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ALONG-FAULT MOVEMENT OF FLUIDS IN THE DIAPIRIC PROVINCE OF THE NIGER DELTA BASIN: A CASE STUDY OF THE LL# WELL, LULU NORTH FIELD.

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ABSTRACT
The Lulu Field is one of the Deepwater Offshore Blocks in Niger Delta allocated in 1993. It is located in deepwater offshore Nigeria on the continental slope seaward of the Niger Delta. During the drilling of the LL# well on the Lulu Field, there were several fluid flows which were not predicted and factored into the well design. The work was aimed at analyzing the contribution of faulting to the fluid flow. A 3D seismic data, three wells and a sidetrack were used for the analysis. LL# well lies in an area with several faults, going into sub-seismic scale. Faulting originates from shale diapirs which control the Lulu main structure. The faulting increases towards the crest of the structure where the LL# well is located. The interpreted faults are mostly low angle to listric normal gravity sliding extensional growth faults. The seabed is punctuated and breached by numerous fault scarps which are expressions of fluids that migrated from deep seated reservoirs. Along-fault migration has therefore been suggested as the mechanism responsible for the fluid flow in the Lulu North Field.

Keywords: Faults, Fluid Flows, Mobile Shale, Shale Diapir, Fault-Scarp, Sub-Seismic

INTRODUCTION
The Lulu Field is one of the Deepwater Offshore Blocks in Nigeria allocated in 1993 (Figure 1) It is located in Deepwater Offshore Nigeria in Block OML 118; formerly OPL 212 on the continental slope seaward of the Niger Delta

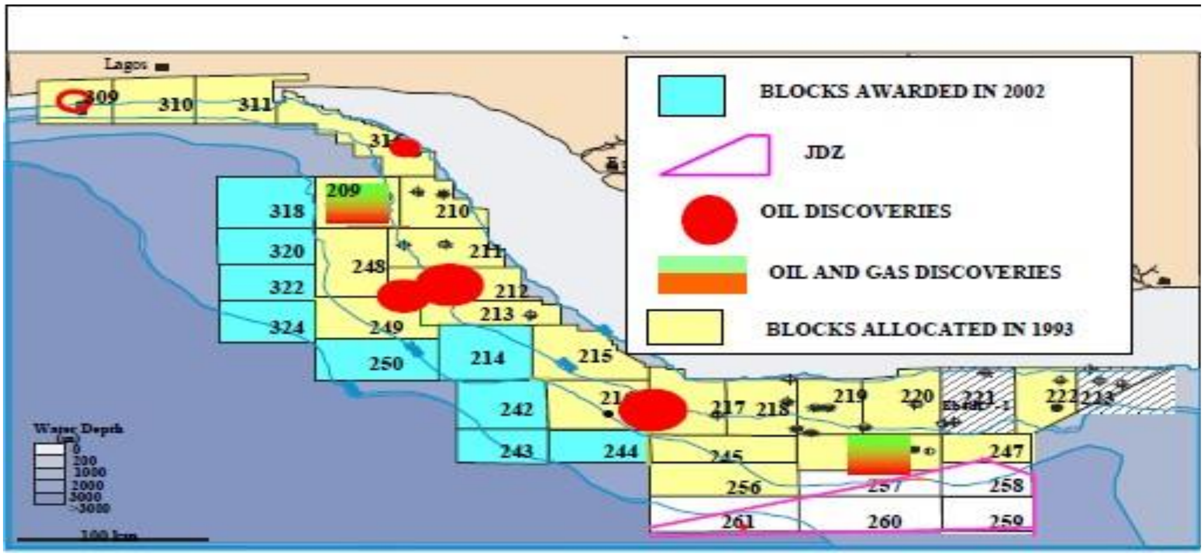

Figure 1: Lulu Field, OML 118, formerly OPL 212 was one of the Deepwater Offshore Blocks in Nigeria allocated in 1993 (Directorate of Petroleum Resources).

During the drilling of the LL# well on the Lulu North Field, there were several fluid flows which were not predicted and factored into the well design. The research is aimed at analyzing the effects of faulting on fluid flow.

LL# well lies in an area with several faults, going into sub-seismic scale. The Lulu structure is a shale induced anticline covering an estimated area of 230km^2 and dips in the magnitude of 6^o to 8^o (Shell Technical Report, 2014). The LL# well is situated on the crestal part of the structure. Faulting originates from shale diapirs which control the Lulu Main structure. Lulu north is localized on the West flanks of the Lulu diapir with large faults providing the lateral trapping elements on the North and South flanks. They are classified as combination-stratigraphic traps.

