

# Structural, Environmental deposition and well logs studies of OML XY block, Offshore, Niger Delta, Nigeria

## Abstract

The concept of sequence stratigraphy in explaining sediment accumulation and preservation trends within basin fills has become a highly successful exploration tool in the search for hydrocarbon resources. The sequence stratigraphy of OML XY block, Niger delta study approach involved the integration of lithostratigraphy, seismic stratigraphy, and biostratigraphy to help unravel the depositional environment and petroleum play concept within the block. The block covers an area of about 400sqkm in shallow water between 2m - 45m. Thirteen (13) fields have been discovered to date, they include: - Akam, Kita Marine, Inagha, North Oron, Oron West, Oron East, Adanga, Ebughu, Bogi, Ukpam, Mimbo, Antan, and Ebne fields. It is also necessary to note that about seventy (70) wells have been drilled to date. This paper aims to understand the depositional environment and structural trend within the asset using 3D seismic data, analysis of wireline logs, and biostratigraphy analysis and how they aid in hydrocarbon accumulation, influence reservoir quality, and best describe the regional play concept within the block. Three predominantly prograding depositional sequences bounded by sequence boundaries were delineated. Biostratigraphy report indicates that sediment ages within the OML XY block range from Early Pliocene to Late Miocene. Depositional systems identified include prograding shoreline or delta and backstepping shoreline. The environment of deposition identified within the block range from upper to lower shoreface. Sedimentary deposits within the block include; marine shales, delta front sand, upper shoreface sands, lower shoreface sands, mouth bar sands, barrier bar sediments, and beach ridges sediments.

Keywords: Prograding depositional sequence, Backstepping shoreline; shoreface deposit; Beach sands sediments; Barrier bar sediment, hydrocarbon plays, structural trend.

## 1. Introduction

The Niger Delta is one of the most prolific hydrocarbon-producing regions in the world, with significant reserves of oil and gas. However, the geology of the region is complex, characterized by a series of depositional cycles that have produced a heterogeneous and compartmentalized reservoir architecture. Sequence stratigraphy has emerged as a powerful tool for understanding the depositional history of the Niger Delta and predicting the distribution of hydrocarbon-bearing reservoirs. The subdivision of a basin's sedimentary deposits into time stratigraphically constrained depositional packages is imperative in unravelling its development and inherent hydrocarbon potentials [10]. The lithostratigraphic subdivision of the Niger Delta sediments cut across timelines and their lateral associations suggest that the sedimentary deposits were strongly influenced by a change in sea level and tectonics. Our

analysis is based on the integration of high-quality 3D seismic data, well logs, and Biostratigraphy data. We use a combination of seismic interpretation, chronostratigraphic, and sedimentology to identify depositional sequences and systems tracts that are bounded by unconformities and characterized by distinct facies associations. Recent studies have highlighted the importance of sequence stratigraphy for understanding the depositional history of the Niger Delta. For example, Ola-Buraimo [8] used sequence stratigraphy to predict the distribution of reservoir sands in the Niger Delta and found that the depositional cycles are related to changes in sea level and sediment supply. Similarly, Alimi [3] applied sequence stratigraphy to characterize the depositional environment of the offshore Niger Delta and identified several depositional systems that control the distribution of hydrocarbon-bearing reservoirs. Okosun [9] used sequence stratigraphy to unravel the stratigraphic architecture of the shallow marine deposits of the Niger Delta and identified the depositional systems that control the distribution of hydrocarbon reservoirs. Sequence stratigraphy thus facilitates the subdivision of the Niger Delta basin into packages of sediments that are essentially bounded together by Chronostratigraphically significant surfaces. Our study builds on these recent advances in sequence stratigraphy and provides a comprehensive analysis of the OML XY block in the offshore Niger Delta. Our results have significant implications for hydrocarbon exploration and production in the region and can aid in the optimization of drilling locations and production strategies. The direction of this research is to define the structural trend and delineate Para sequence sets and sequences within the asset to better understand the depositional trend for reservoir characterization and prospect analysis. In summary, this study provides a comprehensive sequence stratigraphic analysis of the OML XY block by elucidating the depositional environment, structural trend, para sequences, and sequences within the asset through the use of 3D seismic data, wireline log analysis, and biostratigraphy analysis, and demonstrating how these factors contribute to hydrocarbon accumulation, affect reservoir quality, and provide the best description of the regional play concept within the block.

## **2. Geological Setting and Tectonic Evolution of Niger Delta**

### **2.1 Geological setting**

The Niger Delta Basin is located in Nigeria (Fig 1.) and is one of the most prolific hydrocarbon basins in the world [7]. The basin is composed of sedimentary rocks that were deposited over a period of approximately 70 million years [12]. The geological setting of the Niger Delta Basin is characterized by a thick sequence of sedimentary rocks that were deposited in a variety of environments, including marine, deltaic, and estuarine settings [7]. The basin is underlain by basement rocks of Precambrian age and is bounded to the north and east by highland areas of crystalline rocks [7]. The sedimentary rocks of the Niger Delta Basin were deposited in a series of cycles that were driven by changes in sea level, tectonic activity, and climate [12]. These cycles resulted in the deposition of alternating layers of sandstone, shale, and mudstone that are collectively referred to as the Niger Delta Formation [7]. The sedimentary rocks of the Niger Delta Basin contain significant amounts of organic matter that have been converted to hydrocarbons over millions of years [7]. This has resulted in the formation of extensive oil and gas reserves that are economically important to Nigeria and the world as a whole. The tectonic evolution and structural style of the Niger Delta Basin are the result of a complex interplay between geological and tectonic processes that have occurred over millions of years. The tectonic evolution of the Niger Delta Basin can be broadly divided into three major stages: rifting, passive margin development, and compression [13]. During the

Late Jurassic to Early Cretaceous, the basin experienced rifting due to the breakup of the supercontinent Gondwana (Fig.2) [6]. This rifting led to the formation of grabens and horsts, which were subsequently filled with sedimentary rocks. The passive margin stage began in the mid-Cretaceous and continued until the Palaeocene [12]. During this time, the basin was characterized by a stable margin with a low rate of subsidence, which allowed for the accumulation of thick sequences of sedimentary rocks. The compression stage began in the Late Eocene to Early Oligocene, and it was associated with **the collision of the African and Eurasian plates [6]. This compression led to the inversion of some** of the earlier faults and the formation of new thrust faults. The structural style of the Niger Delta Basin is dominated by growth faulting, which is the result of differential subsidence between the basement and sedimentary layers [12]. These faults act as traps for hydrocarbons and are the main targets for exploration and production in the basin.

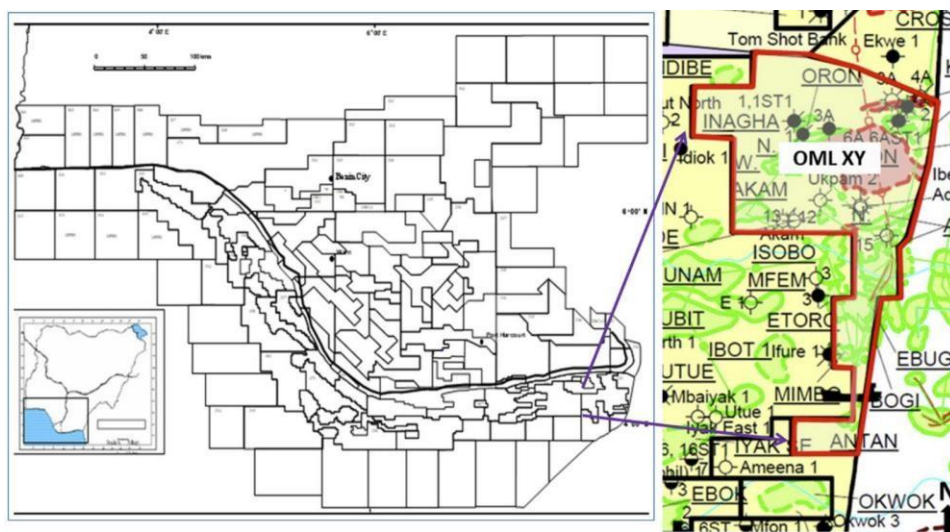


Figure 1: Location Map of OML XY.

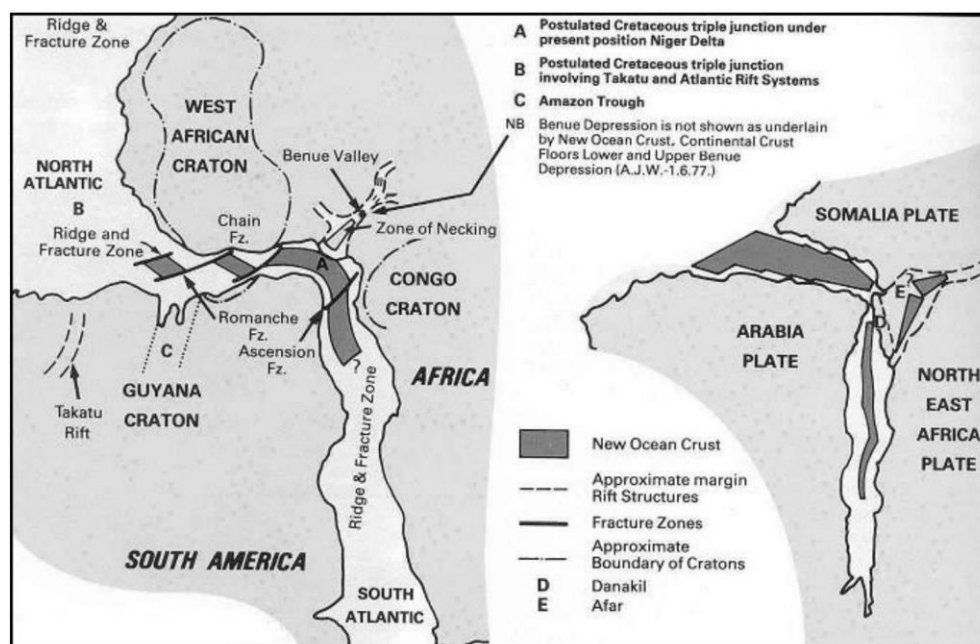


Figure 2: Shows the Cretaceous to Recent Palaeogeographic evolution of the Nigerian rift and Continental margin deltas.

## 2.2 Stratigraphy

The tectono-stratigraphy of the Niger Delta Basin can be divided into four main units: the Akata Formation, the Agbada Formation, the Benin Formation, and the Older Coastal Plain Sands (Fig.3). The Akata Formation is the oldest unit of the Niger Delta Basin, dating back to the Late Cretaceous period. It consists of shale and mudstone deposits that were formed in a deep water marine environment. The Akata Formation is known for its high organic content, which has led to the formation of extensive hydrocarbon reserves. Recent studies have focused on the sedimentological and geochemical characteristics of the Akata Formation, revealing its potential for unconventional gas exploration [13]. The Agbada Formation is the most extensive unit of the Niger Delta Basin, consisting of interbedded sandstones, siltstones, and shales. It was deposited during the Palaeocene to Eocene periods in a deltaic environment, and is characterized by its high reservoir potential. Recent studies have focused on the stratigraphy and sedimentology of the Agbada Formation, as well as its reservoir quality and heterogeneity [1]. The Benin Formation is a relatively thin unit of the Niger Delta Basin, consisting of sandstones and shales that were deposited during the Oligocene to Miocene periods. It was formed in a deltaic environment and is known for its shallow marine deposits. Recent studies have focused on the depositional environment and sedimentary architecture of the Benin Formation, as well as its reservoir properties [2]. The Older Coastal Plain Sands are the youngest unit of the Niger Delta Basin, dating back to the Late Miocene to Pleistocene periods. It consists of well-sorted, medium to coarse-grained sands that were deposited in a fluvial to shallow marine environment. Recent studies have focused on the sedimentary architecture, depositional environment, and provenance of the Older Coastal Plain Sands, as well as their potential for hydrocarbon exploration [4].

