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

Abstract: The Deepwater environment of the Niger Delta Basin is one of the hydrocarbon exploration frontiers believe 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 microreservoirs 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. A 3D seismic dataset and geological data from Oil Mining License 121 in Deepwater environment of Niger 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 undertake delineate the reservoirs and sand in deepwater environment Niger Delta as it is applicable to channel reservoirs and floodplain. 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 compartmentalization within the sub-channel and the sand development pattern within the channels and the floodplain. The result of this study can provide significant contribution to further hydrocarbon exploration in deepwater 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 deepwater system transported through gravity flow process in a marine environment. Sea depth more than 500m (1640ft) could ordinarily be referred to as deep water environment. Concerted effort and processes have been ongoing for over four decades in exploring for reservoirs located in present-day deepwater, and these have resulted into many prolific discoveries. Deepwater exploration in the Gulf of Mexico, Brazil, and west Africa is a target 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.

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, importance of channels and conduits for bypass to the basin floor probably was not fully appreciated until recently. Ever since large volumes of sand were recognized to occur down dip of muddy slopes systems (e.g., Angola and the northern Gulf of Mexico [13]).

It has been discovered that Deepwater marine sandstones are often prolific reservoirs where they occur. They commonly contain

oil fields because of the interfingering of gravity-flows sandstones with source rocks that are marine in nature [14]. The interfingering of the Upper Jurassic submarine fan 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 out 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.

A range of sediment types from very fine particle: 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 geological processes and continental environments that happened in the past and also going on currently. [4].

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]

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 [1, 18].

The Basin was formed during the Precambrian by build-up of sediments over a crustal tract established by rift faulting [17]. 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 [15]. Most active is shale tectonism where gravity-driven fold and thrust belts are widely developed [7]. The Niger Delta Basin is confined by the Benin Axis Line to the north west and the Cretaceous ridges on the Abakaliki high to the north east while the Cameroon Volcanic line marks the eastern offshore extent of the basin [16].

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 overlap syndepositionary growing diapirs and drape them when sedimentation can compensate topographic relief, with channel lobe systems continuing the down-dip flank of the diapir. Major sediment thickness is recorded within inter-diapir depocenters, indicating 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 [11]. 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 a mix of fluvial, tidal, and wave-related deposits and landforms. [2]

3. Location of the Study Area

Only one petroleum system is identified with the Niger Delta Basin [9, 3] 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 depths range from 200 m to 900 m, increasing from the NE toward the SW corner.

The field was discovered with Oyo-1, the first well drilled in the field in 1995 and followed by Oyo-2, -3 & -4 drilled between 2006 and 2007. Oyo-2 and -3 found oil/gas in the Oyo West area, while Oyo-4 appraised the Oyo central discovery. Oyo-5 and -6 were drilled as producers into T1 A reservoir in Oyo Central and Oyo West respectively during 2008 and 2009. Oyo Far East is yet to be tested. Also, the deeper Miocene prospects in OML 120 remain largely untested.

Location of the Study Area

The study is carried out in 'OYO' DW Block, in Deepwater environment of Nigeria.

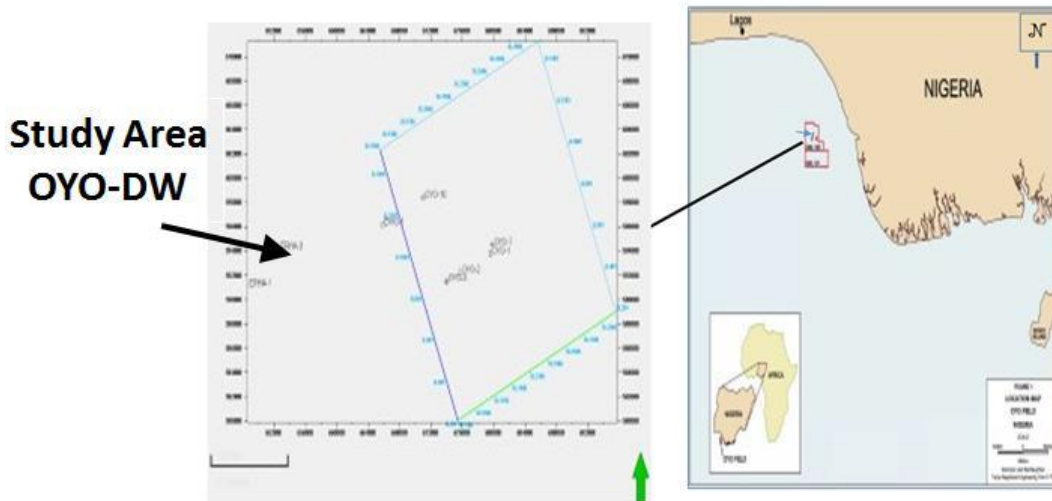


Figure 1. location and base maps of oyo field in niger delta.

