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Integrated Reservoir Characterization of "DAT Asset" Using 3D Seismic and Well Log, Onshore, Niger Delta Basin of Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author IFA performed data interpretation, dataset analysis, and manuscript writing. Author SAA carried out data correction, data Interpretation from software, and manuscript writing. Authors OVA and VMA performed data interpretation, validation, manuscript review, and update. Author SO was the overall supervisor of this paper's research and contributor to the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

An integrated interpretation of 3D seismic and composite well log data analysis over the "DAT" Asset characterizes the reservoir rocks using petrophysical properties, seismic interpretation and quantitative seismic attributes analysis within Nigeria's offshore Niger Delta Basin. The petrophysical analysis identified three hydrocarbon-bearing reservoirs (sand D, E, and F). The porosity of the reservoirs ranged from 17% - 26%, water saturation 17% - 45% and hydrocarbon saturation 55% - 83%. The three reservoirs were mapped in the "ADT" field and across the entire "DAT" Asset at a depth range of -9573 ft. (sstvd) to -11200 ft. (sstvd), with a thickness range of 35 ft. - 42 ft. A high amplitude burst area was recognised in the upthrown block of the discovered "ADT" field. Seismic attribute maps revealed that high amplitude corresponds to reservoir sands in the "ADT" field. These high amplitudes are structurally supported and prominent around the discovered hydrocarbon-bearing zones and other prospective zones, the prospect was named GAMMA prospect. The probable hydrocarbon volume estimation results for the identified reservoir

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and prospective GAMMA regions are satisfactory for further exploration. Integration of various tools in reservoir characterization limits uncertainties and yields a better result, which aids in hydrocarbon production and prospecting.

Keywords: Prospect; volumetrics; hydrocarbon saturation; reservoir; structural map; petrophysics; RMS amplitude; velocity model.

1. INTRODUCTION

Reservoir characterization is a quantitative approach to understanding reservoir dynamics Adagunodo et al. [1]. Characterizing reservoirs has been the primary aim of most reservoir geologists. Reservoir characterization is advancing with time; it has significantly evolved through multidisciplinary integration of petrophysics, geological analysis, and engineering [2]. Adequate seismic interpretation and petrophysics analysis has significantly helped reduce drilling risk and increase reservoir productivity [3]. A multidisciplinary approach involving the 3D seismic and well logs geophysical and geological data was integrated with modern probabilistic and risk analysis techniques to produce a better reservoir model [2]. Many researchers have concluded that integrating seismic and well log data with seismic attribute analysis plays a vital role in determining a field's geological structures, depositional environments, hydrocarbon reserves, and drillable prospects [2], Fajana et al. [4]; Olatunbosun et al. [5], Oyedele et al. [6], Owolabi et al. [7].

"DAT Asset" was acquired to efficiently search for hydrocarbon and profitably produce discovered petroleum accumulations that are recoverable and present in commercial quantities. However, existing wells were probably drilled based on a seismic dataset that did not fully resolve some structural details of the subsurface within the study area. Therefore, proper knowledge of the reservoir is essential for safe and cost-effective drilling of wells and assessing exploration risk, such as the sequence of sediment deposition and migration of formation fluids. However, it is essential to investigate various regions of the study area using a multidisciplinary integrated approach to determine additional drillable petroleum prospects in the asset. This is necessary to explore and exploit more hydrocarbon resources that may be present in the asset area. Therefore, the multidisciplinary approach for this study is to characterize the reservoir using an integrated method. This is achieved through Well correlation, sequence stratigraphy, well-to-seismic tie, structural (fault) interpretation, horizon interpretation, volumetric estimation, amplitude extraction, and analysis of the identified prospect.

1.1 Geological Settings

The "DAT" asset is located within the coastal swamp depo-belt of the Niger-delta. The study area is a simple normal listric faulting system with a major fault traversing east to west. The discovered "ADT" field exists on the regional fault's downthrown area. The regional fault controls deposition in the study area. The sedimentation is a paralic sequence of sand and shale deposits.

The Niger Delta Basin (Fig. 1) is a rift basin situated in the Gulf of Guinea along the West African coast [8]. The basin is a clastic wedge-formed along the failed arm of a triple junction system (Fig. 2) that originated during the separation of South American and African plates in the late Jurassic, and the other two arms of the triple junction became a passive margin along the south-western and south-eastern coast of Nigeria and Cameron [9]. Three primary depositional cycles have been identified within the Niger Delta Basin; the first two are mainly marine deposits during the middle cretaceous to Eocene time, and the third cycle has six depobelts (Fig. 1) which are separated by the synsedimentary fault zone [10]; Doust and Omatosola, [11]. The Niger Delta clastic wedge has been deformed by Normal faults triggered by ductile marine shales that are deeper and over-pressured; these faults are mainly growth faults formed by the prograding delta and slope instability on the continental margin [12]. Structural complexity and hydrocarbon traps are (Fig. 3) flank and crestal folds, which occurs along individual faults, rollover anticlines, which developed because of listric geometry and differential loading of deltaic sediments above ductile shales, and swarms of faults cut more complex structure with varying amounts of throws, including collapsed-crest features with dome shape and strongly opposing fault dips

Michele et al. [13]. The lithostratigraphic units in the Niger Delta Basin are the (Fig. 4) Akata, Agbada and Benin Formation, which are deposited in marine, deltaic and fluvial environments, respectively reflecting a gross upward-coarsening clastic wedge [14] The Akata Formation is characterized by dark grey shale and silts with occasional streaks of sand with probable turbidite flow origin [8]. It contains rich foraminifera fauna making it the potential source rock, and it crops out offshore in diapirs along the continental slope [11]. The Agbada Formation overlies the Akata Formation in the Niger Delta. It consists of alternating sandstones and shales of delta-front, distributary channels deltaic plain origin making it the reservoir rock of the basin [15]. The Benin Formation comprises the top part of the Niger-Delta clastic wedge, consisting of predominantly massive, highly porous fresh-water bearing sandstones with local thin shale inter-beds of braided stream origin [10].

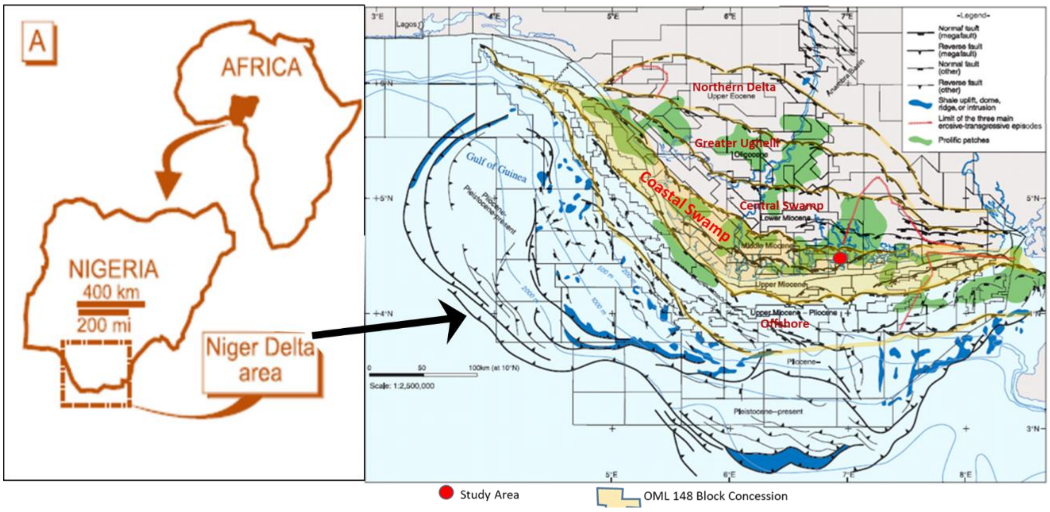

Fig. 1. (A) Niger Delta region (B) Map of the various depobelts and locations of the Study Area modified after Doust and Omatosola [8]

