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

ABSTRACT

The interpretation of 3D seismic and well logs 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. Two reservoirs were mapped from the well 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 were picked across the seismic section. Most of the major faults delineated in the area trends Southward, cutting across the low structural area. The generated Isochron and Isopach Map shows the area is characterized by low structural features but some high anticlinal structures were observed at different flanks on the map generated, these areas are likely to be good prospect for the accumulation of hydrocarbon. Most of the anticlinal structure within the region are fault independent.

Keyword: Faults, well logs, lithology, reservoir, Isochron Map, Isopach 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}. 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. 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 have been used by past workers to study its sedimentology, structural and economic prospects. Seismology is no doubt an efficient tool for these purposes. It provides a potential framework for interpreting much of the rock records, and has considerable economic significance as it helps in identifying exploration prospects and predicting source rocks, seals and potential reservoir traps {3}.This study therefore utilizes it to enhance an understanding of the structural and economic potential of the 'SUYI'-Fields in the Niger delta to aid further exploration activities within the field of study.

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 3^0' N and 6^0N and longitudes 5^0'E and 8^0E (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 {4}. The province covers 300,000 km^2 and includes the geologic extent of the Tertiary Niger Delta (Akata-Agbada) Petroleum System, 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 {5, 6}. 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 {7}.

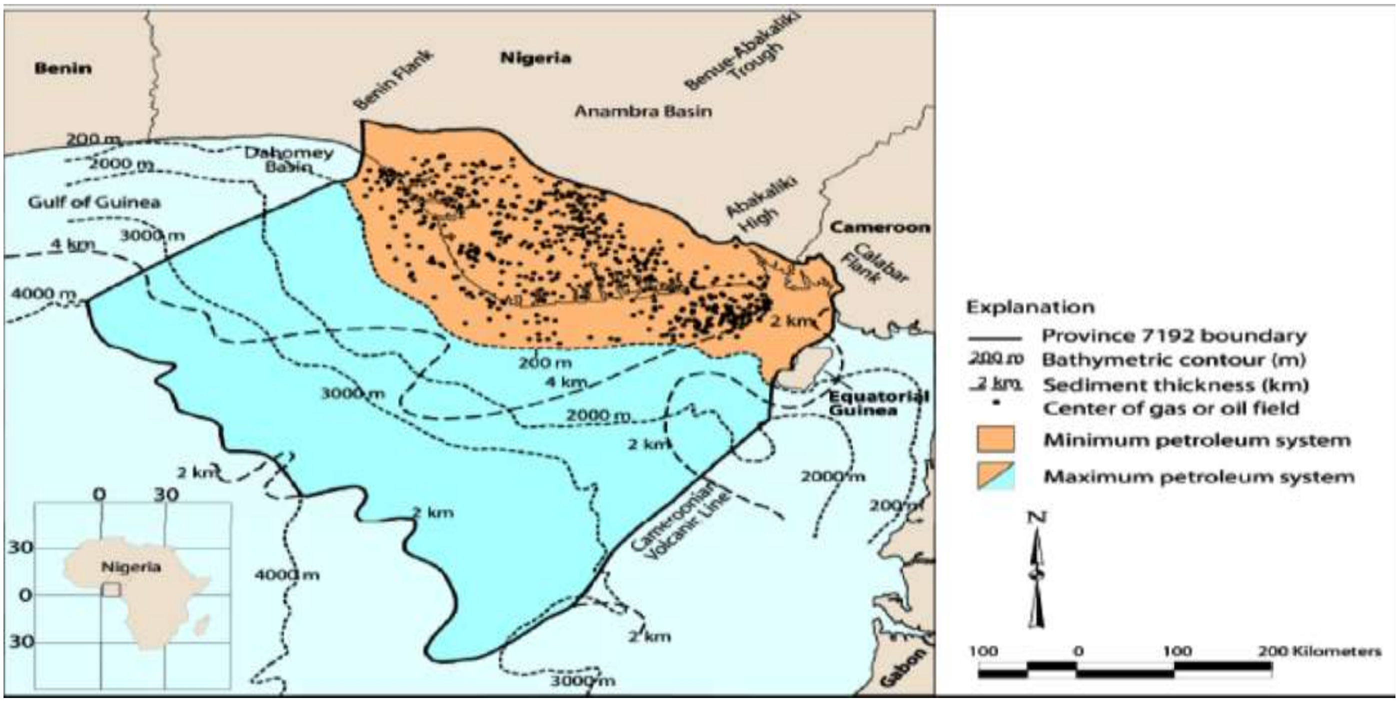


Fig. 1: Map of Niger Delta showing province outline (maximum petroleum system); bounding structural features; minimum petroleum system as defined by oil and gas field center points (Modified from Petroconsultants, 1996, as cited in {4}.

