Fault Seal Analysis: A Case Study of the Mixed Clastic Baka Field, Coastal Swamp Niger Delta Basin

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ABSTRACT

Known column heights in the Baka Field were used to calibrate the traditional exploration column height prediction tool – mainly based on fault seal. Traditionally, fault seal analysis has been dominantly deterministic or a combination of deterministic and stochastic method. The deterministic approach is sensitive to uncertainties associated with mapping of horizons in the proximity of faults and the inherent uncertainties in the static fault interpretation in both position and fault zone complexity. All hydrocarbon bearing reservoir levels and faults were interpreted in detail on seismic and a structural framework model was built for juxtaposition analysis and fault shale gouge ratio calculation. The columns in the field are mostly controlled by structural spill points, implying that the faults affecting the accumulation must be sealing. Some reservoirs are under filled, indicating that the faults are leaking. It was shown that these fault intervals have a relatively low SGR. There is high degree conformity between field column heights and the stochastic column heights predicted from the shale gouge ratio. The calculated shale gouge ratio quite matched with the shale gouge ratio related column height distribution use in exploration. Top shale thickness played a role (impede up dip fluid conduit), but not a major factor in the reservoirs as regards to column controls. Faults in the Baka Field leaks at <20% shale gouge ratio with varying weak points, mainly 20 – 35% shale gouge ratio and more. Good fault seal capacity exists in the Baka Field at >40% shale gouge ratio. Shale gouge ratios are higher at the boundary fault.

Keywords: Fault Seal, Fault Leak, Trap, Shale Gouge Ratio, Modelling,Stratigraphy, Column Height

INTRODUCTION

The problems of: (1) Understanding of what controls column height in the Baka Field for future prospect evaluation and application, (2) Fault Seal and Leak Assessment, (3) Assessment of Top Seal (Overlying Shale Thickness) if it's a factor in Baka Field, and (4) Investigation of how calculated Shale Gouge Ratio values and Column Heights fit with our exploration Shale Gouge Ratio class and Column Height Statistics; forms the main focus of this study.

Fault seal analysis is the study of the likelihood of fault to allow fluids to move across the fault plane (leak) or not (seal); (Lashin and Abd El-Aal 2004). Fault seal analysis had been carried out by many researchers including Needham *et al.* (1996), Yielding *et al*. (1992), Yielding (1997, 1999a & b), Yielding (2002), Knai and Knipe (1998), Manzochi *et al.* (1999), Manzocchi *et al.* (1999) and (2000), Lehner and Pilaar (1997), Freeman et al. (1998 & 2004), Hesthammer and Fossen (2000), Bretan *et al.* (2003), Gibson and Bentham (2003), James *et al.* (2004), Steven *et al.* (2021), Růta *et al.* (2020), Emma *et al.* (2020), etc.

The Baka Field fault seal analysis involved using known column height in the Baka Field to calibrate the traditional exploration column height prediction tool – mainly based on fault seal. Also, structural spill points and leak points controlled by juxtaposition, shale gouge ratio calculations, column height controls and fault seal capacity were evaluated.

Location of the Study Area

The study field location is as shown in Figure 1. That is, the Baka field is located in the coastal swamp depo belt of the Niger Delta. Also, the distributions of the drilled wells is as shown in the inset base map of the area.

