Original Research Article

LITHOLOGY AND FLUID DISCRIMINATION USING ROCK PHYSIC MODELLING AND RESERVOIR PROPERTIES ANALYSIS IN "KOLA" FIELD NIGER DELTA

ABSTRACT

Aims: This study is to predict reservoir behaviour with respect rock physics, elastic properties and presence of fluid within the study area “KOLA” Field, Niger Delta.

Place and Duration of Study: The study is an offshore field located within and latitude 05^{0}51’55N to 05^{0}52’03N and longitude 05^{0}41’27E to 05^{0}42’05E in the Niger Delta. Niger Delta basin is one of the seven sedimentary basins in Nigeria where active petroleum exploration activities is carried out. Study took place between August 2023 and August 2024.

Methodology: Seismic attribute e.g Vp/Vs ratio, Lambda-Rho, Mu-Rho, and P-Impedance were estimated. Rock physics cross-plots of the attributes were used to discriminate fluid and lithology in the reservoirs sands of ‘KOLA’ Field Offshore Niger Delta. The seismic attributes were colour-coded with various reservoir properties from well logs such as gamma ray and resistivity in order to differentiate the lithology and zones charged with hydrocarbon from zones charged with brine.

Results

The results the analysis showed that hydrocarbon sands have low P–Impedance, VP/VS, Lambda-Rho and Mu-Rho values. P–Impedance and VP/VS are sensitive to both fluid and lithology whereas Lambda-Rho is only sensitive to fluid and Mu-Rho (rigidity) is only sensitive to rock matrix. The results showed that both mu-rho and density are lithology discriminators, with density also being a fluid discriminator.

Cross-plot of Vp/Vs and Acoustic impedance was used to differentiate the reservoirs into hydrocarbon charged zone and water charged zone. Cross-plot of Lambda-rho (incompressibility) and velocity ratio differentiate the reservoir lithology into sands and shale units. Lambda-rho (λρ) and mu-rho (μρ) cross-plots classified the reservoir unit into three zones namely water saturated sand, oil saturated zone and gas saturated zone confirmed by density and neutron cross-plot.

Keywords: *Rock physics, seismic attribute, Property attribute Fluid and lithology*

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1. INTRODUCTION

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A reservoir is a subsurface rock which is described in terms of its lithology and pore fluid saturation. This influence the reservoir development and its management. According to Bello, (2015) subsurface reservoir with good effective porosity and permeability containing accumulation of hydrocarbons within a porous or fractured rock formations is commercially exploitable. Prospectively reservoir zones in mature fields sometimes requires unconventional exploration tools Bello, (2015). There are many risks associated with the exploitation of hydrocarbons, particularly the potential drilling location.

The ultimate goal of any Rock Physics analysis is to gain insights into the physical properties of a reservoir. These consist of properties such as lithology, porosity, and permeability, or dynamic properties like fluid content or pressure. A geophysical Rock Physics analysis will make use of the measured elastic properties from seismic data to generate attributes that yield relevant information about the reservoir rocks/sand. Pelletier and Gunderson, (2004). According to Pelletier and Gunderson, (2004), there are, several other sources of Rock Physics information that can and should be used to by the analyst’s to understand the study area. These other sources are petrophysical, geophysical, and/or geological in nature. (This includes wireline logs, mudlogs, core, DST/RFT pressure and fluid analyses, VSP, and checkshot surveys. This will help in understanding the reservoir because the more tools we use, the more risk associated with an exploration/exploitation undertaking will be reduced.

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1.1 Aim and Objectives

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The aim of the model is to predict reservoir behaviour with respect rock physics, elastic properties and presence of fluid within the study area “KOLA” Field, Niger Delta.

The objectives are to:

i. Identify and discriminate fluid type within reservoir unit along wellbore
ii. generate and analyze crossplot models for elastic and rock physic properties.
iii. analyze elastic and rock physic properties response to identify hydrocarbon zone.

