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Hydrocarbon prospectivity of selected block wells, Southern Niger-delta, Nigeria

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ABSTRACT

The block wells are located in the South-eastern Niger Delta area. It extends between latitude 4° 18¹ N and 4° 42¹N to Longitude 7° 6¹and 7º 36¹ E. Low hydrocarbon production recently recorded that led to the abandonment of the block wells is the drive towards this assessment. IN-3A, IN-4A and IN-5A wells were thus re-evaluated to shore-up the hydrocarbon production potential. Well logs, seismic, isochron data, time and depth structural maps generated from petrel platform are exploration tools for the study. Findings has shown that IN-3A has about 8 reservoir units ie BQC, AC-1, BMS (P-4), BPS (1-1), BPS (1-2), BPS (1-3_2), (1-4) and 1-5 that constitute its play potential out of which BPS (1-3_2) and 1-5 constitute new pay sand units. IN-4A depositional sequence with 10 reservoir areas mapped out as its hydrocarbon play and include BPS (-1), BPS (1-2), BPS (1-1), 1-2, 1-3_2, 1-4, 1-5, J-1, J-2 and J-3 out of which BPS (1-1), 1-2, 1-3_2, J-1, J-2 and J-3 constitute new pay sand units mapped out with a high potential for more hydrocarbon production. Conversely, in IN-5A well, its depositional sequence revealed out of 10 reservoirs mapped out, no single pay zone was recorded. Mapped reservoirs included BMS (P-4), BPS (1-1), 1-1, 1-2, 1-3_2, 1-4, 1-5, J-1, J-2 and J-3 as such fracking will be needed to initiate new reservoir zones. The hydrocarbon producing potential of the studied wells are high due to cross linkages across the migrational conduits of the structural features in the block wells that will need little fracking. They are mostly footwall, hanging wall growth faults, anticlines and some unconformity traps with few horst and graben structures. In essence, this cross-linking fracking episode will improve on the porosity, permeability and oil saturation of the wells sediment for more hydrocarbon productivity.

Keywords: Depositional Sequence, Hydrocarbon Pay sand, Foot wall, Hanging wall and Reservoir.

1. INTRODUCTION

Hydrocarbon exploration and exploitation is crucial to human habitation on earth. In the majority of its development, the description of its reservoir is achieved through

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integrating well log, seismic data and other critical components of block wells. Almost all oil and gas produced today comes from accumulations in the pore spaces of reservoir rocks like sandstone, limestone or dolomites. The amount of oil or gas contained in a unit volume of such a reservoir is the product of its porosity, permeability and the hydrocarbon saturation (Ejedawe et al., 1984). The Niger Delta Basin, also referred to as the Niger Delta province, is an extensional rift basin located in the Niger Delta and the Gulf of Guinea on the passive continental margin near the western coast of Nigeria with suspected or proven access to Cameroon, Equatorial Guinea and São Tomé and Príncipe.

This basin carries high economic value as it contains a very productive petroleum system. It is one of the largest subaerial basins in Africa. It has a subaerial area of about 75,000 km2, a total area of 300,000 km2, and a sediment fill of 500,000 km3. The sediment fill has a depth between 9–12 km. The article explains the hydrocarbon potential of selected block wells in the southern part of the area. They are composed of bands of sediments about 30–60 km wide with lengths of up to 300 km. They contain major fault– bounded sequences which is of shoreface alternating sand/shale sequence limited at the proximal end by a major boundary growth fault and at the distal end by a lithofacies change, a counter- regional growth fault, a major boundary fault of a succeeding depobelt, or any combination of these.

2. LOCATION OF THE STUDY AREA

The block sediment is a coastal deposit through shallow water to offshore area of the block, located in the Southeastern Niger Delta, it extends between latitude 4° 18^1 N and 4° 42^1N to Longitude 7° $6^1$and 7º 36^1 E. Thirteen (13) fields have been discovered till date in the studied well area, they include Akam, Kita Marine, Inagha, North Oron, Oron West, Oron East, Adanga, Ebughu, Bogi, Ukpam, Mimbo, Antan and Ebne. It is also necessary to note that about seventy (70) wells have been drilled till date. Its depobelts (Afam, Opuoma and Qua Iboe channels) are sites of great accumulations of sediments for further petroleum exploration activities (Figure 1).

Depending on sea level changes, local subsidence and sediment supply in the selected block area, the investigated deposit experienced phases of regressions and transgressions as dictated by its system tracts pattern. They are composed of bands of sediments about 30–60 km (Figure 2) wide with lengths of up to 300 km. They contain major fault– bounded sequences which is of shoreface alternating sand/shale sequence limited at the proximal end by a major boundary growth fault and at the distal end by a lithofacies change. The deposit of the study area ended with the syn-rift phase with basin inversion in the Santonian (Late Cretaceous).

