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Evaluation of Hydrocarbon Reservoir in the "SIMA" Field of Niger Delta Nigeria from Interpretation of 3D Seismic and Petrophysical Log Data

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Abstract

3D seismic and petrophysical log data interpretation of reservoir sands in "SIMA" Field, onshore Niger Delta has been undertaken in this study to ascertain the reservoir characteristics in terms of favourable structural and petrophysical parameters suitable for hydrocarbon accumulation and entrapment in the field. Horizon and fault interpretation were carried out for subsurface structural delineation. In all, seven faults (five normal and two listric faults) were mapped in the seismic section. These faults were major structure building faults corresponding to the growth and antithetic faults in the area within the well control. The antithetic fault trending northwest-southeast and the normal fault trending northeast-southwest on the structural high in the section act as good trapping mechanisms for hydrocarbon accumulations in the reservoir. From the manual and auto-tracking methods applied, several horizons were identified and mapped. The section is characterized by high amplitude with moderate-to-good continuity reflections appearing parallel to sub-parallel, mostly disturbed by some truncations which are more fault related than lithologic heterogeneity. The southwestern part is, however, characterized by low-to-high or variable amplitude reflections with poor-to-low continuity. Normal faults linked to roll-over anticlines were identified. Some fault truncations were observed due to lithologic heterogeneity. The combination of these faults acts as good traps for hydrocarbon accumulations in the reservoir. Reservoir favourable petrophysical qualities, having average NTG, porosity, permeability and water saturation of 5 m, 0.20423, 1128.219 kD and 0.458 respectively.

Keywords

Seismic Interpretation, Hydrocarbon Accumulation, Porosity, Reservoir, Niger Delta, Petrophysical Properties, Faults, Horizons

1. Introduction

Hydrocarbon accumulations have been located in all the depobelts of the Niger Delta in good quality sandstone reservoirs belonging to the main deltaic/paralic sequence consisting essentially of the Agbada Formation. Most of the larger accumulations occur in roll-over anticlines in the hanging walls of growth faults, where they may be trapped in either dip or fault closures. A substantial quantity of un-associated gas has been discovered also. The hydrocarbons are found in multiple pay sands with relatively short columns and adjacent fault blocks usually having independent accumulation. [1] studied the model of the hydrocarbon entrapment mechanism. [2] studied the depositional history of the reservoir sandstones at Akpor and Apara oil fields, eastern Niger Delta and showed that they were dominated by paralic sequences dominated by channel sands. Several authors have indicated the petroleum prospects and lithologic characteristics of the Niger Delta [3] [4] [5] [6].

The presence of a network of granulation seams throughout and faulted sandstone may act as permeability barriers within the reservoir. Interpreting field scenarios accurately before making huge capital investments can increase hydrocarbon extraction at minimal cost in time and money [7]. Well logs have been very useful in reservoir evaluation [8] [9]. [10] had successfully employed the petrophysical analysis method in their evaluation of the Mpera Well in Exploration Block 7, Offshore Tanzania to determine the significance of the reservoir in terms of the reservoir potential.

This study seeks to exploit the possibility of integrating 3D seismic and petrophysical data for an improved quantitative reservoir evaluation in overcoming the challenge of accurately interpreting the structural and stratigraphic characteristics of reservoir sands of the complex but oil-rich Niger Delta using seismic data only. Thus, to assess the reservoir potential in terms of the reservoir characteristics.

1.1. Regional Tectonic Setting

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 Atlantic. The fracture zone ridges subdivide the margin into individual basins, and in Nigeria, form the boundary faults of the Cretaceous Benue-Abakiliki trough which cuts far into the West African Shield. The trough represents a failed arm of a rift triple junction associated with the opening of the South Atlantic. In this region, rifting started in the Late Jurassic and persisted into the Middle Cretaceous [11]. Rifting in the region of the Niger Delta diminished altogether in the Late Cretaceous.

After rifting ceased, gravity tectonism became the primary deformation process. Shale mobility induced internal deformation and occurred as a response to two processes [12]. First, shale diapirs formed from the loading of poorly compacted, over-pressured, prodelta and delta-slope clays (Akata Formation) by the higher density delta-front sand (Agbada Formation). Secondly, slope instability occurred due to a lack of lateral, basinward, and support from the under-compacted delta-slope clays (Akata Formation) [13].

For any given depobelt, gravity tectonics were completed before deposition of the Benin Formation, and are expressed in complex structures including shale diapirs, roll-over anticlines, collapsed fault crests, back-to-back features and steeply dipping, closely spaced flank fault [14] [15]. These faults mostly offset different parts of the Agbada Formation and flatten into detachment planes near the top of the Akata Formation. [16] [17] had studied the structural geology of the Cenozoic Niger Delta, and concluded on its diapric nature of the shales resulting from roll-over processes in the delta.