The Niger Delta is a structurally dominated province typified by growth faults and roll-over structures developed in relation to gravitational sliding and/or squeeze flow of the underlying mobile shale (Evamy *et al*. 1978). Shale diapir and shale ridges which are caused by shale upheaval ridges are also associated with these growth faults (Damuth, 1994). The shale diapir occurs on the basinward side of the faults, enhancing sedimentation on the upthrown side. Most of the faults are listric normal faults; others include structure-building crestal faults, flank faults, counter regional faults and antithetic faults (Evamy *et al*. 1978).

The main structural style ranges from extensional, translational to compressional zones (Corredor *et al*, 2005) (Figure 2). The extensional zone is characterized by basinward dipping and counter-regional growth normal faults, the translational zones by diapir while the compressional zone is characterized by toe-thrust (Damuth, 1994).

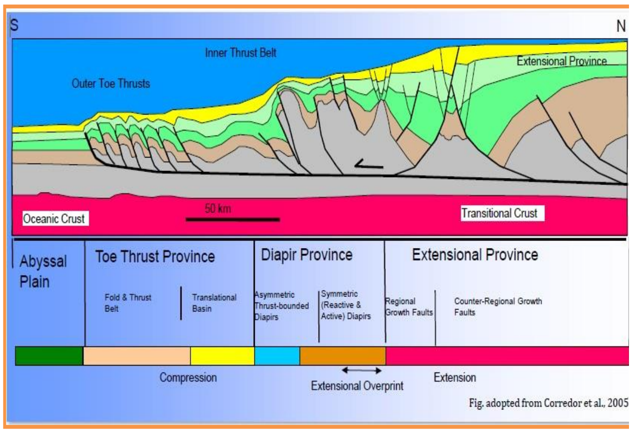

Figure 2: Structural styles in the Niger Delta (Corredor et. al., 2005). Lulu Filed lies within the Diapir Province

The Lulu Field lies within the translational zone which corresponds to the Diapiric Province. The translational zone lies between the growth fault domain and the deep water thrust-fault dominated area. The shale diapir province is located beneath the upper continental slope and it is characterized by active, passive and reactive mud diapir (Corredor *et al*. 2005). Vertical mud diapir form mud volcanoes at the seafloor and inter-diapir sub-basins (Damuth, 1994)

Growing structures such as mobile shales, mud diapir and growth faults in this region influenced depositional processes and sedimentation, and hence determine the development, distribution and architecture of reservoir facies (Corredor *et al.* 2005). The growth faults act as migration pathways and/or structural traps depending on the prevailing conditions and the associated roll-over anticlines act as traps for hydrocarbon accumulations (Connors *et al.* 1998; Corredor *et al.* 2005).

According to Weber and Daukoru, 1975, overpressures within a given fault block are usually stratigraphically oriented.

Three stratigraphic units have been identified in the Niger Delta: Akata Formation, which is overlained by the Agbada Formation and capped by the Benin Formation (Figure 3).

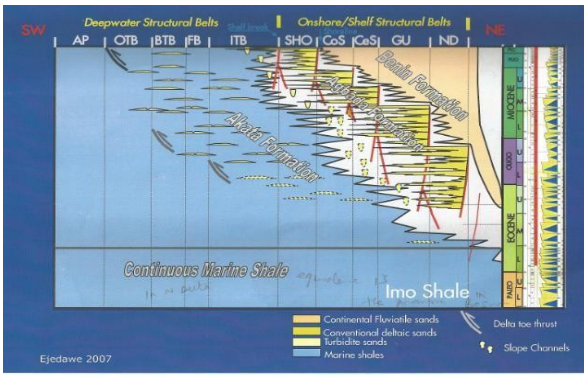

*Figure 3: Generalized Niger Delta Stratigraphy and Lithofacies Subdivision (*Ejedawe, 1981).

The three diachronous lithostratigraphic formations (Eocene to Recent) were deposited as the delta prograded. There is the over pressured prodelta marine shales of the Akata Formation (Oldest), with sporadic turbidite sands as in Lulu Field. The marine Akata shales represent the major source rock in the Tertiary Niger Delta (Ekweozor and Daukoru, 1984). It is considered as the main detachment horizon for the compressional toe structures. The Paralic sediments of the Agbada Formation (predominantly shelf deposits of alternating sands and shales) form most of the reservoirs and seals in the onshore and shelf fields (Burke, 1972). The Benin Formation is the Youngest. It is characterized by fluvial deposits and generally water bearing.

