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ROCK PROPERTIES FOR LITHO-FLUID DISCRIMINATION IN LOWER AGBADA RESERVOIR SAND NIGER DELTA, NIGERIA

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Abstract

The exploration and exploitation of hydrocarbons are usually associated with many risks, particularly the potential drilling location in order to mitigate these risks, it is important to describe a reservoir in terms of its lithology and pore fluid content. A quantitative rock physics analysis has been carried out to remove the uncertainties that usually accompany the conventional approaches in determining lithology and discriminating pore fluids using well logs. Density, compressional wave velocity and shear wave velocity were used as inputs and applied in an integrated approach to identify and delineate hydrocarbon charged reservoirs in" Tolujobi" field, offshore, Niger Delta. Shear wave velocities were derived empirically using the Castagna's mud rock line relationship. Cross plotting of the rock properties were used to discriminate lithology and pore fluids which responded in different ways by showing visible separation and identifiable cluster trends from the background trends. The crossplot also discriminated the fluids into gas and brine. This study has been able to discriminate hydrocarbon reservoirs using well logs in the field of study from which gas sands, brine sands and shales were successfully characterized.

Keywords:
Hydrocarbon, Reservoir, Well logs, Crossplotting, Lithology.

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1.0 Introduction

This study is part of an effort to complement conventional approaches for fluid discrimination and lithology identification as a means of ultimately reducing exploration risks. There are many risks associated with the exploitation of hydrocarbons, particularly the identification of potential drilling location. To reduce these risks, it is important to describe a reservoir in terms of its lithology and pore fluid content [1]. This work is aimed at using rock physics analysis of well log data to discriminate the lithology and fluid properties. Rock physics knowledge is required to analyse the elastic properties (P- and S-wave velocities, density, impedance and ratio of P- and S-wave velocities) which acts as a bridge that links the elastic properties to the reservoir properties such as water saturation, porosity and shale volume [2]. [3] constructed a rock-physics model using the effective medium model and fluid substitution theory to analyze the offshore seismic AVO characteristics in the Makran accretionary prism, Pakistan. The reservoir parameters such as lithofacies, porosity, pore fluid type, saturation and pore pressure can be very well understood with the help of rock physics. All of those parameters are directly or indirectly sensible to seismic velocity of the subsurface formation. Thus, rock physics can be applied to predict reservoir parameters, such as lithologies and pore fluids derived from seismic attributes, especially in undrilled areas and thereby reducing risks of exploration. Statistical techniques or Cross plotting enable evaluation of lithology and pore fluid variations on both regional and detailed reservoir scales [4,5]. [6] as well as [7] demonstrated that many different lithologies like coal, shale, sandstone, gas saturated sands and carbonates can be identified from cross-plots of well logs. It has been shown through solution of the Knott energy equations (or Zoeppritz equations) that the energy reflected from an elastic boundary varies with the angle of incidence of the incident wave [8]. The behavior was studied further by [9], who established that the change in reflection coefficient with the incident angle is dependent on the Poisson's ratio difference across an elastic boundary. Poisson's ratio is related to the P-wave and S-wave velocities of the elastic medium. [9] also proposed analyzing the shape of the reflection coefficient versus angle of incidence curve as a method of interpreting lithology. Using Lamé impedance terms $\lambda\rho$ and $\mu\rho$, however, provides an alternative interpretation template that does not use only ratios and can improve insight into rock properties [10].

1.1 Location and Geology of the Study Area

The study area is located in the offshore block, south-eastern part of the Niger Delta, Nigeria (Figure 1). The Niger Delta is a prolific hydrocarbon province with a regressive succession of clastic sediments which reaches a maximum thickness of 10-12 km. The area is characterised by an upward regressive sequence of tertiary sediments that progressed over passive continental sediments. Three major sedimentary cycles have occurred in the Niger Delta structural basin since the early Cretaceous era. The subsurface stratigraphic units associated with the cycles are, the Benin, the Agbada and the Akata Formations [11], [12]. The Benin Formation is about 1800 m thick and consists essentially of loose and unconsolidated sands. The sand constitutes about 90 % while the shale/clay makes up only about 10 % [13]. The sands in the Benin Formation are fine to coarse grains and gravel and are also poorly sorted, sub-angular to well-rounded and contains lignite streaks and wood rubble [12]. The Agbada Formation underlies the Benin Formation and it consists of intercalations of shale and sandstone lithologies. The Agbada Formation is the main reservoir rock of the basin while its shale layers as well as those of the underlying Formation serve as the source rocks [14]. The Akata Formation is significantly made up of shale with sand constituting only about 10 %. The shale is understood to be over pressured and under-compacted. It is rich in hydrocarbon and constitutes the source rock for hydrocarbon [11].

