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Research Article
3-D Seismic Attribute Analysis for Enhanced Prospect Definition of "Opu Field'', Coastal Swamp Depobelt Niger Delta, Nigeria

Opara Alexander Iheanyichukwu and Osaki Lawson Jack

Department of Geology, Federal University of Technology PMB 1526, Owerri, Imo State, Nigeria

Abstract

Background and Objective: Analysis of seismic attributes has been an integral part of reflection seismic interpretation for over two decades now. Seismic attributes facilitates structural and stratigraphic interpretation as well as offer hints to formation type and fluid content estimation with the potential benefit of detailed reservoir characterization. The current study evaluated the use of seismic attributes generated from 3D seismic and well log data for characterization of the reservoirs of ''Opu Field'', Coastal Swamp Depobelt, Niger Delta. **Materials and Methods:** Root mean square (RMS) amplitude, instantaneous frequency and interval average maps were extracted on seismic events with pronounced bright and dim spots. These maps were used to establish the diagnostic ability of 3D seismic attribute analysis in enhancing seismic interpretation and volumetric estimation of the mid Miocene to Pliocene Agbada Formation reservoirs within the Coastal Swamp Depobelt, Niger Delta basin. The methodology involved a well-defined procedure which included the delineation of the various lithologies from the gamma ray log, identification of reservoirs from the resistivity log, regional well correlation, determination of petrophysical parameters, horizon and fault mapping, time to depth conversion, attribute analysis and reserve estimation. **Results:** Two main reservoirs identified as Sand-A and Sand-B were mapped in the study area using seismic data. Similarly, seven faults labelled F_1-F_7 and four horizons were mapped within the field. Depth structure maps generated revealed a massive Northeast-Southwest (NE-SW) trending anticlinal structure. Petrophysical analysis revealed a mean porosity value of 18% while the mean permeability values ranged from 63-540 md across the two reservoirs. Water saturation and volume of shale (V_{sh}) across the reservoirs ranged from 38-90 and 17-82%, respectively. **Conclusion:** This study revealed that the"Opu Field" has high hydrocarbon potentials and excellent petrophysical characteristics favourable for hydrocarbon accumulation and production. The benefits of integrating structural interpretation, petrophysical evaluation and seismic attributes analysis in prospect identification and reservoir prediction was therefore highlighted in this study.

Key words: Seismic attributes, Niger delta, reservoir characterization, structural interpretation, petrophysical interpretation

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Corresponding Author: Opara Alexander Iheanyichukwu, Department of Geology, Federal University of Technology, PMB 1526, Owerri, Imo State, Nigeria Tel: +234-8033884315

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Detailed mapping of geological features associated with hydrocarbon reservoirs has remained the paramount goal of seismic exploration and interpretation especially in the Niger Delta[1-6]. Several studies on reservoir delineation and characterization in the Niger Delta have been carried out using conventional techniques of seismic interpretation using seismic and well log data sets as the input[7-11]. Despite the several achievements made in the areas of structural interpretation, reservoir characterization and volumetric estimation from conventional seismic interpretation, a lot of interpretational challenges still exist especially in complex geological settings. These challenges include poor resolution around sub-seismic faults and within stratigraphic features like channels among others. In a geologically complex hydrocarbon habitat like the Coastal swamp depobelt Niger delta, several transient features characterized by unknown locations and time extents which generally constitute stratigraphic anomalies in a 3D seismic volume are known[12]. In addition to seismically mappable fault structures which can ordinarily be mapped using the conventional seismic method, a large number of faults below the limit of seismic resolution also contribute to sub-surface deformation. These fault structures which have been classified into seismically resolvable and sub-seismic scale (subtle) faults can be interpreted more effectively with the aid of seismic attributes[13-17]. Seismic attribute analysis also help to identify faults missed using the conventional methods of interpretation[17]. Seismic attributes have been used for many years to delineate faults and stratigraphic features that are difficult to map using standard amplitude seismic data[18]. Though the seismically resolvable faults may be interpreted using traditional diagnostic criteria (e.g., abrupt reflector cut off, kinks, etc.), the subtle faults like sub-seismic faults which are of immense exploration significance are usually not visibly imaged by the conventional seismic sections and time slice displays. The poor imaging of sub-seismic faults is because they have smaller throws relative to the resolution limit of the seismic survey, which is a factor dependent on the frequency content, signal to noise ratio of the dataset and the depth to the reflecting horizon. Identification of these subtle traps are therefore, essential for effective identification and characterization of very complex reservoirs[19-21].

Within the past two decades, it has become possible to characterize reservoirs using seismic attributes especially when the attributes are calibrated with available well data[22-24]. Over time, the application of seismic attributes have proliferated at a rapid rate and have helped in making accurate predictions in hydrocarbon exploration and development[25]. Though seismic attributes have been used by seismic interpreters worldwide for lithological and petrophysical prediction of reservoir properties, the technique is yet to be fully embraced and integrated into reservoir studies carried out within the study area[26,27]. Seismic attribute is defined as any measure of seismic data that helps an interpreter to visually enhance or quantify features of interpretation interest[28]. The concept of seismic attribute has been applied in many sedimentary basins worldwide with over 35 different surface and volume attributes generated from both post-stack and pre-stack seismic data sets[28].

Given the benefits of these seismic attributes, some key attributes were applied to enhance reservoir characterization in the study area. They were used to resolve serious interpretational challenges associated with sub-seismic faults and subtle stratigraphic features which most often result to poor seismic resolution. The geological importance of seismic attributes as a useful tool in defining lithological anomalies, bedding continuity, bed spacing/thickness, depositional environment, geological structures, gross porosity, fluid content, abnormal pressure, temperature and polarity of seismic data have being highlighted by several scholars[29,30]. While structural attributes help in picking horizons and faults, seismic attributes relating to log and rock properties help in defining a better petrophysical and facies model which reduces uncertainty[31,32]. For a more robust analysis, surface attributes may be compared with other textural attributes which helps in defining the sandstone distribution and connectivity of the hydrocarbon bearing facies. In the present study therefore, variance-based coherence, root-mean-square amplitude, interval average and instantaneous frequency attributes were extracted from the original seismic volume and analyzed in order to enhance the structural and stratigraphic characterization of the reservoirs within the study area. The objective of this study was therefore, to use seismic attributes in resolving complex structural and subtle strati graphical features of the mapped reservoirs.

MATERIALS AND METHODS

This study is part of a Master of Geophysics research work carried out at the Geophysics Workstation of Federal University of Technology, Owerri, Nigeria, between the 15th of January, 2015 to the 17th of October, 2015.

