3-D Seismic Interpretation and Fault Sealing Assessment of 'X'-Field, Deep Offshore Niger Delta

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Abstract : The understanding of sealing integrity of faults are crucial to reservoir management and productivity studies in the Niger Delta field. Faults are geological structures which can serve as seals or migration pathway for reservoir fluids. This research involved the use of Shale Gouge Ratio (SGR) algorithm to assess the sealing capacity of faults in the 'X' Field, Deep Offshore Niger Delta. Well logs and seismic data were utilized for the study and petrophysical parameters of the reservoirs such as volume of shale, porosity, permeability and water saturation were estimated. Faults, structural maps, fault juxtapositions, fault flow parameters (such as Shale Gouge Ratio, Fault Permeability and Fault Transmissibility) were mapped and further computations were carried out to help determine the capacity of faults that may eventually prevent the flow of hydrocarbons in and out of the mapped reservoirs. The results of the research revealed two distinct reservoirs B and C having their petrophysical values estimated. The reservoirs have porosity range of 20-35%, excellent permeability (>10000 mD), shale volume of <15%. The presence of three fault sealing mechanisms were revealed to be shale smears, cataclasis and philosilicates. Permeability models of the fault gouge are <10 mD in some regions along the fault plane while their transmissibility ranges between 0 and 0.2 which indicate a good percentage of the faults that are sealed and may prevent the free flow of fluid through the fault gouge.

Keywords - Fault, Fault Permeability, Fault Transmissibility, Shale Gouge Ratio, Juxtaposition.

1.0 Introduction

Petroleum trap is an element of a petroleum reservoir, a place where oil and gas are barred from further movement, Levorsen *et al., (*1967). Basically, traps can be classified into four major types: structural, stratigraphic, hydrodynamic and combination. Fault seal predictions play a vital role in the assessment of reservoir productivity in the study area, deep offshore Niger Delta due to the structural complexities in the fold and trust belt. The Niger Delta basin is between latitudes 4°N and 6° N and longitudes 3°E and 9°E (Fig.1) (Clapp et al., 1910). It has a 12km thick classic wedge that contains the 12th largest known accumulation of recoverable hydrocarbons, with reserves exceeding 34 billion barrels of oil and 93 trillion cubic feet of gas, Tuttle *et al., (*1999). Various researchers have worked to determine the sealing mechanisms of fault in the Offshore Niger Delta. Among them are Kawekwune and *oti.,* (2016), they examined the effects of mud diapirism and its impact on sedimentation, reservoir development and hydrocarbon entrapment in the 'Odeiga Block' Offshore, Niger Delta and they concluded that faults exhibit good shale gouge ratio within their interface which constitutes an efficient seal. Oyeyemi and Aizebeokhai (2015), studied the structural trapping mechanism of the Afam Field, Offshore Niger Delta by utilizing seismic attributes and wireline logs. They concluded that the trapping mechanism in the field were the anticlinal structure which is tied to the rollover structures assisted by faults that are located at the centre of the field. To further enhance the chances of identifying economically recoverable hydrocarbon in reservoirs of potential field within deep offshore Niger Delta, a proper fault seal analysis would require the application of well logs and 3-D seismic method of prospecting by utilizing empirically derived equations (Shale Gouge Ratio (SGR), Shale Smear Factor (SSF)) and Manzocchi *et al*. 1999 to reveal the seals and leakages along the fault planes of faults in the study area. The seismic method is essential because of the better focusing it exhibits and also, denser data are needed to look for subtle clues to reservoir quality and hydrocarbon presence (Bacon *et al.,* 2003).

1.1 Study Location

The 'X'- Field is located within the western margin of the offshore, Niger Delta (Fig. 1). The general orientation of crossline is the strike direction (North-South), while inlines are in dip direction (East-West). The base map (Fig. 2) is a plot of shot and receiving point locations obtained from the seismic survey in relationship to their X and Y coordinate.

