3D Structural Interpretation and Petrophysical Evaluation of Reservoirs in the 'M' Field, Onshore Niger Delta, Nigeria.

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Abstract

An integrated reflection seismic and well log data interpretations of reservoirs in the 'M' Field located in onshore Niger Delta were carried out to map the complex subsurface structures and characterize the reservoirs in order to predict the hydrocarbon potential of the field. The methodology includes delineation and assessment of rock properties of reservoirs from logs of five wells, faults and horizons mapping from 3D seismic data, time to depth conversion, generation of time and depth structural maps of identified reservoirs. Structural interpretation shows presence of five main faults (F1-F5) while petrophysical evaluation delineated two hydrocarbon bearing zones (reservoirs 1 and 2). The quality of the delineated reservoirs in the "M-field" Niger Delta is good as revealed by the various petrophysical parameters estimated. The reservoirs are also considerably thick to host hydrocarbon in commercial quantities. The exploratory wells are producible as shown by the values estimated for water saturation and hydrocarbon saturation. The time and depth structure maps shows that the identified faults are fault dependent and fault-assisted closures and are thus regarded as good hydrocarbon traps

Keywords: Niger Delta, reservoir, hydrocarbon trap, structural map

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1. Introduction

Several researches have shown that the Niger Delta Basin of Nigeria is a proven prolific hydrocarbon system (Emujakporue *et al*., 2012; Bayowa *et al.*, 2021). Presently, the major challenge before the oil industry is the uncertainty in the delineation of hydrocarbon reservoirs due to poor definition of reservoir properties. The goal of hydrocarbon exploration is to identify and de-lineate structural and stratigraphic traps suitable for economically exploitable accumulations and delineate the extent of discoveries. Seismic and well log data are widely used in petroleum exploration to map the subsurface. The integration of well log and seismic data would provide a high degree of reliability in mapping subsurface structural and stratigraphic changes both vertically and laterally as both data sources are complementary. Ekweozor and Okoye (1980) supported the claim of Weber and Daukoru (1975) that the source rocks are shale of the Akata Formation. Orife and Avbovo (1982) observed that hydrocarbons are trapped in stratigraphic traps which are in addition to known structural traps of roll-over anticlines having worked on some seismic sections of the Niger Delta. The shales of the Agbada Formation are mature and contain Type III organic matter which is capable of generating oil and gas (Nwachukwu and Chukwura, 1986).

In order to provide information of oil Field reservoir's imaging and characterization, the use of structural interpretation and well log analysis is required. The objectives of the present work are to make detailed use of available seismic and well-log data to image and delineate the subsurface structures, identify the structures which are probable zones of hydrocarbon accumulation. Detailed study of the petrophysical results of the field will provide an understanding of net pay, gross pay, net to gross ratio and porosity.

2. Location & Geology of the Study Area

The Niger Delta is situated on the Gulf of Guinea, between Longitude 4 – 6^0 E and latitude 4 – 9^0 N on the west coast of central Africa (Fig. 1). The delta forms one of the world's largest extending more than 300 km in length and accumulating about 12000 m of regressive wedge clastic sediments (Doust and Omatsola, 1989). The basin consists of three basic formations. They are namely the Akata, Agbada and Benin Formations. They range in age from Paleocene to Recent. The Akata Formation which is the oldest unit is composed of thick shale sequences, clays and silts. It serves as the potential source rock and is of marine origin. At the beginning of Paleocene, it is assumed that the formation was formed as a result of the transportation of terrestrial organic matter and clays to deep waters (Tuttle *et al*., 1999). This formation is estimated to be about 7000 m thick. The Agbada Formation is the transition zone and consists of intercalation of sand and shale. This formation which has been shown to be cyclic sequence of marine and fluvial deposits (Weber, 1971), is the major oil and gas reservoir of the Basin with over 3700 m thickness. The Agbada Formation is overlain by Benin Formation and is composed of sands of about 2000 m thick (Avbovbo, 1978). The 'M' field is located onshore Northeastern Niger Delta between Longitude $6^0$30'E-$7^0$00'E and Latitude $5^0$30'N-$7^0$00'N (Fig. 2).