1.2 Previous Works

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Pelletier and Gunderson, (2004) presented a case study from the Brazeau River 3D to illustrate how the integration of a petrophysical analysis was used to actually directed the course of a successful geophysical analysis. The Rock Physics Analysis identified two targets, one clastic and one carbonate. The clastic target was the Viking sand interval with the project goal to identify the fluid content. The carbonate target was the Nisku formation where lithology differentiation would be the key to success. Good well control was available in the area with wells penetrating both the Viking and Nisku intervals. The petrophysical analysis workflow involved: a) log edits and reconstructs as necessary; b) standard formation evaluation; c) lithology driven shear estimation for missing shear sonics based on local Vp/Vs trends for sand, shale, and carbonates; d) calculation of AVO and Rock Property attributes; and e) attribute interpretation. The petrophysical “feasibility” study was instrumental in providing a roadmap to focus the geophysical study. The geophysical work proceeded with a) extraction of the pre-stack information through various AVO methodologies; b) inversion of these AVO products to convert the reflectivity attributes into layer properties; c) calculation of Lamé parameters (LMRTM) attributes; d) cross-plotting and interpretation, and e) calibration/comparison with the petrophysical results.

Mithilesh Kumar *et.al.,* (2018) characterized Eocene reservoir in Chandmari oil field of Assam-Arakan basin, India. Using petrophysical properties and rock physics modeling to evaluate six wells, estimating fluid and mineral types, and rock or pore fabric types, for both invaded and virgin zones, was calibrated with core data where available. The results from rock physics analysis revealed the influence of porosity, mineral composition, and fluid saturation on subsurface elastic properties. it revealed that the Eocene reservoirs consisted primarily of sandstone with incidental clay and some calcareous cementation, effective porosity ranging from 15% to 22% and water saturation varying widely, with the lowest at 5%. This distinguished hydrocarbon-bearing sands, brine sands, and shale based on lithology variability and pore-fluid types.

2. METHODOLOGY

LOCATION AND GEOLOGICAL SETTING OF THE STUDY AREA

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2.1 Location of the Study Area

The study is an offshore field located within and latitude 05^{0}51’55N to 05^{0}52’03N and longitude 05^{0}41’27E to 05^{0}42’05E in the Niger Delta. Niger Delta basin is one of the seven sedimentary basins in Nigeria where active petroleum exploration activities is carried out (Fig.1). It covers an area of 300 sq km. Niger Delta province is the twelfth richest in petroleum resources, with 2.2% of the world's discovered oil and 1.4% of the world's discovered gas (Petro consultants, Inc. 1996a).

2.2 Geological setting of the Study Area

Niger Delta Basin to date is the most prolific and economic sedimentary basin in Nigeria by the virtue of the impact size petroleum accumulations, discovered and produced as well as the spatial distribution of the petroleum resources to the Onshore, Continental Shelf through Deepwater terrains. Classic integrated geological studies have shown that several different depobelts are abound in the Niger delta basin. Figure 1. While three (3) categories of structural styles are common in the Niger Delta Onshore, Continental Shelf and Deepwater terrains. They are the Extensional Zone (Growth faults), Translational Zone (Diapirs) and Compressional Zone (Toe thrust). The Niger Delta Basin is situated in the Gulf of Guinea in equatorial West Africa, between latitudes 3° N and 6° N and longitudes 5° E and 8° E (Reijers *et al,* 1996). It is framed on the northwest by a subsurface continuation of the West African Shield, the Benin Flank. The eastern edge of the basin coincides with the Calabar Flank to the south of the Oban Masif (Murat, 1972). Well sections through the Niger Delta generally display three vertical lithostratigraphic subdivisions: an upper delta top facies; a middle delta front lithofacies; and a lower pro-delta lithofacies (Reijers et al, 1996).

2.3 Stratigraphy of the Niger delta

These lithostratigraphic units correspond respectively with the Benin Formation (Oligocene-Recent), Agbada Formation (Eocene-Recent) and Akata Formation (Paleocene-Recent) of Short and Stauble (1967). In the Niger delta, this sequence is modified by the numerous transgressions which have occurred from time to time, breaking the continuity of the main overall regression, and becoming stratigraphically superimposed (Short and Stauble, 1967). The thick wedge of the Niger delta is considered to consist of three units Benin, Agbada and Akata formations (Figure 1).

