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Flood Plain and Channel Sand Reservoir in Deepwater Environment - A Case Study of 'Oyo-Dw' Field Niger Delta, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The Deepwater environment of the Niger Delta Basin is one of the hydrocarbon exploration frontiers believed to be promising and highly prolific if properly harnessed. Some of the reservoir units are affected by multi-scale compartmentalization resulting from structural, stratigraphic and/or diagenetic processes. Reservoir compartmentalization can compromise the lateral and vertical connectivity of other micro reservoirs thus having significant impact on the estimation of oil-in place and / or recoverable reserves, as well as the placement of exploration development and production wells. "OYO 10" was drilled within the northwest part of the field, all reservoir levels predicted using Amplitude as Direct Hydrocarbon Indicator analysis draped on structural maps. Disappointedly, all reservoir levels show poor sand development with poor hydrocarbon columns. A 3D seismic dataset and geological data from Oil Mining License 121 in the Deep-water environment of Niger

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Delta was analyzed to assess and quantify the architectural elements that influence the compartmentalization of delineated reservoir units. The key aim of this study was to delineate the reservoir sands in deepwater environmental Niger Delta as it is applicable to channel reservoirs and flood plain. This study involved calibration of seismic-to-well tie, determination of spatial distribution patterns of submarine channels; establishment of hydrocarbon control; evaluation of the reservoir compartmentalization and trapping mechanism over the prospect area. It is important to understand the spatial distribution of Submarine channels because they are made up of important potential reservoir strata. Large channels with numerous smaller channels are laterally scattered across the study area. Attribute analysis revealed the degree of compartmentalisation within the sub-channel and the sand development pattern within the channels and the floodplain. Variance attributes reveal that previous producing wells drilled within the study area were all located within the channel compartments which are also made of micro channels. The results of this study can provide significant contributions to further hydrocarbon exploration in the deep-water area of Niger Delta and hence lead to more discovery and increase in the crude oil reserve.

Keywords: Deepwater; floodplain; channel sand; flat spot; chronostratigraphy.

1. INTRODUCTION

Deep water could literally mean two different things to anyone that comes across it. In geological reference, it could mean a deepwater system transported through a gravity flow process in a marine environment. Sea depth more than 500m (1640ft) could ordinarily be referred to as a deep water environment. Concerted effort and processes have been on-going for over four decades in exploring for reservoirs located in present-day deep water, and these have resulted into many prolific discoveries. Deep-water exploration in the Gulf of Mexico, Brazil, and west Africa is targeting and finding a large number of hydrocarbon pools in deep-water marine-sand systems, about 1/5th of these reservoirs had been developed recently to about two decades ago [1].

Significant attention has been given to Deepwater channels in the petroleum industry during the past decade, and this is due to the important discoveries that have been made in several deepwater basins in which reservoir performance was critical to development decisions and strategies. However, the importance of channels as sand conduits for bypass to the basin floor probably was not fully appreciated until recently. Ever since large volumes of sand were recognized to occur downdip of muddy slope systems (e. g., Angola and the northern Gulf of Mexico [2].

Uncertainty of the subsurface is at peak during the early stage of development when there is inadequate information and seismic resolution may not be sufficient to capture the subsurface heterogeneities that exist within the reservoirs of interest [3].

Understanding the petroleum system elements and processes appropriately in period and place leads to enormous oil and gas exploration and boosts development chances [4].

It has been discovered that Deep-water marine sandstones are often prolific reservoirs where they occur. They commonly contain oil fields because of the interfingering of gravity-flow sandstones with source rocks that are marine in nature [2]. The interfingering of the Upper Jurassic submarine fans of the UK North Sea with the Kimmeridge Clay Formation source rock is a practical example that occurs in the province, e. g., the Magnus and Claymore fields. Deep-marine sandstones have been found to exhibit reservoir quality that is among the best of the various sedimentary environments that comprise reservoirs, petrophysical qualities such as porosities, permeabilities, and net-to-gross ratios are typically high. In some unfavorable conditions, deep-water reservoir sandstones may be ponded and stacked vertically into very thick, sand-rich intervals, examples of this can be found in Bonga, Agbami and Erha of Nigeria [5,6].

