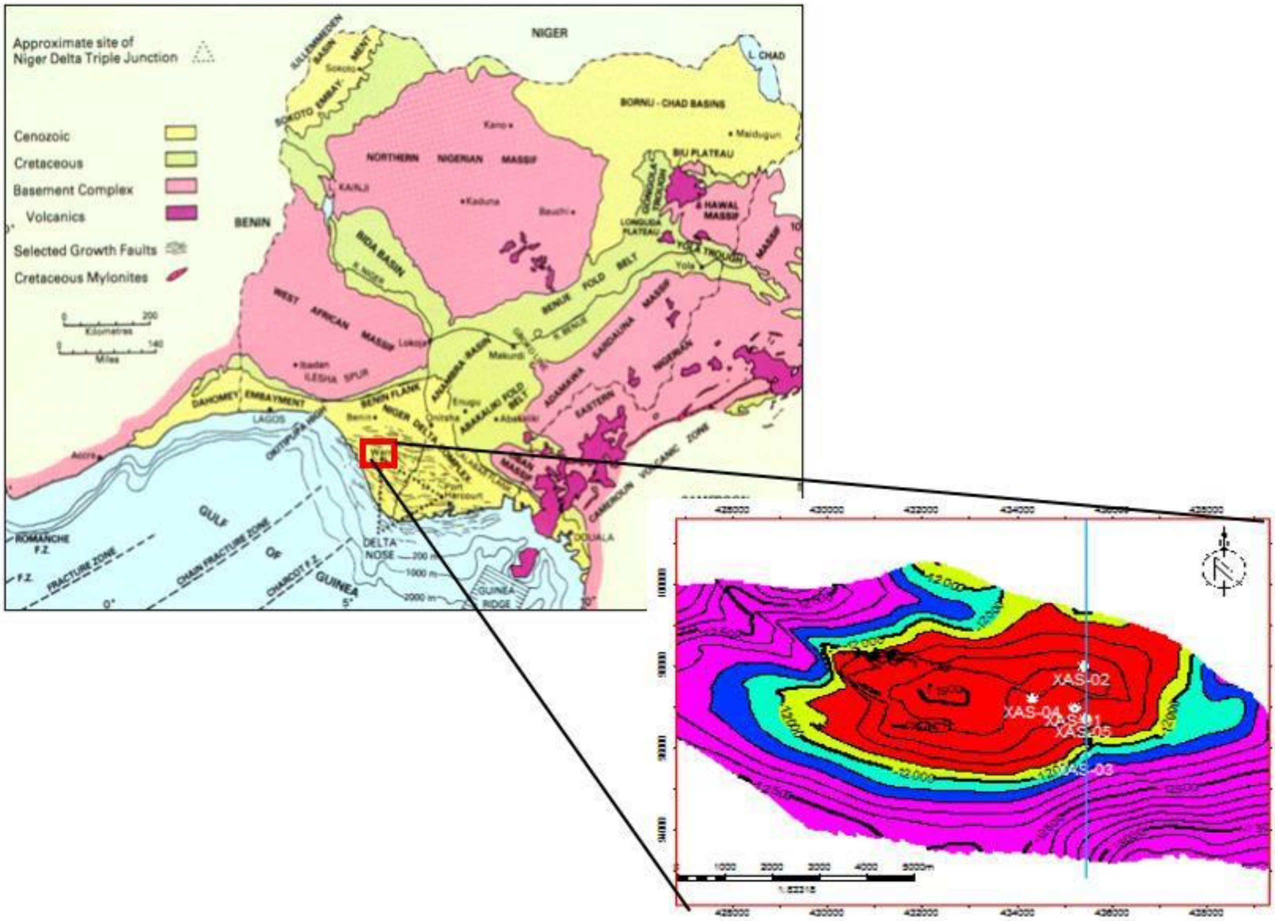

Figure 1a. Nigerian map showing area of study and model seismic cross section

3.0 MATERIALS AND METHODS.

3.1 Available Data.

3D seismic volume (Depth) - Good quality and continuity
Gas and Oil Water Contacts -11660 ft and -11918 ft
Well Logs over reservoir section.

Table 1: Summary of wells logs available for the study.

