NIPES

Journal of Energy Technology and Environment

Journal homepage: www.nipesjournals.org.ng

Integration of Petrophysical and Rock Physics Analysis for the Characterization of M-Field of Niger Delta Basin

Tahiru I.T[a]*, G. E. Maju-Oyovwikowhe[b], John Osazee Japheth[a]

[a]Physics Department, University of Benin, Benin City, Edo State, Nigeria

[b]Geology Department, University of Benin, Benin City, Edo State, Nigeria

[a]Corresponding author email: Ibrahim.tahiru@uniben.edu +2347036596054

Article Info

Article history:
Received 04 May 2021
Revised 02 June 2021
Accepted 04 June 2021
Available online 10 June 2021

Keywords:
Petrophysics, Rock physics, Cross plots

https://doi.org/10.37933/nipes.e/3.2.2021.6

https://nipesjournals.org.ng
© 2021 NIPES Pub. All rights reserved

Abstract

M field is located in deep offshore Nigeria, in water depths ranging from 1110m to 1750m. Predicting lithologies and pore fluid accurately is very important in petroleum prospecting and reservoir characterization. The purpose of this work is to carry out characterization of M-field in terms of fluid content and lithology by integrating petrophysics and rock physics analyses. This involves carrying out rock physics analysis in order to understand elastic parameters relations with velocities and impedances of the M field. Cross plots were used to understand the rock behavior that better discriminate the reservoir. Cross plots of acoustic p-wave velocity (Vp) versus Acoustic impedance (AI) are useful to characterize the reservoir more confidently. While cross plot of Vp/Vs against AI is useful for discriminating between the fluids. Analysis was carried out on two reservoirs, Res1 and Res 2. It was observed that the three wells considered for this study encountered both oil sands and water sands. By integrating petrophysics and rock physics analysis the lithology and fluid scenarios can be predicted accurately.

1. Introduction

It is very important for reservoir engineers and geoscientists to have accurate information in order to intelligently judge the risks and opportunity involved in the development of a reservoir. Among the processes carried out for this development, is to identify lithologies and predict the fluid content associated with the lithological bed. This makes lithology delineation of geological beds a very important step in reservoir characterization [1]. It is also important to accurately determine the fluid encased in the pores of these lithologies and the shapes and sizes of the pores for effective petrophysical analysis that are key elements for efficient exploration and production of hydrocarbon through porosity and reserve volume estimation, clay volume, and net pay calculation as well as water saturation and permeability determination [2, 3].

Although predicting lithology and fluid content accurately is challenging, their calculations will aid in determining porosity, saturation, permeability and other reservoir characteristics accurately. The most reliable approach of determining lithology and fluid content is by observing core samples directly from the interval of interests. However, this process is very expensive and thus necessitated the need for alternative inexpensive and indirect method through well logging response known as petrophysical analysis. Interpreting well logs conventionally involves prediction of bed lithology using the response from gamma ray log to discriminate between sand and shale based on the presence of radioactive minerals in them. This method of interpretation also involves the

combination of neutron-density log as well as resistivity log to predict reservoir's pore fluid content. The problem with this approach is that it is full of uncertainties. There is a tendency of misinterpretation due to radioactive element among others. In order to minimize the uncertainties associated with this conventional method of prediction of lithology and pore fluid, it is important to integrate petrophysics and rock physics [4]. Both analyses have the ability to correctly construct a subsurface model. While petrophysics involves the transformation of resistivity, gamma ray, and porosity tool measurement into reservoir properties, rock physics is the transformation of petrophysical result into elastic parameters such as compressional and shear waves velocities as well as density. These elastic parameters are necessary for the complete understanding and visualization of seismic data and future production and reservoir engineering activities. In other words, rock physics is the link between material properties (reservoir) and the observed seismic response.
The aim of this work is to leverage integrating rock physics model with petrophysical analysis for geological lithology and fluid content prediction from well log. This study will include derivation of elastic parameters like acoustic impedance, Vp/Vs ratio and Poisson's ratio from density, p-wave velocity and s-wave velocity log in other to carry out comprehensive lithology prediction. The fluid content of these lithologies will be determined using Vp/Vs ratio against acoustic impedance cross plot. The result of this study can be used to interpret elastic inversion results which will aid seismic data interpretation and prediction of lithologies without the use of additional well log data.

1.1. Geology of the Study Area

The M-field is situated in the Niger-delta basin. The Niger Delta basin sit on top of the Gulf of Guinea, which is located on the edge of the West African continental margin as shown in Figure 1 [5]. The structural traps in the Niger Delta basin resulted from gravity tectonism followed by shale mobility deformation processes [6]. The delta prograded southwestward from Eocene to modern day. Depobelts amounting to the largest regressive deltas in the world were formed afterwards [4]. There is only one petroleum system that was identified. This is called the Tertiary (Akata-Agbada) [7,8]. The tertiary Niger Delta can be divided into three formations that represents the prograding depositional facies of sand and shale. [1,5,8,9]. The base of the delta called the Akata formation is of marine origin. It composes of thick shale sequences, turbidite sand and minor amount of clay and silt. This shale is a potential source rock while the turbidite sand is a potential deep-water reservoir. The major unit bearing petroleum resources is the Agbada formation. It began in the Eocene until the recent. This formation consists of paralic siliciclastics that represent the actual deltaic portion of the sequence. It is around 3700m thick. The clastics accumulated in delta-front, delta-topset, and fluvio-deltaic environments. In the lower Agbada Formation, shale and sandstone beds were deposited in equal proportions, however, the upper portion is mostly sand with only minor shale interbeds. The third formation called the Benin formation began from latest Eocene until Present. It Overlays the Agbada formation and it is a deposit of alluvial and upper coastal plain sands that are around 2000m thick [9].

Figure 1: Location of M-field

3. Methodology

There are 3 wells available for this study. The well comprises of log suites such as gamma ray, neutron, density, resistivity, and sonic (DTP and DTS) logs. These suites of the composite well logs were used for interpretation with the aid of PETREL on a workstation. The statistical values of the wells OLX01, OLX04 and OLX05 log parameters are given in Tables 1, 2, and 3. Figures 2, 3 and 4 shows the curves of the various well logs of OLX01, OLX04 and OLX05.

