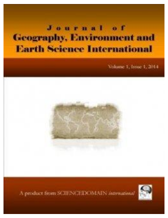

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3D Seismic and Structural Analysis of Middle Agbada Reservoir Sand, Offshore Niger Delta, Nigeria

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Authors' contributions

This work was carried out in collaboration with all authors. Author FOO design the study, wrote the protocol, interpreted and analyses the data. Authors OA, OJE, ASI and JIE contributed in the interpretation, analysis and also read and approved the final manuscript.

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ABSTRACT

The interpretation of 3D seismic and well logs data from 'SUYI' Field reveal that the reservoir sand is in the parallic sequence of the Agbada Formation and also typical structural features of the Niger Delta, namely: The roll over anticline and growth fault with a promising good hydrocarbon accumulation. In this paper, 3D seismic data and well logs data were interpreted and analyse to delineate potential reservoirs and map structures favourable to hydrocarbon accumulation, this will aid further exploration activities within the field of study. Two reservoir sands were delineated from the well logs using gamma ray logs for the lithology identification and resistivity logs for the fluid content identification. Seven faults (F1, F2, F3, F4, F5, F6, and F7) were delineated while three horizons (Horizon 1, 2 and 3) were picked across the seismic section. Most of the major faults delineated in the area trends east-west, cutting across the low structure area. The generated time and depth structure maps shows the area is characterized by low structural features but some high anticlinal structures were observed at different flanks on the maps generated, these areas are likely to be good prospect for the accumulation of hydrocarbon.

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Keywords: Faults; well logs; lithology; reservoir; time structure map; depth structure map.

1. INTRODUCTION

Increasing demand for oil and gas, worldwide has caused an increase in exploration and development in pre-explored area such as the Niger Delta [1,2]. Hydrocarbon exploration and exploitation requires that the spatial and depth distribution and interplay of factors favorable to hydrocarbon accumulation in large quantity are thoroughly appreciated. These factors include the source rock, reservoir rock, and migration pathways, the fidelity of sealing mechanisms, and timing, relationship between formation and the expulsion of hydrocarbons from the source rock. The distribution of these elements of the petroleum system is a result of the tectonic history and fill processes within a basin. As hydrocarbon exploration moves into geologically and economically more challenging environments, such as deeper subsurface locations, deep water regions, subice in the Artic, and into geologically more complex environments, the costs of exploration is bound to be on the rise and the risks associated with field development greater [1]. Continued success in the hunt for Oil and Gas reserves therefore, depends upon a thorough understanding of the subsurface geology of exploration fields, the ability to accurately predict and delineate the spatial and depth distribution of subsurface geologic facies (source rock, reservoir rock and seal) and the ability to discriminate the fluids saturating reservoirs (oil, gas or brine) and possibly quantifying such [2]. Exploration for oil and gas has been an ongoing work in the Niger Delta basin.

Various tools such as gravity and magnetics have been employed by past workers to study sedimentology, structural and accumulation of hydrocarbon in economy quantities. Seismic reflection studies which is a significant tool in detecting large scale subsurface geology at great depth is coherent in distinguishing lithologies [3]. Seismic study is no doubt an efficient tool for hydrocarbon exploration, it provides a potential framework for interpreting several rock records. It has considerable great significance as it helps to identify prospects, predict source rocks, seals and potential reservoir traps [4]. This study therefore utilizes Seismic data to enhance the understanding of the structural and economic potential of 'SUYI'-Fields in the Niger delta to aid further exploration activities.

2. LOCATION OF STUDY AREA

The Niger Delta is situated in the Gulf of Guinea on the west coast of Central Africa (Fig. 1). It is located in the southern part of Nigeria between latitudes 3°' N and 6°N and longitudes 5°'E and 8°E (Figs. 1 and 2). It is bounded in the south by the Gulf of Guinea (or the4000 m bathymetric contour) and in the North by older (Cretaceous) tectonic elements which include the Anambra Basin, Abakaliki uplift and the Afikpo syncline. In the east and west respectively, the Cameroon volcanic line and the Dahomey Basin mark the bounds of the Delta [5]. The province covers 300,000 km^2 and includes the geologic extent of the Tertiary Niger Delta (Akata-Agbada) Petroleum System. The Akata formation (Paleocene to Recent), at the base of the delta, consists of thick shale deposited under marine conditions which is the source rock. The overlying Agbada Formation (Eocene into the Recent) consists of inter-bedded shale and sandstones which is the reservoir rock and is overlain by the Benin formation (latest Eocene to Recent), which is composed of coastal plain sands [6]. The Cenozoic Niger Delta is situated at the intersection of the Benue trough and the South Atlantic Ocean where a triple junction developed during the separation of South America from Africa [7,8]. It ranks among the worlds' most prolific petroleum producing Tertiary deltas that together account for about 5% of the worlds' oil and gas reserves. It is one of the economically prominent sedimentary basins in West Africa and the largest in Africa [9].

2.1 Geological Settings of the Niger Delta

The Niger Delta is one of the world's largest tertiary delta systems and is situated on the West African continental margin at the apex of the Gulf of Guinea [10]. The Niger Delta basin covers an area of 75,000 km^2 [6]. It was formed during the continental breakup in the cretaceous era, with the delta developing from Paleocene. The lithostratigraphic sequence of the Niger Delta is divided into three formations. The Akata formation (Paleocene to Recent), the base of the delta, consists of thick shale deposited under marine conditions. The overlying Agbada Formation (Eocene into the Recent) consists of inter-bedded shale and sandstones and is overlain by the Benin formation (latest Eocene to Recent), which is composed of coastal plain sands [6,11]. The source rocks for crude oil in the Niger Delta are the marine shale facies of the upper Akata formation and the shale inter-bedded with paralic sandstone of the lower Agbada formation. One petroleum system has been identified in the Niger Delta province referred to as the tertiary Niger Delta (Akata-Agbada) petroleum system [5].