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 an always a close to horizontal positive reflections because of positive impedance contrast on the seismic data whenever a fluid contact such Gas/Oil, Gas/Water or Oil/Water is present in 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 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 [5].

5. Statement of Problem

OYO10 was drilled on the field as an exploratory well within the Northwest block of the field on the flood plain 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 mud logging data indicated hydrocarbon levels after drilling, however, formation fluids sampling suggests the reservoirs are wet with traces of liquid hydrocarbon despite high gas readings with good gas chromatograph analysis. This necessitated investigation into possibility of reservoir compartmentalization, sand development and establishment of flood plain drill in of well in contrast to drilling within reservoir channel on the field.

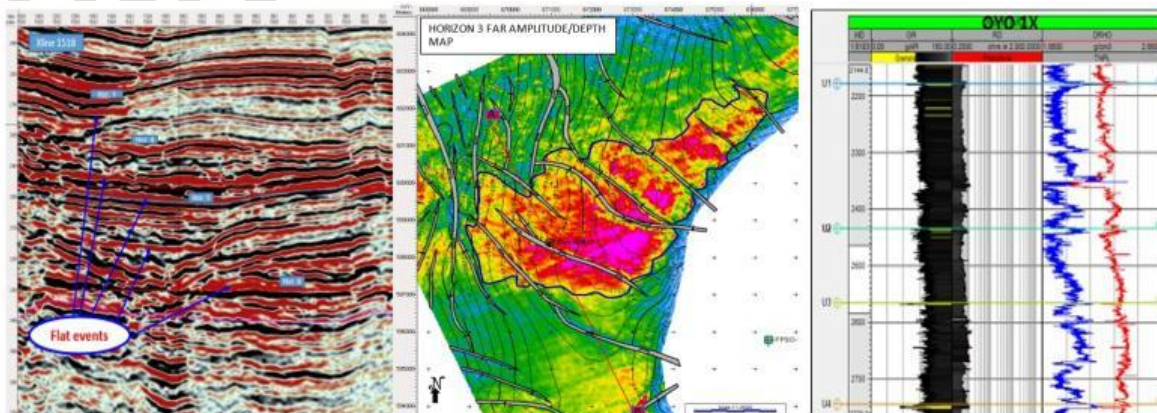


Figure 2. Pre-drill amplitude map extraction and Oyo 10 well log.

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

Despite all the positivity in the predrill studies and indicators of hydrocarbon that were carefully analyzed, the result however did not match the predrill studies. 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 in 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 well

s, deviations surveys, well logs in las file format and biostratigraphy data. Petrel version 2018

7. Results and Discussions

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 represent both 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. [10]