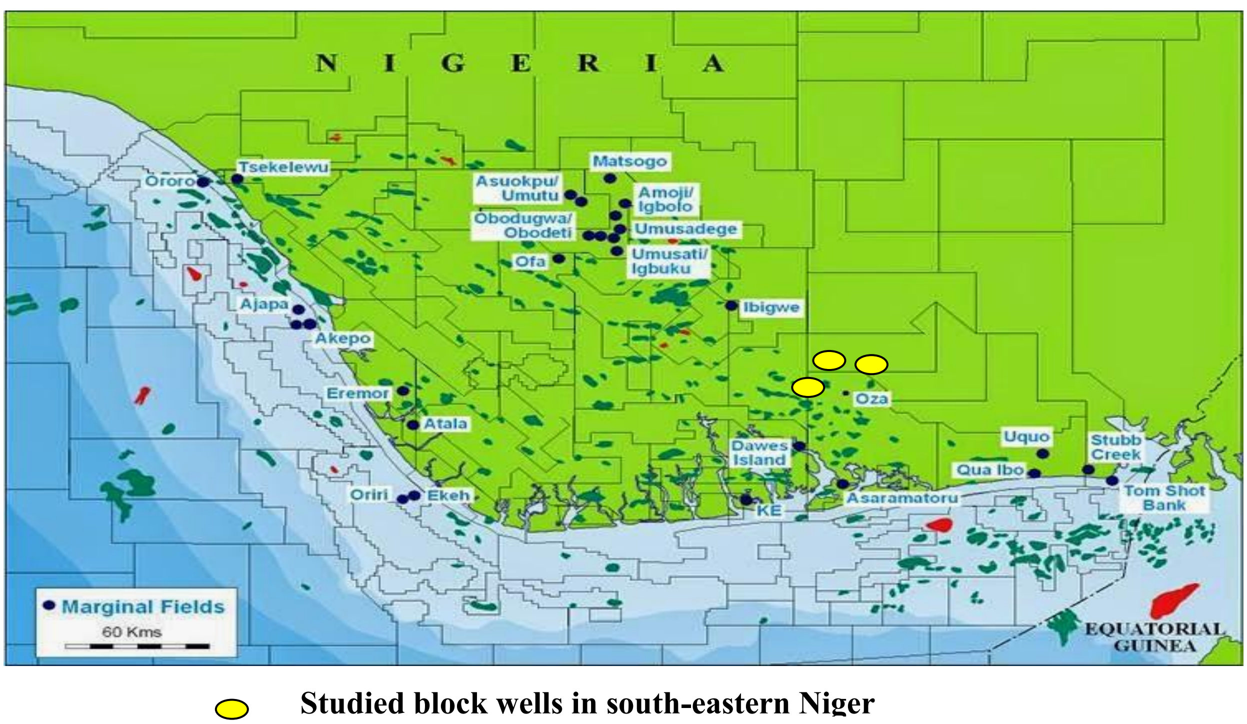


Figure 1 Satellite image showing the study area of the block wells

The Geology of the Delta and block wells

It is composed of several different geologic formations that indicate how this basin could have formed, as well as the regional and large-scale tectonics of the area. The Niger Delta Basin is an extensional basin surrounded by many other basins in the area that all formed from similar processes. It lies in the south westernmost part of a larger tectonic structure; the Benue Trough The other side of the basin is bounded by the Cameroon Volcanic Line and the transform passive continental margin. The block well sediment is controlled by marine transgressive/regressive cycles related to eustatic sea-level changes with varying durations (Ibrahim et al., 2019; Ibrahim et al., 2020). The various sea-level cycles were in or out of phase with each other and with local subsidence, and interfered with each other, thus influenced the depositional processes of the selected block deposit. At the high inflection points of the long-term eustatic sea-level curve, floodings took place that resulted in delta-wide shale markers in the southern part of the Niger delta and was noticeable in the selected block wells.

Three macro-sequences i.e. depositional sequence developed and were identified in this study with sequence boundaries: BPS (Base P-Shale), BMS (Base M-Shale) and BQC (Base Qua-Iboe Channel). These macro-sequences of the block constitute an important part of this study, as part of sequence stratigraphic position of the block deposit as previously mentioned (Figure 2) (Ibrahim et al., 2020). In a nutshell, the sea level rose faster than the rate of sediment supply in the block area and this gave rise to the formation of all TST i.e. Transgressive system tracts with retrogradational stacking pattern of its beds, as such the shoreline and facie patterns moved landward and led to finning upward sequence. Also, with increased sediment supply to the continental shelf when sea level rise began to slow down, Highstand system tracts of the block formed, and a progradational stacking pattern developed with facies and shoreline moving seaward and led to coarsening upward sequence.