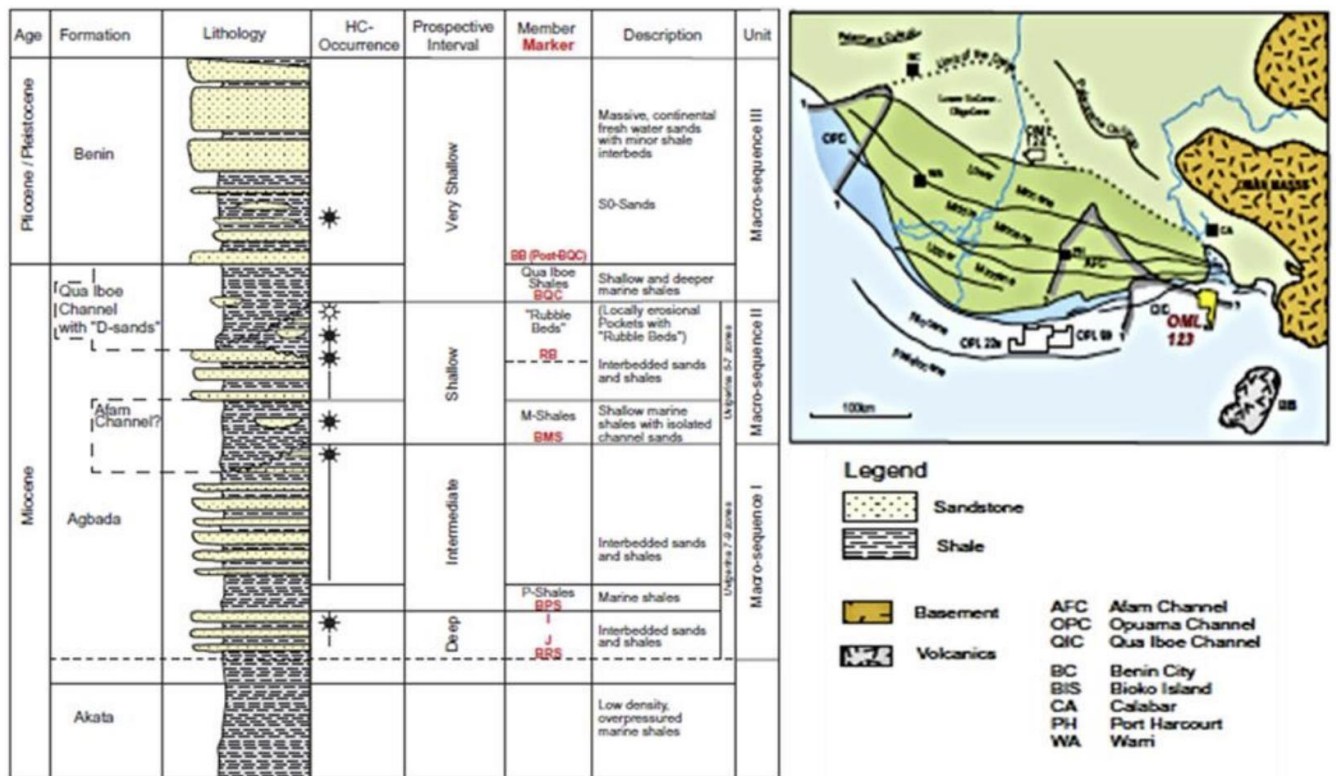


Figure 3: The Stratigraphy column of the Niger Delta showing Three Formations.

## 2.3 Depo Belts

The Niger Delta Basin is characterized by a series of depo-belts that represent different phases of sedimentary deposition and hydrocarbon accumulation. Akata-Agbada Depo-Belt is the most significant and extensive in the Niger Delta Basin. It comprises a thick sequence of sedimentary rocks, including sandstones, shales, and coals, deposited in a deltaic environment during the Oligocene to Early Miocene. The Akata-Agbada depo-belt is the main hydrocarbon reservoir in the Niger Delta Basin and has been the focus of extensive exploration and production activities [6]. The Benin Flank depo-belt is a narrow belt of sedimentary rocks that runs along the western margin of the Niger Delta Basin. It was formed during the Late Cretaceous to Early Paleogene, and consists of sandstones, shales, and limestone deposited in a shallow marine environment [5]. The Anambra Basin depo-belt is a relatively small and isolated depo-belt located in the south-eastern part of the Niger Delta Basin. It comprises a sequence of sedimentary rocks, including sandstones, shales, and coal, deposited in a fluvial to deltaic environment during the Cretaceous to Paleogene [1]. The Abakaliki depo-belt is located in the north-eastern part of the Niger Delta Basin and consists of a sequence of sandstones, shales, and coals deposited during the Late Cretaceous to Early Paleogene in a fluvial to deltaic environment [8]. The Calabar Flank depo-belt is a narrow belt of sedimentary rocks located along the south-eastern margin of the Niger Delta Basin. It comprises a sequence of sandstones, shales, and limestone deposited during the Late Cretaceous to Paleogene in a shallow marine environment [10].

## 3. Methods

### 3.1 Data availability and Quality checking

The data available for the study are: (i) Fairly good 3D Seismic data (SEGY) that covers an approximate area of about 400sqkm. (ii) Well log Data (Composite logs, deviation data and Checkshot data) (iii) Biostratigraphy data (iv) Well report (table 1). The data set were analysed using Schlumberger Petrel software package. The 3D Seismic data quality is fairly good but a poor data zone exists in the northern part of the concession (Fig 4).

### 3.2 Well Log Interpretation

Lithologies were identified with the aid of gamma ray logs and Biostratigraphic reports. A range of 0 to 150 API was used for the Gamma Ray log. Gamma Ray values with deviation to the left of the shale baseline were delineated as sand units while shale was delineated with deviation to the right.

### 3.3 Biostratigraphy

The sequence stratigraphy tops were delineated from foraminiferal contents comprised of benthic and planktonic forams. The stratigraphic tops were integrated with the log motifs of the Gamma-ray (Fig 5) to reconstruct the possible depositional environments, develop a lithofacies model for each well, and delineate Sequence Stratigraphic Surfaces such as Sequence Boundary, Flooding surfaces, and Maximum Flooding Surfaces.

Available Data set for OML-XY Regional Studies					
			Available	Complete?	Comment
Reports	Well report & Biostratigraphic report and Previous studies report	Well report	Inagha-3A, Adanga-16, ADS-7H, ADNG-2A, ADN-11st1, Bogi-5H, Ebughu 13P & 13H, North Oron-2 & 2st, Oron East-1 & 1st, Oron West-1A	No	Well reports not available for wells with biostrat data
		Biostratigraphic report	Inagha-3A & 4A, Akam-1, Ebughu-1	No	Biostrat reports for wells from only 3 fields out of 13
		Previous Studies report	OPL 90/225 Prospectivity Evaluation, OML XY prospectivity review 2004 & enclosures	No	
		Sedimentological report		No	
		Geochemical report		No	
		Seismic processing report		No	
		Pressure study report	Niger Delta pressure study Phase2	yes	
Well	Well information, Wireline logs, Deviation, Location etc	Wireline logs and MWD/LWD	NOR-2, ORE-1, ADN-11st1, ADS-7H, Ebughu-13H, Bogi-5H	No	Wireline logs for wells from 6 fields out of 13. Not available for wells with biostrat reports. Most logs incomplete
		Well header (X&Y, KB, TD)		No	
		Deviation survey	Oron West-1A, ADS-2A, Ebughu-13P, Bogi-5P, NOR-2, ORE-1, ADN-11st1, Ebughu-13H, Bogi-5H	No	Deviation survey received for wells from 7 fields out of 13. Not given for wells with biostrat report
		Checkshot		No	
Seismic	Seismic survey data	3D seismic volume	400sqkm 3D seismic	yes	Quality is fairly good
		2D seismic lines		No	

Table 1: Data availability for OML-XY regional studies

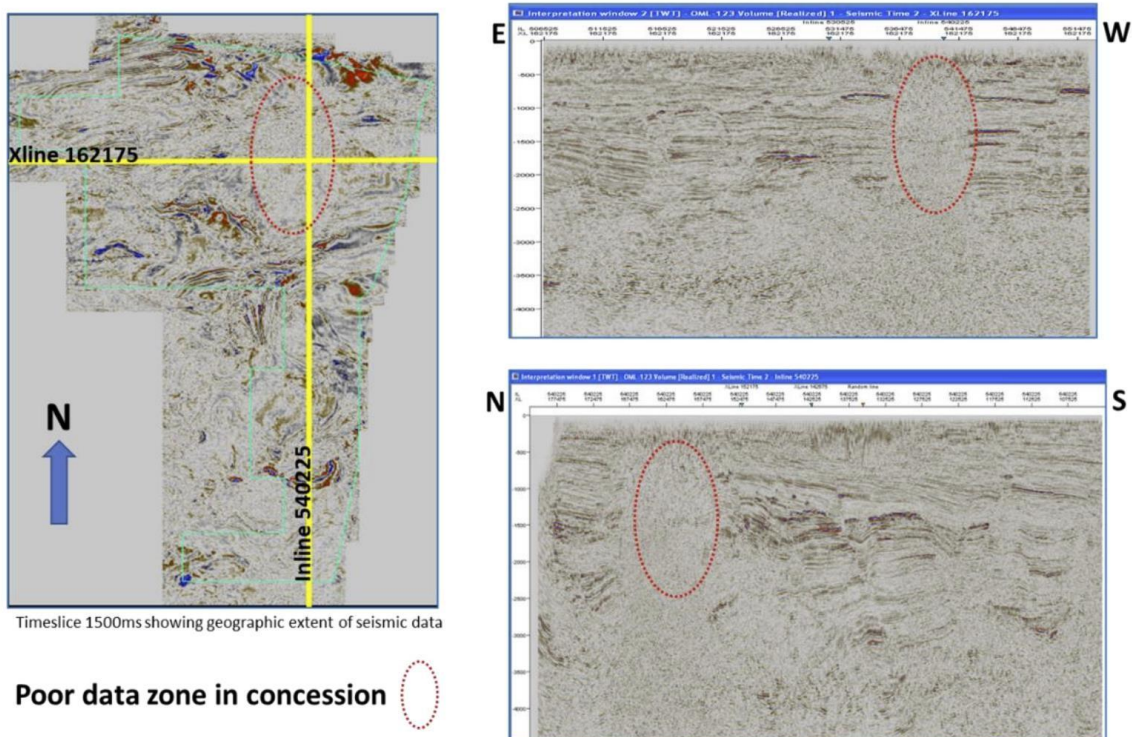


Figure 4: Seismic data coverage area and data quality.

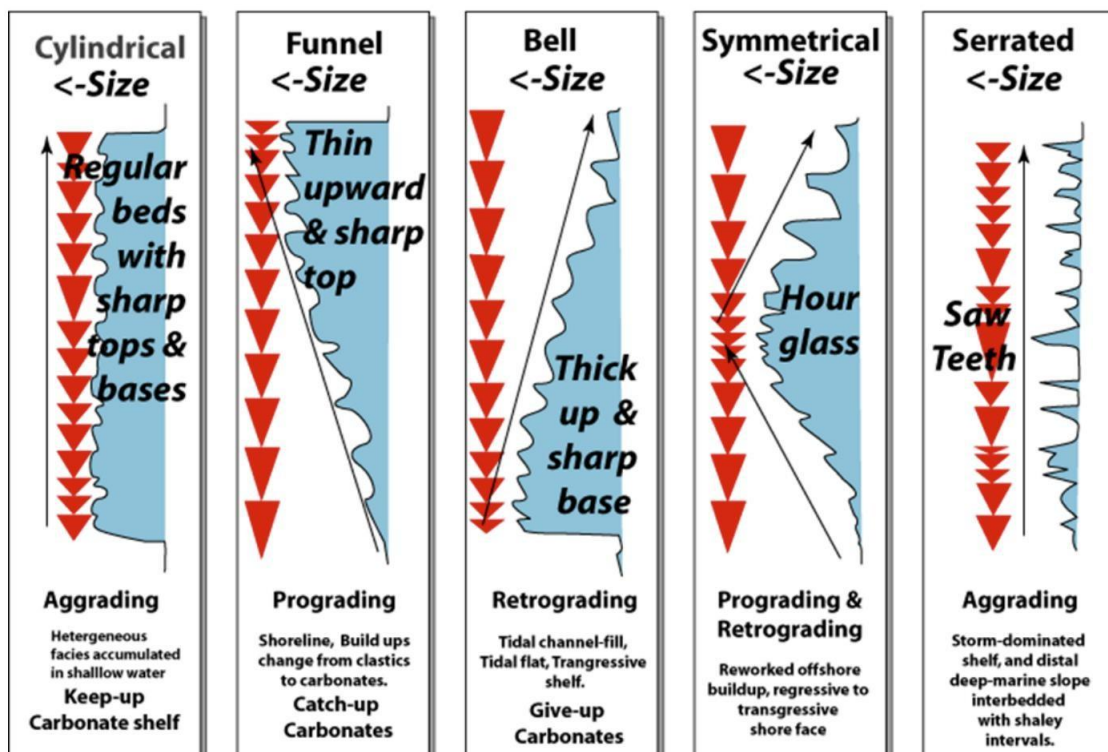


Figure 5: Lithologic logs and corresponding stratigraphic interpretation.