A range of sediment types from very fine particles: clay- to coarse and gravel-size particles that include both terrigenous and organic material deposits are representation of Floodplain sediments. The importance of floodplain sediments is double fold. First, these deposits represent economically important reservoirs of oil, natural gas, and water, and include significant coal reserves. Also, floodplain sediments reveal detailed records of geologic processes and continental environments that happened in the past and are also going on currently [7].

Channels may be braided or meandering, this often leads to the development of a belt in which sands deposited by the channels will accumulate [8].

Hydrocarbons generated from a particular source will depend largely on the nature of the organic matter. Therefore, the quality and quantity of organic matter in source rock is vital as it would provide insight into the paleoenvironment and basin evolution [9].

2. REGIONAL SETTING / GEOLOGICAL CONTEXT

The Niger Delta lies above a triple junction of Gulf of Guinea Translation Zone, South Atlantic spreading ridge system and Benue Trough and this ceased to spread further after short-lived subduction episode [10,11].

The Basin was formed during the Precambrian by build-up of sediments over a crustal tract established by rift faulting [12]. The Niger Delta area and the connecting basins are also located in a tectonically active region and are exposed to pre/post deformation, gravity tectonism is responsible for primary deformation [13]. Most active is shale tectonism where gravity-driven fold and thrust belts are widely developed [14]. The Niger Delta Basin is confined by the Benin Axis Line to the northwest and the Cretaceous ridges on the Abakaliki high to the northeast while the Cameroon Volcanic line marks the eastern offshore extent of the basin [15].

The Tertiary reservoirs of the Niger delta offshore are turbidites deposited within the shale prone Akata formation, and they are of Miocene to Pliocene in age. Turbidite reservoirs are charged by hydrocarbons expelled mainly by early Tertiary mobile shales. Intra reservoir shaly intervals have also been proven to be effective source rocks. Trap formation in area of study is mainly due to diapir uplift in combination with stratigraphic components. Turbidite deposits on lap synsedimentary growing diapirs and drape then when sedimentation can compensate topographic relief, with channel lobe systems continuing the downdip flank of the diapir. Major sediment thickness is recorded within inter-diapir depocenters, indicating a ponding effect within this portion of the slope. Genesis of major clastic sediment fairways, by which turbidite sediments are distributed throughout the continental slope to the basin plain, are likely linked to recurrent collapses of the shelf margin. Shelf margin disequilibrium and collapse phenomena are triggered by phases of rapid progradation occurring during the falling limb of relative sea level change.

The overall sequence architecture corresponds to the long-term evolution of the Niger delta offshore sedimentary basin, with more distal basin plain / lower slope facies overlaid by prograding middle to upper slope successions. The Middle/Upper Miocene succession is constituted by poorly confined and ponded depositional lobes deposited in the inter-diapir areas, rapidly shaling out on diapir flanks. In contrast, the Late Miocene/Pliocene succession is characterised by the occurrence of more confined upper/middle slope channel complexes trending NE-SW**.** The sandstone reservoirs, of sandstones and shales intercalations in quick succession within the Agbada formation account for oil and gas production in the delta [16]. There may be uncertainties in the extent of the Niger Delta but the sedimentary environments in the Niger Delta is heterogeneous in nature indicating that it is s mix of fluvial, tidal, and wave-related deposits and landforms [17].

3. LOCATION OF THE STUDY AREA

Only one petroleum system is identified with the Niger Delta Basin [8,9] and this is referred to as here as the Tertiary Niger Delta (Akata –Agbada) Petroleum System. The overall maximum extent of the petroleum system matches with the boundaries of the province while the minimum extent of the system is demarcated by the areal extent of fields and contains known properties.

The Oyo-DW Field is located within the deepwater environment of the Niger Delta in OML 120 approximately 75 km from the coastline within the range of deepwater classification on the world map. The Oil Mining License is bounded in the north by Agip's OML 125, west by Esso's OML 133, south by OML 121 and on the east by Cavendish's OML 110 and Chevron's OML 89. OML-120 is an eight-sided elongated block with a total area of 910.05 km2. Water depth ranges from 200 m to 900 m, increasing from the NE towards the SW corner.