Table 1: Statistics of well log parameters in OLX01

OLX01	Gamma ray (API)	Density(g/cc)	Neutron (%)	Resistivity(ohm-m)	DTP (µft/s)	DTS (µft/s)
Counts	23482	23780	21822	23751	23405	23405
Minimum	18.88	1.5753	0.0941	0.4984	81.01	153.79
Maximum	178.57	2.5476	0.6413	357.8450	239.90	612.80
Mean	92.26	2.2502	0.3631	8.2639	132.68	304.55
Standard Deviation	26.96	0.1239	0.0901	29.2622	25.07	88.63

Table 2: Statistics of well log parameters in OLX04

OLX04	Gamma ray (API)	Density(g/cc)	Neutron (%)	Resistivity(ohm-m)	DTP (µft/s)	DTS (µft/s)
Counts	19482	15218	15233	15189	15121	15229
Minimum	16.31	1.7152	0.1015	0.4930	89.89	157.88
Maximum	176.93	2.5887	0.8953	479.6309	185.84	673.97
Mean	90.97	2.2508	0.3888	7.7688	129.26	304.05
Standard Deviation	605.73	0.0925	0.1154	30.8932	16.95	72.05

Table 3: Statistics of well log parameters in OLX05

OLX05	Gamma ray (API)	Density(g/cc)	Neutron (%)	Resistivity(ohm-m)	DTP (µft/s)	DTS (µft/s)
Counts	21578	20998	20782	21223	21008	21008
Minimum	18.47	1.9282	0.1385	0.1198	89.10	167.49
Maximum	172.12	2.4918	0.8363	618.0283	162.43	436.84
Mean	81.16	2.2484	0.4147	7.3199	128.89	291.27
Standard Deviation	25.37	0.0848	0.1123	41.6515	14.89	62.46

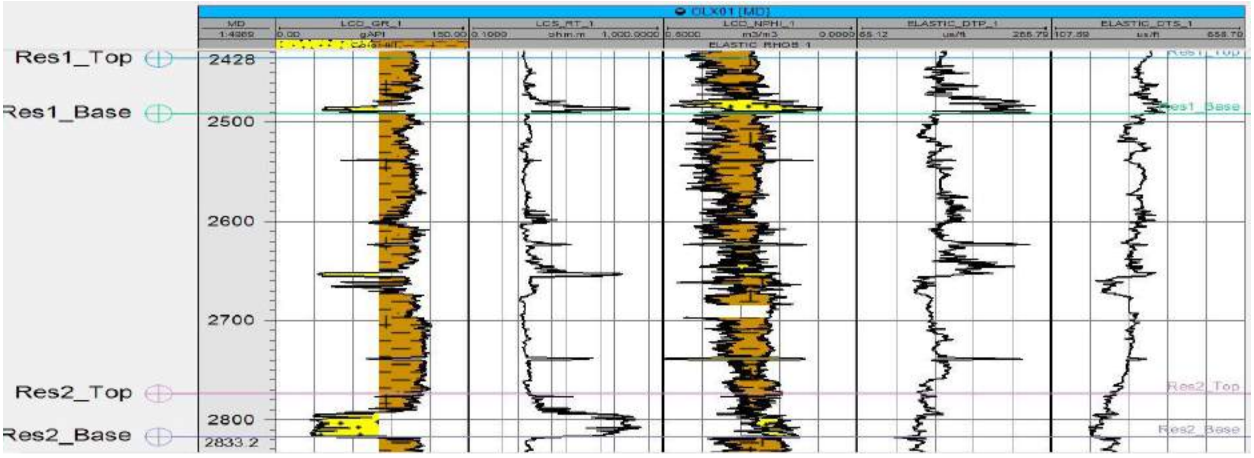

Figure 2: Available logs for well OLX01 (from left GR, resistivity, density-neutron, DTP, DTS)

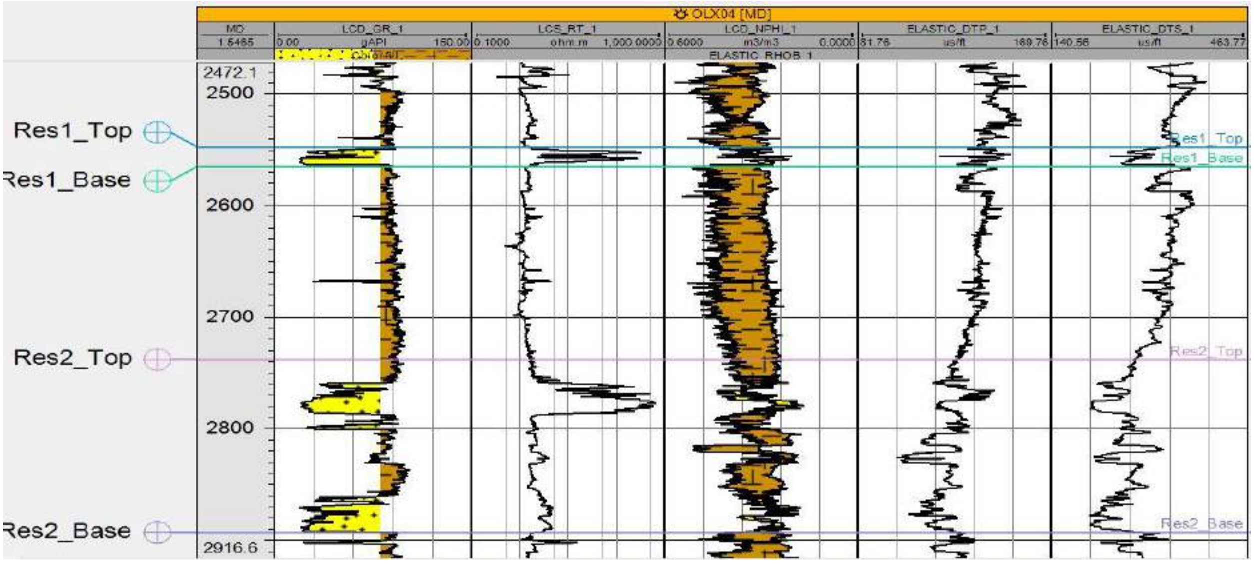

Figure 3: Available logs for well OLX01 (from left GR, resistivity, density-neutron, DTP, DTS)