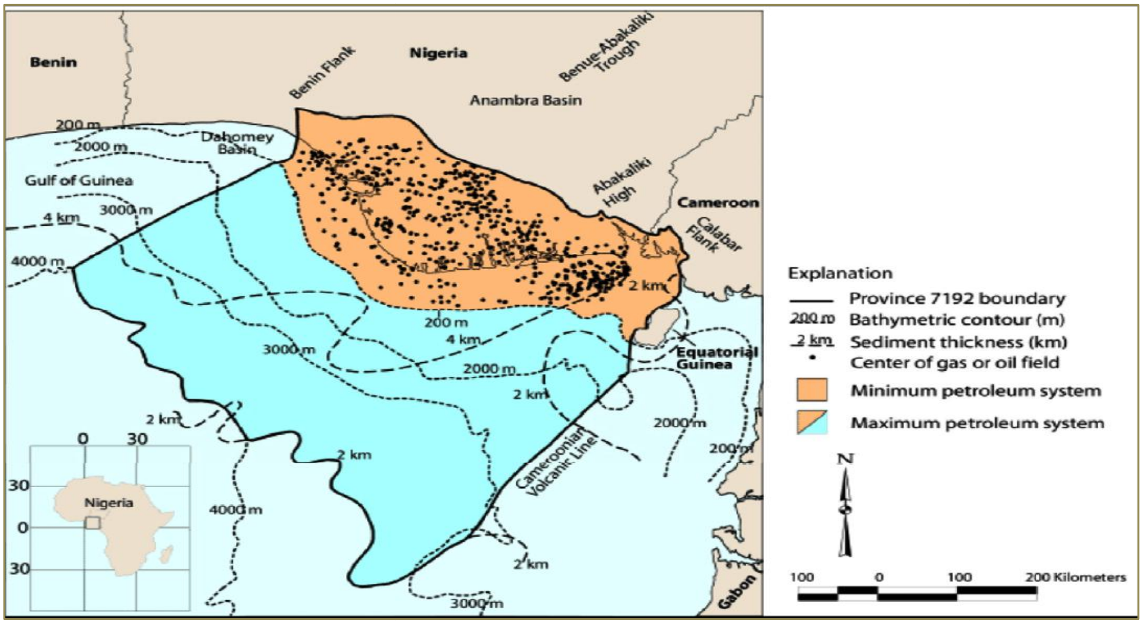


Fig. 1. Map of Niger Delta showing province outline (maximum petroleum system); bounding structural features; minimum petroleum system as defined by oil and gas field center points (Modified from Petroconsultants, 1996, as cited in [5]

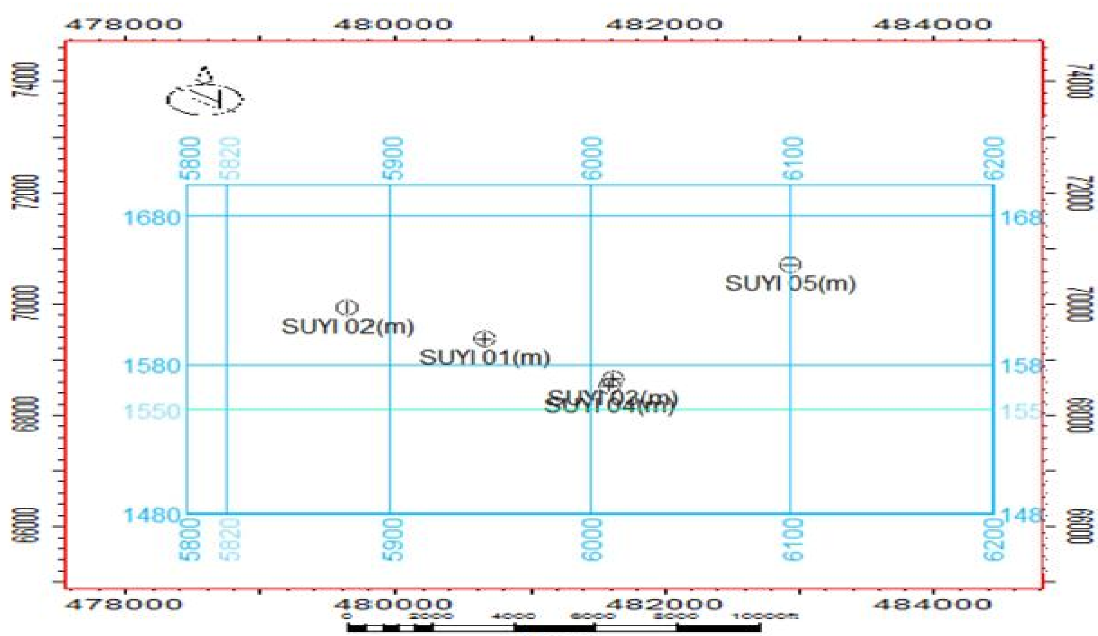


Fig. 2. Basemap of the study area

2.2 Niger Delta Structure

The tectonic framework of the continental margin along the West Coast of equatorial Africa is characterized by Cretaceous fracture zones expressed as trenches and ridges in the deep Atlantic [5]. The fracture zone ridges subdivide the margin into individual basins, and, in Nigeria, form the boundary faults of the Cretaceous Benue-Abakaliki 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 [12]. In the region of the Niger Delta, rifting diminished altogether in the Late Cretaceous. Shale mobility induced internal deformation and occurred in response to two processes [13]. First, shale diapirs formed from loading of poo14rly compacted, over-pressured, pro-delta and delta-slope clays (Akata Formation) by the higher density delta-front sands (Agbada Formation). Second, slope instability occurred due to a lack of lateral, basinward, support for the under-compacted delta-slope clays (Akata Formation). 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 growth fault crests, back-to-back features, and steeply dipping, closely spaced flank faults [14]. These faults mostly offset different parts of the Agbada Formation and flatten into detachment planes near the top of the Akata Formation.

