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EVALUATION OF HYDROCARBON PROSPECT OF TOMBOY C-FIELD OFFSHORE NIGER DELTA, NIGERIA

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Abstract
3D Seismic data and well logs were used to re- evaluate the hydrocarbon prospects of Tomboy C- field located offshore Niger Delta Basin, Nigeria. The study was aimed at identifying the unharnessed hydrocarbon prospects in the field . Three lithostratigraphic units of Niger Delta: Akata, Agbada and Benin Formations were analyzed from seismic reflection time interval of 0 to 5800ms, with the Akata , Agbada and Benin Formations occurring beyond 3800ms, between 1550 to 3800ms and 0 to 1550ms respectively. The depositional environments of the reservoirs were interpreted as distributary channel (lower deltaic plain), distributary mouth bar (part of deltaic front) and lower shoreface (part of pro-delta) in agradation. A total of eight faults (FLT1 to FLT8) were identified and mapped respectively. FLT2 and FLT3 were identified as major growth faults that partitioned the field into three fault blocks named FBLK1, FBLK2 and FBLK3. Thirteen horizons were mapped and integrated with the mapped faults to produce both time and depth structural maps. Facies and petrophysical analysis were carried out with hydrocarbon prospects identified within FBLK2 and FBLK3. Hydrocarbon prospects were identified in the undrilled fault blocks with fault assisted anticlinal closures. Bypassed hydrocarbon prospects identified in the field occur in the form of low resistivity pay zones (low contrast) with a range between 1.50 to 2.02ohms for wellsTMB01 and TMB04 respectively. Stratigraphic traps were identified as pinchout in well TMB01.

Keywords*: Faults, Well log, Seismic Data, Reservoir, and Facies Analysis*

Introduction

The study area is located within the Niger Delta Basin, Nigeria. The Niger Delta Basin is one of the largest regressive deltas in the world with an area of some 300,000km^2 [6], a sediment volume of 500,000km^3[5] and a sediment thickness of over 10km [1]. According to [6], the Niger Delta Province contains only one identified petroleum system. This system is referred to as the Tertiary Niger Delta (Akata-Agbada) Petroleum System.

Nevertheless, oil and gas are the main revenue sources for most countries endowed with hydrocarbon accumulation and Nigeria is no exception. Recent increase in revenue demand for development within Nigeria has informed the need for more oil and gas discoveries. However, the difficulty in finding new fields in the mature Niger-Delta hydrocarbon province has motivated explorationists to re-visit old fields to search for bypassed oil and gas accumulations so as to meet the nation's hydrocarbon resource target of 40 billion barrels by 2020.

Currently, exploration and production effort is ongoing in the frontier deep-offshore Niger Delta. The cost of exploration and production for hydrocarbon within this deep offshore belt is very high due to environmental and technology demand. It is common knowledge that exploration, drilling and production technology were not precise when these onshore and shallow offshore fields were exploited. Consequently, a lot of oil and gas may have been bypassed. This therefore justifies the need to re-visit these fields so as to search for more reservoirs which may hold significant hydrocarbon reserves using available modern cutting edge exploration technology.

Geologic Setting

The Tomboy C-Field lies within the western margin of the offshore Niger Delta. It is located 120km off the coast between water depth of 1000-2000 meters. According to [11], the Niger Delta is a regressive sequence in which the rate of sediment supply far exceeded the rate of subsidence, resulting in the accumulation of a progradational clastic wedge approximately 12km thick.

More so, the tectonic framework of the continental margin along the west coast of equatorial Africa is controlled by Cretaceous fracture zones expressed as trenches and ridges in the deep part of Atlantic Ocean [8]. In Nigeria, rifting started in the late Jurassic and persisted into the Middle Cretaceous; rifting diminished altogether in the late Cretaceous [3]. After rifting ceased, gravity tectonism became the primary deformational process [6].

In addition, shale mobility induced internal deformation occurred in response to two processes. First, shale diapirs formed from loading of poorly compacted, over-pressured, prodelta and delta-slope clays (Akata Formation) by the higher density delta-front sands of the Agbada Formation [14]. Second, slope instability occurred due to a lack of lateral, basin-ward support for the under-compacted delta-slope clay (Akata Formation). For any given depobelt gravity tectonics are completed before deposition of the Benin Formation and are expressed in complex structures, such as shale diapirs, roll-over anticlines, collapsed growth fault crests and steeply dipping closely spaced faults[4,15]. These faults displace various part of the Agbada Formation and roll out into detachment planes close to the top of the Akata Formation. Fig. 2 shows the stratigraphic column of three formations in the Niger Delta

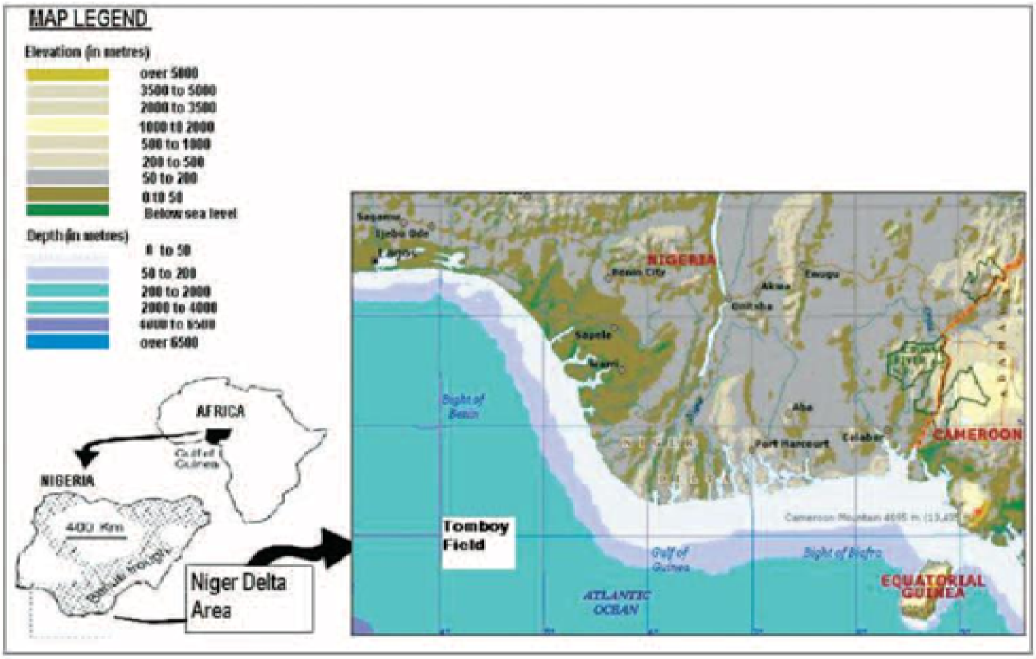


Fig.1: Location of the study area [10]