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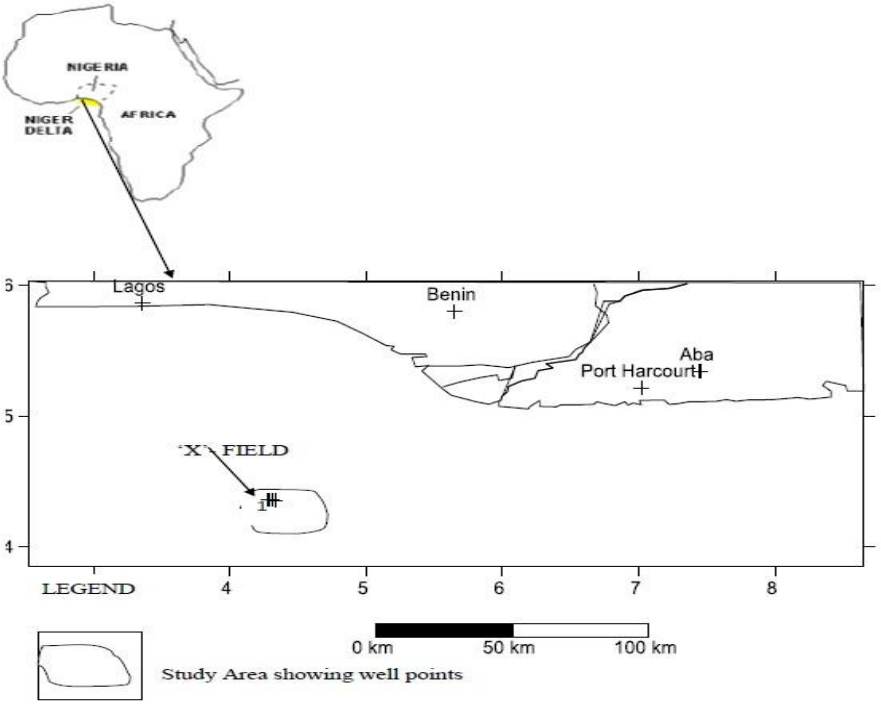

Figure 1: Geographical Map of the Study Area ('X'-Field) and Well Points Locations

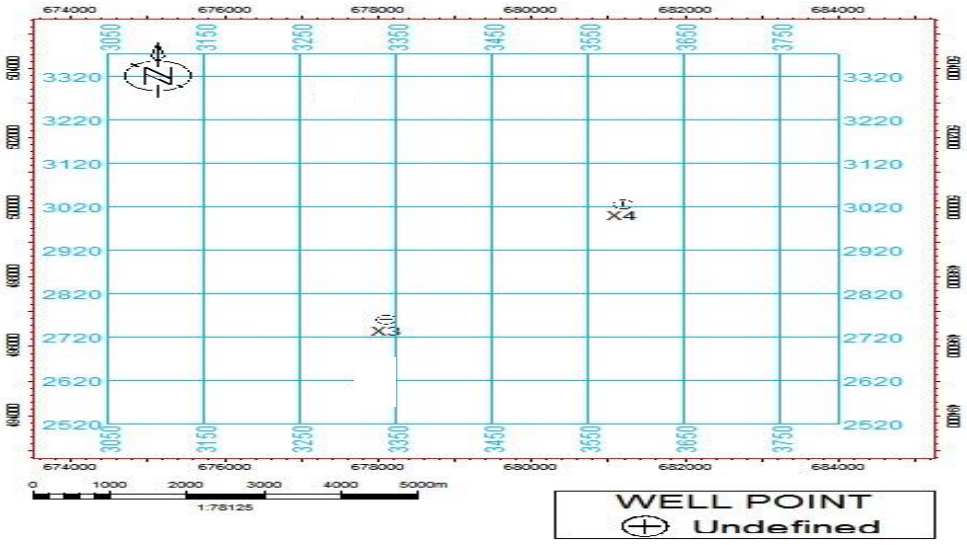

Figure 2: The Base Map of the Study Area Showing the Locations of the Wells and Seismic line

1.2 Stratigraphic Overview

The Tertiary portion of the Niger Delta is sectioned into three formations, prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios (Short and Stauble, 1967). The Akata Formation is at the base of the delta (Fig. 3) is proven to be of marine origin that is composed of thick shale sequences (potential source rock), turbidite sand (potential reservoirs in deep water), minor amounts of clay and silt.

