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## REVIEW ARTICLE

**DELINEATION OF HYDROCARBON SATURATED RESERVOIR SAND USING INTEGRATED 3D PRE-STACK SEISMIC AND WELL LOG DATA IN BONGA – FIELD, CENTRAL SWAMP DEPOBELT, ONSHORE NIGER DELTA, NIGERIA**Innocent Kiani<sup>a</sup>, Aniefiok Sylvester Akpan<sup>b\*</sup><sup>a</sup> Department of Science Laboratory Technology, Captain Elechi Amadi Polytechnic, Rumuola, Rivers State, Nigeria<sup>b</sup> Department of Physics and Astronomy, University of Nigeria, Nsukka, Enugu State, Nigeria.\*Corresponding Author E-Mail: [aniefiok.akpan.pg79875@unn.edu.ng](mailto:aniefiok.akpan.pg79875@unn.edu.ng)

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## ARTICLE DETAILS

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## ABSTRACT

This study has successfully delineated the lateral continuity of hydrocarbon saturated sand reservoir in Bonga field, Niger Delta. 3D pre-stack seismic volume and well logs from two (2) exploratory wells were employed in the pre-stack seismic inversion analysis. The delineated BGA reservoir sand spans across the two (2) wells labelled Bonga-26 and Bonga-30. The reservoir depth ranges from 10490 ft to 10620 ft in Bonga-26 while the reservoir depth ranges from 10390 ft to 10490 ft in Bonga-30. The delineated reservoir is characterized by low gamma ray (< 75 API), water saturation, shale volume and high resistivity as deciphered in their respective well log curves signature. Rock attribute crossplot was carried out to discriminate between the formation fluid and lithology. The crossplot space of  $V_P$ - $V_S$  ratio versus acoustic impedance (AI), discriminates the formation properties into lithology and fluid (gas and brine sand) based on clusters inferring the presence of each formation fluid properties. The inversion cross sections of P-impedance, S-impedance, density ( $\rho$ ) and  $V_P$ - $V_S$  ratio depicts the spread and lateral continuity of the reservoir sand across the well locations. The delineated zones reveal low P-impedance, density,  $V_P$ - $V_S$  ratio and slight increase in S-impedance which further validate the presence of hydrocarbon in the field.

## KEYWORDS

Well log, P-impedance, Density,  $V_P$ - $V_S$  ratio and Crossplots

## 1. INTRODUCTION

The Niger Delta sedimentary Basin in Nigeria has over the years been a blessing to the Nation. The discovery and production of oil and natural gas from the region has made the Niger Delta a globally recognized hydrocarbon production Basin. In spite of the several oil/gas productions carried out in the various field discovered, reports reveal that quite an appreciable volume of hydrocarbon is inherent in the basin. The application of geophysical methods of exploration ranging from seismic, well logs, gravity and magnetic has contributed immensely in understanding the nature and formation of the basin. Seismic methods have predominately aided in the discovery of several oil fields in the basin. The principle of seismic inversion is to convert the seismic interpreter's view of the earth reflections as a function of time to the geologist's view of the earth velocity as a function of depth (Nanda, 2016).

Seismic inversion is a procedure that helps extract underlying models of the physical characteristics of rocks and fluid from seismic and well log data (Maurya and Sarkar, 2016). In other words, inversion uses the seismic data to determine the geology which caused that seismic event. With the aid of inversion we can obtain petrophysical model which fits our acquired seismic data. Seismic amplitude inversion uses reflection amplitudes, calibrated with well data to extract details that can be correlated with porosity, lithology and fluid saturation (Akpan et al., 2020; Hampson, 2015; Domagoj and Stipica, 2015). Seismic inversion provides the most detailed view of the subsurface and because of this efficiency;

inversion method is employed by oil and gas companies to increase the resolution and reliability of the data which improve estimation of rock properties such as porosity and net pay.

