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Reservoir evaluation and hydrocarbon play assessment in a Niger Delta field

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Abstract
Amidst the blend of trepidation about dwindling petroleum reserves, a latent frenzy towards improving reserves worldwide, and the ironical call for replacement of fossil fuels, the need still persists, to leverage on legacy data and increasing technological advantages to re-characterize existing fields for optimal reserve recovery. Reservoir evaluation and hydrocarbon play assessment of a typical Niger delta field has been carried out in this research work. This involved delineation of reservoir rocks, characterizations of the fluid within the reservoir, and assessment of the structural relations of the seal, source, and trap (Play Type) in the study location. By inspection of the signatures of a suit of petrophysical logs (comprising of resistivity, gamma ray, shale volume, and density), the HD2000 reservoir was delineated. The reservoir is sandwiched between two impermeable shale beds (seals/caps) bordering the top and bottom of the reservoir. Using Lambda-Rho, Mu-Rho, P-Impedance, Vp/Vs Ratio, and porosity, petrophysical cross plot analyses was carried out. Advanced post-stack 3-D acoustic impedance inversion yielded petrophysical attribute slices which helped to validate the observations in the cross plots. Results showed that the wells cut through zones of low values of P- Impedance, Mu-Rho, Lambda-Rho, and Vp/Vs ratio, corresponding to hydrocarbon saturated sands. Event time structure maps at both horizons and a seismicsection showing faults, fractures, and an anticline structural trend, confirmed that the play type is a fault and fracture infested rollover anticline, which combines with the delineated seals/caps at the top and bottom of the reservoir to form a structural trap for hydrocarbon within the reservoir. These observations correspond to the characteristics of plays in the oil rich belt of the Niger delta petroleum field, where rollover anticlines in front of growth faults form the main objectives of oil exploration.

Keywords: Reservoir, play, rock properties/attributes, petrophysical volumes

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1 Introduction

The presence of viable reservoirs in any basin in the world is dependent on a mature source rock, a migration path connecting source rock to reservoir rock, a reservoir rock that is both porous and permeable, and a trap and an impermeable seal (Huff, 1980). The Niger delta basin is not an exception and using 3D seismic and well log data from a field in this basin, formations can be effectively evaluated and the play type analyzed taking into consideration the availability of a source, reservoir, trap, and seal.

Formation evaluation, which is the interpretation of a combination of measurements taken inside a wellbore to detect and quantify the oil and gas reserves in the rock adjacent to the well (Bassey, 1996) is used in the exploration, production, and development phases of the value chain to determine whether a potential oil and/or gas field is commercially viable. A play on the other hand is defined as one or more closures of similar structural, depositional, or hydrodynamic style, which result from a specific set of tectonic, depositional, diagenetic, or halokinetic processes within a sedimentary basin, and with suitable reservoir and sealing lithologies, and hydrocarbon charge, may form prospective hydrocarbon traps (Kjempeurd, 2005).

Pratap and Sonare, (2005) worked on the assessment of hydrocarbon play types in the Olpad Formation, North Cambay Basin India. They discerned three distinct plays by integrated studies of available geoscientific data in the area, and also defined the hydrocarbon prospectivity which then, appeared subtle and was characterized by moderate risk-moderate gain. Gabor et al. (2010) investigated the play types and hydrocarbon potential of deepwater NW Egypt. They were able to compare the offshore play extension model to the Sirte Basin in Libya where offshore plays are merely extensions of proven onshore plays. They also discovered at least five other deepwater play types in the block, (The Late Post-Rift Raft, The Early Post-Rift Raft, The Messinian Sub-Unconformity, The Syn-Rift High, and The Hinge Zone Sub-Unconformity). Rock physics modeling and Lambda Mu Rho seismic inversion have been applied in an integrated approach to identify and delineate hydrocarbon charged reservoirs in an oil producing field in the Niger delta basin (Ekwe et al., 2012). The results showed that high values of Mu-Rho were indicative of clean sands and lower values of Lambda-Rho correlated well with areas containing hydrocarbons.