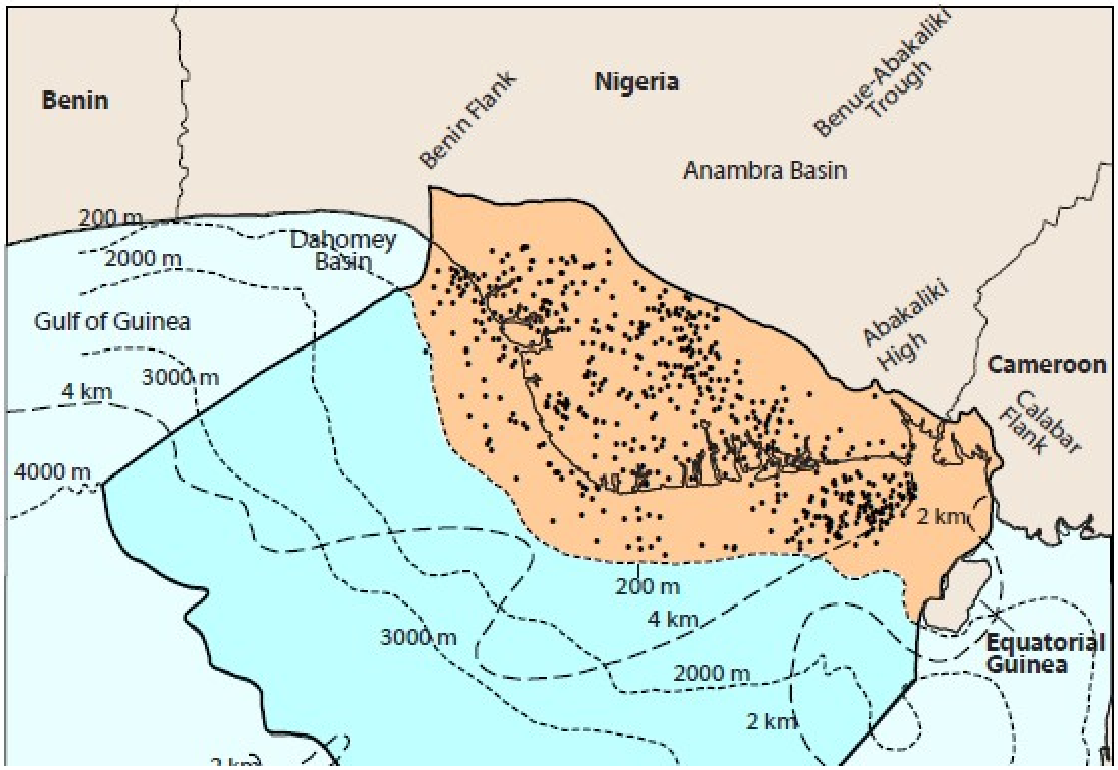


Fig. 1: Map of the Niger Delta showing the delta outline with the bounding structural features. Insert in map of Africa showing location of Niger Delta within Nigeria. (adapted from Tuttle *et al.,* 1999)