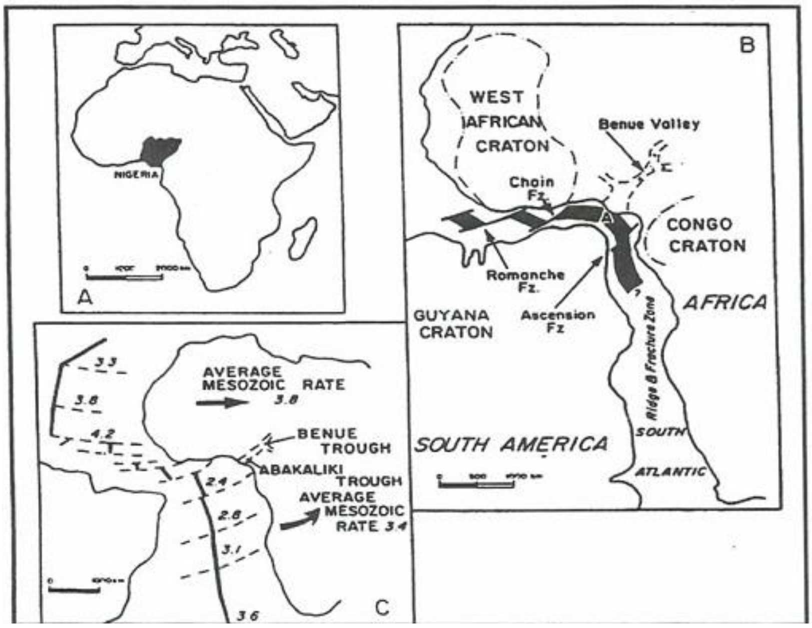

Fig. 2. (A) Location of Nigeria (B) the separation of Africa and South America and Triple Junction (C) Africa-South American plate Mesozoic spreading rates (cm/y) after Shannon and Naylor [16]

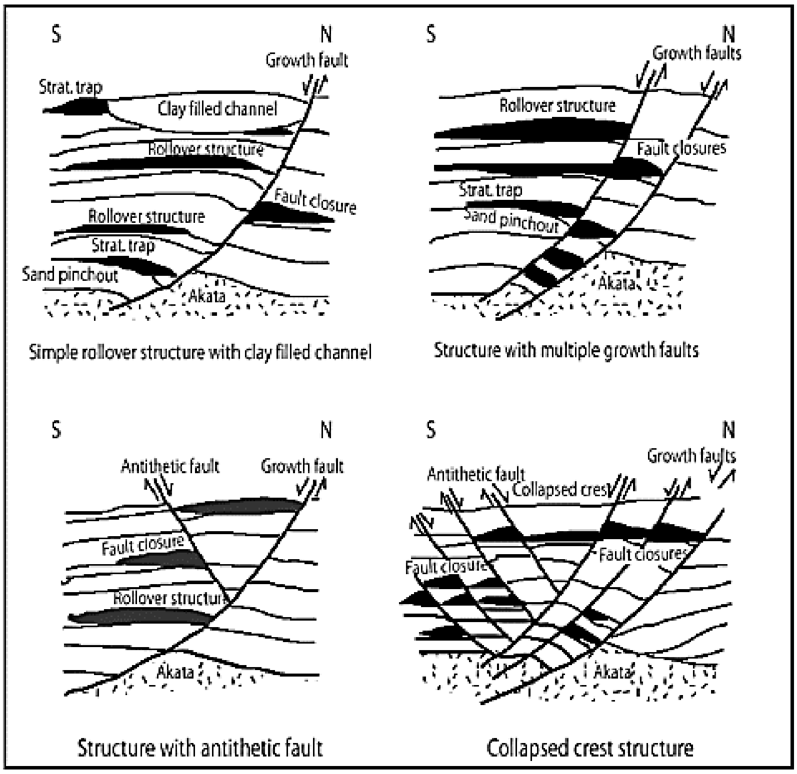

Fig. 1. Schematic indications of the structural styles and hydrocarbon trapping mechanism in the Niger Delta [8]

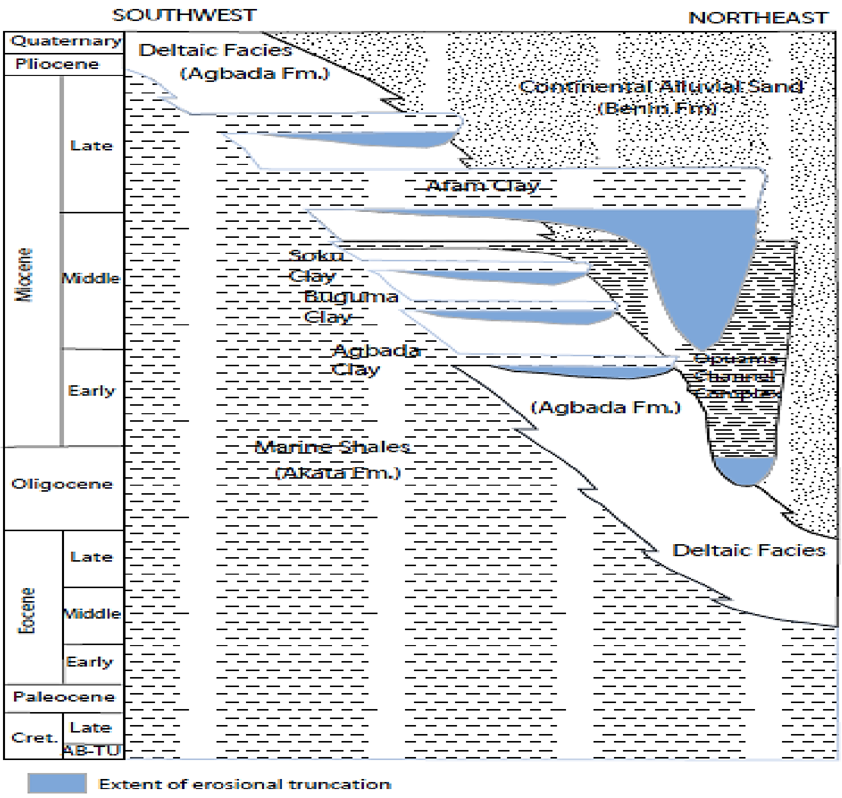

Fig. 4. Stratigraphic column shows the three Formations of the Niger Delta [8]

2. METHODOLOGY

The available data set used for this study is a 3D seismic survey of about 54 square kilometres Fig. 5, composite log (Caliper, Gamma ray, Resistivity, Neutron, Density, Sonic) of six wells named ADT 1 to ADT6, check shot data and biostratigraphic data. These data sets were analyzed using Geographix and Petrel software packages [17,18].