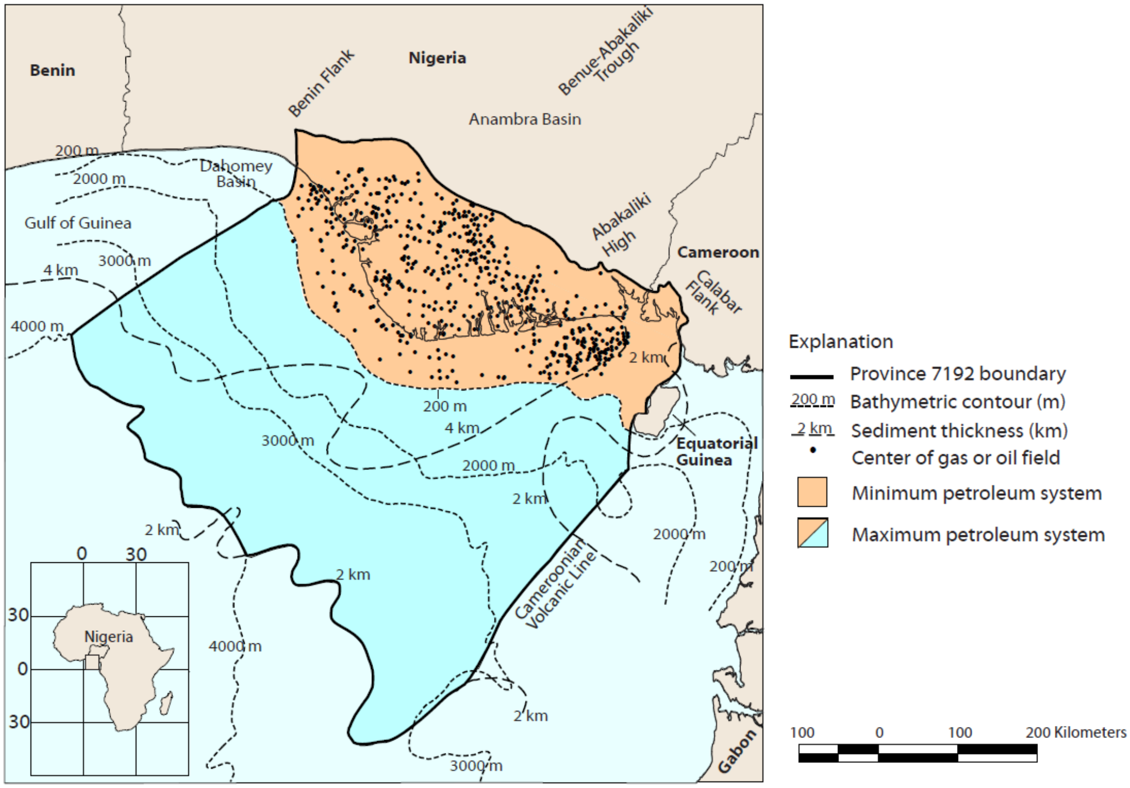

Fig. 1: Index Map of the Niger Delta showing province outline, bounding structural features and minimum petroleum systems[36]

Location and background geology of the study area: The Niger delta is one of the world's major hydrocarbon province (world class oil province) and was situated in the Gulf of Guinea in West Africa[33,34]. Figure 1 shows the location of the Niger Delta which is between latitudes 3°N-6°N and longitudes 5°E-8°E. The regional geology, stratigraphy and structure of the Niger delta basin have been extensively discussed in several key publications by earlier scholars[35]. The tertiary Niger delta covers an area of about 75,000 km^2 and is composed of an overall regressive clastic sequence which reaches a maximum thickness of 30,000-40,000 ft. (9,000-12,000 m)[36-38]. The origin and development of the Niger delta was dependent on the balance between the rates of sedimentation and subsidence. An escalator model was therefore proposed for the deposition within the Niger delta which stipulated that as the offshore marine shales were buried and loaded by the prograding delta, they became overpressured and flowed upward basin ward[38]. This balance and the resulting sedimentary patterns appear to have been influenced by the structural configuration and tectonics of the basement within the study area[39-40]. The tertiary Niger delta consist of three major lithostratigraphic units which include the Benin, Agbada and Akata Formations (Fig. 2). The Akata formation with a thickness of 6096 m is the deepest stratigraphic unit and is chiefly plastic, low density, under compacted and high pressured shallow marine to deep water shales with only local interbeddings of sands and/or siltstones[41]. The Agbada formation represents the paralic sequence of the interbedded fluviatile coastal, fluvio-marine sands and/or sandstones intercalated by marine shales[41]. The depositional environment is generally defined as "Transitional" between the upper continental Benin Formation and the marine underlying Akata formation[42]. This formation is particularly important for oil exploration due to the fact that most hydrocarbon occurrences in the Niger delta have been found in the upper units of its sandy bodies (Fig. 1). The Benin Formation is mostly of Pliocene age in the upper most units and consists of thick sequences of sand, gravels and plant remains[43-45].

The "Opu Field'' is located within the Coastal Swamp Depobelt in the Eastern Part of the Niger delta (a sedimentary basin in the southern part of Nigeria). The study area covered an area of about 74 km^2 of seismic section and was situated within a concession block (OML114) which lies in the Cross River estuary bordering Cameroon, 2 km to the east of the Ntanta Field (Fig. 3).

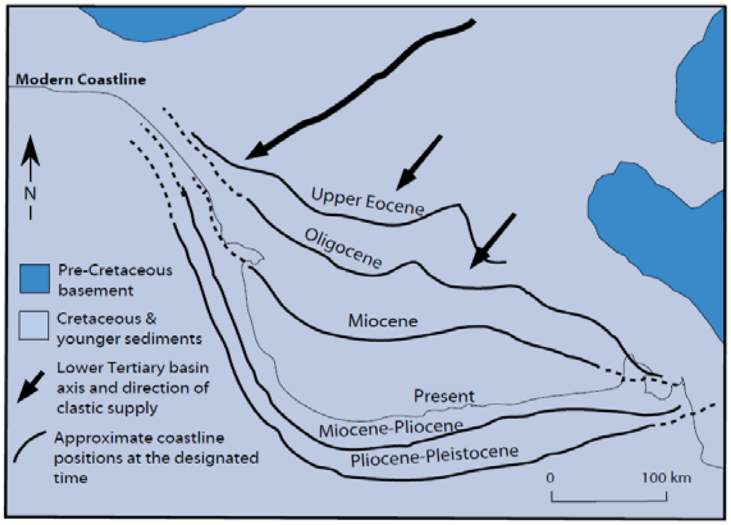

Fig. 2: Development of modern Niger delta with the arrows showing the lower tertiary basin axis and direction of sediment supply[38]

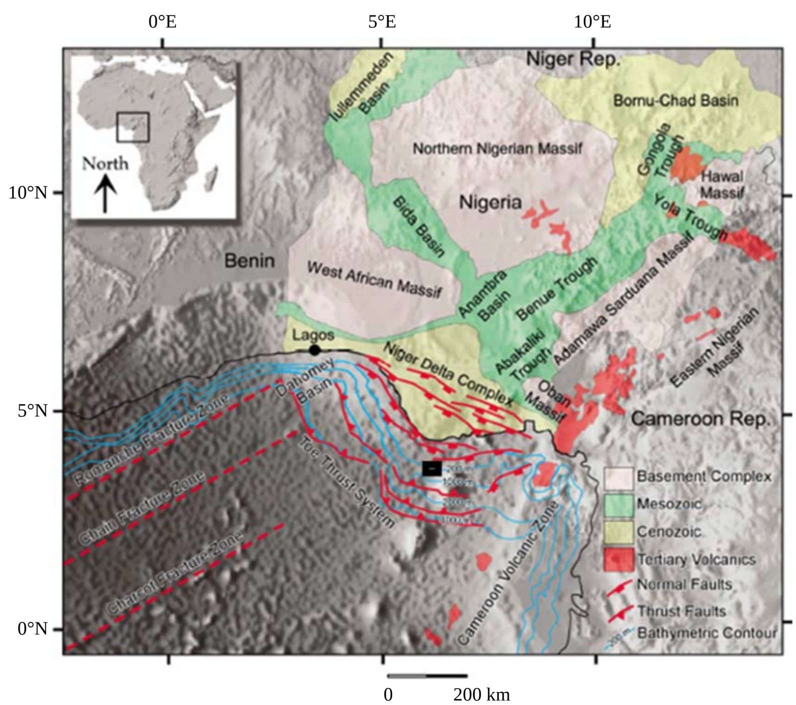

Fig. 3: Map of Niger delta showing the study location[38]

Data and software requirements: The data set used for this study comprised of 3-D seismic reflection data (274 in lines and 256 cross lines), covering an estimated area of 74 km^2 and suites of composite logs (GR, Sonic, Resistivity, Compensated Density and Neutron porosity logs). Part of the dataset include four vertical wells (Osl_2,Osl_7,Osl_9 and Osl_11) and their check shot survey data. Figure 4 shows the base map of the study area with the appropriate location of the drilled wells within the study area. Schlumberger Petrel^{TM} 2015 version (a seismic to simulation and interactive petrophysics (IP) software) was used for this project.