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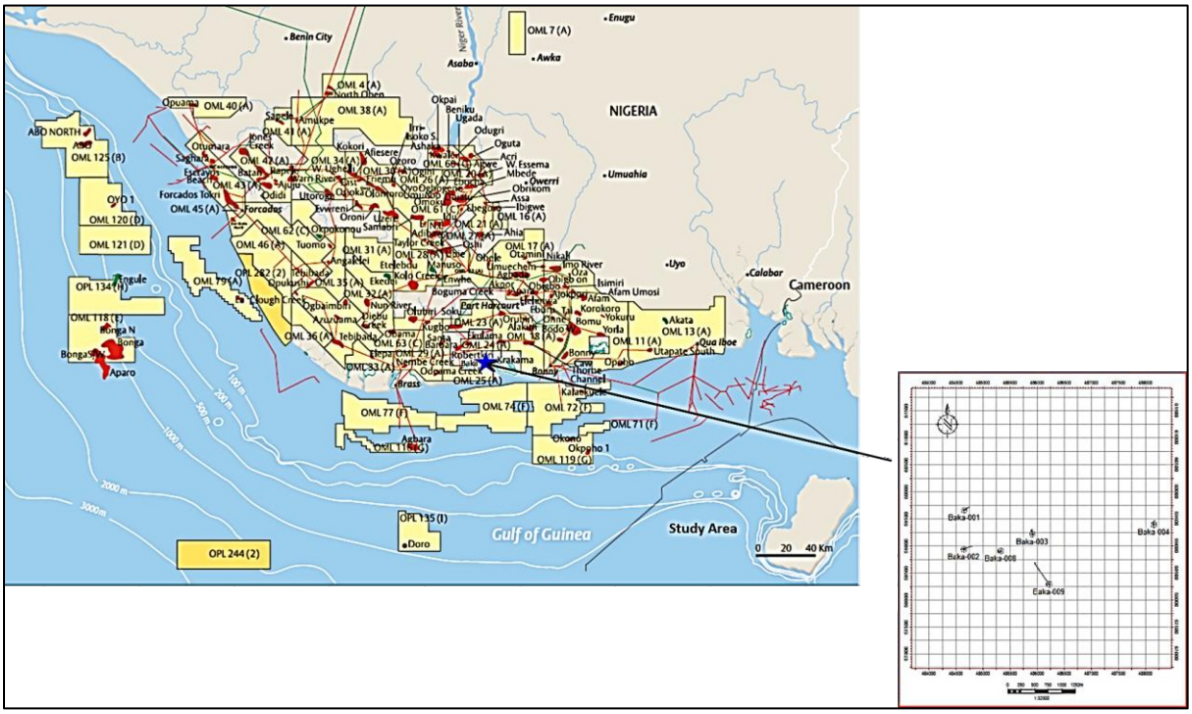

Figure 1: Location map of the study area.

Geological Overview

Presently, the Niger Delta occupies about 75,000km2 of the sedimentary basin of the southern Nigeria. It is situated in the eastern corner of the Gulf of Guinea which is at the intersection of the triple R junction from which the separation and rifting of the South America and Africa was initiated in the middle Cretaceous time. The subsequent instability and subsidence along rift zones led to a marine transgression which terminated in the late middle Cretaceous times. In the late Cretaceous a proto Niger Delta developed which ended with a major transgression in the Paleocene. From Eocene onwards, regression occurred with the deposition of a wedge of fluvio-deltaic sediments which built out into the South Atlantic as the modern Niger Delta (Stoneley, 1966; Short and Stauble, 1967; Burkel, 1972). The Baka field is located in the coastal swamp depo-belt, Niger Delta Nigeria.

A few publications had been made concerning the hydrocarbon reservoir seal studies in the Niger Delta. Such findings includes but not limited to the work of Yielding (2002), as part of his worldwide basin studies, Koledoye *et al.* (2003), Filbrandt *et al.* (2007) etc.

Niger Delta Stratigraphy

Short and Stauble (1967), defined three stratigraphic unit in the tertiary Niger Delta based on the dominant environmental influence. The main sedimentary environments are the continental environment, the transitional environment and the marine environment. The three environments as said earlier are stratigraphically superimposed. The basal parts of the stratigraphic sequence are massive marine shales. The part lying in-between the upper and lower satratigraphic sequence is represented by inter-bedded shallow marine and fluvial sands, silt and clays which are typical of parallic setting. The sequence is capped by a section of massive continental sands.

Based on the history or relative unbroken progradation throughout the Tertiary, these depositional lithofacies are readily identified despite local facies variations, as three regional and diachronons formations ranging from Eocene to Recent age. The three formations are locally designated (from the bottom) as Akata Formation, Agbada Formation and Benin Formation respectively. Of the three formations, the Agbada Formation constitutes the main reservoir of hydrocarbons in the Niger Delta while the Agbada shales mainly constitute the seals. This formation is therefore given greater attention in this study. The stratigraphic distributions of Niger Delta is as shown in Figure 2A is (From Doust and Omatsola 1990) while the stratigraphic column showing the three formations of the Niger Delta is presented in Figure 2B (Modified from Shannon and Naylor, 1989 and Doust and Omatsola, 1990).