One key benefit of seismic inversion process pointed out is the ability to increase the frequency content of the seismic data which is band limited (Latimer et al., 2000). The result of inversion permits lithology differentiation and hopefully the estimation of the fluid content, and not only the interface geometry as given by the amplitude attribute (Veeken and Silva, 2004; Avseth et al., 2005). Hence, the current research employed seismic inversion to delineate hydrocarbon saturated sand reservoir. The study inspects P-impedance, S-impedance,  $V_P$ - $V_S$  ratio and density to delineate the probable reservoir zone. It reveals the superiority of seismic inversion method of geophysical prospecting in the interpretation of seismic data to infer geologic features of the earth's subsurface. The inverted cross sections deciphered the lateral continuity of hydrocarbon saturated bed.

## 2. LOCATION AND GEOLOGY OF THE STUDY AREA

Bonga field is one of the oil/gas fields located Onshore in Central Swamp Depobelt of the prolific Niger Delta Basin (Figure 1). According to the boundaries of Niger Delta Basin lies between latitudes 3°N and 6°N and longitudes 4°E and 8°E (Ejedawe et al., 2007). The Niger Delta Basin is one of the most prolific deltaic hydrocarbon provinces in the world with reservoir rocks reported to be dated to Middle Miocene deposited in para-

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sequence of shallow marine and deltaic plain (Reijers, 2011). The Basin has one petroleum system identified as the Akata-Agbada system of the Tertiary Niger Delta. The Deltaic is made up of three lithostratigraphic units – the oldest Akata Formation, Agbada Formation and the youngest Benin Formation. Along the stratigraphic intervals, hydrocarbon is chiefly produced from sandstone and unconsolidated sands of the Agbada Formation (Ehirim and Chikezie, 2016; Emujakporue and Ngwueke, 2013).

The Niger Delta Basin covers an area of about 75,000 square kilometres which extends from the Calabar flank and the Abakaliki Trough in Eastern Nigeria to the Benin flank in the west and opens to the Atlantic Ocean in the south. The Akata Formation is the oldest lithostratigraphic unit in the Niger Delta Basin. The shales of the Akata Formation serve as the main source rock in the basin while the turbidite sands serve as reservoirs in the deep offshore (Doust and Omatsola, 1990). The Agbada Formation is characterized by paralic interbedded sandstone and shale (Reijers, 1996). The Benin Formation comprises the top part of the Niger Delta clastic wedge from the Benin-Onitsha area in the north to beyond the coastline (Short and Stauble, 1967). Whitman estimated the thickness of the Agbada Formation to be about 280 m and upto 2100 m in region with maximum subsidence (Whitman, 1982).

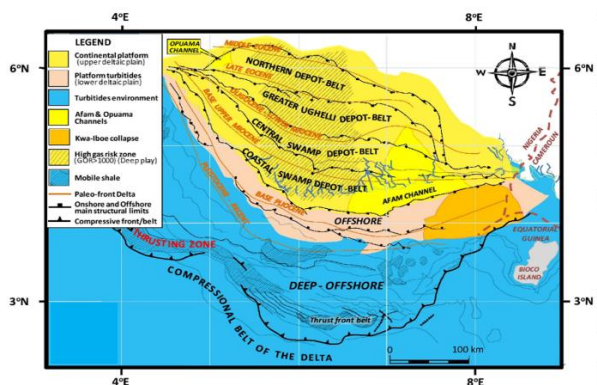


Figure 1: Niger Delta Depobelt map where the study area is situated (Ebong et al., 2019)