LOG	XAS-01	XAS-02	XAS-03	XAS-04	XAS-05
GR	V	V	V	V	V
Resistivity	V	V	V	V	V
Density	X	X	X	X	V
Neutron	X	X	X	X	V
NTG	V	V	V	V	V
permeability	X	X	X	X	V
Porosity	X	X	X	X	V

V	**Available**
X	**Not available**

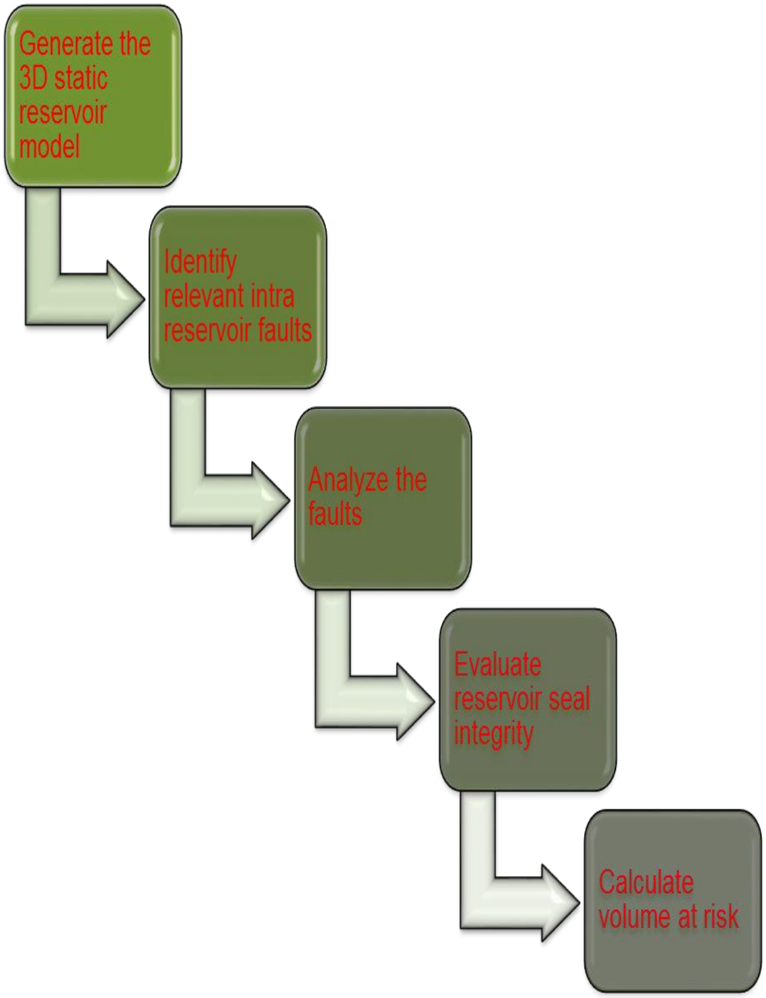

Figure 2: Work flow Chart on data treatment.

4.0 RESULTS AND DISCUSSIONS

4.1 Seismic Interpretations.

30 faults were interpreted. Tops of two reservoirs: XAS Top and T3 reservoir beneath it for stratigraphic control. The structure of the reservoir is anticlinal. Faulting is generally along strike (figures 3a and 3b).

4.2 Structural Model.

29 faults out of 30 interpreted faults were relevant faults for the model, with 12 faults defined to likely impede or act as baffles to fluid flow. Faults F3 and a connecting F8 (figure 3a) segmenting the reservoir into a Northern and Southern accumulations (A, and B), respectively as portrayed in figure 3b. While faults 48, 26, 23, 5, and 28 could further separate the northern accumulation into A1 and A2, (figure 3a).