1.2. Niger Delta Depobelt

Niger Delta is divided into a number of sediment units called depobelts. Depobelts are thought of as transient basinal areas succeeding one another in space and time as the delta prograded southward. [18] showed that the Niger Delta sequence consists of a series of discrete depocenters or depobelts, which were the main belts of deposition of the Agbada Formation that succeeded each other progressively as the delta shifted its loci down dip through time. Each depobelt is a separate unit that corresponds to a break in the regional dip of the delta and is bounded landward by a growth fault and seaward by a large counter-regional fault in the next seaward belt [5] [14]. Major fault building growth faults bounds and determines the location of each depobelt, each with its own sedimentation, structural deformation and petroleum history. The entire sedimentary wedge in the Niger Delta was laid down sequentially in five major depobelts, each 30-60 km wide, with the oldest depobelt lying furthest inland and the youngest located offshore. [5] described three depobelt provinces based on structure. The Northern delta province which overlies a relatively shallow basement has the oldest growth faults that are generally rotational, evenly spaced and increase steepness seaward. The central delta province has depobelts with well-defined structures such as a successively deeper roll-over crest that shifts seaward for any given fault. However, the distal delta province is the most structurally complex and is found to increase from north (landward) to south (seaward). [19] described five major depobelts in the Niger Delta. [20] discussed the world petroleum province and the oil and gas ranking while [11] discussed the structural history of the Atlantic margin of Africa (**Figure 1**).