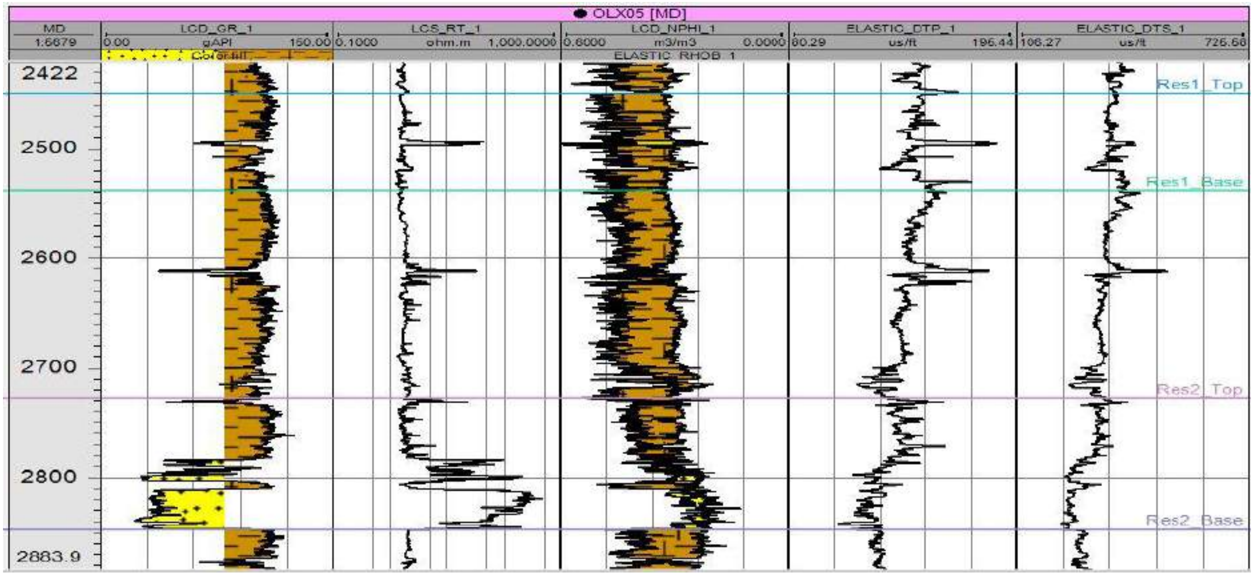

Figure 4: Available logs for well OLX01 (from left GR, resistivity, density-neutron, DTP, DTS)

P-wave velocity (Vp) and S-wave velocity (Vs) were derived using the relationship in equation 1 below [10].

$$V_p = 1000000 * \frac{0.305}{D_{tp}} -------------- (1)$$

$$V_s = 1000000 * \frac{0.305}{D_{ts}} -------------- (2)$$

Rock physics parameters were estimated from the logs using [11]. They include acoustic and shear impedances, velocity ratio, and Poisson's ratio. The relationship between these parameters is given in the following equations.

$$Acoustic\ Impedance, Ip = \rho V_p \quad (3)$$

$$Shear\ Impedance, Is = \rho V_s \quad (4)$$

$$Velocity\ Ratio, \upsilon = \frac{V_p}{V_s} \quad (5)$$

$$Poisson's\ Ratio, \phi = \frac{\lambda}{2(\lambda + \mu)} \quad (6)$$

Discrimination between fluid and lithology is done through cross plotting by combining different parameters. Cross plot of elastic parameters against reservoir properties was carried out using rock physics models that are appropriate for fluid and lithology delineation. A common way to classify seismic inversion data for prospecting hydrocarbon is through the use of Rock Physics Templates [12]. Included in the template is porosity trends for different lithologies, and increasing fluid saturation for sands. The arrows indicate different geological trends as shown in Figure 5.

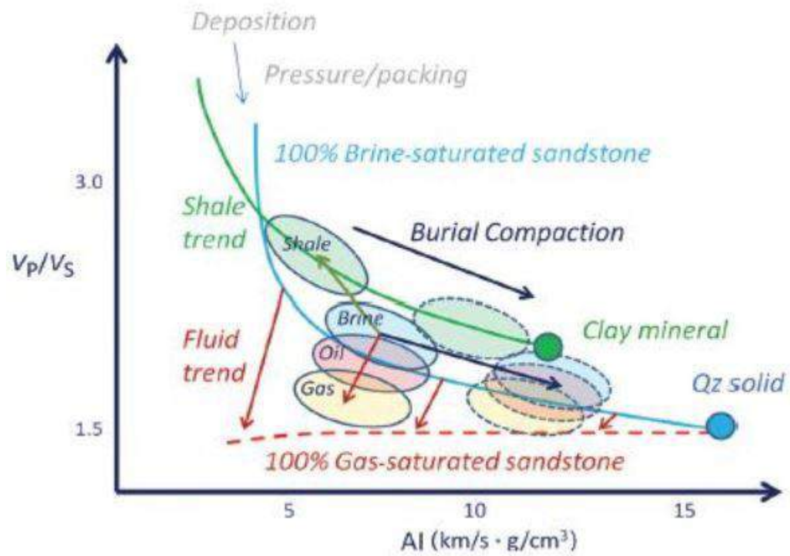

Figure 5: RPT model concept for brine, oil and gas saturated sandstones, and for shales [13]

Rock Physics Template (RPT) form that is commonly used, is the cross-plot of Vp/Vs against acoustic impedance (AI). This allows performance of rock physics analysis both on well logs and

seismic data. However, the model should honor local geological factors including lithology, mineralogy, burial depth, diagenesis, pressure and temperature [12].
Generally, shale has higher Vp/Vs than sand. Similarly, the velocity ratio for hydrocarbon sand is lower when compared to brine sand since Vp is more sensitive to changes in fluid than Vs. Velocity ratio thus was utilized to make discrimination of the formation lithology.