### 3.6 Seismic to Well Tie

The time-depth information obtained from check-shot data was used in the conversion of the well tops from the log data, from depth to time, and post the equivalent horizon on the line at the proper times on the seismic data which is in two-way time.

### 3.8 Mapping of Faults and Horizons

Identification of horizons is based on reflection continuity. This implies that most recognizable and continuous event will be easily traced throughout the seismic section. Mapping of horizons on the seismic section have to do with the proper understanding of the seismic attributes such as amplitude, coherency etc. Major faults were identified and mapped along the dip lines. The faults were picked on the inline first before being traced across the crosslines. Scroll increments of 8 and 16 lines was employed on both in-lines and cross-lines, care was taken in determining the consistency of the fault traces, as faults tend to die out and can be mistaken for another in a complexly faulted field. Faults were identified based on the following criteria; Abrupt termination of reflection events; Breaks in reflection events; Abrupt lateral velocity changes; Overlapping of reflection events; Pattern change of reflection events across a fault; Structural deformation in beds above the zone of faulting and Anomalous dip near the fault zone.

### 3.9 Seismic Stratigraphy Interpretation

Sequence stratigraphy was first carried out on the well logs to interpret depositional systems and then further interpreted the system tracts and depositional surfaces (sequence boundaries and maximum flooding surfaces). The interpreted sequence boundaries were then tied to the seismic section and interpreted across the seismic data.

## **4. Results and Discussion**

### **4.1 Well Correlation**

The well correlation was done using the Gamma Ray log and Biostratigraphic markers identified in the reports provided. The major surfaces delineated are the shale marker beds which were correlated across the whole block. Figures below shows the correlation by fields in the block in the strike and dip direction. (Fig 6 to Fig 8). The wells with Biostratigraphic information are summarized below:

#### **Inagha 3A**

- Depth interval 3660 – 4170ft
- Age – Early Pliocene
- Environment of deposition - outer shelf origin being predominantly associated with Outer Neritic biofacies. Inagha-4A
- Depth interval 1500 – 6880ft
- Age – Late Miocene to Early Pliocene
- Environment of deposition - coastal / shelf facies associated with Coastal Deltaic to Outer Neritic biofacies.
- 1 Maximum Flooding Surface condensed section recognized.

#### **Akam-1**

- Depth Interval 2640-7270ft
- Age - Late Miocene to Early Pliocene
- 3 Maximum Flooding Surface condensed sections recognized
- Environment of deposition - regressive succession of coastal/shelfal facies associated mainly with Inner Neritic with occasional Coastal Deltaic biofacies over the upper horizons

#### **Ebughu-1**

- Depth interval 3430-8430ft
- Age - Late Miocene to Early Pliocene
- Environment of deposition – Coastal deltaic/estuarine

#### **Oron North-1**

- Depth interval 2010-8830ft
- Age - Late Miocene to Early Pliocene
- Environment of deposition – Outer neritic to lower deltaic plain

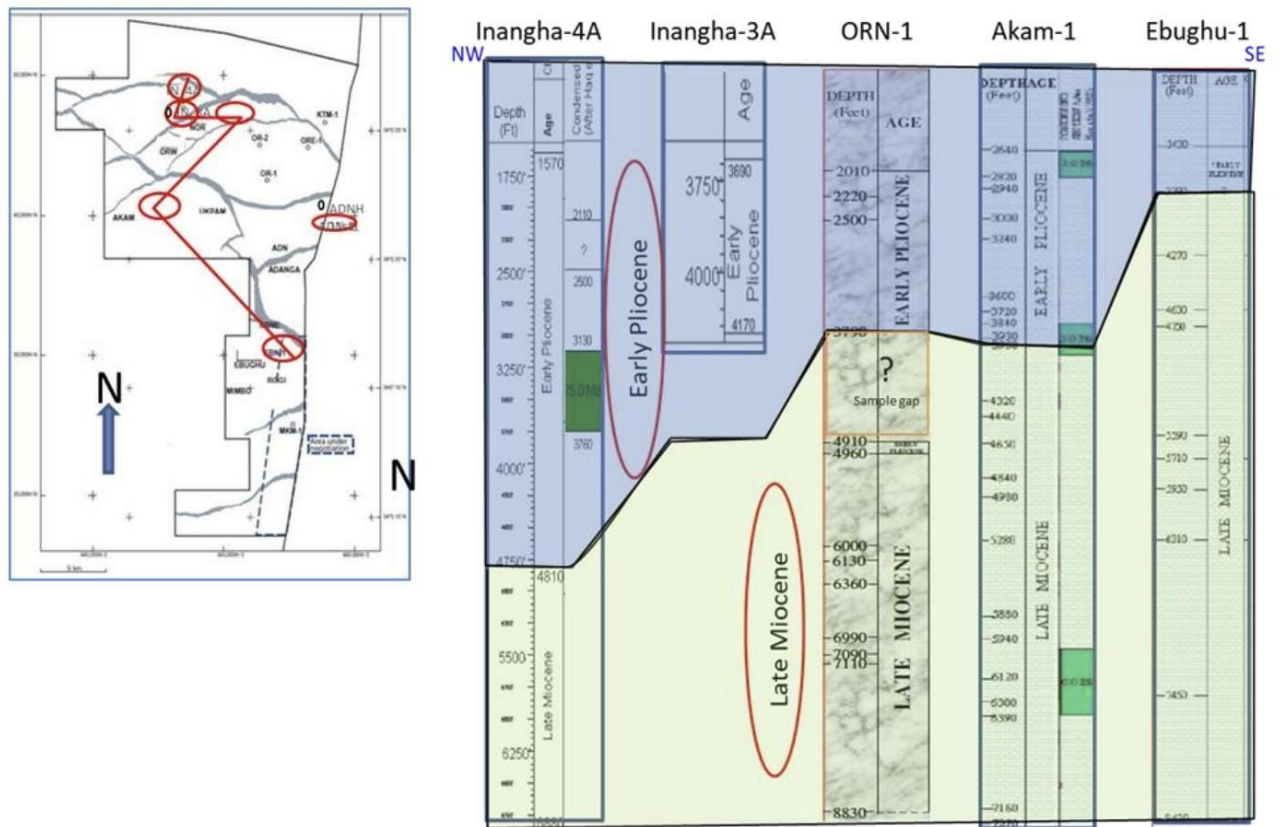


Figure 6: Biostratigraphy Correlation of the wells across the OML XY Field.

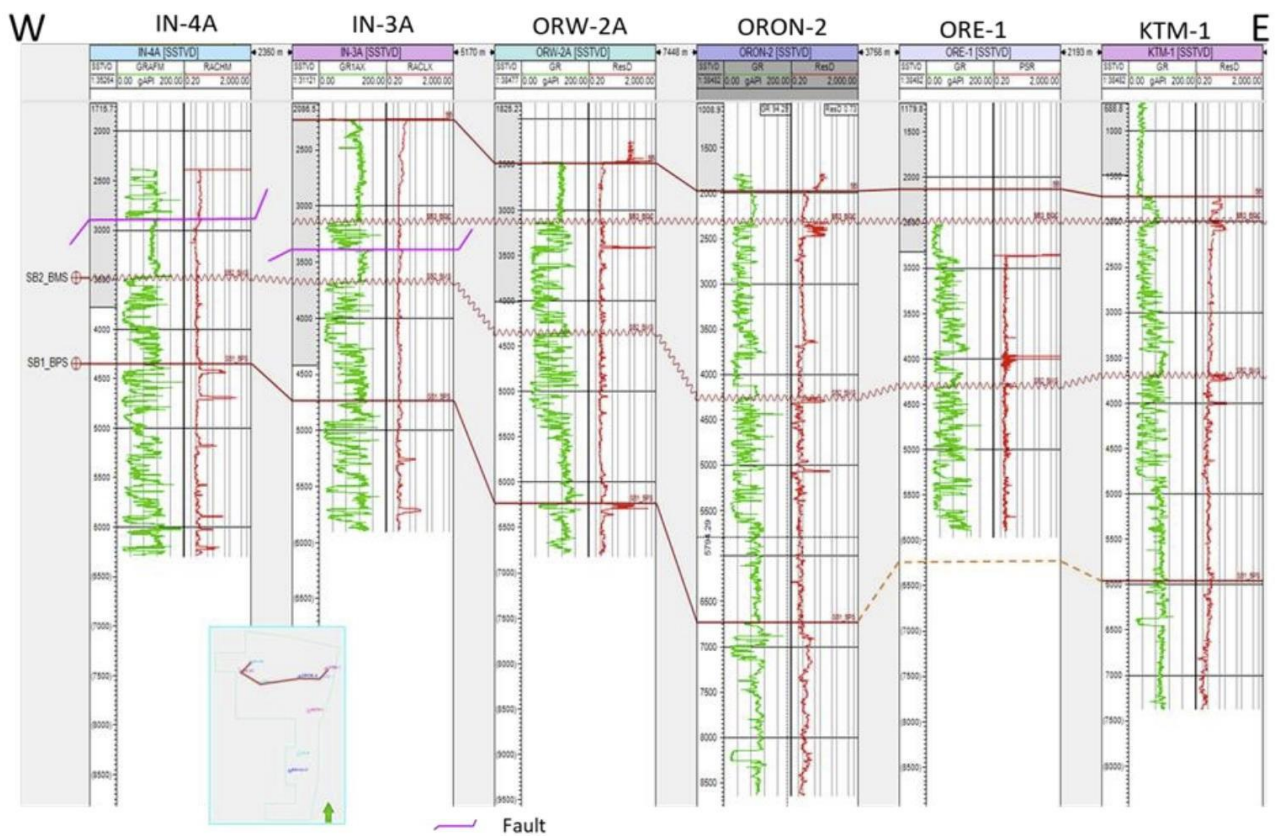


Figure 7: Correlation section of selected candidate wells along strike of OML XY block.

## Adanga North-1

- Depth interval 4720-7000ft
- No nannofossil detected
- Environment of deposition – Shallow marine.

### 4.1.1 Environment of Deposition

OML XY block is located within the offshore depobelt area in Niger delta. Regionally, sediment dispersal was controlled by marine transgressive/regressive cycles related to eustatic sea-level changes with varying duration. The various sea-level cycles were in or out of phase with each other and with local subsidence, and interfered with each other and thus influenced the depositional processes. At the high inflection points of the long-term eustatic sea-level curve, floodings took place that resulted in delta-wide shale markers. Three macro-sequences were identified with sequence boundaries: BPS (Base P-Shale), BMS (Base M-Shale) and BQC (Base Qua-Iboe Channel). The macro-sequences contain regional transgressive units (TST) followed by a range of heterogeneous fine-to-coarse progradation or aggregational siliciclastic (para)sequence sets (HST) (Fig 9 and Fig 10).