Materials and Methods

The data set available for this research work includes geophysical well logs from six wells namely; caliper, gamma ray, spontaneous potential, resistivity, density, neutron and sonic logs, processed Tomboy field 3D Seismic volume (Fig. 3 and Table 1), velocity check-shot data and core petrophysical data. The 3D Seismic volume was provided for this interpretation in SEY-Y format which is a zero phase data with Anti-SEG (American) polarity convention where a peak represents a negative reflectivity or decreasing acoustic impedance. The survey area coverage is 400m x 200m. Petrel 2012 version software was used for this interpretation.

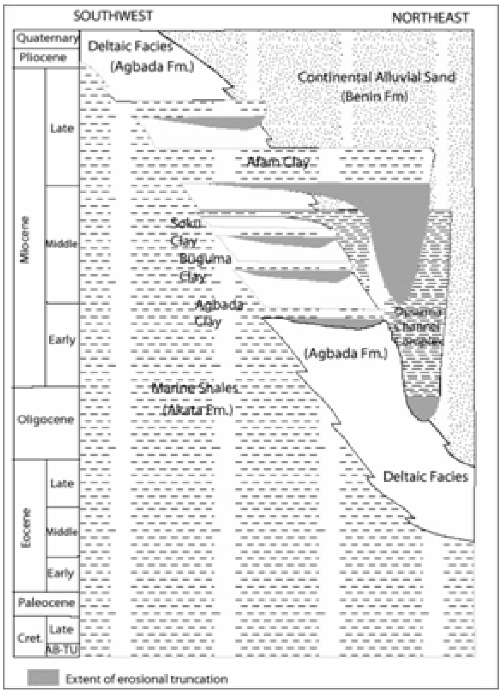


Fig. 2: Stratigraphic column showing the three formations in the Niger Delta [3]

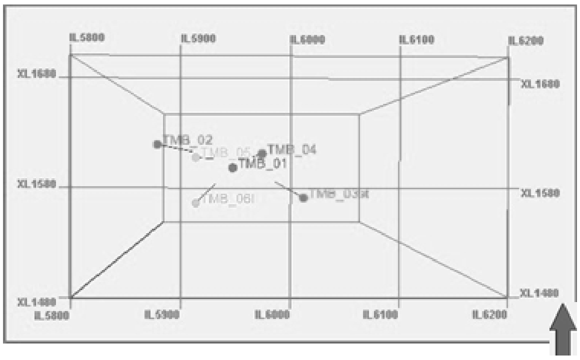


Fig. 3: Base Map of Tomboy Field showing the location of the six wells

Table 1: Summary of well logs in the study area

Well Name	Log Type							
	Cliper	Gamma	Resistivity	S.P.	Sonic	Porosity	Density	Neutron
TMB 01	A	A	A	A	A	A	NA	NA
TMB 02	A	A	A	A	A	NA	A	NA
TMB 03	A	A	NA	NA	NA	NA	A	A
TMB 04	A	A	A	A	A	A	NA	NA
TMB 05	A	A	NA	NA	NA	A	A	NA
TMB 06	A	A	A	A	NA	NA	NA	A

Note: A-Available; NA-Not-available

Detailed Seismic structural interpretation which includes the reservoir geometry and the geologic boundaries of the field generating the structural framework of the reservoirs and creation of a velocity model necessary for the depth conversion were carried out. Mapping of key horizons and faults on 3D Seismic data were done in order to subdivide the section of interest into packages made up of sequences or parasequences. Identification of reservoir in the well logs with prospects for hydrocarbons and well to seismic ties were also performed.

Finally, Seismic and wireline log interpretations were integrated to develop 3D static reservoir model which involved integration of all the structural, stratigraphic and petrophysical data in order to establish a realistic representation of the subsurface geology for prospect identification. The fault blocks within the field will be evaluated for prospectivity using Root Mean Square hydrocarbon (RMS) attribute. RMS attribute will be extracted from the depth map of the mapped horizons to detect the presence of hydrocarbon.

Results and Discussion

Well Correlation

Four wells were correlated across strike line (TMB_02, TMB_05, TMB_01 and TMB_ 04) while two wells (TMB_02 and TMB_06I) were correlated on dip line. Correlation across strike revealed good lateral continuity of the reservoirs. All the mapped horizons were correlated from well to well within the field. Sand development was shown to be better in the western part of the field (TMB_02) and becomes shalier towards the eastern part (TMB_04) (Fig. 4). However, the dip line correlation across the area was more complex and difficult (Fig. 5). This complexity was due to the influence of faulting.

Depositional environments

The depositional environment was interpreted from the Gamma ray signatures and sand/shale ratio of TMB_01 well which is the deepest well penetrated. Three main depositional environments were identified namely; distributary channel (lower deltaic plain), distributary mouth bar (part of deltaic front) and lower shoreface (part of pro delta) (Fig. 6). These three depositional environments are sub environments of the mega-deposition of the Niger Delta. Distributary mouth bar reservoirs identified in the study area are good reservoir as they are well sorted and have good porosity and permeability.

Seismic Interpretation

The seismic to well tie were generated using density log, sonic log and checkshot data from Well TMB_04 (Fig. 7). Thirteen (13) horizons were mapped (Fig. 8) across the field, out of which eight (8) horizons were of interest and they ranged from -1313 to -2796ms. The horizon mapping became difficult after -2796ms because the faults displaced the horizons far apart from each other. Again, the seismic character became chaotic even though there are strong reflection which are not continuous in the deeper part of the seismic section (Fig. 8). Horizons slices (Fig. 9) obtained from horizons of interest showed that the sand distribution is dominant towards the NW- SW direction of the field. The time slices also revealed a sand-shale alternating sequence typical of the Agbada Formation. Eight (8) faults were mapped across the field (Fig.10), out of these, two (2) faults are the major growth faults, dipping in southeastly. These growth faults are syn-depositionally induced by gravity tectonism and they are believed to mostly offset different parts of the Agbada Formation and flatten out near the top of the Akata Formation. The growth faults and the rollover anticlines serve as trap for hydrocarbon accumulation in the field.