4. Results and Discussion

4.1 Petrophysical Analysis

Figure 6 shows the correlation of wells OLX01, OLX04 and OLX05 from West to East cutting across 2 reservoirs (Res1 and Res2). The sand bodies were differentiated from the shales using the gamma ray measurement. Based on the previous studies on the area, gamma ray log measurement below 80 API is characterized to be sand while measurement above 80 API is characterized to be shale [9]. it can be seen that those sands of Res1 and Res 2 have varying sand and shale proportion across the 3 wells. The petrophysical analysis involve the utilization of deep resistivity measurement to discriminate whether the reservoir consist of brine or hydrocarbon. The resistivity log reading is high in Res1 of OLX01, OLX02 and OLX03 as well as Res2 of OLX01, the upper part of OLX04 and OLX05 indicating the presence of hydrocarbon. For the lower part of Res2 of well OLX04, the resistivity reading is low depicting that the well encountered water. It can also be seen that there is a thick column of shale above and below the sand body which would enhance the sealing capability for the hydrocarbon within the compartment encountered by the three wells.

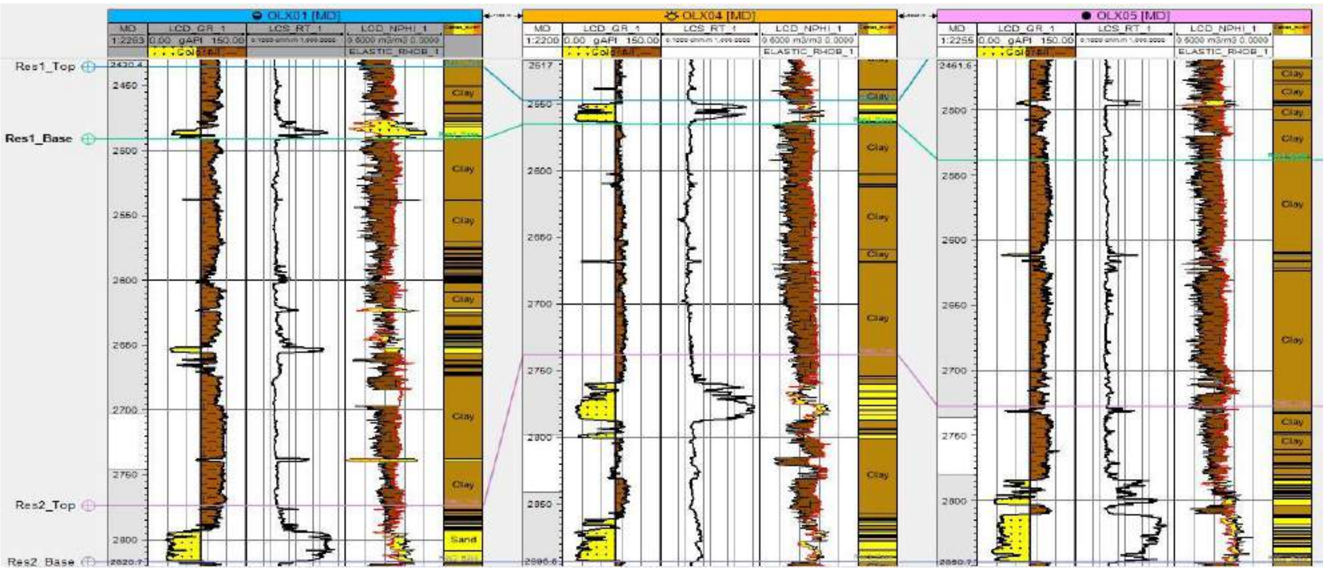

Figure 6: Well correlation for OLX01, OLX04 and OLX05 showing top and base of Res1 and Res2

4.2.Rock Physics Analysis

Rock physics involve cross plotting of elastic parameters and reservoir properties superimposed on some standard rock physics models to analyze fluid and lithology discrimination. The cross plot can identify or detect anomalies that can be interpreted as presence of hydrocarbon or brine as well as lithologies [14].

4.2.1. Lithology Prediction from Impedance Against Vp

The cross plot of acoustic impedance (AI) against p-wave velocity (Vp) for well OLX01 color coded with gamma ray log is shown in Figure 7. Sand and shale can be clearly discriminated on this cross plot with the reddish yellow clusters (green polygon) depicting higher concentration of radioactive particles and thus signify shale, while the purple clusters (yellow polygon) depicting lower concentration of radioactive particles signifies sands. This is clearly the rock physics behaviour that was expected when compared to standard rock physics templates [12]. Since Vp is linearly related to AI, a linear relationship was obtained and could be used to estimate AI from Vp in the absence of density values (Figure 8). The linear relationship is given as:

$$Y = 2.7x - 0.00107 \qquad (7)$$

Y here represents the acoustic impedance while x is the compressional p-wave velocity. The correlation coefficient is 0.956.

In a similar fashion, cross plot of acoustic impedance against P-wave velocity was also carried out for wells OLX04 and OLX05 as shown in Figure 9 and Figure 10 respectively. Both sand and shales can be clearly distinguished from these plots with shales clusters covering the upper parts of the cross plot while sands clusters covering the lower part of the plots in agreement with standard RPT models [13].