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

CHRONOSTRATIGRAPHIC & LITHOSTRATIGRAPHIC CORRELATION

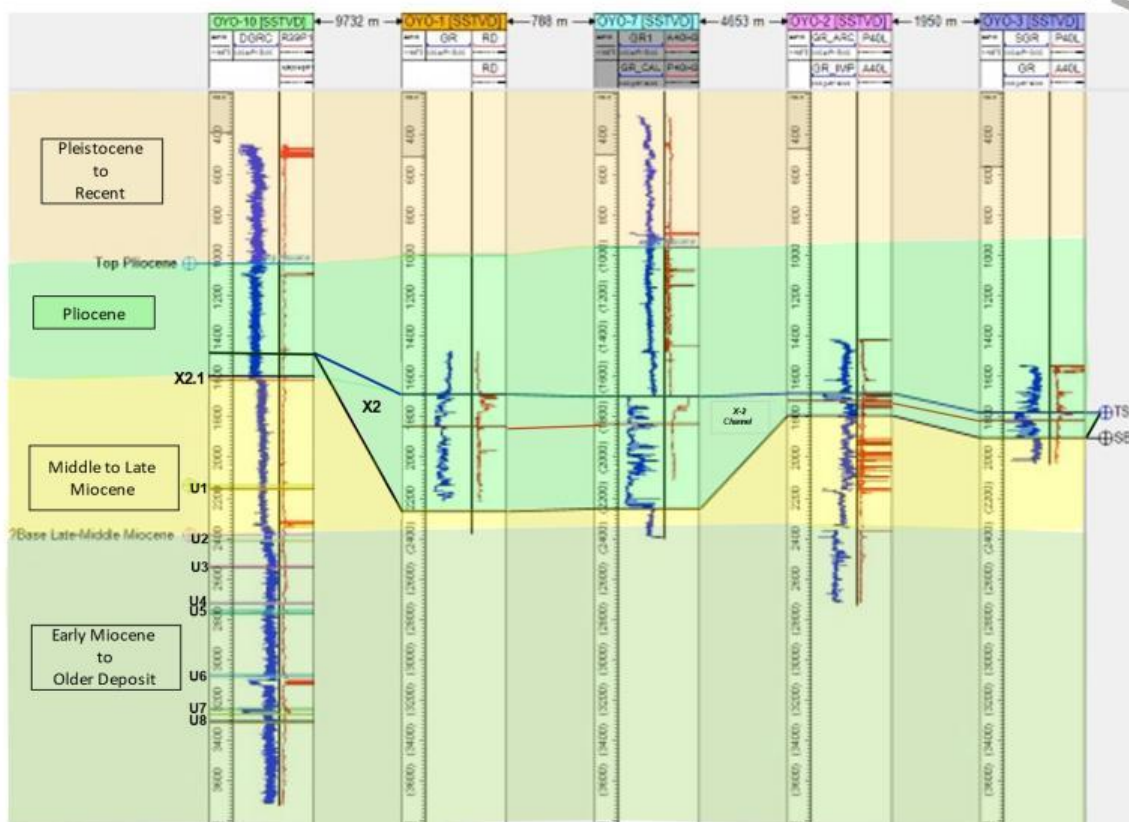


Figure 3. Showing Chronostratigraphic correlation.

FLOODPLAIN AND CHANNEL COMPARTMENTS

WELLS	STRUCTURE	COMPARTMENTS
OYO-10	structure	Floodplain (outside channel axis)
OYO-2 & 3	Stratigraphy	Channel-B
OYO-1 & 7	Stratigraphy	Channel-A

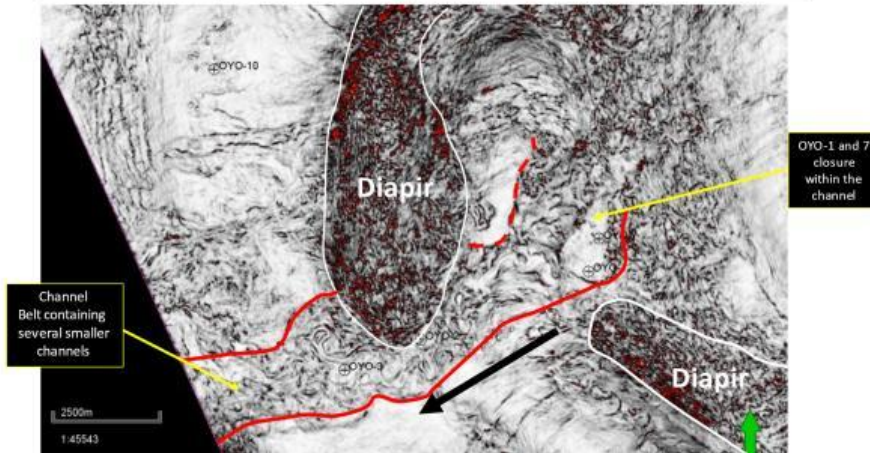


Figure 4. Compartmentalised Channel.