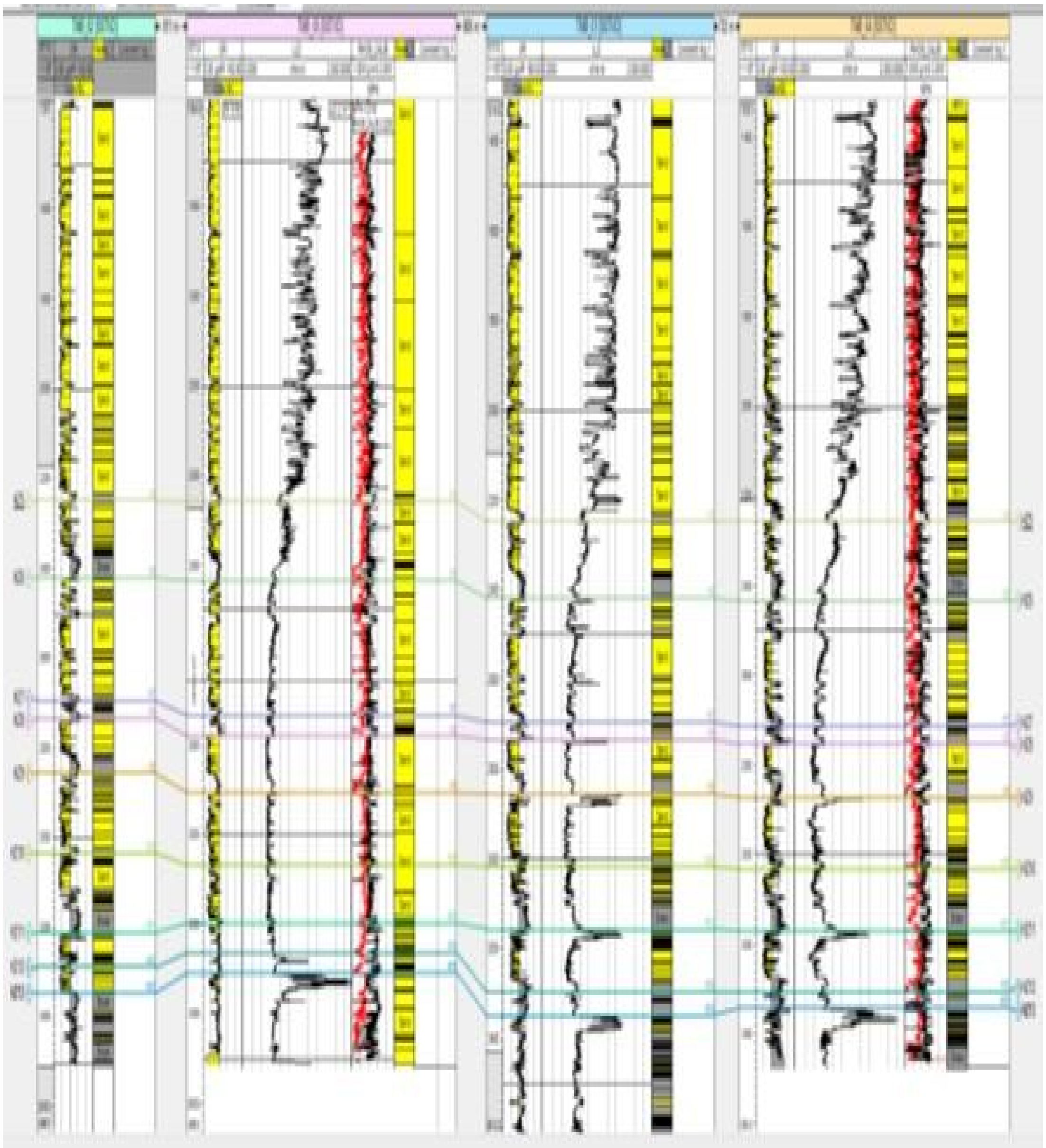


Fig. 4: Correlation Panel of four different wells along strike in the study area

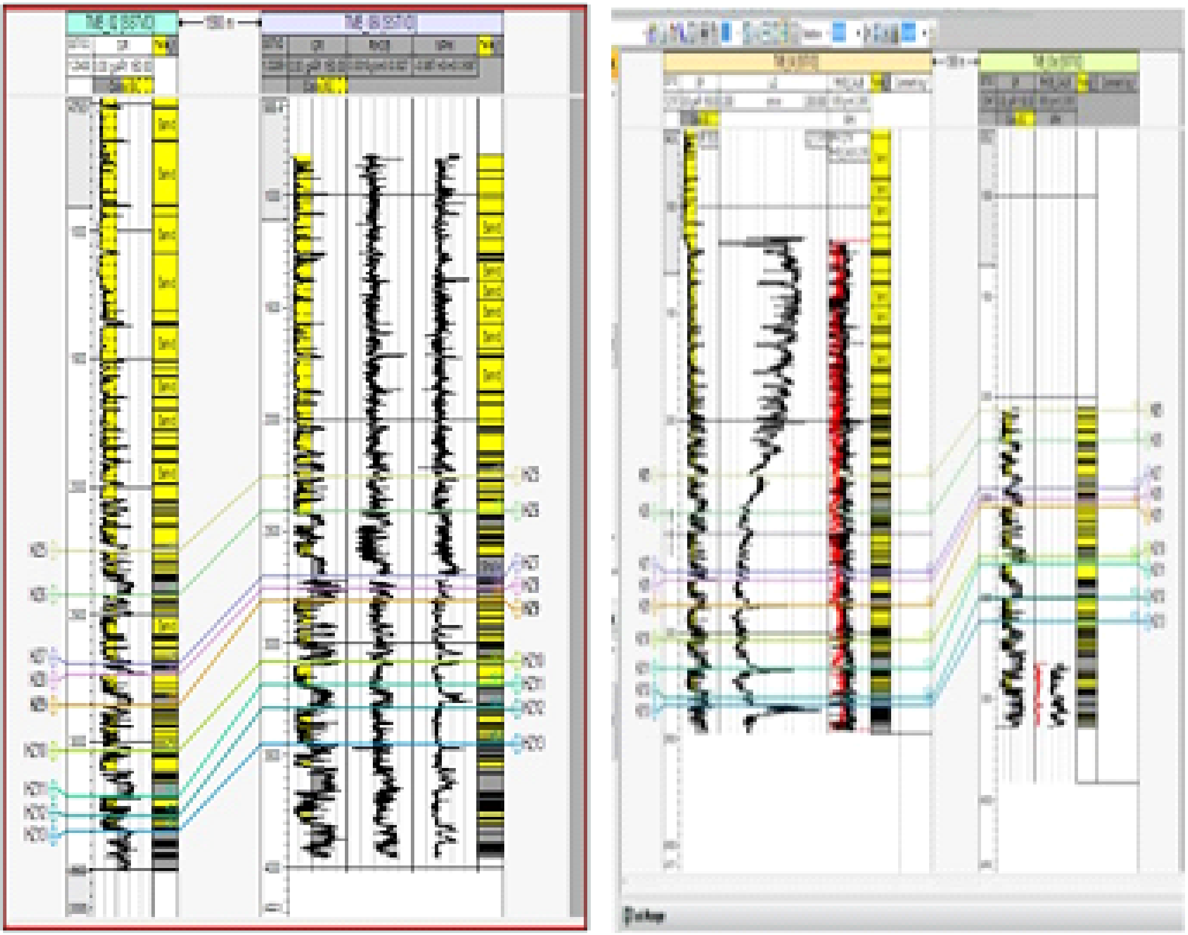