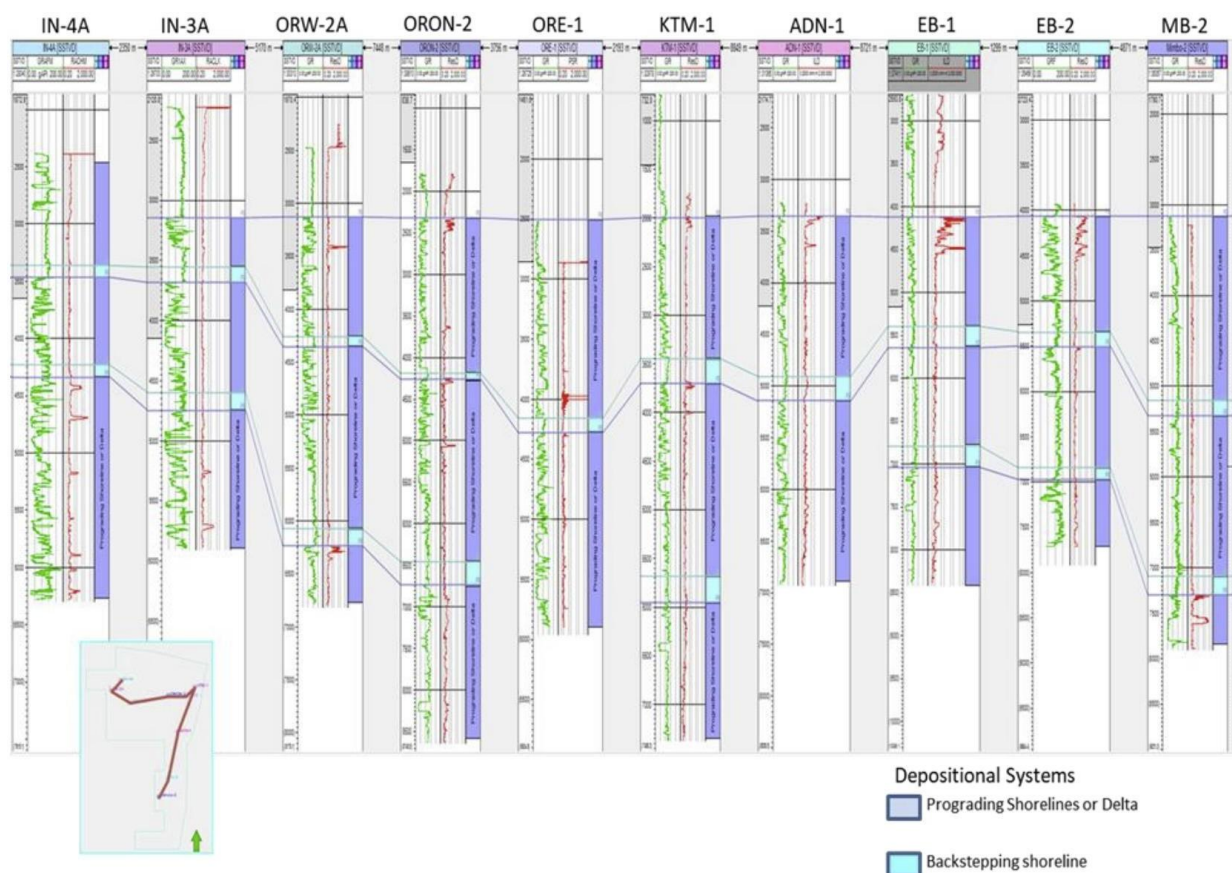


Figure 8: Depositional system OML XY block.

### 4.2 Seismic Interpretation

The faults and identified key stratigraphic surfaces were interpreted across the OML XY block (Fig 9 and Fig 10). Time and depth structural maps were generated as seen in the figures below.

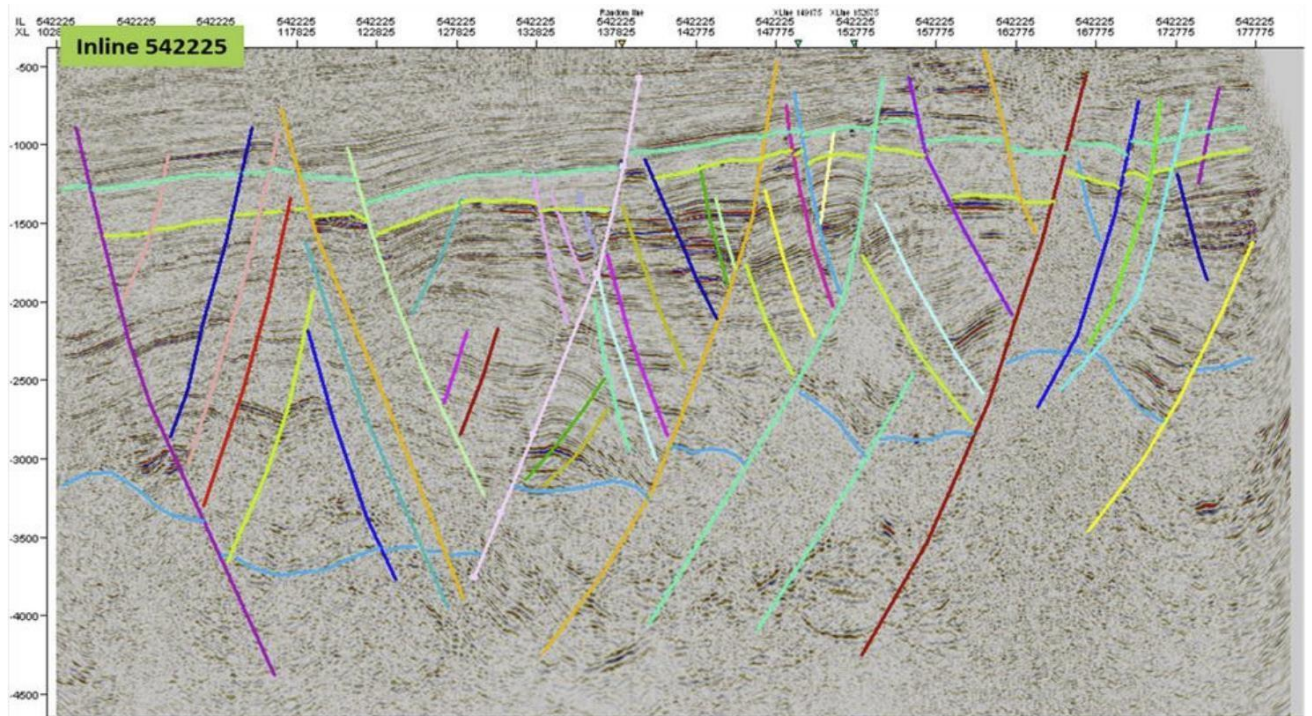


Figure 9: Fault interpretation and horizon interpretation of some stratigraphic surface.

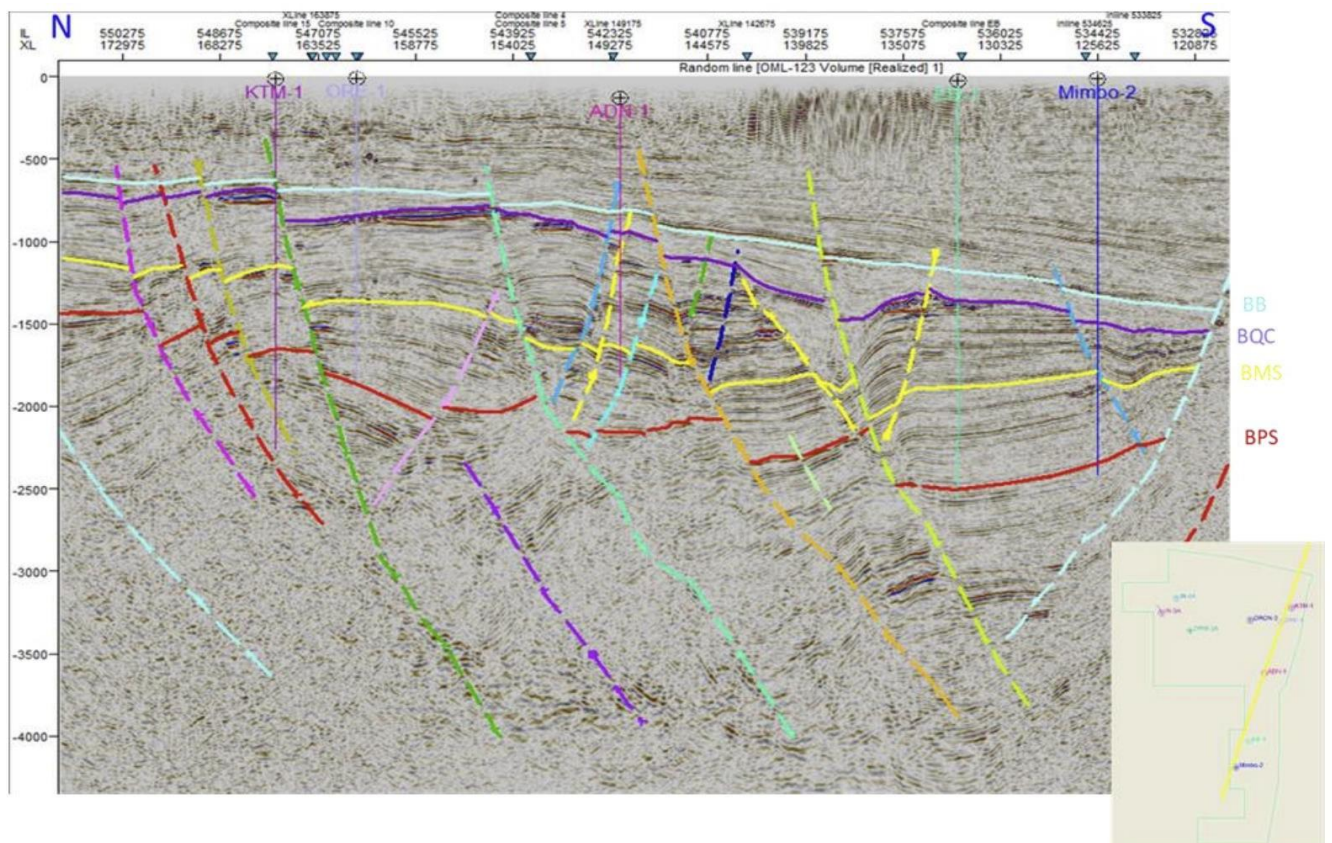


Figure 10: Seismic stratigraphic panel along dip direction.

Chronostratigraphic ages for the key stratigraphic surfaces BQC, BMS and BPS were first identified from biostratigraphic report of Inangha 3, Inangha 4, Oron1, Akam 1 and Ebughu 1 well. BB, BQC and BMS were interpreted to be early pliocene while BPS serves as the

boundary between early Pliocene to late Miocene (Fig 10). Bathymetric ranges of the block was identified in the biostratigraphic report provided. The environment was reported to be between the inner to outer neritic (Fig 11).

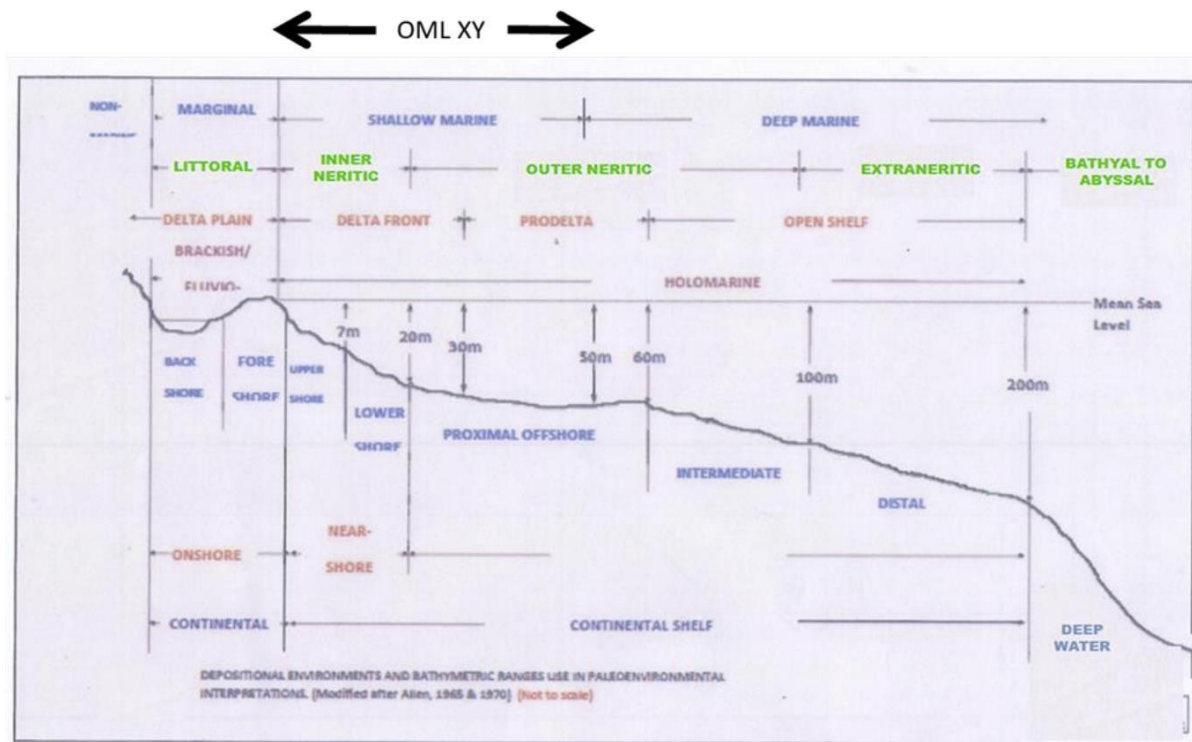


Figure 11: Bathymetric Range of OML XY Block.