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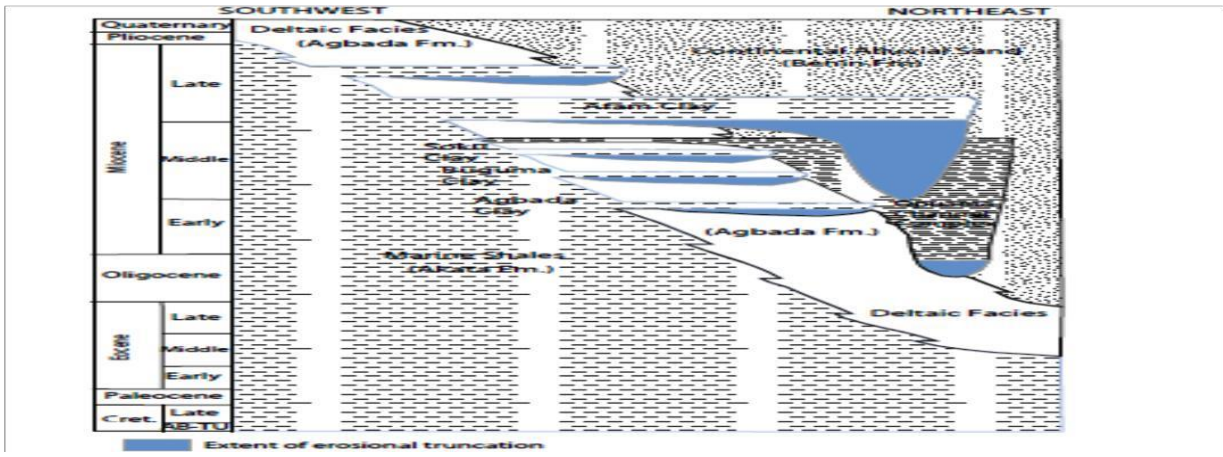

Figure 3: Stratigraphic sections showing the three formations of the Niger Delta. (Doust and Omatsola (1990).

2.0 Materials and Methodology

The research involved the use of Shale Gouge Ratio (SGR) algorithm to assess the sealing potential of faults in the 'X'-Field, Offshore environment of Niger Delta. Materials available for the research include: 3-D Seismic Volume and suite of Well Logs data. Petrophysical and structural analysis of the field were carried out.

3.0 Results and Discussions

The results obtained were presented in the form of logs, tables and graphs. The results obtained from each of the wells were discussed appropriately.

3.1 Lithological Identification and Reservoir Analysis in 'X' - Field

The objective of this procedure is to differentiate the shale and sandstone lithological units from well logs. The guiding principle used for the process considers the response of the gamma ray log to radioactive elements. Shales are attributed with relatively higher radioactive elements when compared to sandstone. The Gamma ray log was principally used for the identification of the different clastic rocks and accompanied with their resistivity logs, the petrophysical parameters of the reservoirs were evaluated (Fig. 4).

3.2 Reservoir Juxtaposition Mapping

Juxtaposition relates to detailed mapping of an area in order to identify reservoir-to-reservoir juxtaposition and possibilities of a non-permeable lithology forming a side seal to reservoirs across a fault plane. Fig. 5 presents the reservoirs juxtaposition model for reservoir 'B' and 'C'. The lithology in yellow colour denotes sand while lithology in black colour denotes shale. The juxtapositions present along the fault plane include: the shale-on- shale, shale-on-sand, or sand-on-shale juxtapositions.

3.2.1 Volume of Shale Estimation

Along fault (F1) plane (Fig. 6), the reservoir B and C are juxtaposed against shale bed on the fault plane and this can be interpreted to have sealed up the fault plane from leaking. This implies that the reservoir B and C may be relatively sealed as a result of the shale content along the fault gouge. The juxtaposed reservoir B along the Fault plane F2 and F3 (Fig. 7 and 8) respectively could be sealed due to the high volume of shale (≥ 0.4) along the fault plane. While horizon C juxtaposed on the fault has shale volume to be low (≤ 0.4) on the leaking fault plane. Along the fault (F3) plane (Fig. 8), reservoir B is partially juxtaposed against shale and itself while the reservoir C is juxtaposed against itself and is likely leaking due to its low shale content.

