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Geophysical 3D Seismic Appraisal of Okpella Field within Offshore Niger Delta Basin of Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Okpella Field is currently experiencing a decline in production which was revealed by the analysis of the production data. The Field had an annual production of 430175 MBO (Million Barrel of Oil) in 2008, but declined significantly to 7839 MBO (Million Barrel of Oil) per annum. Therefore, to sustain the Field hydrocarbon productivity, an appraisal study was carried out to identify viable bypassed hydrocarbon reservoirs for development. This involves integrating 3D seismic interpretation, petrophysical analysis, and production data to characterize and estimate the productivity of the Bypassed hydrocarbon reservoir zones. Six hydrocarbon reservoirs were identified by the producing company: Major reservoirs Sand A, B, C, D, E, and F. Three additional hydrocarbon reservoirs were identified within the study: Bypassed Sand A, Bypassed Sand B, and Bypassed C. From the fluid distribution and analysis within the Bypass Reservoirs, Bypass A is gas, Bypass B is oil and gas while Bypass C is oil. The petrophysical analysis estimated the reservoir's petrophysical parameters such as volume of shale, porosity, net to gross, and water saturation for the Bypassed reservoisr. The Seismic interpretation delineates the structural style and hydrocarbon traps, generates time maps, attribute maps (Root Mean Square attribute), depth maps, and estimates the bulk volumes of the bypassed reservoirs. The stock-tank oil initially in place, gas initially in place, and hydrocarbon productivity were estimated by integrating the results from the petrophysical analysis, seismic interpretation, and production data. From this analysis, the most prolific bypassed reservoir is Bypass B. The productivity of all the Bypassed reservoirs were estimated to sustain the field for an additional three years.

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Keywords: Major reservoir; bypassed reservoir; roll-over structure; hydrocarbon indicator; hydrocarbon type; reserve; hydrocarbon production.

1. INTRODUCTION

Petroleum Statistics reveal that the energy consumption in developing countries is surging and ensuring the availability of global energy is pivotal [1]. Economically viable hydrocarbon has been bypassed in mature fields due to poor analysis, reservoir complexities, and management techniques [2]. To guarantee adequate hydrocarbon productivity and downplay drilling risk, efficient analyses of seismic and petrophysical data are crucial [3]. It is established by researchers in the field of Geoscience that structural framework and hydrocarbon reserves within a field are achieved by integrating seismic interpretation and petrophysical analysis because they play a crucial role in understanding the subsurface geology [4,5,6]. Moreover, by integrating log data with seismic structural and stratigraphic interpretation, geological insight of the depositional environment of the facies can be ascertained and modelled, which is significant to reservoir characterization [7,8,9] (Akm *et al.,* 2016); (Al-Fatlawi, 2018). Over the years, Nigeria has primarily depended on hydrocarbon production to sustain its economy, and in ensuring maximum hydrocarbon productivity, delineating isolated reservoirs and unperforated hydrocarbon-bearing zones is paramount. Reservoir characterization is essential in developing, managing, and optimizing reservoir production by integrating petrophysical analysis, seismic interpretation, and production data [10]. Even within a mature field with a large number of wells and production information, the undrilled areas between wells (or inter well areas) constitute areas of geologic uncertainty that may enhance production significantly, Slatt [11]. Unuevho, Tokurah and Udensi [12] appraised 'Etsako Field' within onshore Niger Delta basin by employing parasequence and parasequence set concepts to analyse open-hole geophysical logs. They were able to reveal opportunities for infill well drilling between existing wells in the field.

The Niger Delta has been producing petroleum for over sixty years now, and its offshore fields are becoming mature. Therefore, considering bypassed hydrocarbons zones in matured fields can sustain productivity and increase recovery [13]. Conventional techniques have been effective in oil and gas exploitation by identifying drillable locations and the recoverable volume of hydrocarbon [14]. However, the deep offshore regions of the Niger-Delta Basin have higher complexities in their structural and stratigraphic frameworks, resulting in meagre hydrocarbon exploration activities because of the uncertainty associated with the reservoir and structural distributions [15,16,17]. Nevertheless, the reservoir heterogeneity and structural complexity of the deep-water Niger Delta have created unexplored hydrocarbon reserves which could lead to an increase in revenue if adequately explored [18].

Okpella Field is a mature offshore field discovered by conventional reservoir mapping techniques, and sustaining its production depends on perforating bypassed hydrocarbon reservoir zones. In identifying and analyzing the bypassed reservoir zones, re-evaluation of the field by integrating petrophysical analysis, seismic interpretation, and production data is crucial. Using 3D Seismic data infusion with composite logs via an integrated interpretation approach would reveal more essential details on the structural styles of the hydrocarbon-bearing closures. This paper aims to employ the concept of well-log correlation, sequence stratigraphy, 3D seismic interpretation, and seismic attributes to delineate hydrocarbon reservoirs within Okpella Field and identify the yet-to-be produced reservoirs within the existing wells. The hydrocarbon volume of the identified reservoir within Okpella field was estimated to provide a basis for a good hydrocarbon production plan and information on commercial hydrocarbon accumulations within the field. The production data analysis of Okpella field provided the hydrocarbon productivity of the matured reservoir, and this information serves as a basis for estimating the hydrocarbon productivity of the bypassed reservoir zones within this study.

2. GEOLOGICAL SETTINGS

The Niger Delta is situated in the Gulf of Guinea, West Africa, covering a 300,000 km^2 area in the onshore and offshore region (Fig.1) [19]. South-westerly progradation has taken place from Eocene to the present, forming a series of depo-belts with sediment thicknesses up to 10 km [20]. The lower marine shale package, the Akata Formation, is the primary source rock in the area, with hydrocarbon production from the overlying Agbada Formation sandstone facies [21]. Oil

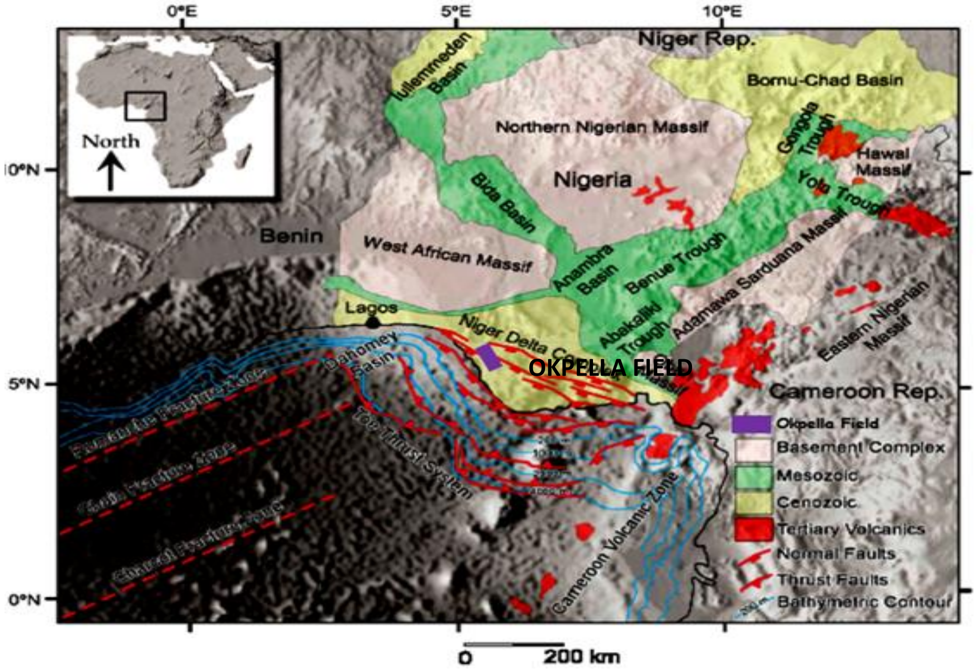

Fig. 1. Geological Map of Nigeria showing the Niger Delta Basin and location of Okpella Field [22]

production started in 1958, and production has expanded and continued to date, despite political instability and security issues, to a current level of approximately 2 MMbbl/d.

The tectonic framework is controlled by Cretaceous fracture zones (Fig. 2a, b and c) associated with the opening of the Atlantic Ocean, with ridges dividing the continental margin into basins [23]. In the Niger Delta area, rifting had stopped by Late Cretaceous and deformation caused by gravitational instability occurred. Shale diapirs resulted from the loading of high-density delta front sands over poorly compacted delta slope clays, and the basinward slope instability occurred due to a lack of support from the clays, which form a detachment surface near the top of the Akata Formation [19]. The evolution of the Niger Delta is closely tied to the origin of Benue trough in the late cretaceous. Breakup of the Central Africa-South America part of Gondwanaland took place in the Mesozoic along a series of rift zones of different orientations that met in a triple junction in the area of the present Gulf of Guinea, in the position now occupied by the Niger Delta, [24].

The depo-belts consist of the three formations, with each successive depo-belt off-lapping the previous. They are the result of variations in sediment supply and rate of subsidence, with sedimentation shifting seaward in response to renewed crustal subsidence. Each depo-belt expresses the deformation results, with structures including shale diapirs, roll-overs, fault crest collapses, and steep, closely spaced flank faults that offset different parts of the Agbada Formation (Fig.3), [25]. The Agbada Formation has intervals that contain organic-carbon contents sufficient to be considered good source rocks. The intervals, however, rarely reach thickness sufficient to produce a world-class oil province and are immature in various parts of the delta [26].

Three formations divide the Niger Delta, distinguished by their sand/shale ratio (Fig.4). The Akata shale was deposited in the Palaeocene during a major transgression. By the Eocene, deposition became tide-dominated, sediments accumulated in the Niger Delta Basin, and the shoreline became more convex with progradation. This pattern continues today. The Akata Formation consists of thick marine shale sequences, turbidites, and minor clay and silt underlying the entire delta [20]. It was deposited during low stands, with low energy conditions and oxygen deficiency. Thickness is estimated at 7km. The Agbada Formation had been deposited above the Akata Formation from Eocene to Recent and is ~4 km thick.

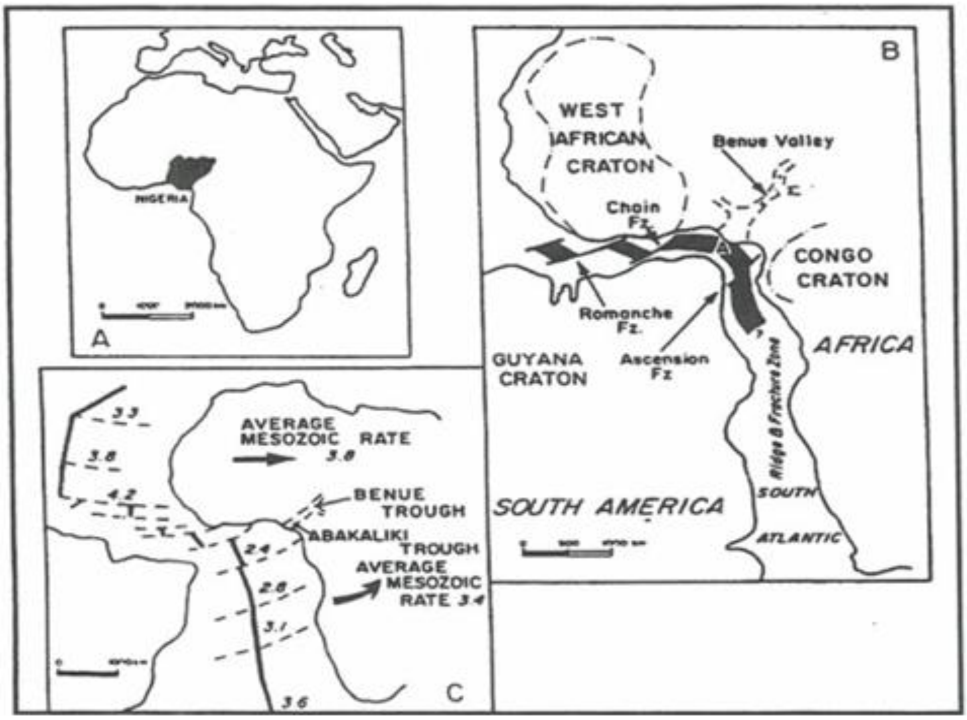

Fig. 2. (a) Location of Nigeria (b) Early cretaceous separation of Africa and South America (c)Mesozoic seafloor spreading for Africa and South America after [27]

The lower Agbada has equal proportions of sand and shale bed, while the upper section is mainly sand with only minor shale inter-beds [28]. The Benin Formation overlies the Agbada Formation, the latest Eocene to Recent alluvial and upper coastal sands of up to 2 km thickness [29].