1.3. The Niger Delta Petroleum System

Petroleum occurs throughout the Agbada Formation in the Niger Delta clastic

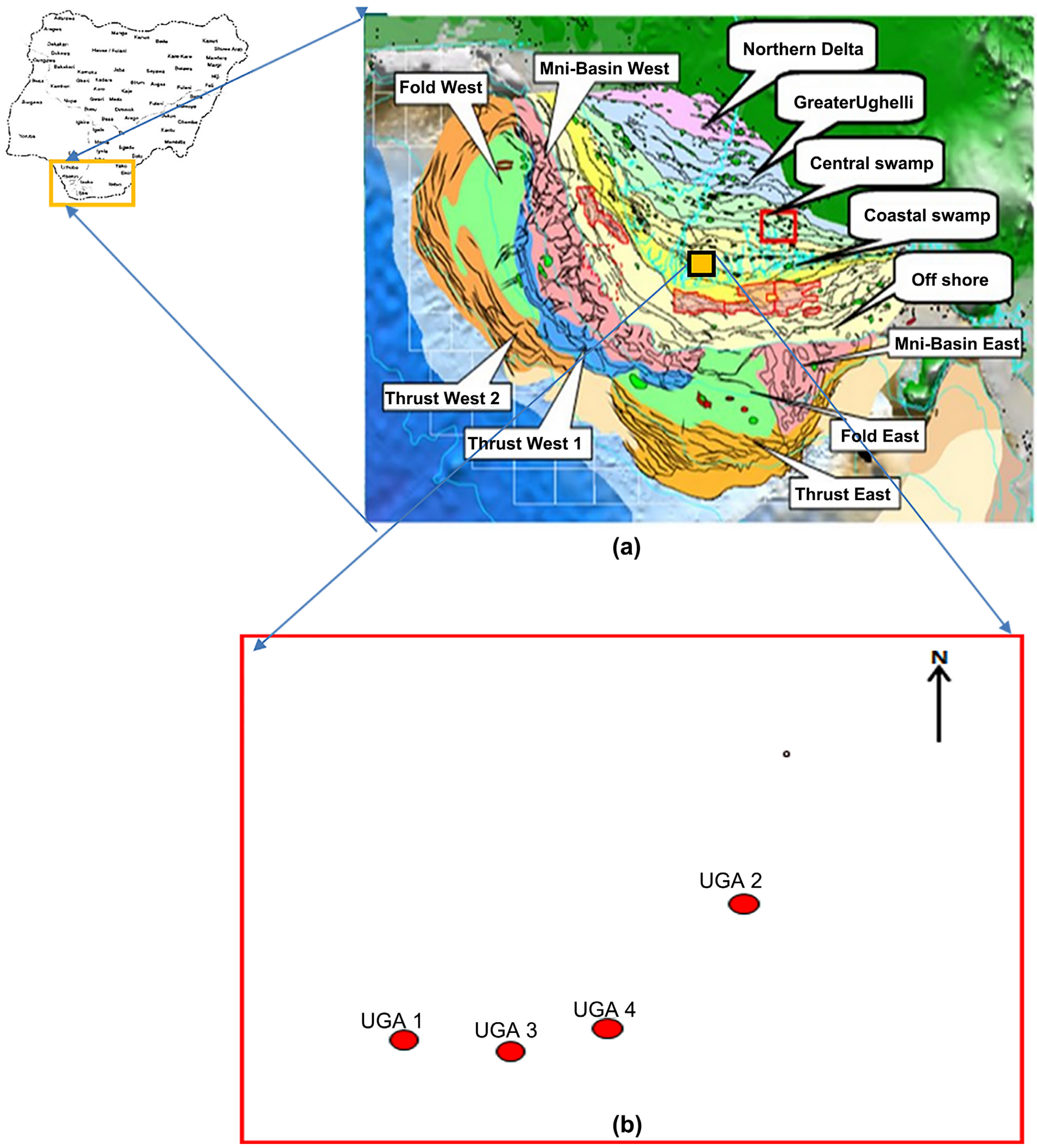

Figure 1. (a) The map of Niger Delta showing different depobelts and the study area (Obiadi *et al.*, 2012); (b) Base map of the study area (SIMA Field) showing 4 Well locations marked in red colour with well names, UGA1, UGA2, UGA3 and UGA4.

wedge [21] [22] [23]. Although the distribution of hydrocarbons is complex, there is a general tendency for the ratio of gas to oil to increase southward within individual depobelts [4]. [18] developed a hydrocarbon habitat model based on sequence stratigraphy of some petroleum-rich belts within the Niger Delta area, and provides a short summary of basin trap, reservoir, and source rock and hydrocarbon character. Gas and oil ratios within the reservoirs were reported by [5] [14]. Reservoirs occur along northwest-southeast "oil-rich belt" and along a number of north-south trends in the Port Harcourt area. [22] suggested that belts roughly correspond to the transition between continental and oceanic crust within the axis of maximum sediment thickness. Other authors have related the oil-rich belts to structural or depositional controls, to an increase in the geothermal gradient, and shifts in deposition basinward within subsequent depobelts [5] [24] [25].

Source rocks in the Niger Delta might include marine interbedded shale in the Agbada Formation, marine Akata Formation shales and underlying Cretaceous shales [5] [6] [14] [26] [27] [28]. Reservoirs in the Agbada Formation have been interpreted to be deposits of highstand and transgressive systems tracts in proximal shallow ramp settings [14]. The thickness of reservoirs ranges from less than 45 ft to a few with thicknesses greater than 150 ft [14]. [12] described the most important reservoir units as point bars of distributary channels and coastal barrier bars intermittently cut by sand-filled channels. Most primary reservoirs were thought by [29] to be Miocene-aged paralic sandstone with 40% porosity, 2 Darcy permeability, and a thickness of about 300 feet.

Reservoir units vary in grain size; fluvial sandstones tend to be coarser than delta-front sandstones. Point bar deposits fine upward; barrier bar sandstones tend to have the best grain sorting. [12] reported that most sandstones are unconsolidated with minor argillaceous and siliceous cement. Potential reservoirs in the outer portion of the delta complex include deep channel sands, lowstand sand bodies and proximal turbidite sandstones [30]. Structural traps formed during syn-sedimentary deformation [14] [18], and stratigraphic traps formed preferentially along the delta flanks, defined as the most common reservoir located within the Niger Delta complex [30].

2. Material and Methods

The research materials include 3D seismic volume, well logs and formation data. The well logs include density, checkshot, resistivity, sonic, porosity logs, Petrel and Interactive Petrophysics software.

3-D seismic data integrated with well logs was used to interpret the structure of the field using Petrel software. Seismic data interpretation is a practical means of imaging the subsurface structural architecture of a reservoir [31]. Petrel software was used to generate maps and well log cross sections. Identification of lithology was done using the gamma ray log while the induction resistivity logs were used for fluid identification. Well-to-seismic tie of the reservoir was carried out using the checkshot data after which fault and horizon interpretation was done. Other processes include identifying seismic reflectors using checkshots, combination of manual and autotracking of horizon, identification of faults (synthetic and antithetic), generation of structural maps (time, depth, thickness) and petrophysical analysis using Interactive Petrophysics software.

3. Result and Discussion

Preliminary study of the well logs revealed a hydrocarbon bearing SIMA reservoir penetrated by four wells (Well 1 - 4), within the depth interval of 3527 m and 3910

m. The reservoir sand bodies are highly faulted (synthetic, antithetic, growth faults) with associated rollover anticlines. Distortions observed in the correlation panel from one well to another was as a result of displacement caused by growth faults [32]. The differences in reservoir development or variation of sand bodies thickness, Figure 2 is a correlation panel showing log suites. The relative displacement of the sand reservoirs seen in adjacent wells was as a result of structural effects (sand bodies were faulted and moved along the fault plane). Hence, the thickness of sands in the hanging wall is greater than that of the footwall.