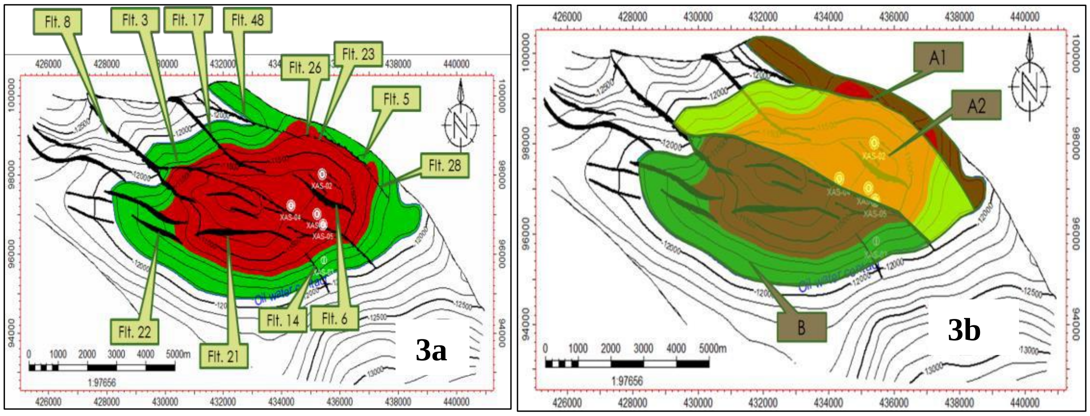

Figure. 3 (a and b): Modelled reservoir faults and the hydrocarbon accumulations and segmentation of the XAS reservoir.

4.3 Reservoir Well Correlations.

The XAS reservoir correlations was achieved using the suites of logs available from all the wells penetrating the reservoir. Correlation panels across the reservoir of the field which is based on GR log signatures was generated, showing detailed reservoir subdivisions as in figures 4 and 4a. Reservoir wide dip section correlation of XAS top and base and T3 top (for stratigraphic control) figure 4a shows that sand quality degrades as portrayed in figure 4 left to right (North to South). This is due to deposition of finer materials basin wards of the reservoir.

4.4 Flow Units and Facies Interpretation.

Five interpreted distinguishable genetic units were identified (channel, lower shoreface, upper shoreface, heterolith and shale) as in figure 4a, with dominant facies units consist of good quality upper shoreface and channel sandstone reservoir units.

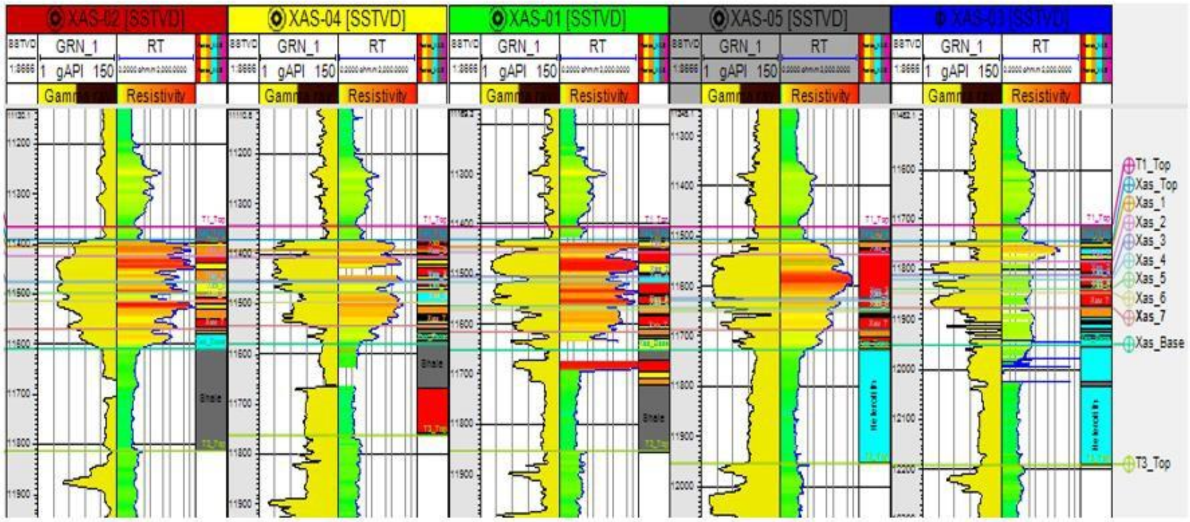

Figure. 4: Correlation panel showing reservoir section showing interpreted facies and flow units.