2.3 Traps and Seals

Most known traps in Niger Delta fields are structural, stratigraphic traps are not uncommon (Fig. 3). The structural traps developed during synsedimentary deformation of the Agbada paralic sequence [14,15]. Structural complexity increases from the North (earlier formed depobelts) to the south (later formed depobelts) in response to increasing instability of the under-compacted, over-pressured shales. [10] describe a variety of structural trapping elements, including those associated with simple rollover structures, clay filled channels, structures with multiple growth faults, structures with antithetic faults, and collapsed crest structures.

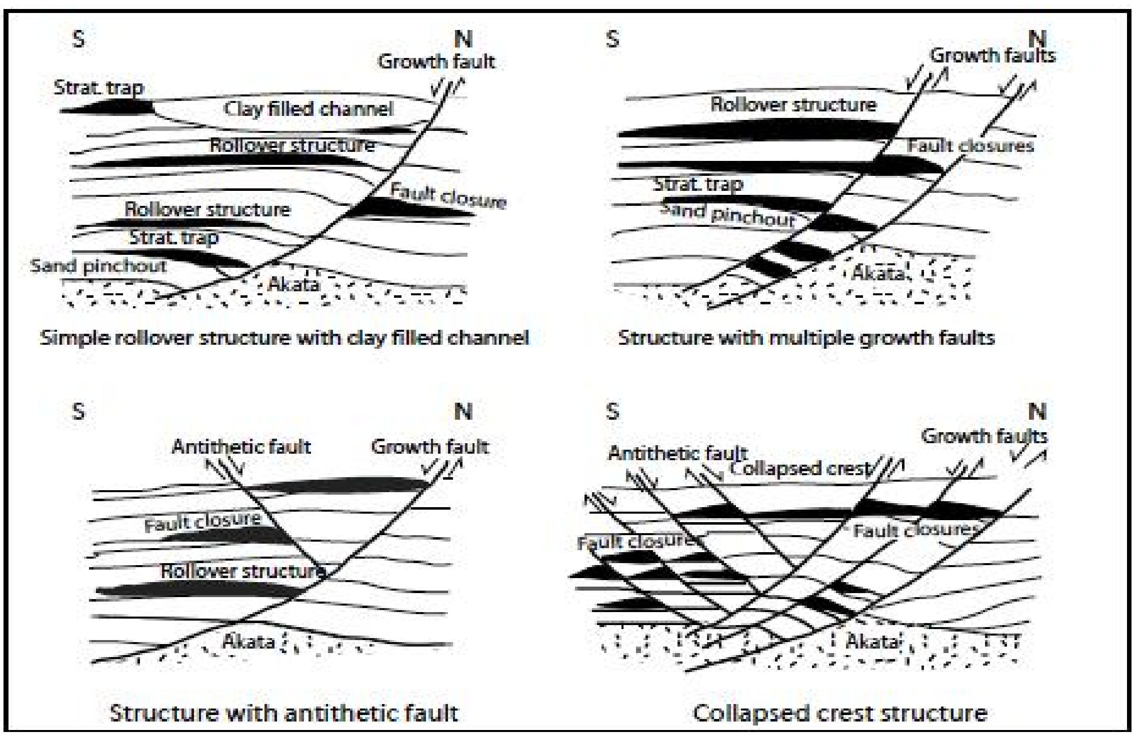


Fig. 3. Examples of Niger Delta oil field structures and associated trap types. Modified from [5,10,15]

On the flanks of the delta, stratigraphic traps are likely as important as structural traps [16]. In this region, pockets of sandstone occur between diapiric structures. Towards the delta toe (base of distal slope), this alternating sequence of sandstone and shale gradually grades to essentially sandstone. The primary seal rock in the Niger Delta is the inter-bedded shale within the Agbada Formation. The shale provides three types of seals—clay smears along faults, inter-bedded sealing units against which reservoir sands are juxtaposed due to faulting, and vertical seals [10].

3. MATERIALS AND METHODS

The materials used for this study includes; Suite of well logs for five well (ASCII format), 3-D Seismic data (SEG Y) and Check shot data, petrel ™ 2009 software. Reservoir rocks in the Niger Delta are made up of sand and shale sequence consisting predominantly of sandstones in the Agbada Formation [10]. The Gamma ray logs measure natural radioactivity in formations [17], they can be used to identify lithologies, and therefore it was used to distinguish lithologies. Two sands were delineated from well five (SUYI WELL 5) as shown. Cut off value of 75API was used in distinguishing the lithologies on the gamma ray log (Fig. 4). Faults were mapped on seismic section, checkshot data was used to convert two way time (TWT) to depth values which was used to convert the time structure map to the depth structure map.

4. RESULTS AND DISCUSSION

Two potential reservoirs were delineated on 'Suyi' well 5, the first sand was picked at measured depth of 2836.61 m (9304.46 ft.) top and 2857.36 m (9374.34 ft.) base for reservoir 1. The second reservoir sand was picked at a measure depth of 2945.63 m (9664.21 ft.) top and 2965.68 m (9729.92 ft.) base of 'SUYI' reservoir 2 (Fig. 4). The 3D seismic data for the