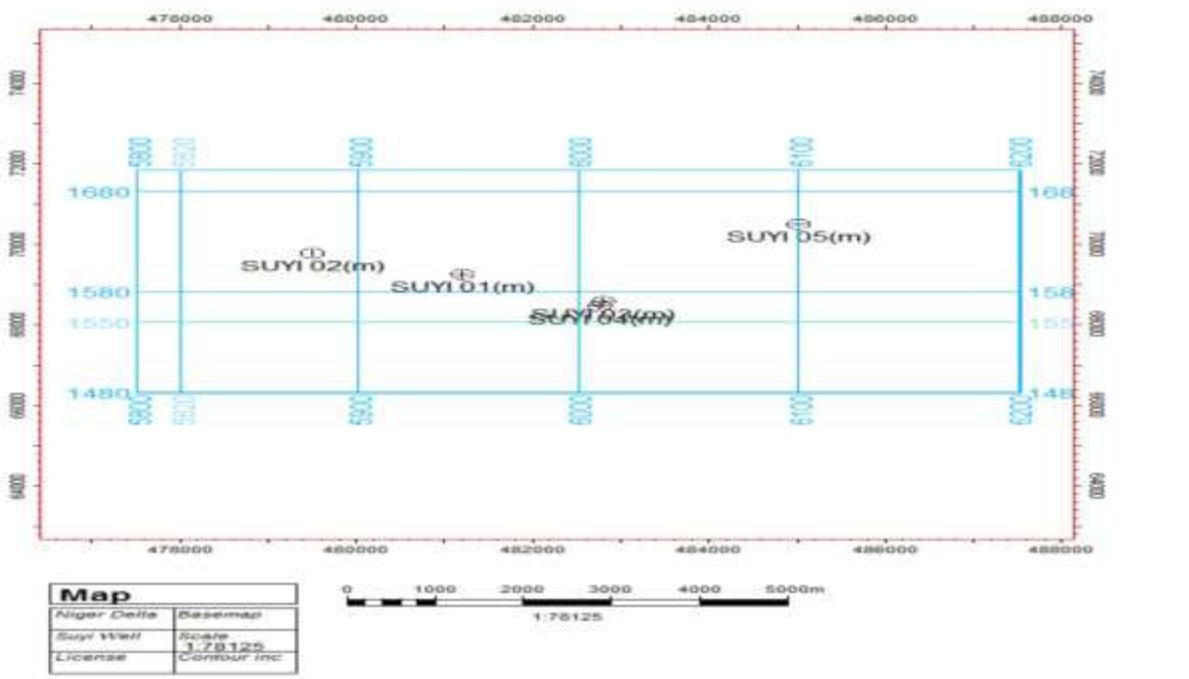


Fig. 2: Basemap of the Study Area.

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 {8}. The Niger Delta basin covers an area of 75,000km^2 {9}. 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 {9, 10}. 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 {4}.

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 {4}. 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 {11}. 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 {12}. 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 (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 {13}. 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 {13, 14}. 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. {8} 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. On the flanks of the delta, stratigraphic traps are likely as important as structural traps {15}. 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 {8}.