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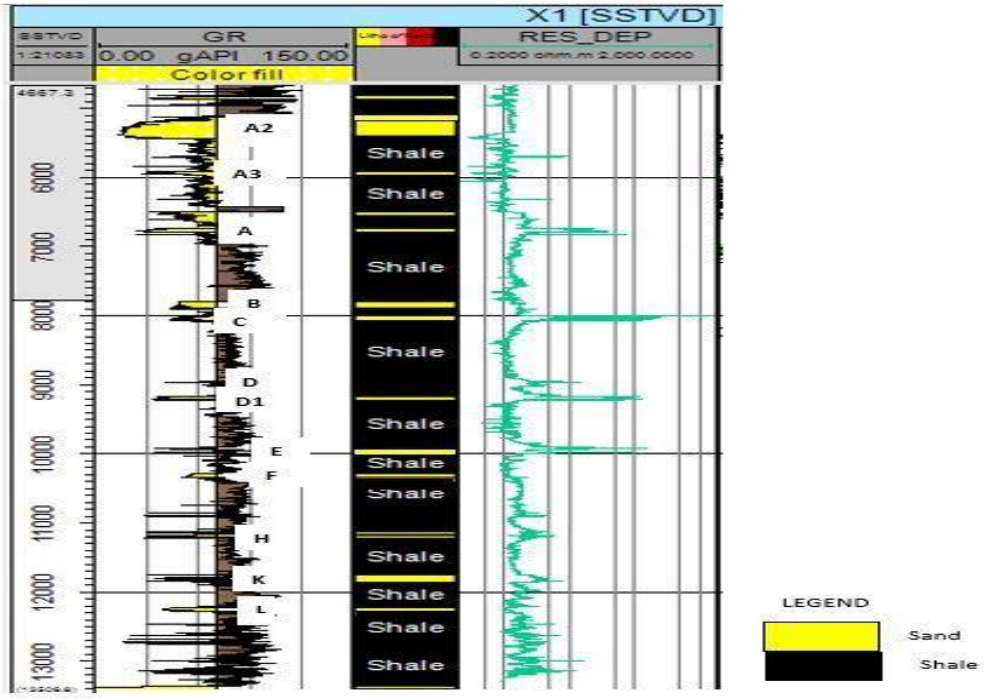