Depositional environment of the reservoir from log motifs show sharp boundary at the base, and subsequently coarsening upwards and then fining upwards. This has been interpreted as channel sands. There are also isolated sands with sand/shale intercalations, and sharp boundaries at the base and top interpreted as mouth-bars. These features are characteristics of a transitional deltaic environment. The gross thickness of the reservoir varied from 71 to 106 m, net thickness varied from 43 to 77 m. Figure 3 shows checkshots matching in SIMA reservoir, while Figure 4 shows the seismic volume with the SIMA reservoir (horizon) that corresponded with the well top at depth of 3738 m at well UGA3.

3.1. Horizon and Faults

Horizon and fault interpretation were carried out for subsurface structural delineation. In all, seven faults (five normal and two listric faults) were mapped in the seismic section. These faults were major structure building faults corresponding to the growth and antithetic faults in the area within the well control.

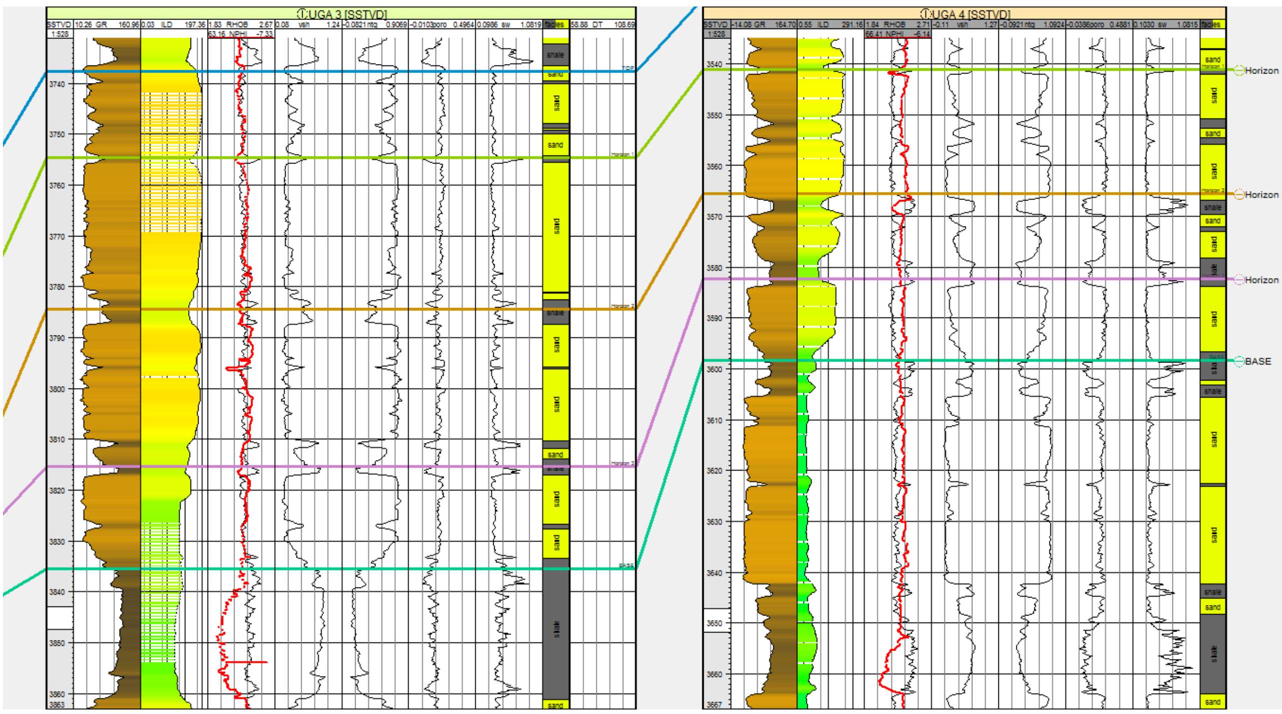

Figure 2. Log suites (given and calculated logs a-d) of Well 3 and Well 4 showing GR, ILD, RHOB and NPHI (merged for sandstone-shale indication), vsh, ntg, porosity, sw and DT logs respectively.