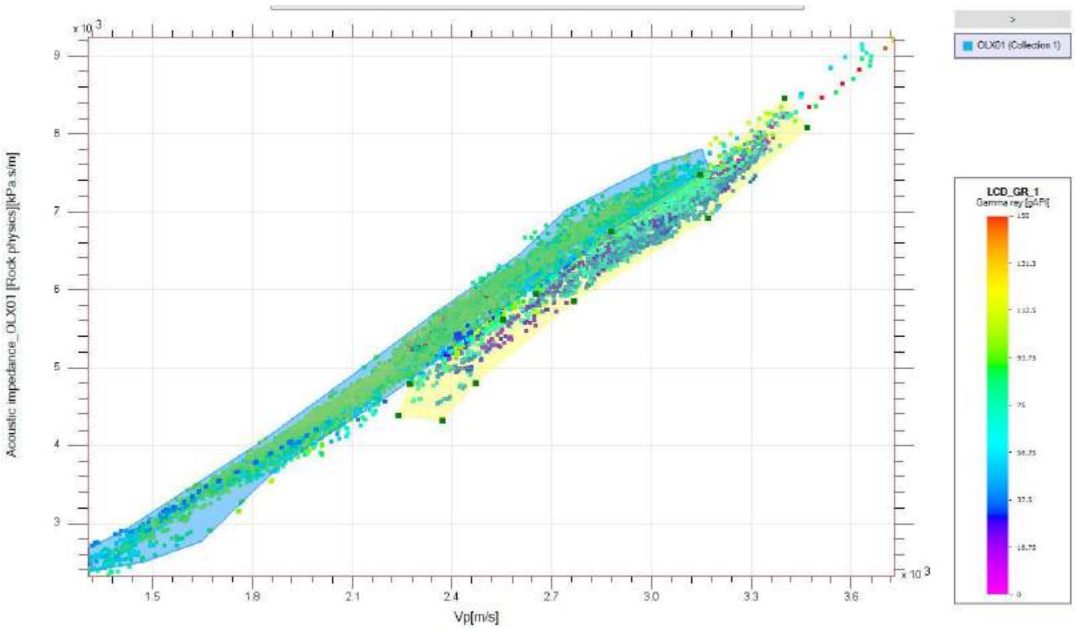

Figure 7: P-wave velocity versus acoustic impedance cross plot for well OLX01

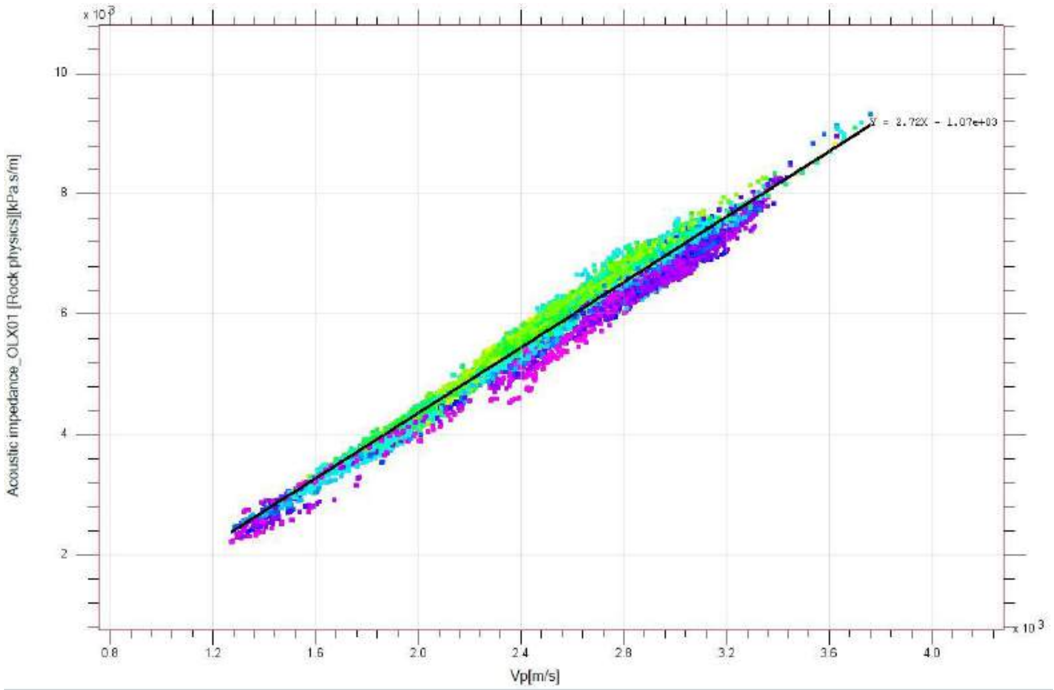

Figure 8: P-wave velocity versus acoustic impedance cross plot for well OLX01 to generate Linear equation.