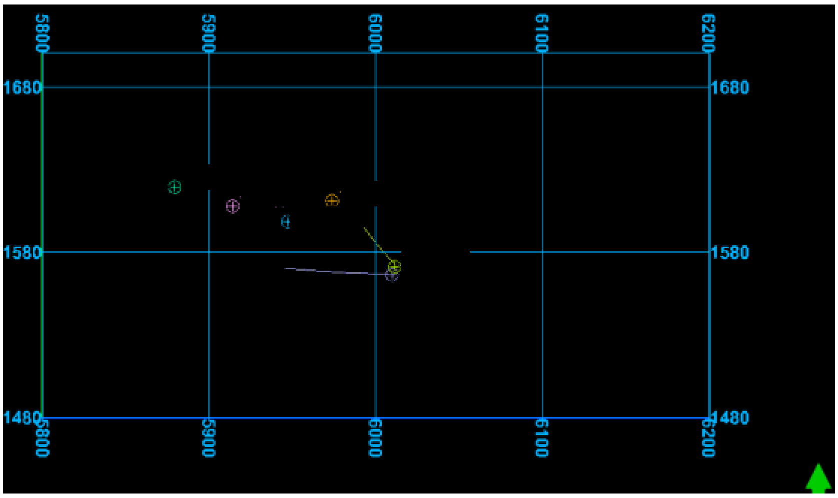

Fig. 5. Basemap of ADT Field in DAT Asset showing the 3D seismic grid and wells

Reservoir correlation: The lithologies were identified and correlated across the wells using a gamma-ray log, and the fluid distribution in the reservoirs was identified using resistivity, neutron and density log.

The volume of shale Estimation: The volume of shale within the ADT field was estimated using the Steiber equation (Eq. 1), where Vshale is the shale volume, IGr is the gamma-ray index expressed as equation 1, where Grlog is the log reading of interest, Grclean is the log reading in nearby clean zones, and Grshale is the log reading for shale.

$$\text{Vshale}=\frac{I_{GR}}{3.0-2.0*I_{GR}} \qquad \text{Equation 1}$$

Porosity Estimation: The porosity of the potential reservoir was determined using Wyllie's equation (Eq. 2), where Pma is the matrix density, Pb is the bulk density, and Pf is the fluid density.

$$\Phi=\frac{P_{ma}-P_b}{P_{ma}-P_f} \qquad \text{Equation 2}$$

Permeability Estimation: The permeability that permits fluid flow in the reservoir was estimated using Wyllie and Rose (Eq.3). Where Ke is the effective permeability, Ø porosity and Swirr is the irreducible water saturation

$$\text{Ke}=\left((250x\left(\frac{\emptyset^3}{S_{wirr}}\right))^2\right) \qquad \text{Equation 3}$$

Water saturation Estimation: The water saturation (Sw) is the percentage of pore volume in a rock occupied by formation water estimated using the Archie equation (Eq. 4). where Sw is the water saturation, Rw is the resistivity of water, F is the formation factor, and Rt is the true formation resistivity. The hydrocarbon saturation was then derived from water saturation.

$$\text{Sw}=\left(\frac{F*R_W}{R_t*\Phi^m}\right)^{\frac{1}{n}} \qquad \text{Equation 4}$$

Seismic Interpretation: The sonic and density log convolved using the Zoepritz equation generated a synthetic seismogram or well to seismic tie. The major faults were identified and mapped along the dip lines using an increment of 16 lines on both In-line and cross-line. The identified horizons were tied to the seismic with the help of the check shot data, and velocity maps were generated from the time maps. The velocity maps produced are then converted to depth maps of the area.

Volumetrics: The well log and seismic interpretation results were integrated to estimate the volume of hydrocarbon in the reservoir using equation 5. Where N is the volumetric reserves, A is the area, H is the net pay thickness, Ø is the porosity, Sw is the water saturation, and Bo is the formation volume factor.

$$N = 7758\frac{AH\emptyset(1-S_w}{B_o} \quad \text{Equation 5}$$

3. RESULTS AND DISCUSSION

Petrophysical Analysis: The hydrocarbon-bearing sands were correlated (Fig. 6) across the wells and named sand D, sand E and sand F. These potential reservoirs were selected based on the Gamma-ray log and Resistivity log. The sands were then evaluated individually by wells for their petrophysical properties and hydrocarbon potentials Table 1. Figs. 7–12 show the Log strip of sand D in ADT 5 and 7 well, Log strip of sand E in ADT 5, Log strip of sand F in ADT 4, and Log strip of sand F in ADT 5 and ADT 6 well. Correlation was carried out in the Northwest-Southeast direction, and hydrocarbon was not encountered in ADT2 as reservoirs were shallower in the Northwest direction.

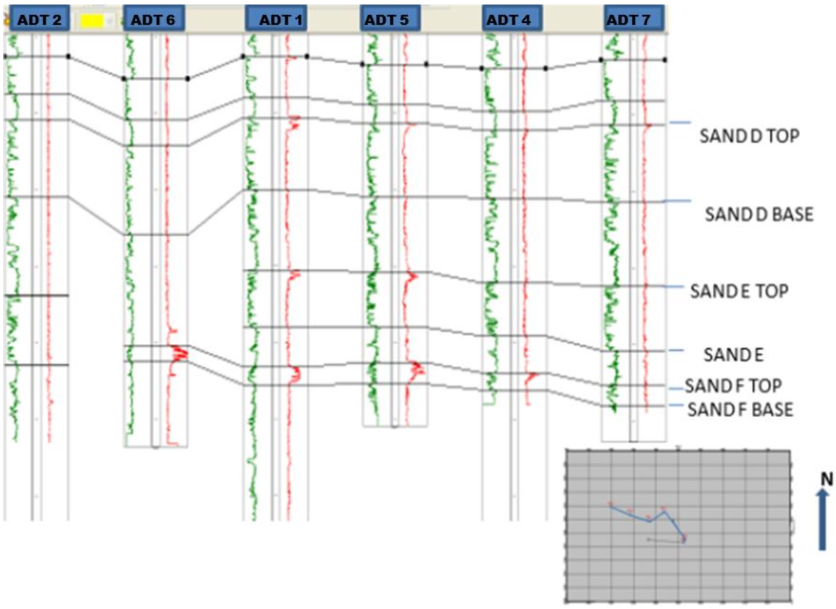

Fig. 6. Well correlation showing the Top and Base across Reservoir D, Reservoir E and Reservoir F