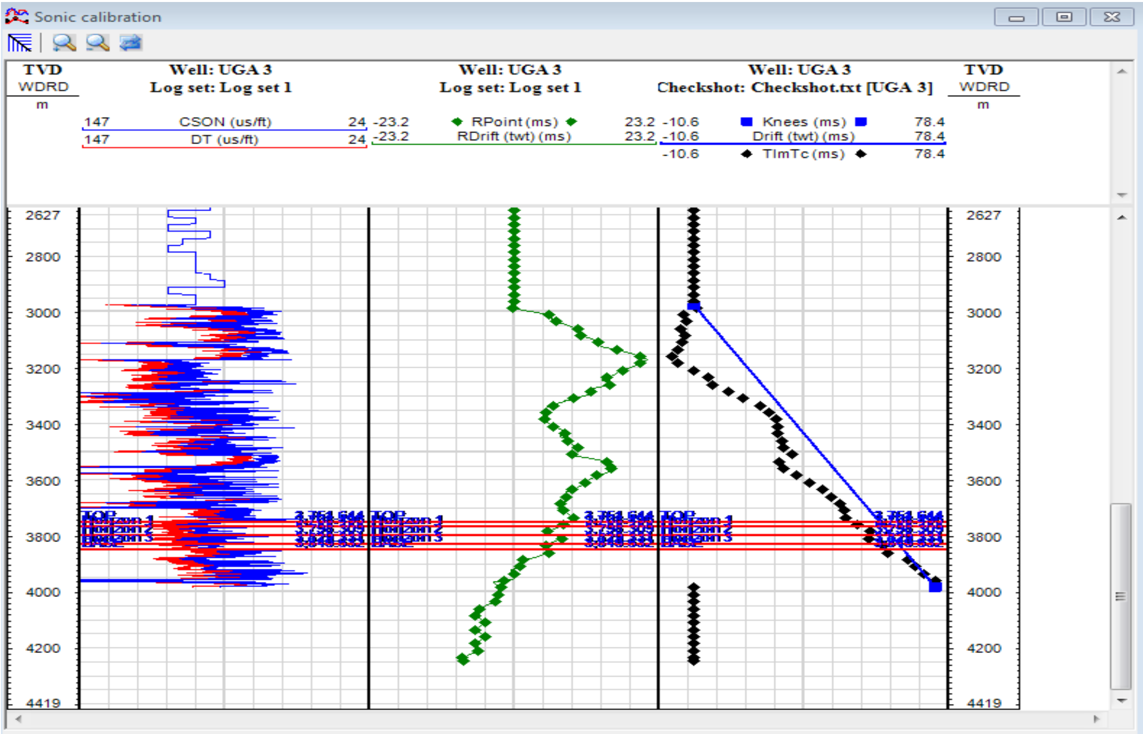

Figure 3. Checkshot matching in SIMA reservoir.

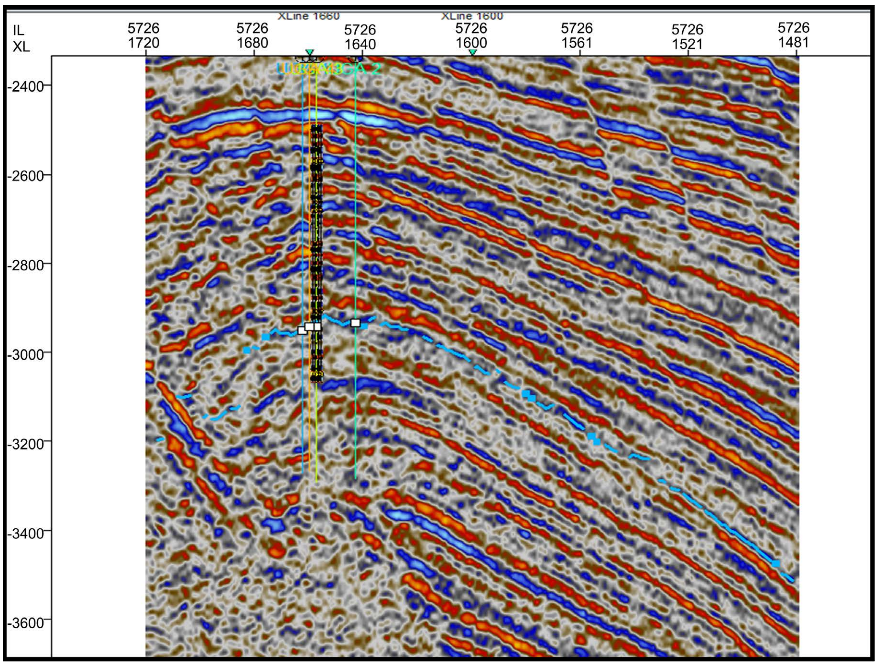

Figure 4. Seismic volume showing the horizon reservoir tying with the well top at 3738 m in well UGA3.

The antithetic fault trending northwest-southeast and the normal fault trending northeast-southwest on the structural high in the section acts as good trapping mechanism for hydrocarbon accumulations in the reservoir. Figure 5 shows fault interpretation on seismic section inline no. 5726.