Methodology and detailed workflow: The datasets were loaded into the Schlumberger Petrel^{TM} Software, 2015 Version. Interpretations of the well logs were carried out from the correlation stage to the evaluation stage of petro-physical

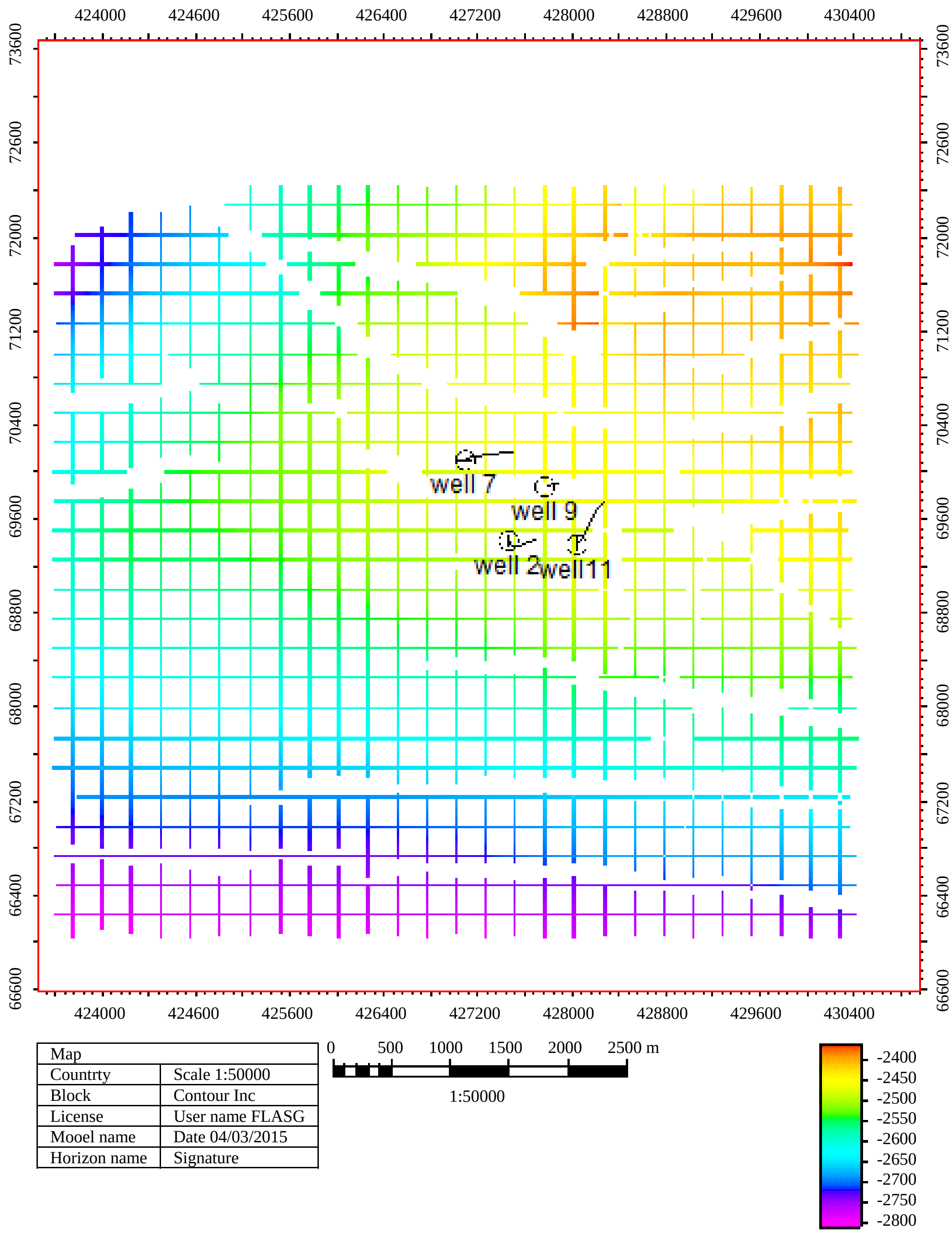

Fig. 4: Base map showing the locations of wells (Osl_2, Osl_7, Osl_9 and Osl_11)

parameters using the Petrel™ software. The study was carried out in two phases-seismic data interpretation and petrophysical data analysis. Detailed workflow include petrophysical evaluation of the wells (Osl_2,Osl_7,Osl_9 and Osl_11), seismic interpretation of the field and hydrocarbon reserve estimation using volumetric methods. Figure 5a shows the regional well-to-well correlation of sand (horizon) tops and bases across the wells within the "Opu Field". The well correlation panel of Osl_2,Osl_7,Osl_9 and Osl_11 was done in the NE-SW direction. The suites of logs associated with these wells are the gamma ray logs, resistivity logs, neutron/porosity and density logs. Two reservoir sands were delineated across the wells in the study area. These reservoir sands are identified as Reservoir Sand_A and Reservoir Sand_B, respectively. Reservoir Sand_A has its top across the wells lying between the depth intervals of 3425-3470 m with

(a)

(b)