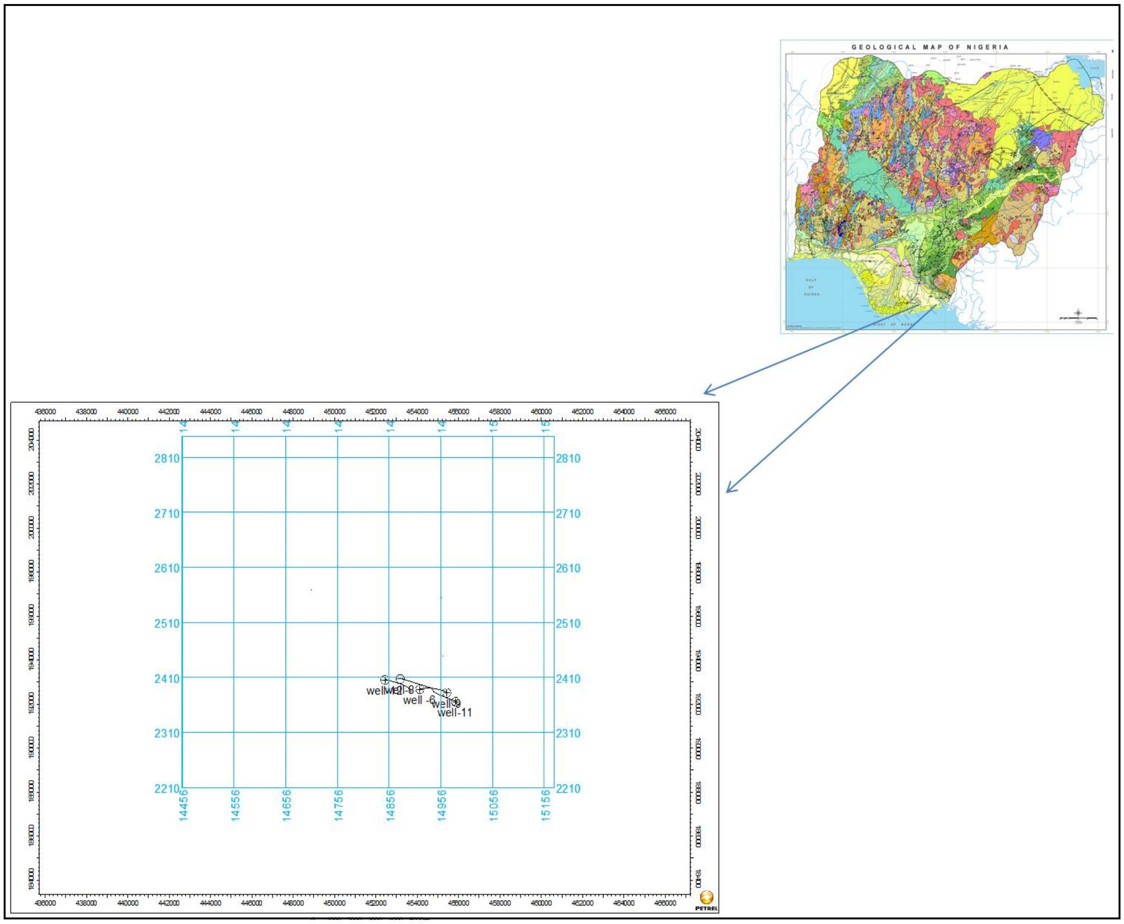


Fig. 2: Location map of 'M' Field, onshore Niger Delta.

3. Materials and Methods

Dataset for this study consist of base map, 3D seismic volumes (638 in-lines and 719 crosslines), suites of log for five wells (gamma, resistivity, density and neutron logs), checkshot data and deviation survey data. Logging data were used to identify lithologies, productive zones, quantify and evaluate hydrocarbon reservoirs in terms of depth, thickness (gross and net), fluid type, hydrocarbon and water saturations and geometric properties (porosity and permeability). Lithologic units in five wells were correlated using gamma ray and resistivity logs to deduce the geologic structures intersected by the wells and elevation of formations within a well compared to other wells. The correlation helps in establishing the continuity and lateral extent of reservoir units, understanding the pattern and direction of sand development as well as bringing up the subsurface image. Faults were picked on the inlines on seismic sections while horizons were picked based on prospectivity from the well logs available. The time-depth structure contour maps were generated for each of the horizons. The depth maps were generated by converting the time maps to depth with the aid of the time-depth curve. The time-depth relationship was determined by using the checkshot data and this data was also used for tying well log to seismic at the reservoir of interest.