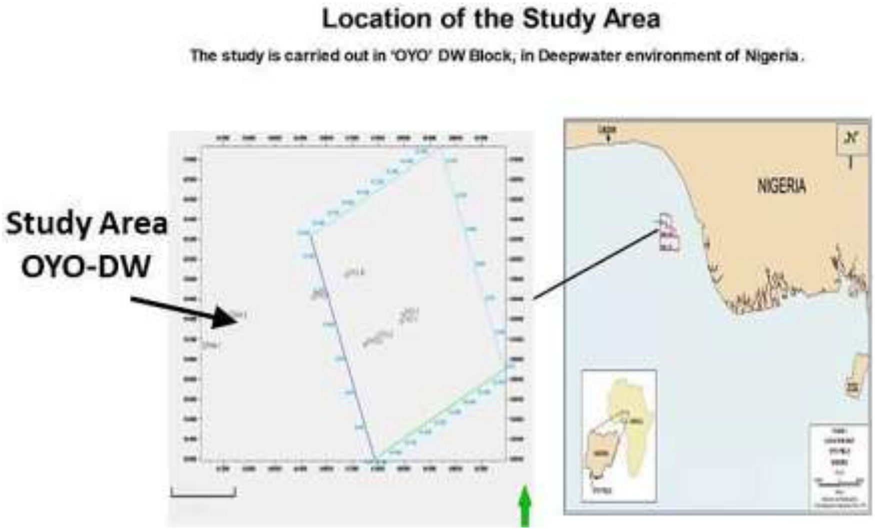

Fig. 1. location and base maps of oyo field in niger delta

4. FLAT EVENTS

Flat events are known to be Direct Hydrocarbon Indicators and could be seen here at almost all levels of the horizon picked for the studies. There is always a close to horizontal positive reflections because of positive impedance contrast on the seismic data whenever a fluid contact such as Gas/Oil, Gas/Water or Oil/Water is present in a hydrocarbon reservoir. Whenever this occurs, it is termed a flat spot, and this is known to be a direct hydrocarbon indicator. This may appear tilted sometimes because of overlying velocity, but they may be unseen when data resolution is insufficient. However, Flat Spots are among the best hydrocarbon indicators. At other times, features such as porosity or cementation changes may produce flat spot not associated with current fluid contact but with a former horizontal reflector. It is easy to recognize Flat spots reflections from the hydrocarbon- water contact because of their non-conformable flatness, the signs are always positive [18]. The seismic data used for this study is characterized with flat events which is a pointer to the fact that there will be presence of hydrocarbon in this environment (Fig. 2).

5. STATEMENT OF PROBLEM

OYO 10 was drilled on the field as an exploratory well within the Northwest block of the field on the floodplain in contrast to existing wells on the field that were drilled within the channel reservoirs. All reservoir levels were predicted using Direct Hydrocarbon Indicator analysis draped on structural maps. Electric logging and mudlogging data indicated hydrocarbon levels after drilling, however, formation fluid sampling suggest the reservoirs are wet with traces of liquid hydrocarbon despite high gas readings with good gas chromatograph analysis. This necessitated investigation into the possibility of reservoir compartmentalization, sand development and establishment of floodplain drilling of wells in contrast to drilling within reservoir channels on the field.

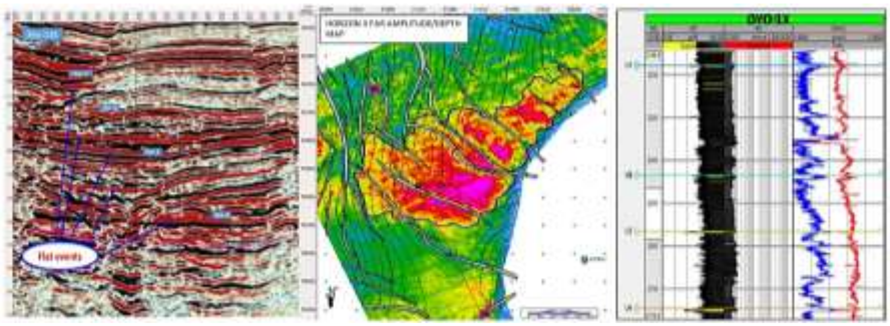

Fig. 2. Predrill anplitude map extraction and Oyo 10 well log. courtesy allied energy resources

Predrill data and study show a lot of positive indications that the location would be productive. Flat events which are Direct hydrocarbon indicators match high amplitude which also supports the fact that drilling will detect hydrocarbon bearing sands.