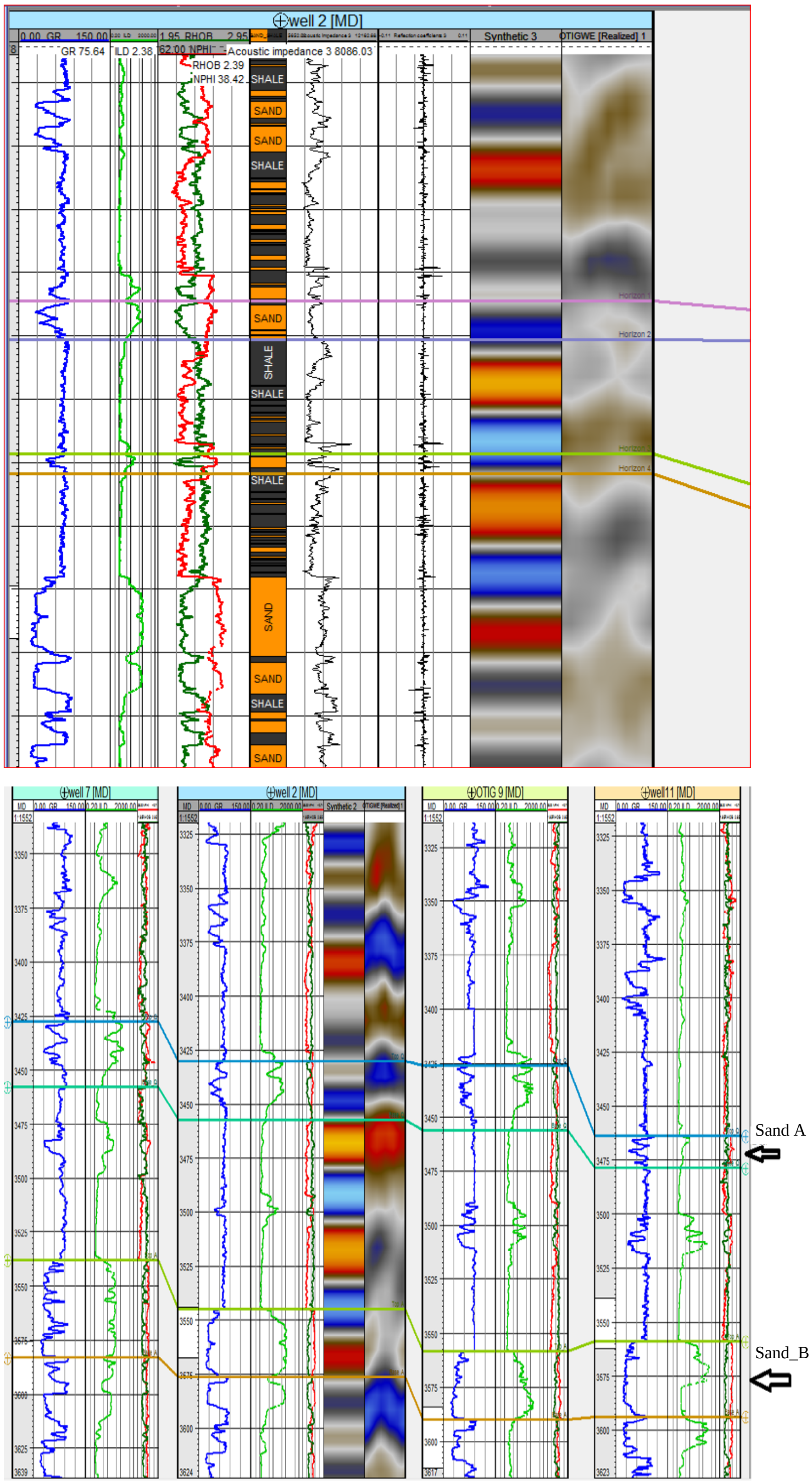

Fig. 5(a-b): (a) Well to well correlation showing well logs and litho-log from Osl_7, Osl_2, Osl_9 and Osl_11 wells and (b) Well to seismic tie of well 2, showing acoustic impedance, reflection coefficient, synthetic seismogram and seismic section (inline) and the four horizons of the prospect zones the base of this reservoir sand located between the depths of 3450-3475 m across the study area (Fig. 5a). The top and base of the Reservoir Sand_A are identified as horizons 1 and 2 on the seismic section. Similarly, tops of Reservoir Sand_Bacross the study area lies between the depth intervals of 3537.5-3557.5 m with their bases lying between the depth intervals of 3582.5-3592.5 m. The top and base of Reservoir Sand_B therefore, is delineated and identified as horizons 3 and 4 on the seismic section. A synthetic seismogram was generated using sonic and density logs from Osl_2 with check shot data from the same well. The seismic calibration was based on a synthetic seismogram using sonic and density logs from Osl_2 well with check shot from the same well. Seismic-to-well tie of the study area was carried out to further correlate tops of horizons already identified in the wells with reflections in the seismic data. Figure 5b shows the seismic-to-well tie for Osl_2 well which revealed a good tie which was however, achieved with a -2.5 msec time shift. This tie formed the most sensitive stage in horizon picking, which corresponded to the tops of the sands for interpretation. Seismic-to-well tie was also done for wells Osl_7,Osl_9 and Osl_11 which showed good ties to the seismic data, thereby increasing the confidence in the picked events. The above information were integrated into the seismic section using synthetic seismogram generated from sonic and density logs from Osl_2 well and check shot data from the same well. A total of 4 horizons corresponding to the reservoir tops and bases of the two reservoir sands (Reservoir Sand_A and Reservoir Sand_B, respectively) delineated in the well suites within the ''Opu Field'' were mapped. Fault picking was carried out along the horizons of interest. Time structural maps of the surfaces were generated and then converted to depth structure maps using the velocity model of the seismic volume. Surface seismic attribute maps (mainly RMS amplitude, interval average extraction and instantaneous frequency) in addition to variance edge map (a volume attribute) were generated from the structural maps with the aim of enhancing the faults and their dips in the seismic section.

RESULTS AND DISCUSSION

Petrophysical analysis: Suites of composite logs for four wells were used to evaluate the petrophysical characteristics of two hydrocarbon bearing sand units in the field. Table 1 and 2 shows the summary of the petrophysical analysis carried out on the two reservoir sands (Sand_A and Sand_B) penetrated by the four wells drilled in the study area. The result of the petrophysical analysis revealed that the porosity across the wells varied between 18.1-20.3% in Sand_A and 13.10-14.9% in Sand_B, respectively. Similarly, the permeability of Sand_A ranged between 63-540 md in Sand_A and 18-80 md in Sand_B, respectively. These results were indicative of a consistent decrease in porosity and permeability values with depth due to compaction resulting from the weight of the overburden. The reservoirs revealed a roughly cylindrical log modify with minor deviations in between (shaly sand) indicating a distributary channel sand. The mean values of the hydrocarbon saturation for both reservoirs in Table 1 and 2 was gotten by adding together the hydrocarbon saturation (%) in wells 2, 7, 9 and 11 in Table 1. Hydrocarbon saturation (S_{hc}) of the reservoirs ranged between 0.04-67.7% with an average of 47.59% for reservoir Sand_A while that of Sand_B ranged between 31-62% with an average of 44.75% indicating the presence of hydrocarbons in the reservoirs within the field. The net-to-gross percentage (N/G%) across the field varied between 22.1-22.4% in Sand_A reservoir and 5.34-12% for reservoir Sand_B.

Table 1: Summary of the estimated petrophysical parameters for the Sand_A reservoir

Parameters	Gross thickness (m)	Vsh	Vsh (%)	Porosity (%)	F	Swirr (%)	K (oil)	Sw	Sw (%)	N/G	N/G (%)	Shc (%)	HCPV
Well 7	33.86	0.49	49.0	19.1	25.7	11.10	309	0.35	35.0	0.22	22.4	64.6	12.0
Well 2	26.77	0.49	49.0	18.1	23.9	41.70	65	0.42	42.0	0.22	22.1	58.0	11.0
Well 9	26.32	0.49	49.0	18.7	24.4	10.97	63	0.32	32.0	0.22	22.2	67.7	12.0
Well11	18.20	0.49	49.0	20.3	28.1	11.13	540	0.96	96.0	0.22	22.2	0.04	2.0

**V_{sh}: Volume of shale, V_{sh} (%): Volume of shale expressed as a percentage, F: Formation factor, S_{Wirr}: Irreducible water saturation, K (oil): Effective permeability to oil, S_w: Water saturation, N/G: Net-to-gross ratio, S_{hc}: Hydrocarbon saturation while HCPV is the hydrocarbon pore volume which is the pore space actually containing hydrocarbons

Table 2: Summary of the estimated petrophysical parameters for the Sand_B reservoir

Parameters	Gross thickness (m)	Vsh	Vsh (%)	Porosity (%)	F	Swirr (%)	K (oil)	Sw	Sw (%)	N/G	N/G (%)	Shc (%)	HCPV
Well 7	77.47	0.17	17	13.1	50.6	15.8	18	0.68	68	0.05	5.34	32	4.0
Well 2	49.13	0.82	82	14.9	40.7	37.7	80	0.38	38	0.12	12	62	9.0
Well 9	31.48	0.29	29	13.1	51.9	15.8	15	0.46	46	0.01	10	54	7.0
Well 11	53.59	0.17	17	13.1	15.6	15.8	18	0.69	69	0.05	5.34	31	4.0

**V_{sh}: Volume of shale, Vsh (%): Volume of shale expressed as a percentage, F: Formation factor, S_{Wirr}: Irreducible water saturation, K (oil): Effective permeability to oil, S_w: Water saturation, N/G: Net-to-gross ratio, S_{hc}: Hydrocarbon saturation while HCPV is the hydrocarbon pore volume which is the pore space actually containing hydrocarbons

Structural Interpretation of the seismic data: The structural geometry of the "Opu Field" was carried out by picking assigned faults segments on inline seismic section with traces appearing on the corresponding cross lines. Figure 6a shows the vertical seismic section as well as the variance edge attributes generated (structural attributes) from the seismic volume around inline 5830 showing enhanced visualization of the fault system and the pronounced dip of the faults. A total of 7 faults were picked (F_1, F_2, F_3, F_4, F_5, F_6 and F_7) on the basis of abrupt termination of events, distortion of amplitudes around a fault zone and change in the dip of an event. The faults identified were mostly growth faults (listric) especially faults F_1, F_2, F_3, F_4 and F_7. These faults generally dip Southward (basin ward) away from the direction of sediment supply while faults F_5 and F_6 (antithetic faults) dip in the north and Northeast directions. Four reflection events (horizons) were picked on the seismic sections (H_1, H_2, H_3 and H_4) across the field as shown in Fig. 6b. Time and depth structure maps generated from the seismic data for each of the horizons are shown in Fig. 7 and 8. The structural maps revealed a faulted rollover anticline dipping in the Northeast-Southwest (NE-SW) direction with faults F_6 and F_5 assisting the closure.

