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# Sequence Stratigraphic, Structural and Stratigraphic Studies of Miocene-Pliocene Deposit in OML XY Block, Southeastern Niger Delta Basin, Nigeria

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**Abstract:** *Hydrocarbon production potential of 6 wells were re-evaluated in the block of southeastern Niger Delta to improve low production recently recorded with the aim to improve on it. Petrel software was used to map out key surfaces, well logs and seismic data for fault identification that also facilitated the identification of the condensed sections of some of the wells, thus anomalous low sedimentation rate of strata in the depositional sequence. The data analysis has revealed 3 horizons of BQC, BMS and BPS that are continuous with the sequence boundaries of SB3_BQC, SB2_BMS and SB1_BQC delineated at different depth intervals of the wells and ranges from 653-1016, 964-1175 and 1376-1888 meters respectively. System tracts delineated were the Lowstand System Tract, Transgressive System Tract and Highstand System Tract mapped at different conditions of the continental-marine realm. Lithological distribution was found to be sand and shale units. Seismic study revealed 7 major mapped faults of F1, F2, F3, F4, F5, F6 and F7 that assisted the migration of hydrocarbon in the wells. Principal structure for hydrocarbon entrapment in the wells are anticlinal, footwall and hanging wall growth faults. The deposit is having a robust sequence*

**Keywords:** *Transgressive, Sedimentation Rate, Sequence Stratigraphy, Sequence Boundary and Anticline*

## INTRODUCTION

Enhancement of hydrocarbon production in the almost depleted block wells using the sequence stratigraphic, structural and stratigraphic controls will go a long way to establish the very importance of utilizing this skill for hydrocarbon production prediction, especially in abandoned oil and gas block/field wells (Posamentier et al 1992 and 1993). Geoscientists have shown with various evidences that Niger Delta basin has spectacular thick, extensive sedimentary apron and salient geological features favourable for such petroleum generation, expulsion and trapping from the onshore through the continental shelf to the deep and ultradeep offshore terrains (Ibrahim *et al.,* 2019). Few published work on the Sequence Stratigraphic architecture of this block and indeed the Niger Delta basin deposit can be found in literatures, hence the need for this study. Re-evaluation of these wells is expected to enhance the low production of oil and gas recently recorded in them and improve on its Sequence Stratigraphic architecture to enhance better oil and gas production prediction.

## Location and Geology of the Basin and Study Areas

The Niger Delta basin is an extensional rift basin, located at the intersection of the Benue Trough and the Southern Atlantic ocean where a triple junction developed during the separation of the continents of Southern America and Africa during the Jurassic to late Cretaceous (Ukpong *et al.,* 2017). OML XY block is located within the southeastern offshore depobelt area in Niger delta, covering 568 $Km^2$ in area extent. Its regional 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 of the sediment in the block. The Miocene to Pliocene sediment of OML XY block lies in southeastern part of the Delta. The block deposit is of shallow water to offshore and of early Miocene to late Pliocene age located around Latitude $4^\circ$ $18^1$ N and $4^\circ$ $42^1$N and Longitude $7^\circ$ $6^1$ and $7^o$ $36^1$ E. (Fig. 1 and Fig. 2). The deposit of Niger delta is composed of 3 lithostratigraphic units and the youngest being the Benin formation composed of massive sand units deposited in continental environment comprising the fluvial realms of braided and meandering river systems (Ukpong *et al.,* 2017).