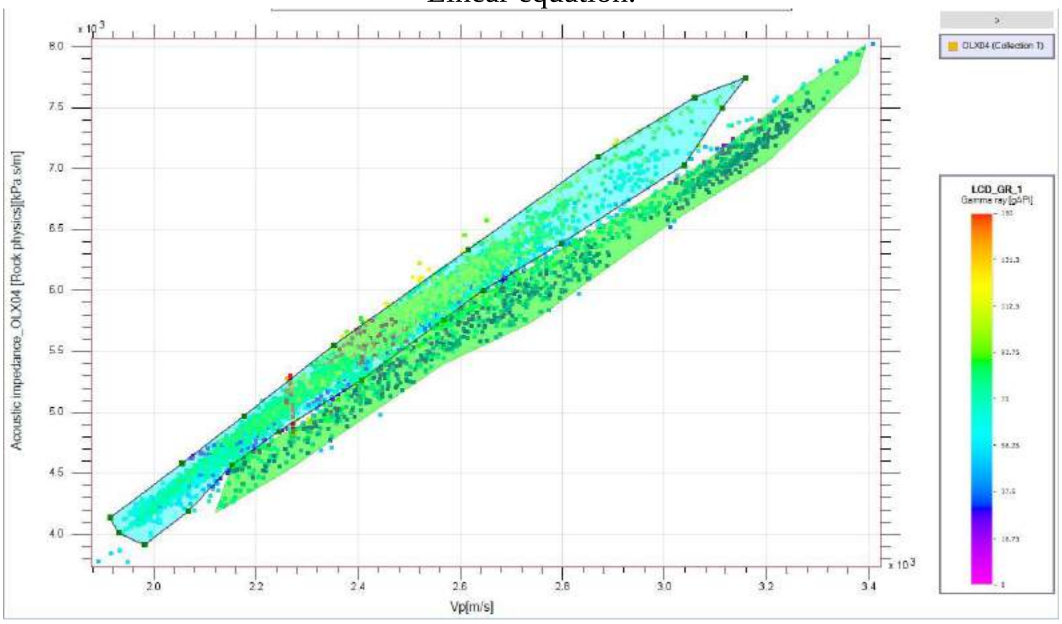

Figure 9: P-wave velocity versus acoustic impedance cross plot for well OLX04

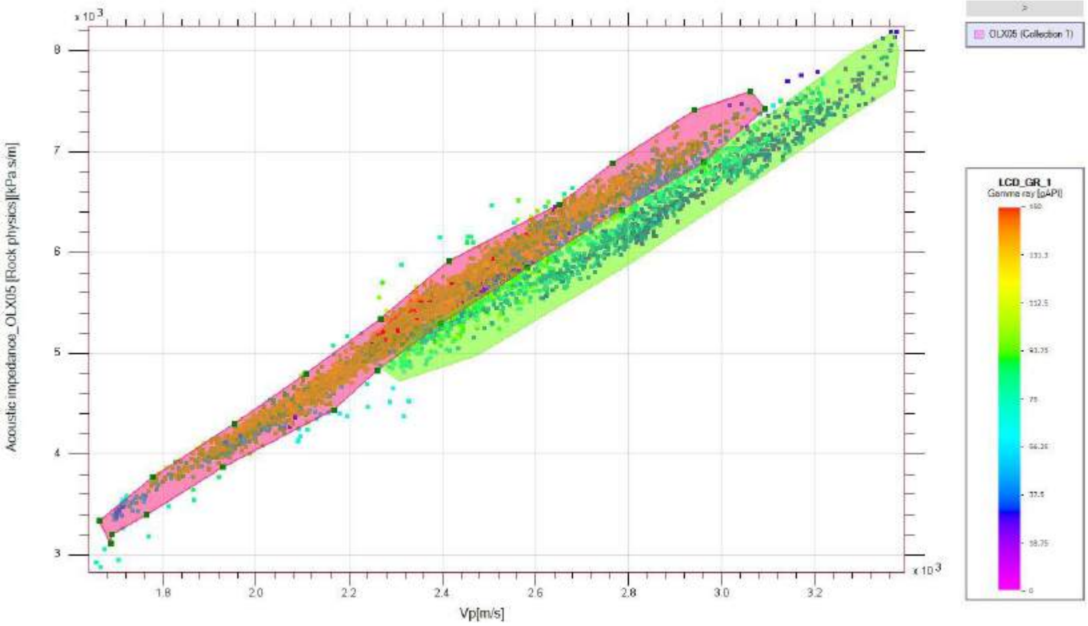

Figure 10: P-wave velocity versus acoustic impedance cross plot for well OLX05

4.2.2. Prediction of Lithology and Pore Fluid using Velocity Ratio (Vp/Vs)

Velocity ratio (Vp/Vs) was cross plotted against acoustic impedance (AI) and color coded with density cutting across the 2 reservoirs in wells OLX01 OLX04 and OLX05. This plot depicts zones of the hydrocarbon sand, brine sand and shale. Lithology discrimination was possible because shale has Vp/Vs and AI values as compared to sand since shear waves does not propagate through fluids. Similarly, hydrocarbon bearing sands has a lower Vp/Vs and AI values compared to both water bearing sands. Thus, Vp/Vs is suitable for the discrimination of pore fluids.

The Vp/Vs ratios for sandstones in the three wells varied between 1.7 to 2.2 and for shales, 2.2 to 2.5. Figures 11, 13 and 15 show the cross-plot of Vp/Vs ratio against acoustic impedance for the zone Res1 for wells OLX01, OLX04 and OLX05 respectively. While Figures 12, 14 and 16 show the cross plot of velocity ratio against acoustic impedance of zone Res2 for wells OLX01, OLX04 and OLX05 respectively. In Figure 11, the clusters enclosed with a brown polygon represent shale while the clusters enclosed in purple polygon represent hydrocarbon sand. Similar behavior can be seen in Figures 12, 14, 15, and 16 respectively. However, in Figure 13, three different zones were delineated. The clusters enclosed in purple polygon with higher Vp/Vs ratio depicting the shale, the clusters enclosed in blue polygon with slightly lower Vp/Vs ratio depicting the water bearing sand and the clusters enclosed in green polygon depicts the hydrocarbon bearing sand with the lowest Vp/Vs ratio values. Again, this rock physics behaviors are in tandem with standard rock physics templates [13]. More so, this rock physis analysis is in agreement with the petrophysical analysis of interval of Res2 in well OLX05 as shown in Figure 3. The upper part of the reservoir clearly shows sand lithology. Since the resistivity value is high, this indicates it contains hydrocarbon. While the lower part of the reservoir also indicating sand but with lower resistivity value indicating water bearing sand. Thus, a subsurface model for this field can be achieved to be utilized for the prediction of lithology and pore fluid wherever there is no well information with the use of seismic data.

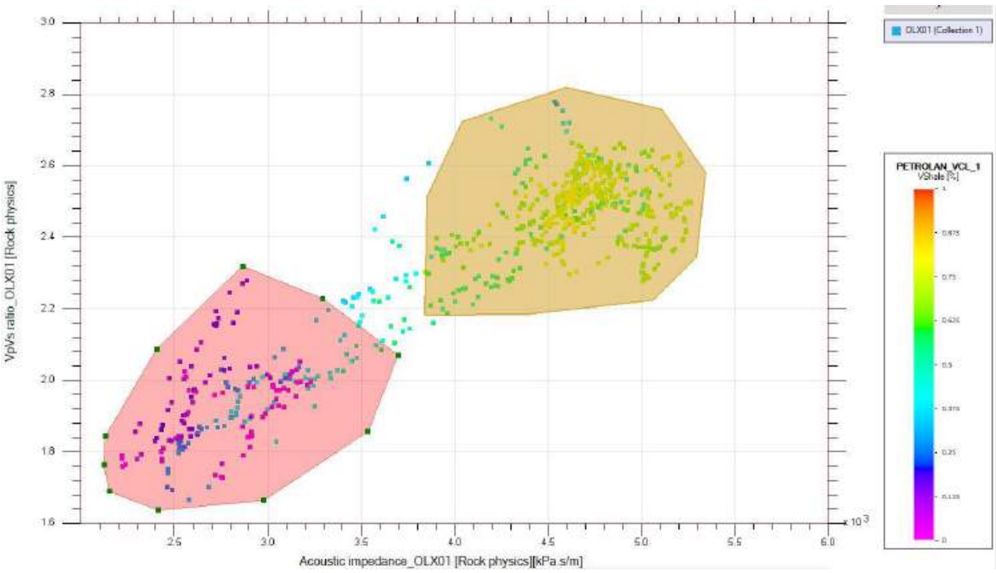

Figure 9: Acoustic impedance velocity versus Vp/Vs cross plot for well OLX01 Res1