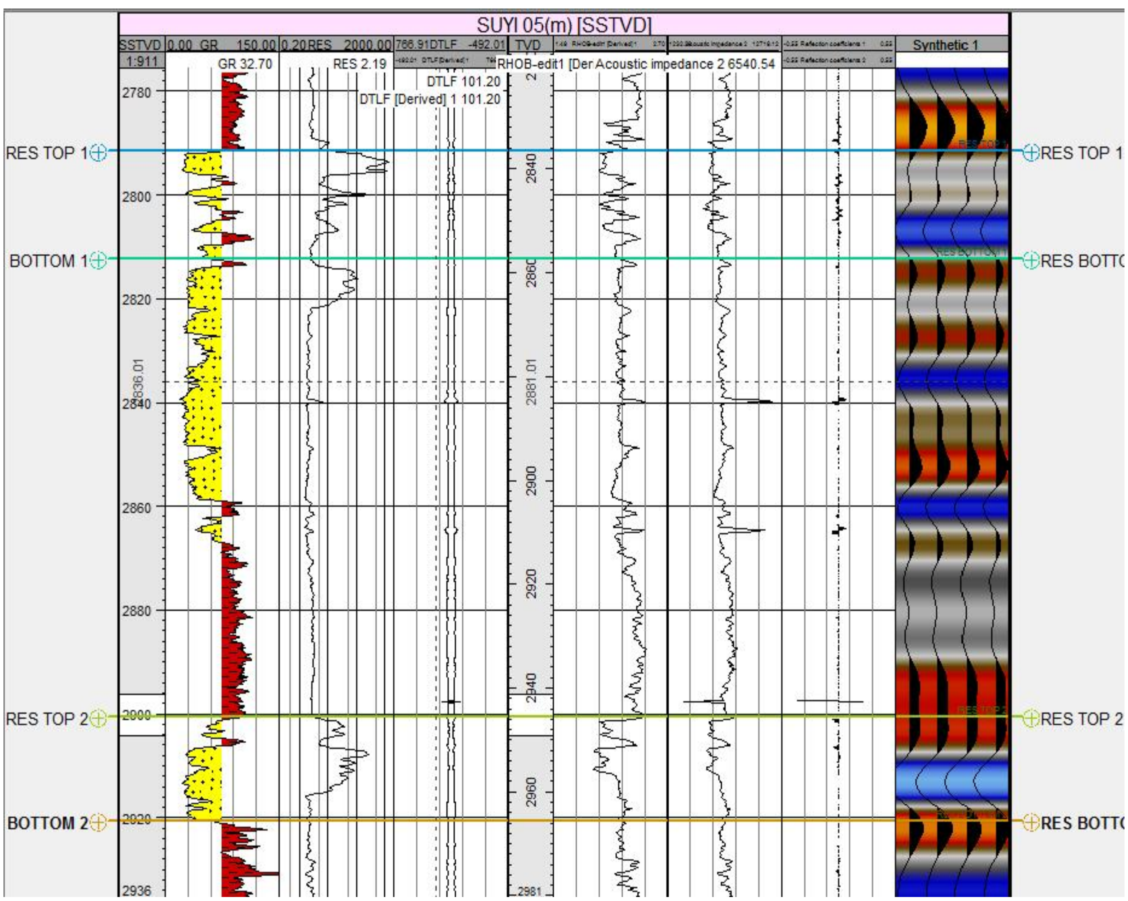


Fig. 4. SUYI 05 Wells with Top and Base of Reservoir 1 and 2 respectively

study area consist of 401 inlines and 221 crosslines and a total of 88,621 post-stacked seismic traces with a record length of 5 seconds, sampled at 4ms interval. The in-line ranges from 5800 to 6200 and the crossline ranges from 1480 to 1700.

4.1 Fault Mapping

Faults were mapped on the seismic sections across the survey area. A total of 7 faults were mapped namely, Fault 1 (F1) to Fault 7 (F7). Four of the faults, F1, F3, F4 and F6 are dipping southwards, two faults, F2 and F7 are dipping southwest while F5 is dipping southeast. The major structure building faults, F1 and F2 are dipping southeast and southwest respectively as observed on the seismic volume and thus, compartmentalize the entire study area into three blocks. All faults in the area are normal faults and are relatively parallel to each other [14]. The seismic data analysis revealed presence of major growth faults labeled F1, F2 , F3 and F4, while F5, F6 and F7 form minor antithetic and rollover fault, (Figs. 5: a, b, c and d).

Faults F1 and F2 are the major structure building faults, which correspond to the growth fault in the area. F1 and F3, F2 and F7 and also F4 and F5 show horst and graben structures as observed on the seismic section (Fig. 5: c and d). Fault population is characterized by mostly East-west trend (normal) faults that are dipping towards the south-west and are parallel to the main boundary faults (F1 and F2). In the North, fault population is characterized mostly by North-South trend (normal) faults. This correspond to the main boundary fault at the West which trends towards the North-South direction. Structural traps like roll-over anticlines, folds which results from growth faults facilitates the entrapment of hydrocarbon [15]. F1, F2 and F3 are observed on the seismic volume as growth faults and can therefore facilitate the entrapment of hydrocarbon. The vertical displacements of the growth faults shows that the amount of throw on both sides of the faults are small and varied from line to line in the seismic survey but with increases in the Northern part of the field for all the horizons considered (Figs. 5: a, b, c and d respectively).

4.2 Mapping of Horizons

From the 3D seismic data, three key horizons (Horizon1, Horizon2 and Horizon 3) were identified, mapped and interpreted using their seismic continuities. The continuities of the fault segments and their continuity were rigorously checked on the seismic sections (Fig. 5a, b, c and d). Some part of the horizons picked were observed to have fallen on chaotic zones at varying intervals on the seismic volume which required keen observation to determine continuity of the horizon at these intervals. Three horizons of different characteristics were picked at random on the seismic section. Horizon 1 is 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 more of fault related than lithologic heterogeneity. Horizon 2 is characterized by high amplitude, moderate-to-good continuity reflections, mostly appearing parallel-to-sub parallel and it is disturbed by truncations which are faults assisted. Horizon 3 is characterized by low amplitude with poor-to-moderate continuity reflections, mostly disturbed by some truncations (Fig. 5a, b, c and d).