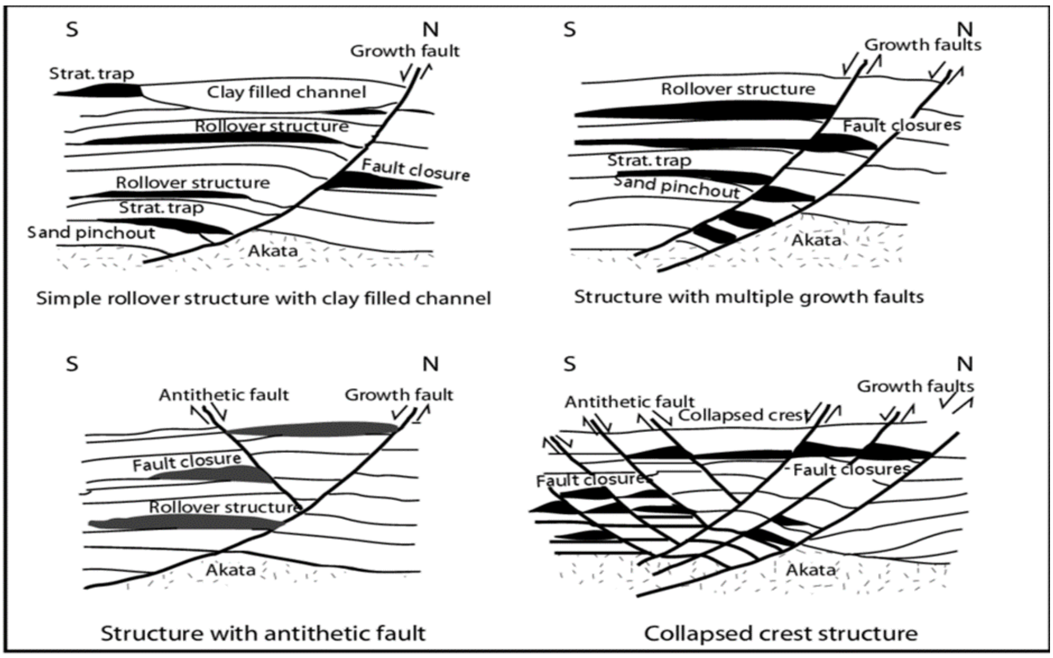

Fig. 3. Schematic Indications of the structural styles and hydrocarbon trapping mechanism in the Niger Delta [20]

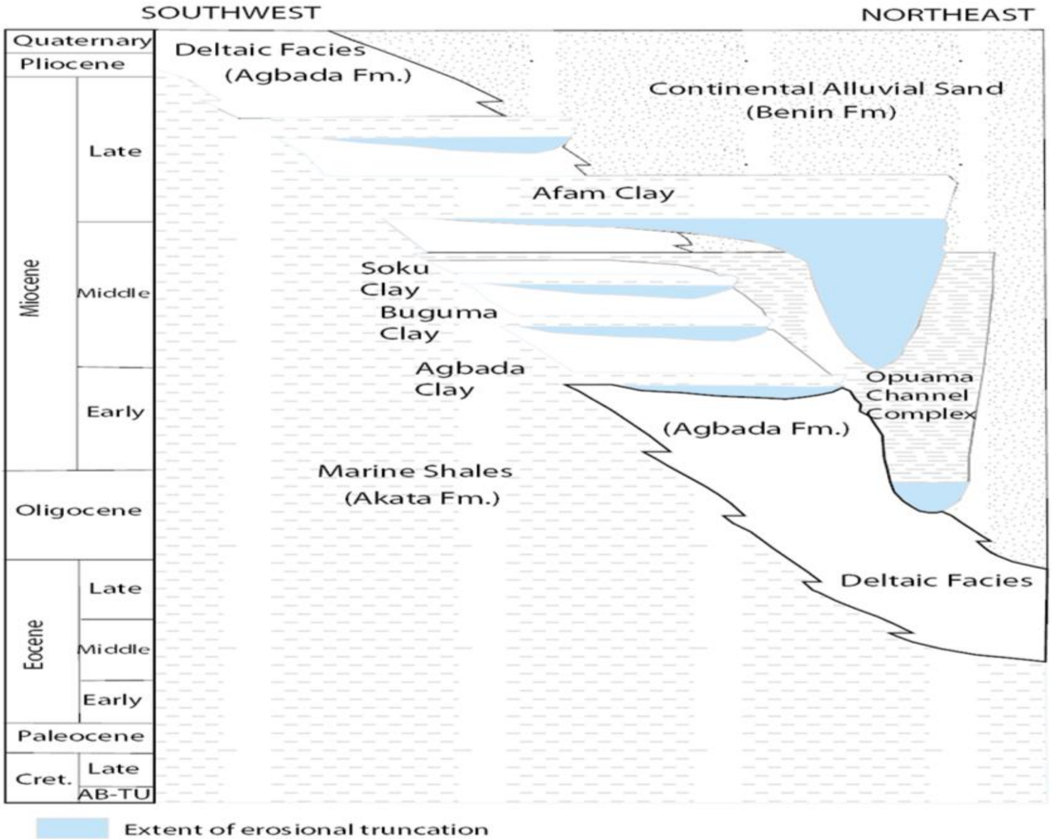

Fig. 4. Stratigraphic Column of Benin, Agbada, and Akata formations of the Niger Delta Basin [20]

3. MATERIALS AND METHODS

3.1 Data Availability and Workflow

The data used for this study are 3D seismic data (Fig. 5) for seismic interpretation, Composite logs for correlation and petrophysics and production data for reservoir productivity analysis Table 1. This dataset was analysed using Interactive Petrophysics software for petrophysical analysis, Petrel Schlumberger software for seismic interpretation, and Microsoft excel for production data analysis.

Table1. Summary of the provided Dataset used for this study

Data Type	Format	Coverage
Seismic Survey	3D Seismic Volume (SegY)	461 km^2/114,000 Acres
Composite Logs	Calliper, Sonic, Gamma-Ray, Resistivity, Neutron and Density logs	10 Wells
Well Header	ASCII	10 Wells
Check shot	ASCII	10 wells
Deviation	ASCII	10 wells
Reservoir Tops	ASCII	10 Wells
Production Data	ASCII	7 Wells (1997 to 2018)
Additional Data	Biostratigraphy data, Core analysis and petroleum Engineering Report	1 Well (TMG-02)

The workflow approach used in this present study involves three major phases. The first phase involves the regional understanding of the study area, which involves a literature review of the tectonic settings, stratigraphy sequence within the basin, as well as the petroleum system of the basin in order to understand the basin and know the best approach to analysing the basin. Phase two involves quality checking and loading the well and seismic data into the software to interpret the dataset to generate petrophysical properties of the reservoir, maps and attributes. The third phase involves providing the volume of hydrocarbon in potential reservoirs by integrating the production data to give reasonable recommendations for the field's present and future development.

The results of the petrophysical analysis and 3D seismic data were integrated to estimate hydrocarbon volume in the reservoirs.

3.2 Petrophysical Analysis

Standard petrophysical interpretation workflow was used to evaluated Okpella Field (Fig. 6). Hydrocarbon bearing reservoirs were identified and correlated across the wells using the gamma-ray and resistivity logs. The production data and the provided well tops were used to identify the bypassed hydrocarbon reservoir zones. The Fluid types, shale volumes, porosity, and water saturation were calculated using appropriate equations and parameters [30].

3.3 Seismic Interpretation

Before interpreting any seismic data, it is essential to establish a relationship between seismic reflections and geological horizons in the well. Synthetic seismograms bridge geological information derived from well-log data in-depth and geophysical data (Seismic in time). This also recalibrates our seismic data from a time domain to a depth domain by establishing time-depth relationships. Acoustic Impedance and Reflection coefficients were calculated, and the reflection coefficients were then convolved with a zero-phased wavelet to obtain the seismic "Wiggle" trace, which was compared with the seismic trace. The faults and seismic horizons tied with reservoir tops were mapped on every fourth inline and fifth crossline section. Seismic attributes extraction was carried out on the 3D seismic data to pronounce regions of horizon discontinuities and bright amplitude reflections. The check short was used to generate a third-order polynomial equation for converting the time map to a depth map (Fig.7). A good Time-Depth trend was established for the fields, and a trend line was fitted, from which a 3rd order polynomial equation was derived from the curve. Fluid contact information from the petrophysical analysis was posted on the depth structure map to ascertain the reservoir area.