Seismic attribute interpretation: Three seismic attribute maps (RMS amplitude, interval average extraction and instantaneous frequency) were extracted from the structural maps of the various surfaces of the reservoirs. The attribute maps revealed lateral distribution of porous units (reservoir) as a result of the amplitude anomaly of acoustic impedance contrast caused by the underlying non porous, dense formations. The zones of interest were correlated with well log data, with the observed bright spots revealing possible hydrocarbon accumulation around the structurally high areas of the reservoirs. Figure 9 showed the RMS amplitude maps of the various horizons revealed high amplitude zones limited to three major colours of the colour bar scale (sky blue, green and yellow). Within the NE-SW area (around the H1 and H2 horizons), the high amplitude zones (sky blue) are believed to be hydrocarbon saturated sand units overlying shales (purple) due to the high acoustic impedance contrast. The sky blue and green coloured areas are believed to be highly porous formation with high hydrocarbon prospect, while the yellow zones are assumed to be porous units but possibly with a different fluid content. The background purple colour was interpreted as a result of lateral change in lithofacies from a porous to non-porous formation. The bright spot areas generally increased from the northeast to the southwest (especially around the H1 and H2 events). This indicated possible direction (NE-SW) of displacement of porous units hence it is believed that the depositional environment is a point bar of a distributary channel. The thicker reservoirs likely represent composite bodies of stacked channels[46]. The interval average extraction maps of the horizons in Fig. 10 showed a great similarity in lateral distribution, lithologic variation and hydrocarbon prospect zones. The bright spots observed in this map are believed to be as a result of decrease in acoustic impedance at the boundary between the sand units and the intercalated shales. The high amplitude areas were observed around the structural high zones (around NE-SW area) which possibly confirmed the choice of location of the wells drilled within the anticlinal structure.

The instantaneous frequency maps of the four surfaces revealed bright spots within the proposed prospect zones in the various surfaces as a result of the fluid fill, which may possibly be gas saturated (Fig. 11). This assertion was made based on the fact that increased gas saturation tends to decrease the density and the P-wave velocity of the reservoir and hence, the observed bright spots. The bright spots (yellow and brown coloured areas) correlated with the locations of the bright spots observed on the RMS and interval average extraction maps which also revealed prospect zones within the structural high areas in NE and SW parts of the area. The displacement of hydrocarbon bearing sands to the South-western part of the study area with respect to the north eastern area may possibly indicate greater accumulation of hydrocarbons basin ward. It may also indicate porous units that trend in the NE–SW direction. A comparative analysis of the features of the attribute maps (RMS amplitude, interval average, instantaneous frequency) extracted and the structure maps themselves revealed a strong positive relationship among the maps with the structural high areas (anticlines) coinciding with the bright spot areas (acoustic impedance contrast) observed on the attribute maps.

Structural characterization of the study area: Results of the structural interpretation of the study area revealed seven regional faults and four horizons mapped within the field. Depth structure maps generated revealed a massive NE-SW trending anticlinal structure. These findings revealed that 1 the trapping mechanism of the study area is a fault-assisted anticlinal structure. The faults identified in the field are mostly growth faults (listric) with very few antithetic faults with most of the faults having a NE-SW trend. This is in line with previous studies in the Niger delta which stipulated that the subsurface of the Niger delta basin is extensively deformed by growth

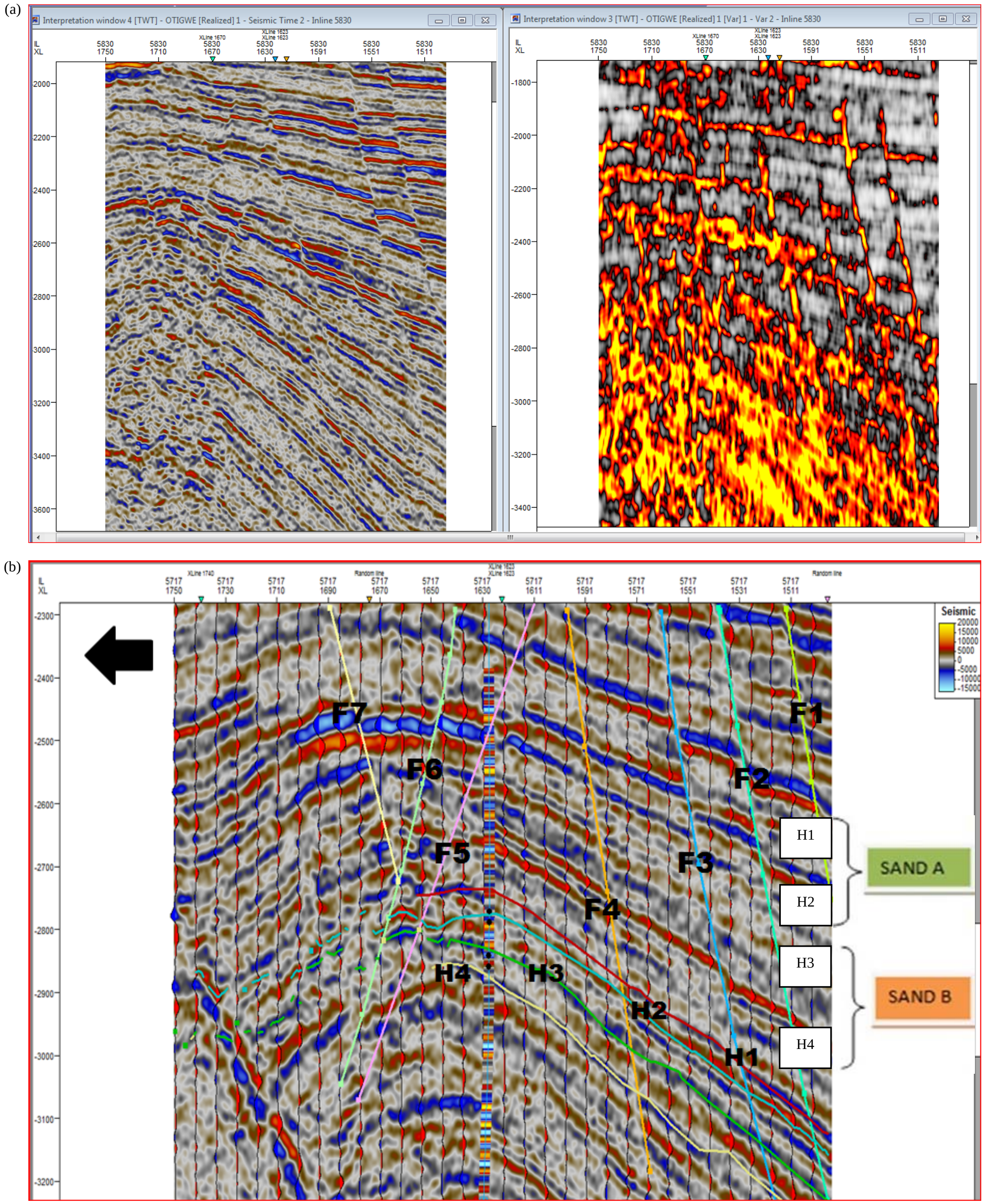

Fig. 6(a-b): (a) Generation of structural attributes (variance edge) of the seismic volume; inline 5830 showing enhanced visualization of fault system and its dip and (b) Vertical section (in line 5717) through Osl 2, showing the faults (F1, F2, F3, F4, F5, F6, F7) of the studied reservoirs and the picked horizons (H1, H2, H3 and H4) where, H1 and H2 represent top and base of sand A and H3 and H4 represent top and base of sand B