In this study, the evaluation of a reservoir in a typical Niger delta field in terms of lithology and fluid content, and a structural analysis of the play in the same field using seismic and well log data from the study location has been carried out. Unlike previous studies (Ekwe et al., 2012, Ibe and Oyewole, 2018, Osisanya et al., 2021) where authors either analyzed cross plots independently or interpreted stand-alone petrophysical attribute slices in the characterization of reservoirs, this study effectively combined cross plot analyses and interpretation of attribute slices in reservoir and structural play characterization. These were achieved by a combination of delineation of reservoir rocks using petrophysical well logs, characterization of the fluid within the reservoir using rock property/attribute cross plots, and assessment of the structural relations of the seal, source, and trap (play type) in the study location.

2 Geology of the study area

The onshore portion of the Niger delta province is delineated by the geology of southern Nigeria and southwestern Cameroon (Fig. 1). The Northern boundary is the Benin flank which is an east – northeast trending hinge line on the southern side of West Africa basement massif. Outcrops of the Cretaceous on the Abakaliki High define the northeastern boundary, while the Calabar flank (a hinge line

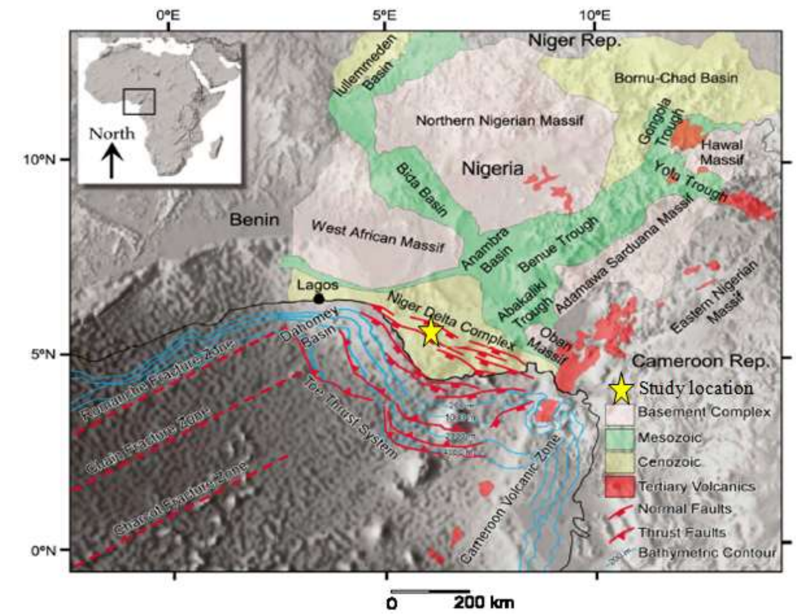

Figure 1. Location map of the Niger delta region showing the study location and the main sedimentary basins and tectonic features. (Modified from Onuoha, 1999 and Azuoko et al., 2021).

bordering the adjacent Precambrian) borders the delta in east-south-east direction.

The Cameroon volcanic line defines the offshore boundary of the province to the east; the eastern boundary of the Dahomey basin (the eastern-most West African transform – fault passive margin) marks the western boundary, while the southern and southwestern area is flanked by the two-kilometer sediment (or the 4000 meter bathymetric contour in areas where the thickness of the sediment is greater than two kilometers). The province covers 300,000 km^2 and includes the geologic extent of the Tertiary Niger delta (Akata-Agbada) petroleum system (Azuoko, et al., 2021; Michele et al., 1999).

Although petroleum occurs throughout the Agbada Formation of the Niger delta, several directional trends form an "oil-rich belt" having the largest field and lowest gas to oil ratio. The belt extends from the northwest offshore area to the southeast offshore and along a number of north-south trends in the area of Port Harcourt. (Azuoko, et al, 2017; Azuoko, 2016; Ejedawe, 1981; Evamy et al., 1978; Doust and Omatsola, 1990)

3 Methodology

Well data obtained from two wells A and B in a typical Niger delta field were used for this study. A median filter using an operator length of 25 was employed to remove the spikes observed in the original suite of logs and check shot correction to better enhance time depth conversion. Additional logs (P-impedance, S-impedance, Vp/Vs Ratio, Mu-Rho, Lambda-Rho logs) were also generated using rock physics transforms, to account for the logs that were not provided in the original suite of logs. Using a suite of logs comprising of gamma ray, shale volume, resistivity, density, and porosity logs formation evaluation was carried out. The subsurface lithology of the well was delineated using a suite of logs comprising of gamma ray and shale volume logs.