### 3. THEORY AND DATA PROCESSING

The acoustic impedance (AI), which determines the reflection or refraction from the interface of the various layers in the subsurface is a product of the velocity ( $v$ ) and the density ( $\rho$ ) given as (Castagna and Bachus, 1993):

$$AI = v\rho \tag{1}$$

The reflected signals to the surface are recorded as “wiggles”. The wiggles are made up of peaks and troughs which give an indication of the conditions at the boundaries of reflection. Statoi processing report, opined that a peak is an indication of transition from a lower AI to a higher AI while a trough indicates a transition from a higher AI to a lower AI which is the SEG (Society of Exploration Geophysics) normal polarity (Statoi, 2007). At the boundaries, the amplitude of reflection is based on the reflection coefficient otherwise referred to as the reflectivity given as (Vekeen, 2007):

$$R = \frac{v_{k+1}\rho_{k+1} - v_k\rho_k}{v_{k+1}\rho_{k+1} + v_k\rho_k} = \frac{AI_{k+1} - AI_k}{AI_{k+1} + AI_k} \tag{2}$$

where  $v_k$  and  $v_{k+1}$  are the velocities of the first and second layers and  $\rho_k$  and  $\rho_{k+1}$  are the densities in the first and second layers respectively.

The data employed in this study were obtained from Shell Petroleum Development Company (SPDC) of Nigeria Limited. The data include 3D prestack seismic volume and suite of well logs (gamma ray, caliper, resistivity, density and P-wave) in addition to checkshot log. Although the Bonga field has five (5) exploratory wells, complete log information is available in two (2) wells which limits the number wells involved in the analysis to Bonga-26 and Bonga-30. The Bonga-26 and Bonga-30 wells have a total logged depth of 11661 ft and 12000 ft respectively. The well log data were checkshot corrected to align the arrival time in milliseconds ( $ms$ ) on the seismic section with the well data logged depth in feet ( $ft$ ).

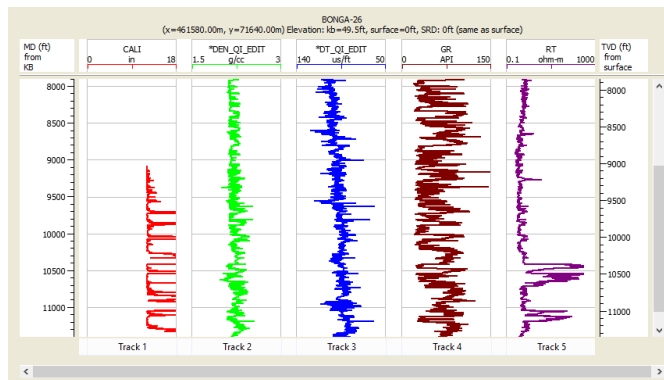


Figure 2: Bonga – 26 well log showing caliper, density, gamma ray and resistivity log signatures

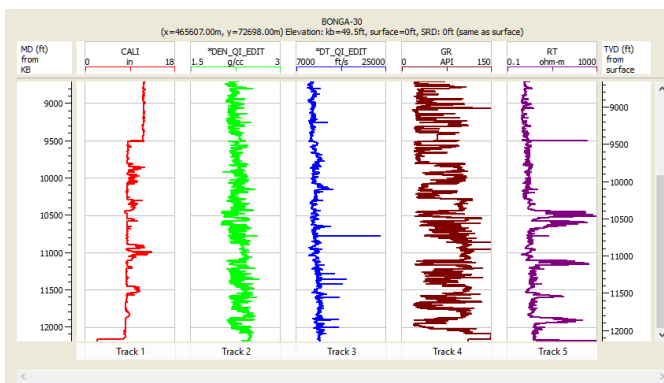


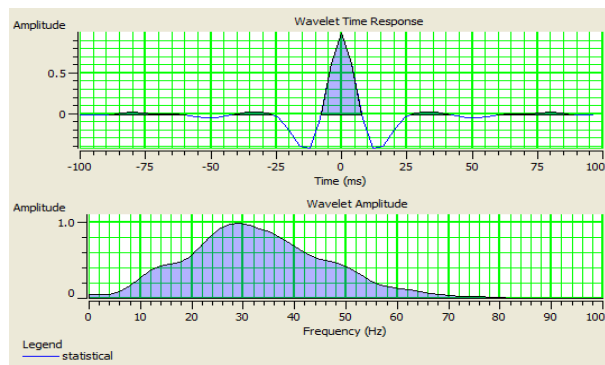
Figure 3: Bonga – 30 well log showing caliper, density, gamma ray and resistivity log signatures