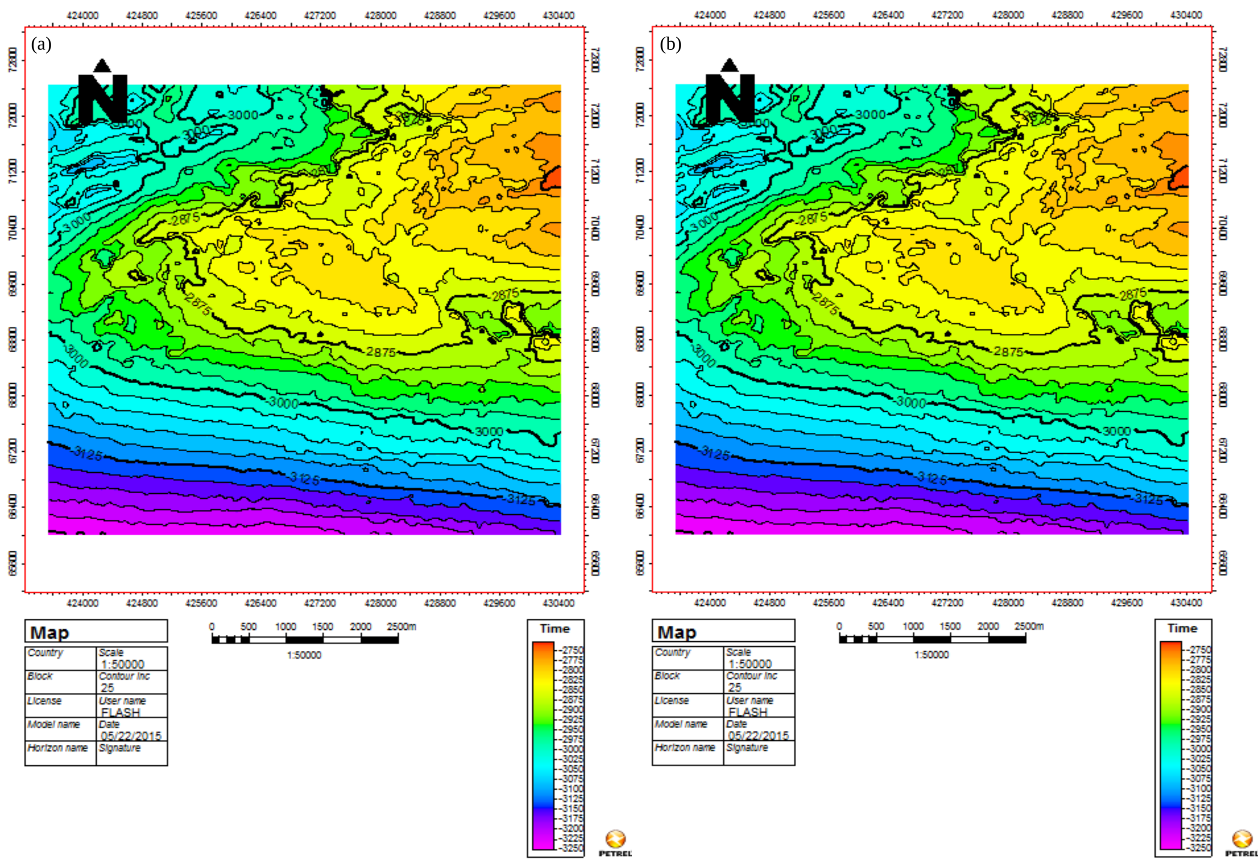

Fig. 7(a-b): Event time structure maps of (a) Horizon H1 (Top of sand_A reservoir) and (b) H3 (tops of Sand_B reservoir) at 2700 and 2800 msec, respectively

faulted structures associated with roll over anticlines[46]. Generally, Niger delta tectonics is believed by several authors to be limited to extensional deformation in the sedimentary fill as basement movements are thought to have played a minor role[46]. Most of these structures are however, interpreted to be syn-depositional as most of the continental sequences typically accumulated over each growth fault bend after the cessation of tectonic activity[46]. Growth faulting which dominates the structural style of the Niger delta are generally believed to be triggered up by the movement of the marine shales of the Akata formation with the movements further increased by slope instability. Generally, the trapping mechanism and style in the Niger delta is related to gravity tectonics within the delta[46-47]. Several authors strongly believe that basement subsidence in the Niger delta resulted to several basement blocks within the delta with structural trends predominantly in the NE-SW and NW-SE directions[46,47]. Whereas, the NW-SE trends are believed to be the result of block faulting that occurred along the edge of the African continent during the earlier stages of divergence, the NE-SW trends appear to be indicative of possible trans-oceanic extension of the Charcot and Chain Fracture Zones into the continental region of the African plate[46-47]. The propagation and interaction of these faults produced different structural features[48]. There is, therefore; the severity and complexity of structural deformation which increases from the Northern Delta and Greater Ughelli Depobelts to the structurally complex Coastal Swamp and Offshore Depobelts.

Hydrocarbon reservoir properties of the study area: Petrophysical analysis of the study area revealed a mean porosity value of 18% while the permeability values ranged between 63-540 md across the reservoirs. Water saturation and volume of shale (V_{sh}) across the reservoirs ranges from 38-90 and 17-82%, respectively. Since it is generally believed by some authors that the sealing capacity of faults in a reservoir is a function of the shale-sand ratio, it therefore, means that the faults of reservoir Sand_A with a mean volume of shale (%) of 49% may be more sealing than the faults of reservoir Sand_B with a mean volume of shale

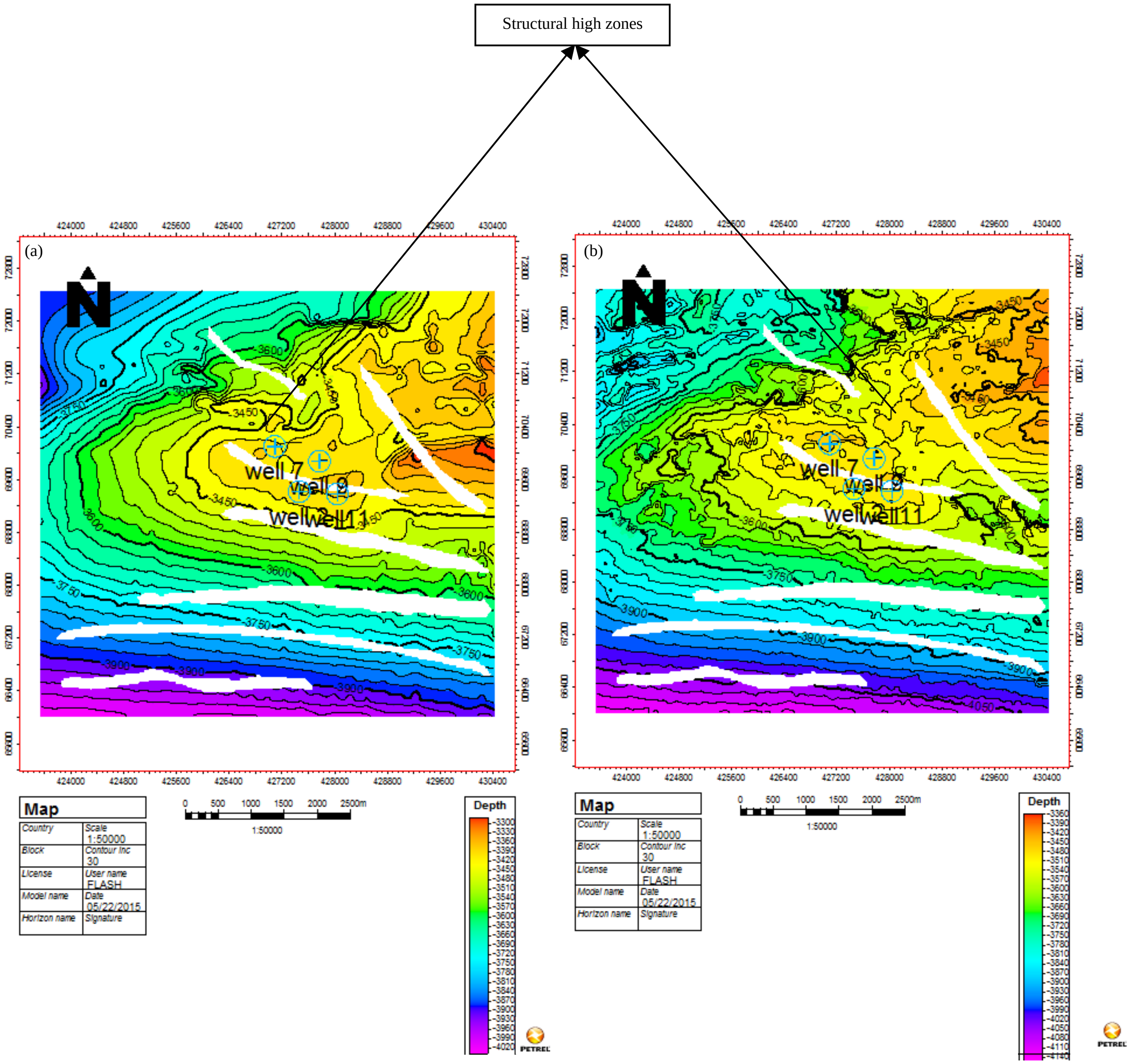

Fig. 8(a-b): Depth structure maps of (a) H1 (top of Sand_A) and (b) H3 (top of Sand_B) reservoirs at 3450 and 3500 m, respectively