MATERIALS AND METHODS

Three wells and a sidetrack as well as 3D High Resolution Seismic Data with Runsum processing applied, was used for the work. The generalized seismic section illustrates very deep water with variable seafloor depression and deep-seated structures. The regional seafloor slope in the Lulu North area is approximately 1° WSW but increases to about >2° because of its proximity to a large shale diapirs complex approximately 2.5km to the NE. Seafloor bathymetry is gently sloping from northeast to southwest.

The Shell Proprietary Interpretation Software (ndi) was the main tool used for the analysis. The wells were used to constrain horizon picks and input to regional seismic lines and cross sections. Faults were mapped and displayed on depth variant colour to enhance faulting. This guided fault interpretation especially in areas of poor seismic data and difficulty in mapping faults. The shallow faults and other potential fluid migration pathways in and around the crest of the structures were mapped in order to better predict the fluid migration pathways. Semblance slices, dips and traverse sections were taken to capture the study intervals and their features. The conductive zones which are expression of fluid movements associated with faulting were documented. Lastly, all interpretations were integrated to determine the fluid migration pathways along the shale-induced faults.

RESULTS AND DISCUSSION

The study area is characterized by active fault scarps which suggest disturbances beneath the seabed. The interpreted faults are mostly low angle to listric normal gravity sliding extensional growth faults. The pervasiveness, flow and movement on the mud diapirs have caused some of the faults to undergo inversion tectonics (Evamy *et al;* 1978). Some of these faults have throws greater than 200ft (61m) regionally. The fault density increases towards the crest where the **LL#** well is situated (Figure 4).

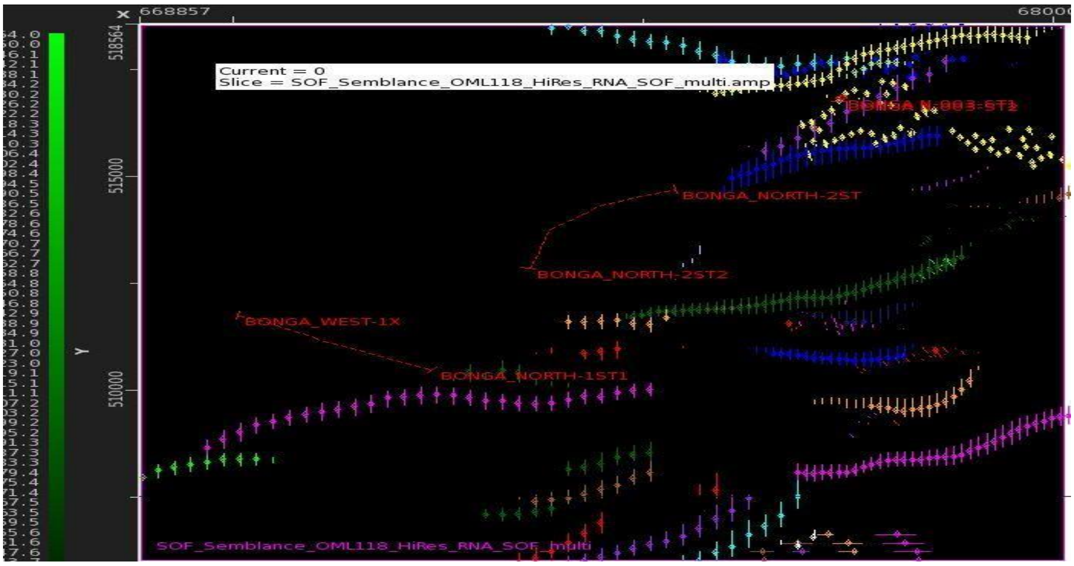

Figure 4: Base map with mapped faults. Lulu North Filed is highly faulted with fault intensity increasing towards the crest where the LL# well is located