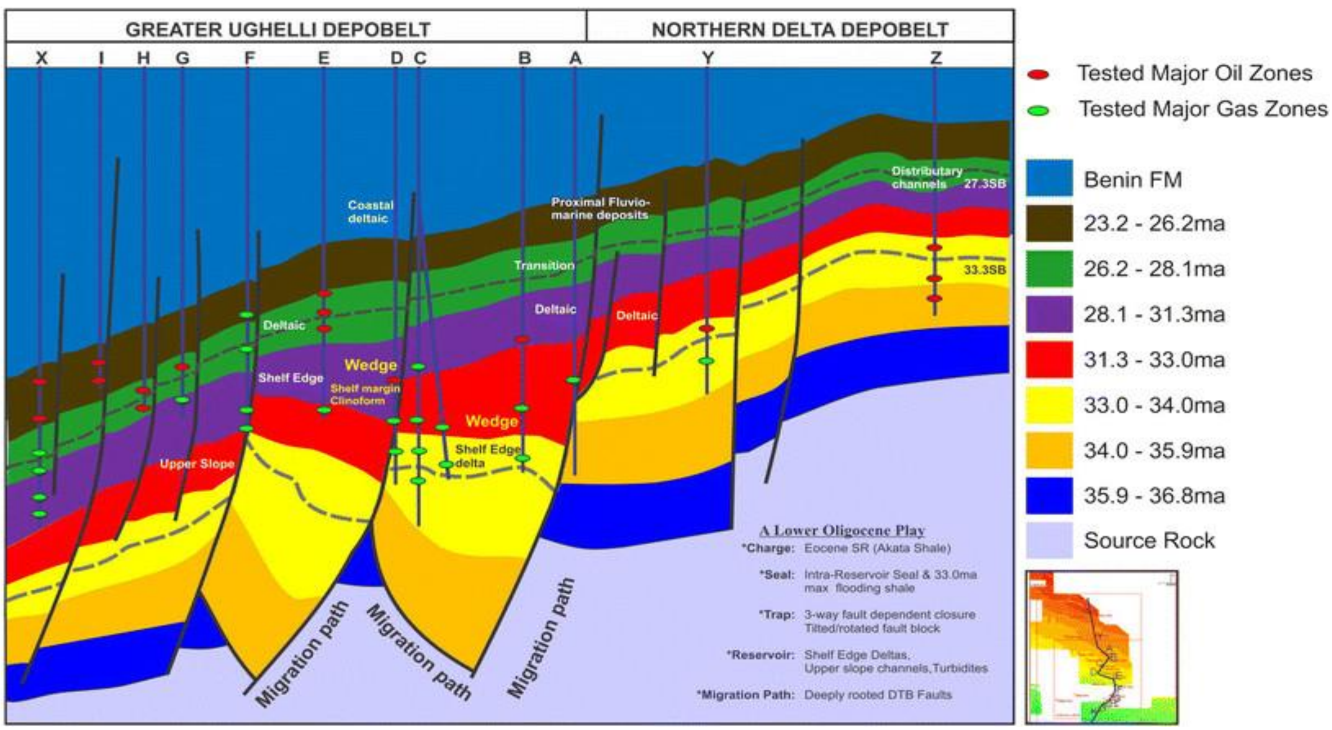


Figure 2 Structural features of the block wells with tested oil and gas zones

Geomorphology of the basin area

The basin area around this coastline was interrupted by series of estuaries that form the Niger Delta swamp at the middle where the Lower Niger River system drain the water of Niger and Benue rivers into the Atlantic Ocean. This delicate mangrove swamp of the Niger Delta covers a coastline of 560 km2, about two-thirds of the entire coastline of Nigeria and the wetland in this region is traversed and criss-crossed by a large number of rivers (Figure 3), rivulets, streams, canals and creeks. The Delta is a rich mangrove swamp in the southernmost part of Nigeria covering over 20,000km² within wetlands of 70,000km² formed primarily by sediment deposition. It is the largest mangrove swamp and wetland in Africa, maintaining the third largest drainage basin in the continent and is also the third largest wetland in the world after Holland and Mississippi. The major drainage systems of the delta consist of seven discrete river systems which lie squarely in the wet equatorial climatic belt.

Methodology of study

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. Saline aquiferous underground water resistivity is low with response to resistivity log, while that of hydrocarbon is high.

TWT generated data of seismic reflection on the deposit and interpretation on petrel interphase facilitated the mapping of the new structural components study of the block wells. Isochron data, time and depth structural maps were generated on the petrel window to further probe the new reservoirs that could produce hydrocarbon in the block wells. Before interpretation, the data were validated, imported and edited to minimize errors. After validation of the available well data, the log data which was in the LAS data format was imported and then the 3-D seismic data which was in the SEG-Y data format was later imported using the local coordinate reference system.

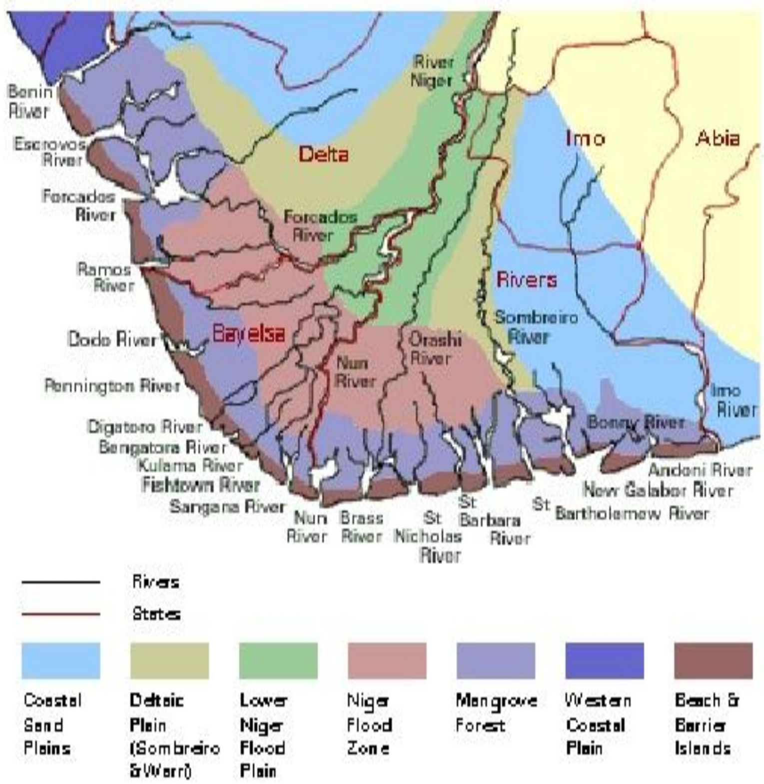


Figure 3 Diagram showing the network of rivers across Niger delta area.