Figure 4a: Lithology Identiication in Well X1

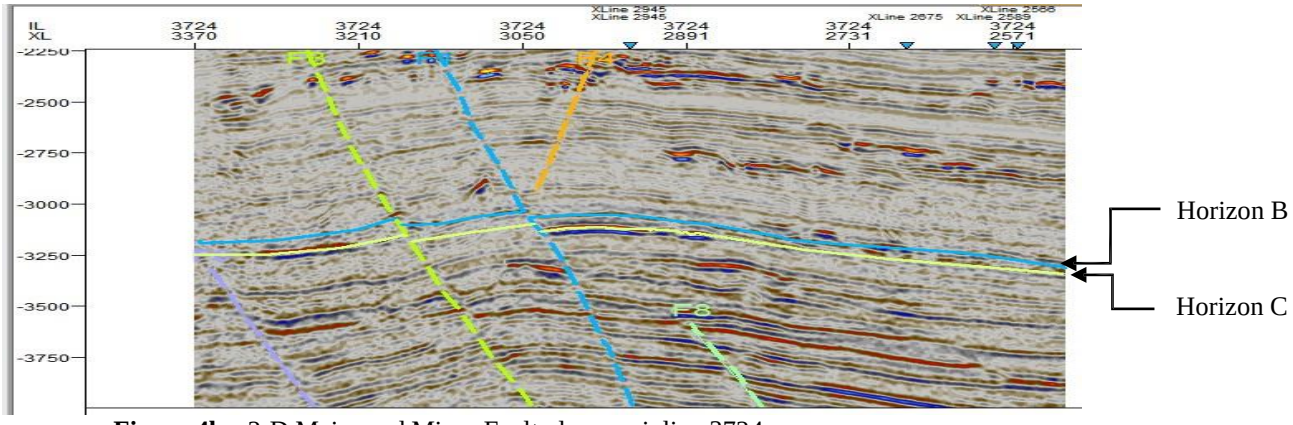

Figure 4b: 2-D Major and Minor Fault plane on inline 3724

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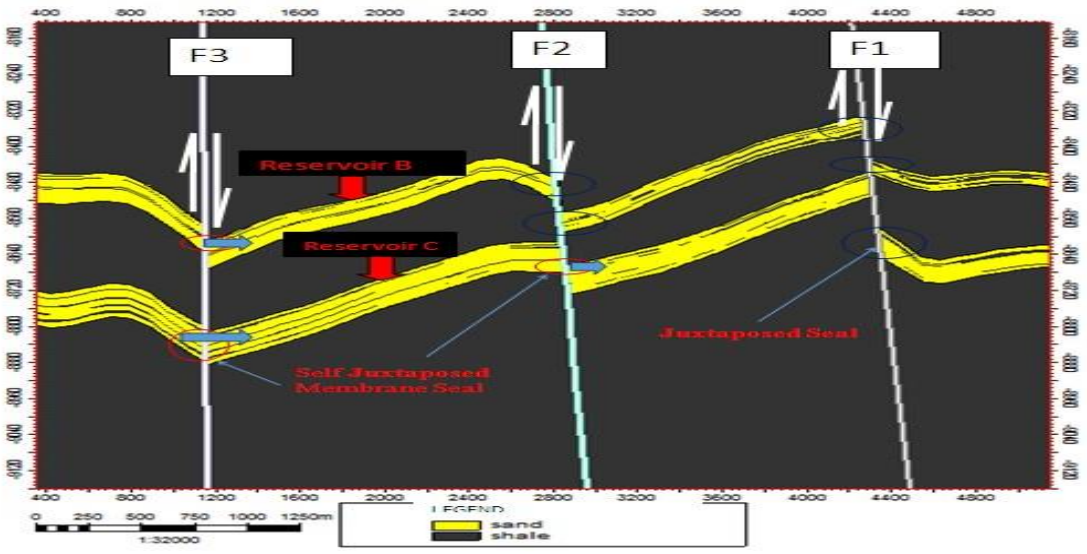

Figure 5: Stratigraphic Juxtapositions along Faults (F1, F2 and F3)

Figure 6: F1, Fault plane Volume of Shale Model

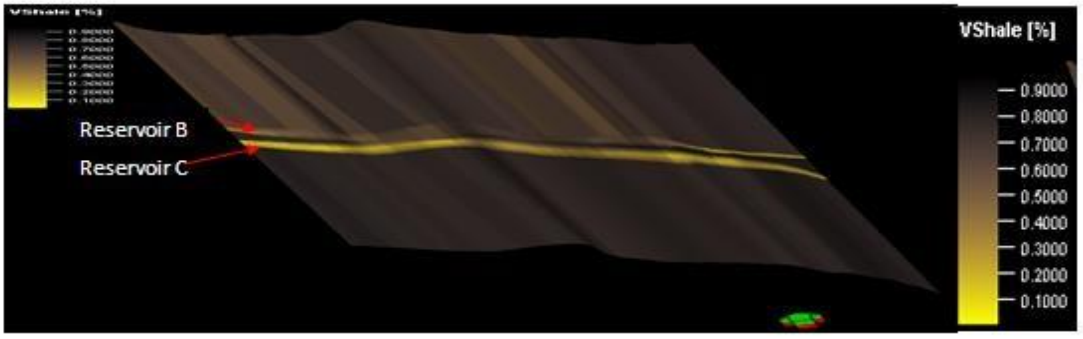

Figure 7: F2, Fault plane Volume of Shale Model

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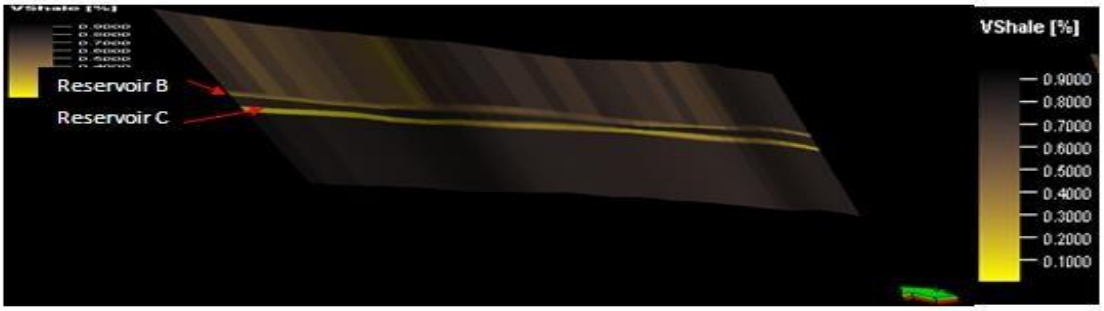