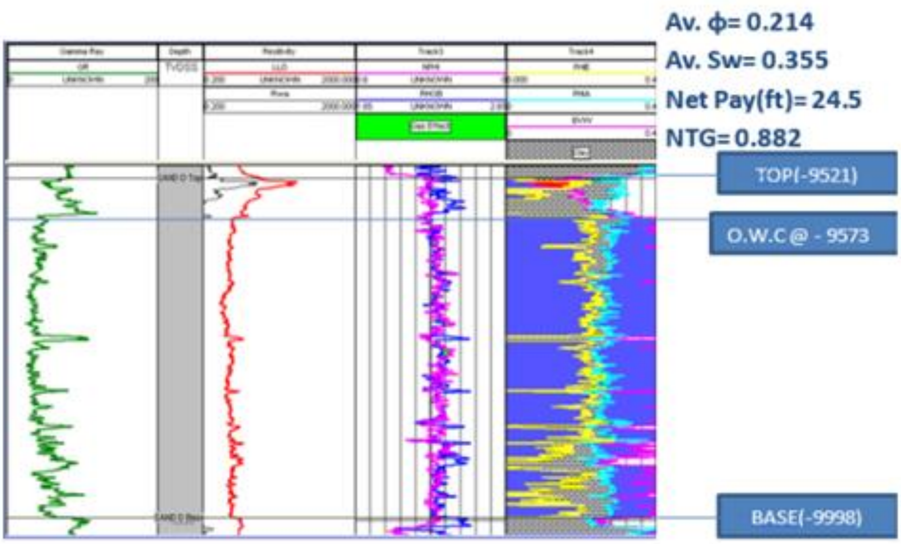

Fig. 7. Log Strip of sand D in ADT 5 Well

Table 1. Petrophysical analysis result summary

Wells	Top TVDSS (ft.)	Base TVDSS (ft.)	Gross Int (ft.)	Net Res (ft.)	Net Pay (ft.)	N/G Res	Sw Pay	Phi Pay	HC Type	Contact (ft.)
SAND D										
ADT-5	-9521	-9998	477	420.71	24.5	0.882	0.355	0.214	Oil	OWC(-9573)
ADT-7	-9525.25	-10039.5	513.25	405.47	17.75	0.79	0.441	0.238	Oil	OWC(-9544)
SAND E										
ADT-5	-10492	-10841	349	286.88	41	0.822	0.347	0.182	Oil & Gas	GOC (-10528) OWC (-10553.5)
SAND F										
ADT-4	-11149	-11198.5	49.5	34.5	33.5	0.78	0.167	0.258	Oil	ODT (-11198.5)
ADT-5	-11083.5	-11200	116.5	71	71	0.61	0.184	0.176	Oil	ODT (-11200)
ADT-6	-10979	-11093.25	104.2	86.03	86.03	0.826	0.179	0.22	Oil	ODT (-11093.25)