These formations are strongly diachronous and cut across the time stratigraphic units which are characteristically S-shaped in cross section. The typical sections of these formations are described by Short and Stauble 1967; Avbovbo, 1978; Doust and Omatsola, 1990; Kulke, 1995. Akata formation, which is composed of marine shales formed the main source rocks for petroleum, the formation is overlain by the paralic Agbada formation which consists of the main reservoir units. The Agbada formation is made up of intercalations of Sand and shale sequences.

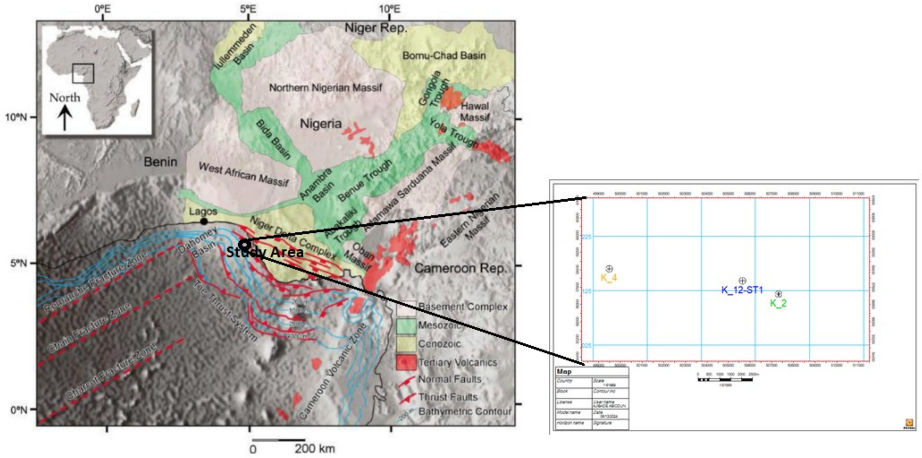

Figure 1: Location map of Niger Delta region showing the main sedimentary basins and tectonic features (adopted from Onuoha, 1999)

3.1 Data set and Data presentation

Three (3) wells log and 3D-seismic data from the study area were used for data analysis. The well data is consisting of composite logs which are gamma ray, sonic, resistivity, neutron and density logs. The 3D seismic volume is in SEG-Y format, while the well log data are in LAS format. The wells data used cover a total vertical depth ranges from 14,931.71 ft (4,551.19 m), 13,133.98 ft (4,003.24 m), and 11,398.05 ft (3,474.13 m) in the study area.

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3.2 Data Analysis

The well logs data served as input logs for computation of relevant rock physics property used for the research. Lithofaces units within the study area were delineated using gamma ray log across the three wells.

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3.3 Rock Physics Analysis

Rock physics parameters were estimated based on the relationships between sediments deposition, pore space and presence of fluid within the study area. The following properties were accurately estimated (LambdaRho, MuRho, acoustic impedance, and compressional and shear velocity ratio) using relations below. They were computed and analyzed to establish their relationship with different types of fluids. Crossplot models were generated to understand the level of incompressibility and rigidity of the sediments in place due to fluids types occupying the pores space,

Lambda/Rho – Mu/Rho

The Lames parameters, were calculated using the following equations:

$$Lambda(\lambda) = \rho\left({V_p}^2 - 2{V_s}^2\right) \quad (1)$$

$$Mu(\mu) = \rho{V_s}^2 \quad (2)$$

where V_p is the primary velocity, V_s is the shear velocity, and ρ is the density. To calculate lambda-rho and mu-rho, the Lame's parameter equations are multiplied by the density.

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$$\lambda\rho = \rho^2\left({V_p}^2 - 2{V_s}^2\right) \quad (3)$$

$$\mu\rho = \rho^2{V_s}^2 \quad (4)$$

4. RESULTS AND DISCUSSIONS

4.1 Lithology and Fluids Type Analysis

Two types of lithofacies (shale and sands) were identified in the study area as shown in Figure 2.

The sands sediments pores space is filled with gas, oil and water as interpreted from resistivity, density and neutron logs signatures shown in Figure 2. This was observed from positive and high resistivity signature for hydrocarbon (gas and oil) while low positive signature indicate water within the sand sediments. Gas is designated with red color, oil with green and water with blue colour. Some relevant estimated rock physics parameters such as (LambdaRho, MuRho, and velocity ratio) explained the relationships between sediments deposition and type of fluid presence within the reservoir. Their respond to elastic parameter was also observed Figure 3.