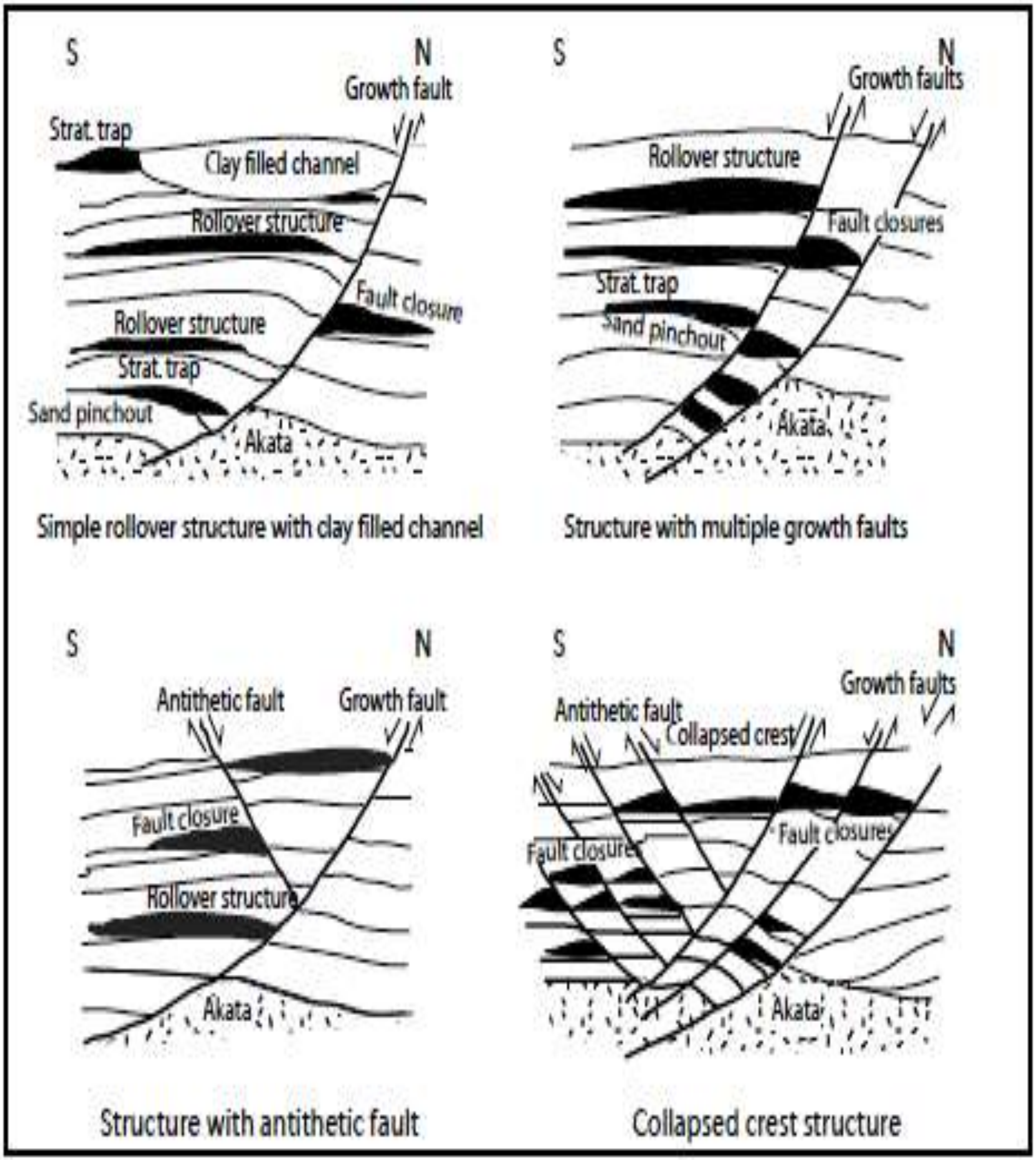


Fig. 3: Examples of Niger Delta oil field structures and associated trap types. Modified from {4, 8, 14}.

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), Check shot data, Base Map of the study area (Fig. 2), petrel ™ 2009 software. Lithology delineation of the sand and shale sequence was done with the gamma ray log because reservoir rocks in the Niger Delta are mainly sandstones predominantly in the Agbada Formation {8}. The Gamma ray logs measure natural radioactivity in formations {16}, they can therefore be used to identify lithologies, two sands were delineated from well five (SUYI WELL 5) as shown in Fig. 4. Cut off value of 75 was used in distinguishing the lithologies on the gamma ray log as show in Fig. 4.Faults were mapped on seismic section, checkshot data was used to convert two way time (TWT) to depth values and vice versa and also used to converting the time structure map to the depth structure map.