Fig. 5: Well correlation across dip line

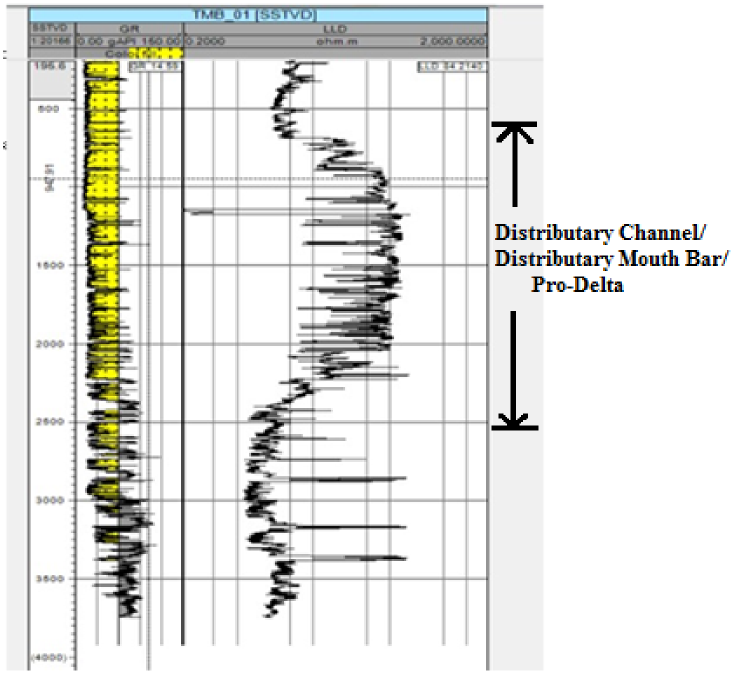


Fig. 6: Identified depositional environments within the subsurface of Tomboy field