Despite all positiveness in the predrill studies and indicators of hydrocarbon that were carefully analyzed, the result however did not match the predrill studies (Fig. 2). The sand is poorly developed to have allowed accumulation of hydrocarbon in commercial quantity. The resistivity values are extremely low compared to resistivity recorded on producing wells within the field, Density / Neutron logs did not indicate the presence of hydrocarbon of commercial quantity, while fluid sampling reveals 90% of water in supposed reservoirs.

6. MATERIALS AND METHODOLOGY

Available Data include, 3D Seismic data, Checkshot for the wells, deviation surveys, well logs in las file format and biostratigraphy data. Petrel version 2018.

7. RESULTS AND DISCUSSION

It is quite possible for different lithologies of sedimentary rocks to be formed at different locations since depositional environments vary from place to place geographically. The term Chronostratigraphy represents both the stratigraphy concept and timing principle of rocks in geological history of the earth. Chronostratigraphy correlation ties rocks that were formed during the same time in history although may be of different petrologies [19].

The chronostratigraphic correlation done reveals that all the wells that produced hydrocarbon in the study area fall within the two channels that were identified as channel X1 and X2 whereas the well being considered is located outside these two channels on flood plain.

Using Variance seismic attributes, it is equally observed that major channels X1 and X2 are made up of other micro channels so there are channels within the major channels as seen in Fig. 4.