4.2.1 Time Structure/ Isochron Maps

The three horizons picked across the seismic volume were used to generate time structure maps. The time structure maps indicate that the area is compartmentalized by the major structure building growth fault into South-East-West trending segments. The time structure map of horizon 1 (Fig. 6a) which lies at the two way travel time (TWT) 1970ms and 2160ms. The structural highs on the maps are found around the central and southern part of the map which lies at two way travel time ranging from 2020ms to 2050ms and 1970ms to 1990ms respectively. The lowest points on this map are found at the flanks of the map with TWT ranging from 2140ms to 2160ms. As observed on the map, no conspicuous high anticlinal structure is evident. The time structure map of horizon 2 (Fig. 6b) lies between TWT 2060ms and 2230ms. Faults (1, 2, 4, 5 and 7) intersect this horizon and is seen to have enclose some low structural features at both the southern and northern part of the map. Major structural features in this map falls in the area with TWT ranging from 2110ms to 2230ms. There is evidence of an anticlinal structural at the Northern part of the map between TWT 2060ms and 2100ms which is likely to serve as good prospect for hydrocarbon. Fig. 6 c shows the time structure map of horizon 3 which lies between TWT 2550ms and 2275ms. Faults F1, F2, F7 intersect this horizon at the central part of the map. Major structures of this map falls in the area with TWT ranging from 2400ms to 2550ms which can serve as a good prospect for hydrocarbon.

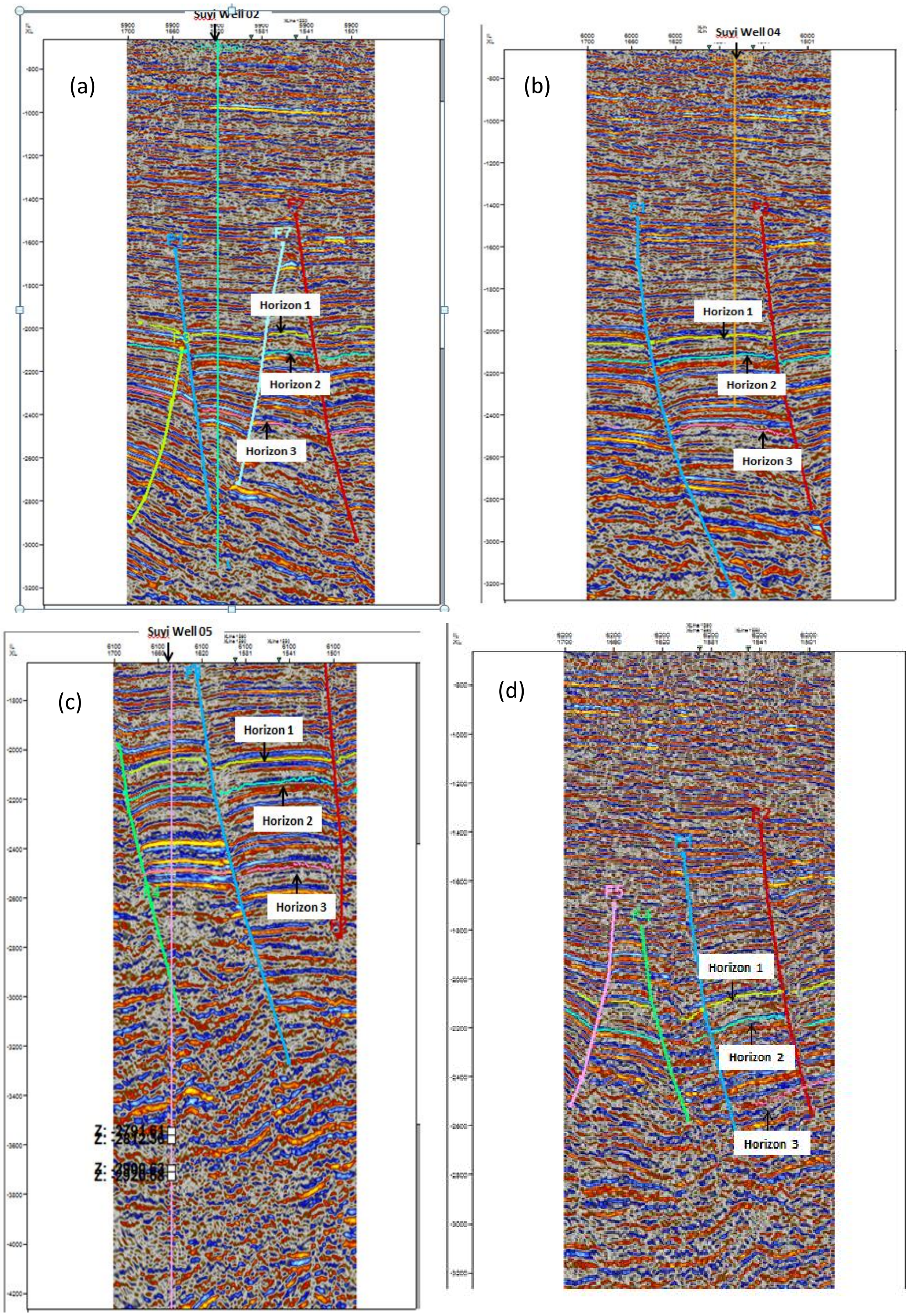
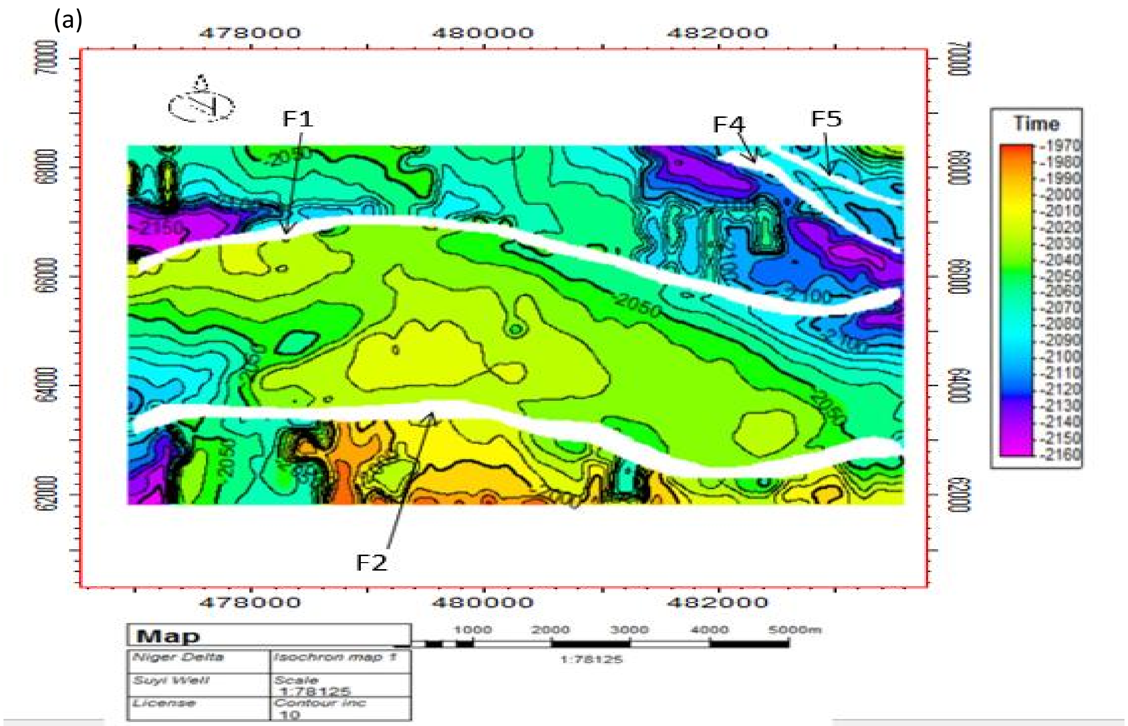