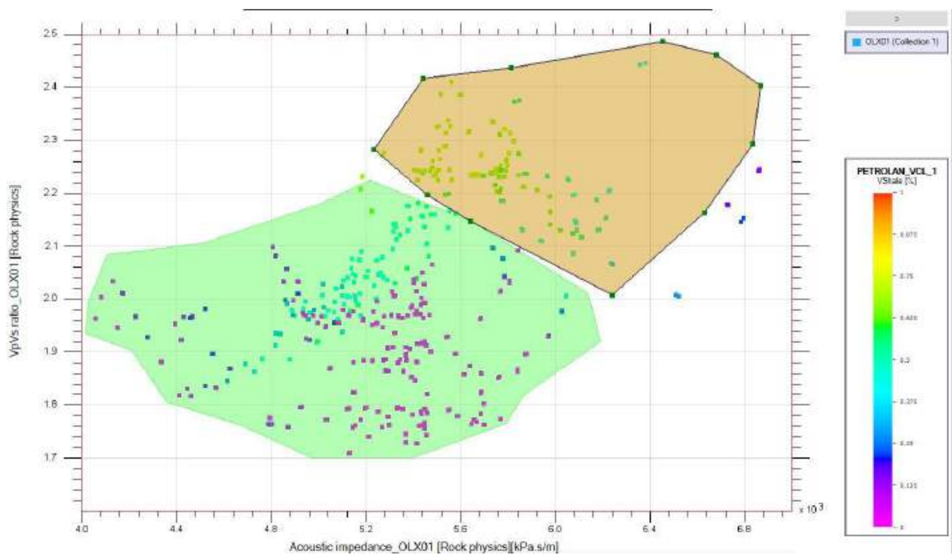

Figure 10: Acoustic impedance velocity versus Vp/Vs cross plot for well OLX01 Res2

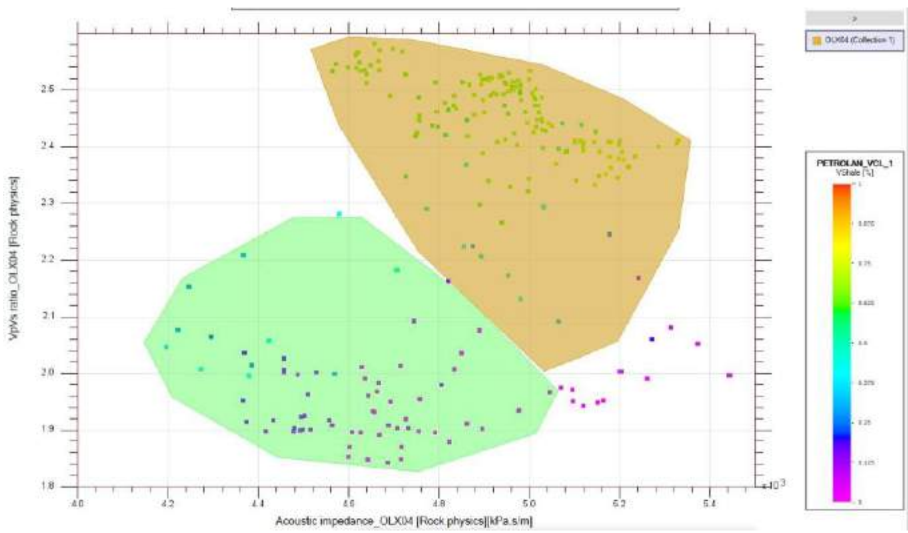

Figure 11: Acoustic impedance velocity versus Vp/Vs cross plot for well OLX04 Res1

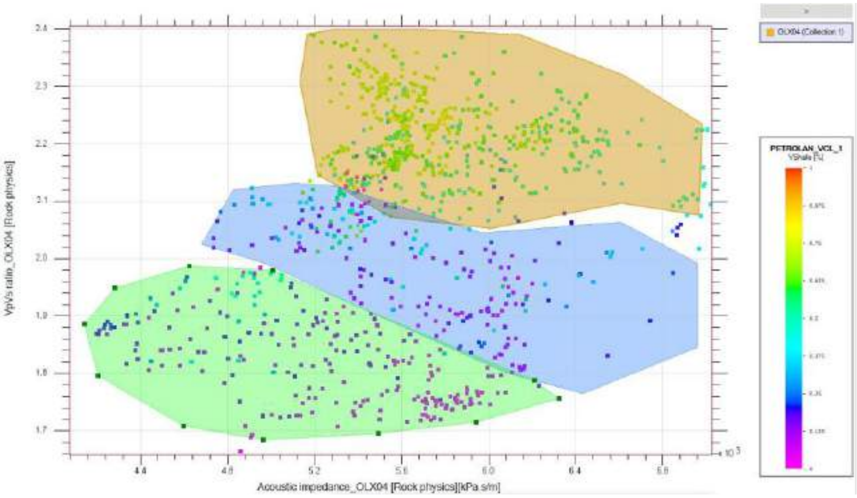

Figure 13: Acoustic impedance velocity versus Vp/Vs cross plot for well OLX04 Res2

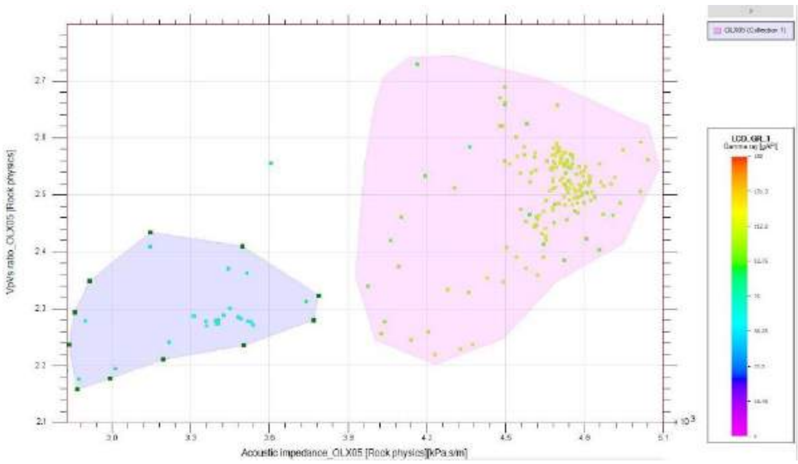

Figure 14: Acoustic impedance velocity versus Vp/Vs cross plot for well OLX05 Res1