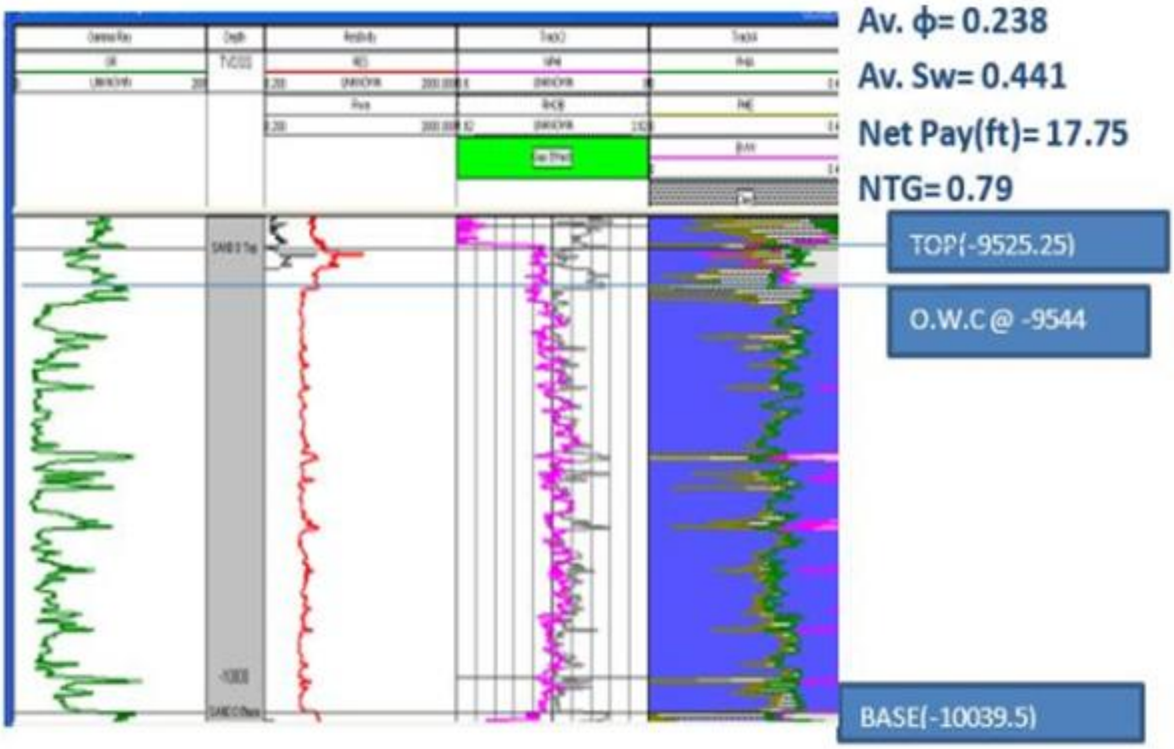

Fig. 8. Log Strip of Sand D in ADT 7 Well

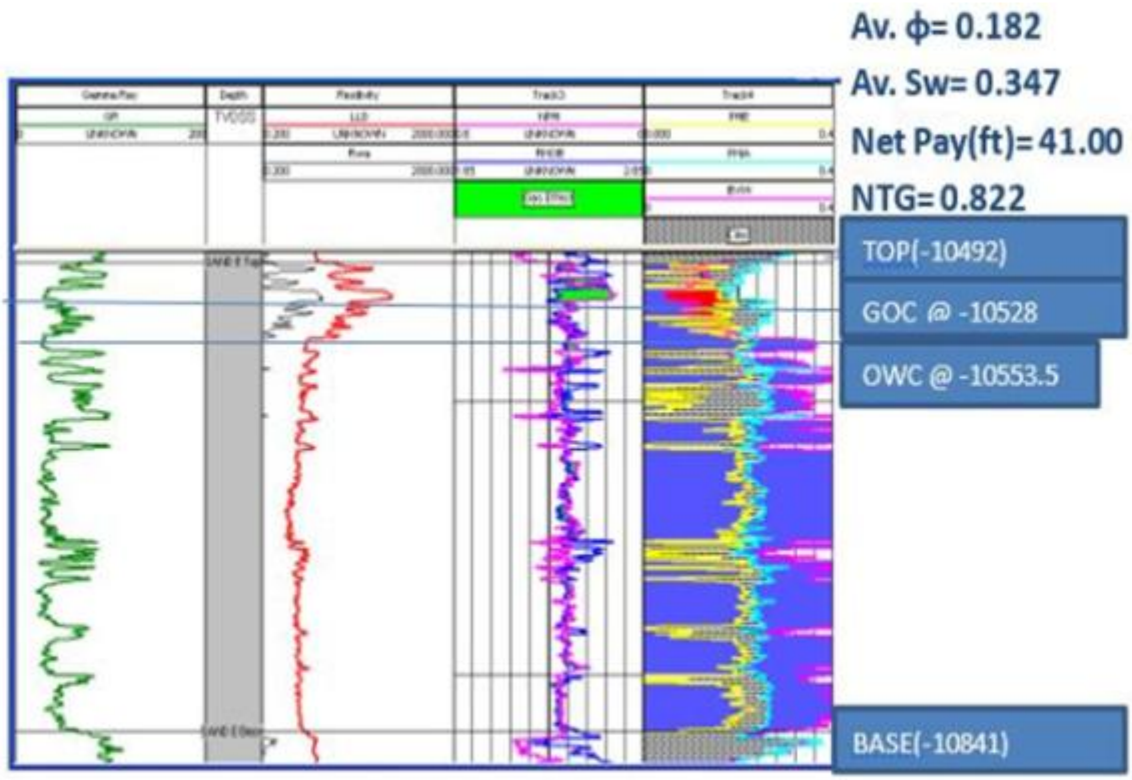

Fig. 9. Log strip of sand E in ADT 5 well

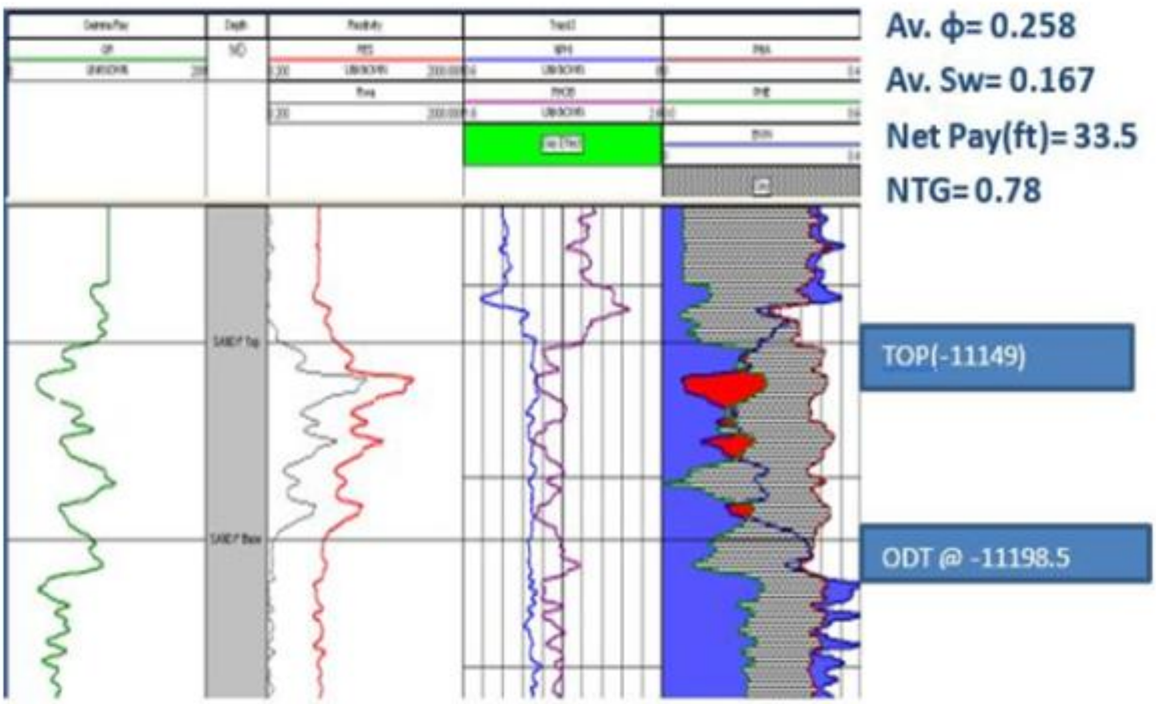

Fig. 10. Log Strip of Sand F in ADT 4 Well

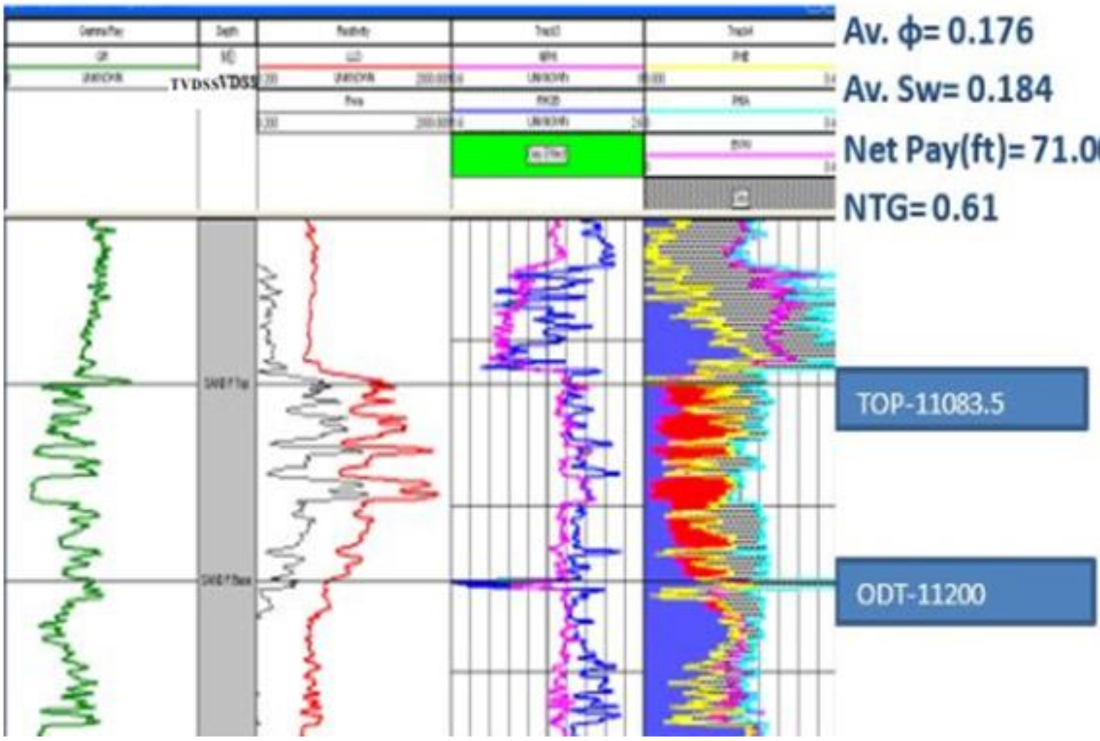

Fig. 11. Log Strip of Sand F in ADT 5 Well

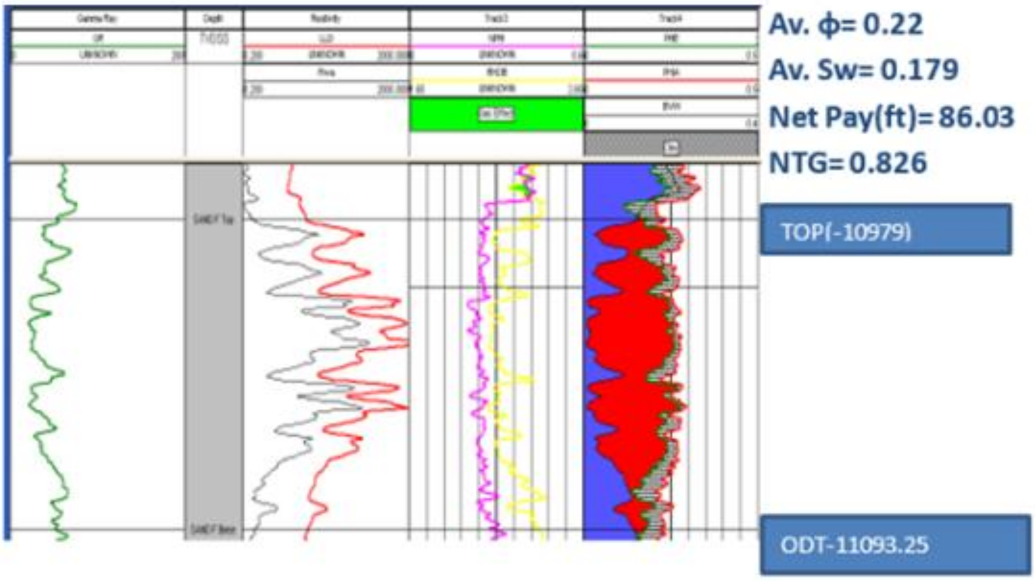

Fig. 12. Log Strip of Sand F in ADT 6 Well

Seismic Interpretation: Faults were picked based on abrupt event termination on inline 5949, as shown in Fig. 13 and Fig. 14. However, the horizon that corresponds to the hydrocarbon-bearing sand was identified using the synthetic seismogram. The hydrocarbon-bearing sands D, E and F, were then posted and interpreted as horizon D, E and F on the seismic section using ADT-1 Check shot data. Isopach maps were also generated to calculate the gross rock volume of the discovered ADT field within the hydrocarbon reservoirs. Two major faults were labelled F-A and F-C, and three minor faults were interpreted. The faults trend in the South-East to North-West direction. The time map was then converted to a depth map using a velocity model generated by the petrel software Fig. 14 to Fig. 16. The Oil zones (red) and gas zones (green) were identified on the depth map using the oil-water contact and gas-oil contact from Table 1.