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

J-1 STRUCTURE MAP: OYO-COMPARTMENTS & PROSPECTS

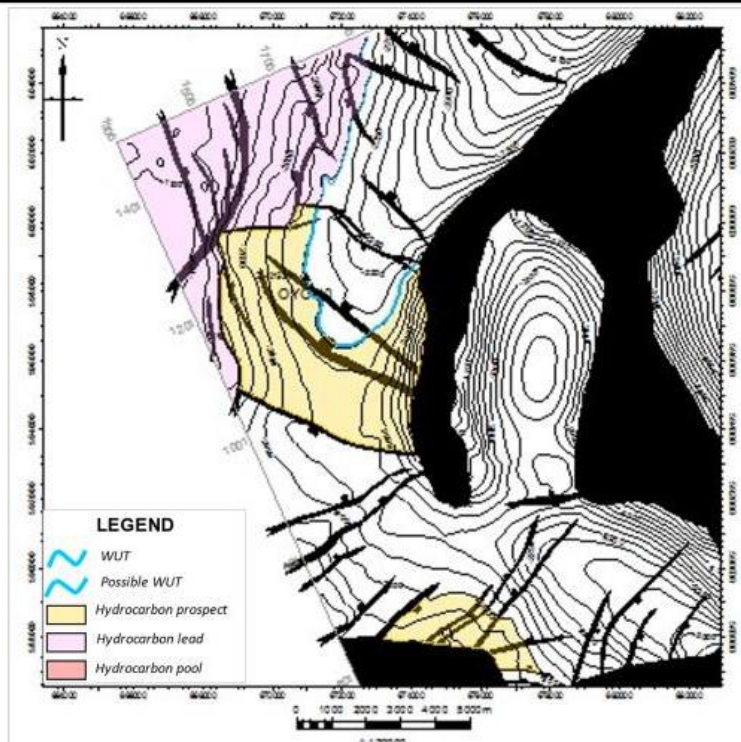


Figure 5. Time Map with Channel Polygon.

Time map was superimposed on the Channel polygon (Figure 5), contours can be seen closing against the shaded diapir whereas something 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 floodplain where OYO 10 is located, same could not be mentioned. The contours along the fault plane are constant depicted that the discontinuities may be

racturesandprobablynotfaultswithremarkabledisplacements.

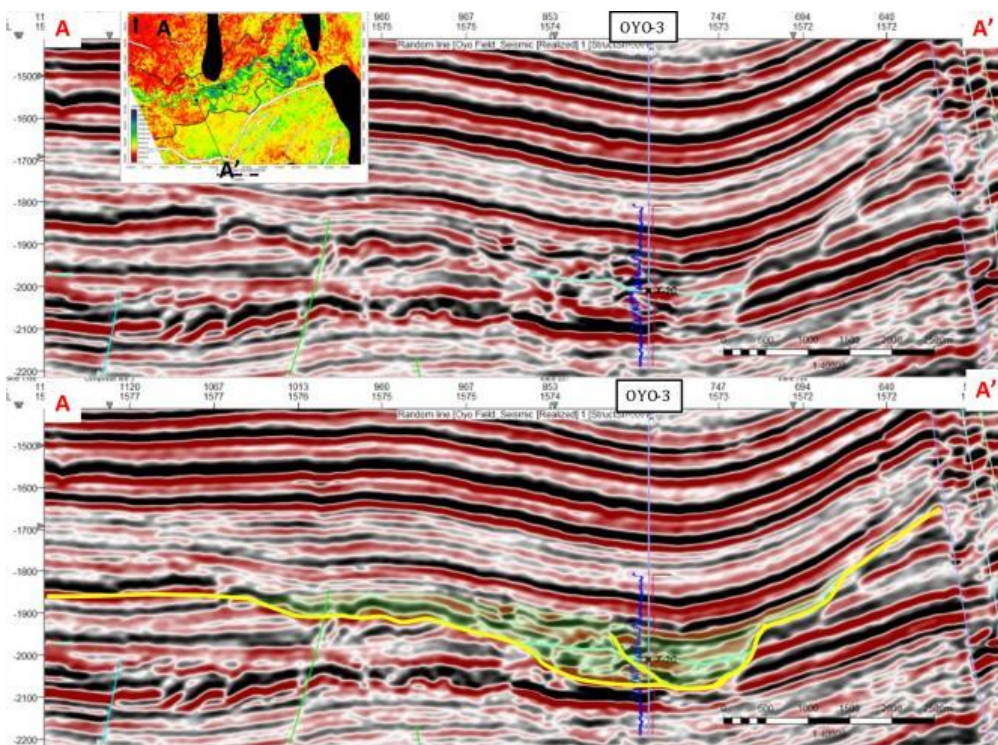


Figure6. Seismiccrosssectionofwell3withinthechannelreservoirsand.