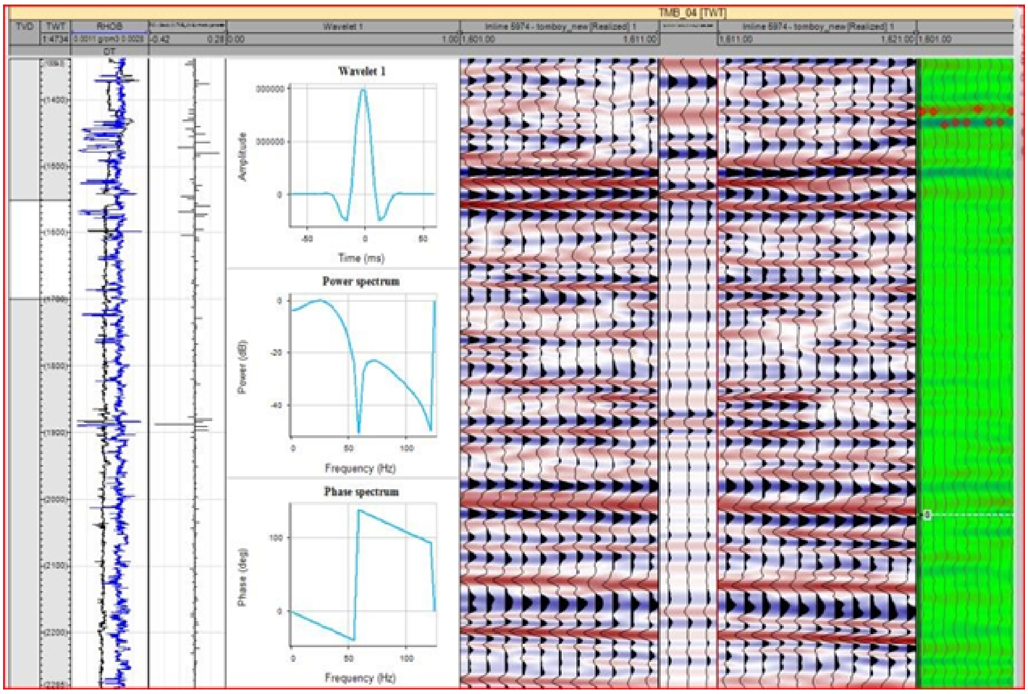
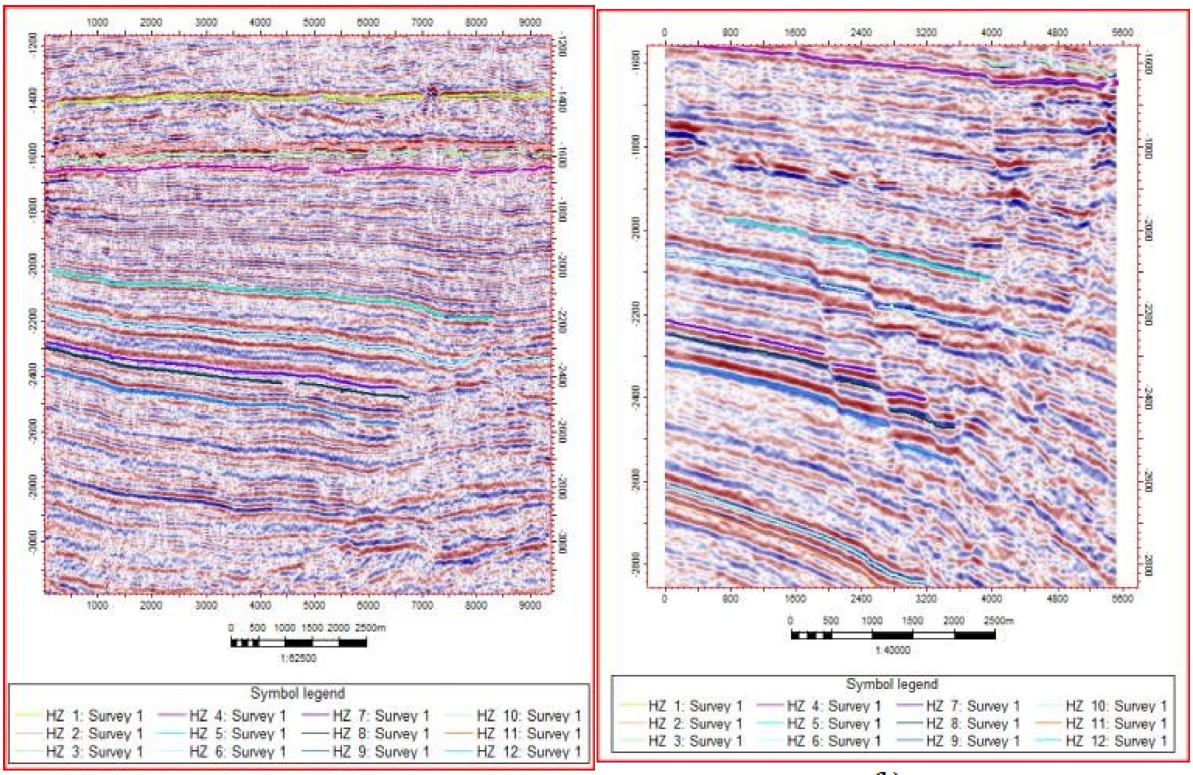


Fig. 7: The synthetic seismogram of the Tomboy field at well 4



(a) **(b)**

Fig. 8: Mapped Horizon in (a) Seismic crossline (b) Seismic Inline

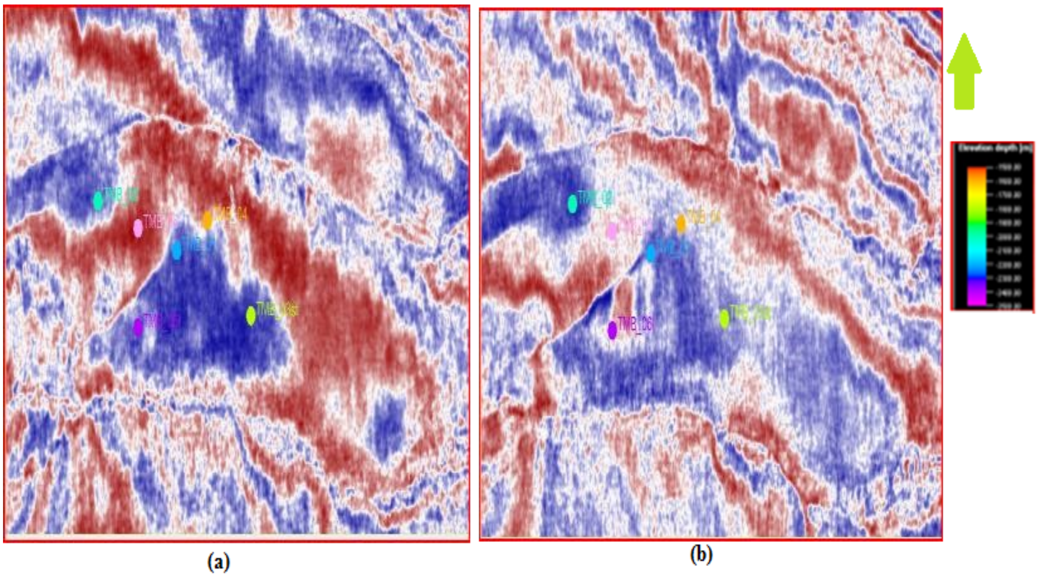


Fig. 9: Time slice at 2372ms and 2649ms: (a) Z slice across Horizon-5 and (b) Z slice across Horizon-6