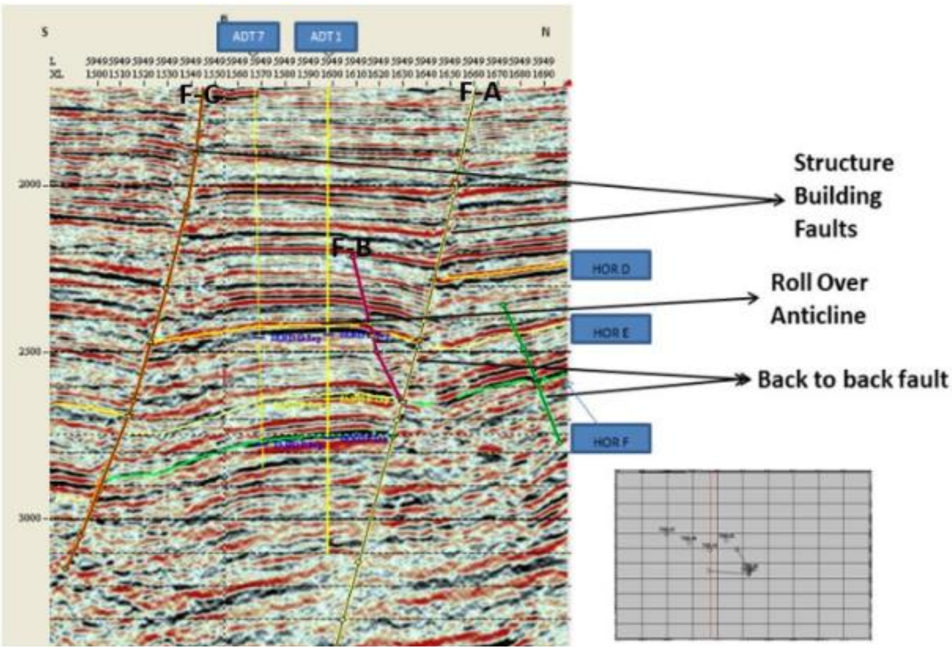

Fig. 13. Inline 5949 shows Two Major Fault

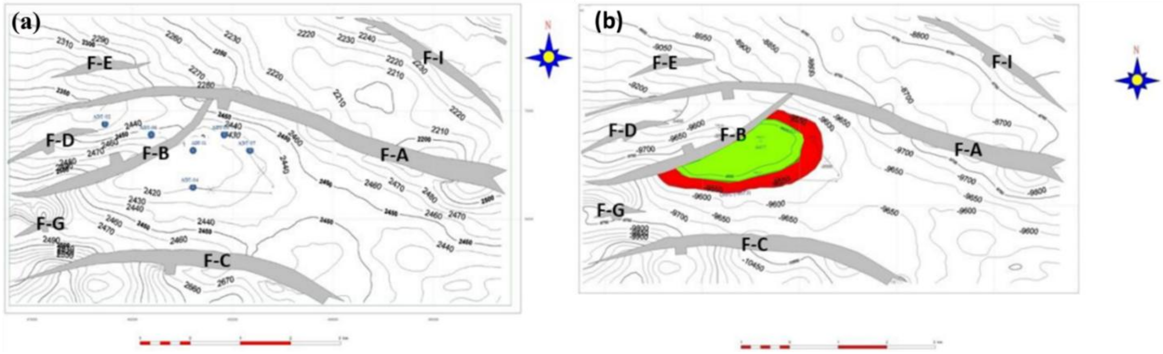

Fig. 14. (a) Sand D Time-Structure Map (b) Sand D Depth-Structure Map

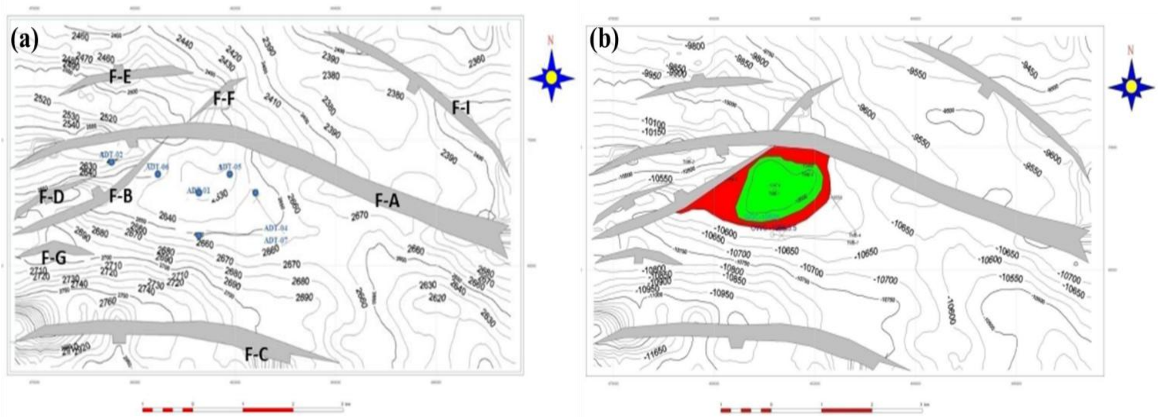

Fig. 15. (a) Sand E Time-Structure Map (b) Sand E Depth-Structure Map

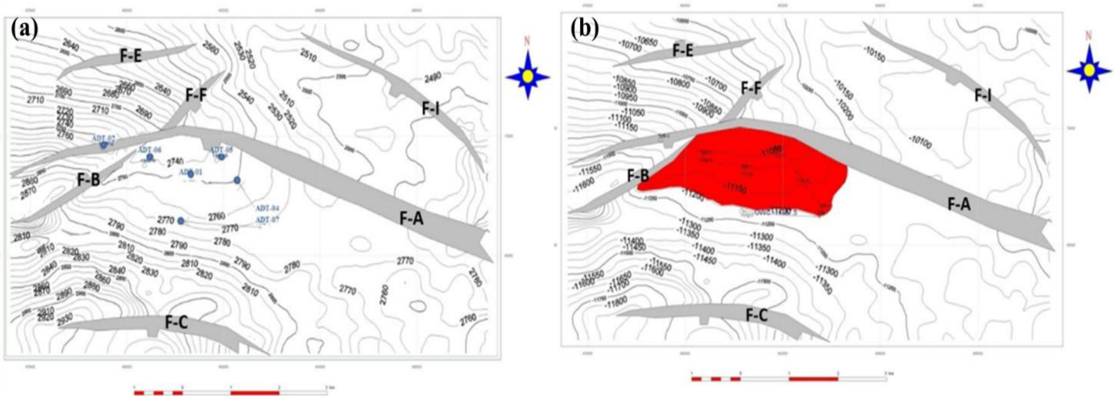

Fig. 16. (a) Sand F Time-Structure Map (b) Sand F Depth-Structure Map

Volumetrics: The hydrocarbon volumes were calculated using the Probabilistic approach, and the Monte Carlo simulation was adopted with the aid of at Risk. The standard volumetric equation used was:

- OOIP = 7758*Net Rock Volume*Porosity*(1-Sw)
- STOOIP calculated using a varied Bo of 1.2, 1.25 and 1.3
- GIIP = 43560*Net RockVolume*Porosity*(1-Sw)/Bg
- GIIP calculated using a varied Bg of 0.003, 0.0035 and 0.004.

Table 2. Calculated Volume (OIIP) and (GIIP) of ADT Field

Probabilities	OIL (mmbbl)	GAS (BCF)
Sand D		
P10	12.3	
P50	13.5	
P90	14.8	
Sand E		
P10	7.5	5.4
P50	8.1	5.6
P90	8.7	5.8
Sand F		
P10	40.4	
P50	47.1	
P90	55.6	

Prospect Analysis: The discovered hydrocarbon ADT field is situated in the hanging-wall block of the main structure-building fault, and a prospect called 'Gamma' lies in the footwall compartment of the same fault. This was identified while interpreting the 3D seismic data where high amplitude (Fig. 16 and Fig. 17) contrast exists and was further analyzed by extracting RMS amplitude.

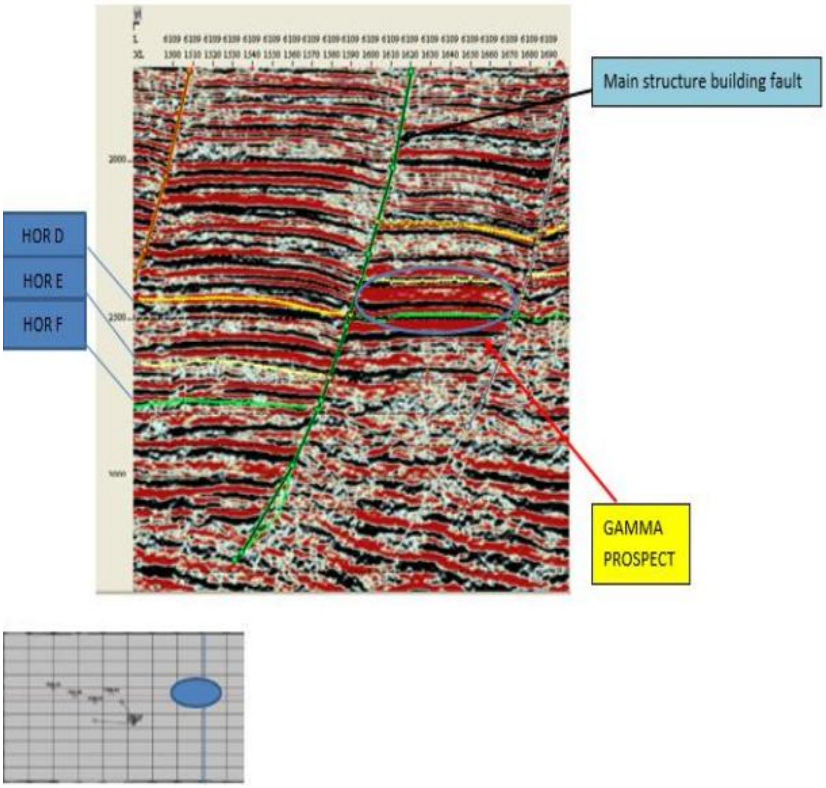

Fig. 17. Gamma Prospect Area with High Amplitude on Inline 6109

The first high amplitude (Fig. 17) corresponds to reservoir sands in the discovered hydrocarbon ADT field, while the other high amplitude at structural high in the right compartment of the fault corresponds to the gamma prospect area. Seismic Surface Attribute (surface RMS amplitude extraction) was generated for horizons E and F with a window at 10ms below horizons E and F, respectively, as they correspond to the high amplitude (gamma prospect) area on the seismic section Figs. 18 and 19.

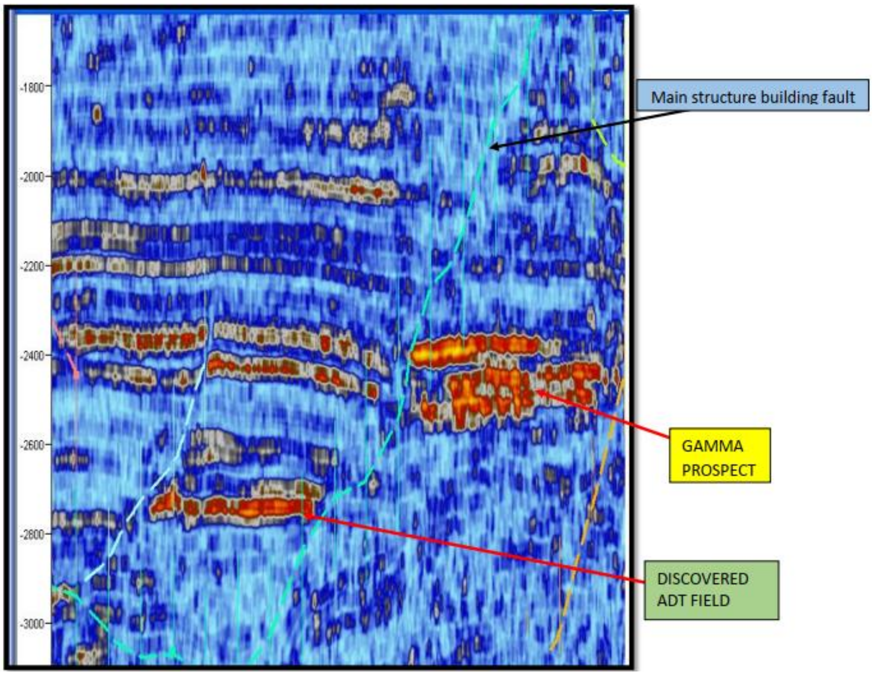

Fig. 18. RMS Volume Amplitude Extraction Showing Gamma Prospect (Crossline 1610)