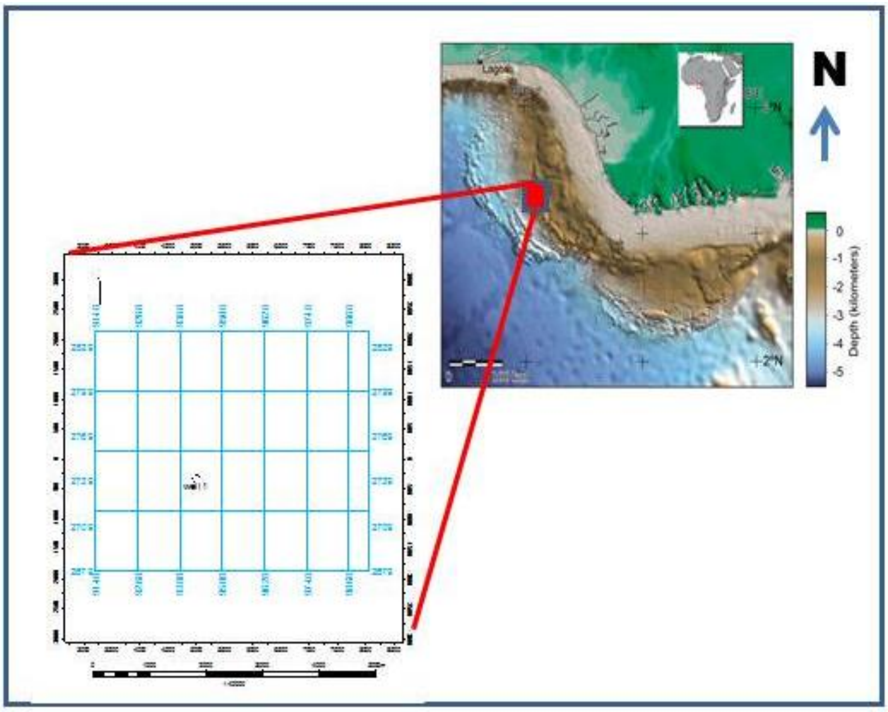

Figure 1: Location and Base Map of the Study Area

2.0 Materials and methods

The data set used for this study comprises of a suite of well logs comprising gamma ray, resistivity, sonic, density and neutron porosity logs covering the target reservoir of interest. The study was carried out using Hampson Russell's and Rockdoc integrated suite of geophysical interpretation tools for reservoir characterization. The depth of investigation ranges from 2079 to 2745m. Using rock physics algorithm, rock properties were extracted from the well data. The crossplot analysis was carried out to determine fluid and lithology response of the rocks. The goal of this rock physics analysis is to determine the feasibility of discriminating between reservoir facies and imaging architecture using seismic attributes. Several crossplots was done, but the ones with the most significant discriminating power between litho-fluid facies was used for the analysis. Cross plot analysis were carried out to determine the rock properties / attributes that better discriminate the reservoir [15]. Cross plotting appropriate pairs of attributes so that common lithologies and fluid types generally cluster together allows for straightforward interpretation.

3.0 Results and discussion

The crossplot of P-Impedance and Velocity Ratio, (figure 2) helps in discriminating between fluid and lithology. Velocity ratio indicates the fluid type since compressional velocity is sensitive to fluid changes and P-impedance shows a better discrimination which can better describe the reservoir conditions in terms of lithology and fluid content. The clusters formed falls within the range of 2079 and 2745 m which is the reservoir region. Hence, the presence of gas within the pore space of the reservoir rock makes the compressional wave velocity (V_p) to be low because the time taken for the wave to travel down to gas will be less as compared to oil or water and since the velocity ratio depends on compressional wave, the velocity ratio is expected to be low. P-impedance of a reservoir also depends on the density of the saturating fluid, as gas sand exhibit a low-density property, P-impedance which is a product of density and P-wave, it is expected that the P-impedance is low in a reservoir filled with gas. This was eventually observed in the crossplot. The crossplot of Lambda-Rho and Mu-Rho (Fig. 3) reveals clusters of rock types separated from the background trend. The gas sand becomes isolated from the background trend. This makes Lambda-Rho a fluid indicator and Mu-Rho a matrix indicator which help to provide direct geological meaningful information about the target. From the cross plot of Poisson's ratio and vertical depth (Fig. 4), the reservoir zone has the Poisson's ratio values ranges from 0 to 0.32 and within the depth of 2079 to 2745m. Poisson's ratio was relatively low within the reservoir zone, where a separate cluster was formed. This deviation from the background trend is an indicative of gas saturated region because poisson's ratio depends on compressional wave and since compressional wave decreases, poisson's ratio will also decrease. This crossplot has shown the greatest ability to discriminate the reservoir fluids and lithology within the study field. Figure 5 is the crossplot of compressional wave reflectivity (P-reflectivity) and vertical depth. This was used to observe the reflections at the top and base of the reservoir. The depth ranges from 1200 and 3000 m, while the P-reflectivity ranges from -0.07 to 0.07. There is a good linear trend between -0.064 and 0.052 reflectivity values at reservoir zones (1542-2018 ms). The cross-plot have shown, a strong negative and positive P-reflectivity values at the reservoir zone which means the amplitude has opposite sign and this is an indicative of a typical Class IV gas sand. Crossplot of P-Wave versus Velocity Ratio (Fig. 6) with gamma ray as the colour key. Clusters formed in the deviation from the background trend falls within the range of 94 to 134 us/ft for the compressional wave velocity with velocity ratio less than 2 and gamma ray reading ranging from 5 to 63 API, these range of values implies that the compressional wave velocity, velocity ratio and gamma ray are low within the reservoir zones. The result revealed that the reservoir is predominantly gas saturated. Hence, the response observed in the deviated region makes gamma ray a lithology discriminator and both P-wave and Velocity Ratio as fluid indicators.