3. DATA ANALYSIS AND DISCUSSION

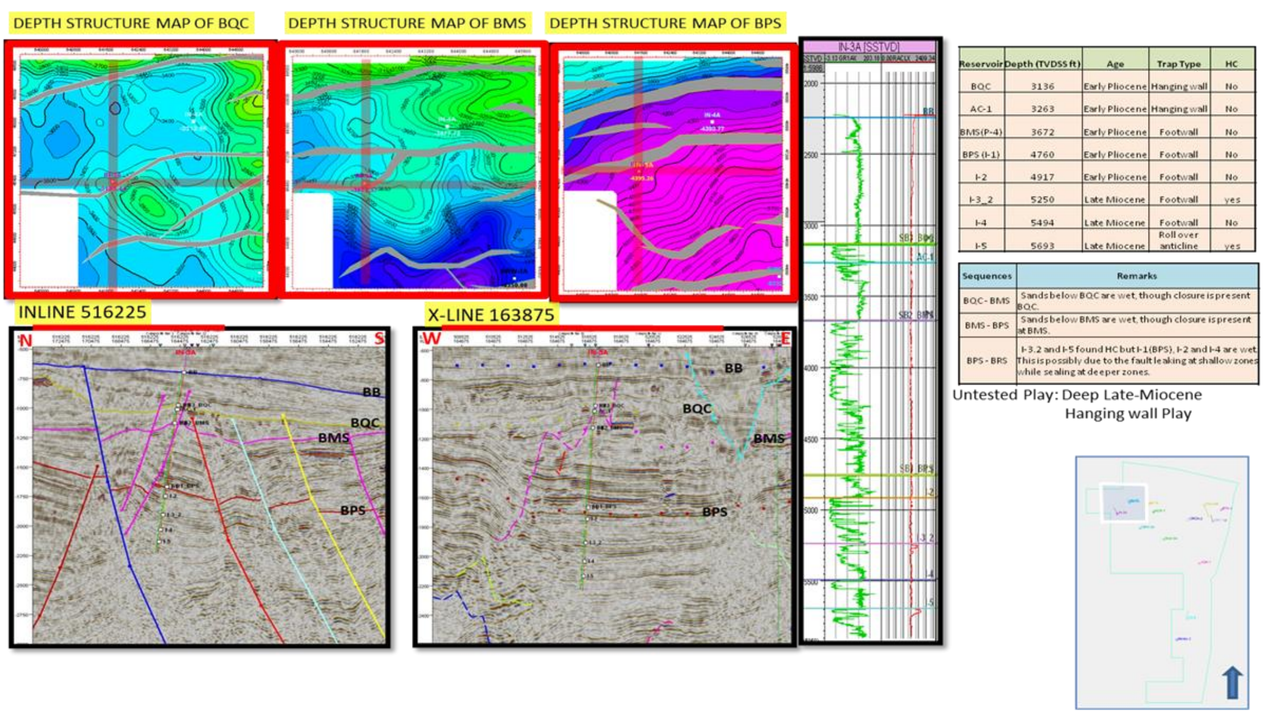
3 wells in the block area were analyzed for this study for the sequence boundaries, new fault network and more importantly, reservoir zones for the hydrocarbon productivity of the well. In essence, the re-evaluation revealed new findings that will shore up the production of the wells if harnessed.

Sequence boundaries and fault network of IN-3A well

Sequence boundaries of IN-3A well i.e. BB, BQC, BMS and BPS were mapped at various intervals along the seismic profile (strike and dip). More importantly on the well log, these surfaces were identified at various depths of the well. As such, at 716 meter, surface BB was identified, SB1_BQC at 998 meter, SB2_BMS at 1168 meter and SB3_BPS at 1514 meter. It is worthy of note that, other sub-reservoir units of these main reservoirs were also identified to constitute part of the play in the IN-3A well. The BB sequence boundary surface extends from the southern part at inline of 516225 to the northern part of the seismic profile. This sequence boundary surface also struck the most prominent fault at its proximal end in the seismic profile along the North-Southern trend. It is very extensive, but not connected to most fractural trends in the seismic profile. BQC is another boundary surface identified on the seismic profile with a limitation of extensiveness but cuts across many faults in the profile.

It can be traced to a depth of about 1099 meter in the N-S trend of the well and 1049 meter in the E-W direction of the seismic profile. BMS surface is better delineated in the N-S trend of the seismic profile at an inline of 516225 and was studied to be interrupted by faulting in the southern part of the profile of the IN-3A well. BMS surface continued to the northern side of the seismic profile and was struck by the IN-3A well at a depth of 1099 meter (Figure 3). The regional growth faults which are listric in nature and are concave basinwards are common with hanging and footwall component. They are mainly dipping in the same direction as the main fault with a few antithetic faults that dip in opposite direction to the main fault. The main fault and the minor faults were picked by tracking an alignment of terminating events on the seismic profile.

The faults were identified, correlated, assigned unique names and marked with different colours, also they are continuous with their surfaces by common colour codes. It has 6 mapped faults with F1 being reddish in colour and has a depth range from 1407 meter to 2824 meter in the northern end of the profile and cutting through SB1_BPS surface. It was revalidated as a better major fault at the southern end with depth ranging from 926 meter to the bottom of the profile and passing through BPS and BMS surfaces. F2 fault is blue in colour, passing through BQC, BPS and BMS surfaces terminating at the base of the profile and not revalidated elsewhere.



Reservoir	Depth (TVDSS ft)	Age	Trap Type	HC
BQC	3136	Early Pliocene	Hanging wall	No
AC-1	3263	Early Pliocene	Hanging wall	No
BMS(P-4)	3672	Early Pliocene	Footwall	No
BPS (I-1)	4760	Early Pliocene	Footwall	No
I-2	4917	Early Pliocene	Footwall	No
I-3_2	5250	Late Miocene	Footwall	yes
I-4	5494	Late Miocene	Footwall	No
I-5	5693	Late Miocene	Roll over anticline	yes

Sequences	Remarks
BQC - BMS	Sands below BQC are wet, though closure is present BQC.
BMS - BPS	Sands below BMS are wet, though closure is present at BMS.
BPS - BRS	I-3.2 and I-5 found HC but I-1(BPS), I-2 and I-4 are wet. This is possibly due to the fault leaking at shallow zones while sealing at deeper zones.