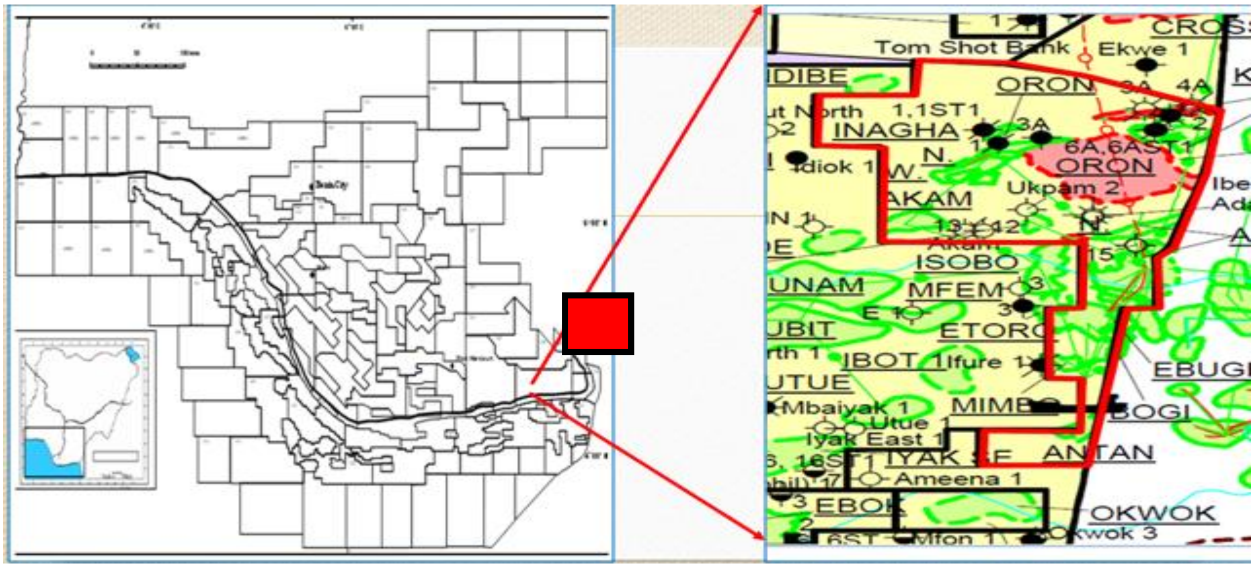


Fig. 1 Location map of OML XY block showing different oil and gas fields

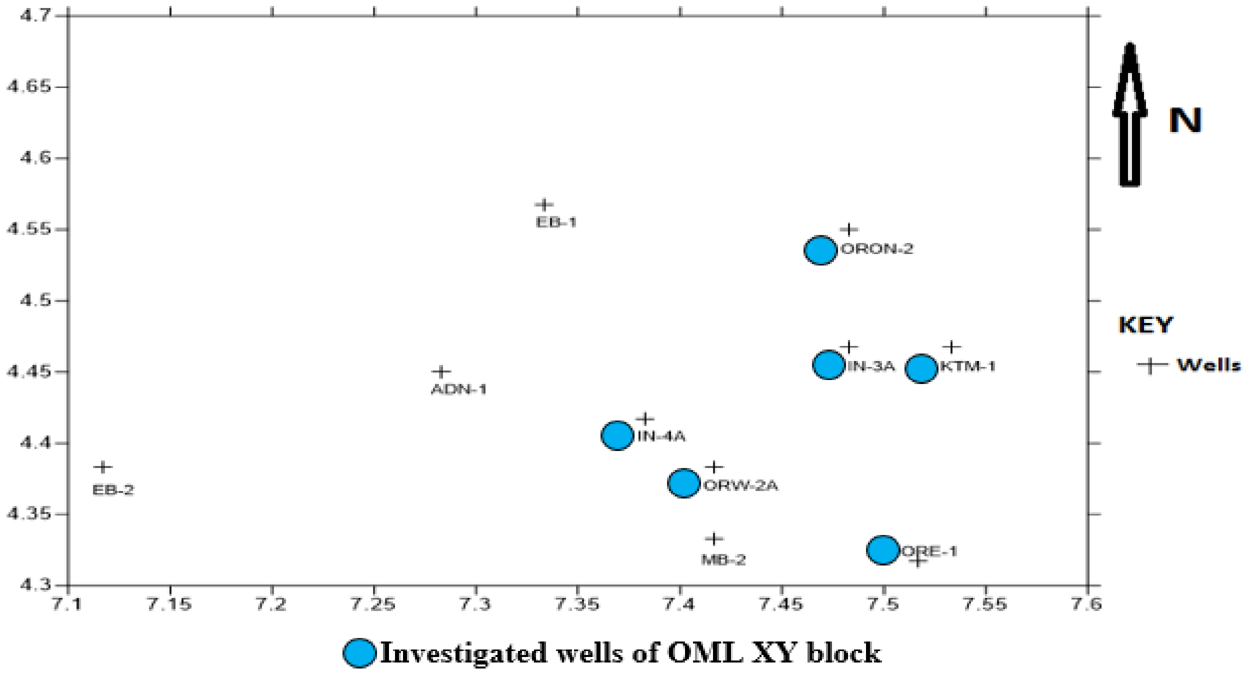


Fig. 2 Base map of studied wells in OML XY block

The Agbada Formation consists of alternating sand and shales representing sediments of the transitional environment comprising the lower delta plain (mangrove swamps, floodplain, marsh), the coastal barrier and fluvio-marine realms. Agbada formational unit is laterally extensive and thick enough for hydrocarbon production, accumulation and migration from the onshore to the deep offshore and ultra deep offshore terrains of the delta. It is a paralic sequence of sandstone and shale underlying the Benin formation (Fig. 3). It consists of the sandy parts, which serve as the main hydrocarbon reservoir of the Delta and shale as the cap rock. This sequence is associated with syn-sedimentary growth faulting (Nwajide. and Reijers, 1996). The depositional environment is therefore defined as "transitional" between the upper continental Benin formation and the marine underlying Akata formation. The formation was deposited beginning from the Eocene and continued into Recent (Fig. 3). The Akata formation was deposited unconformably on the Precambrian basement rocks. This unit is composed of deeper marine shale (hydrocarbon kitchen) and forms the deepest stratigraphic unit of the Delta where the bulk of hydrocarbon in the delta is been generated (Oyanyan *et al.,* 2012 and Oresajo *et al.,* 2015).