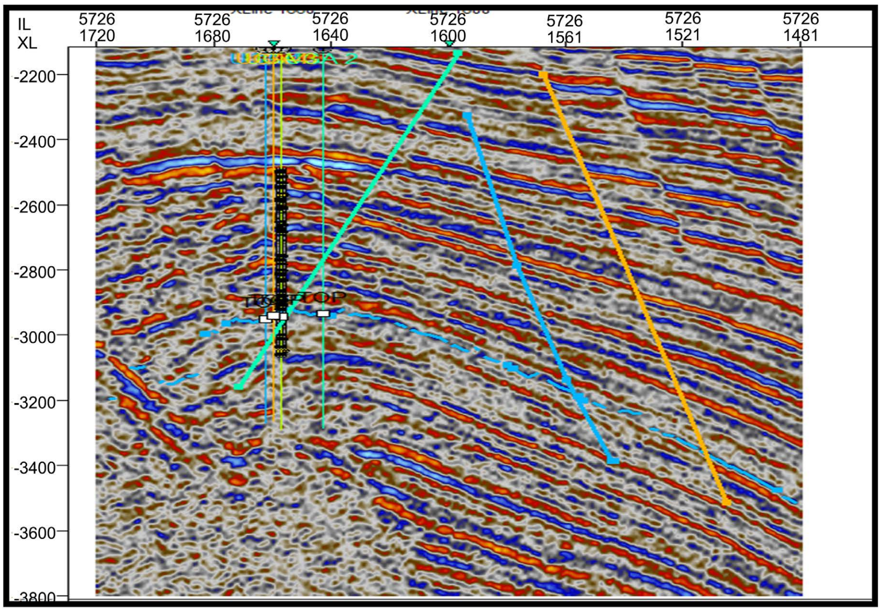

Figure 5. Fault and horizon interpretation on seismic section inline 5726.

Manual and auto-tracking of horizon shown in **Figure 5** was carried out. The section is characterized by high amplitude with moderate-to-good continuity reflections appearing parallel to sub-parallel, mostly disturbed by some truncations which are more fault related than lithologic heterogeneity. The south western part is however, characterized by low-to-high or variable amplitude reflections with poor-to-low continuity. In some places it is disturbed by some truncations which are related to lithologic heterogeneity.

Normal and listric faults were mapped within the area of well control which may have resulted from roll-over processes during sediment accumulations: present on the structural highs of SIMA reservoir. The combination of these faults acts as good traps for hydrocarbon accumulations in the reservoir.

The horizon slice of the pay-zone reflector extracted from the instantaneous amplitude attribute (reflection strength) in **Figure 6** shows the Variance edge seismic attribute with faults trending in East-West direction.

The time, depth and thickness structural maps generated from SIMA reservoir are shown in **Figures 7-9** respectively. The hydrocarbon entrapment in the field is on the structural high located in the southwest direction from the centre of the field which corresponded to the crest of the roll over structure observed in the seismic sections (**Figure 4**). In the time map, structural highs are observed in the northeast while structural lows are observed in the south from the centre of the map. The growth and antithetic faults in respect to the roll over structure (structural high), acts as good traps for the accumulation of hydrocarbon in the reservoir. From the depth map generated from SIMA reservoir, the depth to the top of the reservoir is about 3500 m.

The structural highs in the time map of the two-way travel time of 3000 ms and depth of 3500 m are possible closures which tallied with the crest of roll-over

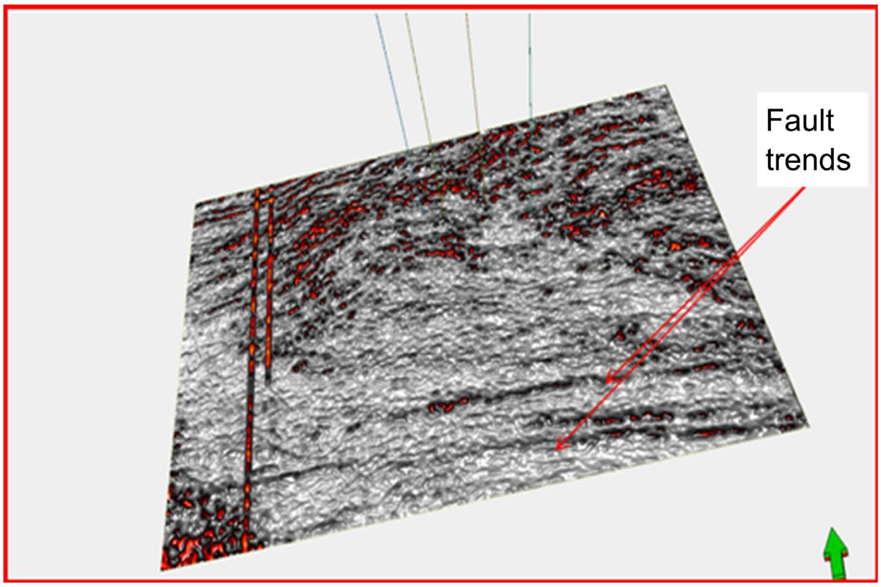

Figure 6. Variance edge seismic attribute showing fault trends in a Seismic time slice (3010 ms) in 3D window.