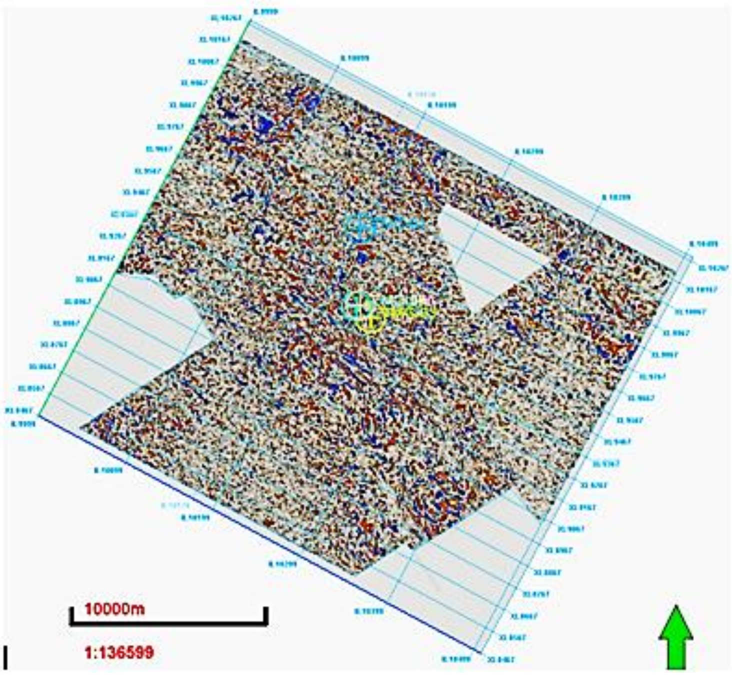

Fig. 5. Basemap of the TMG Field with Seismic coverage and Well locations

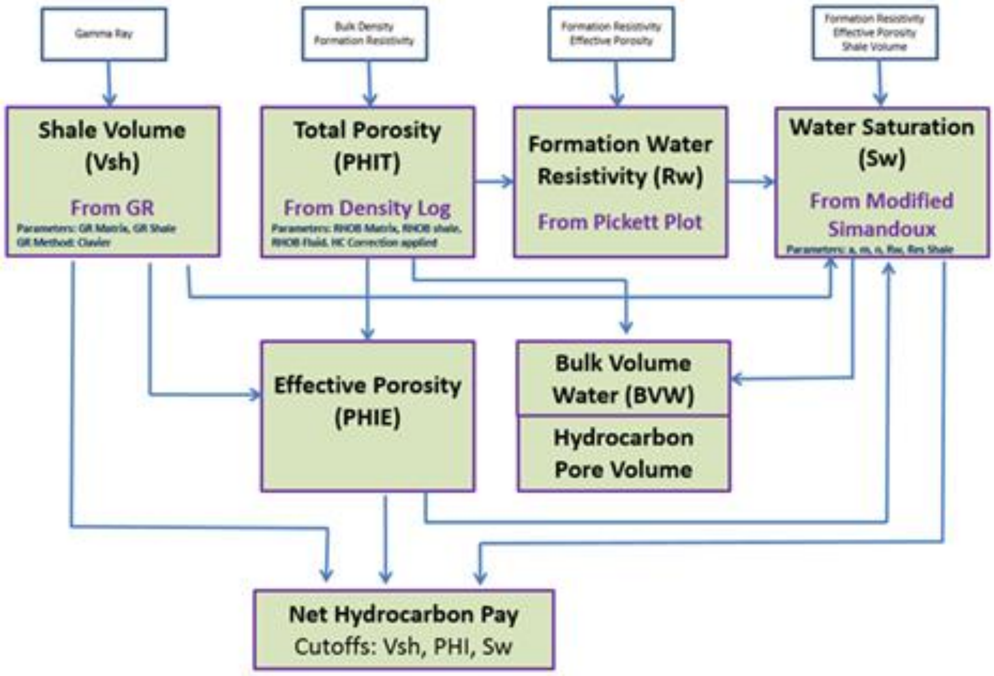

Fig. 6. Petrophysical workflow utilised in evaluating Okpella Field

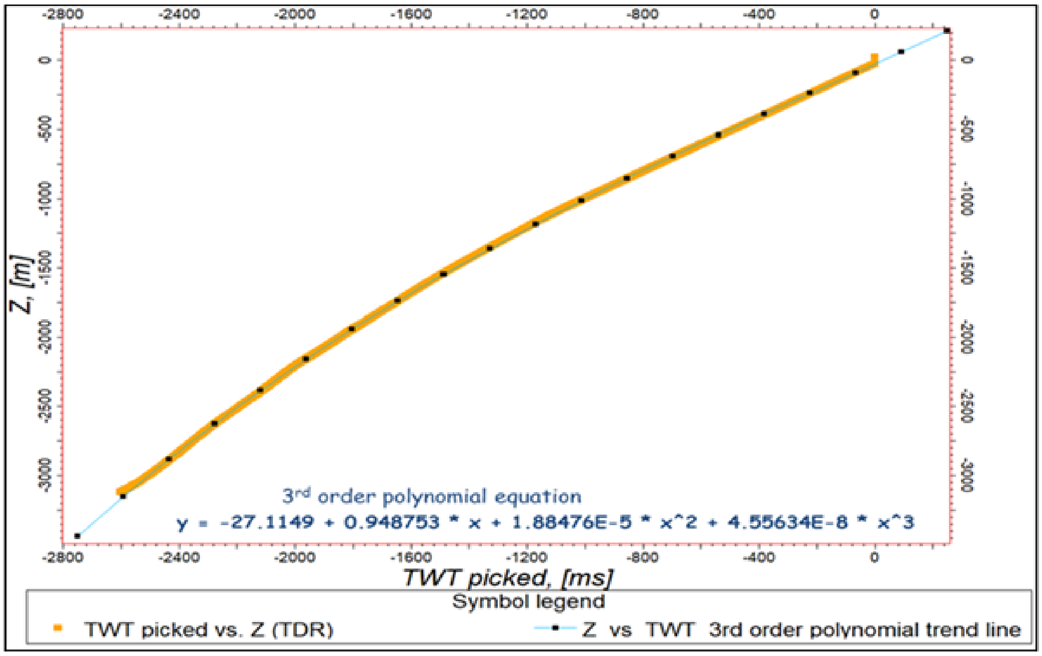

Fig. 7. Time-Depth relationship plot of TMG-02 with the 3rd order polynomial function used to generate depth maps

3.4 Volumetrics

Reservoir Fluid volumes were estimated from the Gross rock volume based on the contacts defined in the wells for the Major and Bypassed reservoir zones. Gross rock volume calculations and Petrophysical parameters were used as input in Equation 1 to estimate oil initially in place volume using all the water saturation scenarios.

$$\text{STOOIP}= \frac{GRV \times NTG \times \emptyset \times (1-S_W)}{B_O} \qquad (1)$$

$$\textbf{GIIP} = \frac{GRV \times NTG \times \emptyset \times (1 - S_w)}{B_g} \qquad (2)$$

where: STOIIP = Stock Tank Oil Initially in Place; GIIP =Gas Initially in Place; GRV= Gross Rock Volume; NTG= Net-to-Gross ratio, Φ = Porosity; Sw= Water saturation; Bo= Oil Formation Volume Factor; Bg = Gas Formation Volume Factor.

The In-Place volumes were evaluated using a probabilistic approach by estimating a Proven Case Scenario (P50), Low Case Scenario P10 and Best-Case Scenario (P90). The lowest known contacts were used as the hydrocarbon contacts for all scenarios (ODT=OWC). The production data was then used to estimate the productivity of the bypassed reservoir based on the productivity of the Major reservoir.

4. RESULTS AND DISCUSSION

4.1 Petrophysical Analysis

The pay zones that the operating company did not identify are the bypassed reservoirs which were identified based on the production data and well tops provided by the operating company (Fig. 8). The petrophysical properties of the Bypassed reservoir zones are estimated for each well in Okpella Field (Fig. 9) and Table 2, [30]. The hydrocarbon bearing reservoirs are associated with the low-stand systems tract as identified from the biostratigraphic data.

The fluid distribution in Bypass A is gas, Bypass B is oil and gas and Bypass C is oil (Fig. 9). From the well log correlation Bypass A and B are relatively at a shallow level between the depth of 1041 m and 1061 m respectively. Well TMG-01 was the only well that encountered Bypass C reservoir at a depth of about 2330 m (Fig. 8). From the Petrophysical analysis Table 2, Bypassed A has a net pay of about 3 m, porosity of 28% and hydrocarbon saturation of 38%. Bypass B has net pay of 10m, porosity of about 23% and hydrocarbon saturation of 72%. Bypass C has a net pay of about 3 m, porosity of 26% and hydrocarbon saturation of 58%. The lowest known contact is taken as the hydrocarbon-water contact for both oil and gas. Based on the net pay and hydrocarbon saturation the most prolific reservoir is the Bypass B reservoir with a net pay of 10m and hydrocarbon saturation of 72% (Table 2).

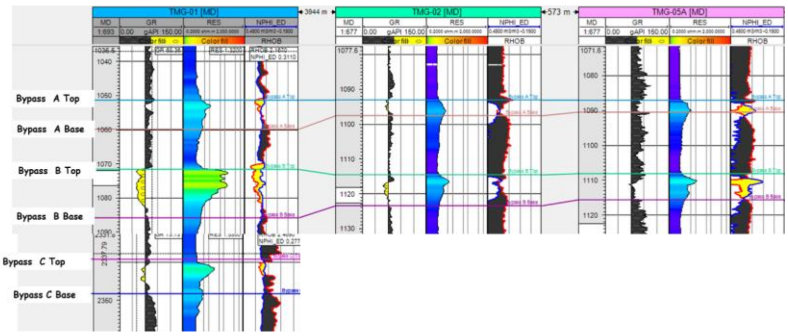

Fig. 8. Reservoir correlation of the Bypassed reservoirs

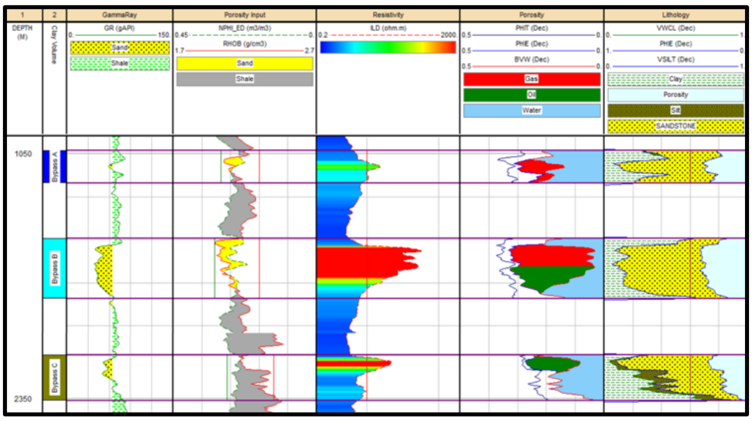

Fig. 9. Petrophysical plot showing the fluid distributions in the Bypassed reservoirs

Table 2. Petrophysical properties estimated for bypassed reservoirs

Zone Name	Top (sstvd)(m)	Base (sstvd) (m)	Gross	Net pay	N/G	Av vcl	Av Phi	Av Sw	Av Sh	Contact	Fluid
Bypass A	1041	1049	7.62	3.05	0.4	0.147	0.287	0.619	0.381	-1049	**GAS**
Bypass B (gas)	1061	1071	8.1	6	0.717	0.13	0.27	0.269	0.731	-1071	**GAS**
Bypass B (oil)	1071	1075	6.3	4.01	0.7	0.13	0.23	0.251	0.722	-1075	**OIL**
Bypass C	2330	2340	10.67	3.05	0.286	0.085	0.26	0.416	0.584	-2337	**OIL**

4.2 Seismic Interpretation

An extracted variance attribute from the 3D seismic cube at -853 ms was used to delineate the faults within the study area (Fig. 10a and b). The variance time slice shows the various positions and orientations of the major and minor faults within the study area. Four major faults labelled F1, F2, F3 and F4, and over 23 minor faults were interpreted to be synthetic and antithetic to the major faults. The faults trend in the North-West to South-East direction and dip in the western direction (Fig. 10b). The major faults divide the TMG field into three main blocks (block 1, block 2 and block 3), but only blocks one and two will be considered because of the presence of wells to have tested the potential of these blocks; block one is penetrated by well TMG-01 and all the wells penetrated block two, and no wells penetrated block 3, (Fig. 11b). The faults were interpreted on every fourth inline and fifth crossline within the study area, and the faults are growth faults (Fig. 11b) which implies that they originate as a result of shale migrations as sediments were being deposited into the basin. The faults within the study area could also serve as a potential migration pathway and trapping mechanism for hydrocarbon accumulation into the reservoirs [23].

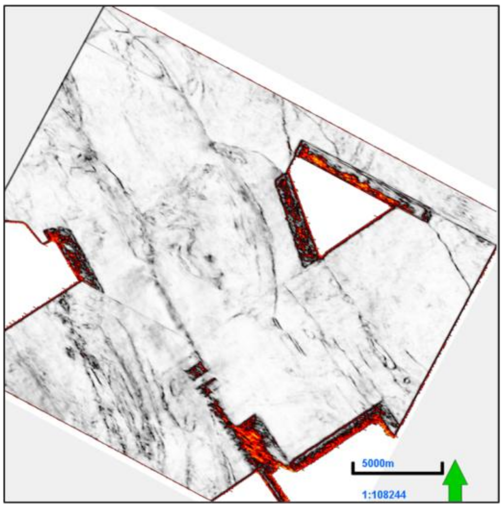

Fig.10. (a) Uninterpreted variance attribute time slice

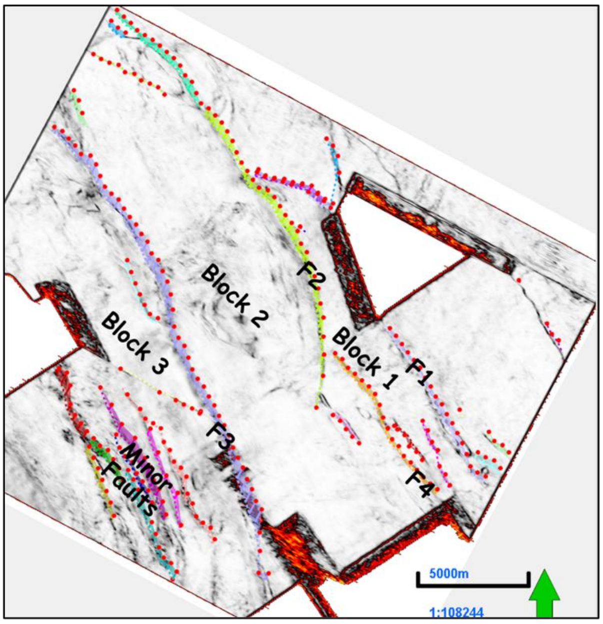

Fig.10. (b) Interpreted variance attribute time slice at -853ms showing faults and blocks within the Okpella Field

