Direct Hydrocarbon Indicator Pitfall and Sand Development in Deepwater Environment : A Case Study of ‘Oyo-Dw’ Field Niger Delta, Nigeria

Abstract: The high cost of deepwater developments and the limited reach from offshore platforms requires operators to have a good understanding of the sand development in delineating reservoirs using Direct Hydrocarbon Indicator. The key aim of this study was to undertake a seismic- scale qualitative and quantitative analysis of the sand development of suspected reservoir units within the study area in Deep-water environment of Niger Delta using methodologies that can be applied to other continental margins worldwide. This study involved calibration of seismic-to-well tie, determination of spatial distribution patterns of submarine channels; establishment of hydrocarbon control; identification of various channel reservoir units and trapping mechanism over the prospect area. A well “OYO”-10 was drilled with all reservoir levels predicted using Amplitude as Direct Hydrocarbon Indicator analysis draped on structural maps. The results came out with poor sand development in the well drilled and reservoir sand appeared wet in contrast to the expectation of a prolific well. This study shows the complexity of Deepwater using “OYO” wells as a case study of why sand development needed to be investigated before interpreting Direct hydrocarbon indicators in deepwater environment. A 3D seismic dataset and geological data from OML 121 in Deep-water environment of Niger Delta was analyzed to assess and quantify the architectural elements that influence the compartmentalization of delineated reservoir units. The RMS amplitude extraction was done which reveal that the real amplitude is from the meandering X2 channel turbidities reservoirs while variance attribute identified major and micro channels within the study area.
Is is best to structure the abstract in the format below for a good flow:

Keywords: Niger Delta Deepwater, Seismic Attributes, Seg Y, Well Logs, Well Correlation, RMS Amplitude

1. Introduction

“In deepwater exploration a crucial, and arguably the most critical single issue, is whether oil has been generated, and if it has, what can be determined, before making costly decisions, regarding the quality, maturity, and the age of the source succession” [7]. “Deepwater sedimentation is an important factor in current oil and gas exploration However, the study of its reservoir architecture model has lagged that of fluvial, alluvial, and deltaic deposits”. [12] “During the past decade, global exploration in deepwater setting has significantly increased. Only about 25% of the discovered deepwater resources are developed and less than 5% have been produced. Most exploration activity has been concentrated within only three areas of the globe, with most of the discovered resources in the Gulf of Mexico, Brazil, and West Africa” [9].

The main goal of hydrocarbon exploration is to recognize and define both structural and stratigraphic features that are commonly associated with hydrocarbon generation, deposition, migration, and entrapment [8]. With the choicest deepwater acreage continuing to attract large signature bonuses and with wells in some cases costing more than $US 50 million, a reliable means of exploring in deepwater is required. Whilst trap geometry details and reservoir horizons can be predicted from seismic with increasing degrees of confidence, no fail proof method exists for remotely predicting the composition of reservoir fluids and gases.

“DHIs are anomalous type of seismic amplitude that may occur due to the presence of hydrocarbons. They occur due to change in pore fluids, which cause a change in the bulk rock’s elastic properties. Seismic amplitude attributes may signify reservoir property variations to a certain extent, so seismic amplitude attributes are usually applied to qualitatively evaluate reservoir development” [10]. “Even though the DHI anomalies help interpreters make smarter decisions on prospect evaluation, DHI may also misguide exploration in several ways. It is well known that seismic amplitude anomalies can be caused by factors other commercial hydrocarbons” [6]. Some of such geologic conditions are: Low-saturation gas, clean blocky wet sand, low-velocity shale or marl and low-porosity gas sands can be interpreted as high-porosity oil sand.

DHIs are used in hydrocarbon exploration wells, mainly to reduce the geological risks. [13]

Examples of DHIs are:

“Bright Spots which are referred to as spots with a local increase of amplitude associated with hydrocarbon accumulations, Dim Spots which are caused by highly consolidated sands with much greater acoustic impedance than the overlying shale, Flat Spots that represent a hydrocarbon contact seismic response where it is apparently flat, Phase Change which is also known as polarity reversal and occurs when the overlying reservoir has a lower velocity of the reservoir rock. This can occur when a partially consolidated sand becomes wet and gas chimney that occurs when a defectively sealed hydrocarbon buildup leaks gas from a deeper level into the subsurface, which is usually along a fault plane. Bright Spot Technology is a method used to detect oil and gas accumulated in traps based on real amplitude, which became an important or indispensable means in oil-gas exploration with good results in practical application" [1]. "The use of direct hydrocarbon indicators to predict structural, lithological, or combined traps is also a necessary that can be used to solve exploration problem" [15].

"OYO" 10 was drilled on the field as an exploratory well within the Northwest block of the field, 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.

Seismic Direct Hydrocarbon Indicators (DHI) amplitude anomaly has been used as a tool to discover commercial hydrocarbon accumulation in "OYO" field until these days. The DHI anomalies such as: bright spot, flat spot, polarity reversal, and dim spot are commonly observable in field.