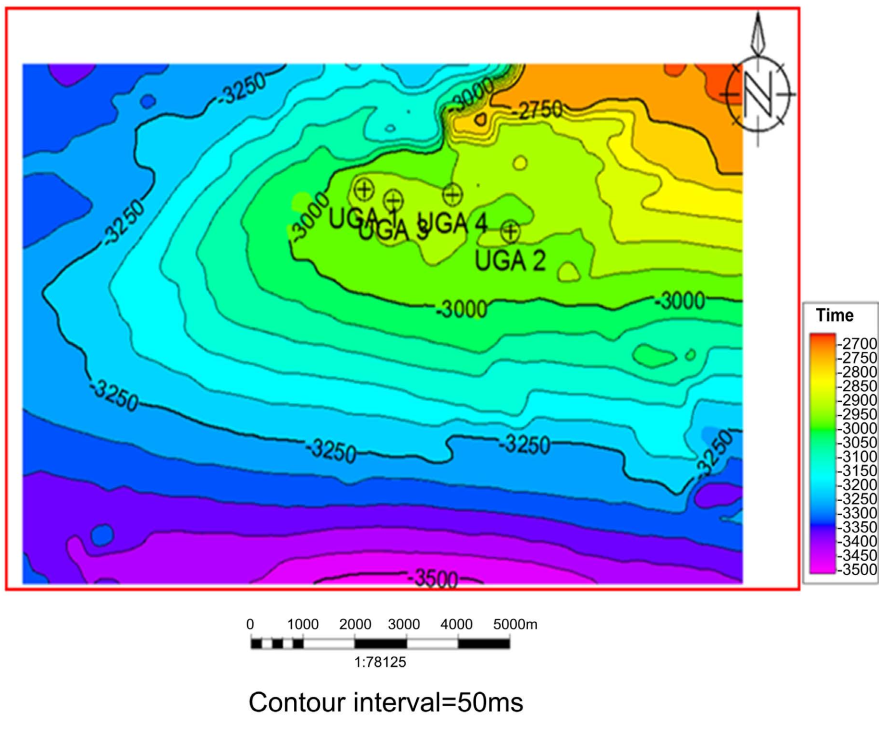

Figure 7. Time map of SIMA reservoir.

anticline observed in the vertical seismic section. Well information reveals hydrocarbon shows in all the wells. This is indicative of hydrocarbon accumulation within good traps with the embedding shales serving as seals (Table 1).

3.2. Petrophysical Properties

In Well 3, net-to-gross varied from 0.1484 to 0.7583 with a total of 5.028 in the

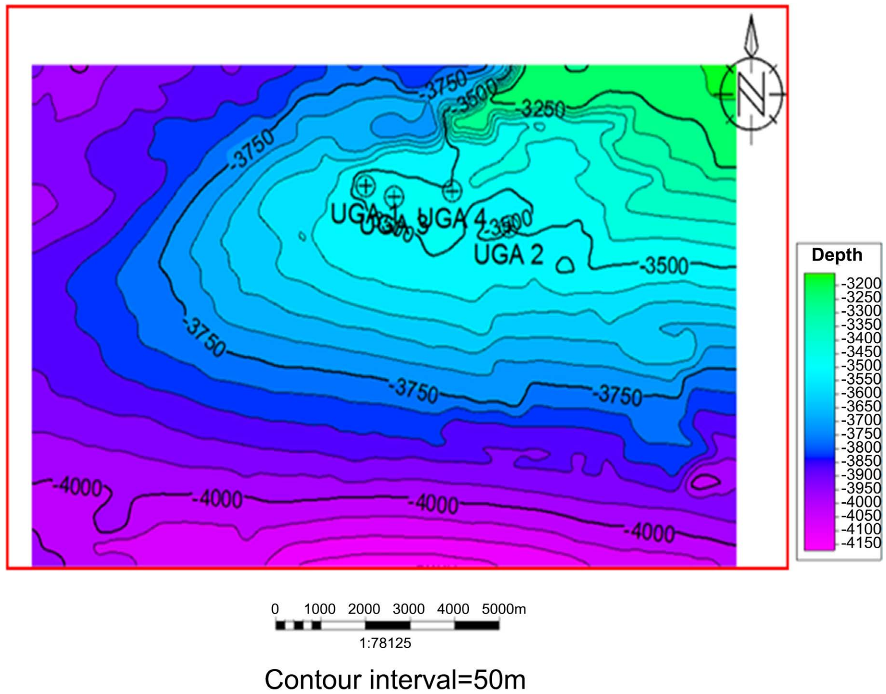

Figure 8. Depth map of SIMA reservoir.