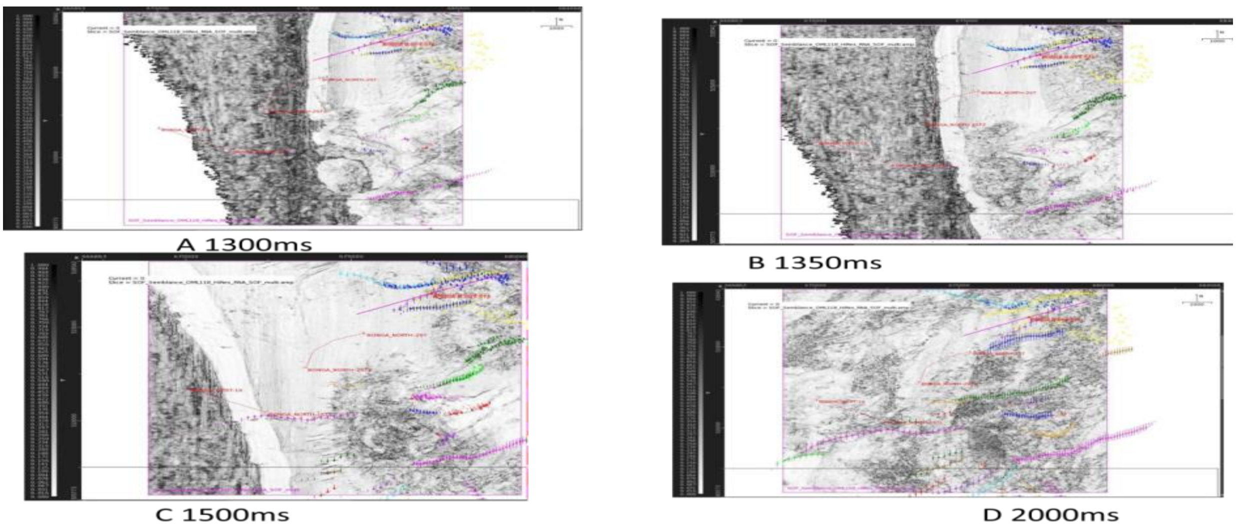

Figure 5: Semblance time slices at 1300ms, 1350ms, 1500ms and 2000ms showing variations in structural geometries and topographic expressions through time. Faults are consistent at different time slices, circular features are diapirs

Figure 5 shows semblance time slices at 1300ms, 1350ms, 1500ms and 2000ms to illustrate the variations in structural geometries and topographic expressions through time. Faults are consistent through time. Earliest faults are cut by subsequent ones at depth. The circular features are diapirs and are few kilometres wide at these times. The overpressured shales use these faults to get to the surface and form mud volcanoes on the seabed.

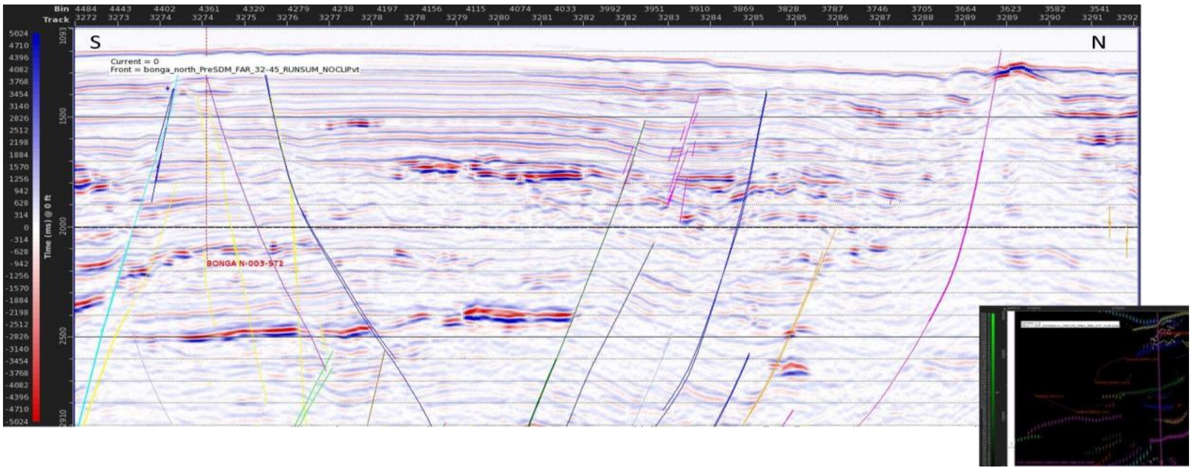

Figure 6: Dip section across along X=677325 and Y=515708. Note faults penetrating reservoirs and can act as conduits. Faults are active to the surf ace. Growth of faults is ongoing

Deep faults are emerging on the seafloor (Figure 6). The seafloor cutting faults serve as the lateral trapping elements on the north and south flanks of Lulu North Field. Faults are shallow in this section and can bring fluids to the surface. The wipe-out zones and data distortion observable in the lower section of the seismic slice (figure 6) is due to faulting and shale flows.

Figure 7 is a traverse section connecting high amplitudes on seafloor which may correspond to faulting or poor data/low amplitude areas (gas chimneys indicating presence of undercompacted sediments). A, B and C are expulsion chimneys.