Figure 8: F3, Fault plane Volume of Shale Model

3.2.2 Fault Throw Calculation

The throw of the reservoir beds along the fault plane (F1, F2 and F3) were analyzed. The fault interpretations are bound by the area of interest that signifies that the faults are not necessarily expected to show less displacement towards the end of the interpreted fault plane (Fig. 9). The hanging-wall is the major contributor to the accumulation of hydrocarbons since it is the moving part of the fault. It is shown that the centre of the throw is always its maximum displacement (characterized by red colour). Reservoir B and C throw represent normal throw distributions. The red colour at the middle of the throw showed maximum displacement, followed by the yellow, green light blue, blue and purple colour (towards both tips). The purple colour indicates minimum throw distribution.

3.2.3 Shale Gauge Ratio Interpretation

SGR method is made a choice of algorithm here because of its ability to predict physically measurable parameter and invariably used to predict other properties that are compositionally controlled. The most significant of these is fault-zone permeability, which can vary by many orders of magnitude between cataclasites and shale smears. Fig. 10 shows the 3-D model of SGR for the faults F1, F2 and F3. The SGR can be grouped into four zones as depicted with colour codes: leaking fault displays green colour, poor sealing displays yellow colour, moderate sealing displays orange colour, and sealing fault displays red colour. However, low SGR corresponds with regions along the fault plane that displays green colour while high SGR corresponds with regions along the fault plane that displays red colour. The faults were identified to be leaking, poor sealing and moderate sealing zones that are evidently shown towards the upper part of the faults plane. Analysis of this region is paramount because it constitutes where the hydrocarbon bearing horizons are located.
However, horizon B and C juxtaposed on the Fault F1 plane, having their SGR model interpreted to be higher than the poor sealing zone (SGR of 20 - 40 %) along the fault plane.