Fig. 5. Seismic Section with Faults and Horizons (a): Inline 5900 and Well 02. (b): Inline 6000 S and Well 04. (c) Inline 6100, Well 05, the Well Tops and Bottoms of the Reservoirs (d): Inline 6200


(a)
478000
480000
482000
F1
F2
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Time
-1970
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-2100
-2110
-2120
-2130
-2140
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Map
Niger Delta
Isochron map 1
Suyi Well
Scale 1:78125
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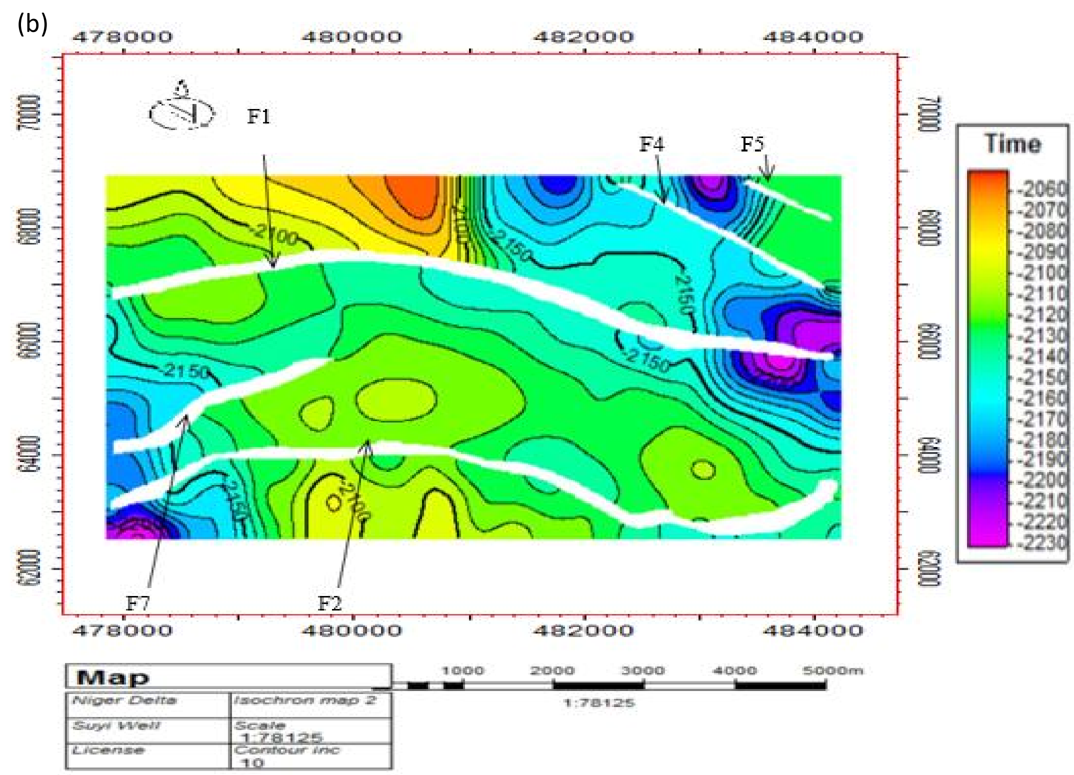
(b)
478000
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F2
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F5
F7
Time
-2060
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-2100
-2110
-2120
-2130
-2140
-2150
-2160
-2170
-2180
-2190
-2200
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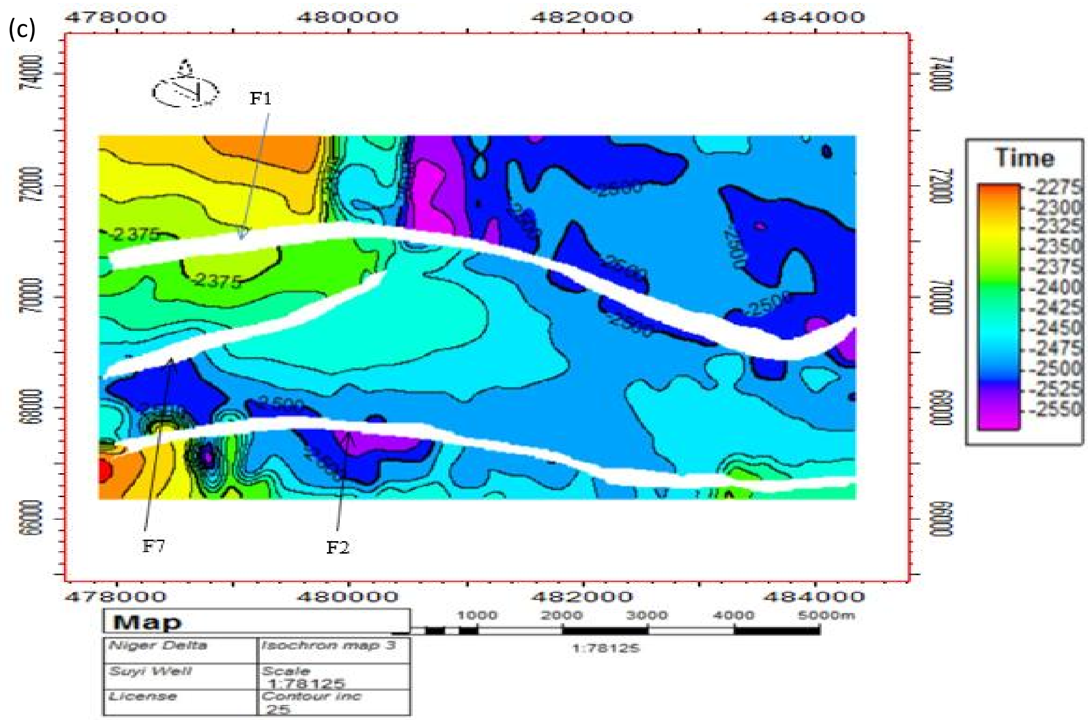
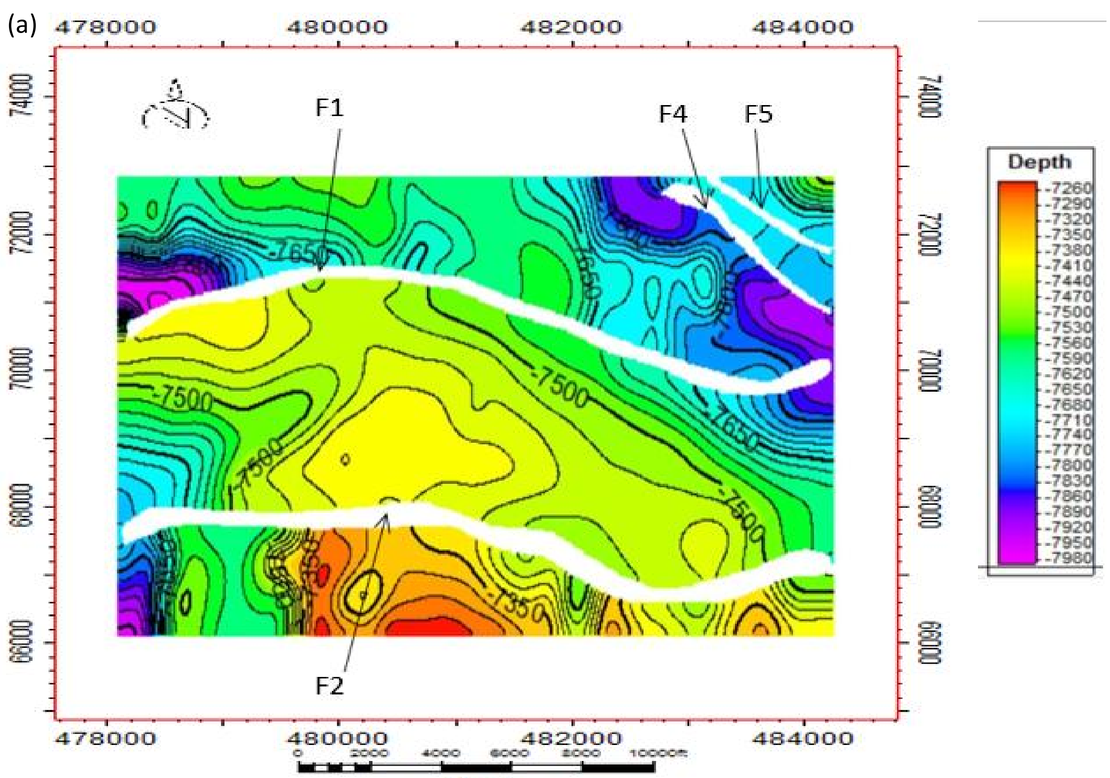