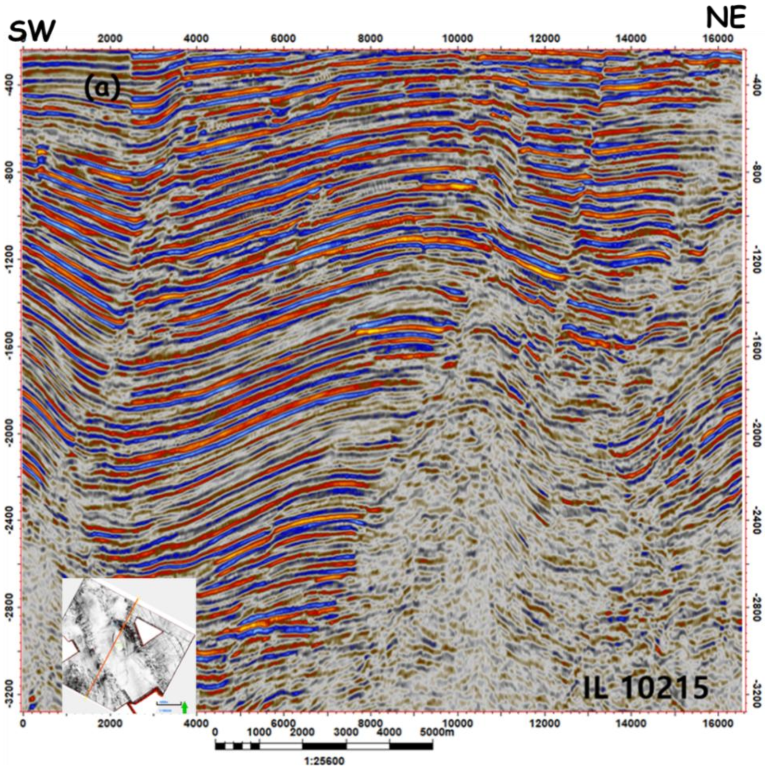

Fig. 11a. Uninterpreted Seismic Inline

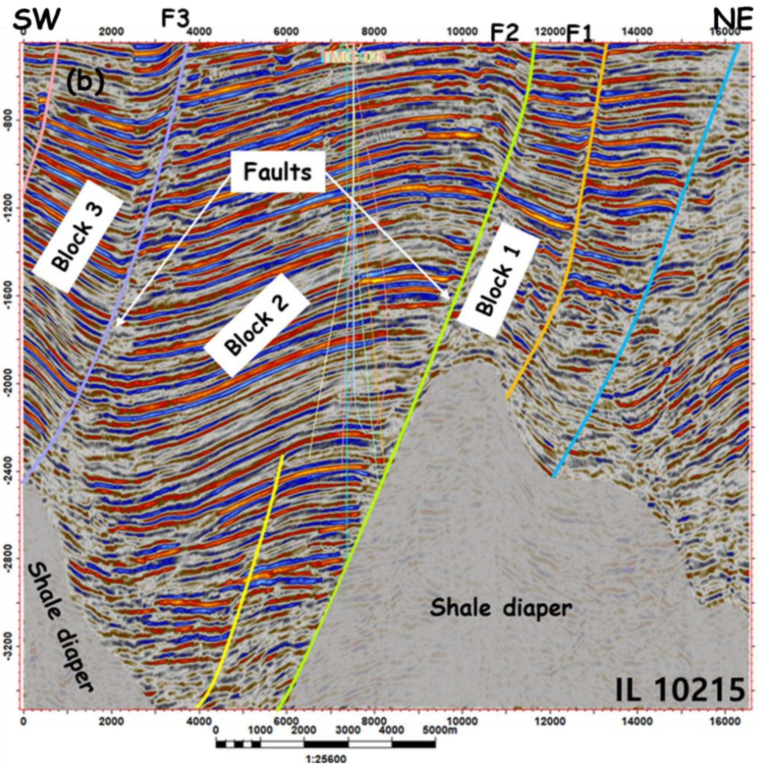

Fig.11b. Interpreted Seismic Inline showing the growth faults, shale diapirs and associated blocks within Okpella Field

4.3 Synthetic Seismogram

The generated synthetic seismogram was used to identify the events that coincide with each reservoir's top (Fig. 12). Sonic calibration and seismic to well tie were carried out using well TMG-02 because it is the only well that penetrated most of the reservoirs. The synthetic seismogram was generated using the extended white deterministic wavelet method. Adjustments required to fit the well tops to the seismic markers were made within the limit allowed in Niger Delta.

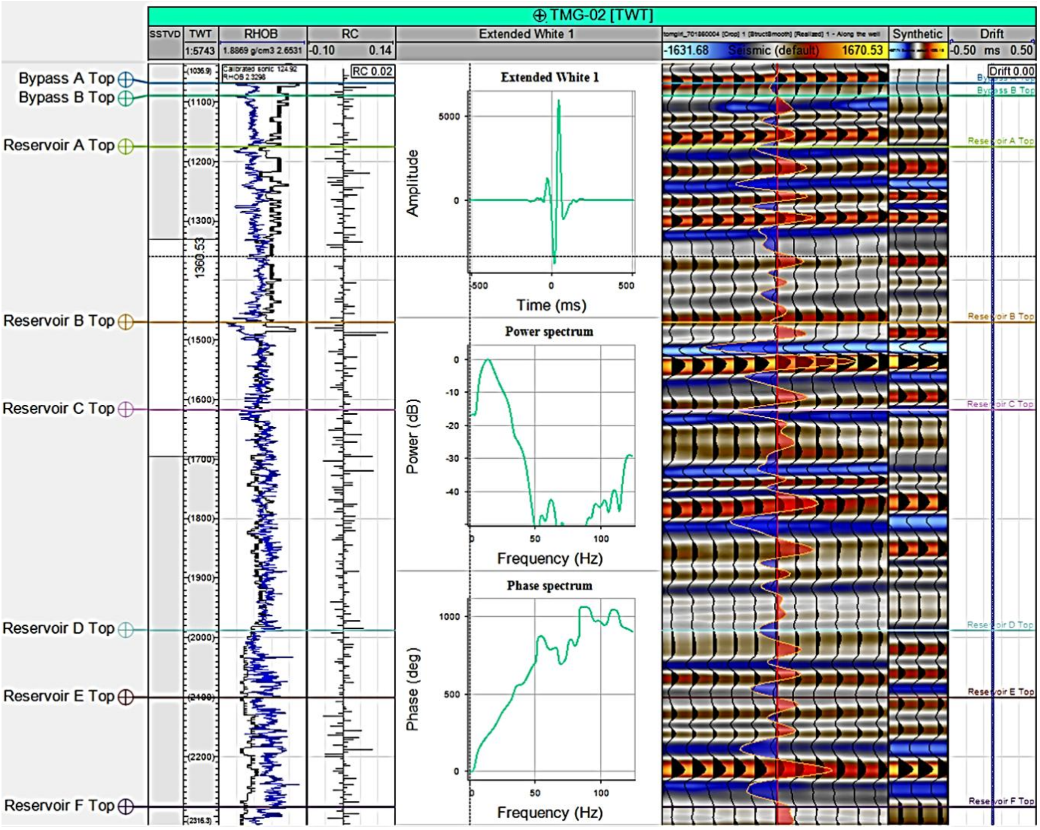

Fig. 12. Well to seismic tie of TMG-02 showing events that coincide with the tops of the reservoirs

4.4 Horizon Interpretation

From the synthetic seismograph generated (Fig. 12), the tops of the Bypassed reservoirs that coincide with the peaks of the seismic horizon were mapped across the seismic volume (Fig. 13). Interpreted Horizons are either terminated or interpolated across fault zones (Fig. 14). Horizons were interpreted on every fourth inline and eighth cross line across the cropped seismic volume of Okpella Field.

4.5 Seismic Facie Analysis

A seismic reflection that indicates the presence of hydrocarbons was observed around the Bypass B horizon at the point where well TMG-01 penetrated the Bypass A and B horizon (Fig. 15a). The bright flat reflection is suspected to be due to the presence of hydrocarbon water contact within the Bypass B. The Bypass B reservoir also shows a roll-over structure (Fig. 15b) associated with all the prolific reservoirs within this study, and this structure usually serves as a suitable trapping mechanism within the Niger Delta Basin. Fig. 15c shows the seismic cross line across Well TMG-01 with the variance time-slice.

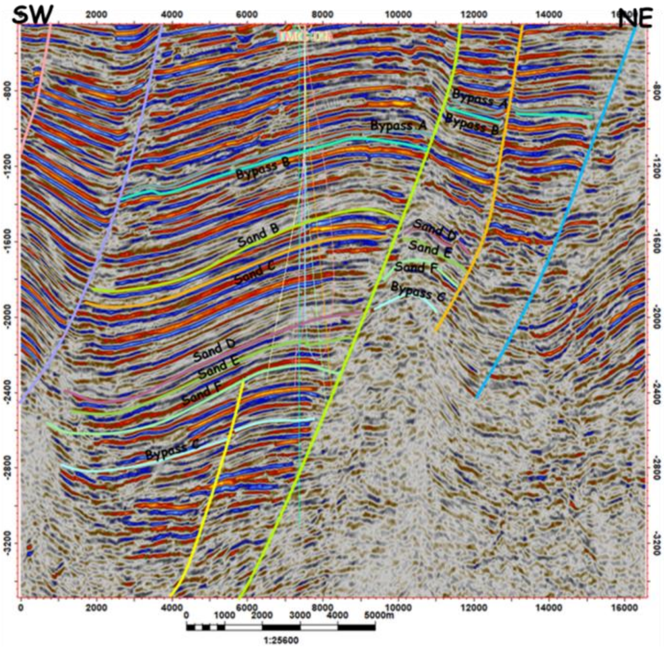

Fig. 13. Interpreted Inline 10215 showing the mapped Horizons and interpreted faults

4.6 Time and Depth Structure Maps

The hydrocarbon-bearing horizons interpretation around Okpella Field was completed, fault polygons were drawn, and time structure maps were generated (Figs. 16a, 16b, 17a, 17b, 18a, and 18b). The Available check-shot from TMG-02 was used to generate the time-depth relationship curve used in the velocity modelling for depth conversion. The generated depth map was flexed to the well tops. The fluid contacts derived from Petrophysical evaluation were used to create contacts in the depth structure maps to estimate the bulk volume and also to view the fluid distributions across the prolific reservoirs. Bypass C has hydrocarbon in block-1 while the remaining reservoirs have hydrocarbon in block-2 (Figs. 16a, 16b, 17a, 17b, 18a, and 18b).

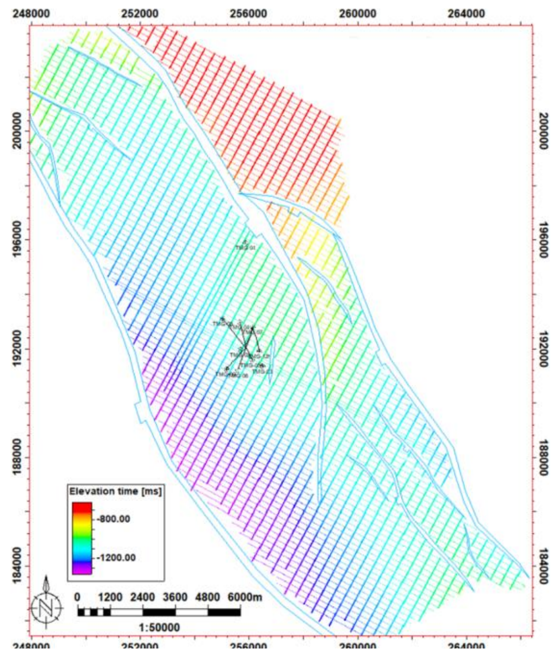

Fig. 14. Interpreted horizon grid of the Bypass B across the 3D Seismic of Okpella Field

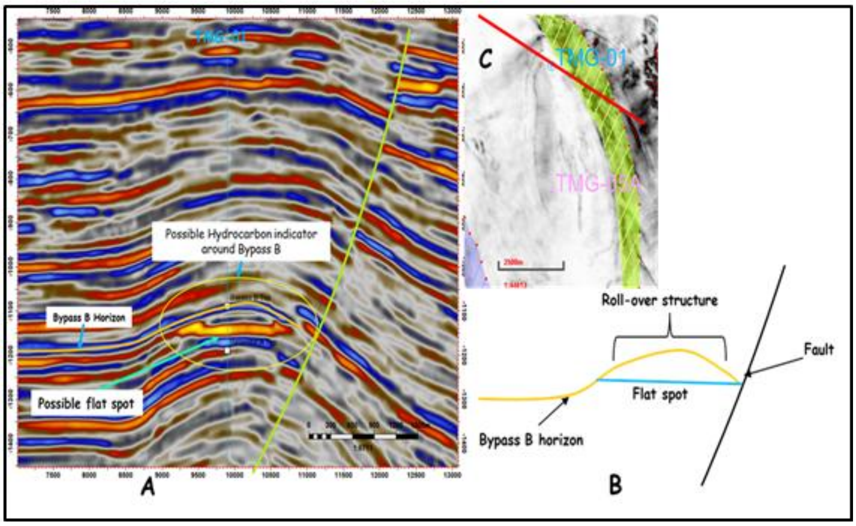

Fig. 15. (a) Shows the presence of anomalous bright amplitude around the Bypass B horizon, which could be a pointer of the Direct Hydrocarbon Indicator (D.H.I.) (b) Shows the schematic interpretation of the seismic structural behaviour around the Bypass B horizon and (c) shows the seismic crossline across well TMG-01 along with the variance Time-Slice