This DHI inadequacy phenomena indicate that there are other aspects need to be addressed when prospecting for hydrocarbon in the field "OYO" field. This study results suggested that DHI features are not necessarily related to economic hydrocarbon accumulation. In 1970, the seismic amplitude for the first time was used as a tool to directly predict the hydrocarbon accumulation. It was found that hydrocarbon traps could be associated with bright-spot amplitude anomalies. These amplitude anomalies, later known as Direct Hydrocarbon Indicators (DHI) were successfully used in hydrocarbon explorations. Nevertheless, some drilled bright spots showed dry holes in numerous cases. [14]

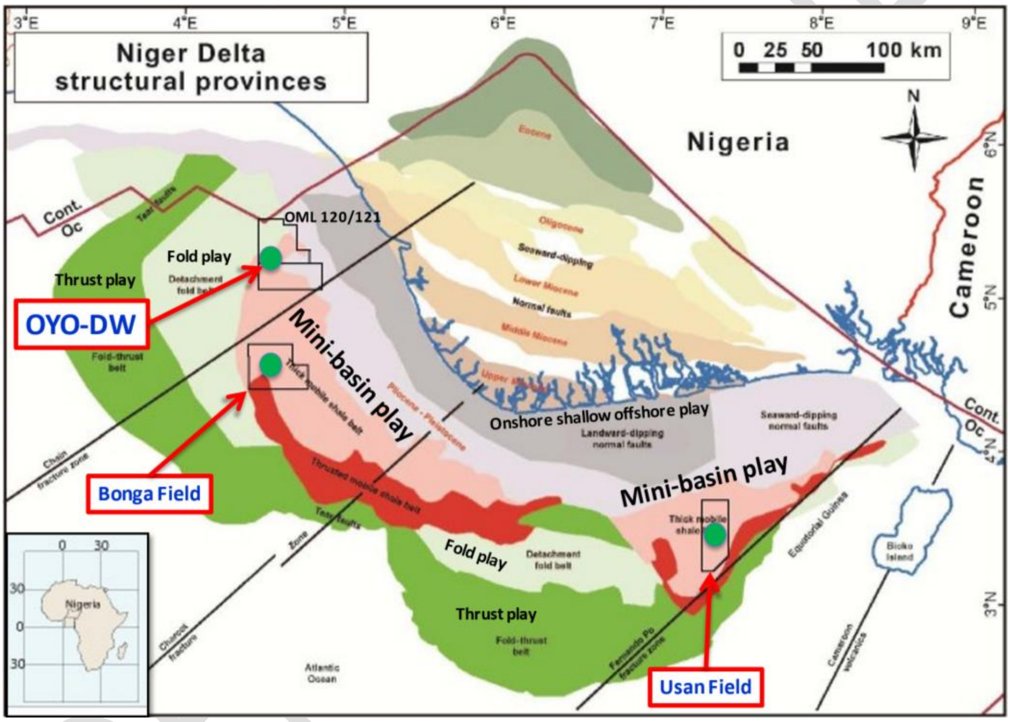


Figure 1. *Deepwater Niger Delta Structural Provinces and Play Type Courtesy Weiner and AI 2010.*

Regional Setting / Geological Context:

The Niger Delta of Nigeria is located on the central West African coast within the Gulf of Guinea and is bounded to the west by Benin and to the east by Cameroon. The islands of São Tomé & Príncipe lie to the south. The Niger Delta deep offshore area may arbitrarily be subdivided into western and eastern components by a line running along the main distributaries of the Niger River and extending it in a south-western direction into the Atlantic basin. The Niger Delta Basin is ranked as one of the most prolific deltaic systems in the world with respect to hydrocarbon accumulations or reserves [5]

The Niger Delta deep offshore basin can be divided into several hydrocarbons play segments of differing habitat styles. The study area is situated in the western part of the offshore Niger Delta, within the boundary of collapsed crest and shale diapir play segments. Diapirs and normal faults are the result of gravity tectonic processes driven by sediment loading occurring during progradation of the huge Niger Delta sedimentary succession onto marine mobile and under-compacted shales during late Cretaceous – Paleogene (mobile shales).

The intermediate diapirs and faulting zone are contained within the inner extensional province on the continental shelf, characterised by both basinward dipping, regional and counter-regional growth faults, and the external domain at the lower slope; a detachment fold zone passing basinward to a fold and thrust belt.

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.

2. Location of the Study Area

The Oyo Field is located offshore Niger Delta in OML 120 approximately 75 km from the Nigerian coast at an average water depth of about 350 m. The Oil Mining License (OML) 120 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 km^2. Water depth ranges from 200 m to 900 m, increasing from the NE towards 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 T1A 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. This OML is within the Niger Delta depositional system, the deepwater play types drilled were quite different than anything known on the Nigerian shelf on onshore.