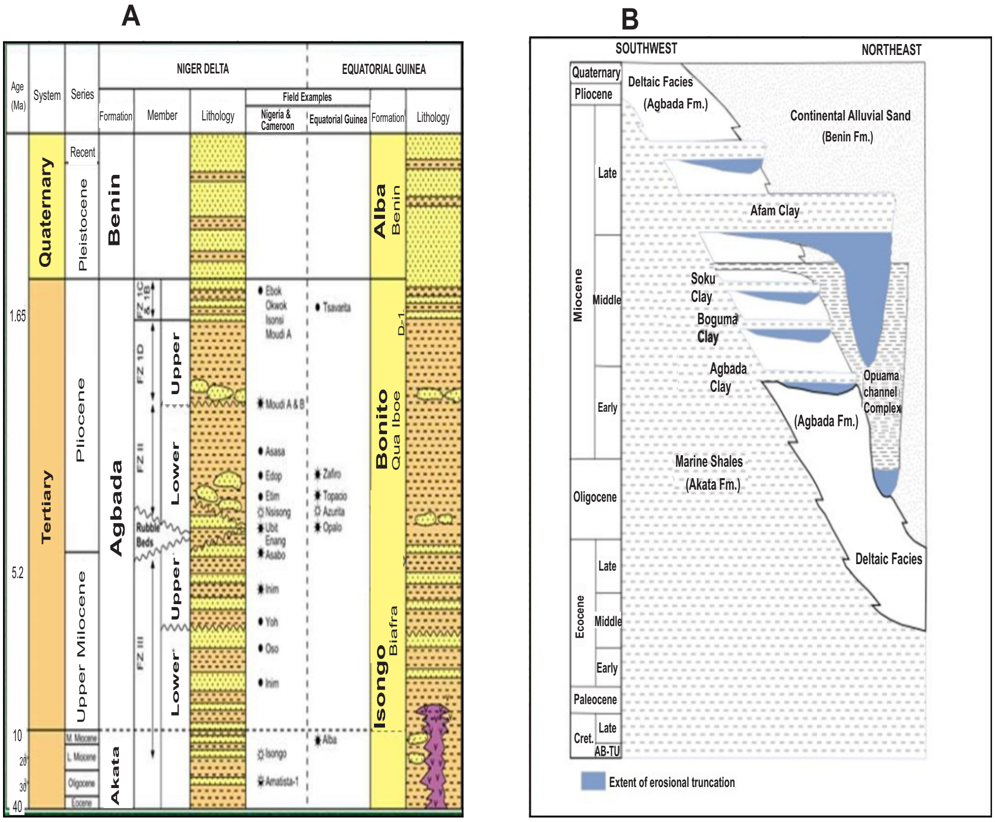

Figure 2: A- Stratigraphic Map of Niger Delta (From Doust and Omatsola 1990); B -Stratigraphic column showing the three formations of the Niger Delta. Modified from Shannon and Naylor (1989) and Doust and Omatsola (1990).

Niger Delta Structure:

The Niger Delta basin is not much disturbed at the surface but the subsurface is affected by large scale syn-sedimentary features including the growth faults, rollover anticlines and diapirs. Typical of Niger Delta oil field structure and associated trap types is as shown in Figure 3A; modified from Doust and Omatsola (1990) and Stacher (1995). Also, Niger Delta Depobelts and Niger Delta Regional cross-section; showing structural belts is demonstrated in Figure 3B (Adopted from Hooper et al. 2002).