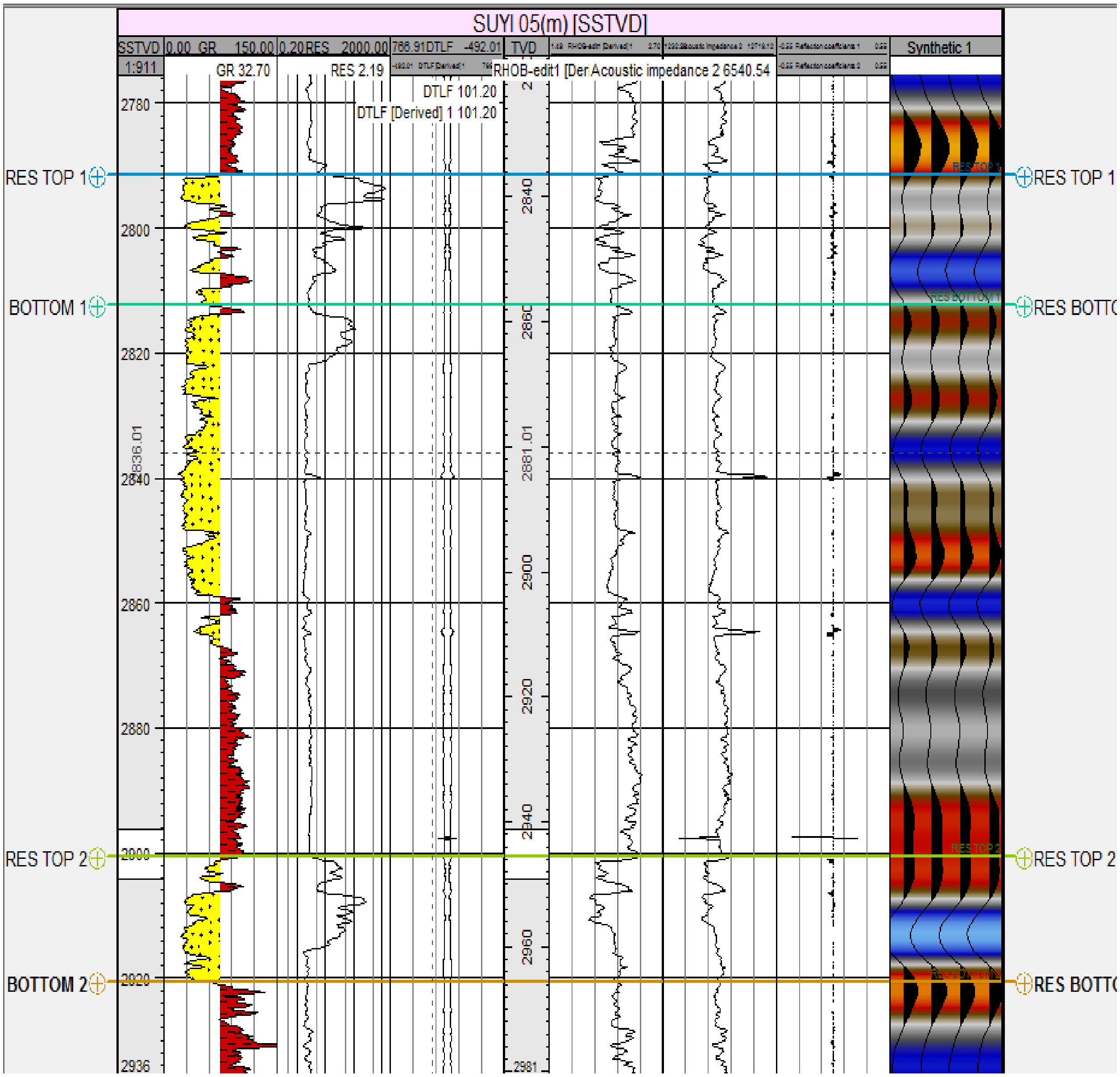


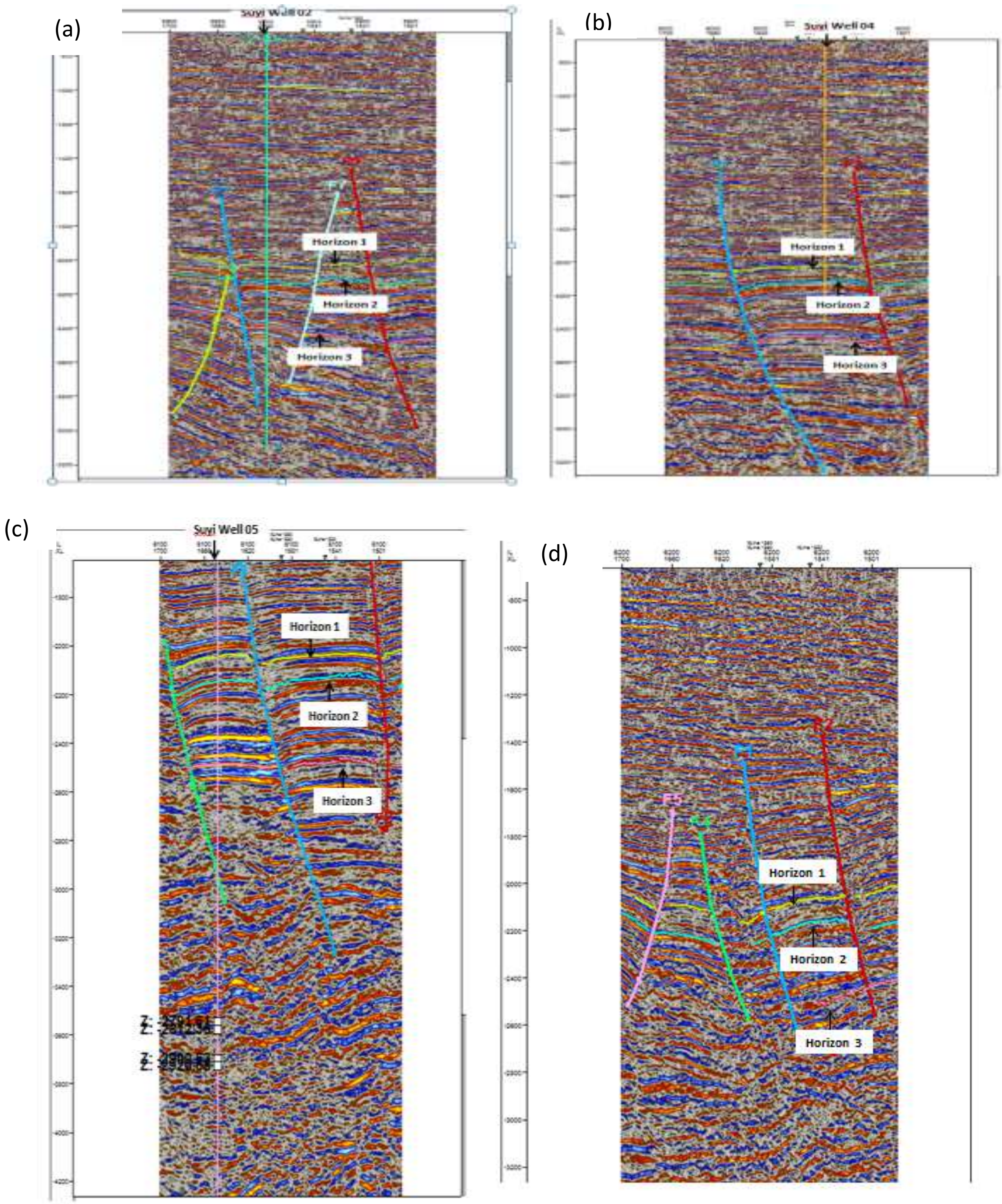
Fig. 4: SUYI 05 Wells with Top and Base of Reservoir 1 and 2 respectively