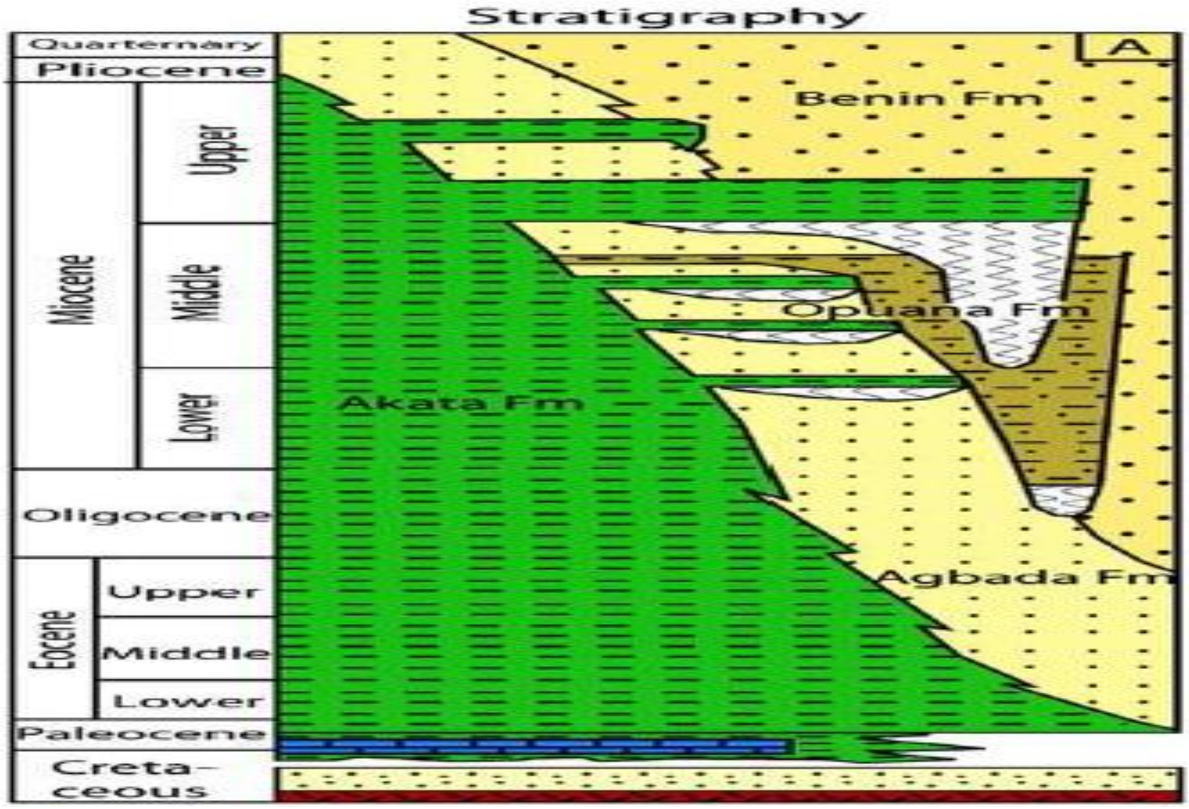


Fig. 3 Geological lithostratigraphic chart of Niger Delta deposit

It is mostly represented by plastic, low density, under-compacted and high-pressured shallow marine to deep water-shale with only local inter-beddings of sands and/or siltstones. It is deposited as the high-energy delta advanced into deep water. In general, the shale is over-pressured and this provides the mobile base for subsequent growth faulting associated with the deposition of the overlying paralic sequence. It serves as the hydrocarbon source in the Niger Delta. OML XY block is located within the southeastern offshore depobelt area in Niger delta, covering 568 $Km^2$ in area extent. Its regional 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 of the sediment in the block. Three macro-sequences were identified with sequence boundaries: BPS (Base P-Shale), BMS (Base M-Shale) and BQC (Base Qua-Iboe Channel). The macro-sequence contain regional transgressive units of retrogradational stacking pattern, followed by a range of heterogeneous fine-to-coarse grained progradational or aggradational siliciclastic parasequence sets of HST, TST to LST. OML XY block, thus, has 3 depobelts of varying thickness and lateral extensiveness and include the Afam, Opuoma and Qua Iboe channels harboring sediments of various geologic ages (Fig. 4).