Figure 4 Macrostructure of IN-3A well showing the reservoir zones

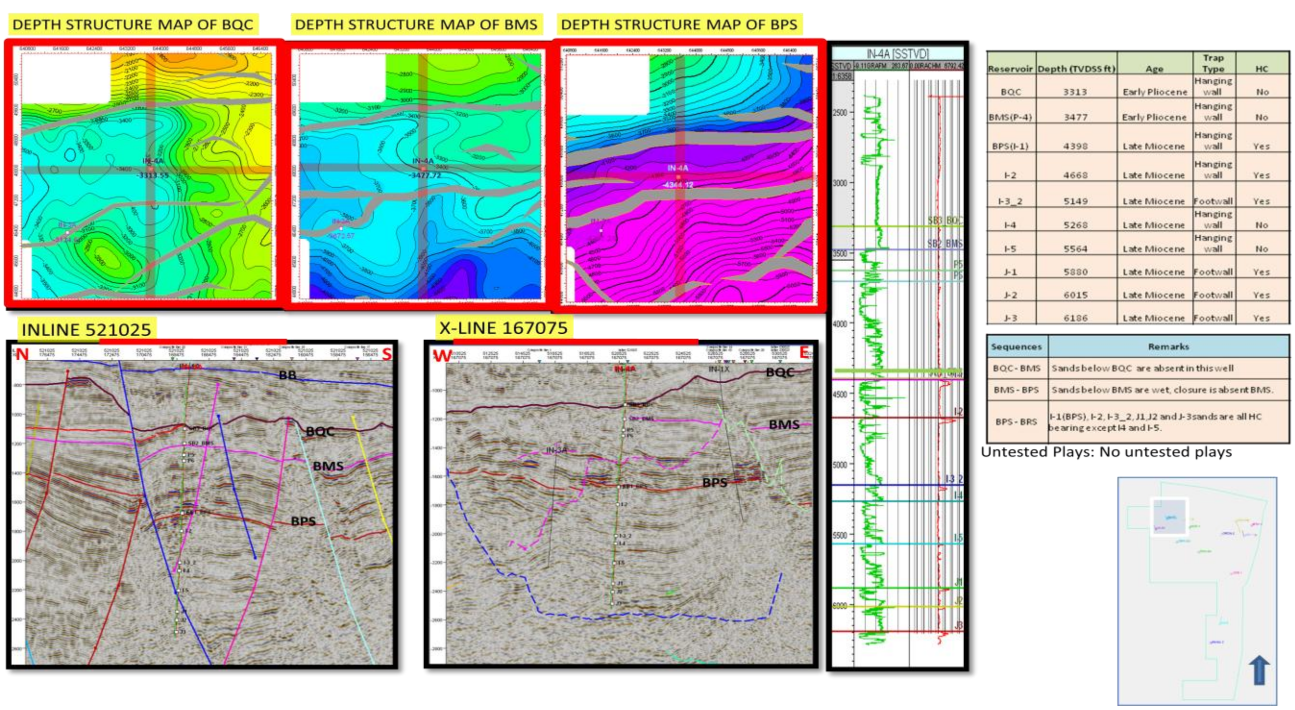
F3 fault is purple in colour with depth ranging from 823 to 1820 meter. It was revalidated in 2 other areas of the profile in the same colour. F4 is greenish in colour at the southern end at a depth of 930 meter to the base of the profile. F5 is at the southern end of the profile colour coded yellow and range from a depth of 1003 meter to the base. Reservoir zones mapped in the N-S and E-W ends of the profile include BB, SB3-BQC and AC-1 at 624, 893 and 924 meter respectively. Others include BMS, BPS, 1-2, 1.3-2. 1-4 and 1-5 at 1140, 1630, 1695, 1890, 2009 and 2185 meter respectively. On well log, the mapped reservoir units include BQC, AC-1, BMS 1-2 at 998, 1038, 1168 and 1514 meter respectively. 1-3-2, 1-4 and 1-5 are 1670, 1748 and 1811 meters respectively.

Sequence boundaries and fault network of IN-4A well

In the N-S trend, the 7 mapped faults (F1, F2, F3, F4 and F5) were analysed with their sequence boundary surfaces of BB, BQC, BMS and BPS. F1 fault is denoted colour yellow and runs from 903 meter to 1459 meter before disappearance. It was revalidated at the extreme southern end of the seismic profile, running at 1051 meter and trends to a depth of 1902 meter. F2 fault in colour red in the northern side of the profile shows it runs from a depth of 603 meter to 1909 meter. It was revalidated in the same colour at the southern side at a depth of 1500 meter through to the bottommost part of the profile. F3 fault has been denoted colour blue and is located at the northern side of the IN-3A well before disappearance, only to be revalidated at the southern side of the profile. F4 fault has been pink colour coded. It runs from a depth of 800 meter to 2100 meter, cutting across BQC, BMS and BPS surfaces with other minor traps in the sequence.

It terminates at 2100 meter, but revalidated at the southern end of the profile and runs from depth 1100 meter to the bottommost part of the seismic profile. F5 fault was coloured green in the N-S section of the seismic profile of well IN-4A and runs from the northern to the southern side of the profile at a depth of 1100 meter to the bottommost part of the profile (Figure 4). The IN-4A well in this N-S profile penetrated SB3_BQC, SB2_BMS, P5, P6, SB1_BPS, 1-2, 1.3-2, 1-4, 1-5, J1, J2 and J3 from top to the bottom of the seismic profile including the E-W trend of the profile. Reservoir units on log pattern are BQC was mapped at 1054 meter, BMS at 1106 meter, BPS was at 1399 meter P5 to be 1152 meter, P6 at 1177 meter, 1-2 at 1485 meter, 1.3-2 was mapped at 1638, 1-4 at 1676, 1-5 at 1770. J1, J2 and J3 at 1871, 1914 and 1968 meter respectively.