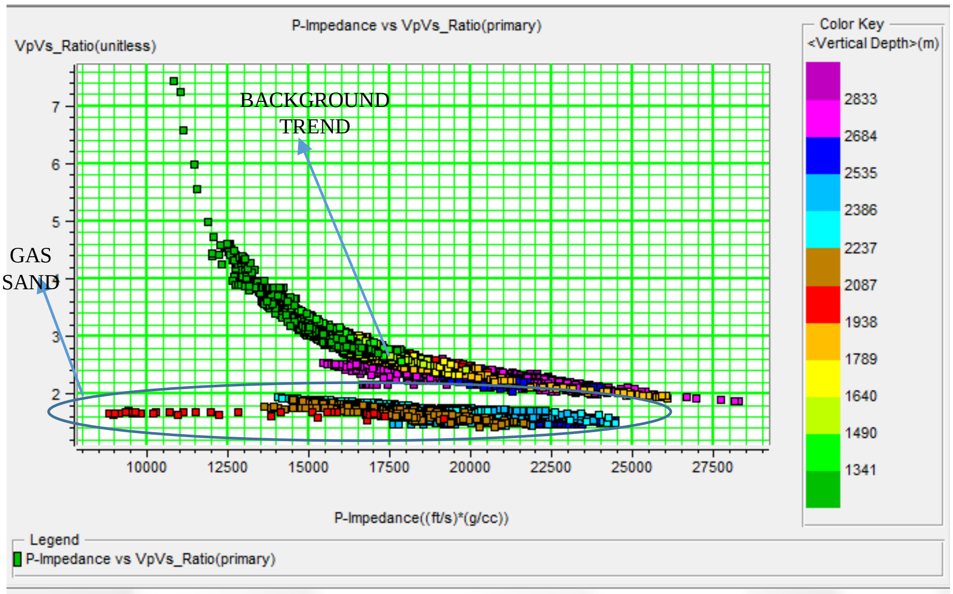

Figure 2: P-Impedance versus Velocity Ratio

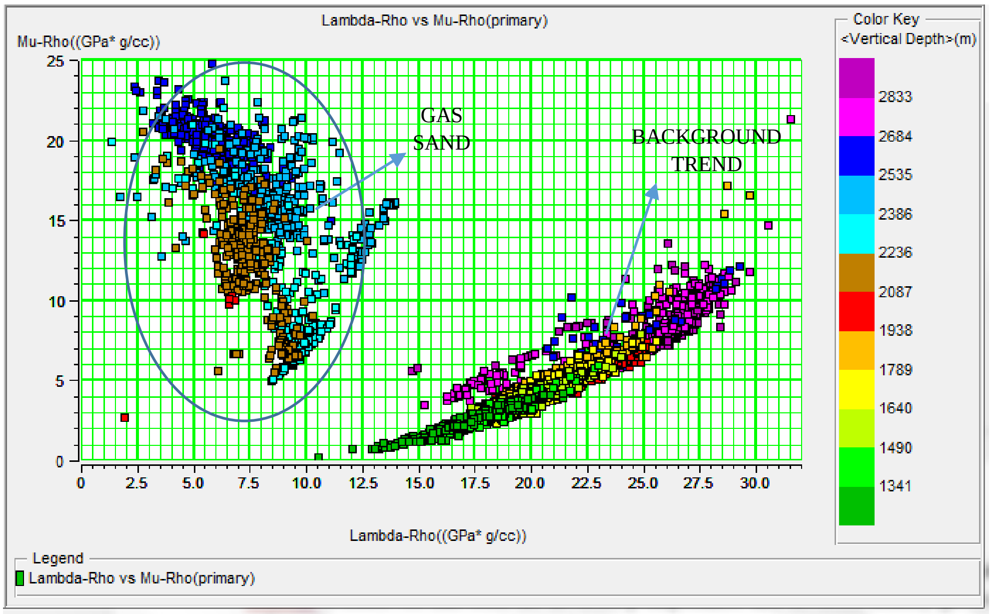

Figure 3: Lambda-Rho versus Mu-Rho

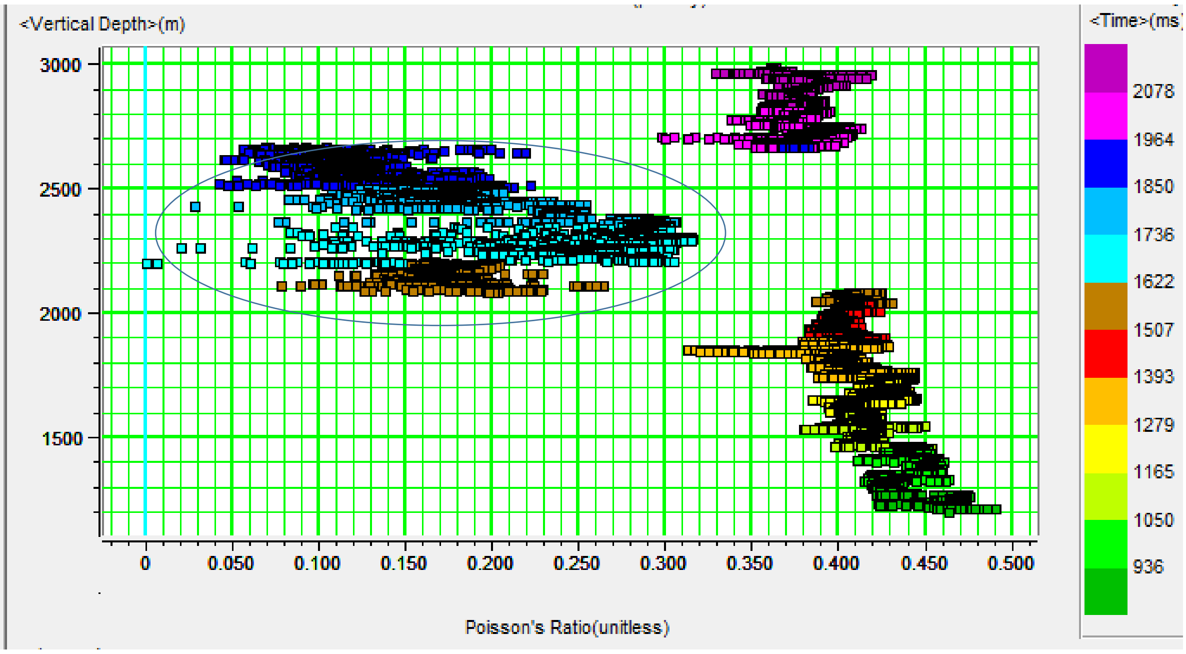

Figure 4: Poisson's Ratio versus Vertical Depth

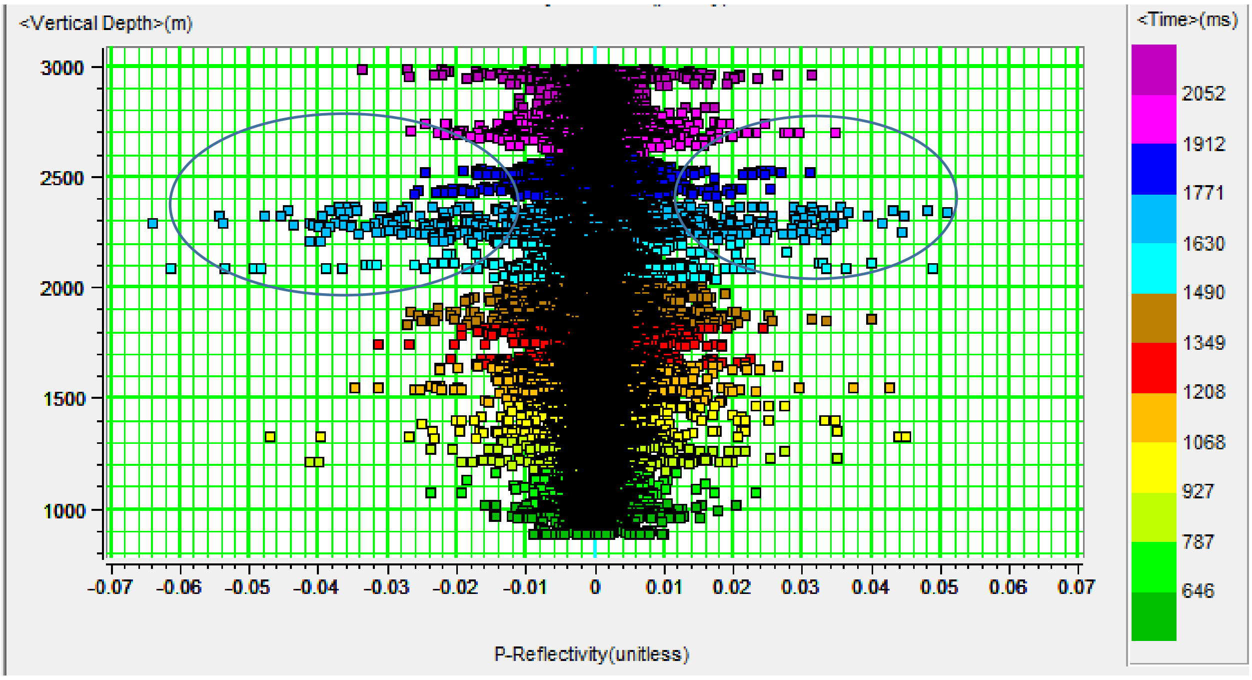

Figure 5: P-reflectivity versus Vertical Depth

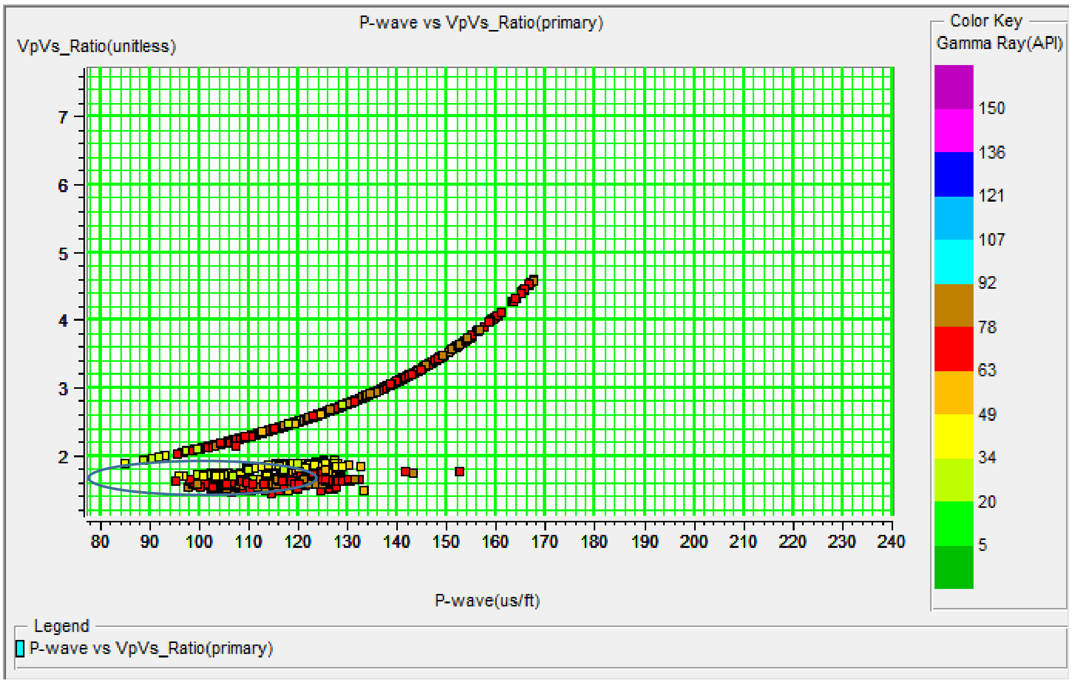

Figure 6: P-wave versus Velocity Ratio

Crossplot of Lambda-Rho versus Velocity Ratio (Fig. 7) presents low Lambda-Rho between 0 to 14 Gpa*g/cc and low Velocity Ratio less than 2 within the depth range of 1938 to 2535m which falls within the depth at which the reservoir occurs. The cluster formed within this reservoir region are better aligned towards the Lambda-Rho axis, this makes it a better lithology discriminator. The low response of Velocity Ratio within the zone of interest is an indicative of gas saturation. From the cross plot of P-wave versus S-wave (Fig. 8) it could be observed that clusters were formed around the P-wave value of 95 and 135 us/ft reflecting a low Vp value, where as it falls below 250 us/ft in the S-wave axis. Generally, gas saturation does not caused substantial decrease in shear wave velocity. This is because shear waves do not propagate through fluids but through the silicate framework of the reservoir rocks. The clusters formed in the deviation from the background trend falls within the reservoir zone which are better align towards the P-wave axis.

The crossplot of Poisson's Ratio and P-wave (Fig. 9) shows the deviation from the background trend of low compressional wave and low velocity ratio within the reservoir zone (2079 and 2745 m). Generally, P-wave reduces substantially in a gas filled reservoir and since Poisson's ratio depends on compressional wave velocity, the Poisson's ratio response is expected to be low. Hence, the result reveals the reservoir to be saturated with gas. Figure 10 is the cross plot of Mu-Rho against density with density as the colour key. Both Mu-rho and density are lithology discriminators, with density also being a fluid discriminator. Mu-rho values are high for sand and low for shale. Conversely, the density of shale is higher than that of sand. Furthermore, brine is denser than hydrocarbon (oil and gas). Thus, the blue ellipse indicates hydrocarbon bearing sand, the yellow ellipse shows the brine saturated region, while the black section describes the shale region. The Cross plot of Gamma Ray against Density (Fig. 11) shows separation into two zones that can be inferred to be probable shale (black eclipse) and hydrocarbon sand zone (blue eclipse) which was confirmed by low gamma ray, low density, and high resistivity values. High resistivity values cluster is visibly noticed within the hydrocarbon sand zone.