4. RESULTS AND DISCUSSION

Four horizons of two sands were picked and correlated on the well logs, the first and second horizons were picked at measured depth of 2836.61m and 2857.36m which both serve as the top and base of the 'SUYI' reservoir A respectively. The third and fourth horizons were picked from a measure depth of 2945.63m and 2965.68m which serve as a top and base of 'SUYI' reservoir B respectively (Fig. 4). The seismic digital data for the 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 picked on the seismic sections and correlated across the survey area. A total of 7 faults were mapped in the study area 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 Southward and Southwest respectively 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. 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 respectively, (Figs. 5: a, b, c and d respectively).



Figs. 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.

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 on seismic section (Figs. 5: c and d). Fault population is characterized by mostly East-west trend (normal) faults that are dipping towards the south-west, parallel to the main boundary faults (F1 and F2). In the North, fault population is characterized mostly by North-South trend (normal) faults. This is in response to the main boundary fault to the West of the 'SUYI FIELD' which trends North-South direction. The identified growth faults (F1, F2 and F3) are significant in trapping 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).

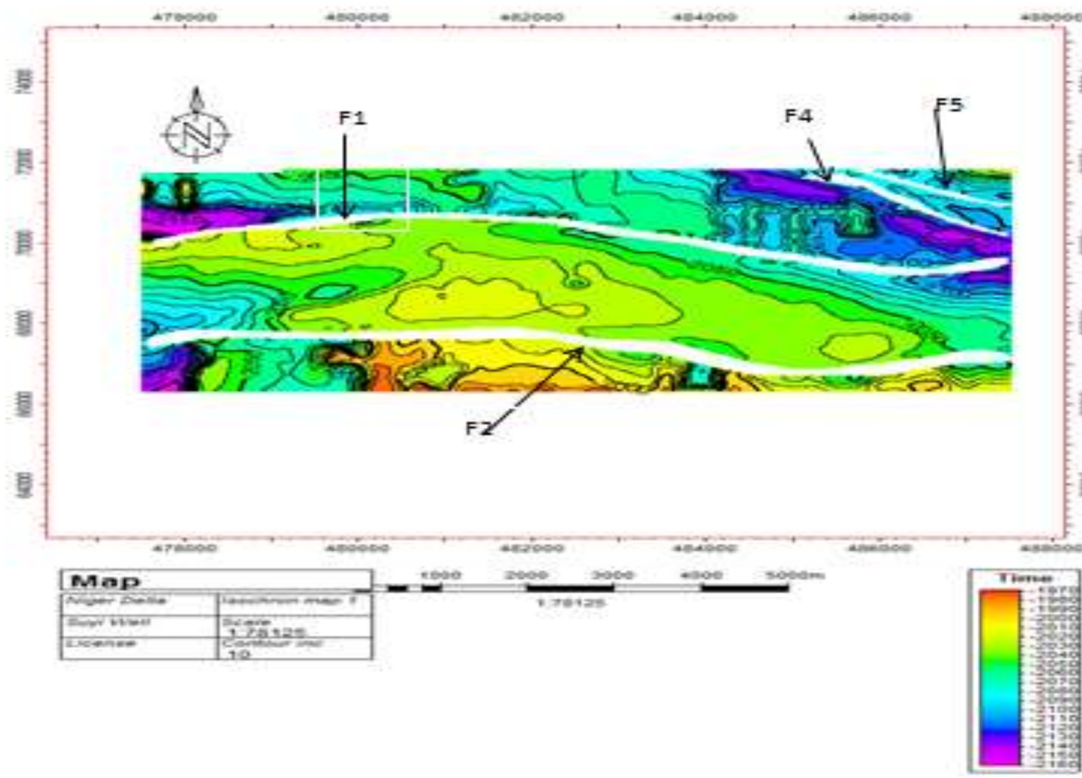
4.2 Mapping of Horizons

The 3D seismic data was interpreted on an interactive workstation. 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 assignment were rigorously checked on the seismic sections (Figs. 5: a, b, c and d respectively. The well tops horizon of the potential reservoir sand mapped on the well logs were seen to have fallen in the chaotic part of the seismic section enabling the tying of the well tops with the seismic section but 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. Horizon 3 is characterized by low amplitude with poor-to-moderate continuity reflections, mostly disturbed by some truncations (Figs. 5a, b, c and d respectively).