Petrophysical rock property/attribute cross plots (P-impedance, Lambda- Rho, Mu-Rho, Vp/Vs ratio, Poisson's ratio) were generated by taking into consideration, the rock physics relationship between these properties. Seismic data from the same source was correlated with the wells, with optimum correlation ensured by first

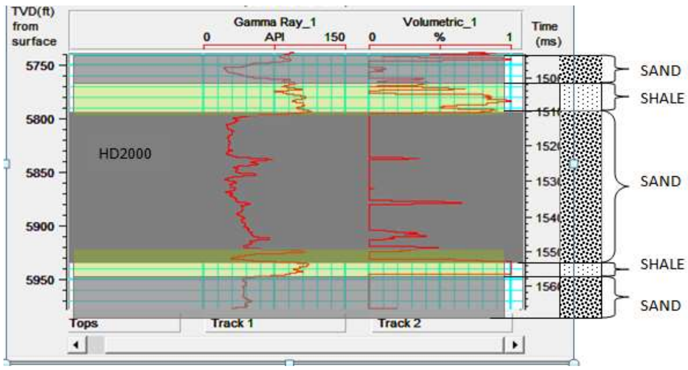

Figure 2. Illustration of lithology delineation using gamma ray and volumetric logs.

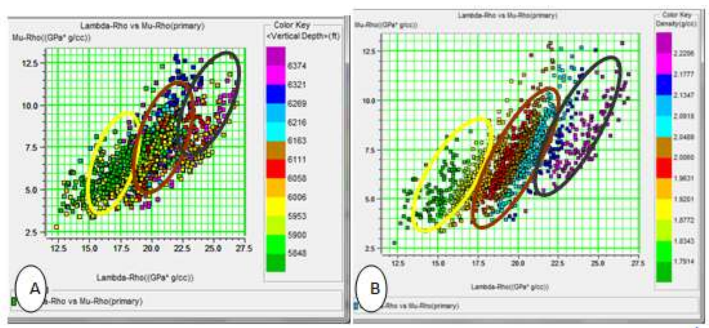

Figure 3. Cross plots of Lambda-Rho and Mu-Rho.

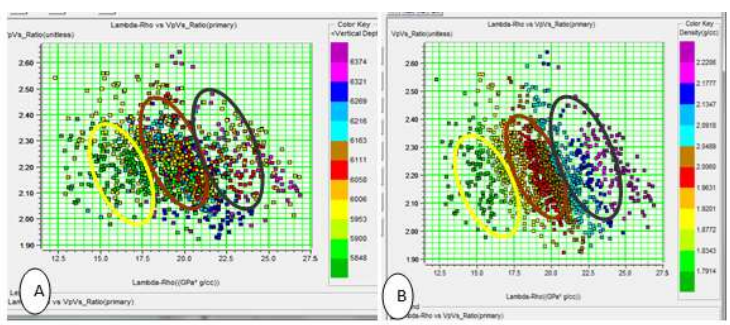

Figure 4. A cross plot of Lambda-Rho and Vp/Vs ratio.

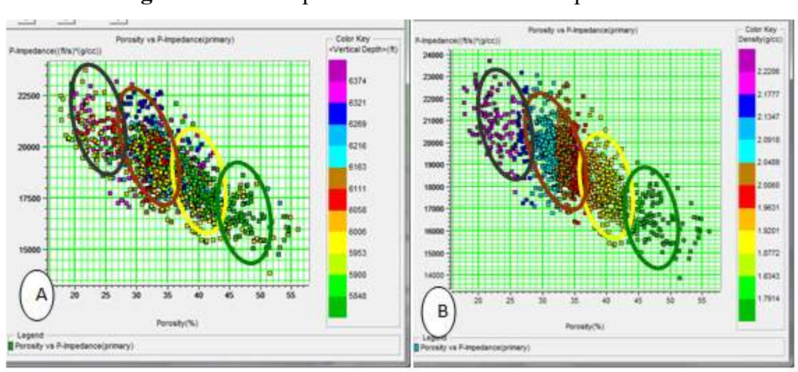

Figure 5. A Cross plot of porosity and P-Impedance.