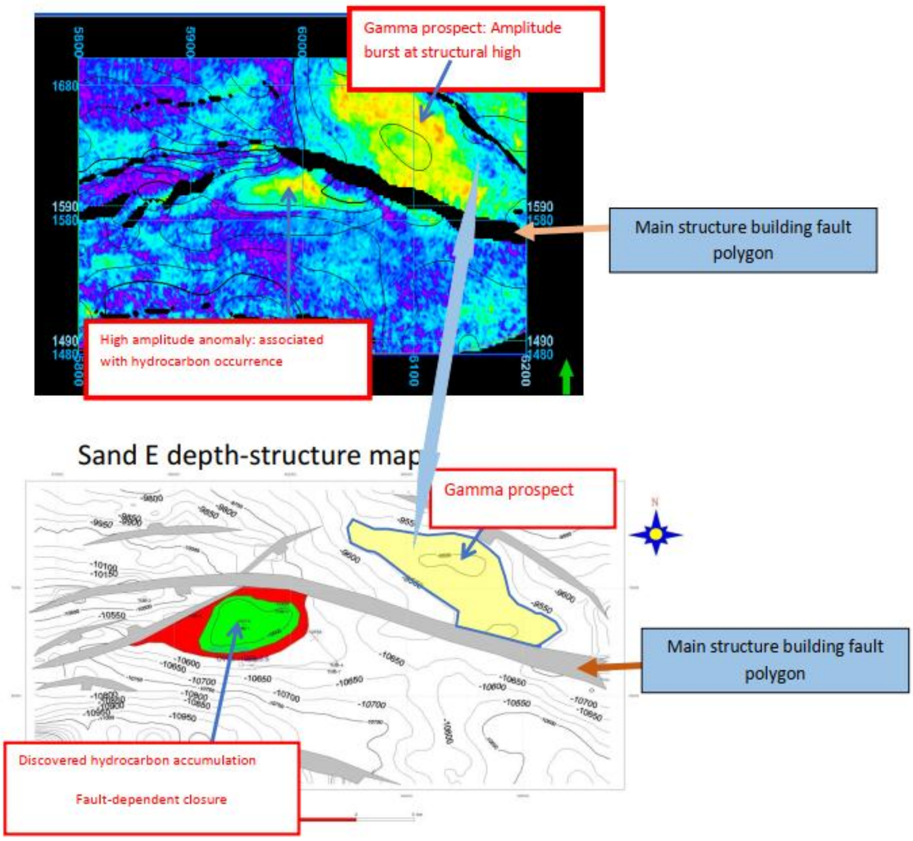

Fig. 19. Sand E seismic attribute (surface RMS amplitude extraction) Map

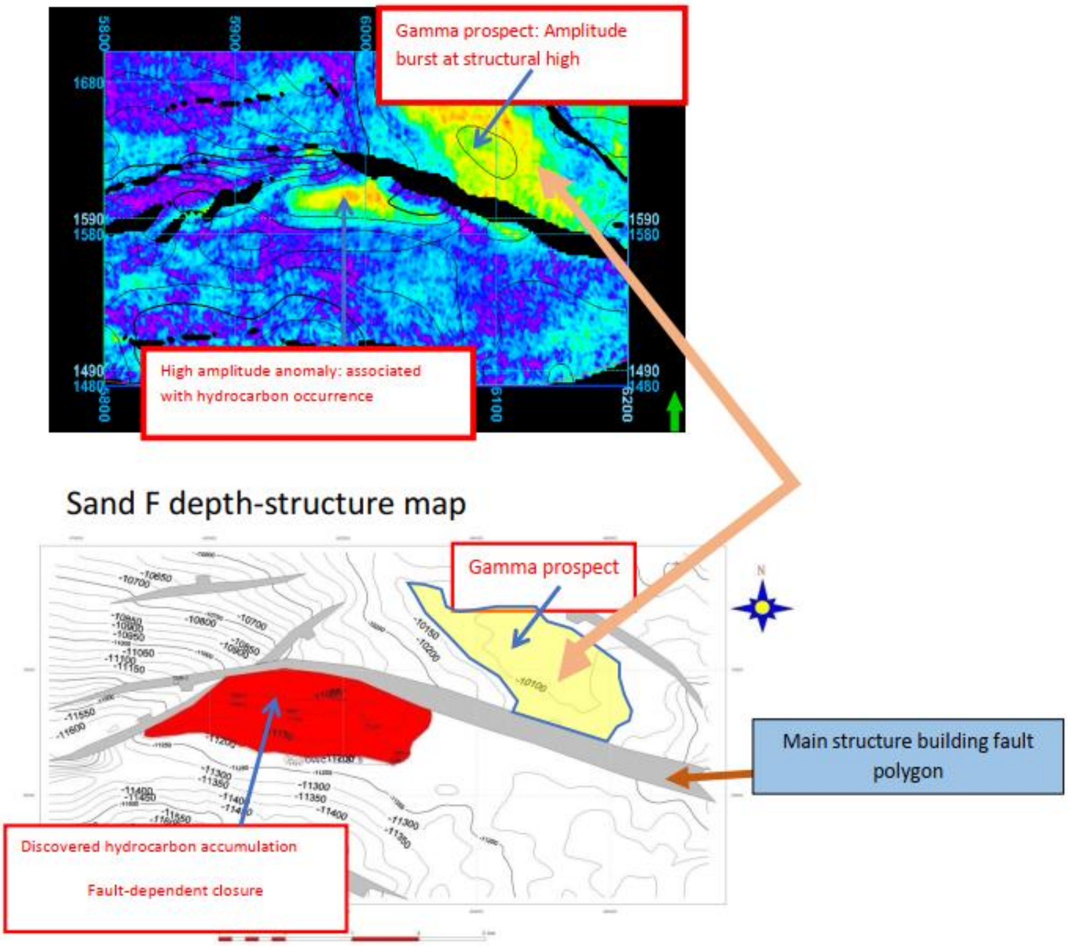

Fig. 20. Sand F Seismic Attribute (surface RMS amplitude extraction) Map

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

When integrated with well log data, information derived from the 3D seismic data volumes resulted in more understanding of the structural style and architecture of the reservoir delineation in the DAT asset. Three reservoirs were interpreted to be hydrocarbon bearing and correlated across the field, which is Sands D, E and F, were evaluated in the DAT asset. From the Petrophysical and Seismic analyses done, Sand F proved to have the highest Reserve in the ADT field, and Sand E has the highest probable volume in GAMMA prospect. The traps in the discovered DAT asset are fault dependent closures. The unavailability of porosity logs for wells 1 and 2 made their petrophysical analyses impossible. There is a north-eastern Gamma prospect in the upthrown compartment of a major growth fault in the DAT asset. The occurrence of amplitude anomalies and a bright spot in this prospect area increased the level of confidence that there may be hydrocarbon in the structural closure.

4.2 Recommendation

An exploratory well should be planned and drilled in the Gamma prospect to test the structure and confirm hydrocarbon occurrence in the upthrown block of the major fault within the DAT asset. Additional studies on the distribution of lithological and stratigraphic facies from future drilled wells within GAMMA prospect should also be carried out.

AVAILABILITY OF DATA AND MATERIALS

All materials and data should be available at the University of Lagos Geoscience Department. The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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