Figure 12 shows Lambda-Rho (Incompressibility) against Mu-Rho with density as the colour key. The Cross plot shows separation into three zones that can be inferred to be probable shale (black eclipse), brine (yellow eclipse), and hydrocarbon sand zone (blue eclipse) confirmed by lowest density values. Gas in sand does not affect its rigidity but sand has high rigidity, so the result is a significant AVO response which depends on the contrast between incompressibility and rigidity as observed in the λρ-μρ volume. Figure 13 shows the plot of density against compressional wave with gamma ray as the colour scale. The Contact-cement model describes the behavior of the velocity with cement volume at high porosity, and is used to model the porosity reduction because of the increasing cementation. The crossplot shows separation into two zones that can be inferred to be probable hydrocarbon sands (blue eclipse) and shale (black eclipse). The result show low density and low compressional velocity values within the hydrocarbon sand region with corresponding low gamma ray reading which makes it a lithology discriminator. Figure 14 is the density against compressional velocity wave with resistivity as the colour scale. This crossplot shows two separations which can be inferred to be probable hydrocarbon sands (blue eclipse) and shale (black eclipse). Cementation increases within the hydrocarbon sand zone with low density, compressional velocity and confirmed by high resistivity values.

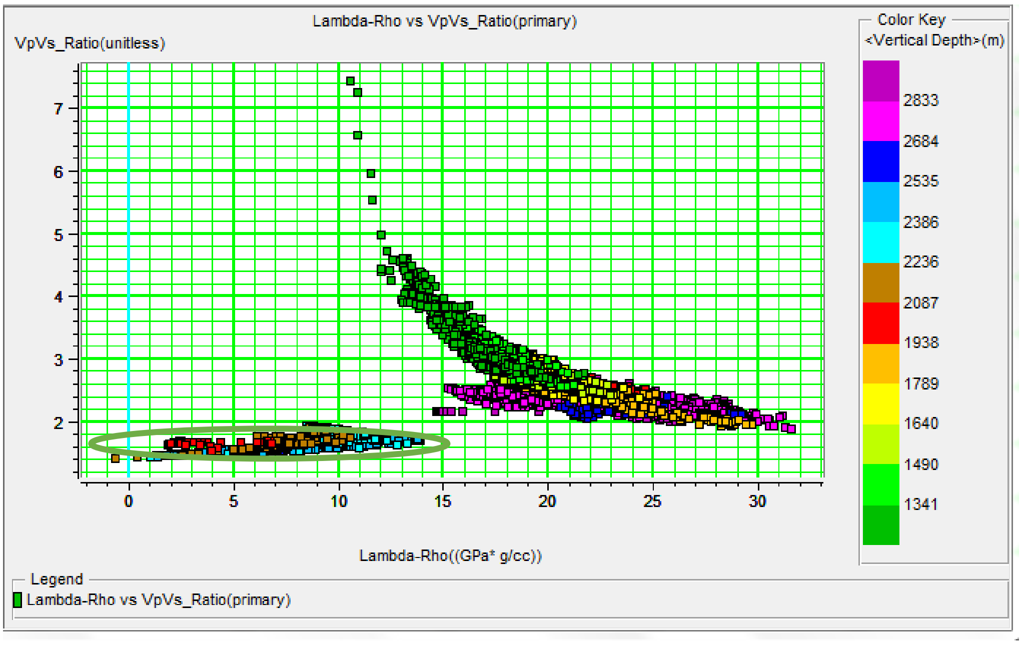

Figure 7: Lambda-Rho versus Velocity Ratio

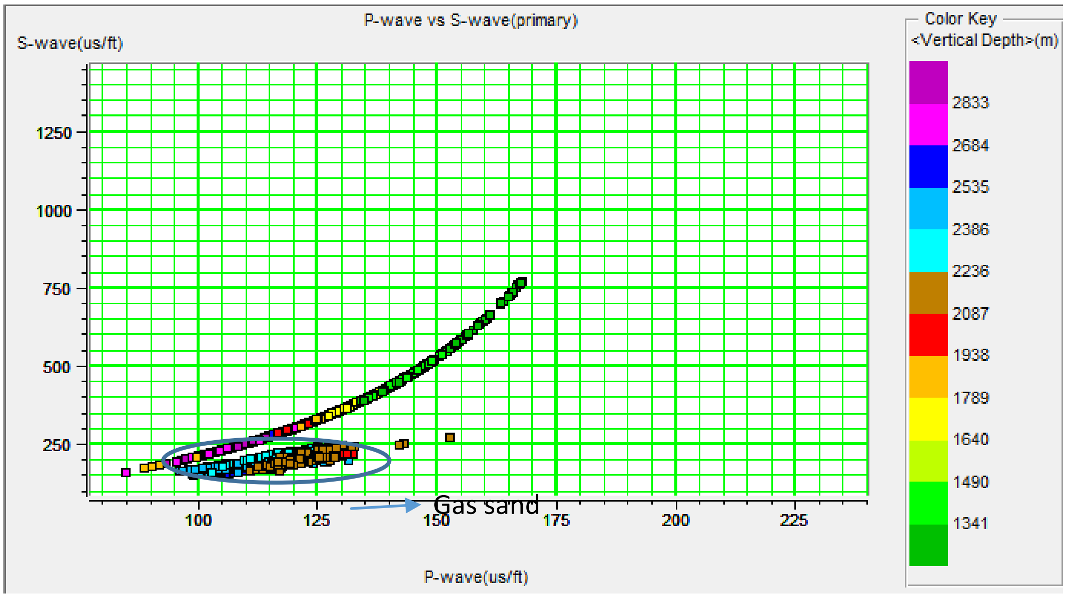

Figure 8: P-Wave versus S-Wave

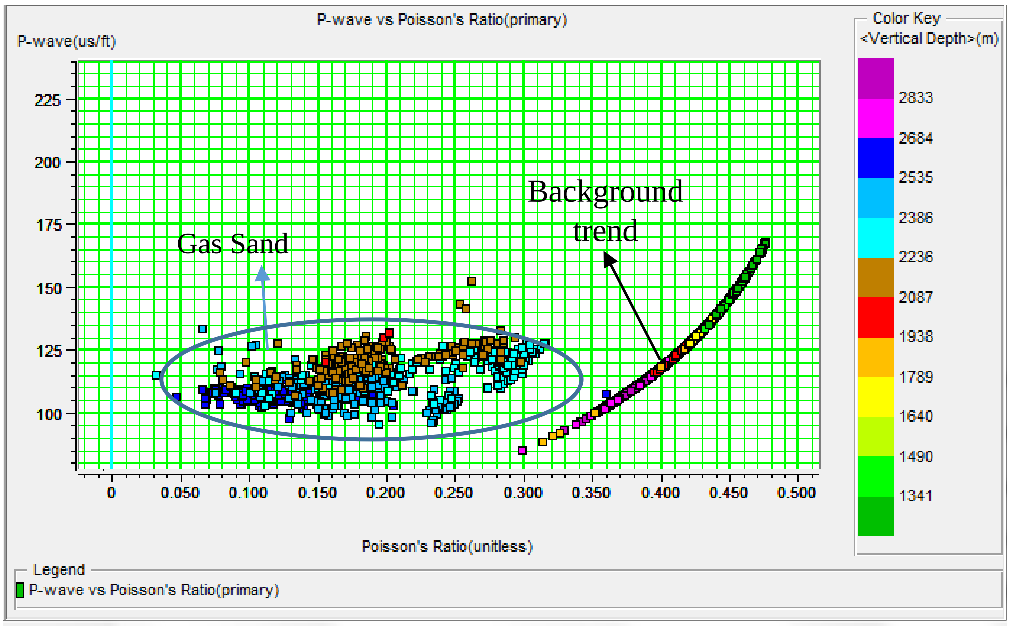

Figure 9: Poisson’s Ratio versus P-Wave

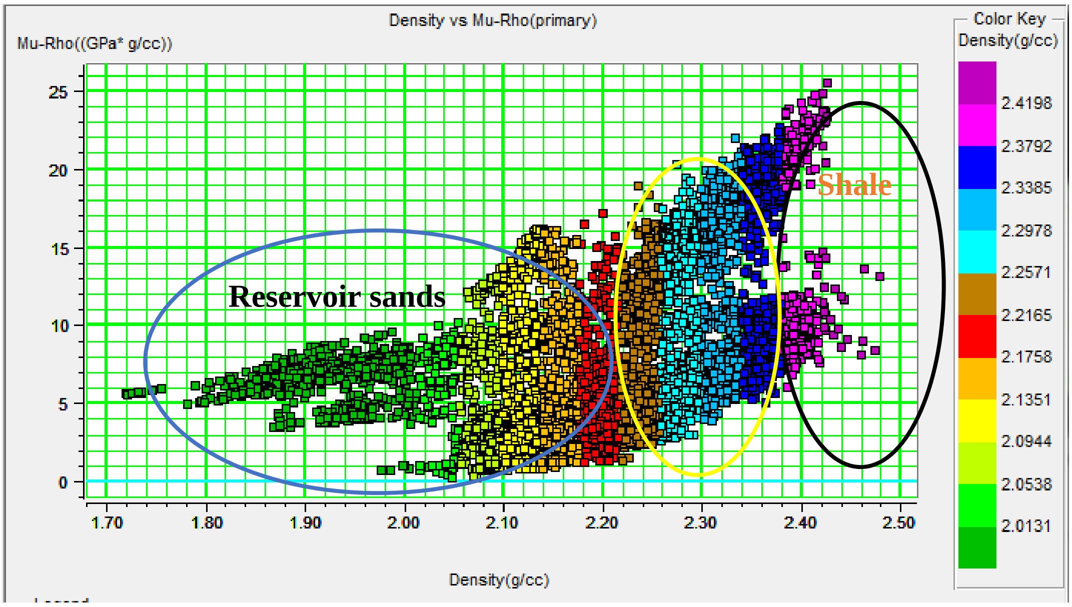

Figure 10: Mu-Rho against Density

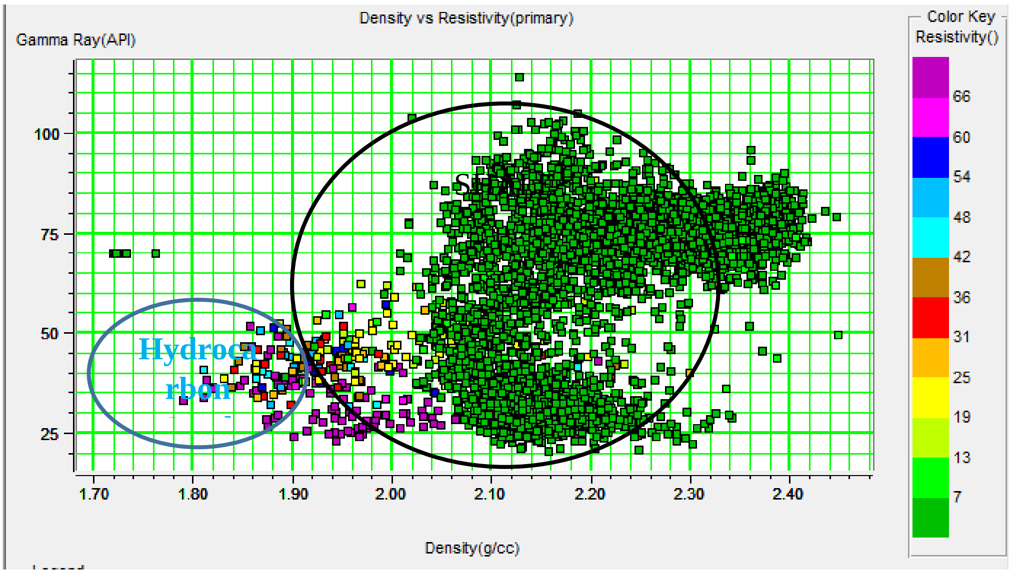

Figure 11: Gamma Ray against Density

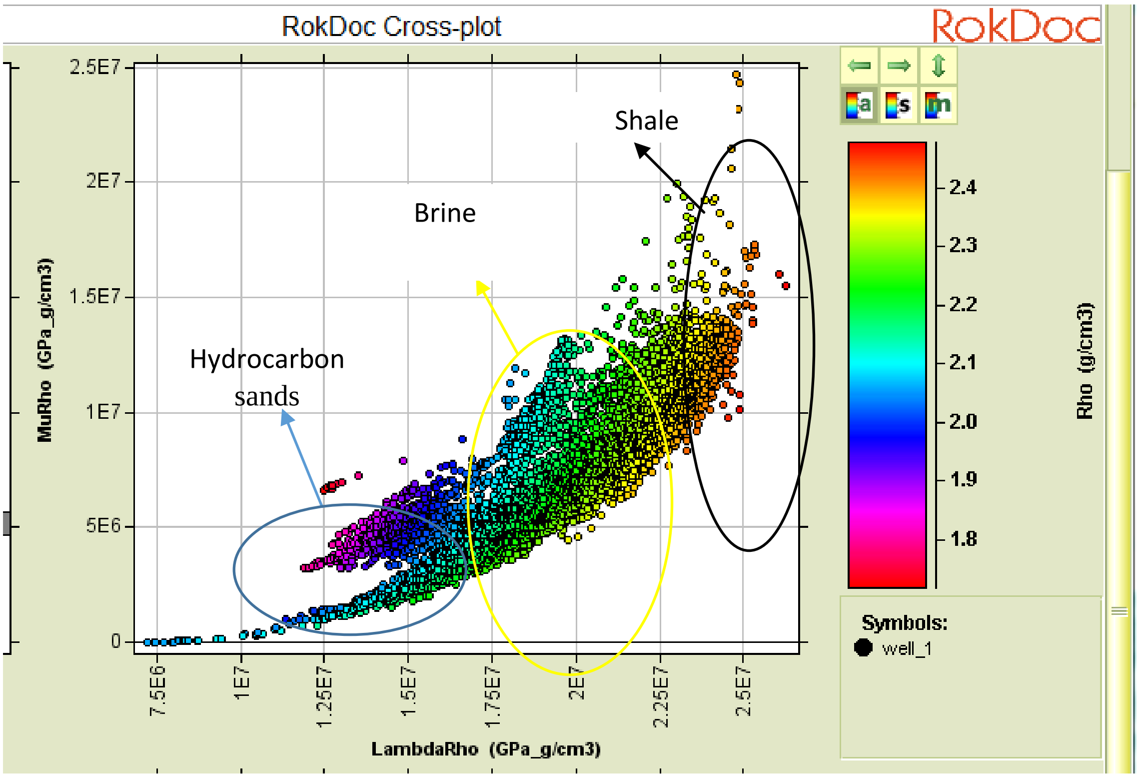

Figure 12: Mu-Rho against Lambda-Rho with Density as the Colour Scale

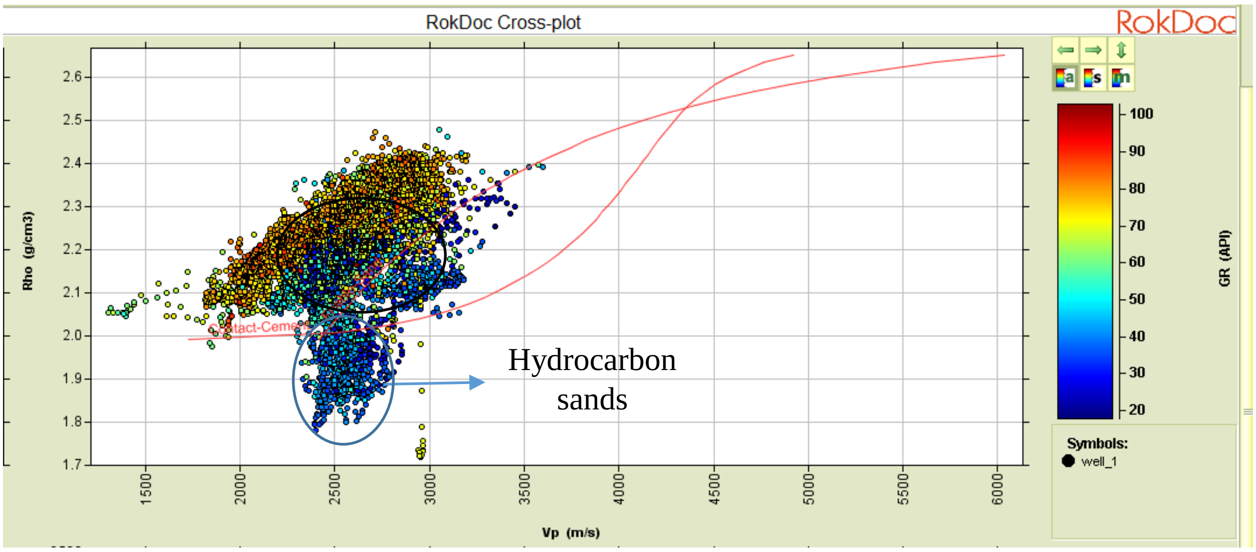

Figure 13: Density against Compressional Velocity Wave with Gamma Ray as the Colour Scale