Fig. 6. a, b and c. Time structure map of Horizon 1, 2 and 3 respectively



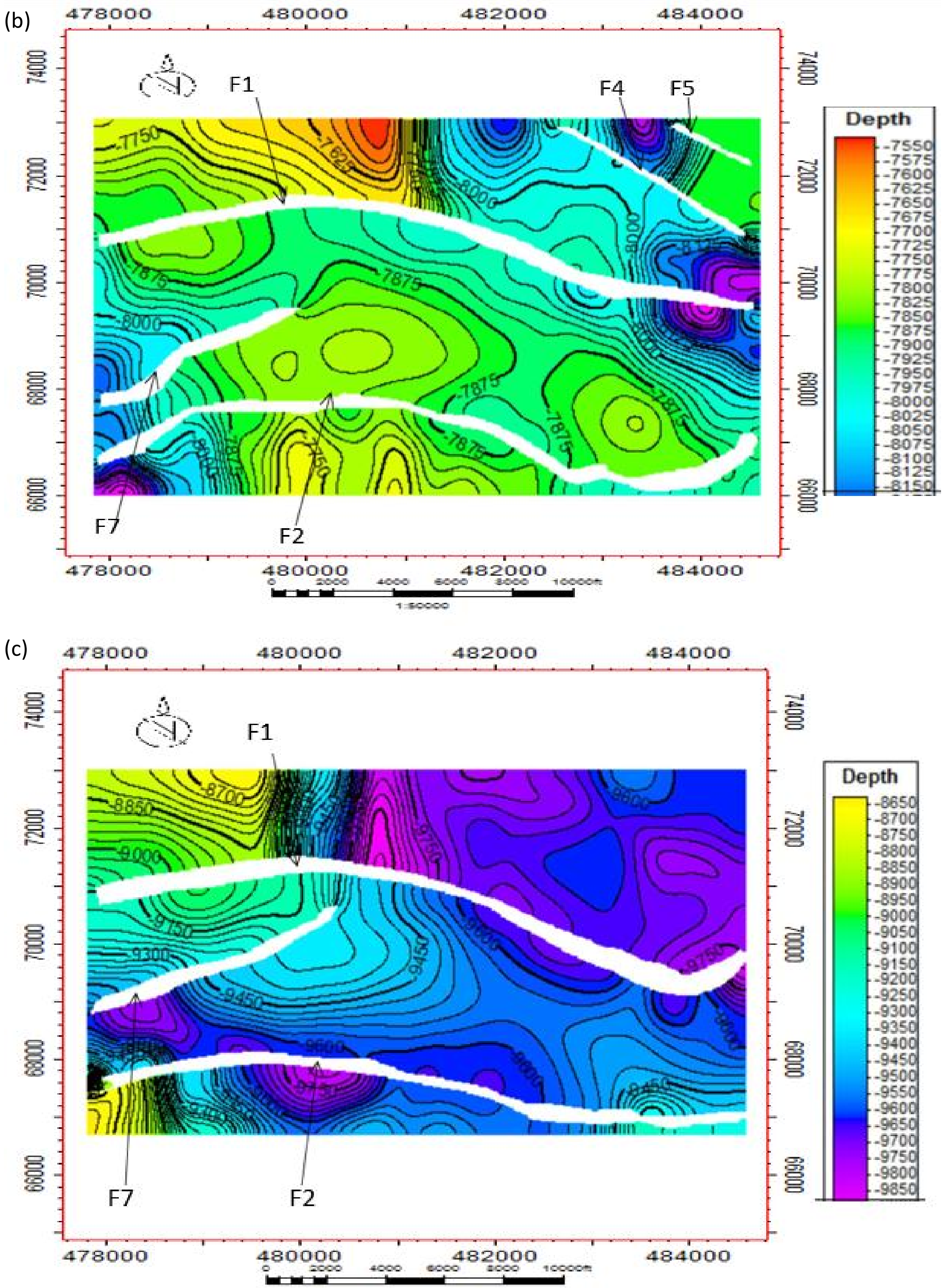


Fig. 7. a, b and c. Depth structure map for Horizon 1, 2 and 3 respectively at varying depth intervals

4.2.2 Depth Structure/ Isopach Maps

The depth structure map was converted to depth structure map using a time-depth relationship model. The depth structure map for the three horizons confirms the structure already delineated from the time structure map. Low value in two way travel time correspond with low depth value in the depth map depicting a low structural area and high value in two way travel time corresponds to high depth value depicting an anticlinal structure that can house hydrocarbon. Figs. 7 a, b and c shows depth structure map for horizon 1, horizon 2 and horizon 3 at depth interval of 7260 ft (2212.85 m) and 7980 ft (2432.30 m), 7550 ft (2301.24 m) and 8150 ft (2484.12 m) and also 8650 ft (2636.52 m) and 9850 ft (3002.28 m), respectively.

5. CONCLUSION

The interpretation of 3-D seismic and well logs from the 'SUYI' Field revealed that the reservoir sands are in the parallic sequence of the Agbada and also typical structural features of the Niger Delta, namely the roll over anticlines and growth faults with a promising good hydrocarbon accumulation. Two reservoirs were mapped from the well using the gamma ray logs for the lithology delineation and resistivity logs for the fluid content identification. Seven faults (F1, F2, F3, F4, F5, F6 and F7) were delineated while three horizons were picked at random across the seismic section. The generated time and depth structural maps shows that the area is characterized by low structural features but some high anticlinal structure were observed at different flanks on the maps generated, these areas are likely to be good prospect for the accumulation of hydrocarbon. Due to the nature of the wells within the field, none of the wells as observed show to have commercial quantity of hydrocarbon (SUYI WELL 5). The 'SUYI' Field is highly faulted with a total of 7 faults mapped and it is compartmentalized into E-W trending blocks by major structure building growth faults (Fault 1 and Fault 2) creating 3 mini-depobelts as observed on the maps. There are antithetic faults, compensating for extensional stress due to the structure building (growth) faults. The subsurface horizons of the 'SUYI' Field are rolled over into the fault plane of faults 6 and 7 (F6 and F7) thereby forming suitable anticlinal contour closures. The structural interpretation of the 'SUYI' Field has been used to accurately produce structural maps for each horizon mapped that show possible structure that can house hydrocarbon.

6. RECOMMENDATION

It is recommended that integrated study be conducted to predict hydrocarbon saturation in the area in order to enhance optimum recovery of hydrocarbon.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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