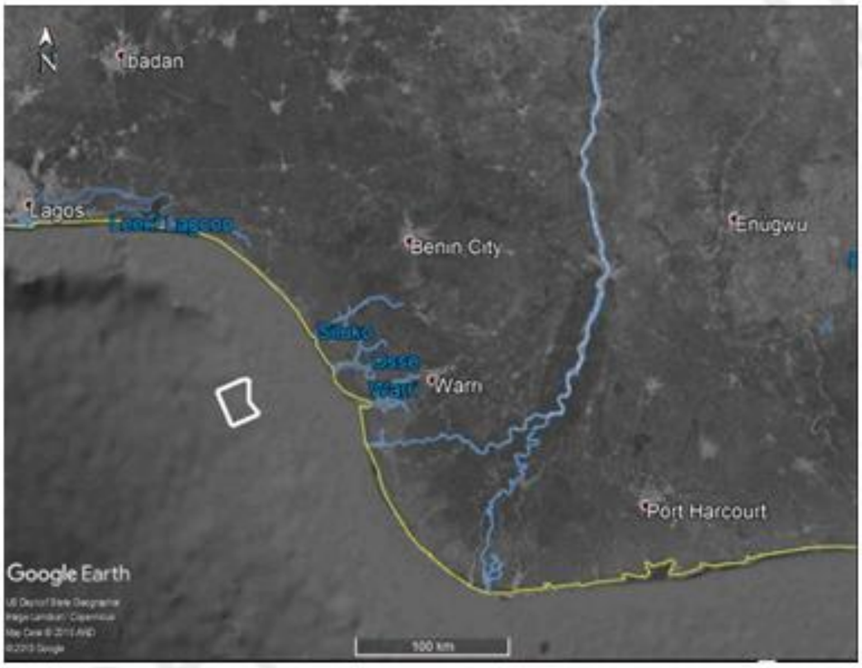


Figure 2. *Map of Niger Delta Showing the study area.*

3. Materials and Methods

Available Data included, 3D Seismic data, Checkshot for the wells, deviation surveys, well logs in las file format and biostratigraphy data. Petrel interpretation software was used for this work to plot ??? (please elaborate here on which data was used in the plotting).

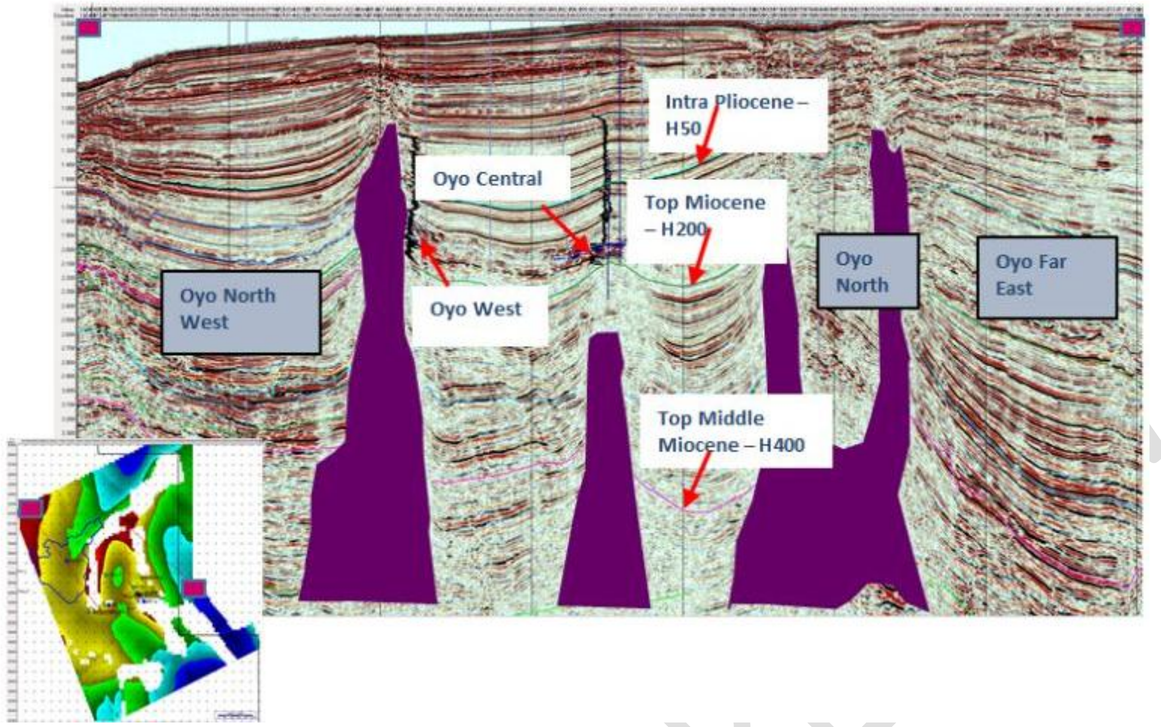


Figure 3. *Arbitrary Line showing Oyo NW, Oyo field & prospects with Shale Diapir Intrusions.*