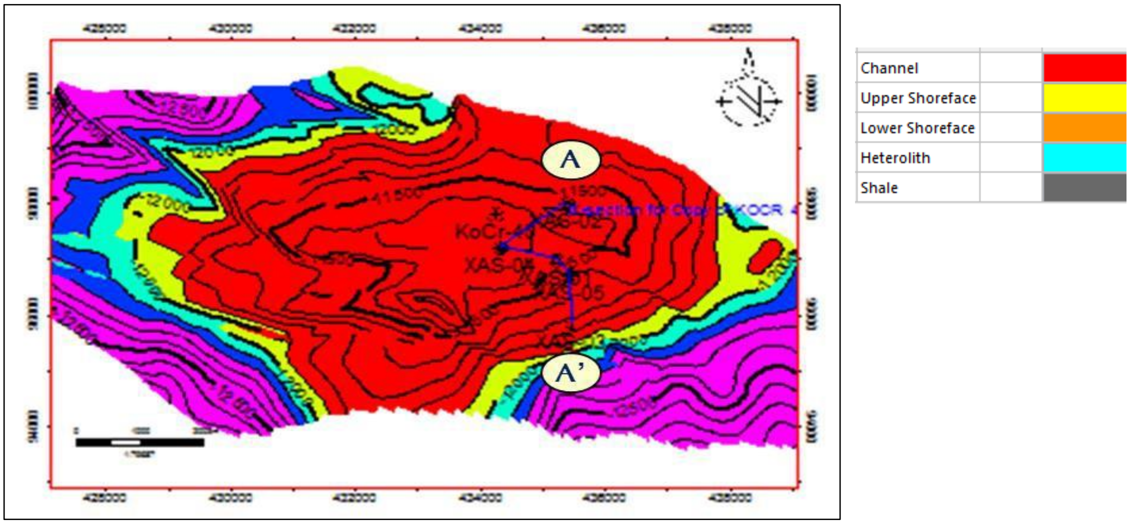

Figure 4a. 2D Reservoir section showing interpreted facies and flow units.

4.5 3D Facies and Petrophysical modelling

The variogram settings for the facies modelling are based on Niger Delta facies description. Channel and Shoreface facies are dominant. Shoreface facies are extensive East–West, while the channels cut through the Shoreface in the North–South direction. Petrophysical models were biased to the facies model.

The conditions considered by Onyeagoro *et al*., (2001) and Yielding *et al*., (2010) is being used to assess the potential for hydrocarbon fluid flow across faults.

These considerations are:
1. Shale Gouge Ratio (SGR), must be < 30 %.
2. Fault thickness range must be 2-20 ft.
3. Reservoir permeability (*K*) ~ 1000 mD
4. Fault zone permeability (*k*) > 1 mD

Juxtaposition analysis shows that Central faults have large juxtapositions while boundary faults have no juxtaposition, and the juxtaposition of interest are those above the oil water contact - 11918 ft (figure 5).

4.6 Fault Thickness

Fault thickness range for juxtaposed areas from the model ranges from 2.5 ft. to about 4 ft, and it corroborates with Onyeagoro *et al*., (2001) and Yielding *et al*., (2010) and such will permit hydrocarbon fluid flow across the faults (figure 6)

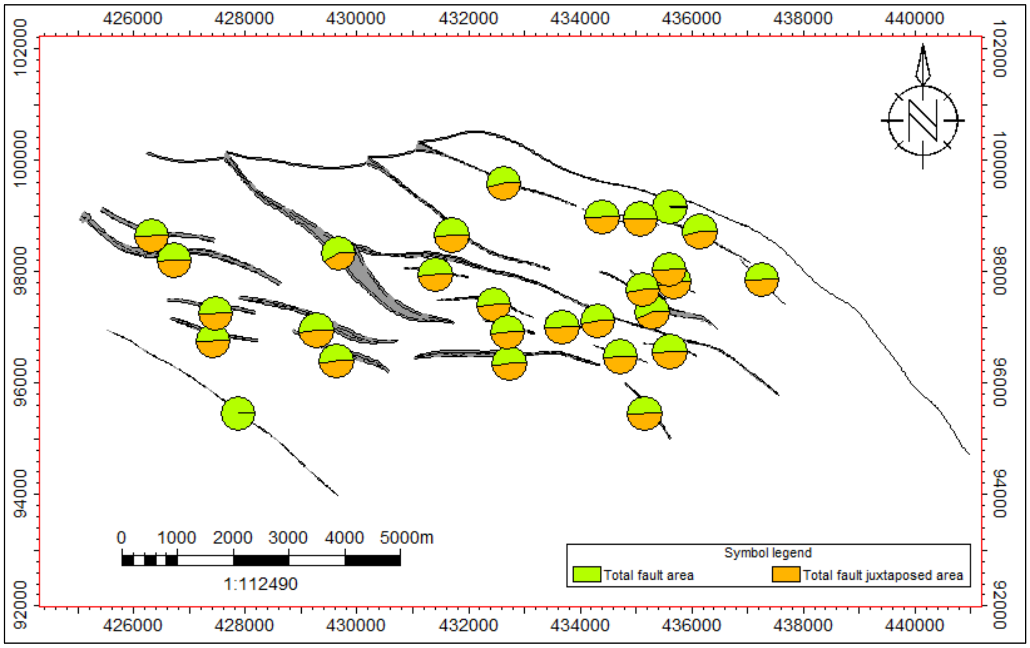

Figure. 5: Ratio of fault juxtaposition of the faults.