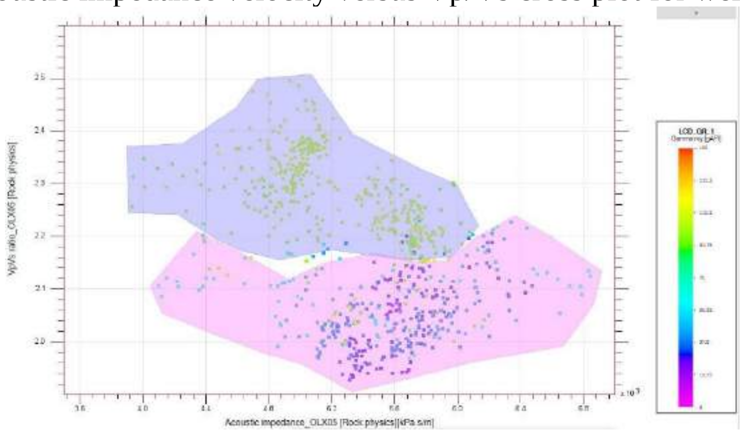

Figure 15: Acoustic impedance velocity versus Vp/Vs cross plot for well OLX05 Res2

5. Conclusion

The integration of petrophysics and rock physics has proven to be very vital in the delineation of lithology and fluid scenarios in this hydrocarbon field. Three wells with the required log suites were available for this study. For the petrophysics analysis, while the gamma ray log is an indicator of lithology based on the number of radioactive particles present in them, combination of resistivity, and neutron-density log is used to discriminate between the fluid. This conventional way of interpretation is not free from uncertainties thus the need for the integration with rock physics modelling. The rock physics analysis involves cross plotting elastic parameters and reservoir parameters giving rise to clusters that can clearly discriminate between the different lithologies as well as fluid contained in them. The cross plot of p-wave velocity against acoustic impedance is a good indicator of lithology while the cross plot of Vp/Vs ratio against acoustic impedance is usually employed to discriminate among the different fluids. Hydrocarbon sand, water sand and shale were all predicted using the various rock physics cross plots.

References

[1] Abbey et al., Application of rock physics parameters for lithology and fluid prediction of TN' field of Niger Delta basin, Nigeria, Egypt. J. Petrol. (2018), https://doi.org/10.1016/j.ejpe.2018.01.001
[2] C. Obeng-Manu, Lithology and pore fluid prediction of a reservoir using density, compressional and shear wave logs: a case study of the tano basin, 2015. pp. 2387–2390
[3] Ukuedojor, K. O., and G. E. Maju-Oyovwikowhe. 2019. "Reservoir Geometry Determination and Volumetric Reserve Estimation of an Offshore, Niger Delta Basin Nigeria". Journal of Geography, Environment and Earth Science International 23 (2), 1-15.
[4] Z. Luanxiao, G. Jianhua, H. De-hua, C. Jiubing, G. Tonglou, Rock physics based probabilistic lithology and fluid prediction in a heterogeneous carbonate reservoir, SEG Houston, 2013, pp. 2387–2390.
[5] H. Doust, E. Omatsola, Niger Delta, in: J.D. Edwards, P.A. Santogrossi (Eds.), Divergent/passive Margin Basins, AAPG Memoir, Vol. 48, American Association of Petroleum Geologists, Tulsa, 1990, pp. 239–248.
[6] Galloway, W.E., 1989. Genetic stratigraphic sequences in basin analysis, architecture and genesis of flooding-surfaces bounded by depositional units. AAPG (Am. Assoc. Pet. Geol.) Bull. 73, 125–142
[7] C.M. Ekweozor, E.M. Daukoru, Northern delta depobelt portion of the AkataAgbada petroleum system, Niger Delta, Nigeria, in: L.B. Magoon, W.G. Dow (Eds.), The Petroleum System-From Source to Trap, AAPG Memoir, Vol. 60, American Association of Petroleum Geologists, Tulsa, 1994, pp. 599–614.
[8] H. Kulke, Nigeria, in, Kulke, H., ed., Regional Petroleum Geology of the World. Part II: Africa, America, Australia and Antarctica: Berlin, Gebrüder Borntraeger, 1995, pp. 143–172.
[9] A.A. Avbovbo, Tertiary lithostratigraphy of Niger Delta, Am. Assoc. Pet. Geol.Bull. 62 (1978) 295–300.
[10] D.O. Ogagure, Localized Vp-Vs relationship for the Niger Delta sediments, Pac. J. Sci. Technol. 9 (2) (2008) 558–561.
[11] W. Goodway, T. Chen, J. Downton, Improved AVO fluid detection and lithology discrimination using Lamé petrophysical parameters; ''kq,'' ''mq,'' ''k/m fluid stack,'' from P and S inversions: 67th Annual International Meeting, Society of Exploration Geophysicists, Expanded Abstracts, 183–186, 1997.
[12] Avseth, Per, Tapan Mukerji, and Gary Mavko. *Quantitative Seismic Interpretation.* Cambridge University Press, 2005.
[13] Avseth, P., Johansen, T.A., Bakhorji, A. and Mustafa, H.M. 2014. Rock physics modeling guided by depositional and burial history in low-to-intermediate-porosity sandstones. Geophysics 79, D115–D122.
[14] Bello, R., Igwenagu, C.L., Onifade, Y.S., 2015. Crossplotting of rock properties for fluid and lithology discrimination using well data in a Niger Delta oil field. J. Appl. Sci. Environ. Manage. 19 (3), 539–546.