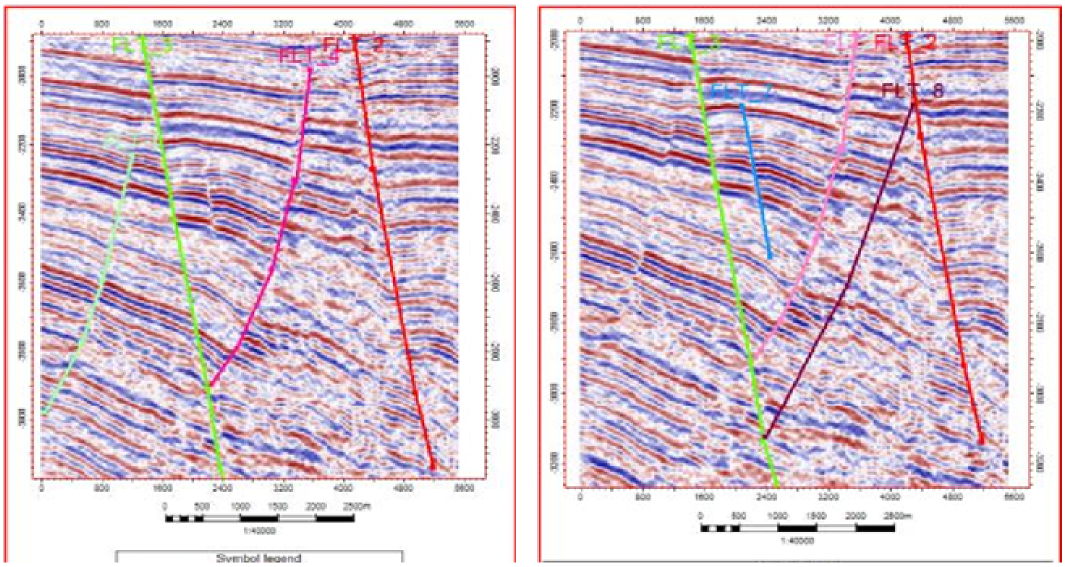


Fig. 10: Fault interpretation along dip line in field

Both time and depth structural contour maps were generated (Fig. 11) from HZ1 to HZ13 and they show similar structural relationship. Structural closures were identified on the time/depth structure map sand suggesting probable hydrocarbon accumulation.

3D Geologic model

The modelled faults and the horizon formed the basis of the 3D structural framework (Fig. 12). The Facies model generated shows two major facies type and their distribution within the field (Fig. 13a). The two major facies identified were sand (reservoir) and shale. There is possibility of huge hydrocarbon accumulation within the identified reservoir.

The porosity model generated shows good porosity distribution ranging from 28 to 34% within the field (Fig. 13b). The porosity obtained in the study falls within the exceptional reservoirs [9]. They have good porosity for hydrocarbon accumulation. The volume of shale model shows shale volume ranging from 20 to 38% in the reservoirs (Fig. 13c). On the other hand, the water saturation distribution varies from 0.3 to 0.4 (Fig. 13d). This shows relatively low water saturation suggesting relatively high hydrocarbon saturation in the reservoir. Generally, four hydrocarbon bearing horizons were identified across the field: HZ8, HZ9, HZ11 and HZ13 (Table 1 and Fig. 14).

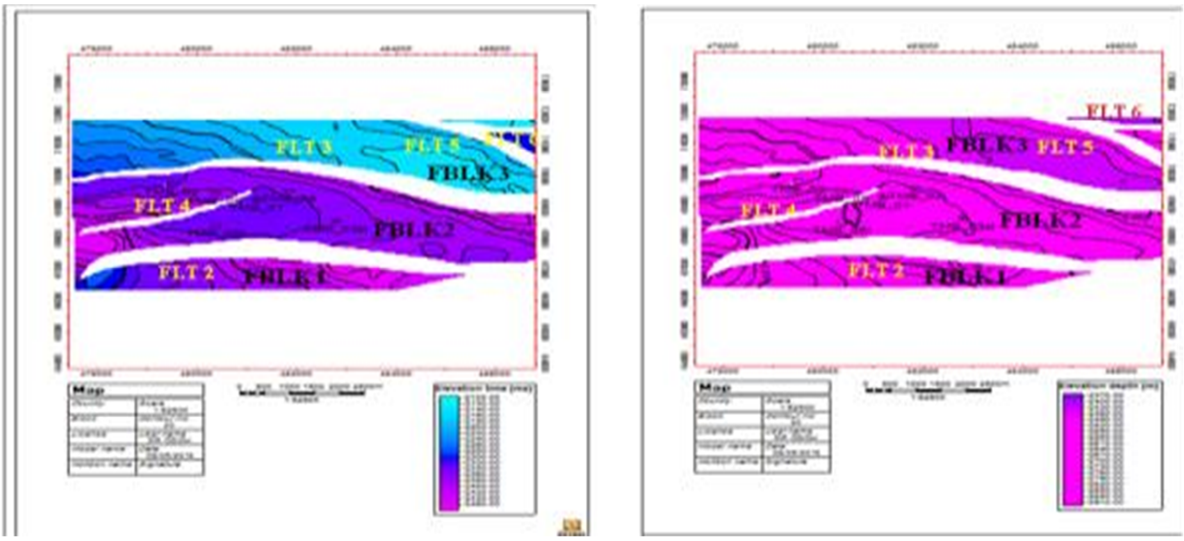
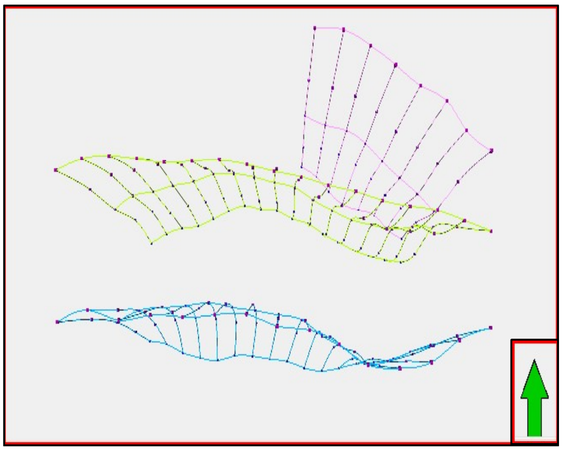


Fig. 11: Time and Depth structure map across the study area showing structural closures



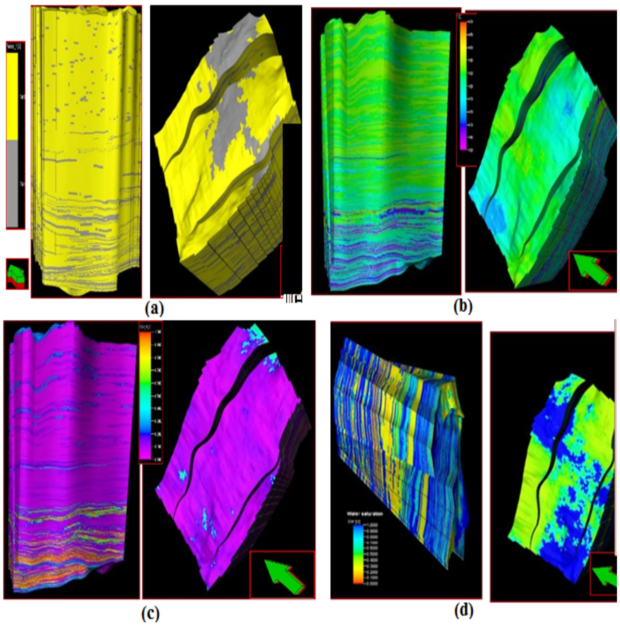


Fig. 12: Fault model of three major identified faults in the area

Fig. 13: 3D Static models across the study area; (a) Facie and incorporated fault models; (b) Porosity model; (c) Volume of shale model; (d) water saturation model