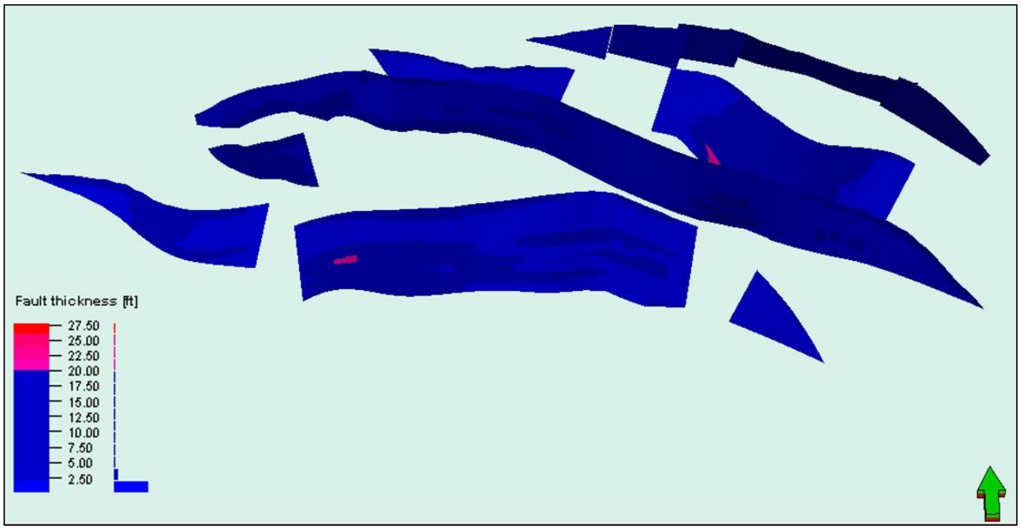

Figure.6: Fault thickness analysis results showing the fault thickness for various faults.

4.7 Shale Gouge Ratio

Shale gouge ratio for juxtaposed areas of faults that will allow hydrocarbon fluid flow across the faults ranges of 10% to 25 %. Parts of the area with SGR above 30 % is circled in black (figure 7). These areas can constraint hydrocarbon fluid flow and may serve as barriers or seals.

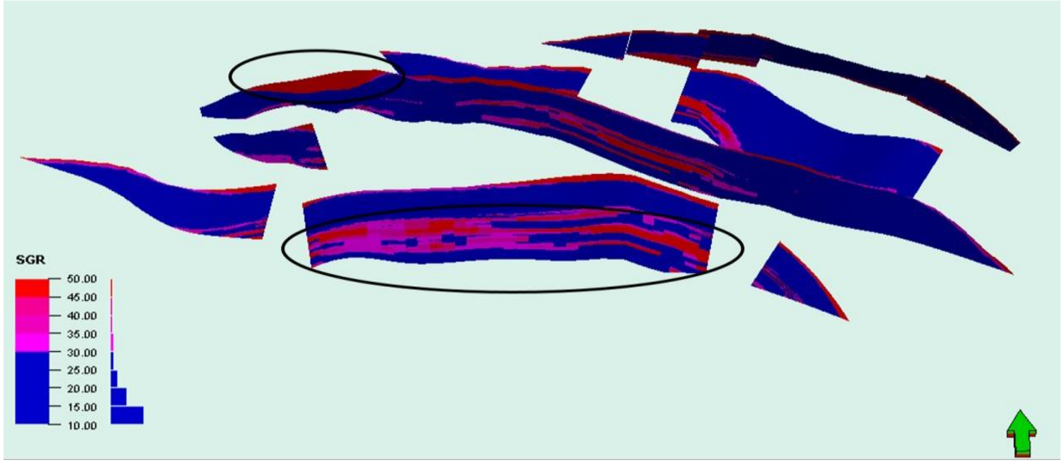

Figure 7: Faults SGR analysis results of the relevant faults.