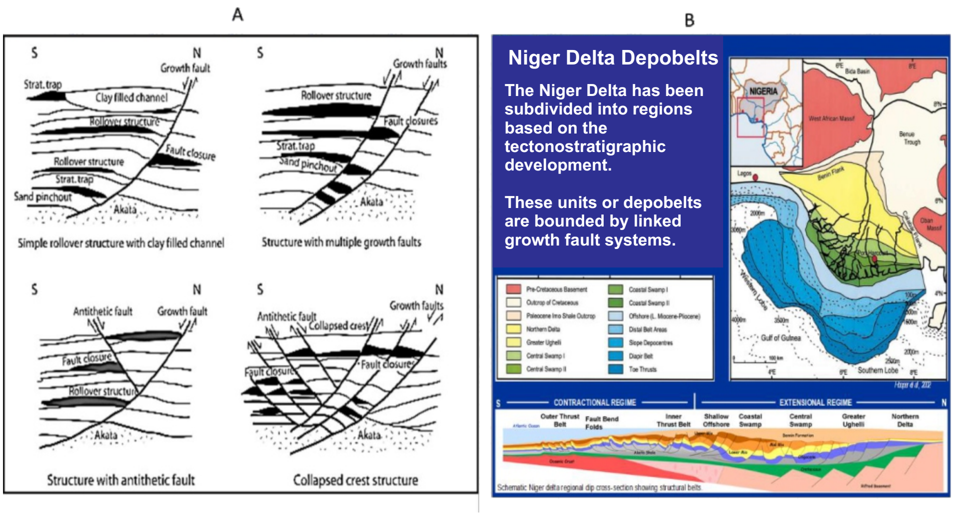

Figure3: A- Example of Niger Delta oil field structure and associated trap types. Modified from Doust and Omatsola (1990) and Stacher (1995); B- Niger Delta Depobelts and Niger Delta Regional cross-section; showing structural belts. (Adopted from Hooper *et al.* 2002).

METHODOLOGY

The applied workflow utilized software's such as 123DI, NDI, Petrel, and Stochastic Trap Analysis and Risking (STAR) plugin module of Petrel. Chrono-stratigraphic correlations were carried out guided with open ends correlation transect line. Faults and structural interpretations and horizons mapping were carried out using Prestack Time Migrated Seismic Data. Depth conversions of interpreted data were made involving corrected check-short, corrected density log, corrected sonic log, utilizing synthetic seismogram and velocity model. Three dimensional (3D) static model and stratigraphic juxtaposition of the hanging walls and foot walls were modeled and the fault surfaces analyzed using shale gouge ratio (SGR) as the seal parameter. The calculated SGR's were used in hydrocarbon columns predictions and calibrations with the known field column heights involving stochastic approach with percentiles as P15, P50 and P85. Structural saddle spill points, fault seal and fault leak points in relation to column height controls were then accessed to complement the seal capacity prediction. Comparison between Calculated SGR and SGR related column height distributions used in exploration were carried out. Typical of the SGR use in exploration is as shown in Table 1 Assessment of reservoir top seal to understand if top seal is a major factor regarding hydrocarbon column control were also carried out.

Table 1: Exploration SGR Classification.

LOW	MEDIUM	HIGH
0.0 – 0.4	0.4 – 0.7	0.7 - 1
MEAN COLUMN: 59FT	MEAN COLUMN: 102FT	MEAN COLUMN: 160FT
MAX COLUMN: 250FT	MAX COLUMN: 450FT	MAX COLUMN: 600FT