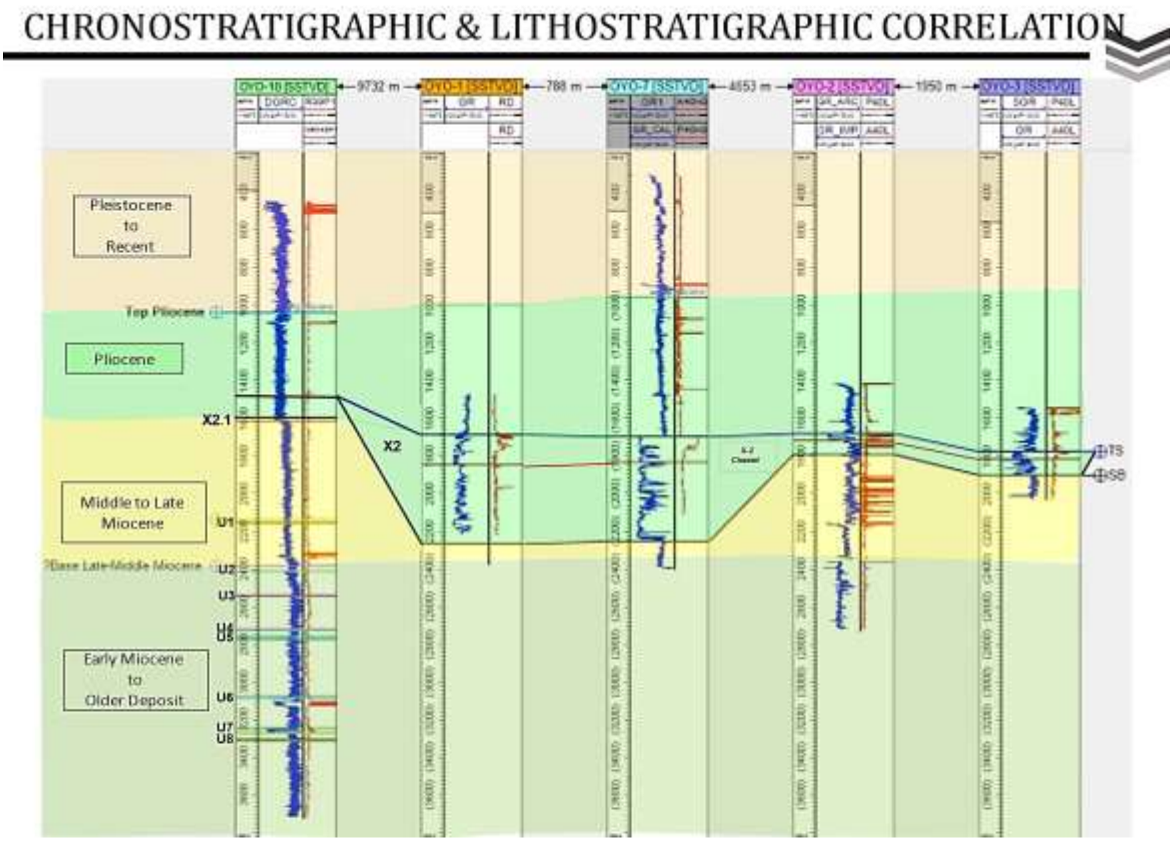

Fig. 3. Chronostratigraphic correlation of wells in the study area

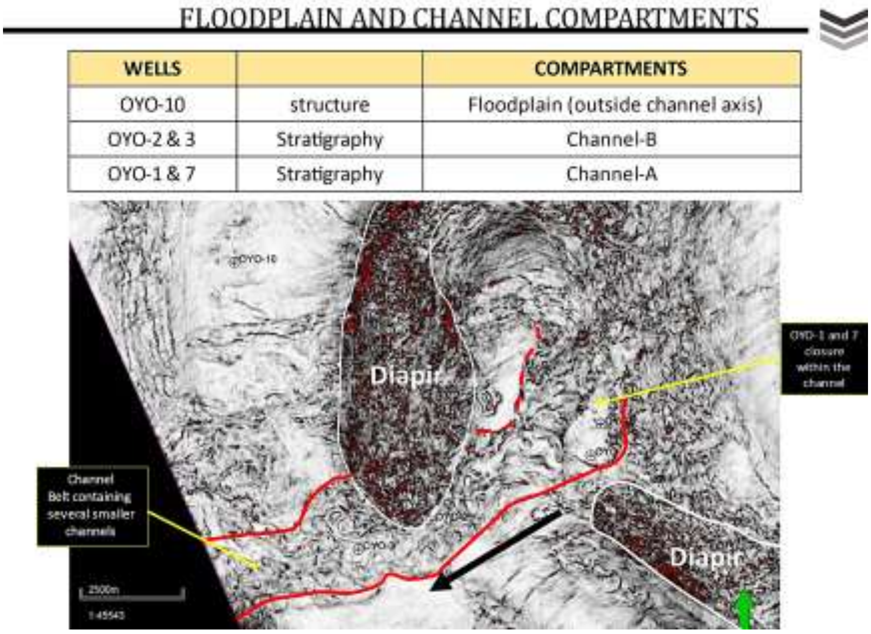

Fig. 4. Variance Attributes of Channel and Floodplain of the study area

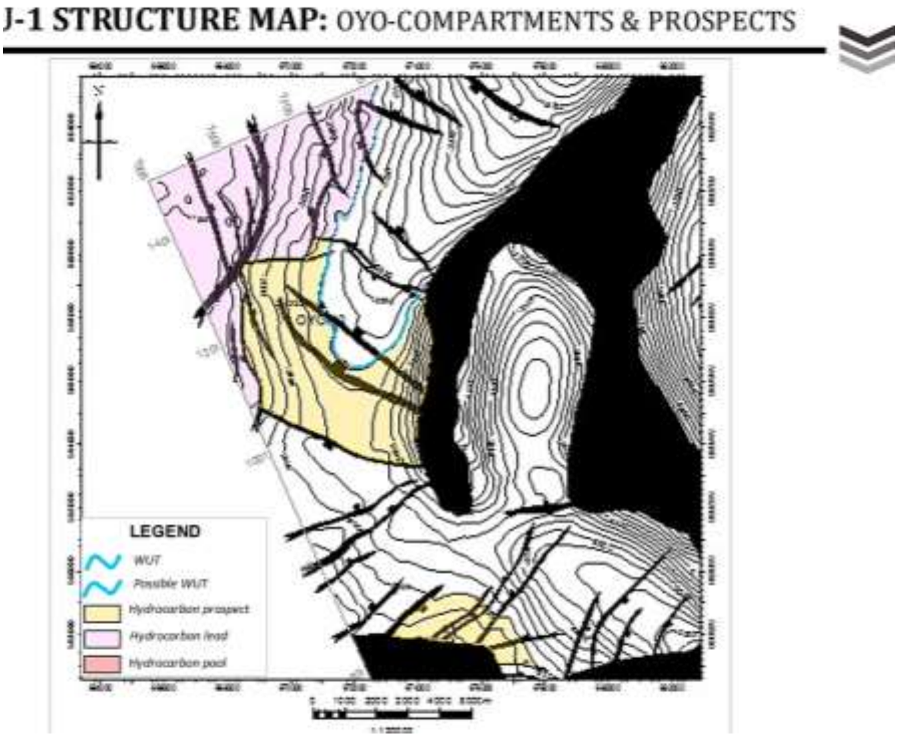

Fig. 5. Time Map with channel polygon showing closure against shale diapir

Time map was superimposed on the Channel polygon (Fig. 5), contours can be seen closing against the shale diapir whereas the same thing could not be said about the floodplain where OYO 10 is located. In addition, both structural and stratigraphic traps could be seen in play within the channel reservoir but on the flood plain where OYO 10 is located, the same could not be mentioned. The contours along the fault plane are constantly depicted that the discontinuities may be fractures and probably not faults with remarkable displacements.