Table 1: Hydrocarbon contacts and their depth of occurrence

Reservoir	Top Depth	Type of contact
HZ8	2741	OWC
HZ9	2882.5	OWC
HZ11	3177.2	OWC
HZ13	3385.3	ODT

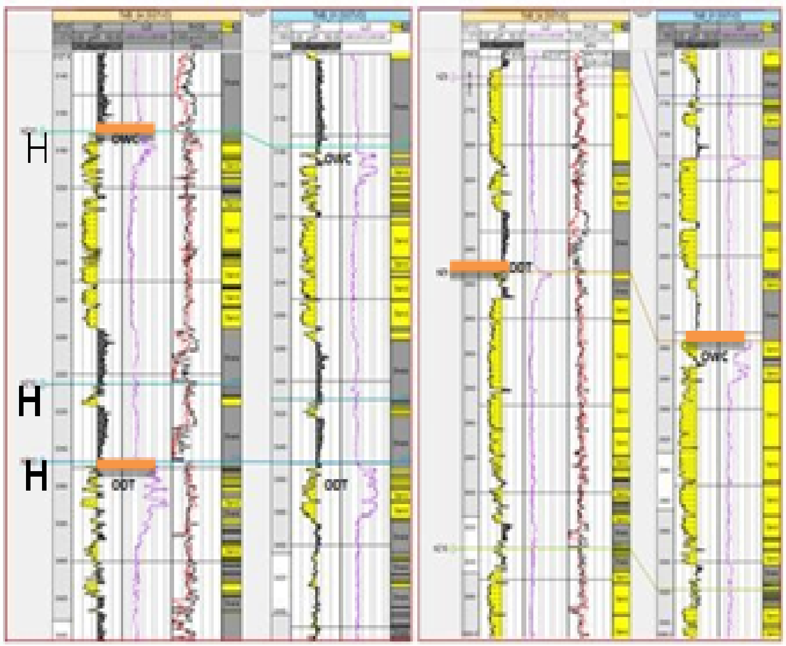


Fig. 14: Hydrocarbon contacts

Evaluation for Hydrocarbon Prospect

The two fault blocks, FLBK 2 and 3 were further evaluated for prospectivity using Root Mean Square (RMS) hydrocarbon attribute (Fig. 15). RMS attribute was extracted from the depth map of the mapped horizons to detect the presence of hydrocarbon. The results show strong amplitude for the above fault blocks thus suggesting the presence of hydrocarbon especially wthin the closures.

Identification of New Prospects

Prospects identified in the field are categorized as bypassed and undrilled prospects. The results of the static models and RMS amplitude analyses revealed that both FLBKS 2 and 3 are prospective since they have all the elements (source rock, reservoir, cap rock, and traps) required for the presence of hydrocarbon. In view of the above, the study therefore proposes the drilling of an exploratory well perhaps to confirm the presence of hydrocarbon in this prospect (Fig. 16).

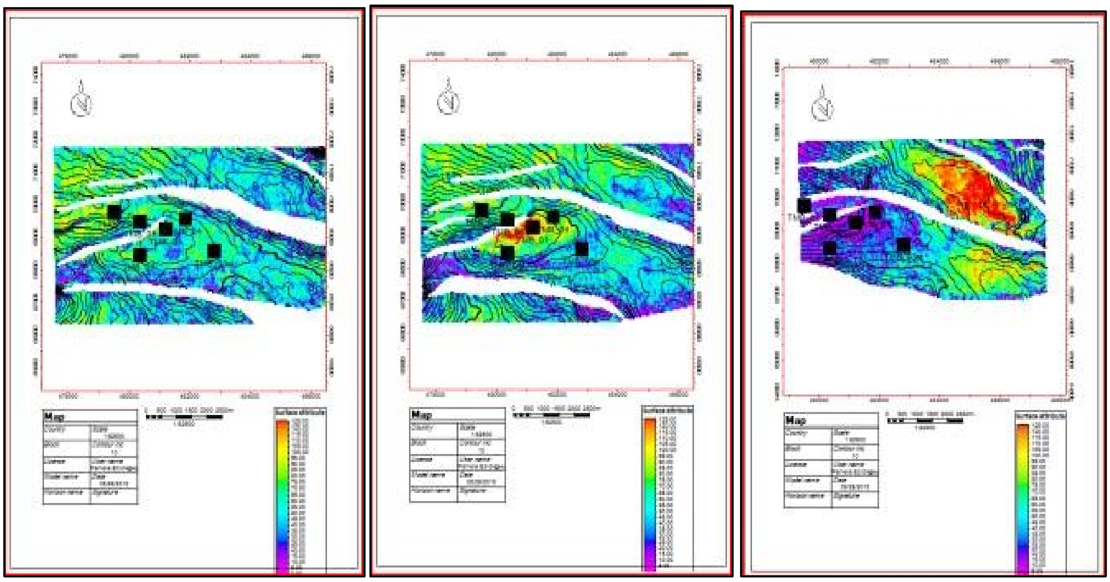
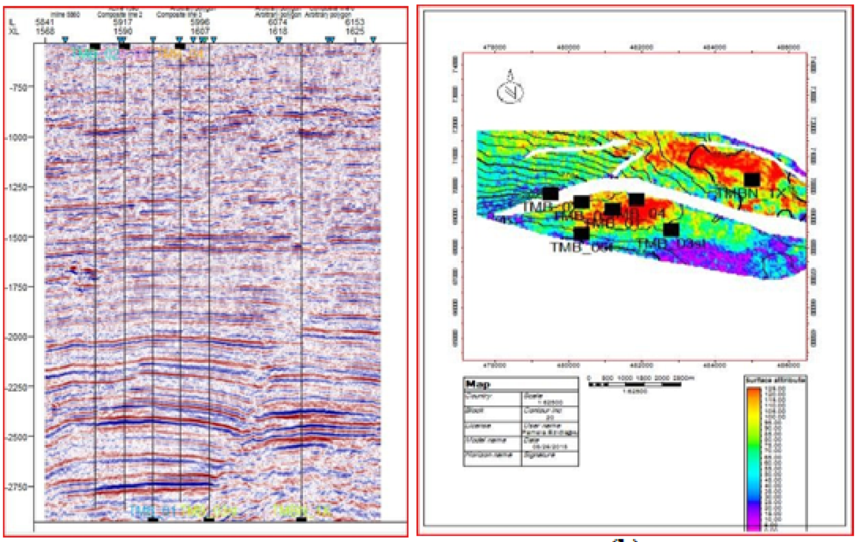