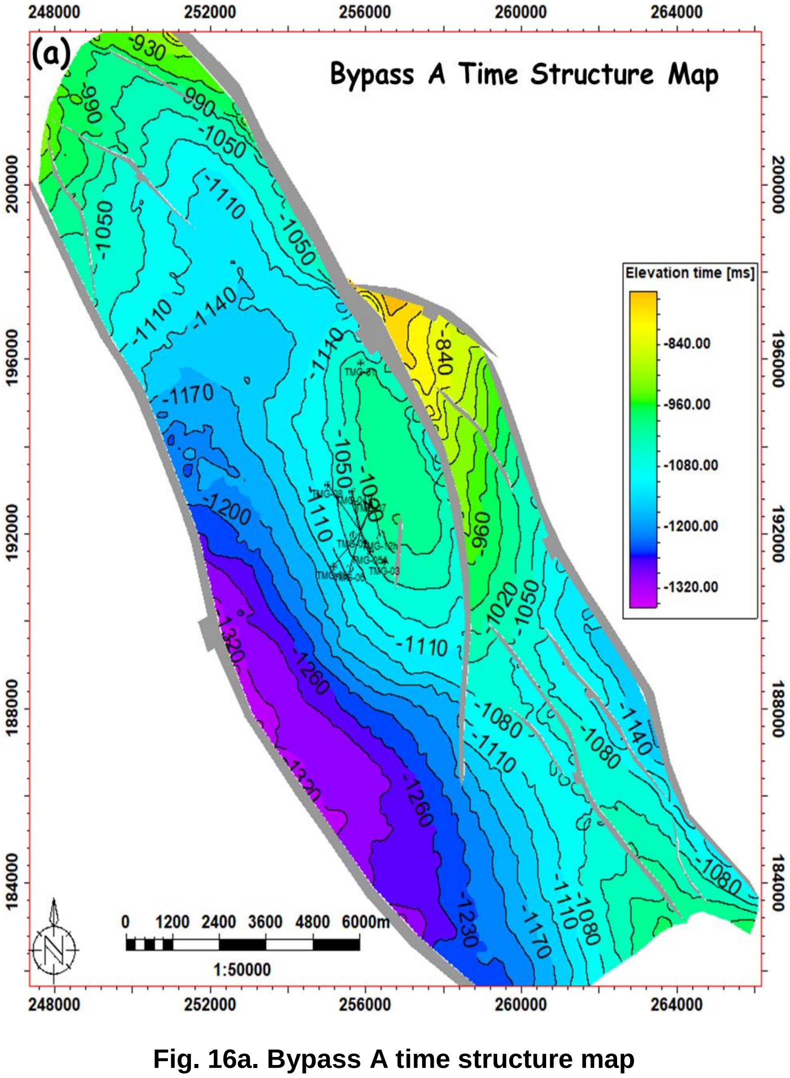

Fig. 16a. Bypass A time structure map

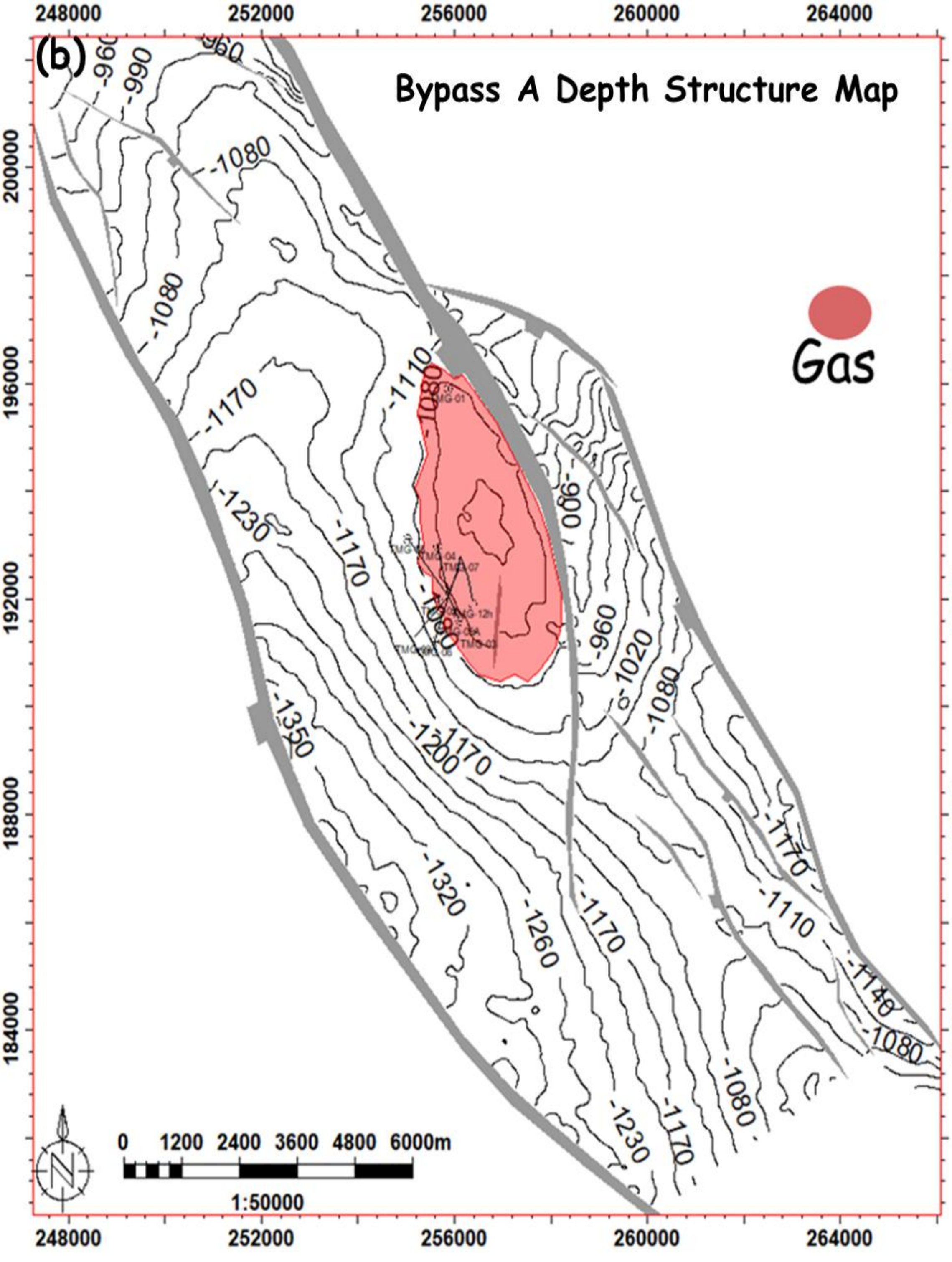

Fig. 16b. Bypass A Depth Structure map and its fluid distribution

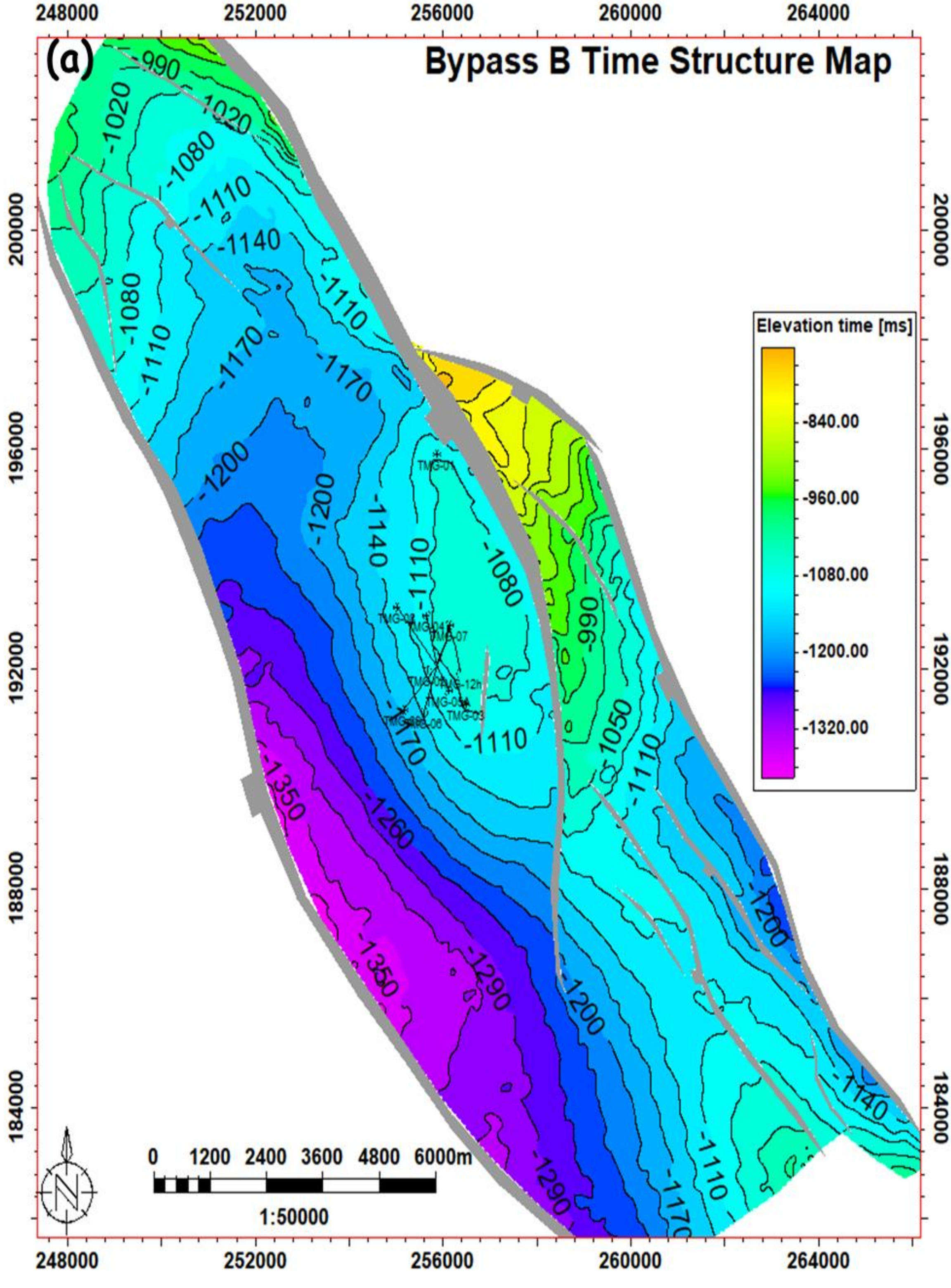

Fig. 17a. Bypass B time structure map

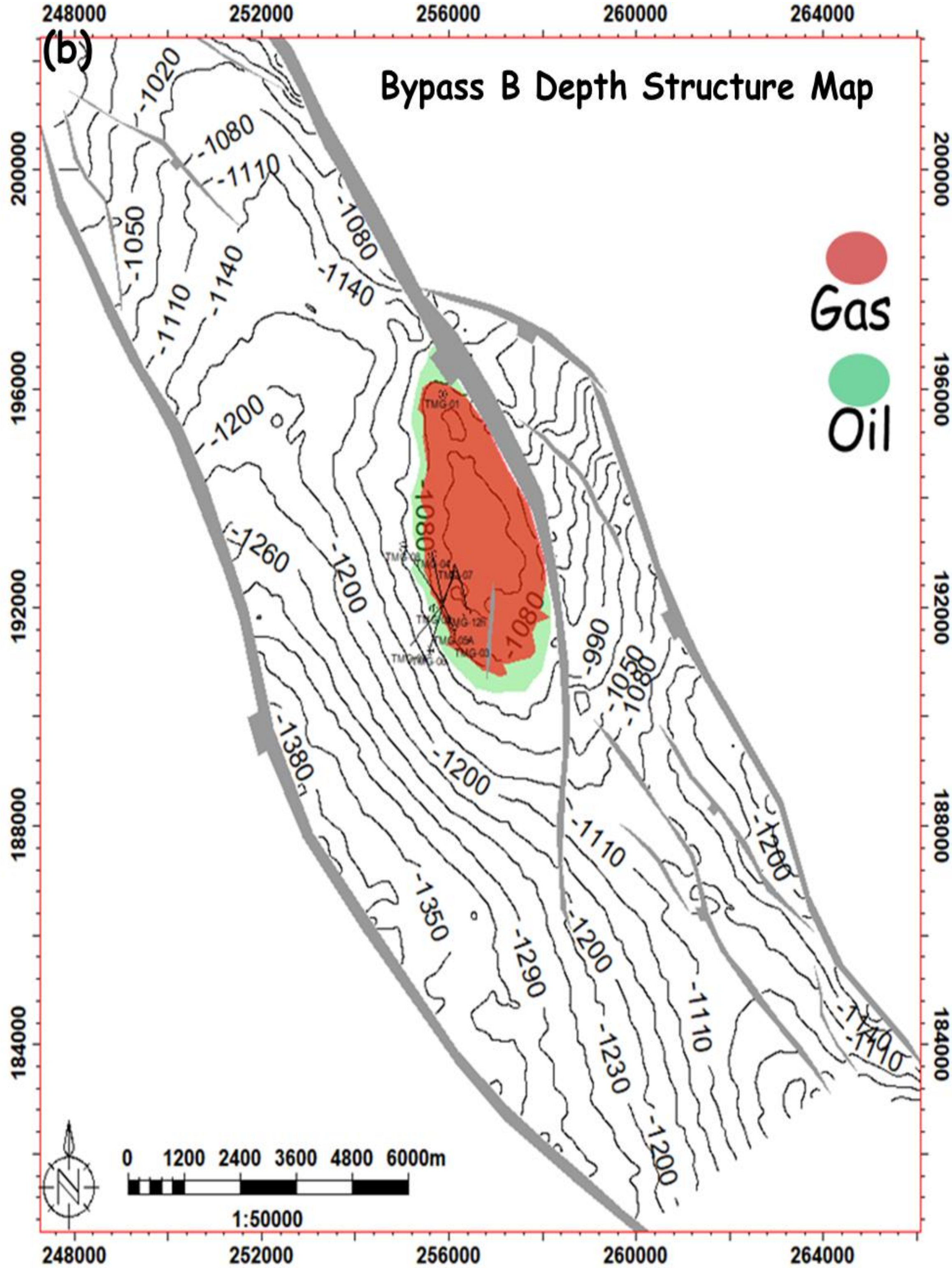

Fig. 17b. Bypass B depth structure map and its fluid distribution

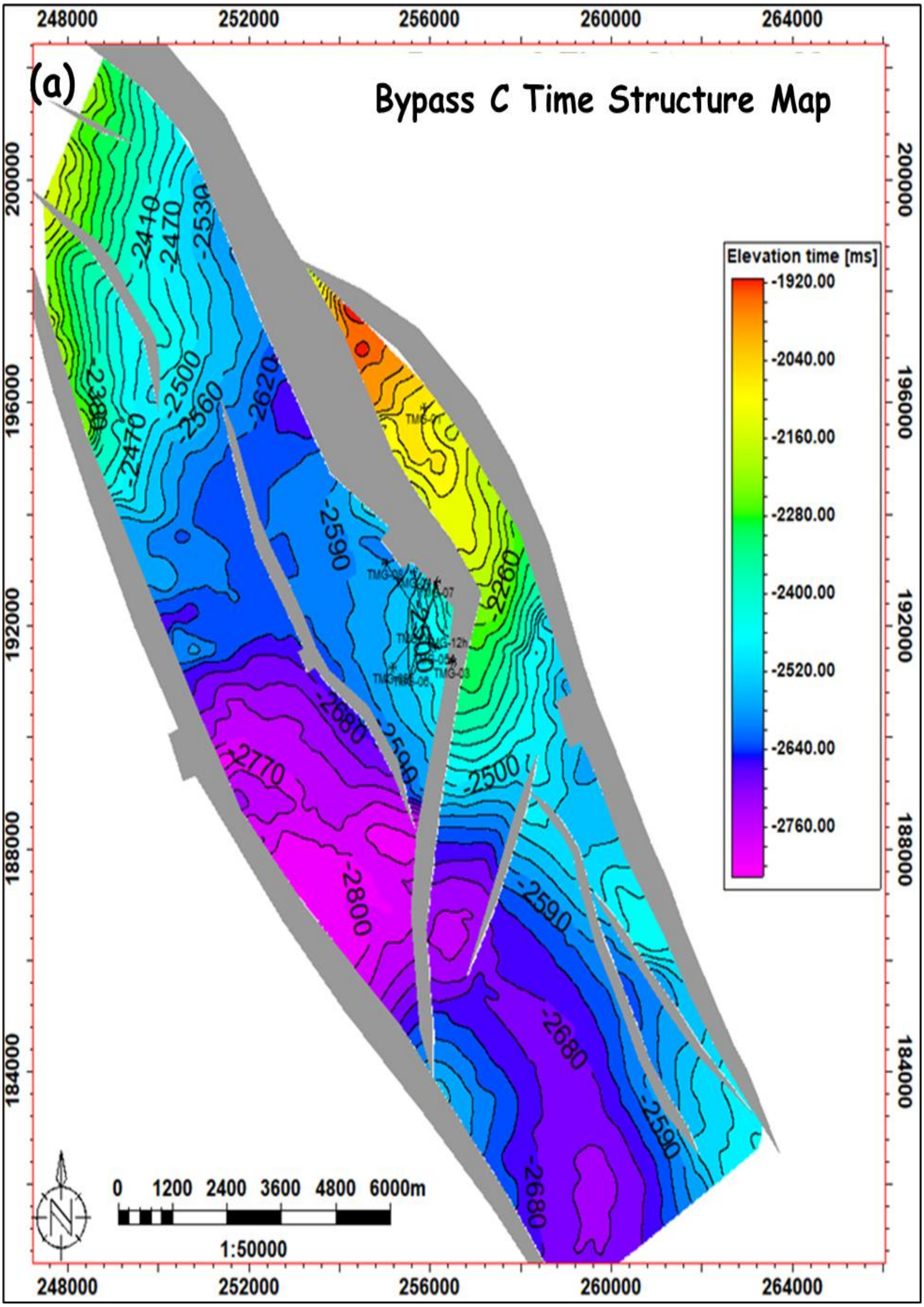

Fig. 18a. Bypass C time structure map

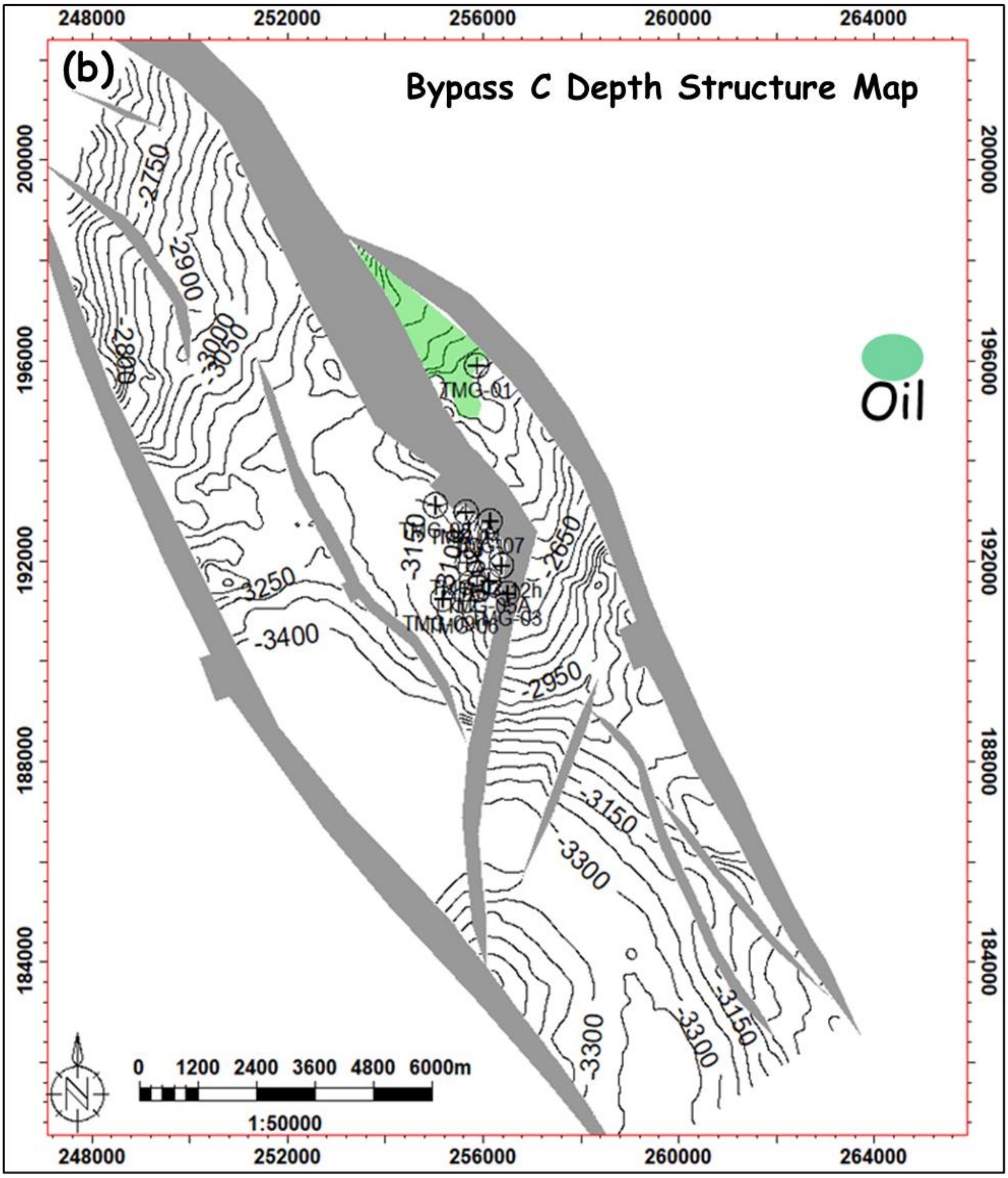

Fig. 18b. Bypass C Depth Structure map and its fluid distribution.

4.7 Seismic Surface Attribute Analysis

Seismic surface attribute analysis was carried out on generated time maps to observe regions that are amplitude supported. The amplitude extraction enhances understanding of the facies distribution and possible fluid distribution across the mapped reservoirs. The Seismic attribute used for this analysis is the R.M.S attribute known as Root Mean Square, which is the square root of the sum of the squared amplitude in a data set divided by the sample size of the data within the desired window. The R.M.S amplitude extraction seems appropriate for this analysis since it demarcates regions of different facies. Marine facies such as shales are usually characterised with a relatively low R.M.S amplitude character compared to marginal marine or non-marine facies such as sands. The presence of brighter amplitude reflection on an R.M.S attribute map usually shows the presence of fluid which could be oil, gas or water, and the facies around such bright regions are usually sand facies since they are capable of housing such fluids. The R.M.S attribute analysis is structurally supported because there are bright amplitude reflections around the drilled wells and faults closures. The R.M.S attribute integrated with the Well log analysis helps to show that sand facies control the bright amplitude around the wells, and there is hydrocarbon accumulation around the fault closures or roll-over anticlines (Fig. 19 a, b, c). The seismic attribute extraction carried out on the Bypassed hydrocarbon reservoirs (Fig. 19 a, b, c) shows bright amplitude anomalies around the wells and structural closures; this infers that there is a presence of sand facies as deduced from the R.M.S map with hydrocarbon accumulation has deduced from the Well log analysis around the structural closures.