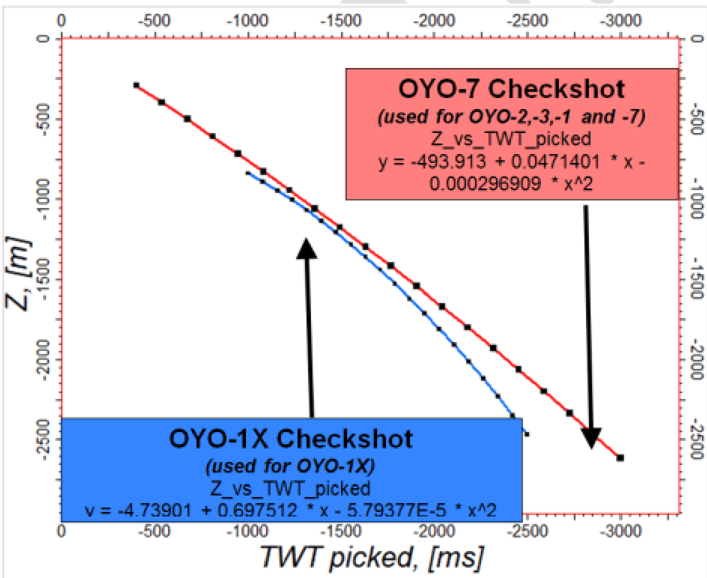


Figure 4. *Plot of Checkshot versus Depth plot OYO 7 and 1X.*

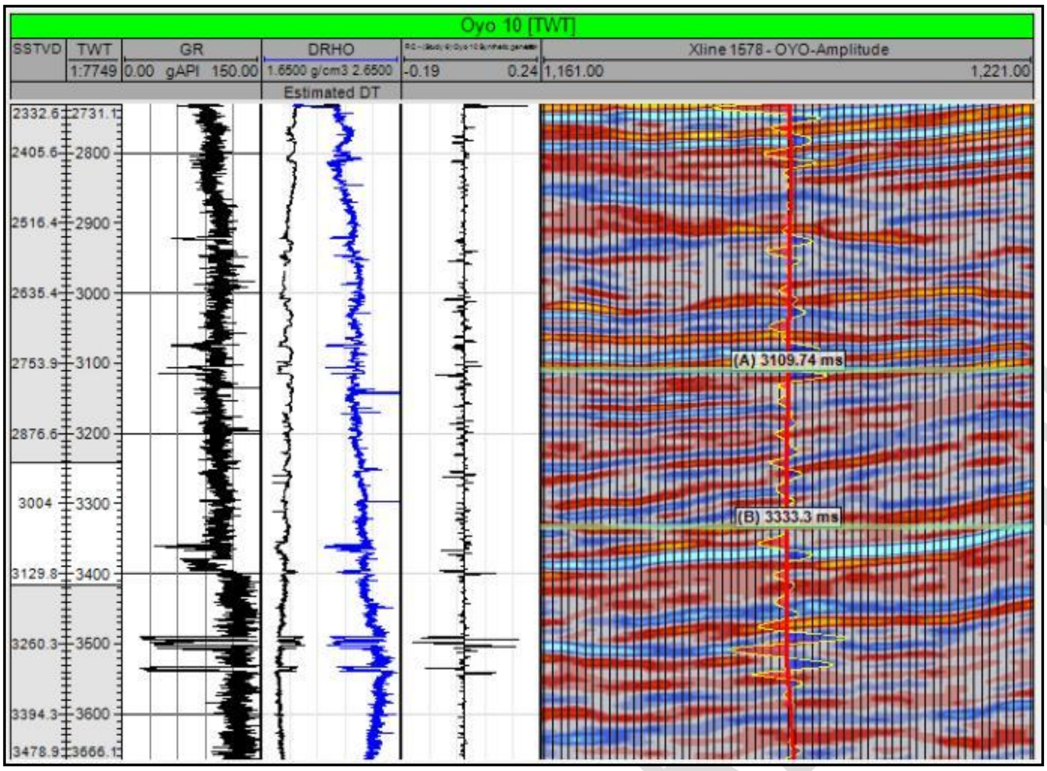


Figure 5. *Synthetic Seismogram Generation.*

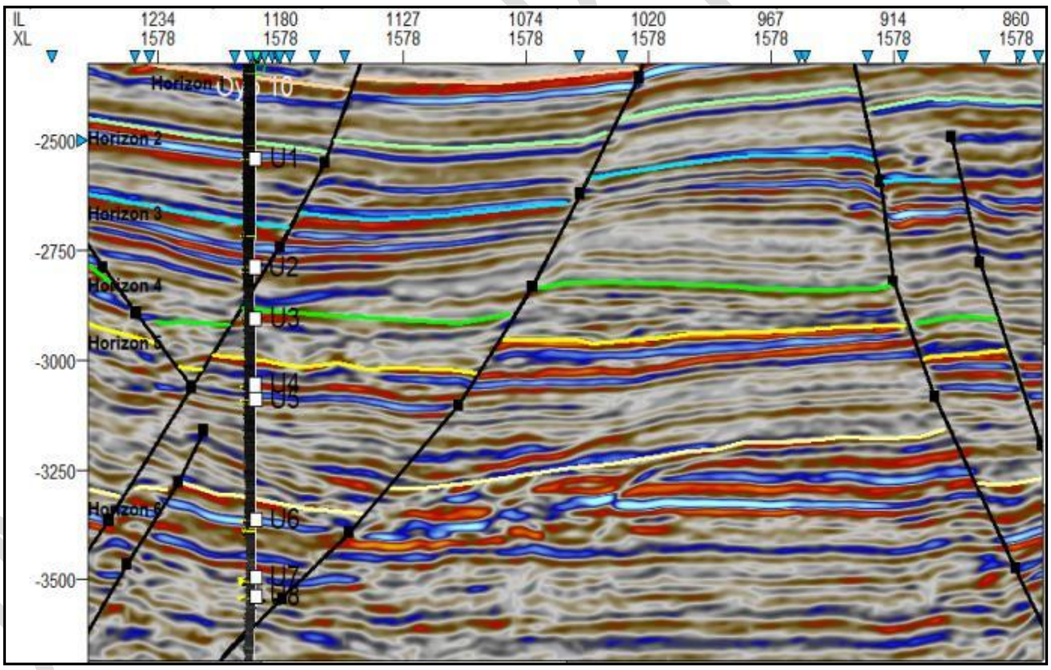


Figure 6. *Well tops to seismic match.*

The objective of understanding well to seismic tie is to correlate the geological information in the well log data with the seismic information. The well to seismic tie focused on the targeted interval and synthetic seismogram used as the correlation tool to tie geological information to accurate depth [11]

Checkshot surveys are used to correct the velocities obtained by the integration of the sonic interval transit times. The adjusted sonic was then used for translation of surface seismic time to depth and in the calculation of formation acoustic impedance necessary for the generation of a synthetic seismogram and eventually seismic to well tie was done. The checkshot generally follow the same trend indicating that there are no significant lateral variations in seismic velocities across the field even if depth of acquisition in Well 10 was shallower than that of the offset well 7.