Median filtering was carried out on the well log signatures to correct for borehole irregularities such as washout, cave in which could introduce anomalous spikes in the data. After series of iterations, an operator length of seven (7) was observed to be suitable to preserve the signal. Shear wave velocity ( $V_s$ ) was estimated for Bonga-26 and Bonga-30 wells using relation given in equation 3 as (Greenberg and Castagna, 1992):

$$V_p = 1.16V_s + 1.36 \tag{3}$$

where  $V_p$  is the compressional wave velocity derived from sonic log data.

Statistical wavelet was extracted (Figure 4a) from the seismic volume and tie to wells. This was done to properly calibrate the time event on both seismic and well logs. BN horizon which corresponds to the delineated reservoir in the well log was picked across the seismic section. The horizon run across the section within a time window of 2000 ms to 2400 ms as shown in Figure 4c. This was followed by cross correlation where series of iterations were carried out till a good match was obtained between the seismic and well log. An excellent correlation coefficient of 85% was obtained as shown in Figure 4b which ascertains the reliability of the inverted results presented in this study. P-impedance model (Figure 4c) was established using the relation given in equation 1 and inversion were carried out for P-impedance, S-impedance, density ( $\rho$ ) and  $V_p$ - $V_s$  and compared to ascertain the zone delineated as probable hydrocarbon sand. The summarized workflow illustrating the study methodology is shown in Figure 5.



(a)

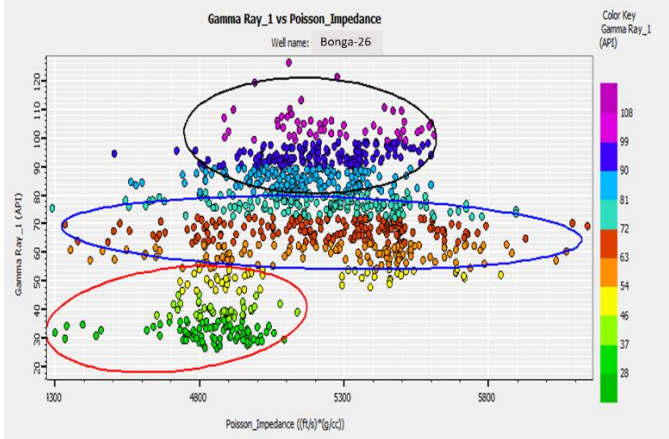
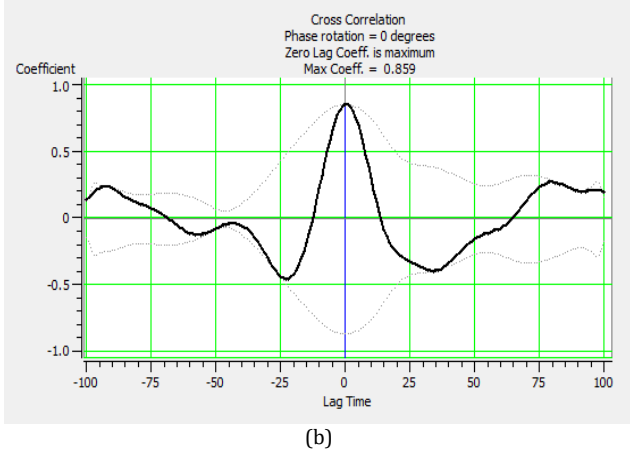