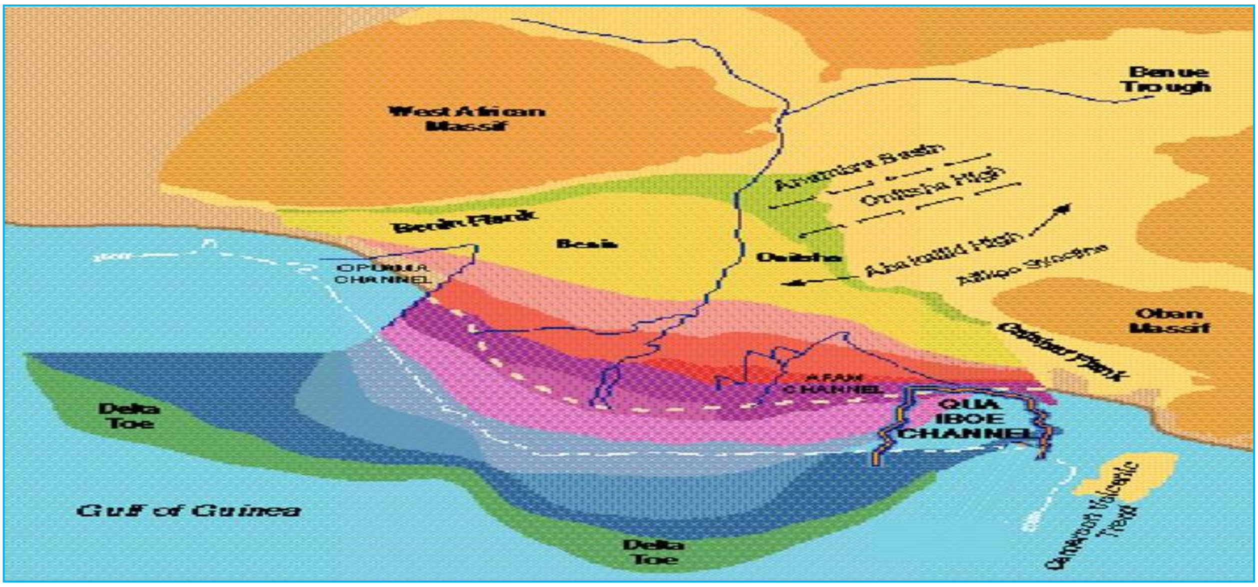


**Fig. 4 Depobelts of the studied wells in OML XY block**

## MATERIALS AND METHODS

Well log data was loaded into petrel software using LASS (**) format, while the seismic data was interpreted using the SEG Y format, all of the petrel software interphase along an inline of 502226-642225 and crossline of 102925-177776. Gamma ray log was used to decipher the lithological distribution of sand and shale components of the studied wells, while the resistivity log was used to delineate the fluid content of the wells, as such used to differentiate between hydrocarbon and underground water content because there is a significant difference in their resistivity values in the investigated wells.

## RESULTS AND DISCUSSION

### *A. Well Log/Formation Evaluation*

Six (6) wells of IN-4A, IN-3A, ORW-2A, ORON-2, ORE-1 and KTM-1 wells were studied with the utilization of gamma ray log and sand units delineated at depth intervals of 1826 to 8654 feets of ORON-2 well. Also, resistivity log was used to study the fluid content of the block in each of the investigated well and the results obtained revealed hydrocarbon presence at 4230, 5377, 6321, 4236, 4006 and 3687 feets of IN-4A, IN-3A, ORW-2A, ORON-2, ORE-1 and KTM-1 wells respectively. The sands vary from blocky, progradational and retrogradational stacking pattern depicting variation in environment of deposition at the continental shelf and slope of all investigated units. The correlation revealed that the reservoirs are of good continuity as the wells witnessed all of the reservoirs at varying depths except ORE-1 well that has a missing section of deposit at the base where erosional truncation has removed packages of beds of the well deposit (Fig. 4). This was traced to incision of a river valley into the deposit. From the analysis of the well logs, the Benin formation from the analysis of the well logs was recognized by low gamma ray count and high resistivity reading of fresh water at the shallow depths ranging from about 606 to 740 meters in all the investigated wells. Sands were encountered at the surface, with the base of fresh water sands (BFWS). It was observed and interpreted that the upper part of the formation is sandier than the lower part. The base of these units were determined in all the wells by the first remarkable changes in the well log responses.