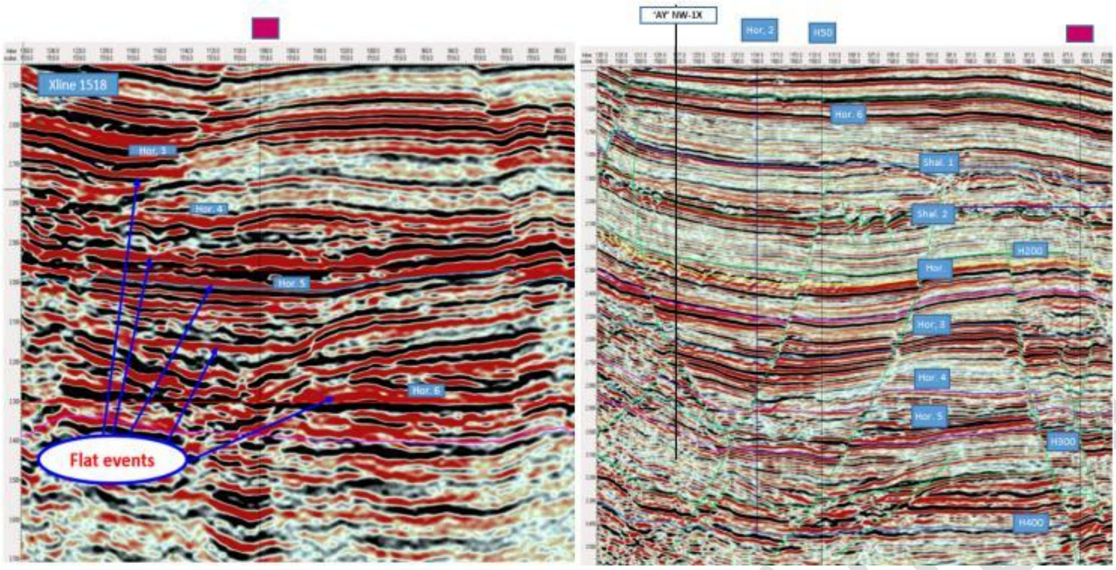


Figure 7. *Seismic section with flat events (DHI) observed at all levels.*

Although most reflections mark unconformities and / or time surfaces, fluid contacts within porous permeable rocks provide acoustic impedance contrast that cut across the bedding. These are responsible for flat spots, one of the most important hydrocarbon accumulation indicators. Acoustic impedance contrasts can be caused by chemical or phase changes. Flat spots were visible on the seismic section (Figure 7) however, the result after drilling proved that the flat spots could be due to some reasons order than hydrocarbon accumulation.

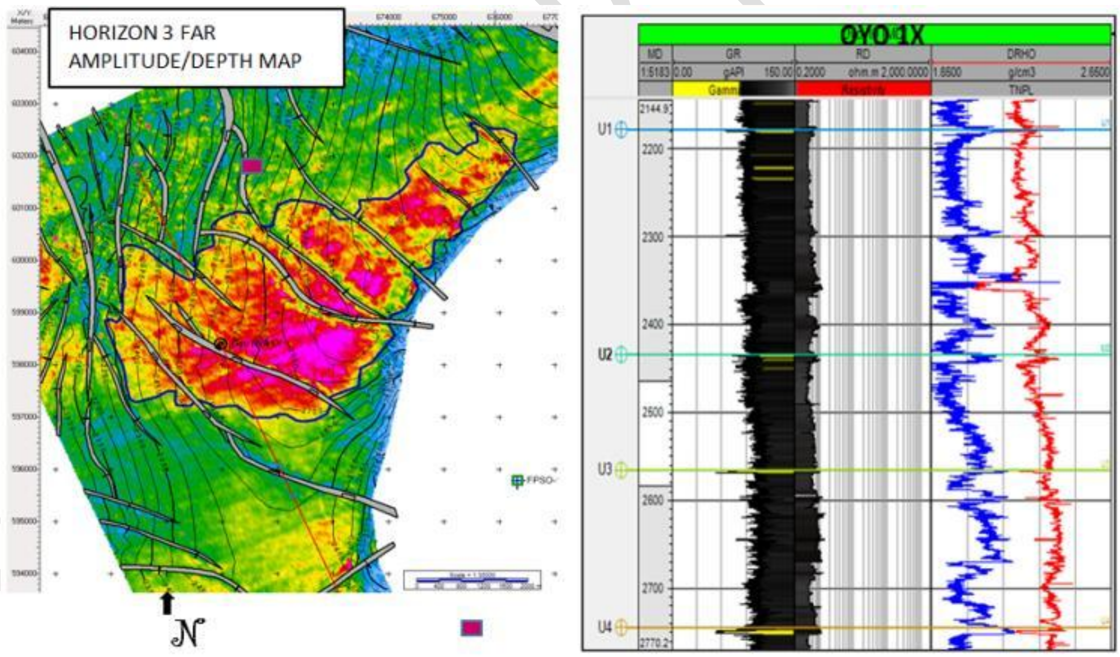


Figure 8. *Interpreted horizon 3 amplitude extraction with the resultant well log with poor sand development.*

Hydrocarbon accumulations are sometimes revealed directly on true-amplitude seismic sections by localized zones of anomalous strong reflections known as bright spots. These high amplitude reflections events are attributable to the large reflection at the top and bottom of gas zones within hydrocarbon reservoir. In contrast as shown in figure the sand development came out poor after drilling despite high amplitude observed on the horizons.