4. Results and Discussion

4.1 Reservoir Identification, Correlation and Evaluation

Two hydrocarbon reservoirs are identified based on gamma ray log (GR) and resistivity log responses in the studied five wells. The shallower Reservoir 1 is encountered in all the analysed five wells (Fig. 3) while the deeper Reservoir 2 is encountered in three of the wells (wells 6, 8 and 9) and missing in remaining two wells (wells 12 and 11). The results of the petrophysical evaluation (depth to top and base, gross and net thickness, net-to-gross ratio and porosity) of the reservoirs in the studied wells are given in Table 1. The top reservoir 1 is encountered at shallowest depth (1617 m; SSTVD) in well 6 and the base is deepest (1731 m; SSTVD) in well 9 with a gross thickness ranging from 76 to 88 m, net thickness (75 - 88 m), net-to-gross ratio (NTG; 75 – 88%) and effective porosity (0.25 – 0.30 v/v). The top of reservoir 2 is also encountered at shallowest depth (1740 m; SSTVD) in well 6 but the base is deepest (1965 m; SSTVD) in well 8 with a gross thickness ranging from 81 – 205 m, net thickness (66 – 84 m), N/G (68 – 135%) and effective porosity (0.26 – 0.29 v/v). These ranges of thickness show that the identified reservoirs in the wells are considerably thick to host hydrocarbons in commercial quantities. Both reservoirs are more saturated in hydrocarbon than water and thus make the wells producible. The effective porosity values of the two reservoirs in the M-field are considered to be good enough to accumulate commercial quantities hydrocarbon.

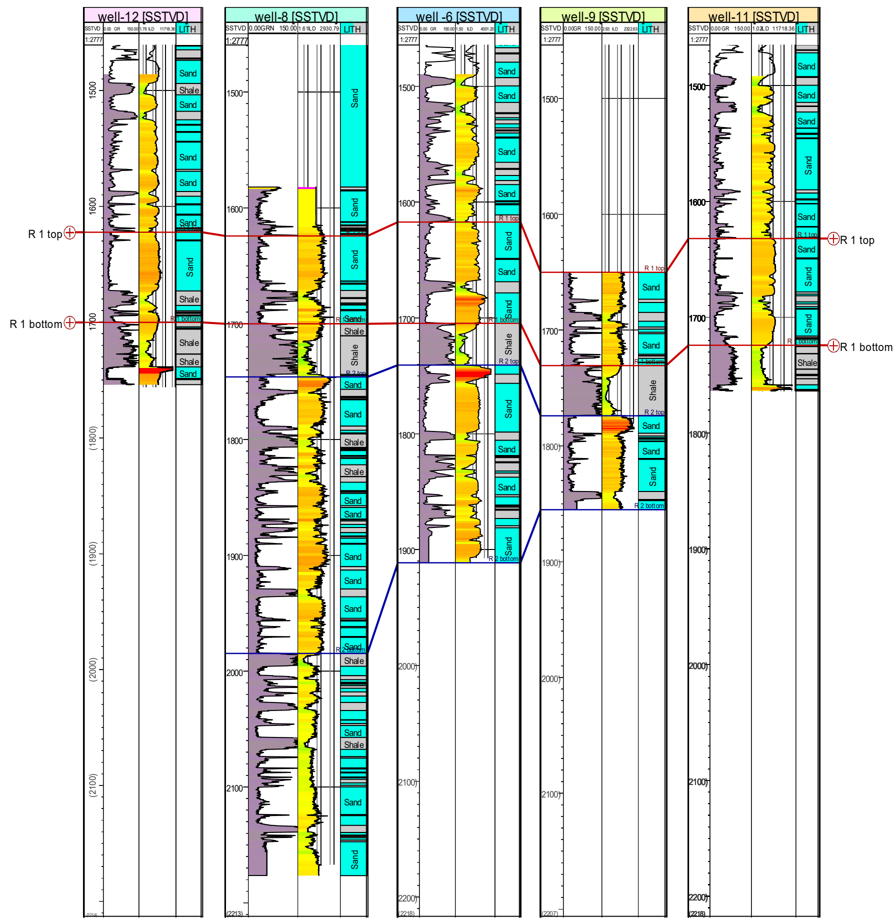


Fig. 3: Well section showing correlation of reservoir units across the analysed five wells