These changes include increase in the number of intervals with high gamma ray readings and high resistivity readings of the sand on the top of the first thick shale bed interval that was identified as the BFWS based on the above mentioned changes (Fig. 3). The sands were unconsolidated, fine to medium grained with interbedded clay to shale facies. The Benin Formation has been interpreted to have been deposited in shallow water depositional environment (Short and Stauble, 1967), (Ekweozor and Daukoru, 1984). As such, in this block, most reservoirs for hydrocarbon are located within the Agbada formation lithostratigraphic unit at depths 1346, 1711, 2011, 1348, 1274 and 1173 meters among others, while only 2 reservoirs falls within the Base of Benin formation of 2265 and 2007 feets of ORON-2 and KTM-1 wells (Fig. 3). Groundwater storability study revealed areas of low resistivity values using the resistivity log pattern and values of the wells to get the aquiferous points of the wells. As a result, delineated aquiferous zones are areas of low resistivity values and indeed high conductivity values that ranges from 1.9Ωm to 6.3Ωm (Fig. 5). The high hydrostatic water zones of the block deposit are commonly slightly salty due to the long interaction with the mineral components of the rocks that gets dissolved with time and different inorganic geochemical components released (notably Ca, Na, K and Cl ions) to form the saline underground water. This respond to resistivity log signatures as low resistivity values that revealed areas of best locations of aquifers that can support the economical exploitation of the underground water. In the IN-4A well, low resistivity values were noticed at 3753 and 5156 feets, with resistivity values of 2.3 Ωm and 3.6 Ωm, as such the zones were delineated as good aquiferous points for the well (Fig. 5). In IN-3A well, it was observed that delineated aquiferous zones falls within 3408 and 5056 feets of 2.9 Ωm and 2.8 Ωm resistivity values of the well as areas of low resistivity values that can serve as best aquiferous points for underground water production. In ORW-2A well, delineated zones include the low resistivity areas at 4950 and 5254 feets of the well with resistivity values of 1.9 Ωm to 3.7 Ωm. In ORON-2 well, it was noted that low resistivity spikes were recorded at 3153, 4501 and 6906 feets with resistivity values of 2.4 Ωm, 3.2 Ωm and 2.7 Ωm respectively (Fig. 5). Worthy of note is the low resistivity values of well ORE-1, occurring at a depth of 3716 and 5752 feets with resistivity values of 3.8 Ωm and 4.2 Ωm (Fig. 5). KTM-1 well had low resistivity values at 4157 and 5906 feets of resistivity values of 3.2 Ωm and 4.1 Ωm to support aquiferous underground water exploitation.