Sequence boundaries and fault network of IN-5A well



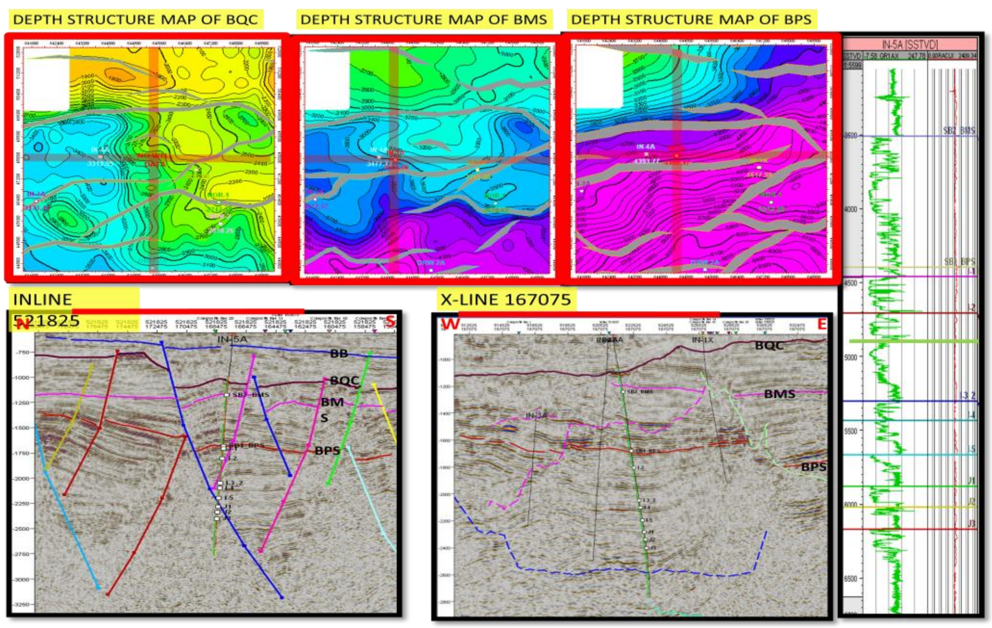
Reservoir	Depth (TVDSS ft)	Age	Trap Type	HC
BQC	3313	Early Pliocene	Hanging wall	No
BMS(P-4)	3477	Early Pliocene	Hanging wall	No
BPS(I-1)	4398	Late Miocene	Hanging wall	Yes
I-2	4668	Late Miocene	Hanging wall	Yes
I-3_2	5149	Late Miocene	Footwall	Yes
I-4	5268	Late Miocene	Hanging wall	No
I-5	5564	Late Miocene	Hanging wall	No
J-1	5880	Late Miocene	Footwall	Yes
J-2	6015	Late Miocene	Footwall	Yes
J-3	6186	Late Miocene	Footwall	Yes

Sequences	Remarks
BQC - BMS	Sands below BQC are absent in this well
BMS - BPS	Sands below BMS are wet, closure is absent BMS.
BPS - BRS	I-1(BPS), I-2, I-3_2, J1,J2 and J-3sands are all HC bearing except I4 and I-5.

Figure 5 Macrostructure of IN-4A well showing the reservoir zones

IN-5A well revealed F1. F2 fault and has been coded yellow and found at the extreme northern part and southern part of the IN-5A well. At the northern end, it runs from 900 meter to 1900 meter, while at the southern side, it runs from 1050 feet to 1520 feet, cutting across the BPS surface. F3 fault has been denoted a brown colour at the northern end of the seismic profile. It runs at a depth of 800 meter to 2150 meter and 1550 meter to 3150 meter of the northern side of the well. F3 fault was denoted deep blue colour with the main fault trending from a shallow depth of 500 meter to a deeper depth of 3150 meter and cutting across the IN-5A well from the northern end to the southern side of the well and seismic profile and cutting across many surfaces. It was revalidated at the southern end from a depth of 1050 meter to 1800 meter.

F4 fault is pinkish in colour in the southern side of the seismic profile, with the first closer to the drilled IN-5A well, occurring at a depth of 770 meter to 2130 meter and cutting across the drilled well at 1.3-2 sub-surface (Figure 5). This fault was also revalidated at a depth interval of 1050 meter to 2650 meter cutting across BMS and BPS surfaces. F5 fault is green in colour i.e. deep and light green mapped at the extreme southern side of the profile. This seismic profile was interpreted to have a drilled IN-5A well encountering reservoir units and sub-units from the N-S to the E-W trend of the well. The corresponding tied well log was interpreted to have a SB2_BMS reservoir at 1117 meter. SB1_BPS at 1397 meter. 1.1 reservoir unit at 1420 meter, 1-1 and 1-2 at 1420 meter and 1496 meter respectively. 1.3-2 at 1687, 1-4 at 1729, 1-5 at 1802 meter. J1, J2 and J3 at 1869, 1914 and 1963 meter respectively.



Reservoir	Depth (TVDSS ft)	Age	Trap Type	HC
BMS(P-4)	3510	Early Pliocene	Hanging wall	No
BPS(I-1)	4392	Late Miocene	Hanging wall	No
I-1	4464	Late Miocene	Hanging wall	No
I-2	4702	Late Miocene	Hanging wall	No
I-3_2	5302	Late Miocene	Footwall	No
1-4	5435	Late Miocene	Hanging wall	No
I-5	5662	Late Miocene	Hanging wall	No
J-1	5873	Late Miocene	Footwall	No
J-2	6016	Late Miocene	Footwall	No
J-3	6170	Late Miocene	Footwall	No

Sequences	Remarks
BQC - BMS	BQC not logged
BMS - BPS	Sands below BMS are wet, closure is absent in BMS.
BPS - BRS	Sands below BPS are wet.