#### 4.3 Hydrocarbon Pathway, Sequence and Seals

The youngest hydrocarbon-bearing reservoir with economic potential is S0-9 reservoir in Benin Formation, which contains gas and oil at a depth of approximately 3,000ft tvdss in Ebne field. Oldest reservoirs penetrated (in Adanga, Ukpam and Inagha) are J-sands, which are expected at approximately 12,000 ft tvdss in the Antan prospect in the southernmost part of the license block. Three major shale sequences of regional importance act as regional top seals to the underlying reservoirs: Qua Iboe Shales, M-Shales and Pshales (Fig 12). Hydrocarbon migration is expected to take place along the major faults, from deep-seated shales in the Akata Formation or early Agbada Formation, into fault-controlled structural traps (four-way dip rollover or fault seal) primarily within the Agbada Formation and locally in the Benin Formation. Traps classified as structural or stratigraphic, or as a combination of the two are found within the OML XY block (Fig 12). At top of shallow reservoir interval (directly below the Qua Iboe Shales) traps are typically stratigraphic (erosional truncation) or of a combined nature of both structural and stratigraphic trap. Traps are generally structural at deeper reservoir levels, mostly formed by fault closure and rollover with four-way dip closures. Fault closures may occur in both the footwalls and in the hanging walls. There is a stepwise deepening of stratigraphic levels from north to south. The main structural trends within the block are North West-South East and East North East-West South West, closely spaced East-West trending faults also occur in KTM area. At top of shallow reservoir interval (directly below the Qua Iboe Shales) traps are typically stratigraphic (erosional truncation) or of a combined nature of both structural and stratigraphic trap. Traps are generally structural at deeper reservoir levels, mostly

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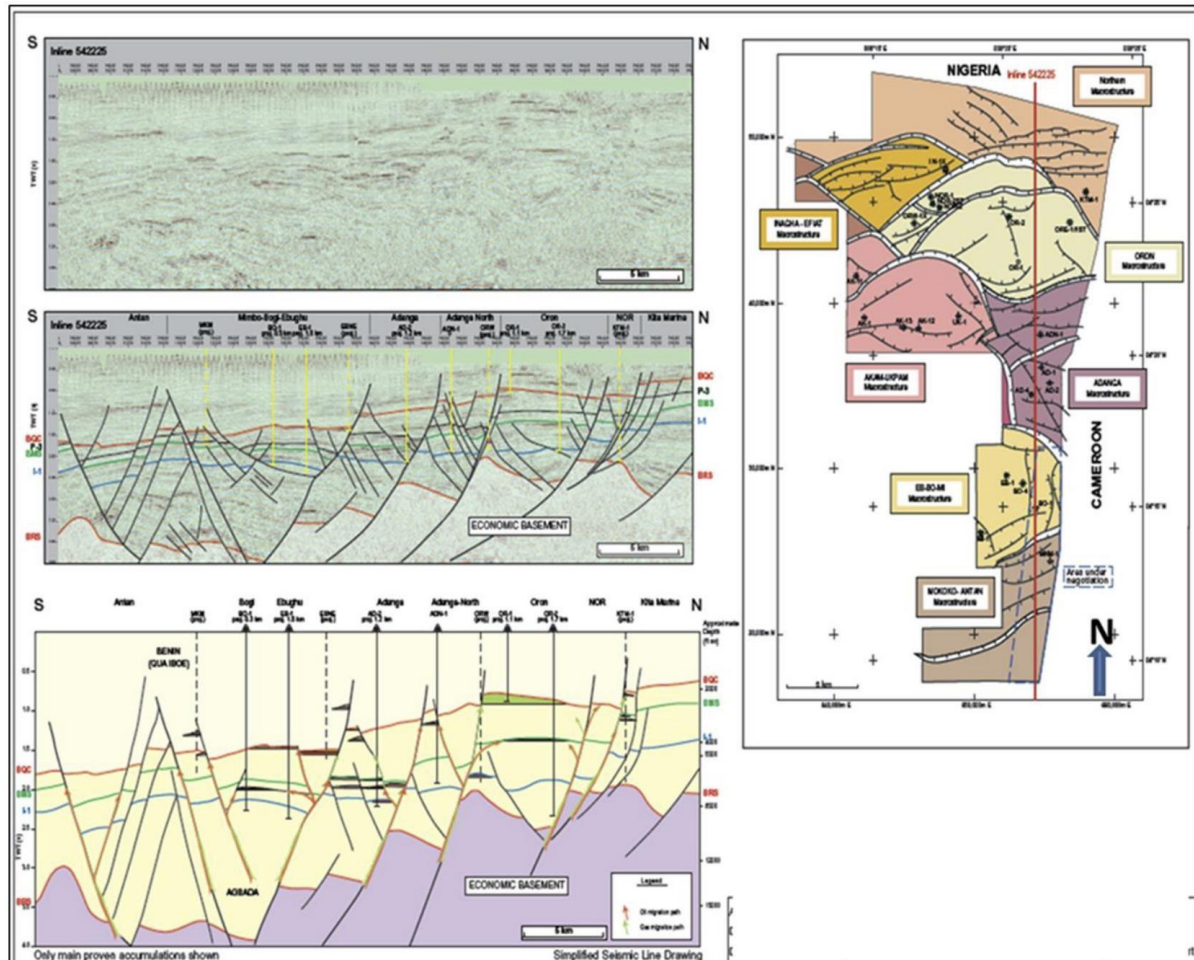


Figure 12: Trapping styles and hydrocarbon distribution of the OML XY block.

#### 4.4 Environment of Deposition Model

After carefully interpreting the data and integrating with the available reports, an environment of deposition model was developed. Various environment identified within the block include upper to lower shoreface. Sedimentary deposits within the block include; marine shales, delta front sand, upper shoreface sands, lower shoreface sands, mouth bar sands, barrier bar sediments, and beach ridges sediments. The depositional model within the block. Environment of deposition distribution was done using the conceptual model and the various distribution maps for the key stratigraphic surfaces are observed Fig 13 and 14.

#### 4.5 Petroleum Play Concepts of OML XY Block

The petroleum play concept can be defined by three characteristics at three levels

– Level 1: The charge linked to stages in basin history

- Level 2: The hydrocarbon bearing reservoir defined either by the formation name/age or lithofacies
- Level 3: The trap type Only two characteristics (formation age and trap type) are used in this study since the charge is believed to be common (Akata formation).

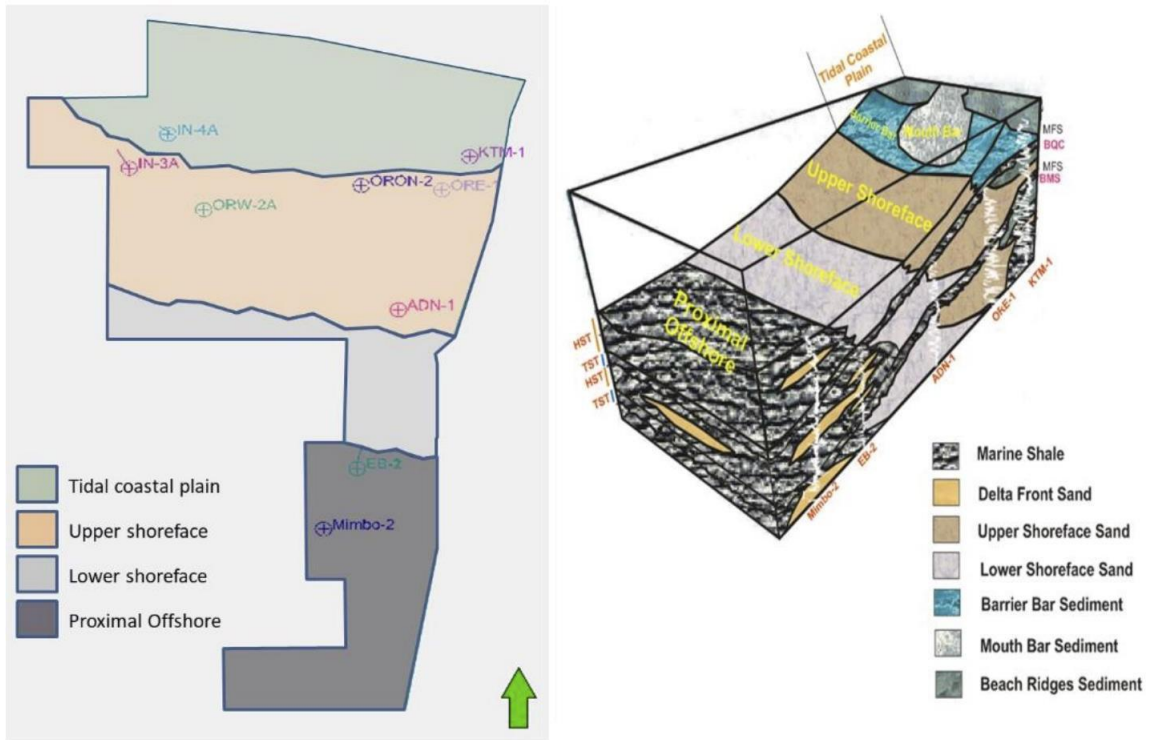


Figure 13: Environment of deposition distribution map below BQC.

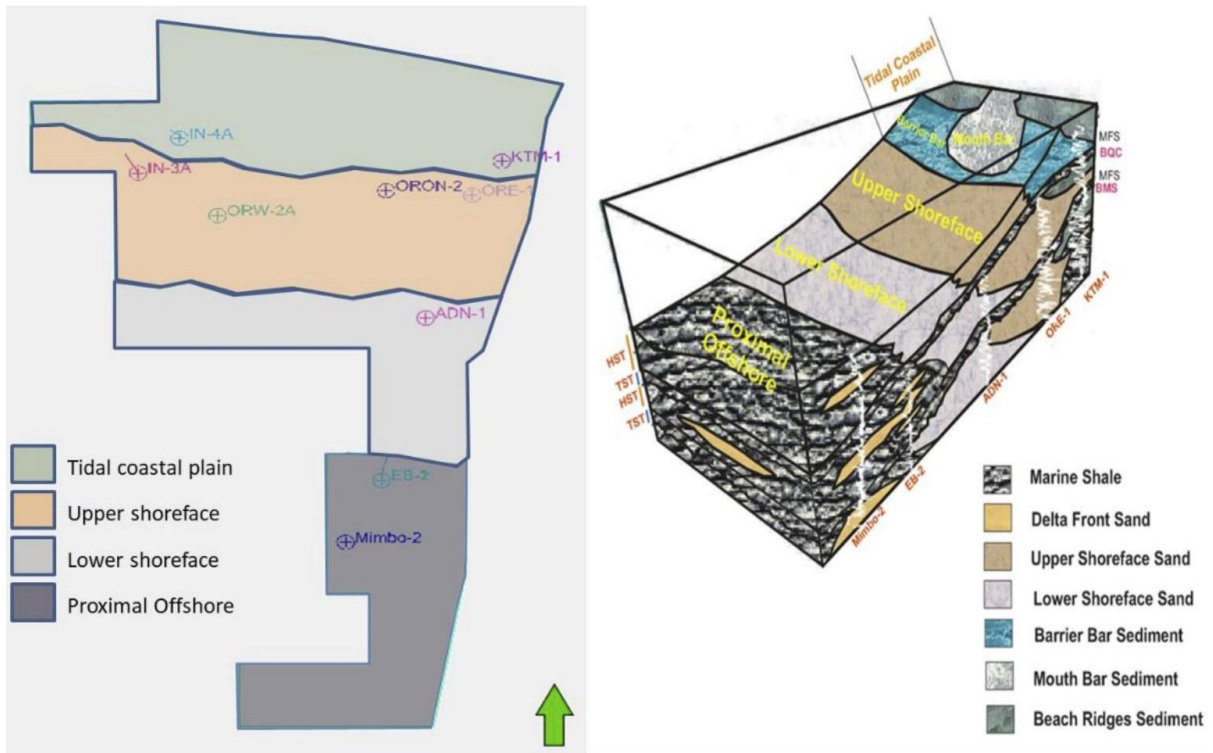


Figure 14: Environment of Deposition distribution map below BMS and BPS.