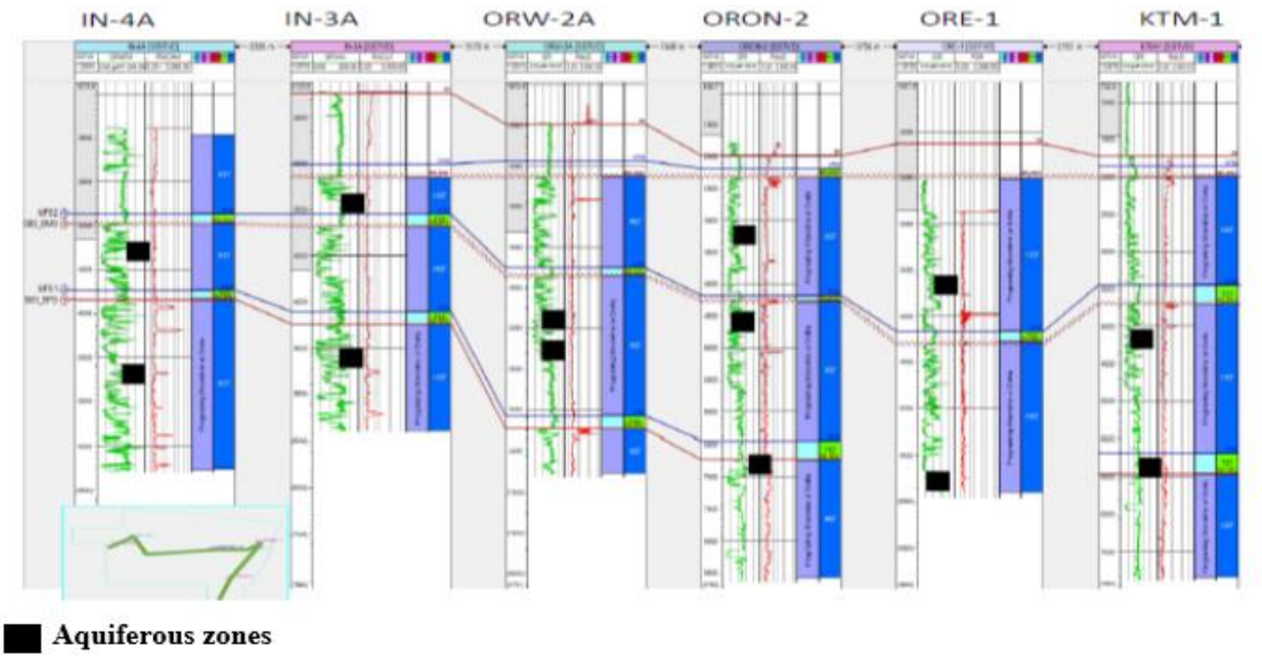


Fig. 4 Delineated aquiferous positions in the investigated wells

*B. Seismic Data Interpretation*

The seismic record is characterized by a series of nearly parallel reflections offset dipping S-W and S-E of the profile. 7 major and several minor faults were mapped and interpreted on seismic section of the block (Fig. 5). Most of the faults dip along the southern end of the seismic profile (Fig. 5). The block is a simple faulted rollover structure with lots of growth structural style fault of hanging and footwalls with large coherent fault block (Fig. 5). BQC, BMS and BPS horizons were also mapped in the seismic profile of OML XY block. Seismic reflection became chaotic deeper within the seismic record, where diapiric movement of underlying mobile shale has complicated reflector geometry. In most parts of the seismic reflection profile, the reflector pattern within the depositional sequences can be vividly divided into chaotic at the lower end of the profile, where the sediment appeared undisturbed with the penetration of seismic waves as such no definite seismic reflector delineated in such region (Ibrahim *et al.*, 2020) and low amplitude slightly inclined reflectors where the reflectors are almost parallel to the depositional beds signifying sandstone massive facies as advanced by (Sangree *et al.*, 1979). It is worthy of note that the syndepositional faulting of the block (Figs. 5 and 6) is likely to have produced bathymetric lows that accumulated sediment more rapidly and influenced sediment dispersal patterns further basin ward to the proximal offshore area. Deposits of the hanging wall blocks tend to be thicker directly basin ward of areas showing the greatest stratigraphic offset across faults and are relatively thinner down basin from areas with lesser fault displacement.

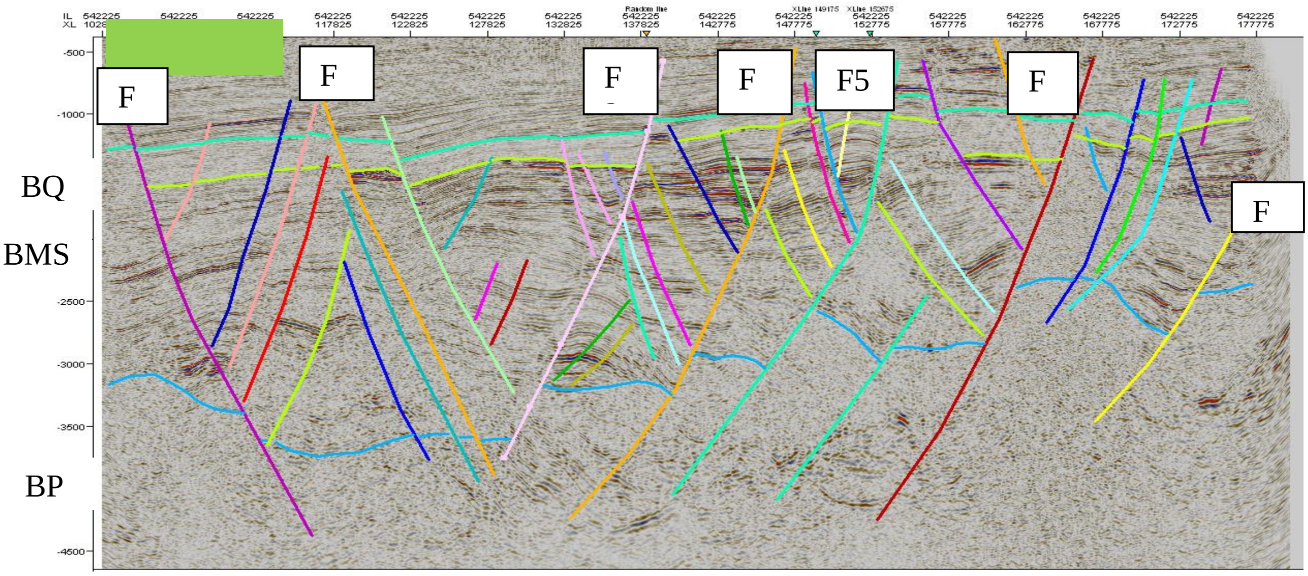


Fig. 5 The seismic profile of OML XY block mapped faults and horizons.

*C. Sequence Stratigraphic Structure*

Lowstand Systems Tract (LST) of OML XY consists of the oldest deposit within each of the depositional sequence of the block, except in ORON-2 well. It consists of basin floor fan (BFF), slope fan (SF), and prograding wedge complex (PWC). The basin floor fan is characterized on gamma ray and resistivity logs by blocky pattern with relatively few breaks (Fig. 6), thus indicating massive sand body across all wells except ORON-2 well. This vividly revealed that ORON-2 deposit, never extended to the continental slope but the shelf. The slope fan sediments of the other wells revealed a typical sand facie with overall rounded shape of spiky sand package on gamma ray log. It represent sediment portion deposited in the continental slope as basin floor fan deposit.