RESULTS

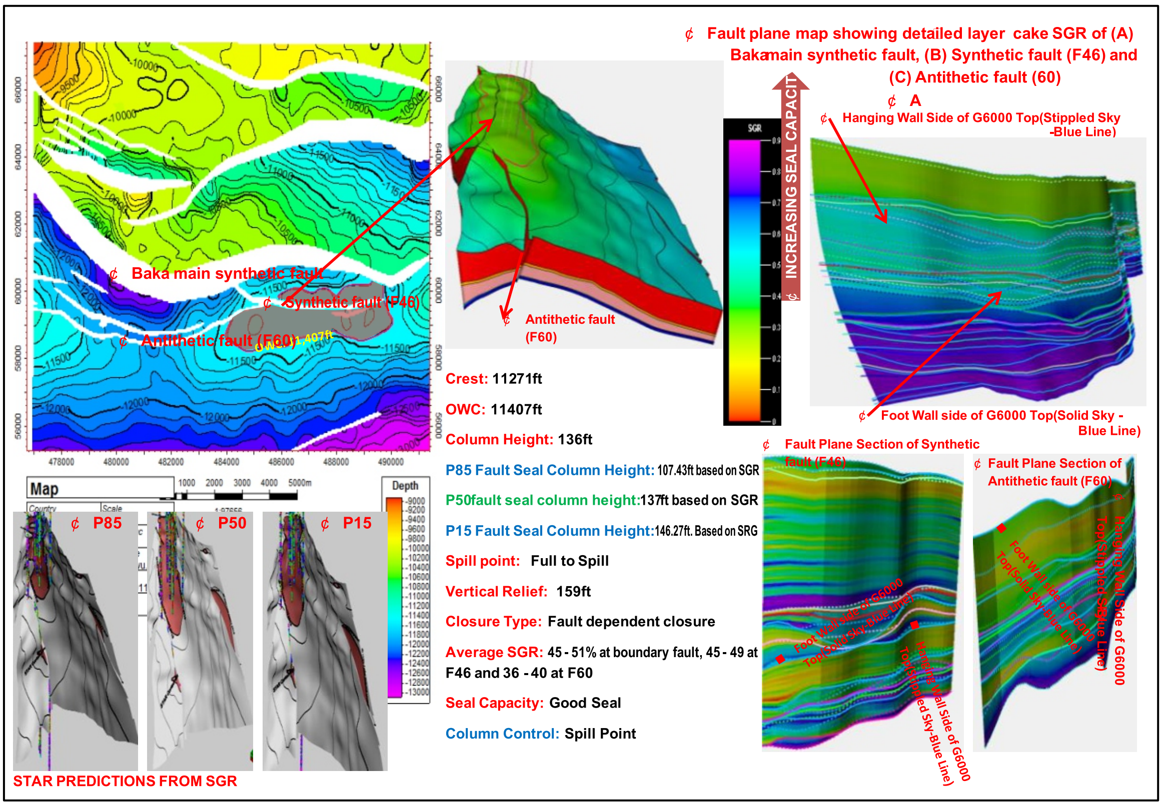

Figure 4: Fault seal analysis showing field column height comparison with fault seal column height at G6000 filled to spill reservoir using SGR seal parameter.