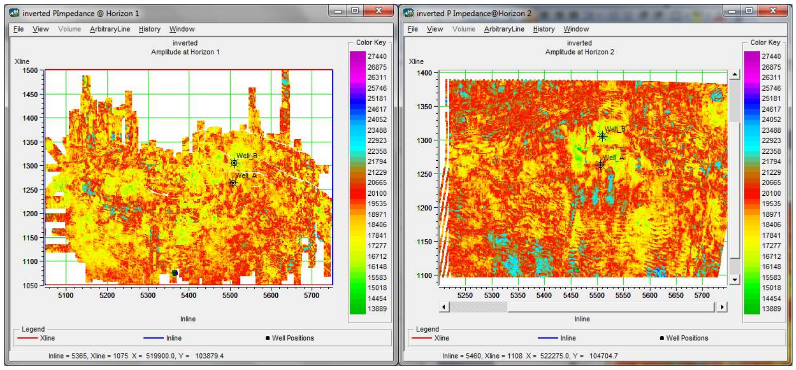

Figure 6. Inverted acoustic impedance volume at Horizon 1 and Horizon 2.

using statistical wavelets, and then wavelets extracted from the wells.

Wavelet extraction was also performed statistically for the full volume, at time range of 0-3000 ms, offset range of 4992-5771 m, X-line range of 1034-1529, and In-line range of 4992-5771. The wavelet 4parameters include wavelet length of 200 ms, tapper length of 25 ms, sample rate of 4 ms, and zero degree phase rotation at constant phase. The number of traces used for wavelet extraction is 140299. The number of dead traces encountered is 246581. The number of data points processed is 105364549.

To ensure that the delineated reservoir corresponds to the actual seismic depth, horizons (Horizons 1 and 2, corresponding to the top and base of the reservoir) were generated. A model based post-stack acoustic impedance inversion of the 3-D seismic volume was implemented, followed by individual inversions of Lambda-Rho, Mu-Rho, Porosity, and Vp/Vs ratio. These properties were next extracted as volumes to validate the observations in the cross plots. The event time structure was used for the structural analysis of the reservoir which corroborated observations in the petrophysical logs.

4 Results

Formation evaluation showed that at the depth range under consideration, low values of gamma ray, corresponding to low values of shale volume (showing minute intrusions of shale) dominate the lithology (Fig. 2) These low values of gamma ray, trending to the left of the midline on the gamma ray log (Fig. 2) are indicative of sand within the formation. A rock property/attribute cross plot of Lambda-Rho and Mu-Rho (Fig. 3) separates the reservoir content into hydrocarbon sand, brine sand, and shale, as shown respectively by the yellow, brown, and gray ellipses. Also, the cross plot between Lambda-rho and Vp/Vs ratio (Fig. 4), maps out the shale zone (gray ellipse), brine sand zone (brown ellipse), and the hydrocarbon saturated sand (yellow ellipse).

The Cross plot of porosity versus P-Impedance (Fig. 5) shows high values of P-Impedance corresponding to low values of porosity and low values of P-Impedance corresponding to high values of porosity. The gray oval is indicative of shale, corresponding to high P-Impedance and low porosity. The brown oval corresponds to a higher value of P-Impedance for brine sands than oil and gas sands. The highest value of porosity is shown by the green oval and corresponds to gas sand.

Horizon attribute slices were next generated using these properties/attributes (P-Impedance, Mu-Rho, lambda-Rho, porosity, Poisson ratio, Vp/Vs ratio, and density) to further validate the observations in the cross plots. Figures 6 to 10 show volumes of the rock properties generated at the horizons 1 and 2 which correspond to the top and base, respectively, of the HD2000 reservoir. In the acoustic impedance slices (Fig. 6), both wells are in low to moderately low acoustic impedance zones, indicated by the color key ranging from yellow to green in the volume.