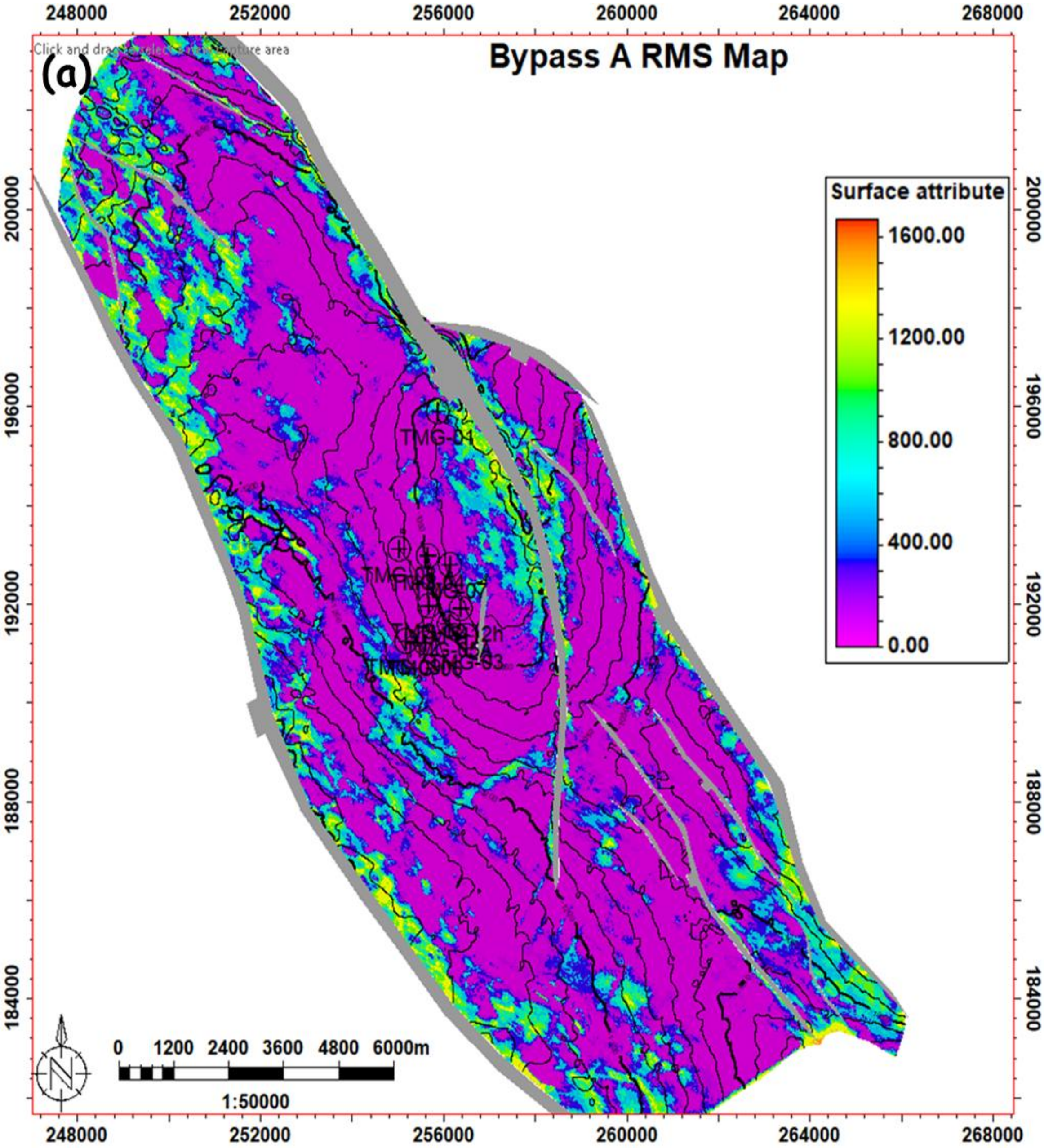

Fig. 19a. R.M.S. amplitude extraction of bypass A map

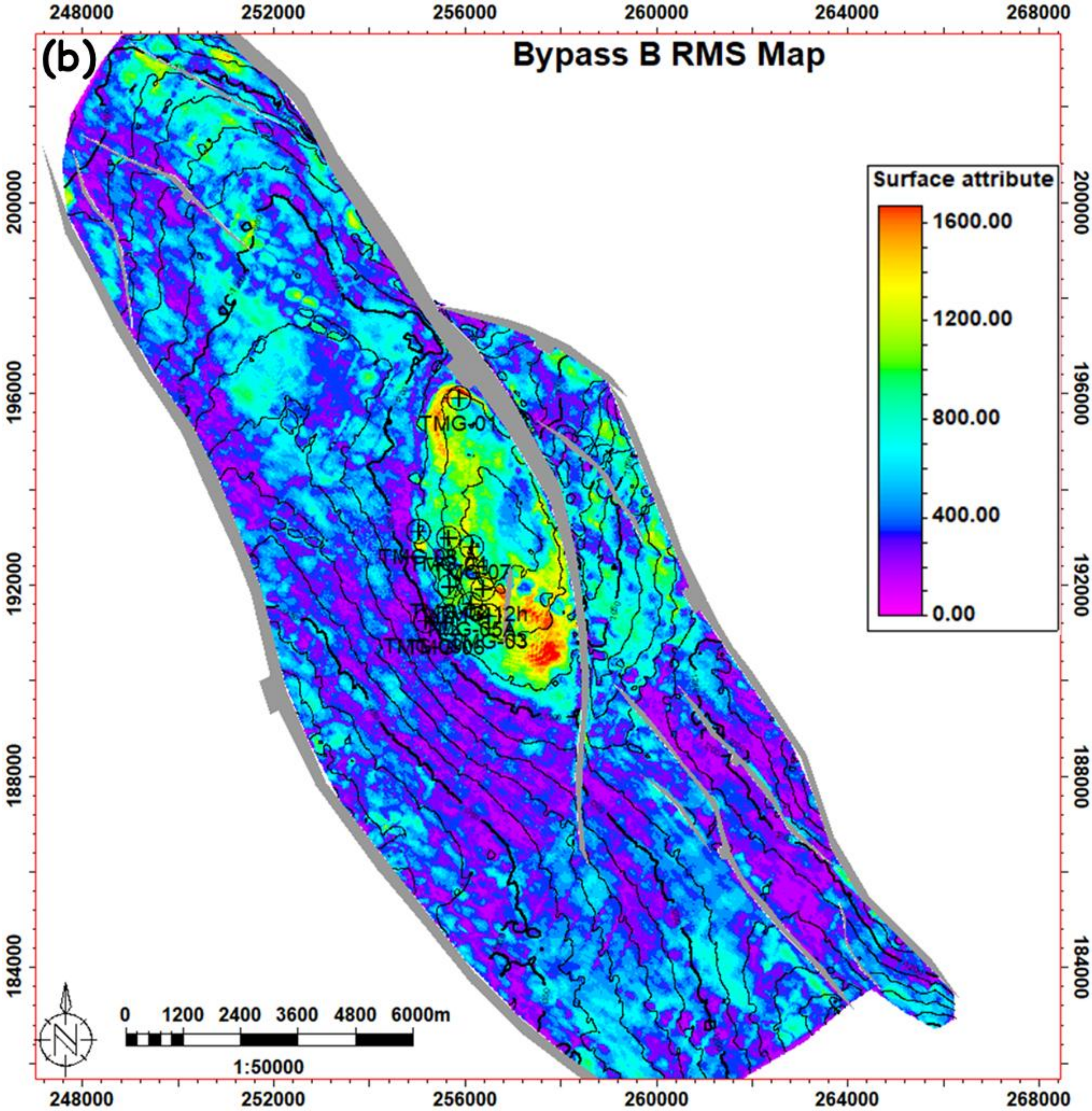

Fig. 19b. R.M.S. amplitude extraction of bypass B map

4.8 Volumetric

The expected recoverable hydrocarbon known as the reserve was estimated for the Bypassed reservoirs Table 3. The reserve was also estimated for the already identified reservoirs (major reservoir) Table 4. The total reserve estimated for oil is about 22.4 million barrels, gas is about 258 billion standard cubic feet, and condensate is about 70.29 million barrels of oil, Table 5. The reserve estimate for the Bypass hydrocarbon zones increased the total reserve estimate by about 5.47 million barrels for oil and 42.8 billion standard cubic feet for gas, Table 3. The production data (Table 6) was reviewed to know the possible effect of the volumetrics of the Bypassed hydrocarbon on hydrocarbon production within Okpella Field. The cumulative production of oil was plotted against the years on a bar chart to view the changes in production over the years (Fig. 20). There was an increase in oil production from the year 1997 to the year 2008, and in the year 2009, the field experience declines in oil production due to changes in the reservoir pressure regime. Secondary recovery began in 2010 until 2018 when it was no longer profitable for the company to keep producing the oil (Fig. 20). The total volume of oil produced from 1997 to 2009 before secondary recovery is estimated to be 3.48 million barrels, and oil produced during secondary recovery is 0.34 million barrels. The minimum estimated volume of recoverable oil is about 11.1 million barrels for the Bypassed reservoir Table 4. Therefore about 31% of the minimum estimated reserve was produced due to changes in reservoir conditions. Considering the knowledge of production within the Okpella Field, we can also expect to produce about 31% of the minimum expected reserves of the Bypassed hydrocarbon estimated in the volumetric Table 4, which is about 3.68 million barrels and 31% of this estimate will give a producible estimate of 1.1 million barrel of oil from the Bypassed reservoir B and C before secondary recovery. Adding about 1.1 million barrels of oil from the Bypass reservoir to the already produced oil of the Major reservoirs will increase the oil production by 10%, and this should sustain the oil productivity of the field for three more years before secondary recovery considering the previous rate of production employed in the field.

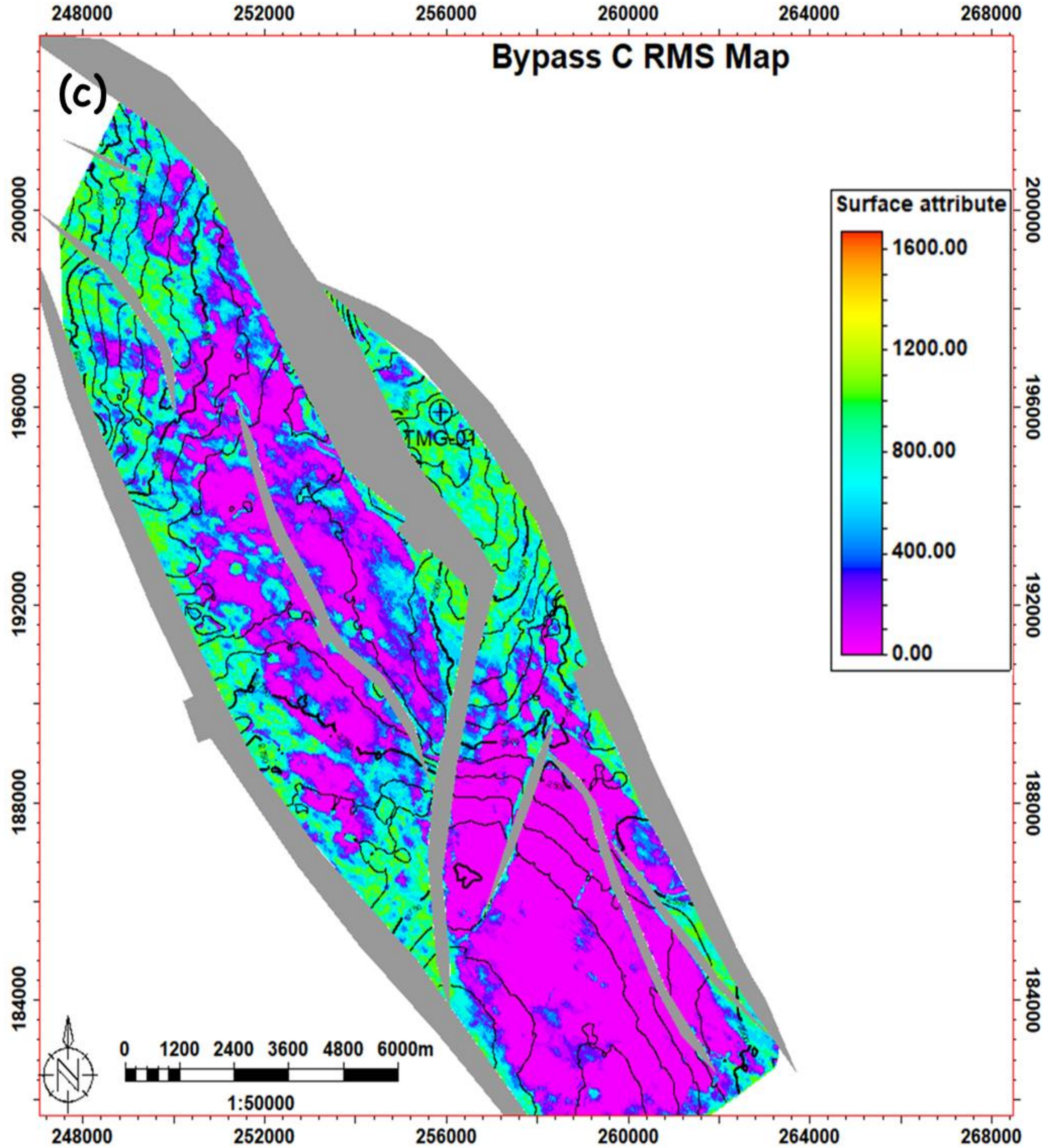

Fig. 19c. R.M.S. amplitude extraction of bypass C map

Table 3. Volumetric estimate and reserve for bypass reservoirs

Volumes	P10	P50	P90
STOOIP (MMbbl)	14.7	18.2	23.13
GIIP (Bscf)	78.29	142.6	222.57
Oil Reserves (MMbbl)	3.68	5.47	8.1
Gas Reserve (Bscf)	19.57	42.8	77.9