These were modeled by cross plotting density against sonic to illustrate fluid distribution and elastic parameter behavior within hydrocarbon reservoir as in Figure 4a, 4b and 4c. It revealed that gas distribution is within high sonic at relative low density, while oil and water were distributed at relatively high density against low sonic with an exception where there is overlapping fluid distributions. It revealed relationship between the petrophysical and elastic rock properties in prediction of reservoir properties away from the well locations.

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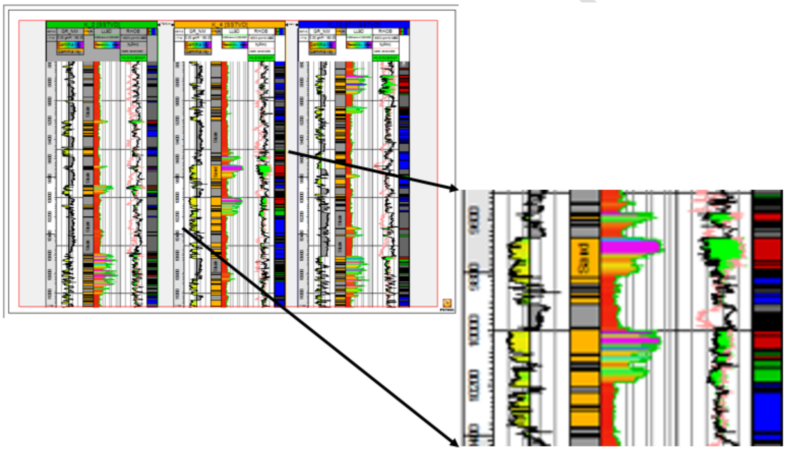

Figure 2: Resistivity, Density and Neutron logs Analysis

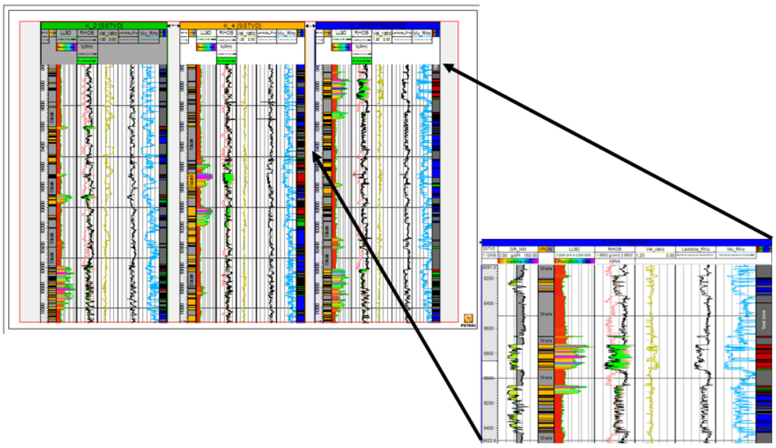

Figure 3: Derived Rock physics Logs (Velocity ratio, LambdaRho and MuRho)