Figure6.showsOYO3welllocatedwithintheChannelX2andw
 ashydrocarbonbearing.OYO1and7whichwerebothproducingat
 asustainable rate were both located within channelsandreservoiri
 ntheTopMioceneage.TheT1AsandandT1Bweredemarcatedwi

thawell-definedfluid contact. That is
 GasOilContact(GOC)andWaterOilContact(WOC)(Fig.7.)Am
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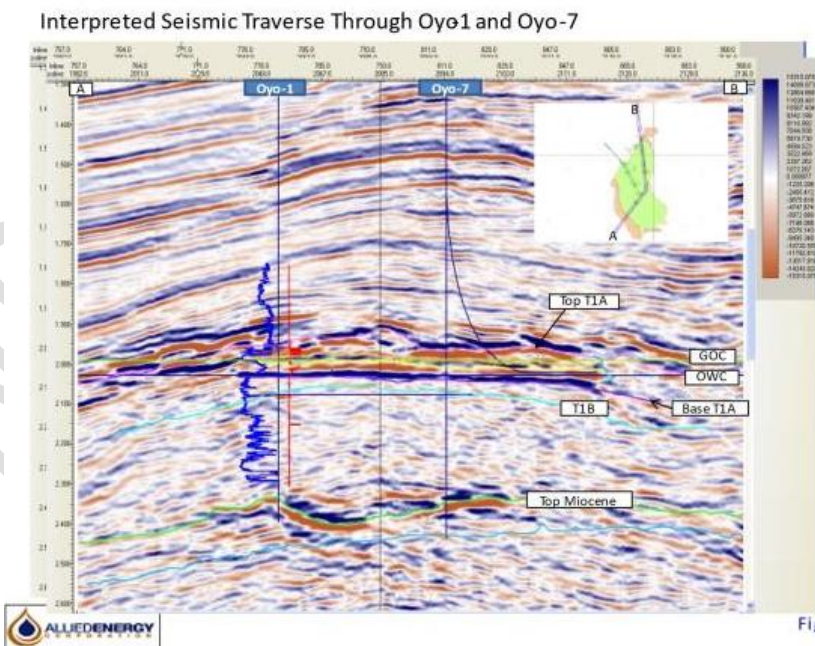


Figure3

Figure7. OYO-1and7locatedwithintheChannelSandCourtesyAlliedEnergy

LITHOSTRATIGRAPHIC CORRELATION (Reservoir – Reservoir)