Table 1: Computed petrophysical parameters for interpreted reservoirs in wells of 'M' Field

Wells	Top (m)	Base (m)	Gross thickness (m)	Net thickness (m)	NTG (%)	Porosity (v/v)
			Reservoir 1			
8	1624	1700	76	65	86	0.30
6	1617	1705	88	77	88	0.29
9	1650	1731	81	61	75	0.25
			Reservoir 2			
8	1760	1965	205	135	66	0.29
6	1740	1911	171	130	76	0.29
9	1774	1885	81	68	84	0.26

4.2 3D Structural Analysis

Seismic sections showing typical fault and horizon mapping within the studied field 'M' onshore Niger Delta is showing in Fig. 4. A total of five faults (F1 – F5) and two horizons (R1 and R2) were mapped throughout the seismic volume. The horizons were picked based on the prospective zones identified from the petrophysical analysis of the well logs. Horizons 1 (TWT of 1950 ms) and 2 (TWT of 2150 ms) represent reflectors that match the top of R1 and R2 sand members respectively. Interpreted faults F1, F2, F3 and F5 are characterized by a northwest-southeast trend but dip differently while F4 is characterized by northeast-southwest trend. The kinds of faults observed on the field are major (counter regional) fault (F1), antithetic faults (F2, F3 and F5) and synthetic minor fault (F4). 3D fault model of the mapped faults reveals their three-dimensional distribution and orientation the across the field (Fig. 5). The time- and depth-structural maps of the top of Reservoir 1 are shown in Fig. 6. Areas labeled as P1 - P3 are the areas of structural highs that are favourable for hydrocarbon accumulation. The significance of hydrocarbon accumulation of P1 being a faulted anticlinal structure (F3) is that if the fault is sealing, it means hydrocarbon would accumulate on a side of the structure whereas if it is not sealing, the hydrocarbon in the reservoir will not be trapped. P2 area is faulted by F4 and F5 which play an important role in hydrocarbon accumulation. P3 area is faulted by F1 and F2 which bounds the area at the same side. Communication is expected only in P1 and P2. This is due to the depression separating P1 and P2 from P3. The time- and depth-structure maps generated from top of Reservoir 2 are shown in Fig. 7. Areas labeled P4 and P5 are the structural high areas believed to be hydrocarbon bearing in Reservoir 2. P4 is bounded by F1 and F2, the sealing potential of the two major faults can make the area one of the most important accumulation areas within the field. P5 is a fault assisted closure bounded one side by F2.

5. Conclusion

Seismic and well log data have been used in 3D structural interpretation of M-field and have proved to be a useful tool. The 3D structural interpretation was possible by creating a time and depth structure maps which showed the trapping styles, image of the subsurface geometry and hydrocarbon trapping potential in M-field, Niger Delta. The two horizons delineated are within the Agbada Formation. The different kinds of fault which served as traps are regarded as good hydrocarbon traps and thus attest to the fact that migrated hydrocarbon from the source rock (Akata Formation) can be trapped within the M-field. Apart from the fact that the faults served as traps, it also acted as conduits which aided the migration of hydrocarbon. The petrophysical parameters estimated show that the reservoirs are thick to host hydrocarbon in commercial quantities. The reservoirs are also producible and are of good quality.