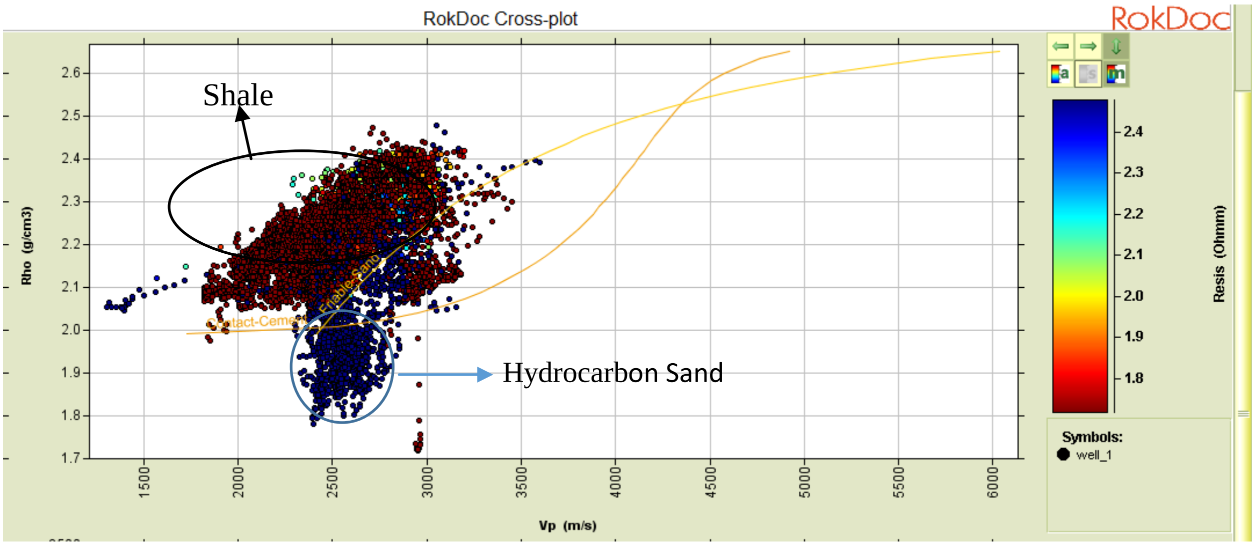

Figure 14: Density against Compressional Velocity Wave with Resistivity as the Colour Scale

4.0 Conclusion

The studied attributes have satisfactorily differentiated gas zones from their background trend surrounding geology. The study has also revealed that rock physics models are useful in diagnosing fluid and lithology. The constant cement model is the best fit applied for P-wave velocity prediction matched with log response. Also, it was discovered that the crossplots has given a more sensitivity of λρ, μρ to fluid detection with an isolation of some clusters (gas sand) from the background trend. Therefore, λ-μ-ρ technique is one of the example of how seismic interpreters are using advanced AVO analysis to accurately identify hydrocarbons and reservoir rocks. The λ-μ-ρ technique was able to identify gas sands; because of the separation in responses of both the λρ and μρ to gas sands. Also, we have greater physical insight into the Lamé's parameters in terms of their seismic responses by isolating reservoir rock properties for pore fluid and lithology. The work has successfully shown that the Lambda-mu-rho technique has shown to be a good discriminator when applied in reservoir delineation.

References

[1] Bello, R, Igwenagu, C. L., Onifade, Y. S. (2015) Cross plotting of Rock Properties for Fluid and Lithology Discrimination using Well Data in a Niger Delta Oil Field, J. Appl. Sci. Environ. Management, vol. 19 (3), pp 539-546.

[2] Avseth, P. (2000): Combining rock physics and sedimentology for seismic reservoir characterization of North Sea turbidite systems. Ph.D. Thesis, Stanford University, USA.

[3] Muhammed, I. E., Nisar, A. and Perceiz, K.: An application of rock physics modeling to quantify the seismic response of gas hydrate-bearing sediments in Makran accretionary prism, offshore, Pakistan: Geosciences Journal, 20 (3), pp 321–330..

[4] Hunze S. and Wonik T. (2007): Lithological and structural characteristics of the Lake Bosumtwi Impact Crater, Ghana: interpretation of acoustic televierwe images. Meteorit Planet Sci, 42(4–5): pp779–792

[5] Lamont M.. G., Thompson T. A. and Bevilacqua C. (2008): Drilling success as a result of probabilistic lithology and fluid prediction: a case study in the Carnarvon Basin, WA. APPEA, 48: pp 1–12.

[6] Gray F. D. and Anderson E. C. (2000): Case histories: inversion for rock properties. European Association of Geoscientists and Engineers. (EAGE). In: 62nd Conference and technical exposition.

[7] Anderson E. C. and Gray F. D. (2001): Using LMR for dual attribute lithology identification. Expanded abstracts. SEG, San Antonio

[8] Foster D. J., Robert G. K, and Lane F. D. (2010): Interpretation of AVO Anomalies. Geophysics, 75(5): pp 3–13.

[9] Koefoed O. (1995): On the effect of Poisson's ratios of rock strata on the reflection coefficients of plane waves. Geophysics Prospect, 3: pp 3–387

[10] Close, D., Taylor, R. and Nixon, S. (2016): A case study in quantitative interpretation ambiguity, lambda-mu-rho, and rock-physics modeling in the Otway Basin, Australia. The Leading edge, pp 43.

[11] Ofomola, M. O. (2011): Uphole Seismic refraction survey for low velocity layer determination over Yom field, South east Niger Delta. J Eng Appl Sci 6: pp 231–236. doi:10.3923/jeasci.2011.231.236

[12] Akpoborie, I. A., Nfor, B., Etobro, A. A. I. and Odagwe, S. (2011): Aspects of the geology and groundwater condition of Asaba Nigeria. Arch Appl Sci Res, 3 pp: 537–550.

[13] Anomohanran, O. (2014): Downhole seismic refraction survey of weathered layer characteristics in escravos, Nigeria. Am J Appl Sci, 11(3): pp 371–380.

[14] Kolawole, F., Okoro, C. and Olaleye, O. P. (2012): Downhole refraction survey in Niger Delta basin: a 3-layer model. ARPN J Earth Sci, 1: pp 67–79.

[15] Omudu, M. L., Ebeniro J. O. and Olotu S. (2007): Optimizing Quantitative Interpretation for Reservoir Characterization: Case Study Onshore Niger Delta: A paper presented at the 31st Annual SPE International Technical Conference and Exhibition in Abuja, Nigeria.