4. Results and Discussions

Two major reservoir units were observed in the study area; the central part named as X2-Channel compartment which is the central portion of the field and the NorthWest block. The X2 Channel compartment is characterized by meadering channel which turbidites reservoirs. All oil and gas producer wells were observed to be located in this which serve as offset wells: Well 1,2,3, and 7 are located within the X2-

Channel reservoirs where as Well 1X was located on the floodplain at the Northwest part of the block. (Figure 9)

CHRONOSTRATIGRAPHIC CORRELATION

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

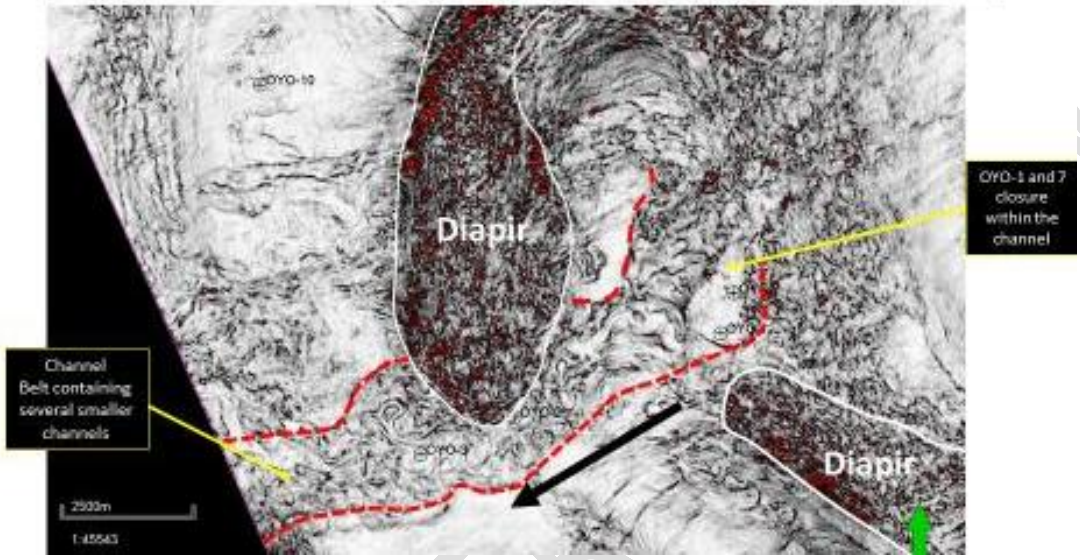


Figure 9. *X2 Channel showing producing wells within the channels OYO 10 located on the Flood plain.*

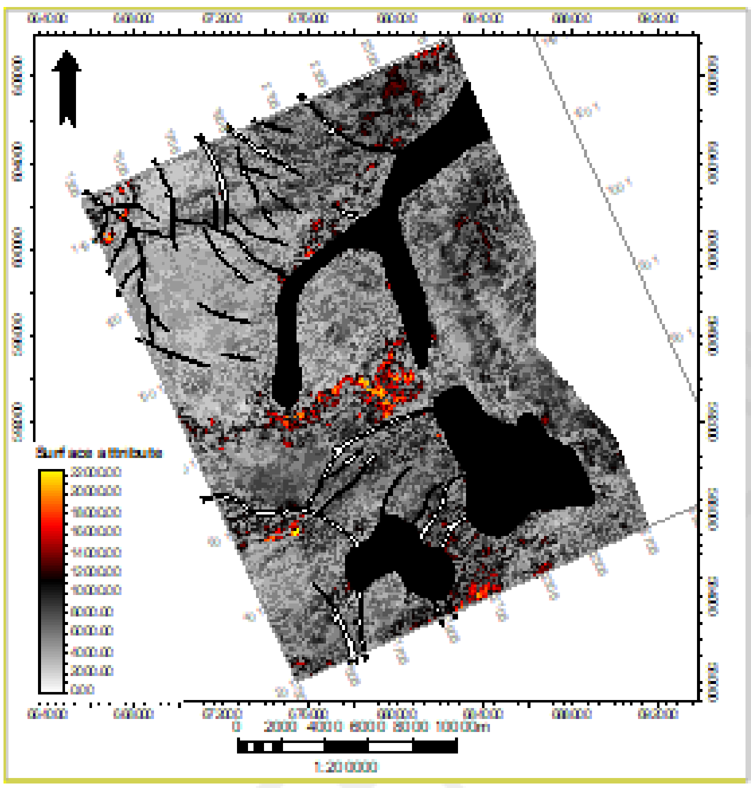


Figure 10. *Diapir and faulting zone as traping mechanism.*

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. 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.