Untested Plays: No untested plays

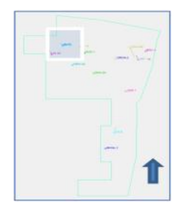


Figure 6 Macrostructure of IN-5A well showing the reservoir zones

It is worthy of note that the faults identified on the block wells of the petrel window were 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.

Horizon analyses of the sequence boundaries of the wells

Identification of horizons is based on reflection continuity. This implies that most recognizable and continuous event were traced throughout the seismic section and found to be more of pocket of isolated sand reservoir units. Mapping of horizons on the seismic section have to do with the proper understanding of the seismic attributes such as the amplitude and the low regions of all horizons and strata slices of the wells are indicative of isolated reservoir zones. This was corroborated by the time slice of the wells at 10 m/s at the intervals of BQC, BMS and BPS of the studied wells. In essence, fracking the network of faults and isolated pocket of sand reservoir will be important to produce more hydrocarbon from this area.

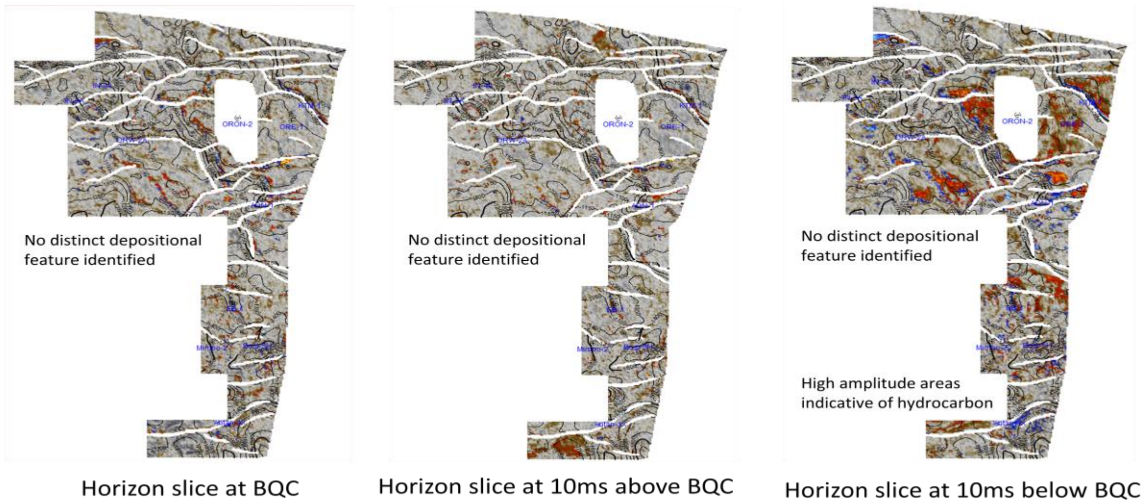


Figure 7 Horizon time slice at the shallowest sequence boundary of BQC surface.

Horizon time slice was done across the mapped sequence boundaries of BQC, BMS and BPS surfaces to view and study the new mapped fault network, paleo depositional condition and possible hydrocarbon indicators of the block wells. This corroborated the findings of possible detection of hydrocarbon fluid with the newly mapped out thick sand reservoir areas of the block wells. More importantly the need of fracking will be unavoidable due to the poor reservoir linkages recorded in some of the wells. The horizon time slice at BQC revealed floating structures that are not properly linked to allow economical exploitation of hydrocarbon (Figure 7, 8 & 9). More importantly, the slice allowed detail imaging of the depositional characteristics to be thick sand floating sand units, low amplitude record which revealed pool of hydrocarbon that could not be produced in isolated condition except they are well linked.

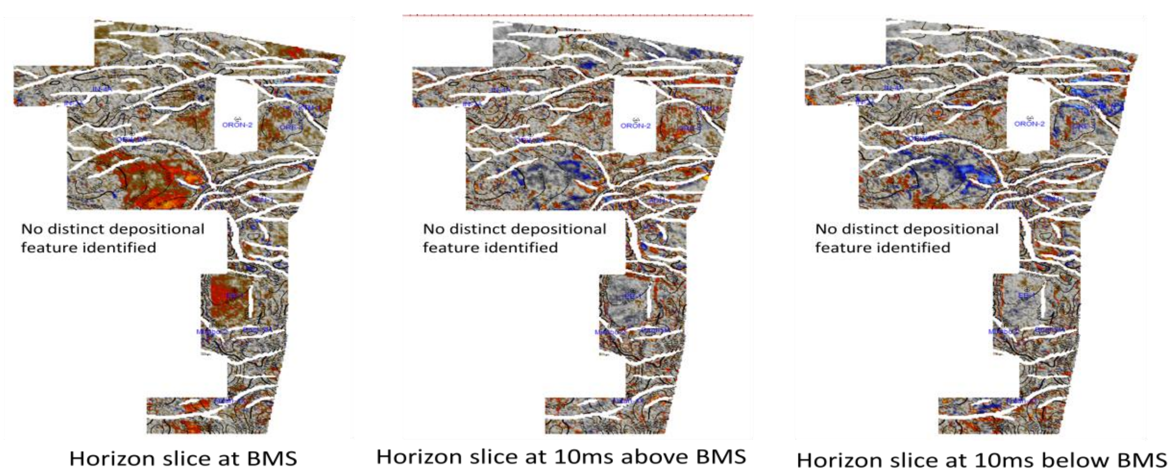


Figure 8 Horizon time slice at the intermediate sequence boundary of BMS surface.