Figure 6: Crossplot of Gamma Ray versus Poisson Impedance for Bonga-26

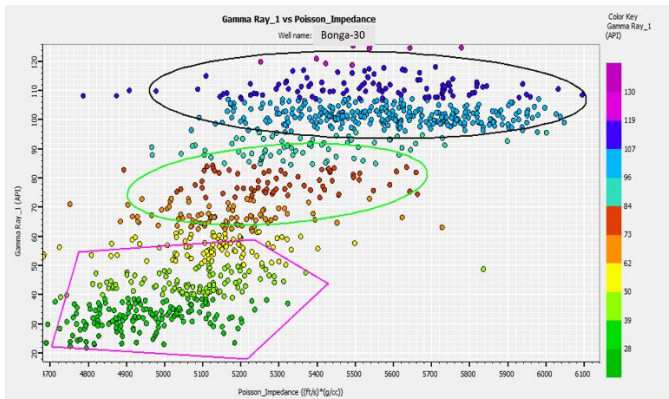


Figure 7: Crossplot of Gamma Ray versus Poisson Impedance for Bonga-30

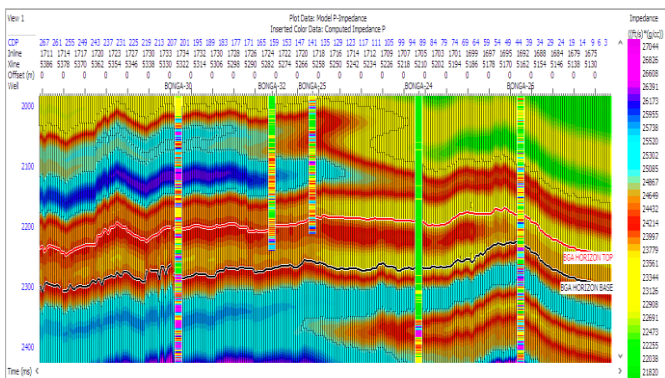


Figure 4: (a) Extracted wavelet (b) well to seismic correlation result (c) P-impedance model section within time window of 2000 ms - 2400 ms

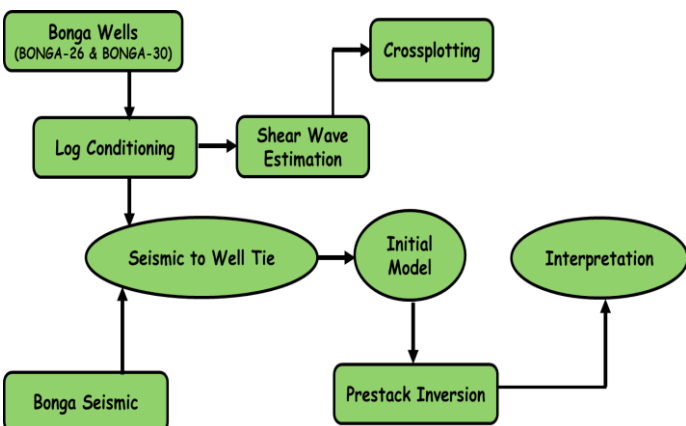


Figure 5: The overall workflow of study methodology

4. RESULTS AND DISCUSSION

The results of the seismic and well log data interpretation which include rock attribute crossplot, inverted P-impedance, S-impedance, Density and  $V_p$ - $V_s$  ratio cross sections are presented in Figures 6–11. The crossplot space of Gamma ray versus Poisson impedance is shown in Figures 6 and 7 for Bonga-26 and Bonga-30 wells respectively. The results decipher converging clusters which discriminates the probable fluid in the delineated BGA reservoir into oil/gas sand, wet sand and shale bed with Gamma Ray colour key. As stated crossplots are visual representation of the relationships between two or more variables which are employed in identifying anomalies that could be interpreted to infer the presence hydrocarbon or other fluid (Omodu and Ebeniro, 2007). Within the crossplot space of Figure 6, oil/gas sand corresponds to clusters in green and yellow circled in red polygon for Bonga-26 crossplot established to discriminate the formation fluid and lithology. The presence of wet sands which could be saturated with brine are deciphered in converging clusters of orange to cyan colours circled in blue. The cap/seal rocks are the clusters in blue to purple circled in black polygon. In Bonga-30 well crossplot space (Figure 7), the converging clusters corresponding to oil/gas sand, wet sand and shale beds are grouped using a trapezium shape in purple colour, orange to cyan circled in blue and blue to purple circled in black polygon.