4.8 Permeability

Fault permeability for juxtaposed areas from the model, show that greater portion of the faults will permit hydrocarbon fluid flow across the faults, since they have fault zone permeability greater than 1mD as in figure 8

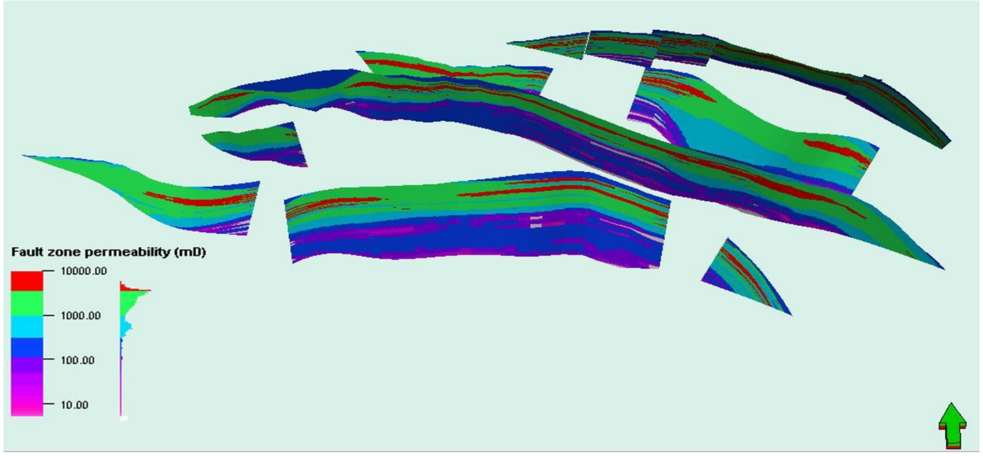

Figure 8: Fault permeability analysis results.

5.0 CONCLUSIONS

The 3D model shows the facies distribution across the XAS reservoir interval.

The model showed 3 (three) major compartments A1, A2 and B. the A1 compartment is the only accumulation without a well.

The fault juxtaposition analysis showed the area of the faults of interest that are juxtaposed above the OWC.

The SGR, fault thickness, and fault zone permeability for the juxtaposed areas bear greater values than the threshold considerations used for delineating faults zone that will constraint fluid flow, thus the faults may not compartmentalize the reservoir into pressure compartments, they may serve as or barriers or baffles to fluid flow across the faults.

The knowledge obtained from this study can be used to optimized well placement and will serve as considerations for efficient production.

6.0 REFERENCES.

Ahaneku, C.V., Okoro, A.U., Odoh, B.I., Anomneze, D.O., Chima, K.I., Ejeke, C.F. & Okoli, *In*. (2016). Sequence stratigraphy, structural framework and hydrocarbon migration of Ariki Field, Nigeria. *Petroleum Exploration and Development*. 43(1), 82-88.

Ainsworth, R. B. 2006. Sequence stratigraphic-based analysis of reservoir connectivity: influence of sealing faults – a case study from a marginal marine depositional setting. Petroleum Geoscience, 12, 127–141.

Amaefule, J.O., Altunbay M., Tiab D., Kersey D.G. & Keelan D. K. (1993). Enhanced reservoir description: using core and log data to identify hydraulic (flow) units and predict permeability in uncored intervals/wells, *In*, Oil and gas strategies in the 21st century. *Proceedings of the 68th conference of the Society of Petroleum Engineers, Houston* (TX), 3-6 October, SPE 26436.

Anomneze, D.O., Okoro, A.U., Ajaegwu, N.E., Akpunonu, E.O., Ahaneku, C.V., Ede, T.A.D., Okeugo, G.C. & Ejeke, C.F. (2015). Application of seismic stratigraphy and structural analysis in the determination of petroleum play within the Eastern Niger Delta Basin. *Journal of Petroleum Exploration and Production Technology*, 5(2), 113-122.

Arch, J., & Maltman, A. J. (1990). Anisotropic permeability and tortuosity in deformed wet sediments. *Journal of Geophysical Research*, 95(B6), 9035-9045.

Avbovbo, A. A. (1978). Tertiary lithostratigraphy of Niger Delta. *American Association of Petroleum Geologist Bulletin*, 62, 295 – 300.