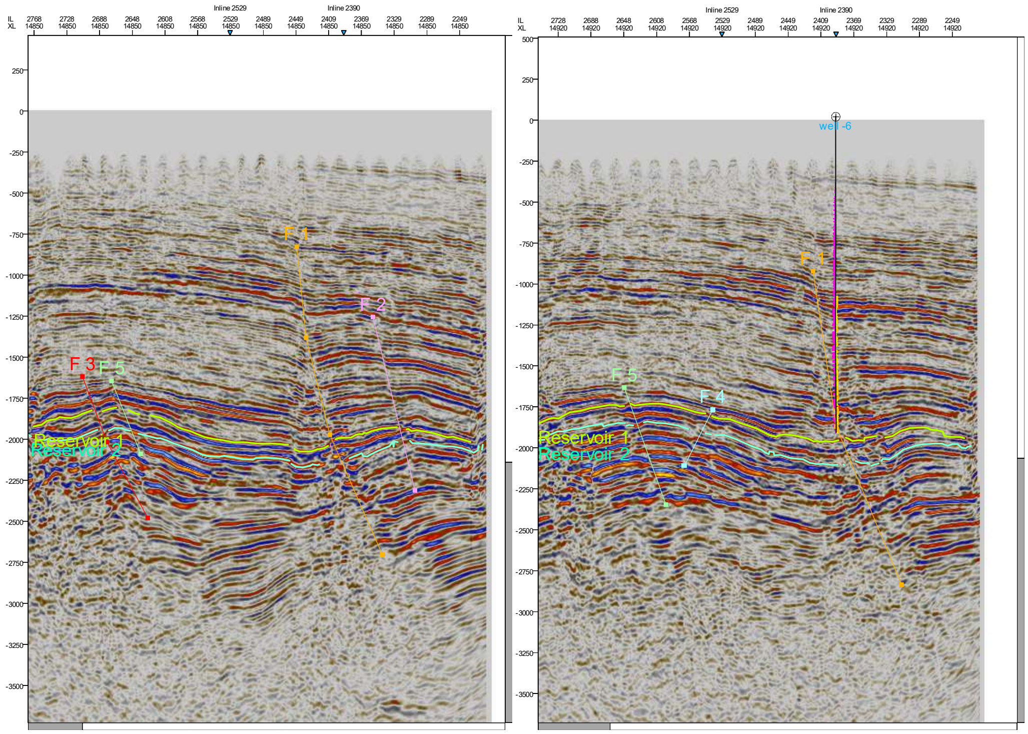


Fig. 4: Typical interpreted sections of seismic volume from 'M' Field, Niger Delta. (a) Section through crossline 14850 showing interpreted horizons and faults F1, F2, F3 and F5. (b) Section through crossline 14920 showing mapped horizons and faults F1, F4 and F5