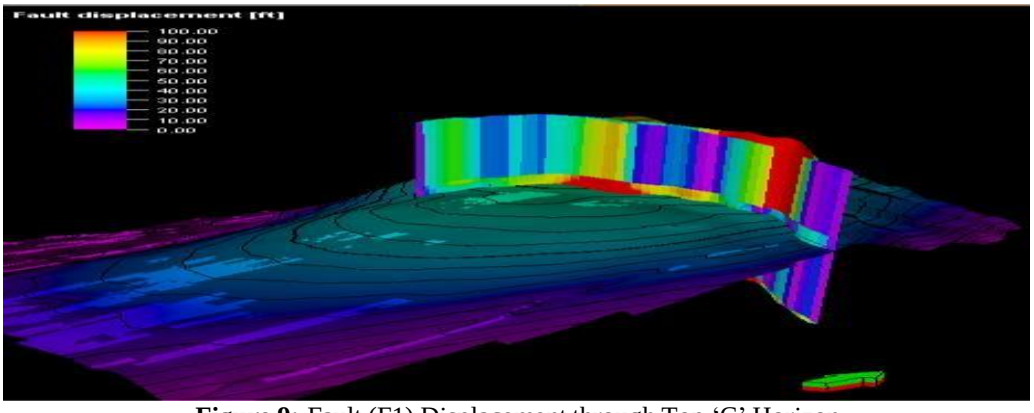

Figure 9: Fault (F1) Displacement through Top 'C' Horizon

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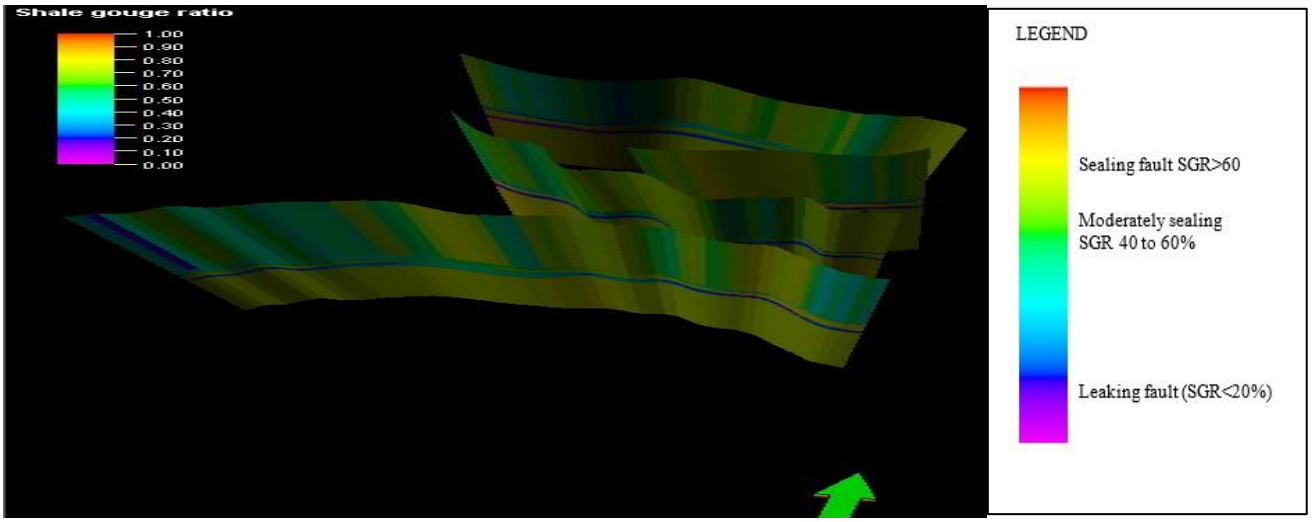

Hydrocarbon are trapped in reservoir B and C but the horizons were located on a moderately sealed zone which suggests that over some period of time, hydrocarbon would migrate from this trap due to the nature of its sealing capacity. Horizon B to horizon C showed that the fault plane supporting these traps belong to moderately sealed fault. Since perfect sealing is not guaranteed in moderate seal, leakage is also associated with this type of seal. Horizon B along the fault plane F2, and F3 have their SGR model located in the poor sealing zone (SGR of 20 -
40 %) along the fault plane which made the hydrocarbon to be trapped in reservoir B but still have the tendency to migrate over a long period of time. While, horizon C was located on the leaking zone (SGR < 20%) along the fault plane, this made a way for the hydrocarbon to migrate easily.

3.2.4 Fault Permeability and Transmissibility Multiplier Modelling

The SGR distribution on a fault plane was then used as an input to generate maps of fault-zone permeability (Fig. 11), which was further used to develop the fault transmissibility multiplier models (Fig. 12) for reservoir simulations. In regions where there is reservoir to reservoir juxtaposition along F2 and F3, the cataclastic fault gouge within reservoir C in the F2 and F3 plane requires further analysis to confirm the sealing capacity of the faults. The Permeability model of F2 and F3 is averagely high (< 10 mD), it thus revealed that the materials filling the fault gouge are less permeable in some regions of the fault plane but leaking in other regions of the fault especially where reservoir C fall on the fault plane.

The permeability model for F1 fault plane (Fig. 11) is averagely low (< 1 mD). Thus the reservoirs juxtaposed on the fault plane are sealed. Their transmissibility model (Fig. 12) revealed that the region where reservoir B falls on the fault plane is (between 0 and 0.2) and is known to be close region. These are regions where sand- shale were juxtaposed; while other regions that consist of sand-to-sand juxtaposition such as reservoir 'C' on the fault plane (F2 and F3) have their transmissibility value as high as one (1). They are interpreted as open zones, because they have the tendencies to migrate fluid over a long period of time.