Bentley, M. R., & Barry, J. J. (1991). Representation of fault sealing in a reservoir simulation: Cormorant Block IV, UK North Sea. *Society of Petroleum Engineers*. Reprint no. 22667, p. 119-126.

Berg, R. R. (1975). Capillary pressure in stratigraphic traps. *American Association of Petroleum Geologist Bulletin*, 59(6), 939-956.

Berg, R. R., & Avery, A.H. (1995). Sealing properties of Tertiary growth faults, Texas Gulf Coast. *American Association of Petroleum Geologist Bulletin*, 79, 375-393.

Bilotti, F.D., & Shaw, J.H. 2005. Deep-water Niger Delta folds and thrust belt modelled as a critical-taper wedge: The influence of elevated basal fluid pressure on structural style American Association of Petroleum Geologist Bulletin, 89(11), 1475 - 1491.

Bouvier, J. D., Kaars-Sijpesteijn, C.H., Kluesner, D.F., Onyejekwe, C.C, & Van der Pal, R.C. (1989). Three-dimensional seismic interpretation and fault sealing investigations, Nun River field, Nigeria. *American Association of Petroleum Geologist Bulletin*. 73, 1397-1414.

Burke, K. (1972). Longshore drift, submarine canyons, and submarine fans in development of Niger Delta. *American Association of Petroleum Geologist Bulletin*, 56(10), 1975 - 1983.

Byrnes, A. P., & Castle J. W., (2000). Comparison of core Petrophysical properties between low-permeability sandstone reservoirs: Eastern U.S. Medina Group and western U.S. Mesaverde Group and Frontier Formation. *Society of Petroleum Engineers*, SPE Paper 60304, p. 1-10.

Castle J. W., & Byrnes A. P., (1998). Petrophysics of low permeability Medina Sandstone, North Western Pennsylvania, Appalachian basin: paper Society of Petrophysicists and Well Log Analysts (SPWLA) 1998-v39n4a3. *The Log Analyst*, 39(4), 36 - 46.

Cohen, H. A., & McClay, K. (1996). Sedimentology and Shale tectonics of the Northwest Niger Delta. *Marine and petroleum Geology*, 13, 313 - 328.

Corredor, F., Shaw, J.H., & Bilotti, F. (2005). Structural styles in the deep-water fold and thrust belts of the Niger Delta. *American Association of Petroleum Geologist Bulletin*. 89(6), 753 - 780.

Cosentino L., (2001). Integrated Reservoir Studies: Editions Technip, Paris, p. 310.

Damuth, J.E. (1994). Neogene gravity tectonics and depositional processes on the deep Niger Delta Continental Margin. *Marine and Petroleum Geology*, 11, 320 - 346.

Doust, H., & Omatsola, E., (1990). Niger Delta, *in*, Edwards, J. D., and Santogrossi, P.A., eds., Divergent/passive Margin Basins. American Association of Petroleum Geologist Memoir 48: Tulsa, *American Association of Petroleum Geologists*, p. 239-248.

Ejeke, C.F., Anakwuba, E.E., Preye, I.T., Kakayor, O.G. & Uyouko, I.E. (2016). Evaluation of reservoir compartmentalization and property trends using static modelling and sequence stratigraphy. *Journal Petroleum Exploration Technology*. DOI 10.1007/s13202-016-0285-z.

Evamy, B.D., Haremboure, J., Kamerling, P., Knapp, W.A., Molloy, F.A., & Rowlands, P.H. (1978). Hydrocarbon habitat of tertiary Niger Delta. *American Association of Petroleum Geologist Bulletin*. 62, 1 - 39.

Hoogendoorn R. M., Overeem I. & Storms J. E. A, (2008). Process response modelling of fluvial deltaic systems, simulating evolution and stratigraphy on geological timescales. *Computer and Geosciences*, 34, 1394-1416.

Jev, B. I., Kaars-Sijpesteijn, C.H., Peters, M.P.A.M., Watts, N.L., & Wilkie, J.T. (1993). Akaso field, Nigeria: Use of integrated 3-D seismic, fault-slicing, clay smearing and RFT pressure data on fault trapping and dynamic leakage. *American Association of Petroleum Geologist Bulletin*, 77, 1389-1404.