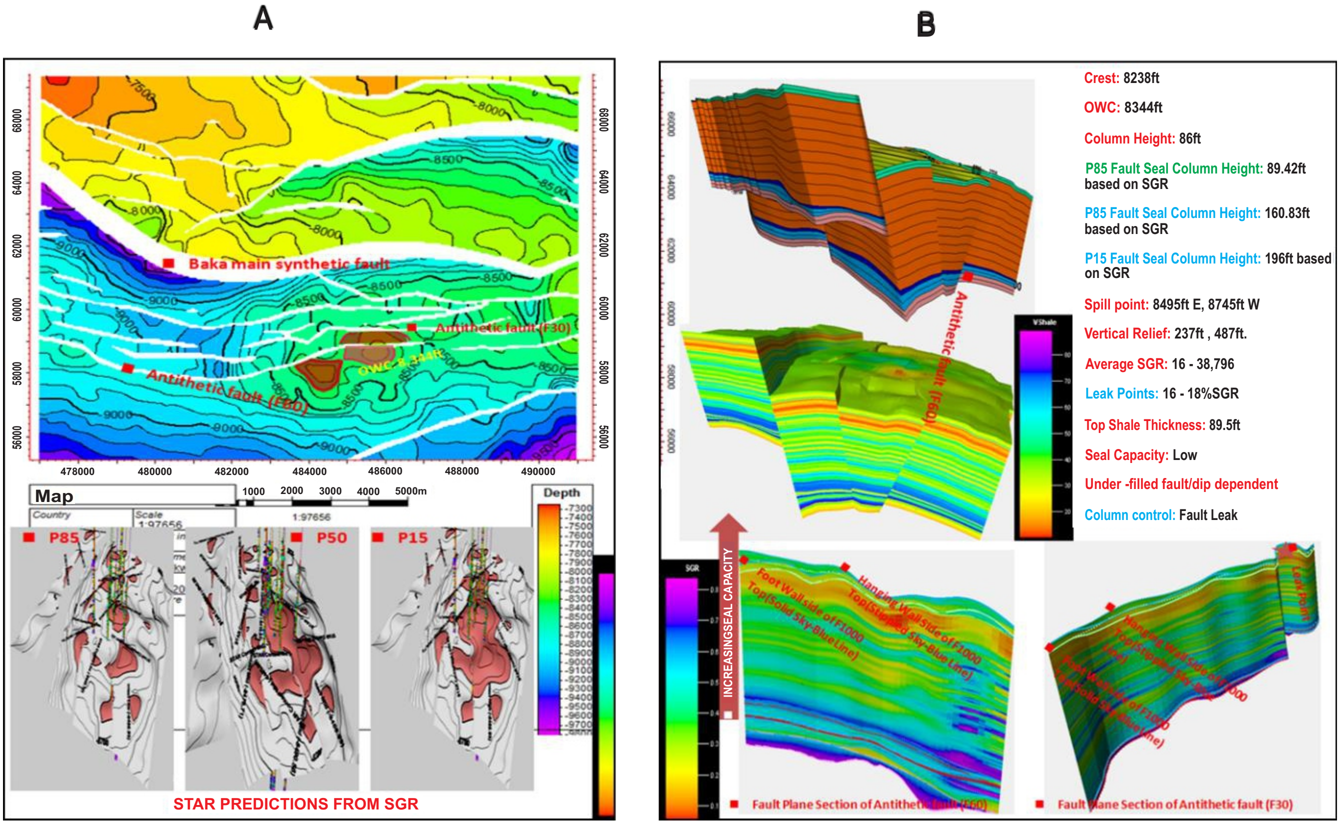

Figure 5: Fault seal analysis showing field column height comparison with fault seal column height at F1000 under filled reservoir using SGR seal parameter.

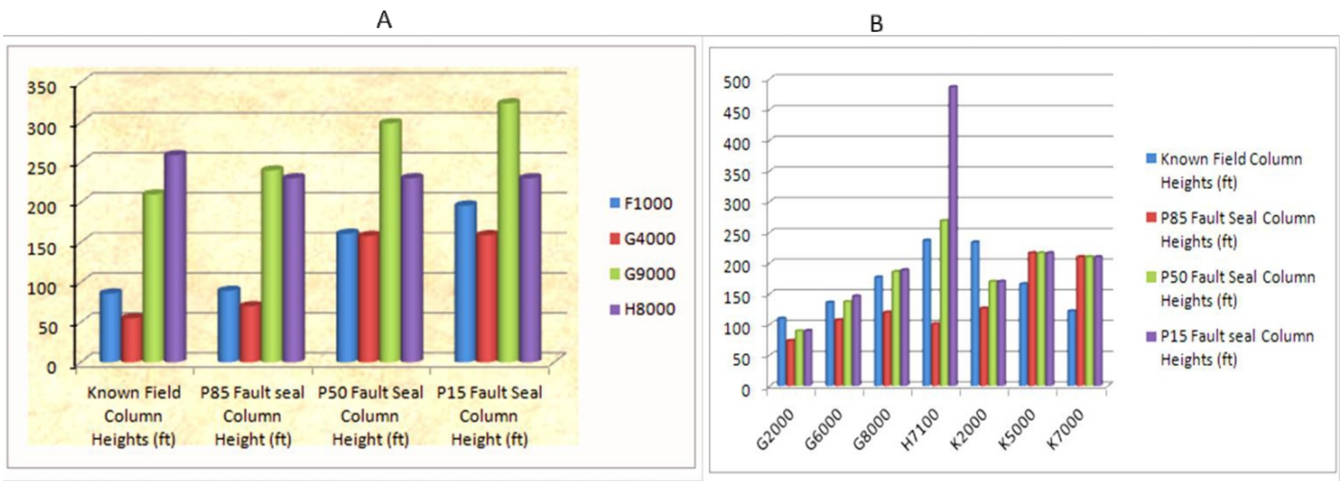

Figure 6: A- Field Column Height versus Fault Seal Column Height at Under-Filled Reservoirs; B - Field Column Height versus Fault Seal Column Height at Filled to Spill Reservoirs.