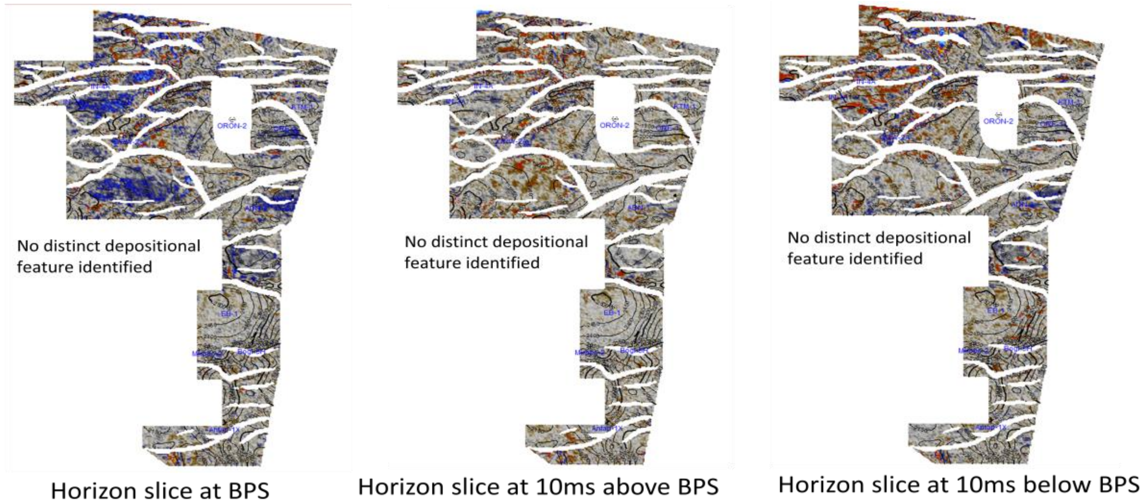


Figure 9 Horizon time slice at the deepest sequence boundary of BPS surface.

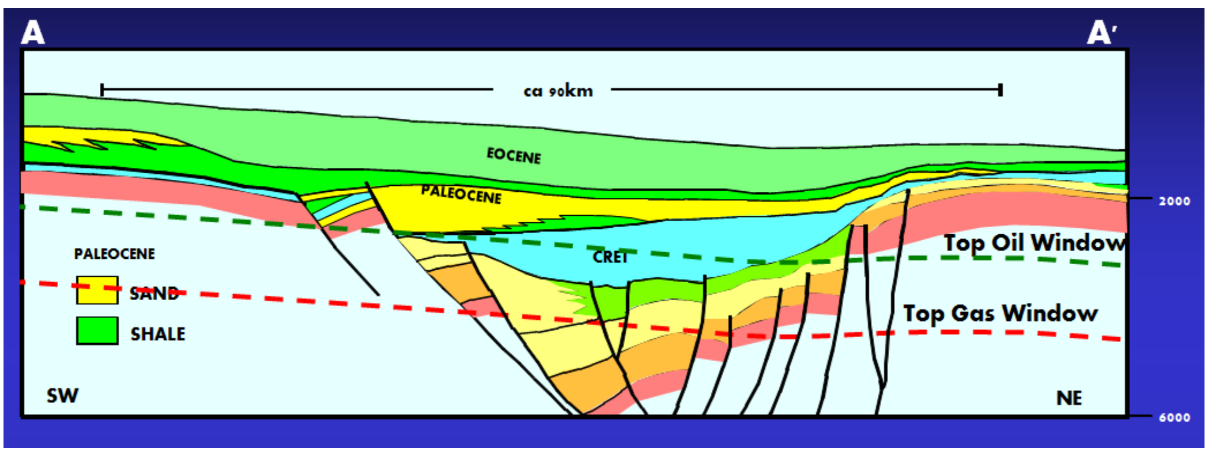


Figure 10 Growth faulting network with oil and gas window of the wells deposit

The oil and gas window of the wells are noticeable at 1673 meters and 1971 meters respectively (Figure 10). More importantly, the sand units are known to be Paleocene and are known to host most of the reservoir zones contained in the wells deposit. However, in the early synrift phase of the sand fill, parallel major fault trends developed in the studied wells and this indicated strong tectonic control on the sand sediment transport that constituted the missed reservoir zones of the well. Alluvial fan sandstone was found as low amplitude regions around all slices of the wells along the key stratigraphic surfaces. Horizon, strata and time slice of the studied wells all indicated pockets of reservoir units that were suspended in the area of study. The time slice was done at 10 m/s to allow proper assessment of the detailed view of the pockets of reservoir zones contained in the studied wells.

4. CONCLUSION

The IN-4A well in this N-S profile penetrated SB3_BQC, SB2_BMS, P5, P6, SB1_BPS, 1-2, 1.3-2, 1-4, 1-5, J1, J2 and J3 from top to the bottom of the seismic profile including the E-W trend of the profile. Reservoir zones mapped in the N-S and E-W ends of the profile of IN-3A included BB, SB3-BQC and AC-1 at 624, 893 and 924 meters respectively. Others include BMS, BPS, 1-2, 1.3-2. 1-4 and 1-5 at 1140, 1630, 1695, 1890, 2009 and 2185 meter respectively. IN-5A well showed its fault revalidated at the southern end from a depth of 1050 meter to 1800 meter. F4 fault is pinkish in colour in the southern side of the seismic profile and occurring at a depth of 770 meter to 2130 meter and cutting across the drilled well at 1.3-2 sub-surface. 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.

They conform with the three predominantly prograding depositional sequences bounded by sequence boundaries delineated. Growth faults with footwall and hanging walls mapped out during the study constitute the main conduits for hydrocarbon storage and movement in the wells. More importantly, the slice study allowed detail imaging of the depositional characteristics that revealed thick sand i.e. floating sand units, low amplitude record which pointed to pool of hydrocarbon that could not be produced in isolated condition of the deposit except they are well linked by fracking and introduction of artificial conduits.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Funding

The study has not received any external funding.

Data and materials availability

All data associated with this study are present in the paper.

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