4.2.1 Isochron/Time Structure Maps

Isochron maps were produced for the three horizons. The isochron maps indicate that the horizons are compartmentalized by the major structure building fault into South-East-West trending segments. The isochron map of horizon 1 (Fig. 6a) which lies at the two way travel time 1970ms and 2160ms. The structural highs on the maps are found around the Central and the Southern part of the map lies at two way travel time ranges between 2020ms and 2050ms, 1970ms and 1990ms respectively. The lowest points on this map are found at the flanks of the map with TWT ranges from 2140ms and 2160ms. There is no good anticlinal structure in this map that can serve as a potential hydrocarbon prospect but there is likely to be good structures at the Southern part of the map. The isochron map of horizon 2 (Fig. 6 b) lies at TWT of 2060ms and 2230ms. Faults (1, 2, 4, 5 &7) intersect this horizon and were seen to have enclosed, 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 low structure with TWT ranges from 2110ms to 2230ms. There is tendency of an anticlinal structural at the Northern part of the map with TWT ranges from 2060ms to 2100ms, which is likely to serve as good prospect for hydrocarbon. Figure 6 c shows the isochron map of horizon 3 which lies at TWT of 2550ms and 2275ms. Faults F1, F2, F7 intersect this horizon and were seen to have enclosed some low structure features at the central part of the map. Major Structures in this part of this map falls in the area with low structure with TWT ranging from 2400ms to 2550ms except at the Northeastern and Southeastern flanks of the map with TWT ranges from 2375ms to 2275ms, which can serve as a good prospect for hydrocarbon.

(a)


F1
F4
F5
F2
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Niger Delta
Suyi Well
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Isochron map 1
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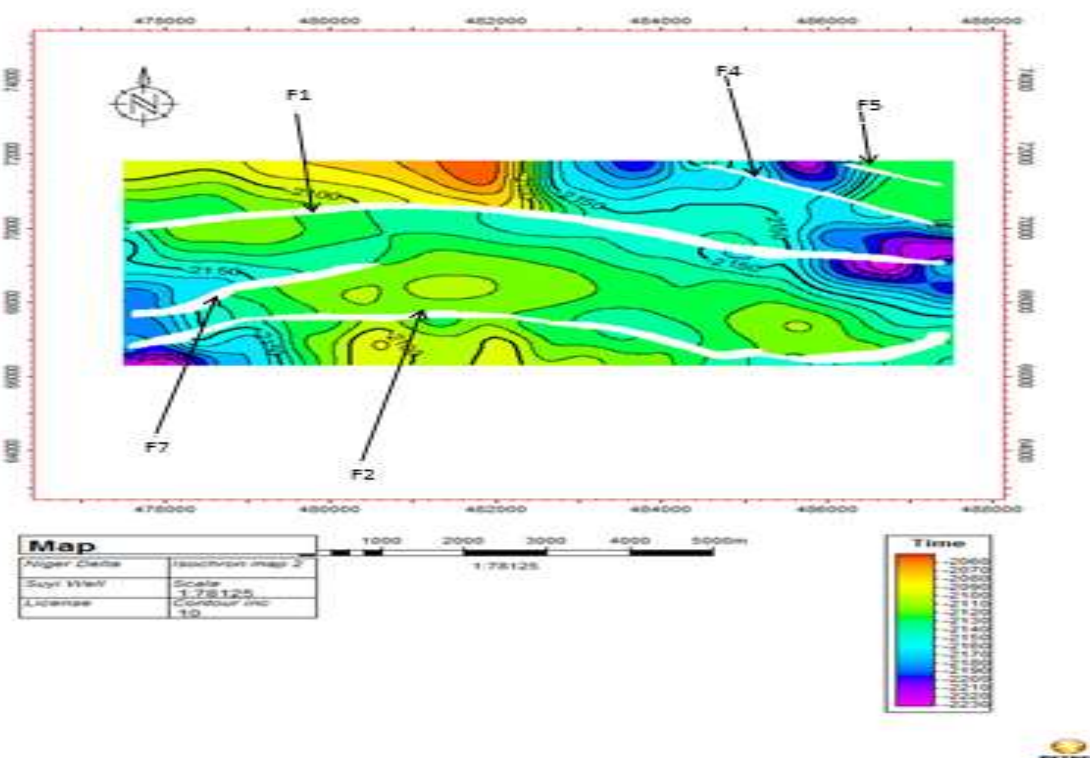
(b)