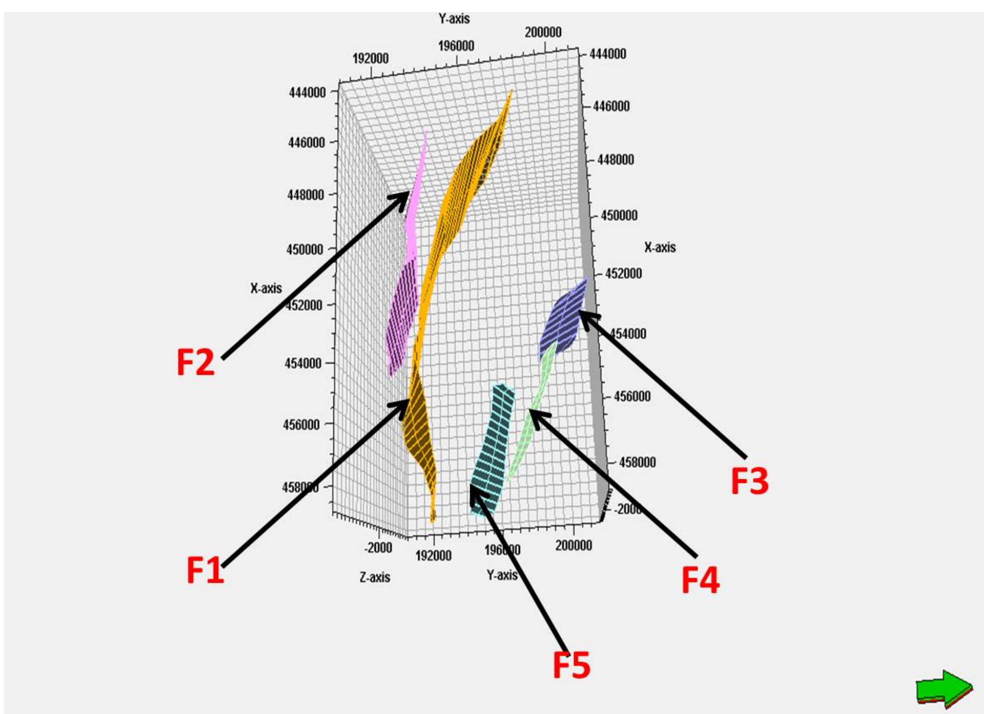
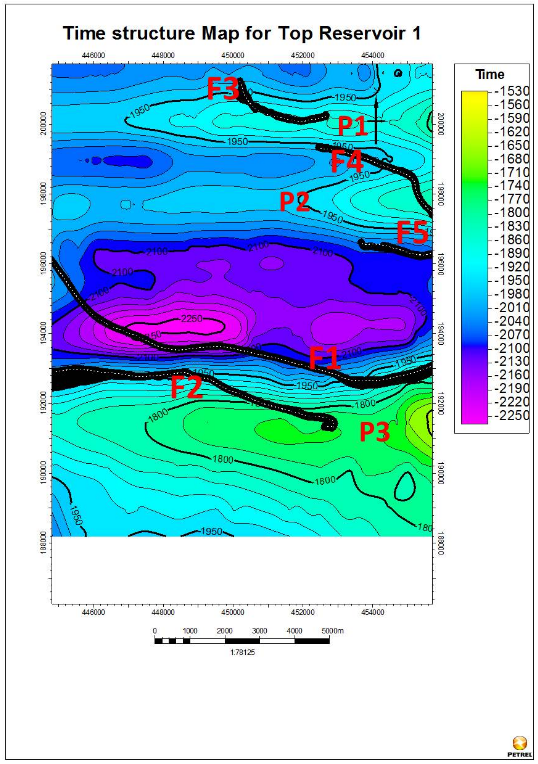
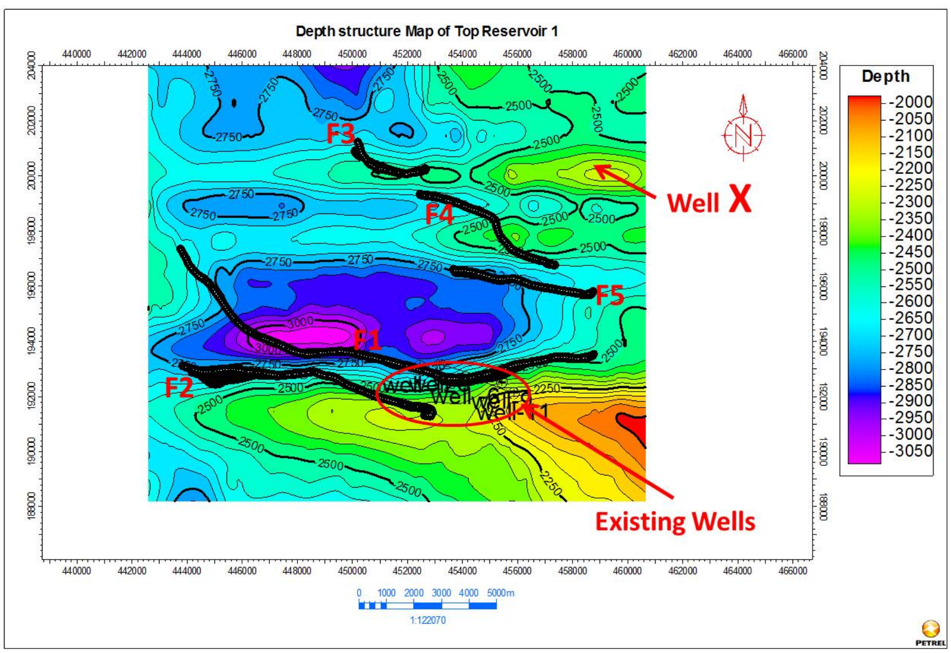


Fig. 5: 3-Dimensional display of the faults model of the 'M' Field , Onshore Niger Delta.