Fig. 15: RMS Amplitude attribute for HZ8 to HZ10



(a) **(b)**

Fig. 16: The proposed wells locations for the new propspect: (a) on a seismic section; (b) in RMS amplitude map

In addition, two bypassed reservoirs *consisting of* low resistivity pay zones have been identified within the field (Figs. 16 and 17**).** They occur as stratigraphic traps referred to as sedimentological dead ends [13]. They are localized channels not laterally extensive. Four (4) low resistivity pay zones were also identified in well TMB_04 with resistivity ranging from 1.5 to 2.02 Ohm-m (Fig. 17). Gamma ray logs revealed that the lithofacies are predominantly sand. Also crossover analysis of both the neutron and density logs within the same depth interval showed the presence of hydrocarbon. However, the resistivity values are very low implying that environment of deposition may be fluvial [7].

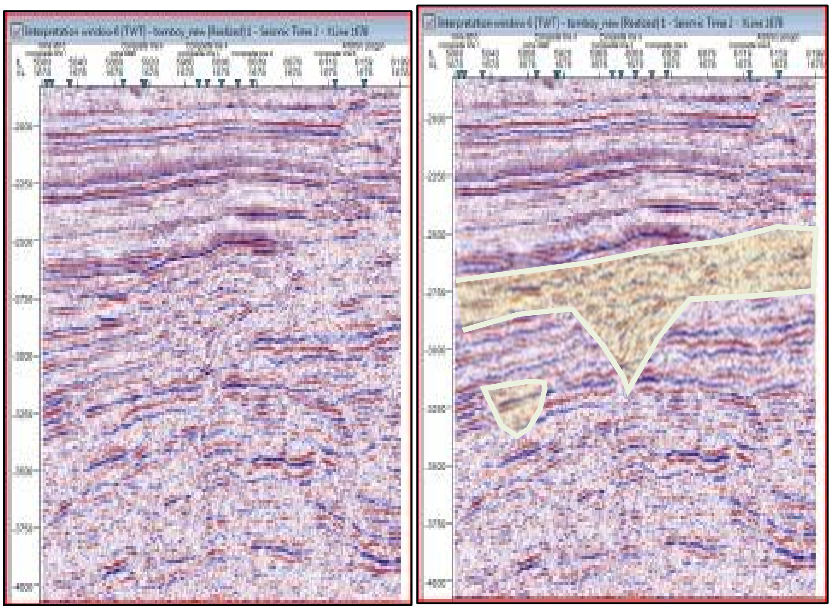


Fig. 16: Possible stratigraphic traps within the study area

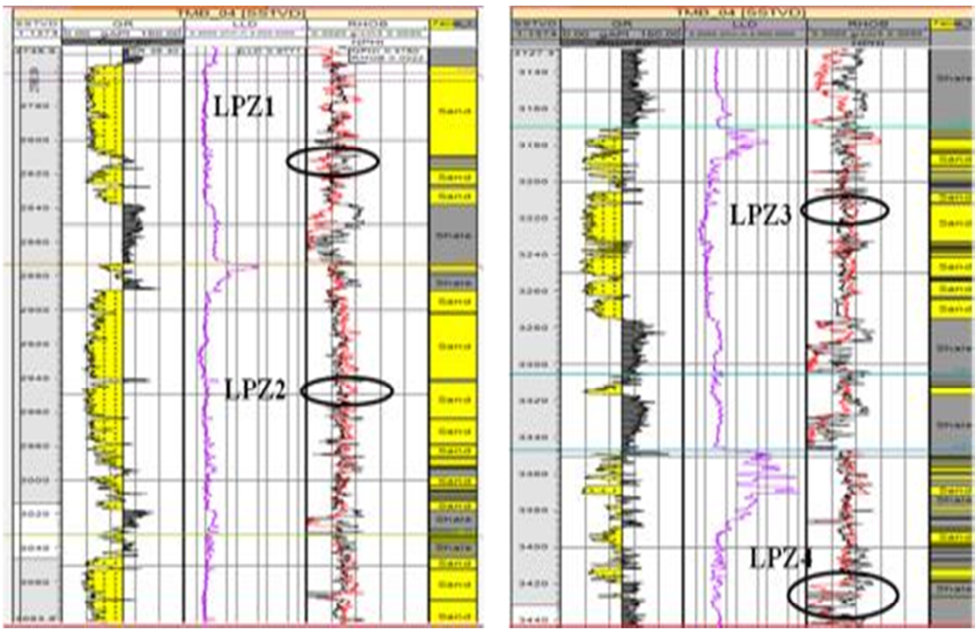


Fig. 17. Low Resistivity Pay Zones

Conclusions

Evaluation of hydrocarbon prospects of Tomboy Field was carried out using 3D seismic and well data. The following conclusions were deduced:

i. The environment of deposition of the reservoirs identified is distributary channel lower deltaic plain, distributary mouth bars and lower shoreface.
ii. The architecture of the field and subsurface structural geometry of identified reservoirs and possible hydrocarbon trapping potential are found to be greatly influence by faults.
iii. Two major growth faults, FLT3 and FLT5 were mapped. These extend throughout the entire field and thus, partitioned the field into 3 major fault blocks, FLBK1, FLBK2 and FLBK3.
iv. The trap in the field was revealed to be a fault-assisted anticlinal structure.

v. Hydrocarbon prospects in both the drilled (as bypassed) and undrilled structures (horizons) were identified in this field.

Acknowledgements

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