The red color and slight bluish coloration corresponds to brine sand, which is seen around the well location. Lambda-Rho slices (Fig. 7) show the well B sitting on Lambda-Rho zones ranging from low to very low, which is consistent with the availability of hydrocarbon. The reddish and bluish coloration observed near the well A location corresponds to the effect of brine on Lambda-Rho value. These observations are in agreement with the behavior of Lambda-Rho in Figures 3 and 4. In the Mu-Rho slices (Fig. 9), Well A is observed sitting on a region of moderate to high values of Mu-Rho, corresponding to the reddish and bluish coloration seen around this well location.

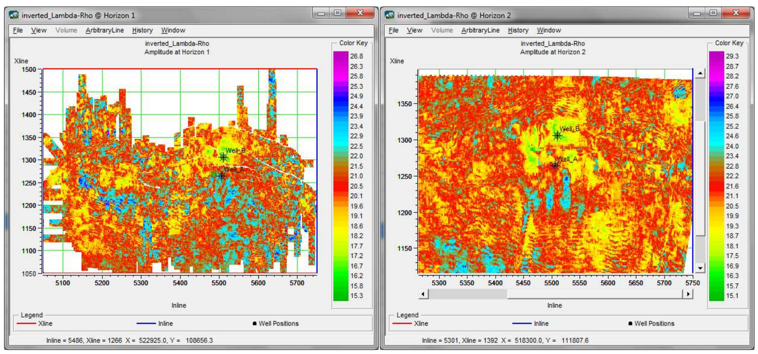

Figure 7. Lambda-Rho volumes created at Horizon 1 and Horizon 2.

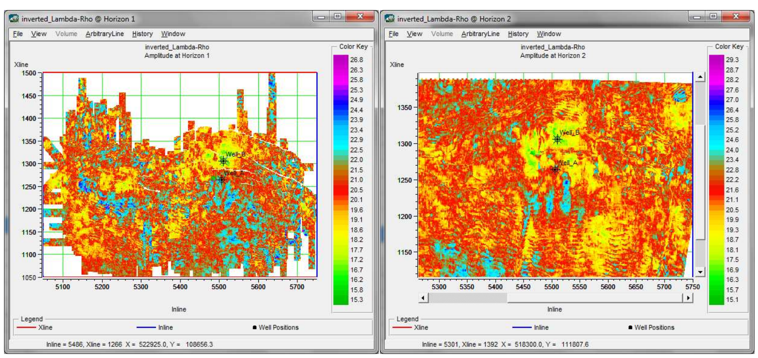

Figure 8. Mu-Rho slices taken at Horizon 1 and Horizon 2.

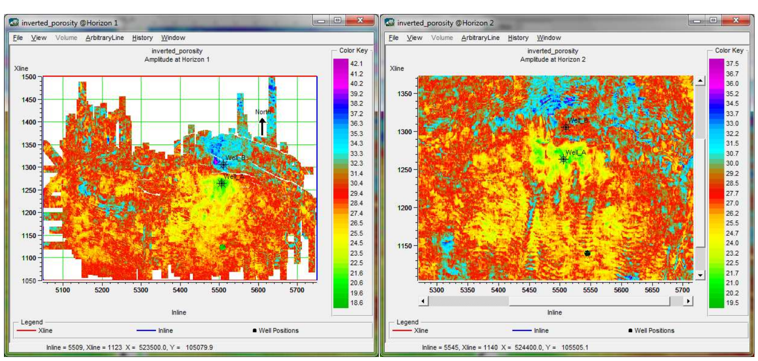

Figure 9. Porosity slices taken at Horizon 1 and Horizon 2.

This observation is consistent with the behavior of the Mu-Rho in the presence of hydrocarbon bearing sand. However, well B sits on yellow and green colorations which correspond to lower values of Mu-Rho, which is indicative of shale. This validates the observation in a cross plot of Lambda-Rho and Mu-Rho.