Only two characteristics (formation age and trap type) are used in this study since the charge is believed to be common (Akata formation).

Play types identified in OML XY include:

- Early Pliocene hanging-wall and footwall plays
- ORW-2A(P.05) – Late Miocene hanging-wall and footwall plays - IN-3A(I-3.2)
- Early Pliocene Anticlinal plays
- Early Pliocene rollover anticline plays - KTM-1(BQC, P-4,P-6)
- Early Pliocene Combination plays - NOR-1
- Early Pliocene Angular unconformity plays - ADN-1(BQC), EB-1(BQC), EB-2(BQC)
- Deep Late Miocene hanging-wall and footwall plays.

Figures 15 to 25 below explains the identified petroleum play concepts interpreted in OML XY block listed above.

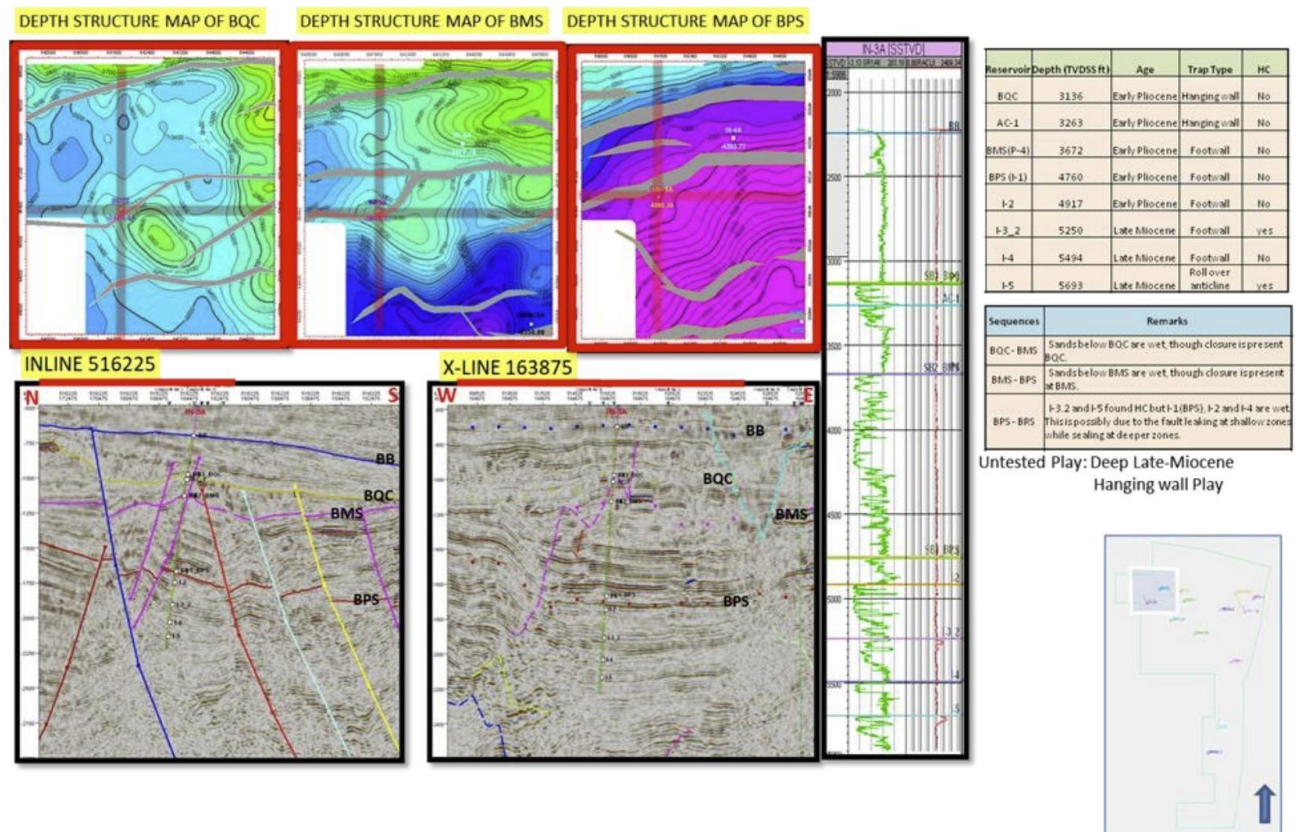


Figure 15: Inagha- Efiat Macro Structure (INAGHA 3A) : Late Miocene Hanging Wall and Rollover Anticline Plays.

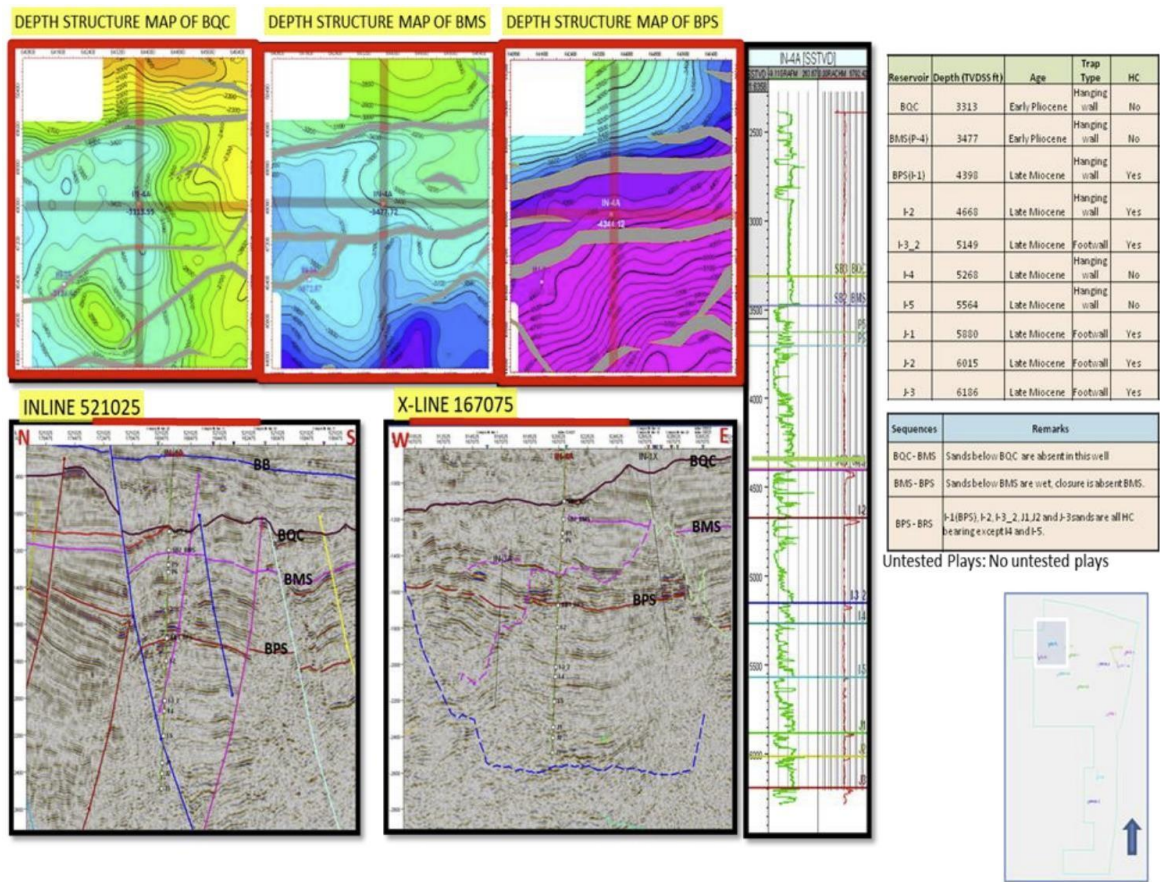


Figure 16: Inagha- Efiat Macro Structure (INAGHA 4A) : Late Miocene Hanging Wall and Foot wall plays.

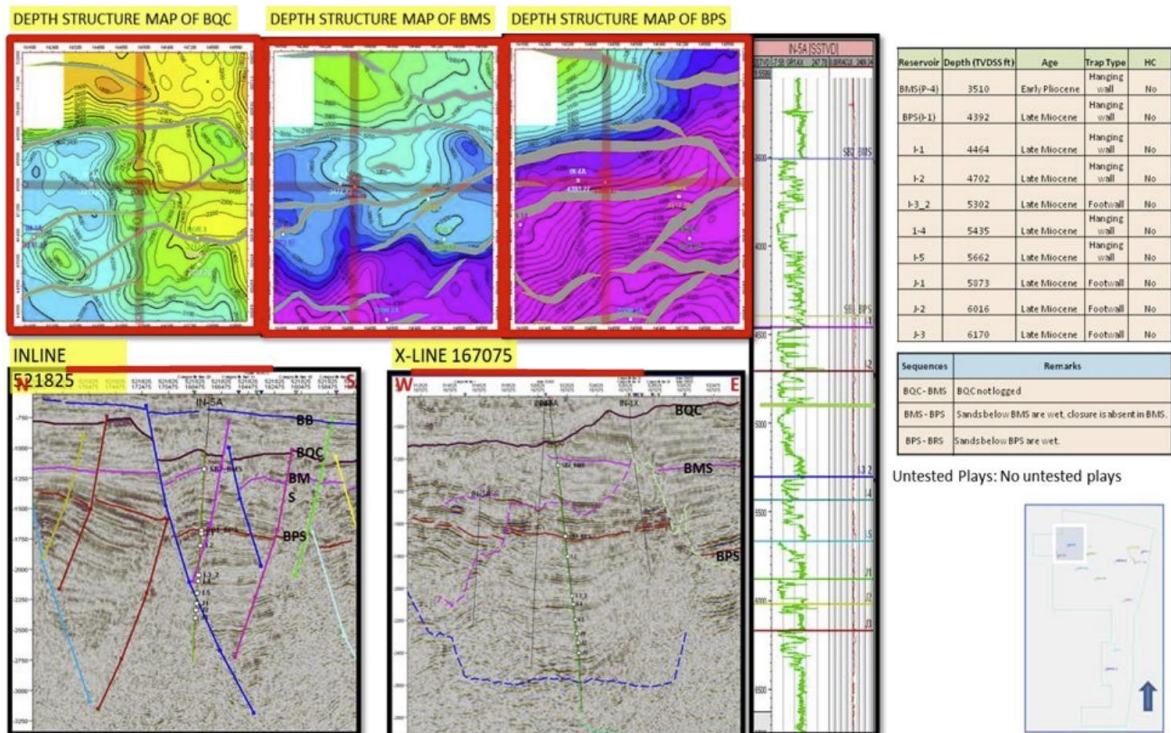


Figure 17: Inagha- Efiat Macro Structure (INAGHA 5A).