Diapirs and normal faults are the results of gravity tectonic processes driven by sediment loading occurring during progradation of the huge Niger Delta sedimentary succession onto marine mobile and under-compacted shales during late Cretaceous – Paleogene (mobile shales).

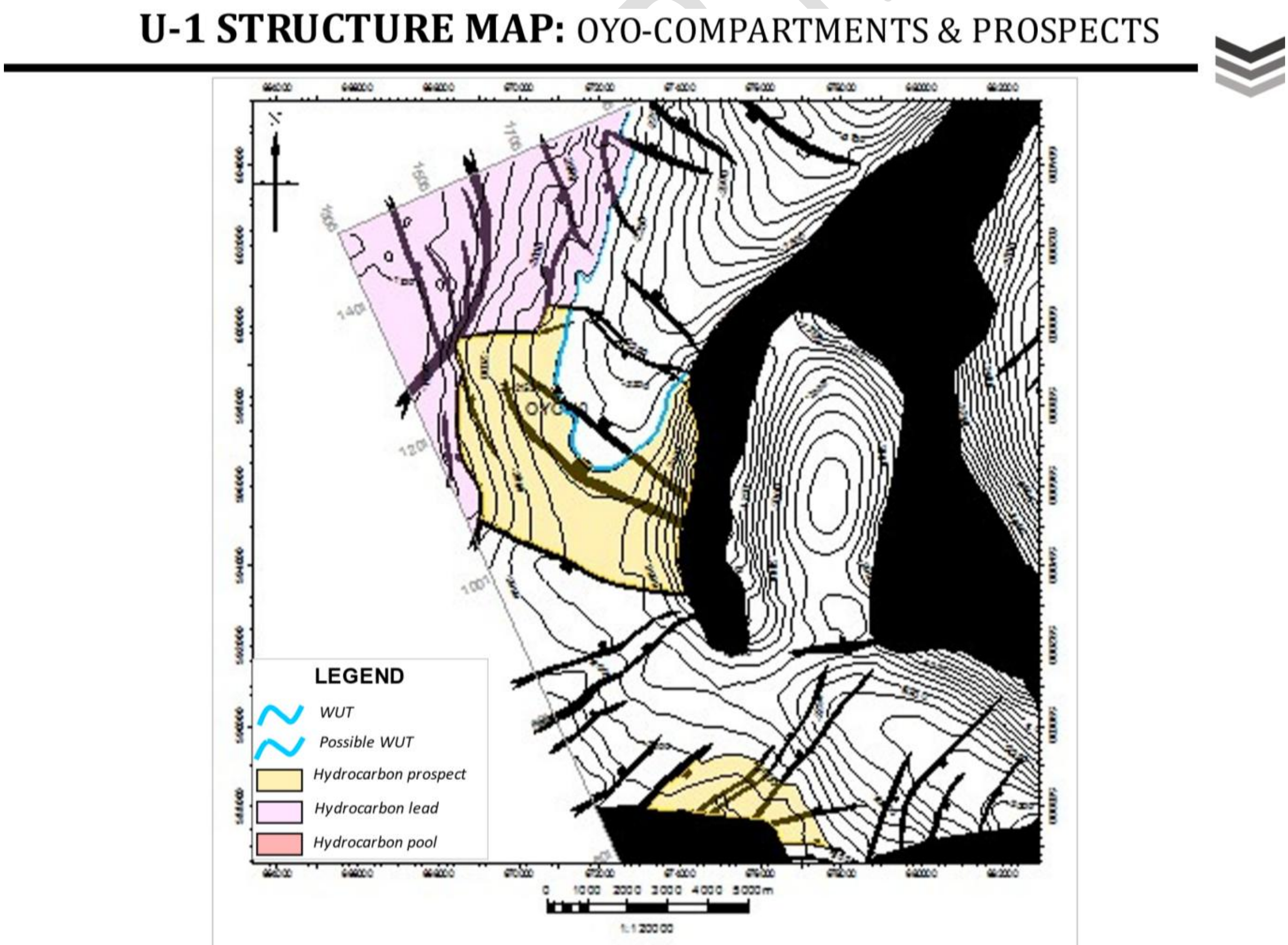
The intermediate diapirs and faulting zone are contained within the inner extensional province on the continental shelf, characterised by both basinward dipping, regional and counter-regional growth faults, and the external domain at the lower slope; a detachment fold zone passing basinward to a fold and thrust belt.

5. Traps

Trap evaluation is fundamental in the analysis of a prospect and an important part in any successful oil and gas exploration or resource assessment program. A trap can be defined as any geometric arrangement of rock, regardless of origin, that permits significant accumulation of oil and gas, or both in the subsurface. [4]

It was well observed that the major trapping formation of the X2 Channel reservoirs where all the Oil producers were located is mainly due to diapir uplift in combination with stratigraphic components. (Figure 11) Turbidite deposits onlap synsedimentary growing diapirs and drape them when sedimentation can compensate topographic relief, with channel lobe systems continuing the downdip flank of the diapir. While on the floodplain, the faulting pattern formed the structural pattern. It was also observed that there all closures are against the shale diapirs where the closures in the floodplain where well 10 was located is against the fault's sfractures.

Displacements are not really observed on the faults forming traps which suggest that they might be fractures and not deep-seated faults.