Well B, as shown by both Horizon 1 and Horizon 2 in the porosity slide (Fig. 9) sits on high porosity moderate to high porosity zone, indicated respectively by the bluish to purple coloration in the well location, while Well A is seen sitting on a predominantly low porosity zone. In both well A and B locations, (Fig. 10) very low Vp/Vs ratios are observed. These correspond to hydrocarbon bearing sand. The low Vp/Vs ratio patches surrounding the producing zone are indicative of brine sand, while the regions of high VpVs ratio (bluish and purple colorations) seen at various sections of both volumes indicate shaly sand. These confirm the observations in the cross plots involving Vp/Vs ratio.

The sequential arrangement of the highs and lows, on an event time structure (Fig. 11) picked at both horizons show the structural trend of the field within which the reservoir lies. The event time structure shows the lithology of the field, by taking into consideration, the deposition time. The wells are situated in the most recent time (as shown by the color key) corresponding to the crest of the rollover anticline. An anticline-trend ending in a major fault in the eastern arm of the section and other minor faults are discernable from a seismic section (Fig. 12). These structural thresholds make up traps, seals, and migration pathway(s), etc., which are the elements of a play.

5 Discussion of results

Reservoir evaluation and hydrocarbon play assessment of a Niger delta reservoir has been implemented using petrophysical well logs and seismic data. This was done using the petrophysical well logs to delineate reservoir sand saturated with hydrocarbon, and generating rock property and attribute cross plots with respect to their petrophysical relationships. The fluid content of the reservoir was characterized using rock property cross plots. These properties include Lambda Rho, Mu-Rho, Vp/Vs Ratio, and porosity. Generally, the cross plots reveal Low values of Lambda rho and Vp/Vs Ratio corresponding to hydrocarbon bearing reservoir sands as posited by Azuoko et al. (2021).

Intermediate values of these properties are indicative of brine sand, while shale-invaded sands are indicated by high values of these rock properties and attributes. The cross plot of Lambda-Rho versus Mu-Rho shows low values of Lambda Rho corresponding to low values of Mu-Rho, which are indicative of hydrocarbon bearing sand, moderate values correspond to brine sand while high values of Mu-Rho (corresponding to high values of lambda-Rho), are indicative of shale (Ekwe et al, 2012; Azuoko et al., 2021). In an ideal situation, however, Mu-Rho value is low for shale and high for sand. This could be as a result of factors like intercalations of shale in the reservoir and unconsolidated nature of sand in the reservoir resulting in reduced incompressibility (rigidity) value. Lambda-Rho versus Vp/Vs ratio delineates the fluid content of the reservoir, with low values of both rock properties corresponding to hydrocarbon and moderate values corresponding to brine. Porosity, plotted against P-Impedance, discriminates the reservoir into fluid and lithology. Low P-Impedance values corresponding to high values of porosity, and are indicative of hydrocarbon sands. This however contradicts the ideal situation, where shale porosity is higher than sand porosity, an anomaly that could be attributed to the unconsolidated nature of the reservoir sand.

When compared to corresponding horizon attribute slices generated after a model based inversion of a 3-D seismic volume in the field the output of the cross plots corresponded to the observations in the attribute slices of P-Impedance, Mu-Rho, lambda-Rho, porosity, and Vp/Vs ratio. These Horizon based slices generated for Horizon 1(top of the reservoir) and Horizon 2(bottom of the reservoir) showed areas of low Acoustic Impedance, Lambda-Rho, Mu Rho, Density, and Vp/Vs Ratios at Well B location, corresponding to hydrocarbon saturated sand. The patches of "high values" of the rock property and attributes observed in the various sections of the slices are attributable to unconsolidation and/intercalations of shale in the reservoir. Furthermore, the porosity of the delineated reservoir sand varies qualitatively between porosity values comparable to porosities of the hydrocarbon reservoirs in the Niger Delta, as detailed in Edwards and Santogrossi, (1990).