Also sediment built up above the fan at the base of the slope to form a lowstand wedge with a pattern of beds initially progradational, becoming aggradational in the lowstand wedge of the block, notably in IN-4A, IN-3A, ORE-1 and KTM-1 wells. The retrogradational deposits in the wells represent the TST deposited at the continental shelf formed during a period of relative sea level rising faster than the rate of sediment supplied to the block area, leading to the formation of the retrogradational stacking pattern as the shoreline and facies pattern moved landward in the depositional sequence. IN-4A, ORON-2 and KTM-1 wells were investigated to have exhibited retrogradational stacking pattern (Fig. 6) at intervals of 5049-5261, 5731-6827 and 1720-2227 feets respectively. More importantly, the beds of the depositional sequence during the period of high sea level of the eustatic cycle of the block were identified as high stand system tracts (HST). The beds revealed an aggradational to progradational stacking pattern as the shoreline shifts seawards across the shelf. Sediment of this depositional sequence were traced to be supplied from the hinterland of the highland and most of the accumulation occurred on the shelf with little sediment reaching the deeper continental slope of the basin as LST basin floor sediment. This was observed in all investigated wells except ORON-2 well of OML XY block.

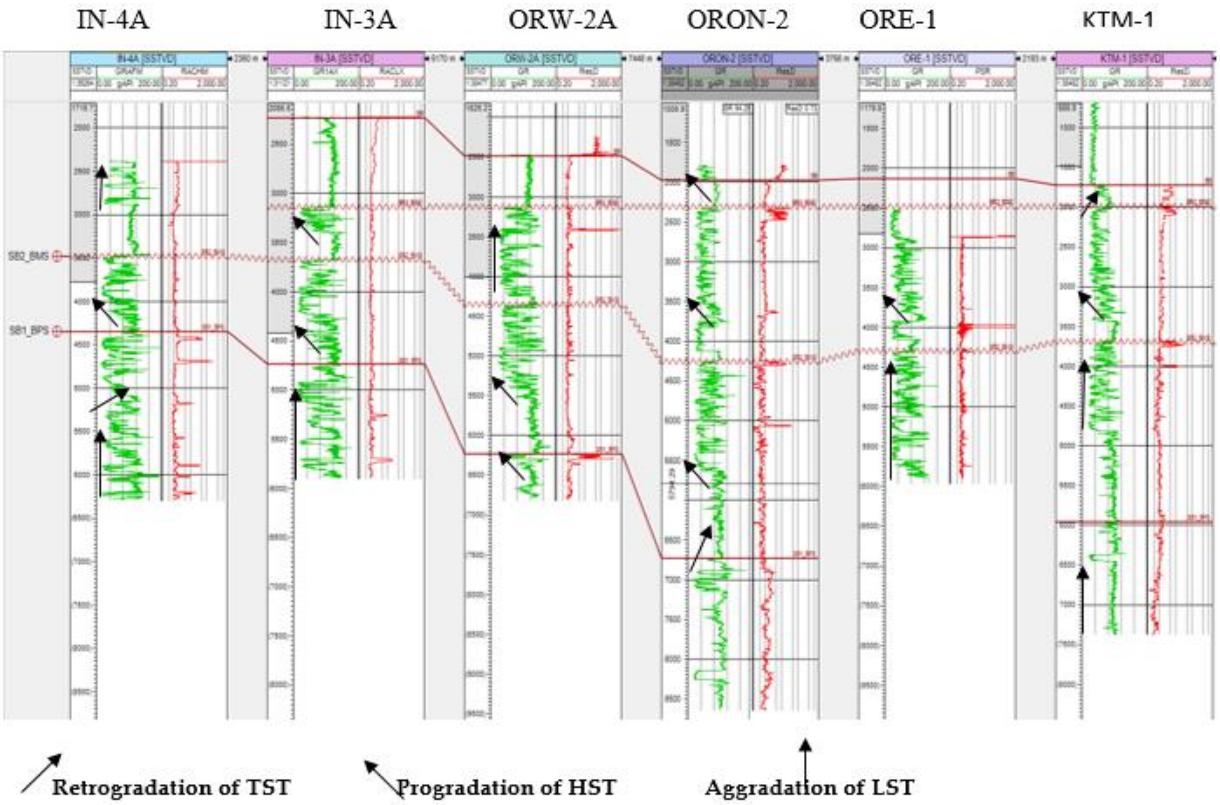


Fig. 6 Stacking pattern of the studied wells showing the mapped system tracts and sequence boundaries.

*D. Biostratigraphic Study*

This study covered 5 of the 6 wells in the OML XY block (Fig. 7) and facilitated the mapping of the age of the deposit to be early Miocene to late Pliocene. Condensed facies of the block were identified in IN-4A and ORON-2 wells (Fig. 7) and they represent the position of anomalously low sedimentation rate at the continental shelf. They provided a further evidence of change in sea level patterns for the OML XY block sediment of slow depositional condition with marine transgression, as such, associated with the Maximum flooding surfaces of the wells and serving as important sequence stratigraphic markers (Ibrahim *et al.*, 2020).