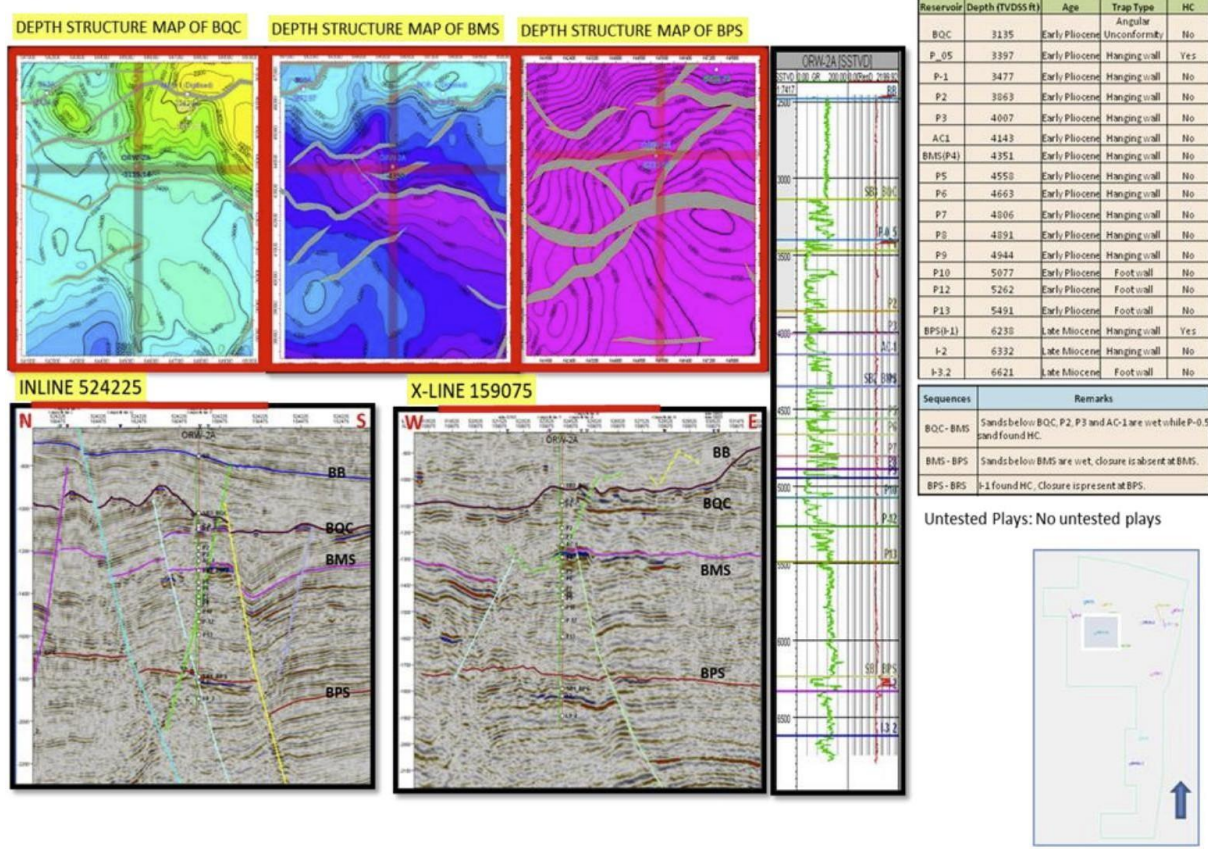


Figure 18: Onron Macro Structure (ORW-2A) : Early Pliocene and Late Miocene Hanging walls Plays.

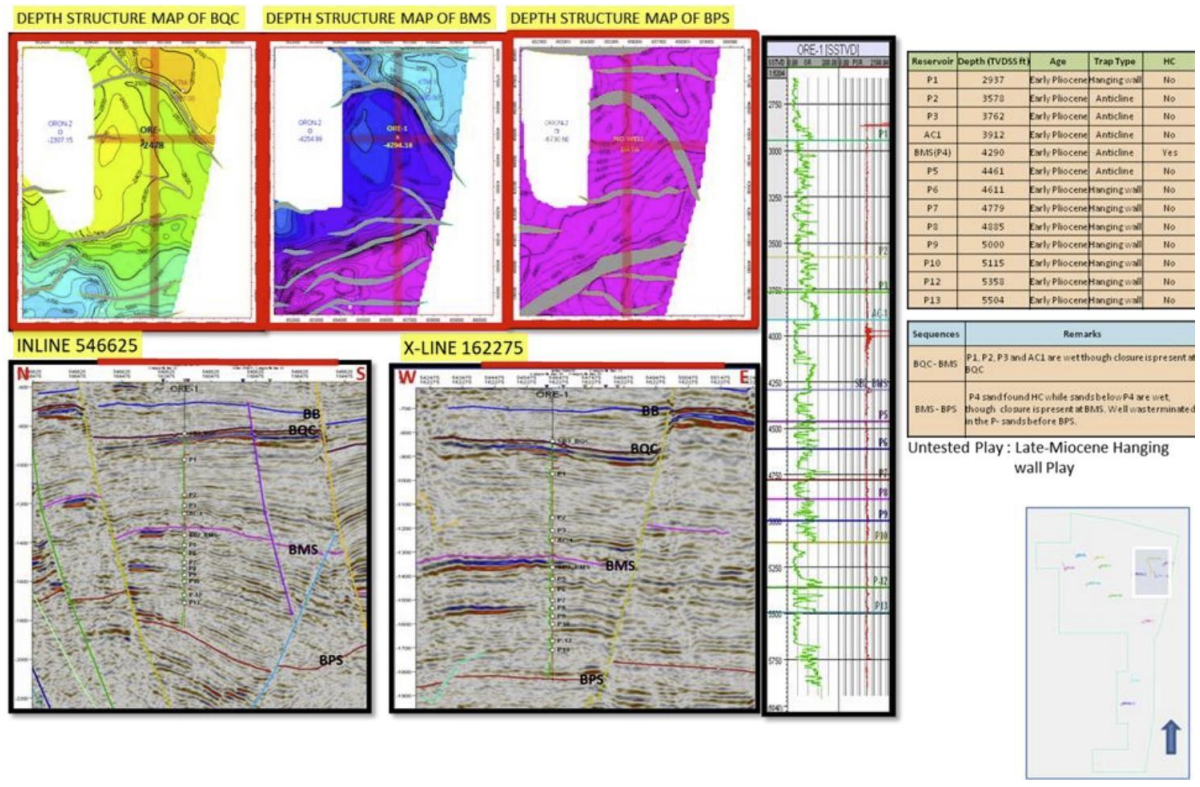


Figure 19: Onron Macro Structure (ORE-1): Early Pliocene Anticline Plays.

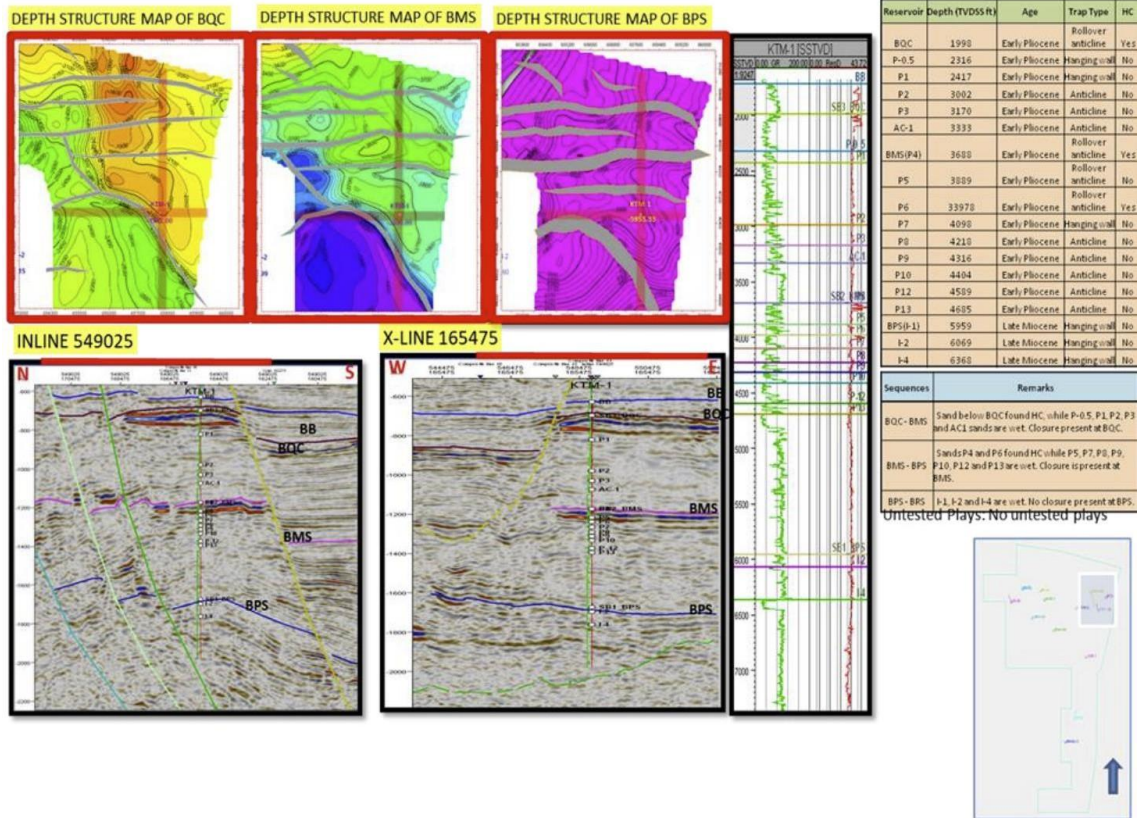


Figure 20: Northern Macro Structure (KTM-1): Early Pliocene Rollover anticline plays.

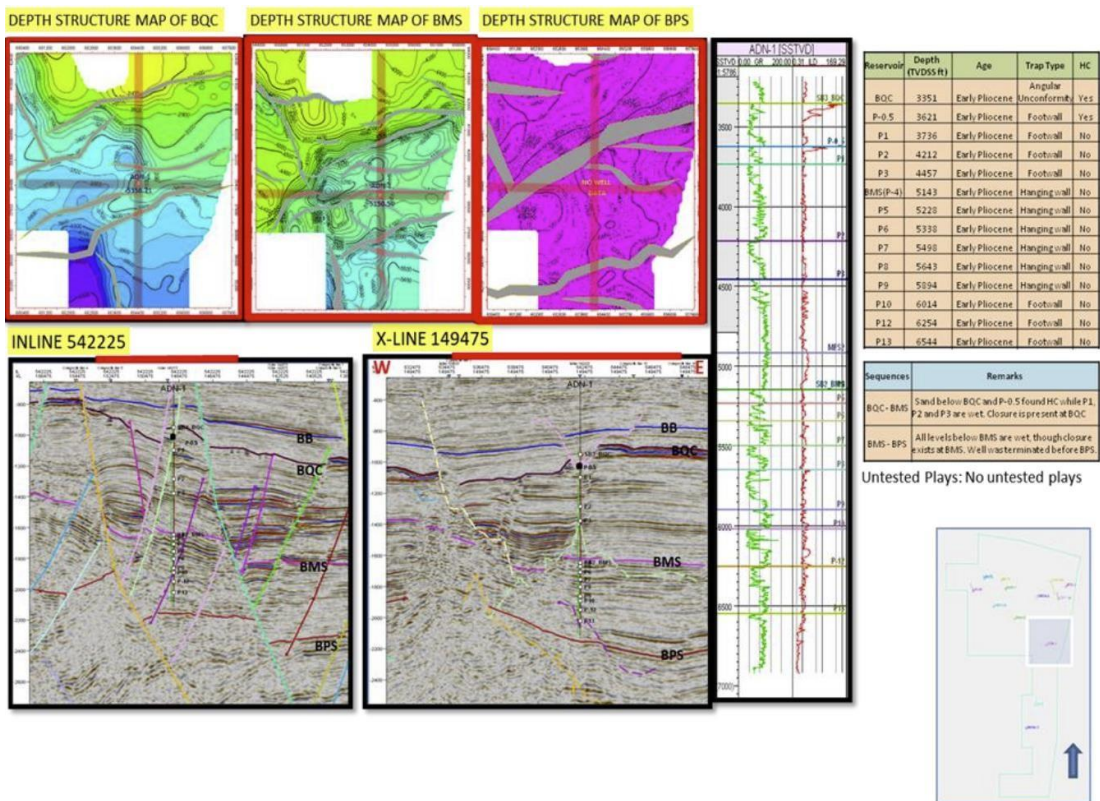


Figure 21: Adanga Macro Structure (ADN-1): Early Pliocene Angular Unconformity and Foot Wall Plays