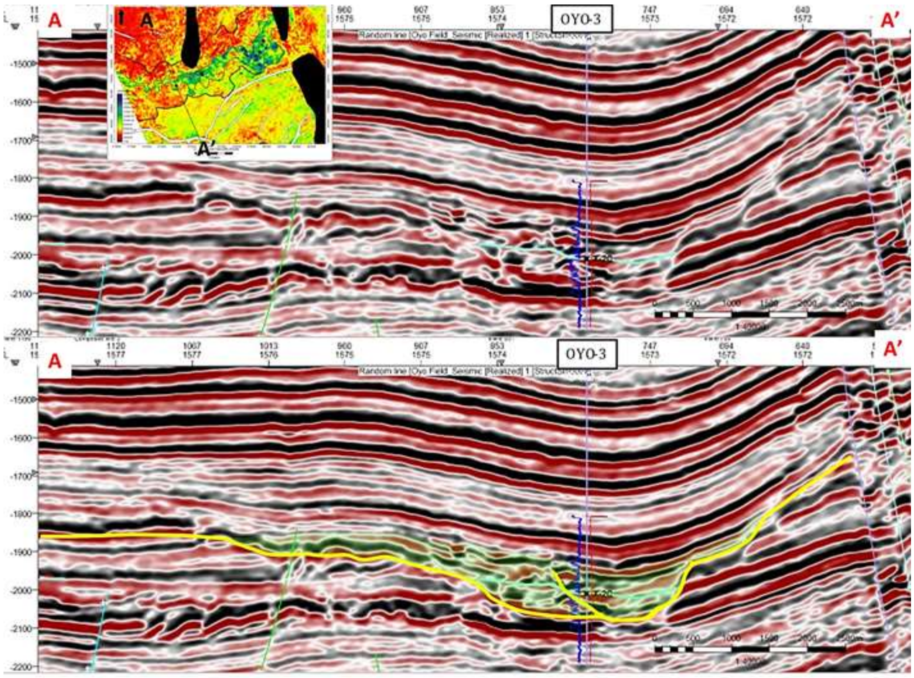

Fig. 6. Seismic cross section of well 3 within the channel reservoir sand

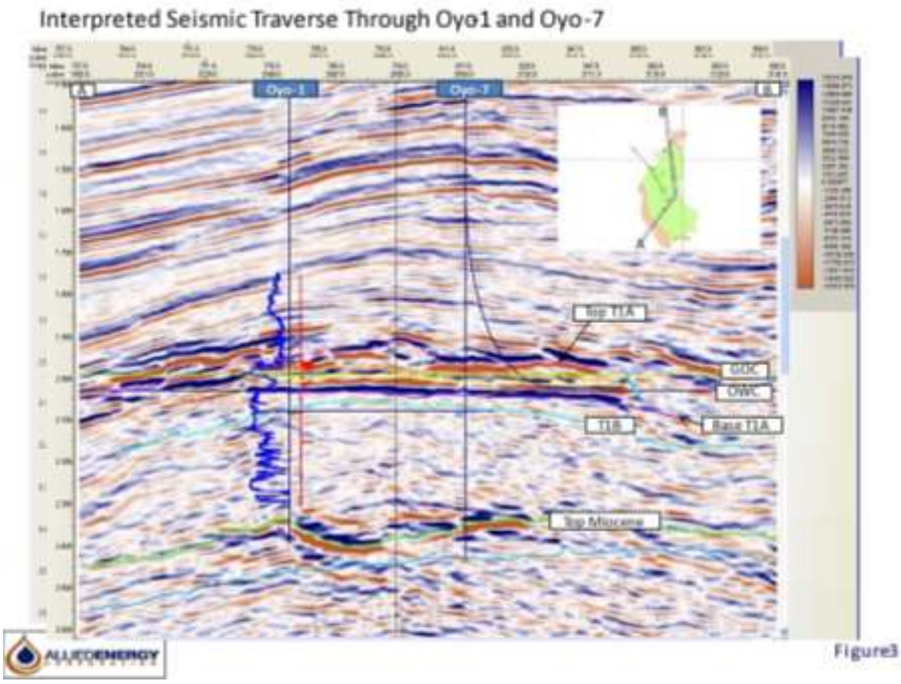

Fig. 7. OYO -1 and 7 located within the channel sand courtesy allied energy

Fig. 6. shows OYO 3 well located within the Channel X2 and was hydrocarbon bearing. OYO 1 and 7 which were both producing at a sustainable rate were both located within the channel sand reservoir in the Top Miocene age. The T1A sand and T1B were demarcated with a well-defined fluid contact. That is Gas Oil Contact (GOC) and Water Oil Contact (WOC) (Fig.7.) Amplitude anomaly also supported the findings. i. e. high amplitude is associated with the channel sand.