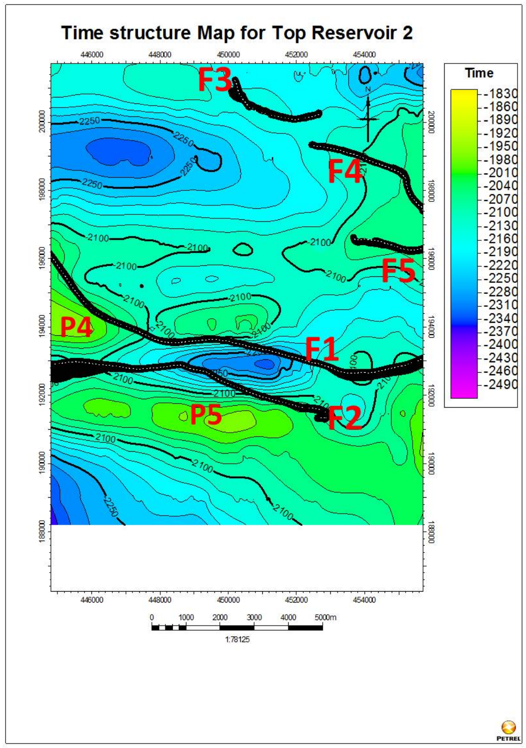


(a)



(b)

Fig. 6a&b: Time – and Depth - structural maps (respectively) of the Top Reservoir 1within 'M' Field. Note the positions of the existing wells and proposed new well X after interpretation



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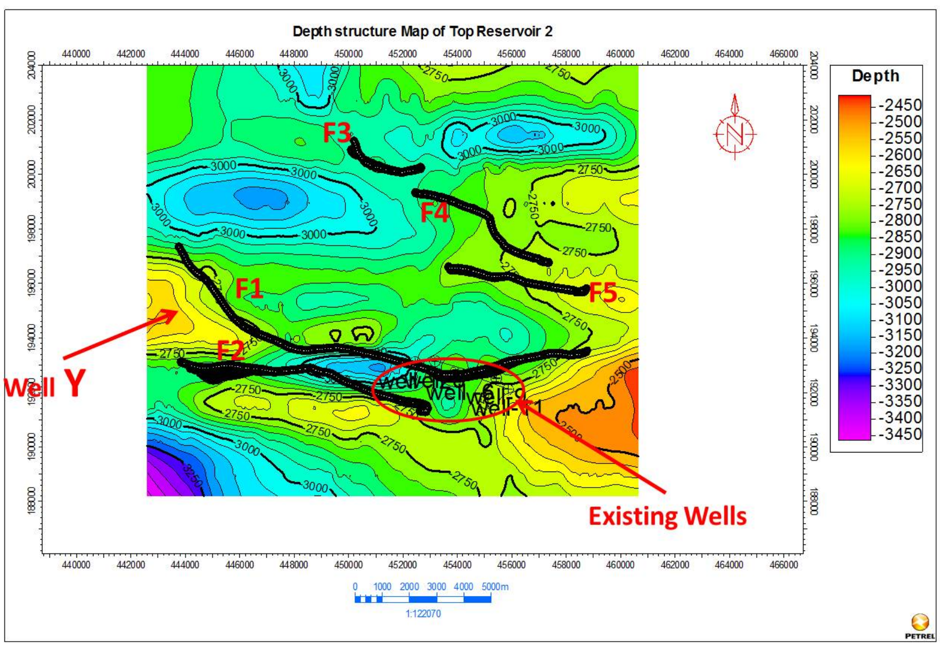

(b)

Fig. 7a&b: Time – and Depth - structural maps (respectively) of the Top Reservoir 2 within 'M' Field, Niger Delta. Note the positions of the existing wells and proposed new well Y after interpretation

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