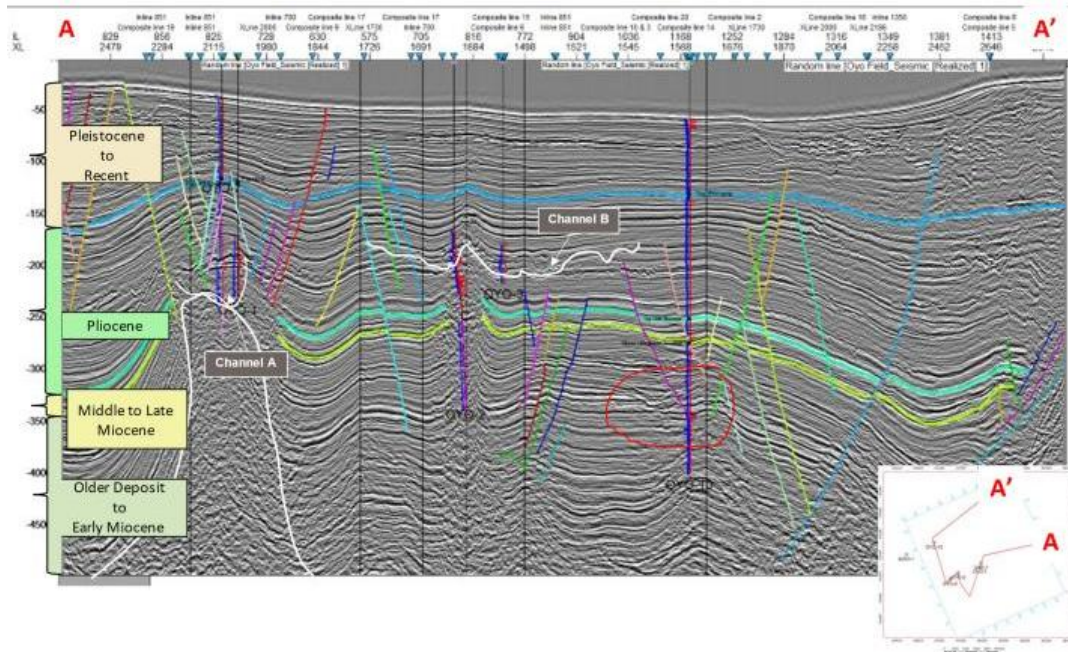


Figure 8. Lithostratigraphic Correlation showing Channelson seismic.

Marine sandstone systems from Deepwater environment may often be tough to characterized 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 none productive where they are isolated during deposition.

The study reveals that the presence both structural and stratigraphic barriers. For the structural traps are recreated by diapiric structure 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 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 rejoin 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 [6]

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 channel and this favors accommodation of hydrocarbon which establishes the fact that the channel sands are better reservoirs within this block.

It looks like OYO 10 well narrowly missed the channel which could have increased the chances of the prospect just like other producing well on other channels (figure 8). The horizon was mapped with an arbitrary line taken SE-NW across the seismic section (Figure 9). It was duly observed that the supposed channel seen on the seismic does not actually exist when variance attributes was run across same

section as seen on. This is because the chaotic signatures that normally characterize channel reservoir was never observed

on the variance attributes, instead, the area is characterized by structural traps resulting from the faults.

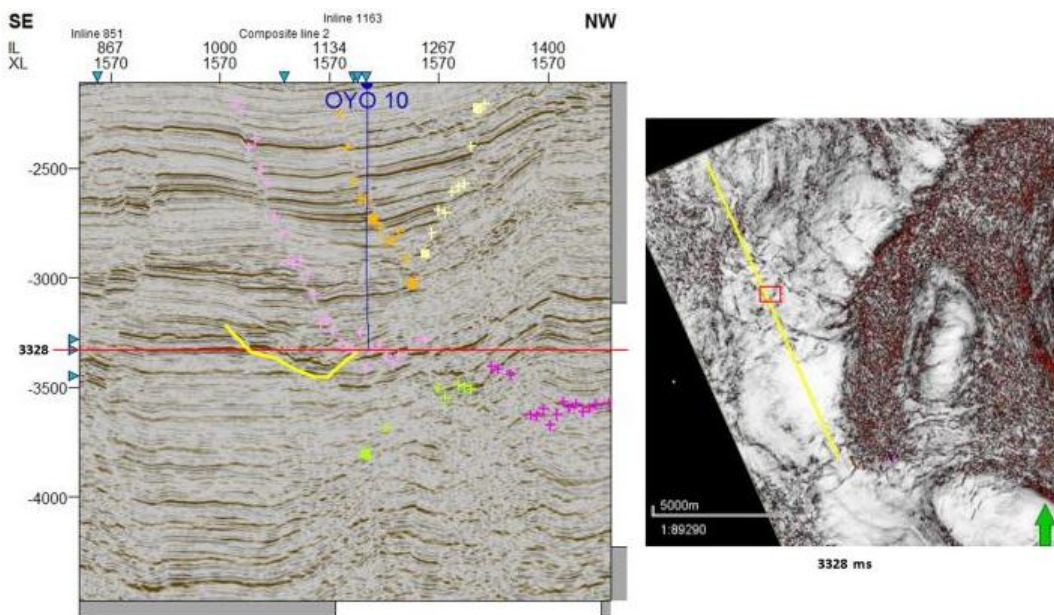


Figure 9. Mapping of horizon through OYO10 Channel.

8. Recommendation

With just one well within the northwest part of the block which falls within the flood plain of the field, it may not be conclusive that hydrocarbon in commercial quantity can only be found in the channel reservoirs and of the field alone and not in the flood plain. Therefore, more studies should be carried out to target the OYO-10 stratigraphy/structure and the channels and to give credence to this claim.

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