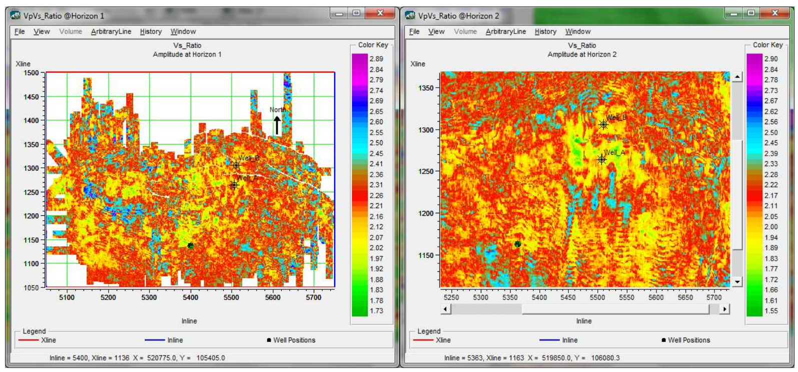

Figure 10. Vp/Vs ratio slices taken at Horizon 1 and Horizon 2.

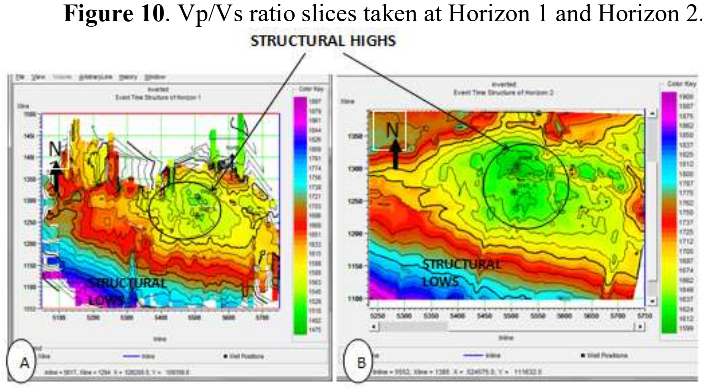

Figure 11. Event time structure picked at Horizon 1 (A) and Horizon 2 (B) showing structural lows and structural highs.

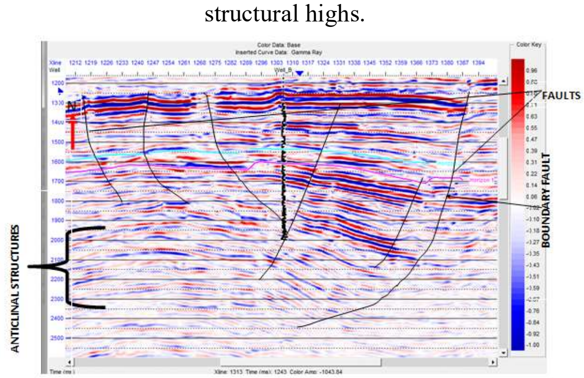

Figure 12. Seismic section showing faults and anticlinal structures.

Tying the formation evaluation performed using petrophysical logs, event time structure maps and a 3D seismic section gives the description of the predominant play type in this field as a multi fractured rollover anticline. The wells are situated on the structural-low of the event time map, which corresponds to the crest of rollover anticline. The bounding faults and an anticlinal trend seen on the seismic section and the top and bottom seals/caps delineated by reservoir evaluation (using petrophysical logs) forms the required structural trap for hydrocarbon in the reservoir. These hydrocarbons, with respect to density, have a gas, oil, and water (GOW) arrangement, in an order of increasing density.

6 Conclusion

Observations from this study corroborate the characteristics of plays in the oil-rich belt in the Niger delta basin which were put forward by Weber (1987).

Results have shown that vintage data from previous exploration ventures, lying in the database of various companies, can be reprocessed to further characterize hydrocarbon reservoirs and reveal further aspects of the structure of the play type. This will definitely drive the development of the hydrocarbon within the Niger Delta, especially the gas reserves towards which exploration ventures in the area are leaning.

Learning from the enhanced grip on qualitative fluid typing which has been demonstrated in this study using the petrophysical cross plot analysis will also go into the characterization and optimum development of other fields.

However, it is very necessary to integrate statistical models using data from the study area, if we must go beyond the structural analysis of the plays and qualitative evaluation of formations, to quantitatively reveal the recoverable reserves in place in the delineated reservoirs within the play.

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Disclosure Statement
The authors report there are no competing interests to declare.

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