In the IN-3A well with a depth interval of 2153-5821ft, the age of the deposit from the recovered nanofossil species of Heliolithus Cantabriae and Heliliotus Kleinpellii species showed the deposit is of early Pliocene with an environment of depositional origin of outer shelf being predominantly associated with outer neritic biofacies. IN-4A well showed a depth interval of 2437-6326 ft with age delineation of late Miocene to early Pliocene with coastal/continental shelf facies associated with coastal deltaic to outer neritic biofacies. ORW-2A well with a depth interval of 2496-6410 ft showed an age delineation of late Miocene – early Pliocene with outer neritic to lower delta plain. ORON-2 well revealed 3 MFS of condensed sections in its profile at its depth interval of 1732-8621 ft, it ranges from early Miocene-late Pliocene with the environment of depositional episode showing regressive succession of coastal/shelfal facie associated mainly with inner neritic zone of the marine setting. ORE-1 well showed a depth interval of 2496 ft-5921 ft with age delineation of late Miocene- early Pliocene and coastal deltaic/estuarine environment of deposition.

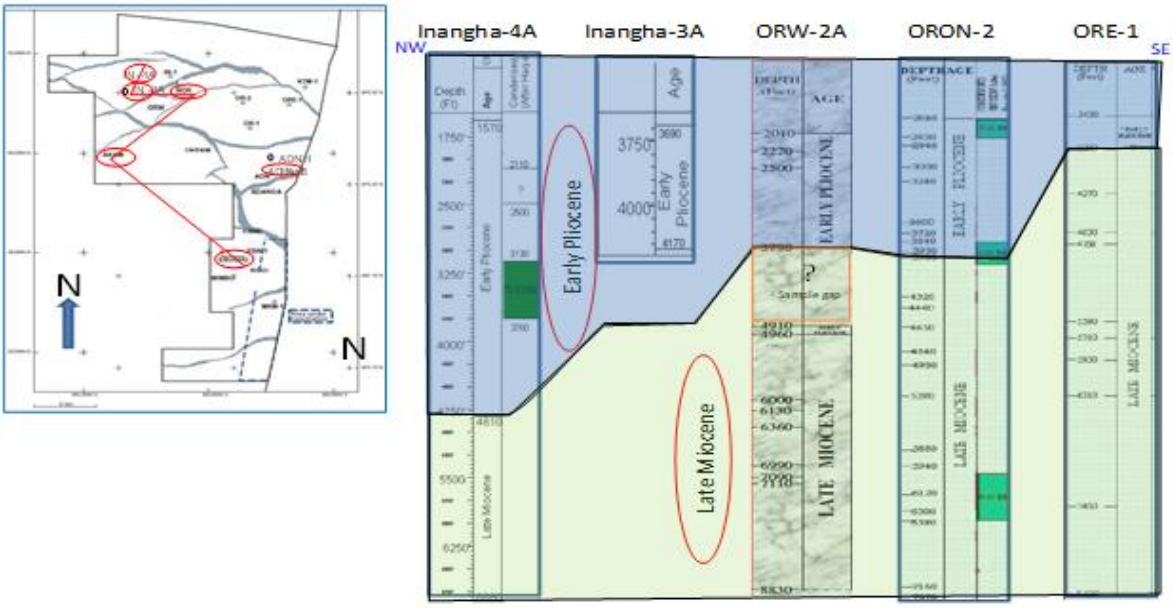


Fig. 7 Age delineation and identification of condensed sections in some of the studied wells

## CONCLUSION

Re-evaluation of OML XY block wells in Southern Niger delta was done for its Sequence Stratigraphic, structural and stratigraphic components and fluid content of 6 wells of the block. Sequence stratigraphic architecture of the wells revealed 3 mapped sequence boundaries of SB3_BQC, SB2_BMS and SB1_BQC that modified the porosity and permeability of the block deposit and are continuous with the mapped horizons of BQC, BMS and BPS, 3 system tracts of HST, TST and LST deposited at various depth intervals of each well showed progradational and retrogradational stacking pattern that varied from the continental shelf to the slope of the marine realm. Lithological distribution evaluation revealed sand and shale depositional sequence and zones of high and low hydrocarbon content of the 6 wells were mapped at depth intervals. Biostratigraphic study with the utilization of nannofossil abundance in 5 wells of the block revealed the condensed sections of some of the wells and verified the sediments ranges from late Miocene to early Pliocene in geologic age.

## RECOMMENDATIONS

Utilization of modern geologic tools like 4-D seismic will improve on the imaging of the deposit.

## ACKNOWLEDGEMENT

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## CONFLICT OF INTEREST

The research work was carried out by me and there is no conflict of interest associated with it.

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