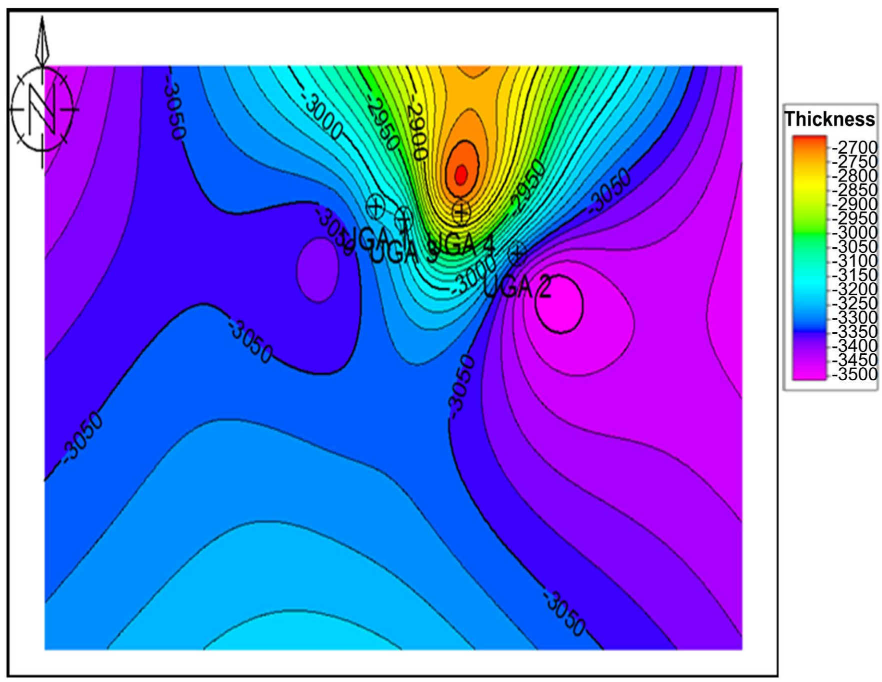

Figure 9. SIMA reservoir thickness map.

borehole column. The porosity ranged from 0.1088 to 0.2606 with an average of 0.20423. The, permeability ranges from 1130.405 to 2125.009 kD, with an average of 1128.219 kD. The water saturation from 0.3147 to 0.7533 and an average of 0.45841. The values of all the petrophysical properties of SIMA reservoir were closely related being taken from the same field. These values are also in agreement

Table 1. Petrophysical data calculated from well logs of Well 3.

Depth (M)	Thickness (M)	Net/Gross	Porosity (Ø)	Permeability (K) (D)	Water Saturation
3740	10	0.1935	0.1781	916.5997	0.4605
3750	10	0.3711	0.1288	515.5671	0.6364
3760	10	0.6403	0.2606	1877.5671	0.3147
3770	10	0.7255	0.2442	1658.713	0.3357
3780	10	0.6956	0.209	1234.234	0.3924
3790	10	0.7024	0.2172	1327.506	0.3775
3800	10	0.3439	0.1893	1026.556	0.4331
3810	10	0.449	0.1673	818.2211	0.49
3820	10	0.7583	0.339	1527.882	0.3905
3830	10	0.1484	0.1088	389.3406	0.7533
Total/Av	900	5.028	0.20423	1129.219	0.45841

with those of the favourable reservoir values obtainable in the Niger Delta as described by [5].

4. Conclusion

A sandstone reservoir penetrated by four wells was investigated in this study using 3D structural interpretation. Hydrocarbon bearing reservoir was identified from well log analysis at the depth of between 3527 m to 3910 m. Seven faults were mapped and horizon tracked from which different structural maps were produced. From these maps, it was observed that the hydrocarbon traps were fault assisted on the structural highs which correspond to the crest of rollover structures in the field. Petrophysical analysis of the reservoir sands shows that the reservoir of average NTG of 5 m was present with porosity of 0.20423, permeability of 1128.219 kD and average water saturation of 0.458 which show that the reservoir is a viable source of hydrocarbon and also in agreement with those found in the Niger Delta.

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Originality of Research

The author hereby declares that the work presented in this paper is original and has not been presented for publication, either in part or whole by the authors to any other journal.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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