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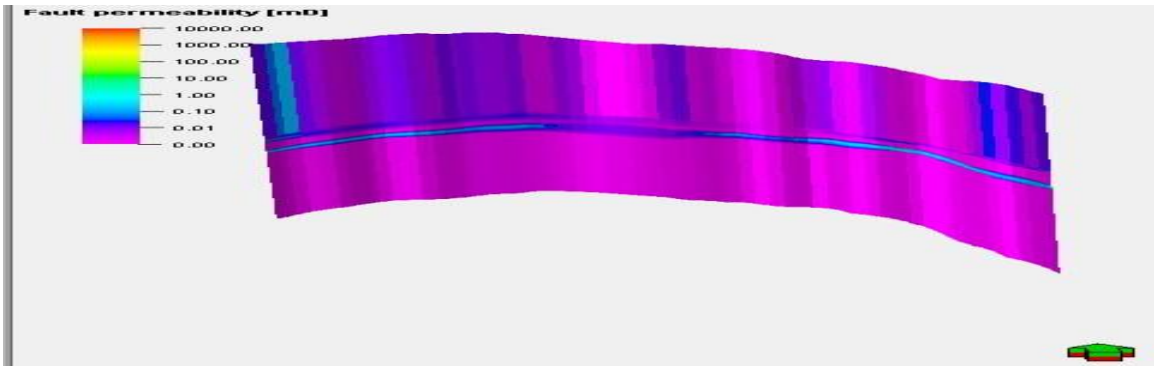

Figure 11: F1, Fault Permeability Model

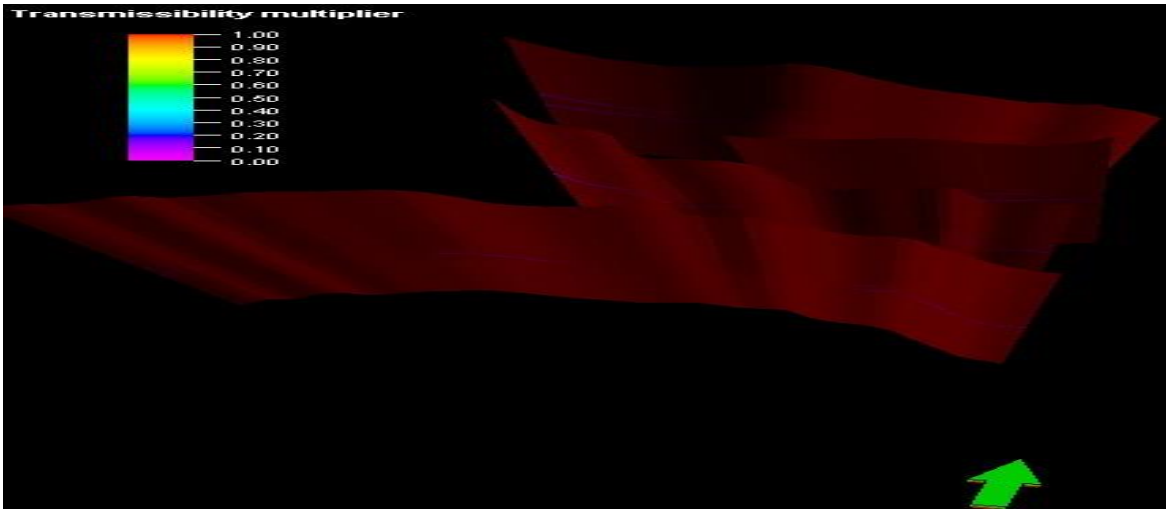

Figure 12: Gross Fault Transmissibility Model

4.0 Conclusions

The sealing potential of faults in the field has been evaluated and the processes that contribute to fault seals were delineated; they vary within the shale smear, phyllosilicates and the cataclasis. The growth faults mapped in the field are the fault F1, the major fault in the field and two other faults 'F2' and 'F3'. The Volume of Shale needed for the shale gouge calculations was successfully generated from gamma ray log using steibers equation and then modeled based on the Facies (Sand and Shale) model. The results show a high V-shale for fault 'F1' plane along the throw window of reservoir 'B' and 'C' beds. Whereas, a low V-shale was recorded in the juxtaposed reservoir 'C' block along the fault ('F2' and 'F3') plane but relatively high along the reservoir 'B' throw window. It was noted that results from shale gouge ratio algorithm is applicable for testing the sealing capacity of the faults in the field. Fault permeability, transmissibility multiplier was used as further proof and test for the sealing potential of 'F2' and 'F3'fault planes such which better described the fault zones as zones that result from cataclastic deformation process. The results from SSF and SGR both confirmed the sealing integrity of the fault plane; regions that are sealed along the fault plane are due to the low values in the SSF which correspond to a high SGR. In the fault flow properties, the fault transmissibility range between 0 and 0.2 which is interpreted as closed region along the fault plane. While, regions along the fault plane having transmissibility value as 1 were interpreted as open zones.

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