F1
F4
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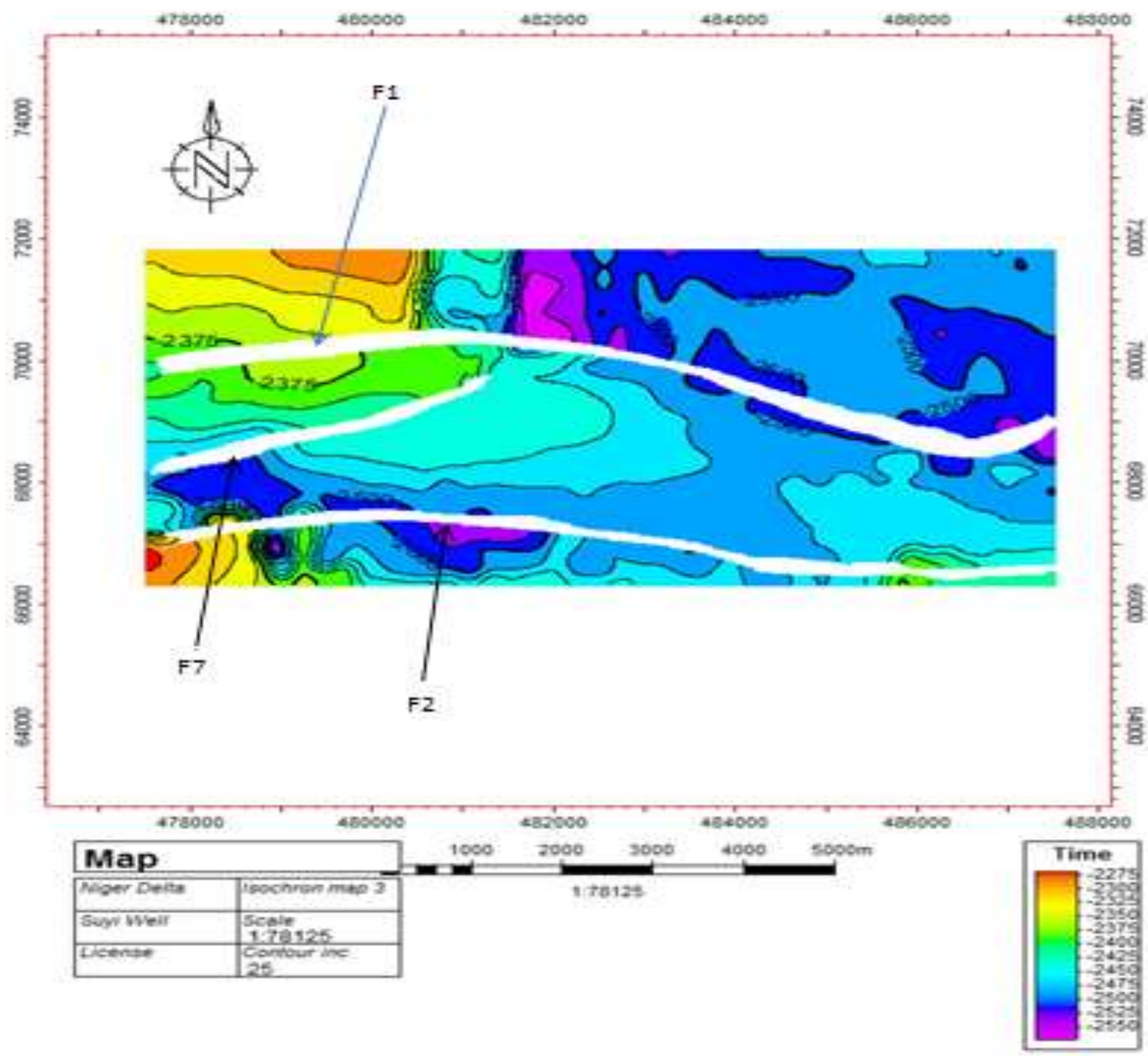

Fig. 6: a, b and c: Isochron Map of Horizon 1, 2 and 3 respectively.

4.2.2 Isopach/Depth Structure Map

The Isopach map for the three horizons confirms the structure already delineated from the Isochron map for the three horizons. 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 with high depth value depicting an anticlinal structure that can house hydrocarbon . Figs. 7 a, b and c shows depth map for horizon 1, horizon 2 and horizon 3 at depth interval of 7260ft and 7980ft, 7550ft and 8150ft and also 8650ft and 9850ft, respectively.