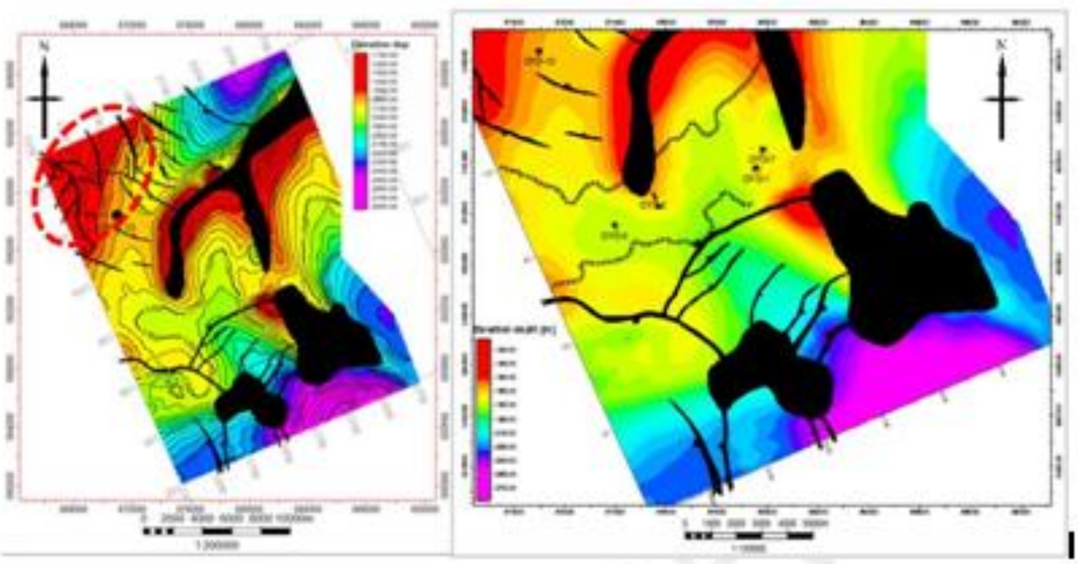


Figure 11. *X2 Channel Trap Mechanism.*

6. Amplitude Analysis

Seismic attribute analysis is significant in interpretation for oil and gas exploration and exploitation for both stratigraphic and structural interpretation [3]. These attributes are derived from seismic data to better understand the physical properties of sedimentary strata [2]

RMS amplitude extracted that covers X2 channel reservoir units which encountered wells 1,2,3 and 7 as well as the location of well 10 was done using -60/+60 ms and -30/+30ms. The amplitude extraction was done to cover the entire reservoirs in the study area. The result of this shows better sand development within the X2 Channel reservoir which is conspicuously absent on well location area (Figure 12). In general, better sand development is observed within the X2 channel which is turbidite reservoirs and progressively reduced towards the southern part of the study but not very visible in the NorthWest area where Well 10 was located.

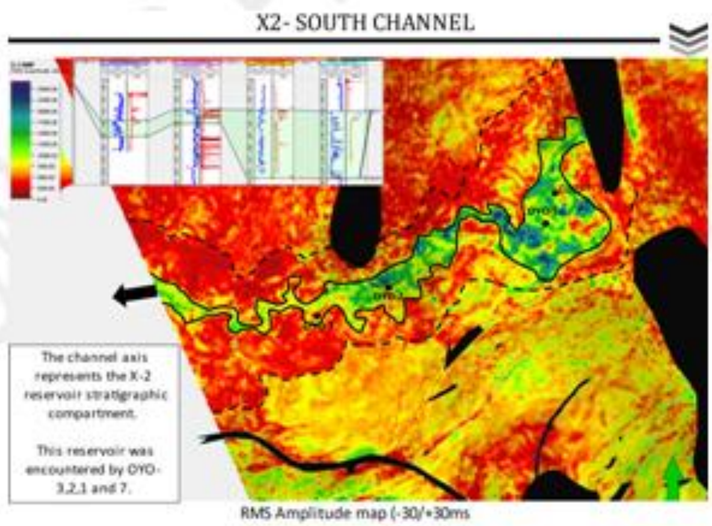


Figure 12. *RMS Amplitude map showing X2 sand development (-30/+30ms).*

7. Conclusions

The study shows that are both structural and stratigraphic traps with the study area. The major oil producers in the study area (X2 channel) are mainly turbidite reservoirs with good sand development.

It was observed from RMS amplitude extraction that this sand reveals the true amplitude which is because of the hydrocarbon content of the reservoirs. The initial amplitude anomaly observed on well 10 could have been caused by factors other than commercial hydrocarbons like low-velocity shale since the sand development in the area is poor according to Mike Forrest.

8. Recommendations

More studies should be carried out to establish if there are other hydrocarbon bearing sands other than the turbidite channel reservoir in the area.

In deep water environment, sand development studies should be carried out first before amplitude extraction analysis to ensure that the amplitude observed correspond to the reservoir sand. The geology of the area vis-à-vis environment of deposition should be well studied to aid the interpretation for hydrocarbon accumulation.

Even though the DHI anomalies help interpreters make smarter decisions on prospect evaluation, DHI may also misguide exploration in several ways as observed in this study therefore, it is very important to have a systematic and consistent work process to interpret and risk seismic amplitude anomalies and there should be multiple positive anomaly characteristics to have a high probability of geologic success.

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