Table 4. Volumetric estimate and reserves for the major reservoirs

Volumes	P10	P50	P90
STOOIP (MMbbl)	44.36	56.57	73.58
GIIP (Bscf)	376.57	718.11	1030.74
Oil Reserves (MMbbl)	11.1	16.79	25.75
Gas Reserve (Bscf)	94.14	215.43	360.76
Condensate Reserve (MMbbl)	47.56	70.29	113.31

Table 5. Volumetric estimate and reserves for all the reservoirs

Volumes	P10	P50	P90
STOOIP (MMbbl)	59.08	74.80	96.72
GIIP (Bscf)	454.87	860.78	1253.32
Gas Condensate (MMbbl)	190.25	234.31	323.75
Oil Reserves (MMbbl)	14.77	22.44	33.85
Gas Reserve (Bscf)	113.72	258.23	438.66
Condensate Reserve (MMbbl)	47.56	70.29	113.31

Table 6. Production data for major reservoir

Primary Recovery		Secondary Recovery	
Year	**Oil production**	**Year**	**Oil production**
1997	3070.169	2010	38126.059
1998	57408.543	2011	41592.064
1999	127329.66	2012	41592.064
2000	189114.059	2013	41592.064
2001	247759.671	2014	41592.064
2002	287815.1	2015	41592.064
2003	327743.556	2016	41592.064
2004	364218.965	2017	41592.064
2005	386893.654	2018	7839.011
2006	406753.58		
2007	421957.378		
2008	430175.497		
2009	238095.412		

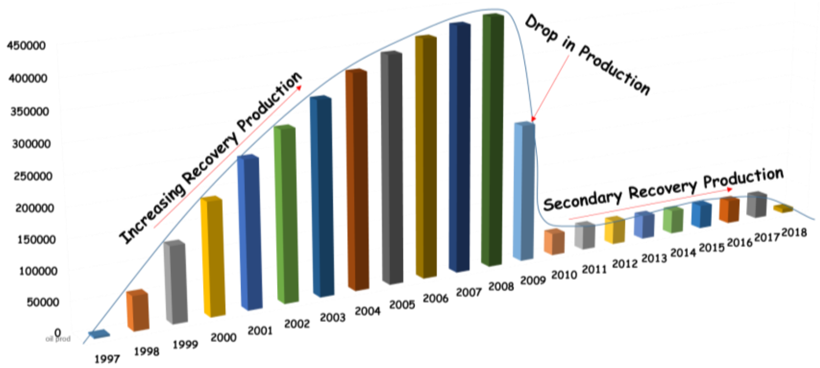

Fig. 20. Plot of cumulative oil production for okpella field from 1997 to 2018 for all the wells

5. CONCLUSION

3D Seismic interpretation was carried out on Bypassed hydrocarbon zones within the Okpella Field offshore Niger delta basin. Four major faults were mapped across the field from the seismic interpretation, dividing the field into three main blocks. The structural style in the field is growth fault and roll-over anticlinal structures typical of the Niger Delta Basin. The Reservoirs' depth map indicates that the hydrocarbons' major trap is a fault dependent closure. Therefore, the fault has offset the continuity of the reservoirs, thereby juxtaposing the reservoir beds (Sands) with non-reservoir beds (Shales), essentially trapping hydrocarbons. The R.M.S attribute maps show that the Bypassed Reservoirs are amplitude supported, indicating the presence of hydrocarbon accumulation around the structural closures. The Root Mean Square Amplitude attribute was used because it is sensitive to amplitude anomalies which could serve as direct hydrocarbon indicators (D.H.I.s). The volume of oil in the Bypass hydrocarbon zones and major reservoir zones was estimated. The Bypassed reservoir zones increased the volume of oil by 5.47 million barrels and gas volume by 42.8 billion standard cubic feet. The production data revealed the oil production from the Major reservoir in the field. This was used to estimate the producible volume of the Bypassed hydrocarbon zones, which was estimated to have a producible oil of about 1.1 million barrels. This extend the field's production life by three years before secondary recovery.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Bob D. BP statistical review of world energy 68th edition. London, UK: BP p.l.c; 2019.
2. Bassiount Z, Velic J. Prospecting for bypassed oil and gas. Geological Croastica. 1996;197-202.
3. Ameloko AA, Uhegbu GC, Bolujo E. Evaluation of seismic and petrophysical parameters for hydrocarbon prospecting of G-field Niger Delta, Nigeria. J Pet Explor Prod Technol. 2018;9(4):2531–2542.
4. Fajana AO, Ayuk MA, Enikanselu PA, Oyebamiji AR. Seismic interpretation and petrophysical analysis for hydrocarbon resource evaluation of 'Pennay' field, Niger Delta. J Pet Explor Prod Technol. 2019;9(2):1025–1040.
5. Owolabi AO, Omang BO, Oyetade OP, Akindele OB. Reservoir evaluation and volumetric analysis of rancho field, Niger Delta, of Rancho Field, Using Well Log and 3D Seismic Data. Open J Geol. 2019;09(13):974–987.
6. Oyeyemi KD, Olowokere MT, Aizebeokhai AP. Hydrocarbon resource evaluation using combined petrophysical analysis and seismically derived reservoir characterization, offshore Niger Delta. J Pet Explor Prod Technol. 2018;8(1):99–115.
7. Norden B, Frykman P. Geological modelling of the triassic stuttgart formation at the ketzin CO_2 storage site, Germany. Int J Greenhouse Gas Control. 2013;19:756–774.
8. Edigbue P, Olowokere MT, Adetokunbo P, Jegede E. Integration of sequence stratigraphy and geostatistics in 3-D reservoir modeling: a case study of Otumara field, onshore Niger Delta. .Arab J Geosci. 2015;8(10):8615–8631.
9. Kalu CG, Obiadi II, Amaechi PO, Ndeze CK. Petrophysical analysis and reservoir characterization of emerald field, Niger Delta Basin, Nigeria. . Asian J Earth Sci. 2019;13(1):21–36.
10. Fred A, Shivaji D. Reservoir characterization. Developments in Petroleum Science. 2013;151-189.
11. Slatt RM. Stratigraphic reservoir characterisation for petroleum geologists geophysicists and engineers. Elsevier, Amsterdam. 2006;473.
12. Unuevho CI, Tokurah MM, Udensi EE. Delineation of time-stratigraphic units on open- hole geophysical logs acquired in etsako field, onshore Niger delta of Nigeria. IOSR Journal of Applied Geology and Geophysics. 2018;6(3):01-12.
    DOI: 10.9790/0990-0603020112
13. Ekwe AC, Onuoha KM. Using rock physics modeling and Lambda Murho inversion to enhance exploration in a mature producing field in onshore Niger Delta basin. In K. M. Onuoha, ed)Advances in Petroleum Geoscience Research in Nigeria (Basin). Analysis and Reservoir Characterisation Studies. University of Nigeria, Nsukka: Published by PTDF. 2017;1-18.

14. Luis FQ, Glenn W, Ehab N, Christof S, Eldad H. Identification of bypassed hydrocarbon through the integration of 3D resistivity imaging and pulsed-neutron logging. SPWLA 59th Annual Logging Symposium. London: SPWLA. 2018;2018-00.
15. Adeoti L, Igiri T, Adams L, Adekunle A, Bello MA. structural style and reservoir distribution in deep-water Niger Delta: a case study of “nanny field”. Br. J. Appl. Sci. Technol. 2014;1375-1391.
16. Sanuade OA, Akanji AO, Oladunjoye MA, Olaojo AA, Fatoba JO. Hydrocarbon reservoir characterization of “AY” field, deep-water Niger Delta using 3D seismic and well logs. Arabian Journal of Geosciences; 2017.
Aavailable: 10.1007/s12517-017-2941-0.
17. Oyetade OP, Fadiya SL, Alao OA. Application of sequence stratigraphy for an enhanced hydrocarbon reservoirs correlation in “OSP” Field, Niger Delta, Nigeria. Journal of Petroleum Exploration and Production Technology. 2020;2721-2736.
18. AdeniyiAmodu, Oluwaseye Oyetade, Suyi Fadiya, Oluwabamiwa Fowora. Sequence stratigraphic analysis and hydrocarbon prospectivity of AMO Field, deep offshore Niger Delta, Nigeria. Energy Geoscience. 2022;80-93.
19. Kulke H. Nigeria, in Kulke, H. (Ed.), Regional petroleum geology of the world. Part II: Africa, America, Australia and Antarctica. Berlin, GebruderBorntraeger. 1995;143-172.
20. Doust HJ, Omatsola O. Niger delta in: Edwards, J. D. and Santoyiossi, P.A. (Ed.). Divergent and Passive Margin Basin. AAPG Memoir. 1990;48:201–238.
21. Ekweozor CM, Daukoru EM. Northern delta depobelt portion of the akata–agbada(!) Petroleum System, Niger Delta, Nigeria. In B. a. Magoon, The Petroleum System-from Source to Trap. Memoir: American Association of Petroleum Geologists. 1994;599-614.
22. Unuevho C, Onuoha KM. Generating new prospects and plays from facies analysis of 3D seismic data: An Example from Eastern Niger Delta Basin. In: Onuoha, K.M. (ed) Advances in Petroleum Geoscience Research in Nigeria (Basin Analysis and Reservoir Characterisation Studies). Published by PTDF, University of Nigeria, Nsukka. 2017;105-125.
23. Weber KJ, Daukoru EM. Petroleum geology of the Niger Delta. Proceedings of the Ninth World Congress held in London United Kingdom. 1975;10-17.
24. Obaje N. Sequence stratigraphic interpretation of Kafe-1 field, offshore Western Niger Delta. International Journal of Engineering Science Invention. 2009;2.
25. Michele LW, Ronald RC, Michael EB. The Niger delta petroleum system: Niger delta province, nigeria cameroon, and equatorial guinea, Africa. Colorado: US Geological Survey World Energy Project, Open-File Report. 1999;99-50-H.
26. Evamy, et al. Hydrocarbon habitat of tertiary Niger delta. American Association of Petroleum Geologists Bulletin. 1978;62:1-39.
27. Shannon PM, Naylor N. Petroleum basin studies. London, UK: Graham and Trotman Limited. 1989;153-169.
28. Weber K. Hydrocarbon distribution patterns in Nigerian growth fault structures controlled by structural style and stratigraphy. AAPG Bulletin. 1986;70:661-662.
29. Short KC, Stauble AJ. Outline of geology of Niger delta. AAPG Bulletin. 1967; 51:761-779.
30. Waziri EU, Udensi EE, Unuevho CI, Jimoh MO, Salako KA, Alhassan, Solomon AA. Geophysical well log appraisal of okpella field within offshore Niger delta basin of Nigeria. Journal of Geography, Environment and Earth Science International. 2022;26(5):28-49.

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