The inverted P-impedance cross section of the target window of 400 ms which ranges from 2000 – 2400 ms is shown in Figure 8. The target window incorporates the BGA reservoir top and base in red and black colour respectively. The Horizon spans across the inverted seismic sections. The reservoir base (red colour) cuts across Bong-24, Bonga-26 and Bonga-30 wells while the reservoir top in black colour spans across all the wells in the field as deciphered in the section of Figure 8. P-impedance is the product of compressional wave velocity and density. The result depicts low impedance in green to yellow which is attributed to hydrocarbon saturated sand. The impedance values of these zone which lies beneath the shale bed in purple colour code ranges from  $2.1 \times 10^4 (ft/s)(g/cc)$  to  $2.3 \times 10^4 (ft/s)(g/cc)$ .

The shale bed which acts as a seal to the hydrocarbon sand is deciphered in purple colour. The shale bed P-impedance value ranges from  $2.6 \times 10^4 (ft/s)(g/cc)$  to  $2.7 \times 10^4 (ft/s)(g/cc)$ . This zone is also deciphered in the S-impedance section shown in Figure 9. For the S-impedance inverted section (Figure 9), the shale beds value ranges from  $1.4 \times 10^4 (ft/s)(g/cc)$  to  $1.5 \times 10^4 (ft/s)(g/cc)$  while the zone corresponding to hydrocarbon sand with low S-impedance values ranges from  $1.1 \times 10^4 (ft/s)(g/cc)$  to  $1.2 \times 10^4 (ft/s)(g/cc)$ . The variation in the impedance values between P-impedance and S-impedance is due to the different properties in which the parameters measures. As stated by low P-impedance values denote a sand lithologic unit with hydrocarbon saturation (Oyeyemi et al., 2017).

The density which gives a measure of the reservoir bulk density is shown in Figure 10. The inverted section depicts zones with low density which corresponds to the area inferred to be hydrocarbon sands in the P- and S-impedance inverted cross sections. The density values within this zone ranges from  $1.21 g/cc$  to  $1.53 g/cc$  for the hydrocarbon delineated bed while the shale bed density values in purple colour ranges from  $2.21 g/cc$  to  $2.31 g/cc$ . The  $V_p$ - $V_s$  ratio which serves as a fluid indicator was estimated to validate the inference made from the P-impedance, S-impedance and density is shown in Figure 11. The inverted section is characterized by low  $V_p$ - $V_s$  ratio within the delineated reservoir zone marked by the BGA reservoir top and base. A well pronounced reservoir region is deciphered in the section with  $V_p$ - $V_s$  ratio values ranging from low in green to yellow and high values in purple colour. The hydrocarbon sand reservoir channel

V<sub>P</sub>-V<sub>S</sub> ratio values in green to yellow colour range from  $1.5 \times 10^4 (ft/s)(g/cc)$  to  $1.6 \times 10^4 (ft/s)(g/cc)$  while the shale bed is deciphered in purple colour with values ranging from  $1.92 \times 10^3 (ft/s)(g/cc)$  to  $1.98 \times 10^3 (ft/s)(g/cc)$ .

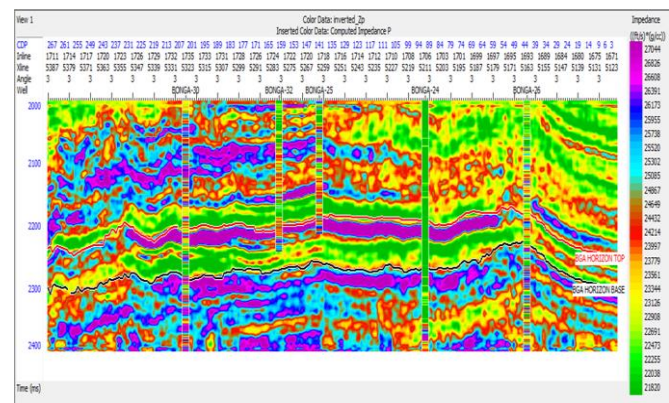


Figure 8: P – impedance inverted section showing the delineated hydrocarbon sand and wells in Bonga field