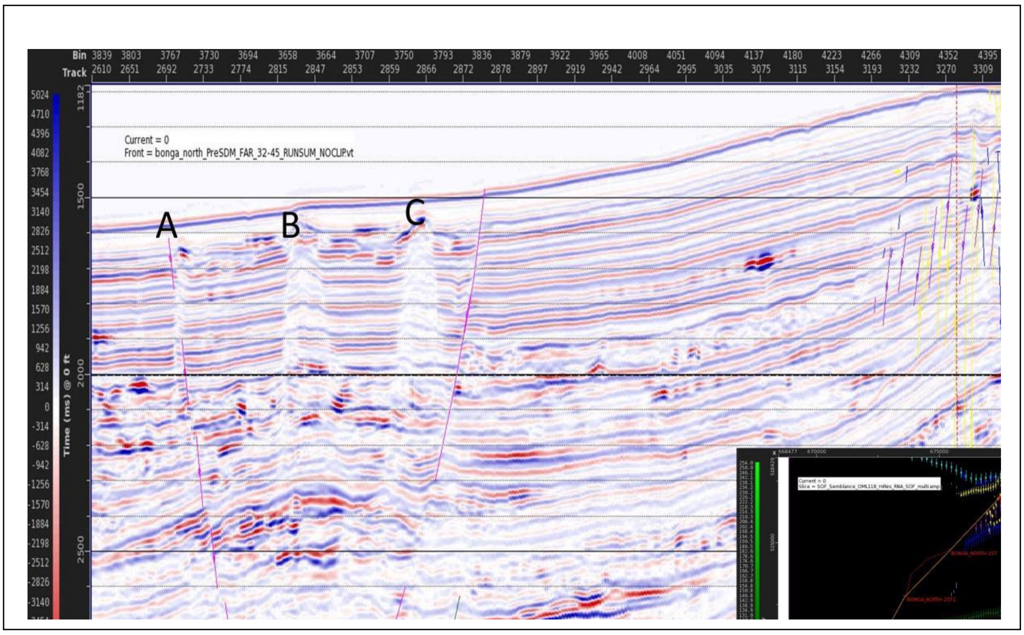

Figure 7: Traverse section connecting high amplitudes on seafloor

Major extensional faults associated with shale in their hanging wall, still actively affecting seafloor topography. Weak seabed/fault scarps are observable expression of the faults.

In the Lulu area, the faults are still very active and deformation is ongoing. Consequently, the faults now serve as pathways for fluid flow. This assertion was not considered in the initial interpretations. This portends the danger of the faults delivering fluids to the surface which could increase well pressure. However, this discovery would help in redesigning the drilling operations to mitigate the dangers of fluid flow along faults.

CONCLUSION

The Lulu North Field is highly faulted. They are believed to result from the movements of fluids from the undercompacted and overpressured marine shales of the Akata Formation and seepages through faults from deeper sources. The fluid movements are believed to be controlled in the subsurface by faults. Along-fault migration has therefore been suggested as the mechanism responsible for the fluid flow in the Lulu North Field.

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REFERENCES

Burke, K.C.,(1972) Longshore drift, submarine canyons, and submarine fans in development of Niger Delta: American Association of Petroleum Geologists, V.56, p.1974-1968.

Connors, C.D., Denson, D.B., Kristiansen, G., and Angstadat, D.M (1998) Compressive anticline of the mid-outer slope, Central Niger Delta (abs): AAPG Bulletin, v.101, no.2, p. 345-353.

Corredor, F., Shaw, J.H., and Bilotti, F.D. (2005) Structural styles in the deepwater fold and thrust belts of the Niger Delta. AAPG Bulletin, v.89, no.6, p. 753-780.

Damuth, J. E. (1994) Neogene gravity tectonics and depositional processes on the deep Niger Delta continental margin: Marine and Petroleum Geology, v.11, no 3, p.3 17-340.

Ejairu, K.O. (2014) Analysis of Fluid Movement along Faults and Shale Diapirs, Bonga North Field, Offshore Niger Delta. M.Sc. Thesis, Imperial College London.

Ejedawe, J.E. (1981): Patterns of incidence of oil reserves in Niger Delta Basin. AAPG, V .65, p.1746-1759

Ekweozor, C.M and Daukoru, E.M. (1984) Petroleum Source bed Evaluation of Tertiary Niger Delta. AAPG Bulletin, V.68, p.397-400

Evamy, B.D., Haremboure, J., Karmerlimg, P. (1978) Hydrocarbon Habitat of Tertiary Niger Delta. American Association of Petroleum Geologists Bulletin, 62, 1-39

Shell Technical Reports (2014).

Weber, K.J and Daukoru, E. (1975) Petroleum Geology of the Niger Delta. Jour. Min. Geol., 12, 9-12.