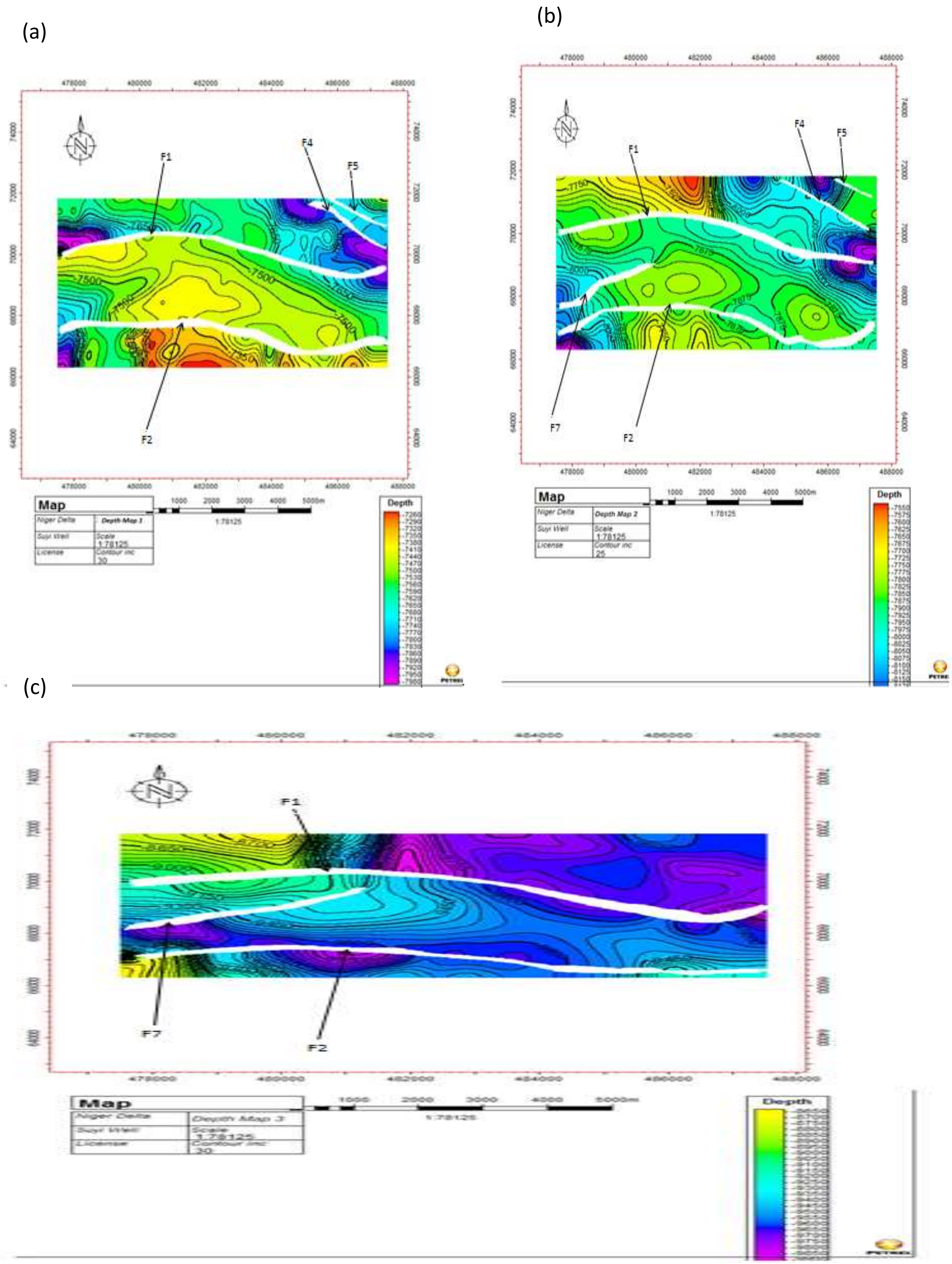

Fig. 7: a, b and c Isopach Map for Horizon 1, 2 and 3 respectively at varying depth intervals.

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. Most of the anticlinal structures at these regions are fault-independent. Due to the nature of the wells within the filed, none of the wells have a good reservoir for commercial hydrocarbon extraction as observed from the two reservoir sands which was delineated from well five (SUYI WELL 5). The 'SUYI'-Field is highly faulted with a total of 7 faults and it is compartmentalized into E-W trending blocks by the major structure building growth faults (Fault 1 and Fault 2) creating 3 mini-depobelts. 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

There should be a study to predict the lithological facies in the study area. These are cardinal to exploration and exploitation of hydrocarbon. However, the nature and saturation of fluids is of even greater importance to potential economic prospect of any field. Therefore it is recommended that further study be conducted to predict hydrocarbon saturation from seismic attributes. Well logs should be used to determine the lithologic facies in the 'SUYI'-Field which can be accurately delineated via porosity and density properties of the subsurface formations and characteristics such as porosity, permeability, saturation and cleanliness of the underlying formations in the prospecting area which is a key factor in accurately delineating the prospective reservoir in the area in order to enhance an optimum recovery of hydrocarbon in the area.

COMPETING INTERESTS

Authors have declared no competing interests exist.

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