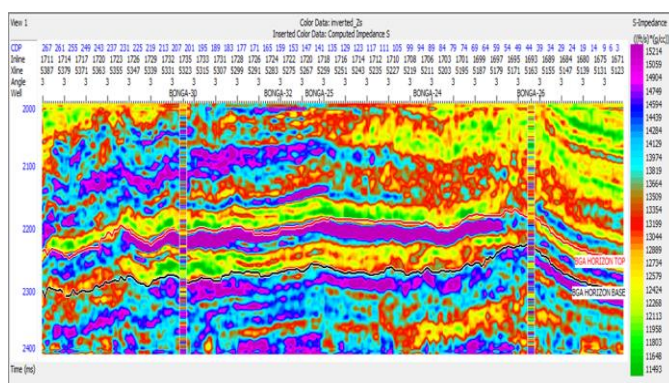


Figure 9: S – impedance inverted section showing the delineated hydrocarbon sand and wells in Bonga field

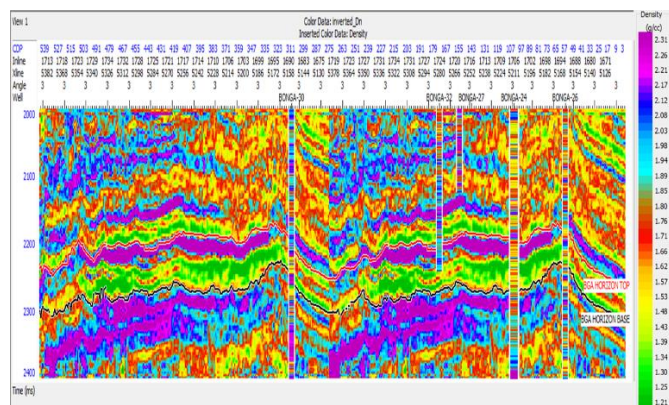


Figure 10: Inverted density section showing the delineated hydrocarbon sand and wells in Bonga field

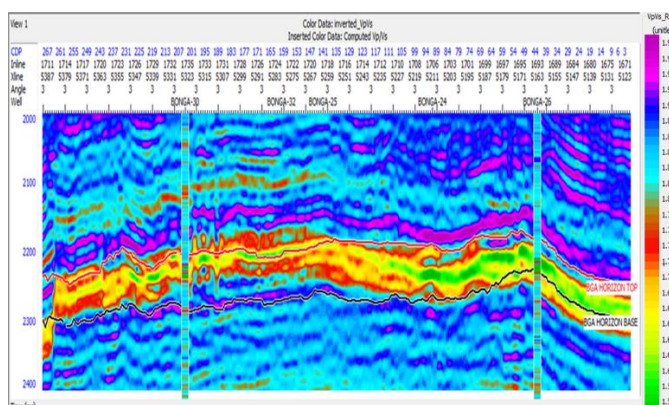


Figure 11: Inverted V<sub>P</sub>-V<sub>S</sub> ratio section showing the delineated hydrocarbon sand and wells in Bonga field

5. CONCLUSION

The lateral continuity of delineated hydrocarbon sand has successfully deciphered in Bonga field. The study accessed P-impedance, S-impedance, density and Vp-Vs ratio in delineating potential prospect saturated with hydrocarbon. The crossplot of gamma ray plotted against derived rock attributes of Poisson’s impedance discriminates the formation fluid into oil/gas, wet sands and shale bed which acts as a seal to the fluid saturated rock. In general, the lateral continuity of the of the suspected hydrocarbon sand are present in all the attributes considered in this study.

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