percentage of 36.5%[48]. There also seem to be a gradual decrease in sand percentage moving away from the structure building bounding faults towards the distal flanks[48]. The stacked thicknesses of the reservoirs ranging between 18.20-33.86 and 31.48-77.47 m for reservoirs Sand_A and Sand_B, respectively are also relatively high. The average net to gross ratio across the reservoirs of 0.01-0.12 were calculated using an average water saturation and volume of clay cut offs values of 0.6 and 0.5, respectively[49]. Though the higher the volume of shale the lower the N/G and the lower the reservoir quality, however, for N/G in terms of hydrocarbon pay, it could be calculated as the ratio between the net pay thickness and the gross pay thickness[50,51]. The net pay thickness excludes the water saturation section and therefore there are other factors in addition to volume of shale that affects the cut-offs for N/G calculation namely water saturation, permeability or connectivity of pay zone, porosity of pay zone, fluid (hydrocarbon) mobility, etc.[52,53]. The hydrocarbon within the "Opu Field" is predominantly gas and since gas flows easily under normal conditions due to lower viscosity and wettability behavior, therefore cutoffs for gas reservoirs are completely different.

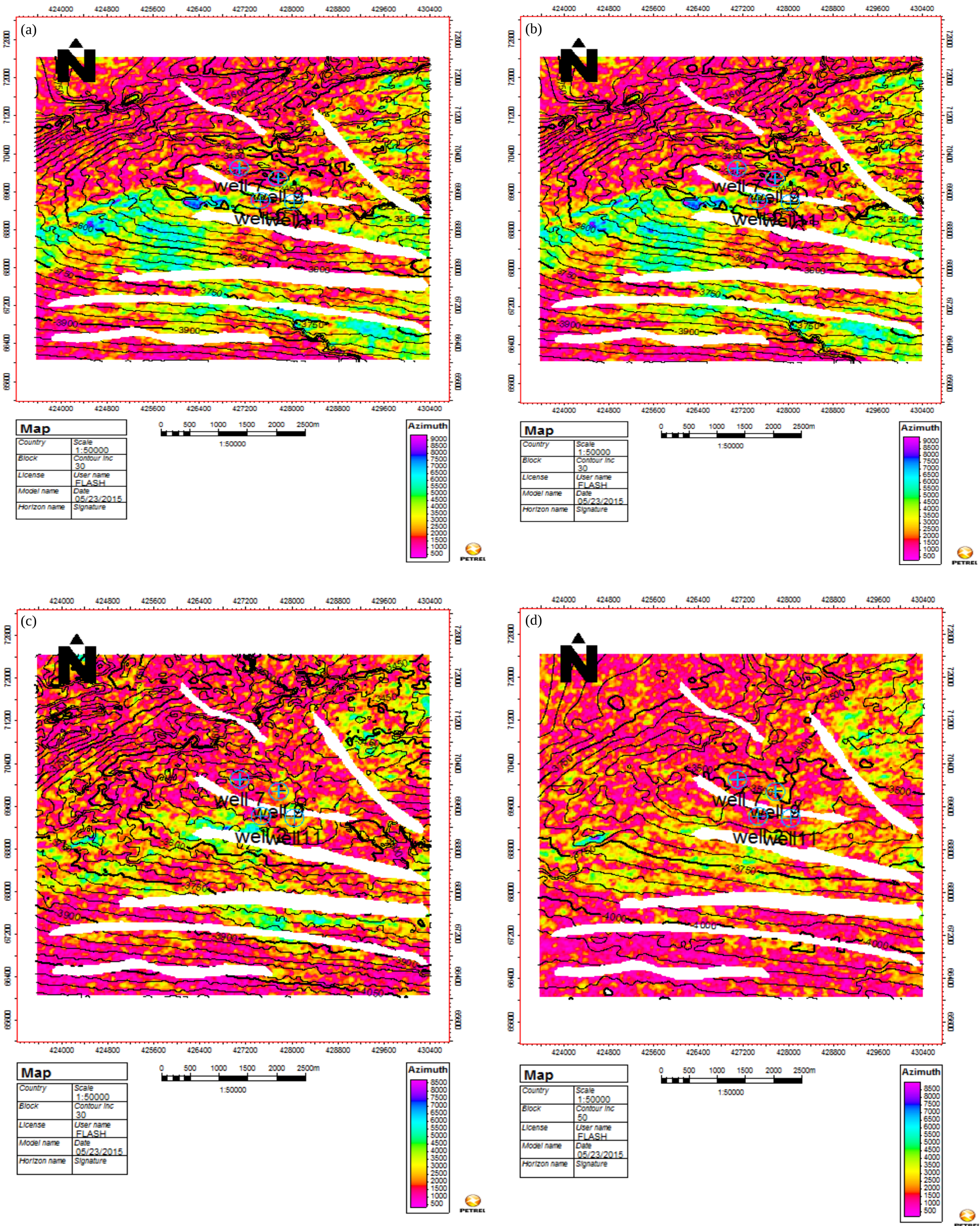

Fig. 9(a-d): RMS Amplitude maps of the horizons (a) Horizon (H1) at 2750 msec, (b) Horizon (H2) at 2780 msec, (c) Horizon (H3) at 2785 msec and (d) Horizon (H4) at 2800 msec showing high amplitude zones (sky blue) which is possible hydrocarbon accumulation (bright spots) areas