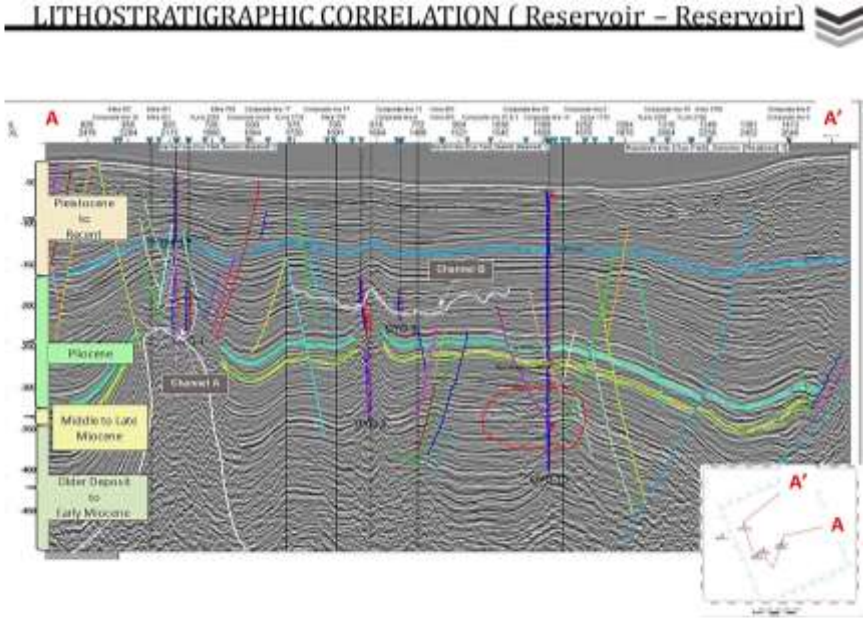

Fig. 8. Lithostratigraphic Correlation showing Channels on seismic

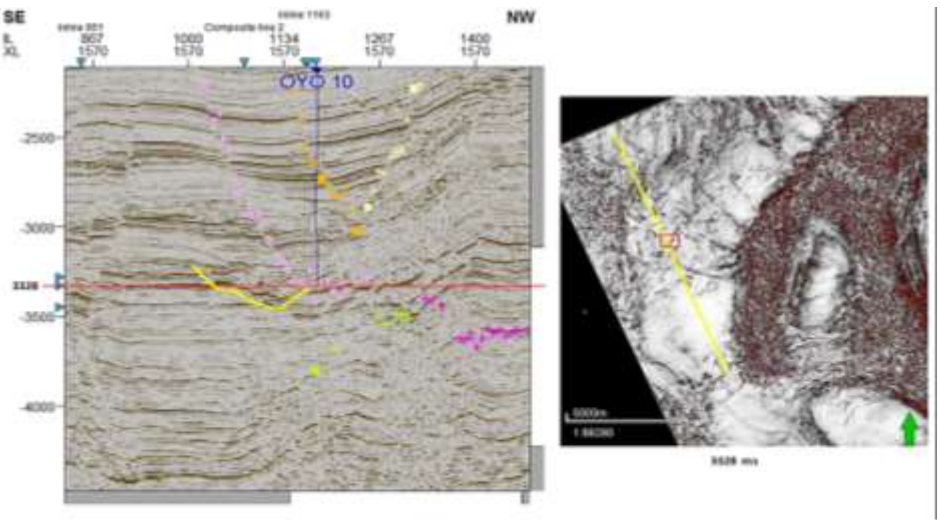

Fig. 9. Mapping of horizon through OYO 10 Channel

Marine sandstone systems from the Deepwater environment may often be tough to characterize in the subsurface and the major challenge is trying to differentiate between sheet sandstones and channel reservoirs. Deep-water marine sandstone systems can be difficult to characterize in the subsurface. The basic problem is in trying to differentiate sheet sandstones from channel complexes. Sheet sandstones are characteristically well connected laterally and can be very prolific, whereas large-scale reservoir connectivity of channel complexes can be very good, where they have merged into connected bodies, or could be non-productive where they are isolated during deposition.

The study reveals the presence of both structural and stratigraphic barriers. The structural traps are created by diapiric structures resulting in intense stratigraphic compartmentalization of the reservoirs. Stratigraphic features such as channels also tend to create stratigraphic compartment(s) at the south of X-2 reservoir. These compartments create traps for hydrocarbon accumulation and were therefore identified and delineated during the study.

The X-2 reservoir is Pliocene in age. This interval was penetrated by all the OYO wells. At the north of this interval, the reservoir was encountered by OYO-10. At the south, OYO-1, -7, -2 and -3 encountered the X-2 sand within a NE-SW trending meandering channel. Other reservoirs such as U-1, -2, -3, -4, -5, -6, -7 and -8 are older to middle Miocene in age and were encountered by only OYO-10.

The contemporary slope and outer shelf of the Niger Delta are characterized by fault-bounded sedimentary depocentres and intervening shale diapirs. The shale structures were defined by Late Miocene time, perhaps in rejoinder to lateral shale withdrawal from beneath the progressing deltaic load, jointly with compressional uplift and folding of pro-delta layers. During Pliocene and Pleistocene time, these structures were concealed by the prograding delta, and extensional growth faulting commenced [20].

The X-2 is characterized by structural and stratigraphic compartmentalization. At the North, The X-2 reservoir in OYO-10 is structurally compartmentalized by the fault structure against the shale diapirs. This therefore defines the structural trap within the reservoir. OYO-10 penetrated the flank of the structure. At the south, the X-2 reservoir is stratigraphically compartmentalized, as the reservoirs were encountered by OYO-2, -3, -1 and -7 within the NE-SW trending meandering channel. Within the channel axis, higher net sand is present at the OYO-1 and OYO-7 area at the east of the channel and lower net sand was observed at the OYO-2 and OYO-3 area at the west of the channel. The sand development is better within the channels and this favors accommodation of hydrocarbons which establishes the fact that the channel sands are better reservoirs within this block.

It looks like OYO 10 narrowly missed the channel which could have increased the chances of the prospect just like others producing well on other channels (Fig. 8). The horizon was mapped with an arbitrary line taken SE-NW across the seismic section (Fig. 9). It was duly observed that the supposed channel seen on the seismic does not actually exist when variance attributes were run across the same section as seen on. This is because the chaotic signatures that normally characterize channel reservoirs were never observed on the variance attributes, instead, the area is characterized by structural traps resulting from the faults

8. RECOMMENDATION

It is also observed that closures were noticed more around the channels and not at the floodplain. There are closures against the shale diapirs which could not be observed on the floodplain (Fig. 5). The channel sand also contains compartments that are also made of micro compartments. With just one well within the northwest part of the block which falls within the floodplain of the field, it may not be conclusive that hydrocarbon in commercial quantity can only be found in the channel reservoir sands of the field alone and not in the floodplain.

9. CONCLUSION

More studies should be carried out to target the OYO-10 stratigraphy / structure and the channel sand and to give credence to the claim that it is the channel Sand alone that is hydrocarbon bearing in the study area. This could mean exploring the North-East side of the block in addition to what has been done in the North-West direction of the block. Multiple tools are always needed to confirm a particular feature before conclusions could be drawn in any given situation.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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