Jolley, S. J., Fisher, Q. J., Ainsworth, R. B., Vrolijk, P. J. & Delisle, S. (eds) (2010). Reservoir Compartmentalization. Geological Society, London, Special Publications, 347, 25–41

Kendall Christopher G. St. C., Abdulrahman S. A., Johnston K. & Ryan S. R., (2000). Can the sedimentary record be dated from a sea-level chart? Examples from the Aptian of the UAE and Alaska: In A. S. Alsharhan and R. W. Scott, Eds, Society *of Economic Petrologists and Mineralogists* (SEPM) Special Publication 69, on the Jurassic/Cretaceous Platform-Basin Systems; Middle East Models; p. 65-76.

Knipe, R. J., (1993). The influence of fault zone processes and diagenesis on fluid flow. *In:* Horbury A.D. and Robinson, A.D. (eds.), Diagenesis and basin development: *American Association of Petroleum Geologist* Studies in Geology, 36, 135-151.

Kulke H., (1995). Nigeria. *In:* Kulke, H., (ed). Regional Petroleum Geology of the World. Part II: Africa, America, Australia, and Antarctica: *Berlin, Gebrüder Borntraeger*, p. 143-172.

Lawrence, S.R; Munday, S & Bray, R. (2002). Regional geology and geophysics of the eastern Gulf of Guinea (Niger Delta to Rio Muni). *The Leading Edge*, 21(11), 1112 -1117.

Lehner, P & De Ruiter, P.A.C. (1977). Structural history of the Atlantic margin of Africa. *American Association of Petroleum Geologist Bulletin*. 61, 961- 981.

Lindsay, N. G., Murphy, F.C., Walsh, J.J. & Watterson, J. (1993). Outcrop studies of shale smear on fault surfaces: *International Association of Sedimentologists, Oxford, Special Publication* 15, 113-123.

Morgan, R. (2003). Prospectivity in ultradeep water: the case of petroleum generation and migration within the outer parts of the Niger Delta apron. In: Arthur, T.J; Macgregor, D.S & Cameron, N.R. (Eds). *Geological Society, London, Special Publicatio*n, 207, 151- 164.

Naruk S. J. (2000). Review of Fault Seal Interpretation. *Software Expert Users Workshop*. p. 15.

Onyeagoro U. O., Naruk S. J., Dula F. W., & Garmezy L. L. (2001). Sensitivity analyses and prediction of dynamic fault behaviour: Sensitivities of cross-fault flow to variations in fault rock properties. Shell International Exploration and Production (SIEP) Report 2001-3125.

Oomkens, E . (1974). Lithofacies relations in Late Quaternary Niger Delta complex. *Sedimentology*, 21, 195 - 222.

Reijers, T. J. A Peters, S.W. & Nwajide C.S. (1997). The Niger Delta Basin in African Basins. *Sedimentary basins of the world*, 3, 151-172.

Short, K.C. & Stauble, A.J. (1967). Outline of Geology of Niger Delta. *American Association of Petroleum Geologist Bulletin*, 51, 761 - 779.

Van Wagoner, J.C; Mitchum, R.M; Campion, K.M; & Rahmanian, V.D. (1990). Siliciclastic sequence stratigraphy in well logs, cores, and outcrops: concepts for high-resolution correlation of time and facies. *American Association of Petroleum Geologist* Methods in Exploration Series, 7, 55.

Watts, N. (1987). Theoretical aspects of cap-rock and fault seals for single- and two-phase hydrocarbon columns. *Marine and Petroleum Geology*, 4(4), 274-307.

Weber, K.J. & Daukoru, E. (1975). Petroleum Geology of the Niger Delta. Proceedings of the 9th World Petroleum Congress, Tokyo. 2, 209-221.

Weber, K.J. & Mandl, G. (1978). The role of faults in hydrocarbon migration and trapping in Nigerian growth fault structures. *10th Annual Offshore Technology Conference.*

Weber, K. J., Mandl, G., Pilaar, W.F., Lehner, F., & Precious, R.G. (1978). The role of faults in hydrocarbon migration and trapping in Nigerian growth fault structures: *10th Annual Offshore Technology Conference proceedings*, paper OTC 3356. 2643-2653.

Yielding G., Gretan P., & Freeman B. (2010). Fault seal calibration; a brief review: *Geological Society, London, Special Publications*, 347, 243-255.