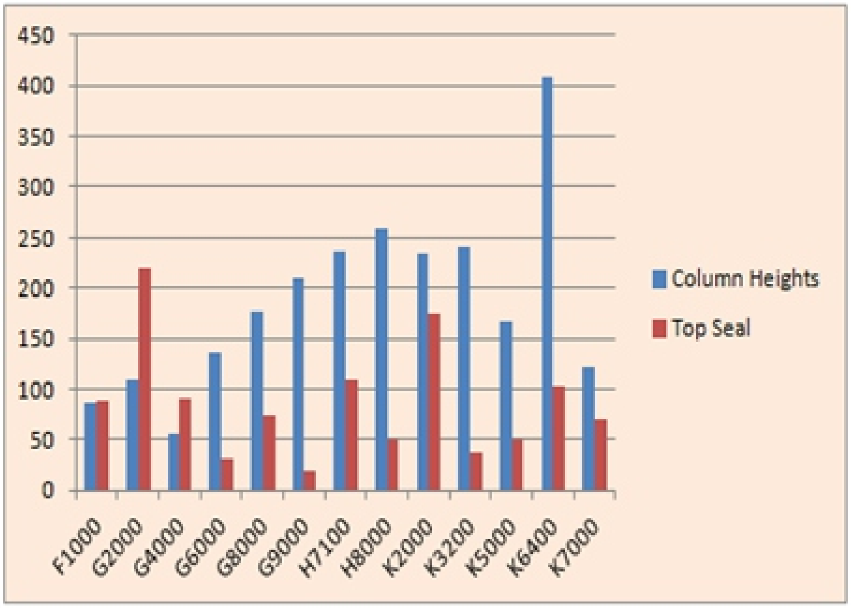

Figure 7: Field Column Heights Distributions versus Top Shale Thickness in Baka Field.

DISCUSSION OF RESULTS

The reservoirs interpreted in Baka Field involved mainly filled to spill reservoirs and a few under filled reservoirs. The faults of the filled to spill reservoirs are sealing and the column heights at these reservoir levels controlled by the structural saddle spill points. Good seal capacity of the faults at these reservoirs mainly exists at ≥ 40% shale gouge ratio. The good seal capacity of the faults in this study is mainly due to non-reservoir rocks juxtaposing reservoir rocks and as such influenced high capillary entry pressure in the reservoir that formed fault closure (see Figure 4). However, cataclasis had resulted from the rock grain crushing during the dip slip of the normal fault also contributed to fine grain non reservoir rock composition in the fault surface (Figure 4). Example of one of the filled to spill reservoirs interpreted in this study is shown in Figure 4. The under filled reservoirs in the Baka Field are mainly due to fault leak points. Fault leak points of the Baka faults exists at < 20% SGR and it's attributed to reservoir sand on reservoir sand juxtaposition (Figure 5). Example of one of the under filled reservoirs interpreted in this study is as shown in Figures 5. Hydrocarbon column heights in the Baka Field are mostly controlled by spill points. Shale Gouge Ratio of the Baka Faults generally matched with the Shale Gouge Ratio related column height distribution use in exploration. Top seal thickness does not seem to play a major role in controlling column height in this study as seen in Figure 7. However, top seal influenced the stopping of further up dip hydrocarbon migration but the thicker the top seal did not imply higher hydrocarbon column in this study because of the differences in reservoir vertical reliefs (see Figure 7). Assessment of the fault seal results indicates that P85 of the stochastic fault seal results predicted best for the under filled hydrocarbon column height (Figure 6A); while the P50 of the stochastic fault seal results predicted best for the filled to spill reservoirs (Figure 6B).

CONCLUSIONS

Good structural understanding of reservoir fluid accumulations and their faults capacities to impede further migration causing hydrocarbon entrapment should be paramount for decision making in the exploratory stage to ensure accuracy of predictions and cost saving. This approach can be applied in any fault dependent closure from any oil field of the world to ascertain the sealing capacities, hydrocarbon column heights and be used to predict recovery certainties and thereby positively impact the global economy. Also, the stochastic applications as seen in this study, has the capacities to predict away from fluid contacts and as such clues for prospect risking, ranking and geological chance of success.

It is evident in this study that faults in the Baka Field generally leaks at <20% Shale Gouge Ratio. Weak points on faults in the Baka Field varies; mainly 20 – 35% and more. Good fault seal in the Baka Field generally exist at >40% Shale Gouge Ratio.

Low Fault seal in the Baka Field range between <40% - ≥20% Shale Gouge Ratio and mostly associated with leak points. Shale Gouge Ratio is greater at the Baka boundary fault and – good seal capacity.

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