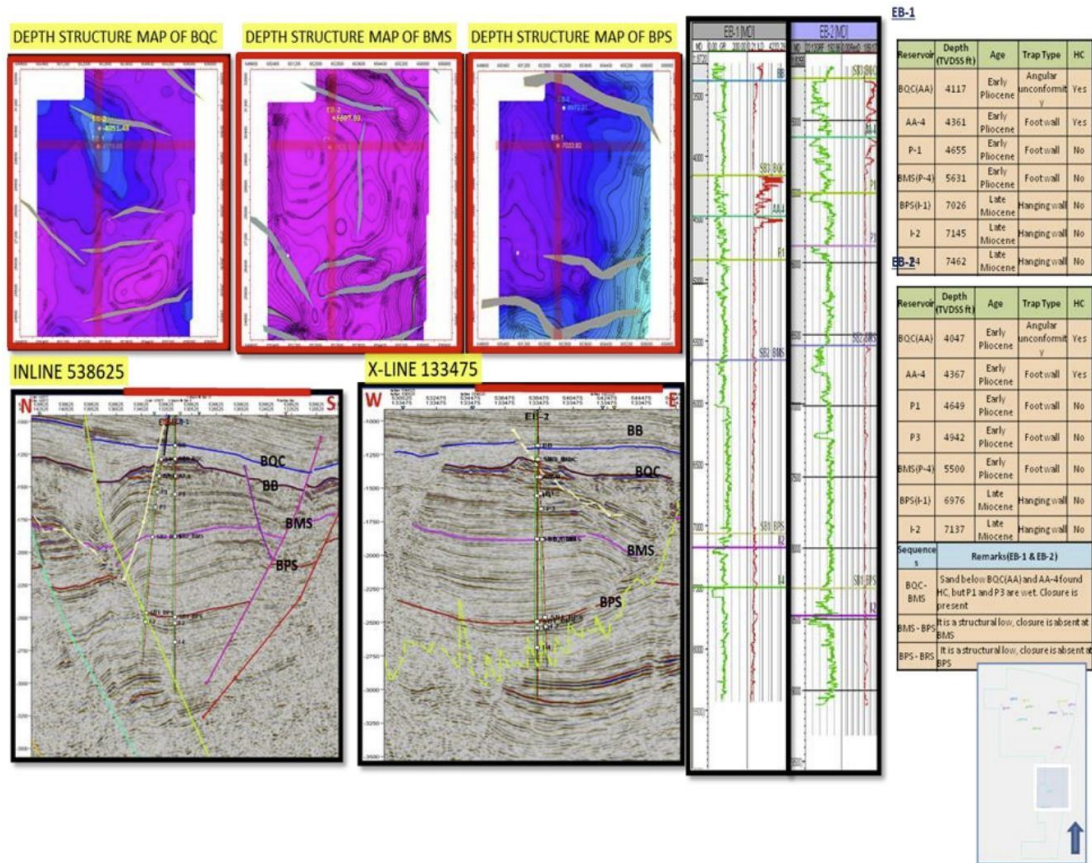


Figure 22: EB-BO-MI Macro Structure (EB-1 & EB-2): Early Pliocene Angular unconformity and Foot Wall Plays.

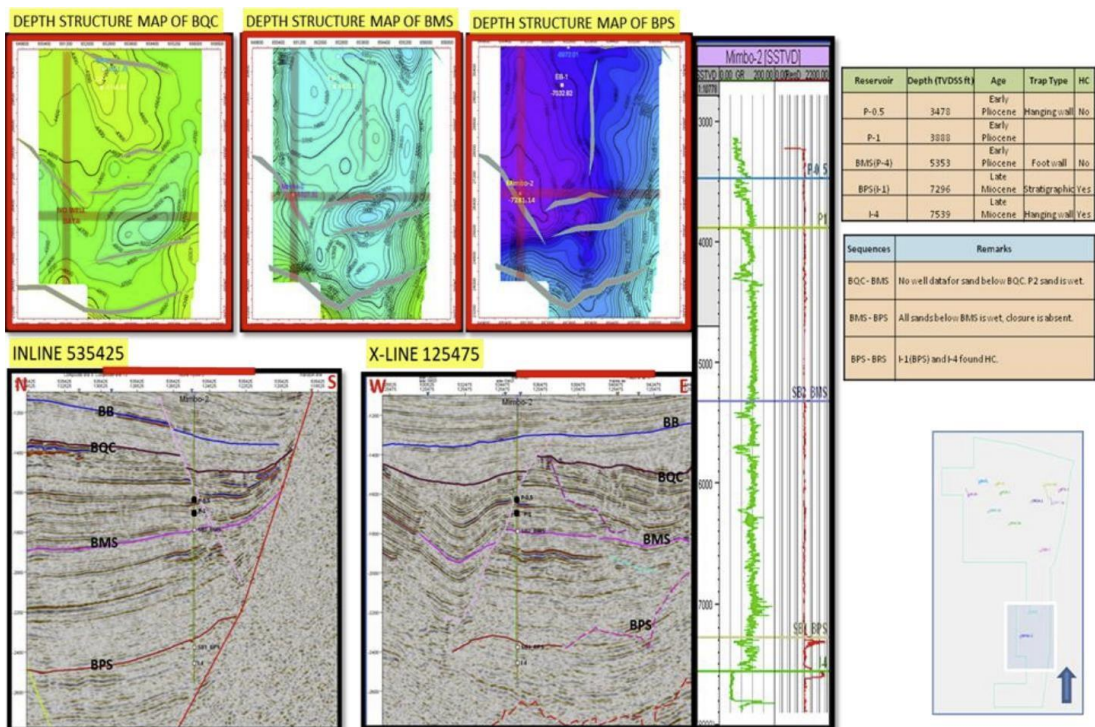


Figure 23: EB-BO-MI Macro Structure (Mimbo-2): Late Miocene Angular Unconformity Plays.

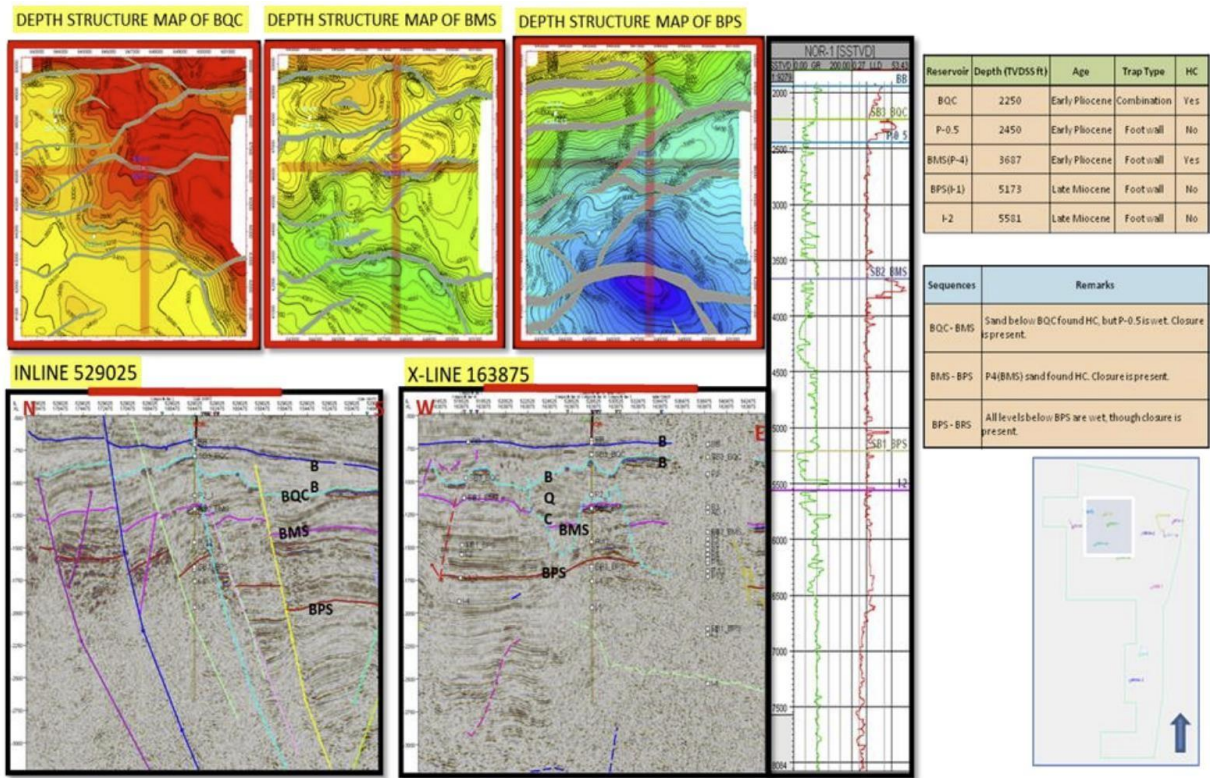


Figure 24: Oron Macro Structure (NOR-1): Early Pliocene Combination Plays.

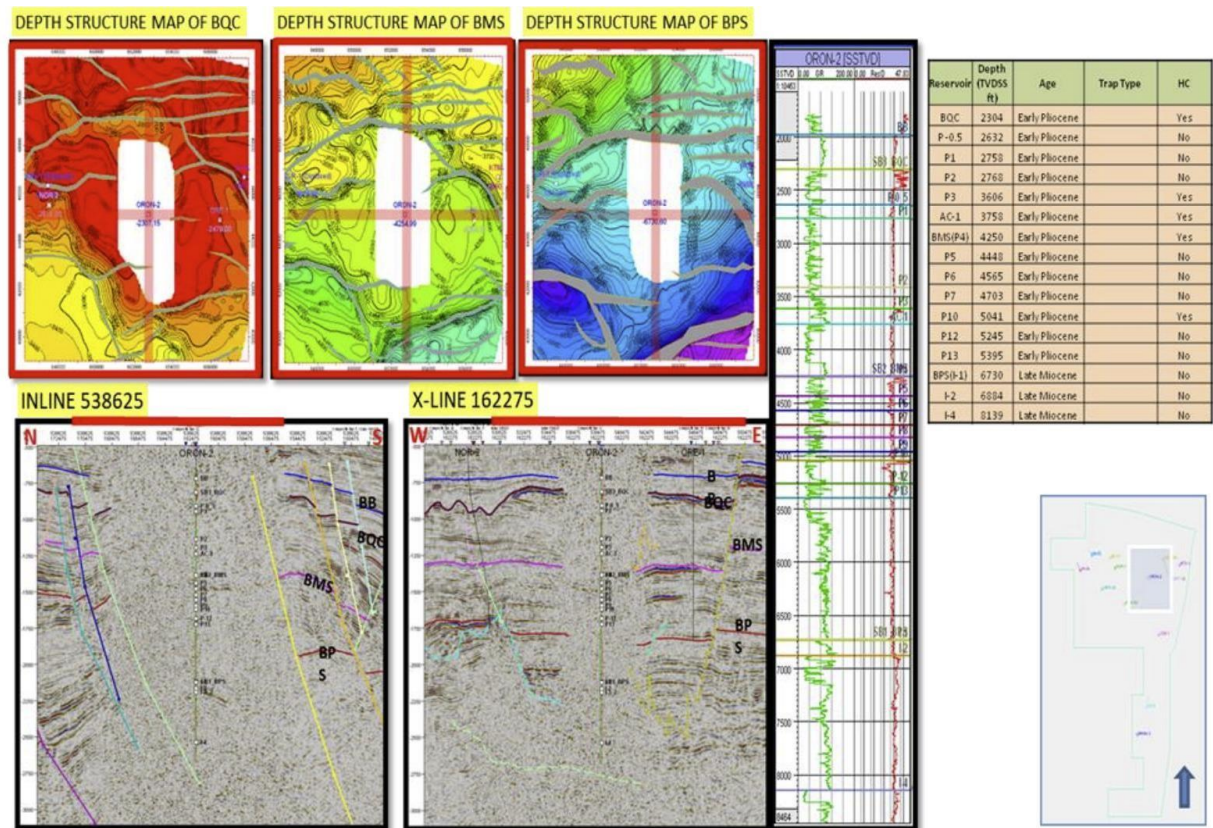


Figure 25: Oron Macro Structure (ORON-2)

## **5. Conclusions**

The base of Benin formation and three key stratigraphic erosional surfaces; BQC (Base Qua ibo channel), BMS (Base M shale), and BPS (Base P Shale) were identified in this study.

Three predominantly prograding depositional sequences bounded by sequence boundaries were also delineated.

Biostratigraphic report indicates that sediment ages within OML XY block range from Early Pliocene to Late Miocene.

Depositional systems identified include prograding shoreline or delta and backstepping shoreline

Environment identified within the block range from upper to lower shoreface. Sedimentary deposits within the block include; marine shales, delta front sand, upper shoreface sands, lower shoreface sands, mouth bar sands, barrier bar sediments, and beach ridges sediments.

## **Abbreviations**

3D Three dimensions; Sqkm: Square Kilometer; m: Meters; API: Unit of measuring gamma Ray log; SEG-Y: Seismic survey format; OML: Block concession in Niger Delta Basin; OPL: Block concession in Niger Delta Basin; MWD: Measurement while Drilling; LWD: Logging while Drilling; BPS: Base of P shale; BMS: Base of M shale; BQC: Base of qua-Iboe Shale; TST: Transgressive Sequence tract; HST: High system Tract; BB: Base of Benin; BRS: Base of R Shale.

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