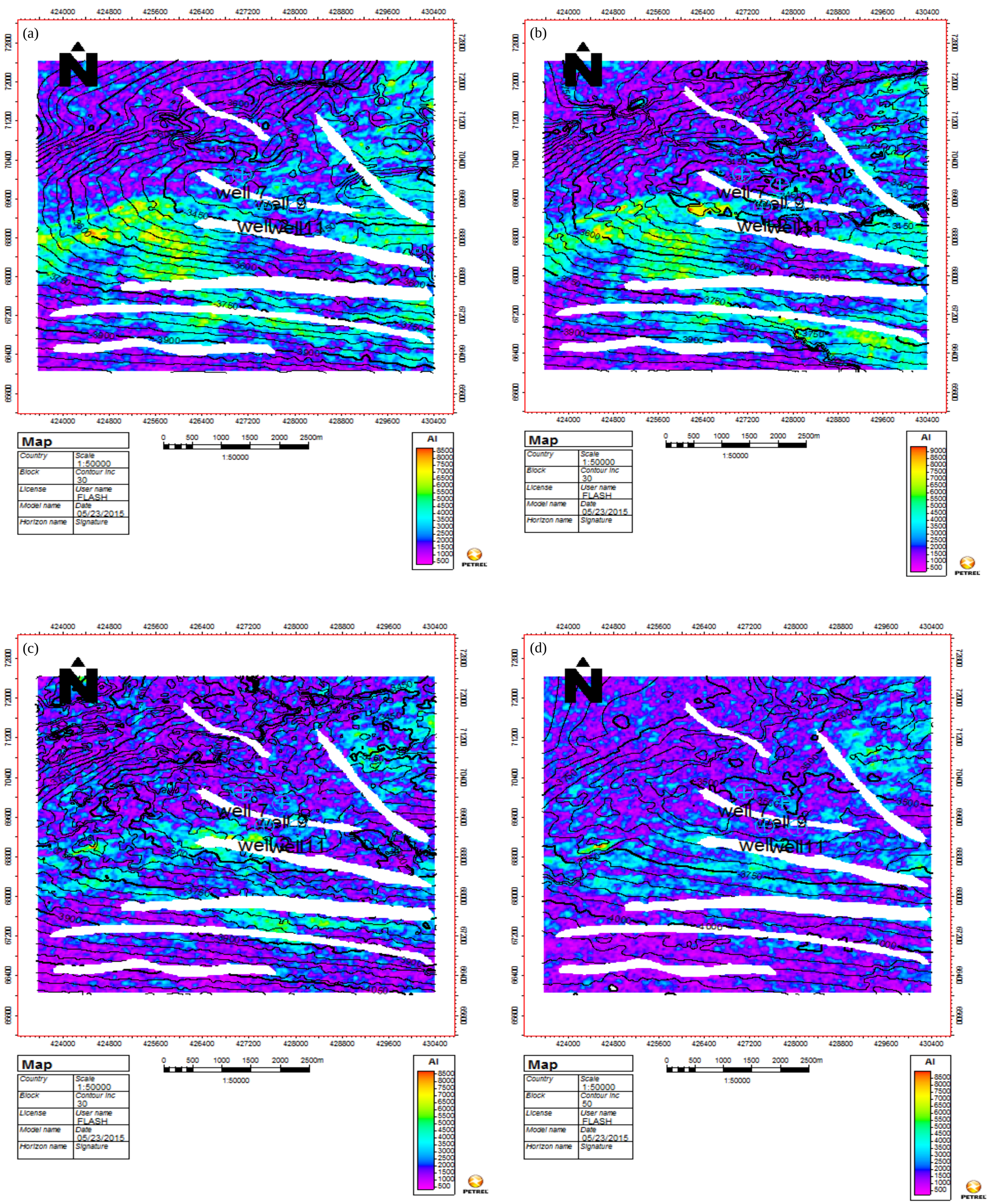

Fig. 10(a-d): Interval average extraction maps of the horizons (a) Horizon (H1) at 2750 msec, (b) Horizon (H2) at 2780 msec, (c) Horizon (H3) at 2800 msec and (d) Horizon (H4) at -2780 msec showing high amplitude zones (red and yellow) which is possible hydrocarbon accumulation (bright spots) areas

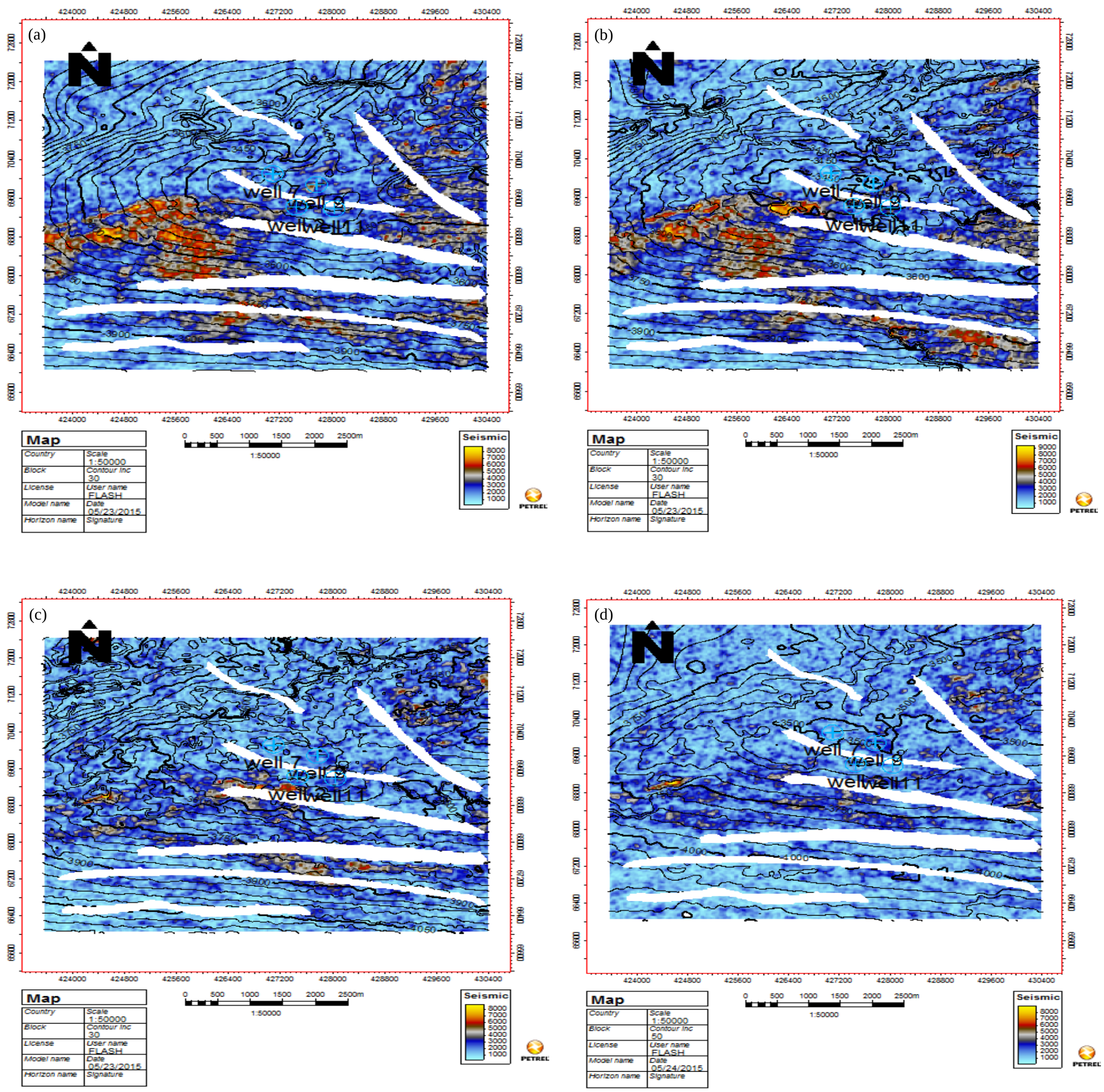

Fig. 11(a-d): Instantaneous frequency maps of the horizons (a) Horizon (H1) at 2750 msec, (b) Horizon (H2) at 2780 msec, (c) Horizon (H3) at 2785 msec and (d) Horizon (H4) at 2800 msec showing high amplitude zones (yellow and brown) which is possible hydrocarbon accumulation (bright spots) areas

CONCLUSION AND RECOMMENDATION

The findings of this study revealed the usefulness of 3D seismic attributes in reservoir characterization in the "Opu "Field, Coastal Swamp Depobelt, Niger delta. Two distinct reservoir sands, seven regional faults and four horizons were mapped across the area. The generated depth structure maps of the study area revealed a massive NE-SW trending anticlinal structure. The summary of the petrophysical analysis carried out on the two reservoirs and revealed a mean porosity value of 18% while the permeability values ranged between 63-540 md across the reservoirs. The study revealed that the"Opu Field" has high hydrocarbon potentials since it has excellent petrophysical characteristics favourable for hydrocarbon accumulation and production. It is therefore, recommended that exploratory wells should be drilled within the mapped structurally high prospect areas.

SIGNIFICANCE STATEMENT

The findings presented in this study has revealed the strong synergistic effect of seismic attributes, 3-D seismic and well log data in resolving complex/subtle hydrocarbon reservoirs. Seismic interpretation aided by 3-D seismic attributes improved reservoir delineation and characterization of the study area as several features of the reservoirs which may have been missed or by passed in conventional seismic interpretation were duly observed. This study will help researchers in hydrocarbon exploration to uncover the critical area of de-risking high level uncertainty in seismic interpretation that many researchers were not able to explore using conventional seismic interpretation. Thus, the findings of this study will give key information to the reservoir engineer (about the extent of reservoir) and a great insight to the production engineer (about the volume of hydrocarbons) and thus reduce the level of uncertainty and optimize production of hydrocarbon fields.

Seismic attributes display maps revealed outstanding strong reflections (bright spot) around structural high regions, indicating reservoir rocks with possible hydrocarbon accumulation. Seismic attribute analysis has been used successfully in this research study to predict reservoir rock properties and was further use to characterize reservoir sands qualitatively. More detailed interpretations such as AVO analysis, rock physics and seismic inversion studies should be carried out for a more robust understanding of the "Opu Field''. Similarly, the drilling of more exploratory wells within the structural high areas accompanied by detailed core sampling and analysis is therefore recommended.

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