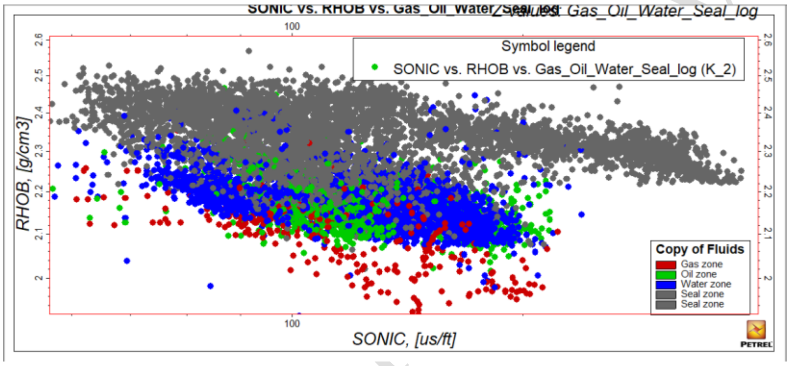

Figure 4a: Density against Sonic Cross Plot Modeled

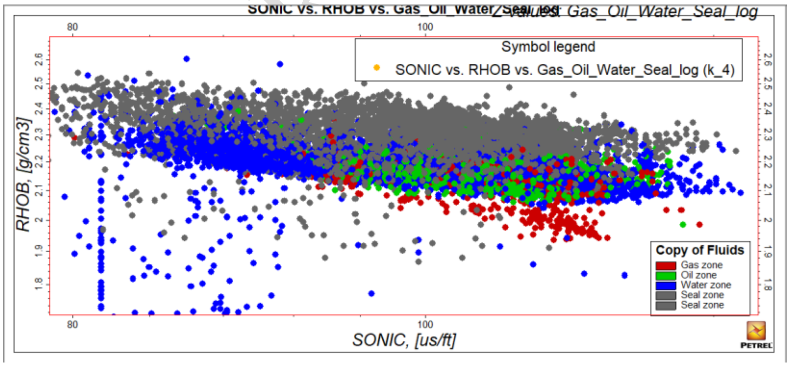

Figure 4b: Density against Sonic Cross Plot Modeled

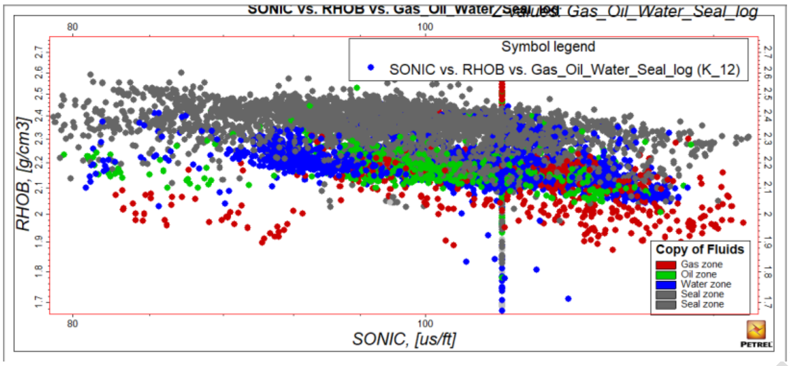

Figure 4c: Density against Sonic Cross Plot Model

4.2 Velocity_Ratio versus Mu_Rho Crossplots Analysis

It was observed that Vp/Vs increased and Mu_Rho decreased within hydrocarbon zone, while it overlapping is observed within water zones. By comparing Figure 5a and 5b, Figure 6a and 6b and Figure 7a and 7b, it could be explained that type of fluid in the reservoir sand made Vp/Vs ratio to be high and Mu_Rho to drop. This is as a result of good interconnection of pore space occupying the sediments and has helped accumulation of fluid in place. The compaction trend analyses from the density and P-sonic log crossplot also explained the cause of Vp/Vs ratio increase and decrease in Mu_Rho with depth in the reservoir sand unit.

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Distribution of litho-fluids in the area along wellbore was also observed from both µρ and Vp/Vs crossplots spaces discrimination, as high µρ and low Vp/Vs (>1.95) depict gas sand while lesser Vp/Vs (1.95) value indicate oil and water within the sand unit. Some level of overlap in the values of the Vp/Vs ratio and µρ also reveal gas sands and brine sands from the crossplots as shown in Figure 9a and b.

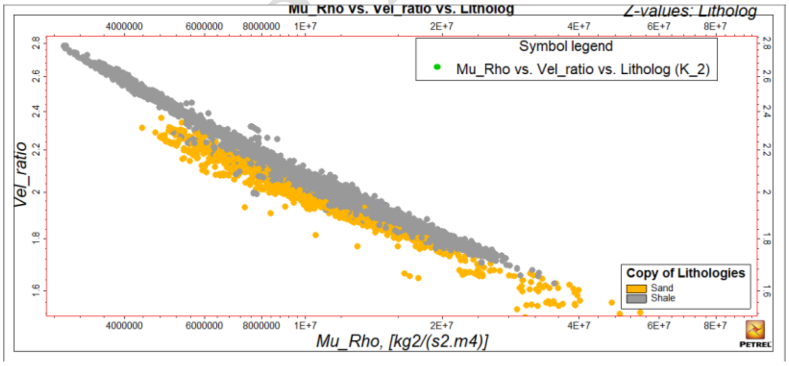

Figure 5a: Velocity_Ratio versus Mu_Rho Crossplots Model

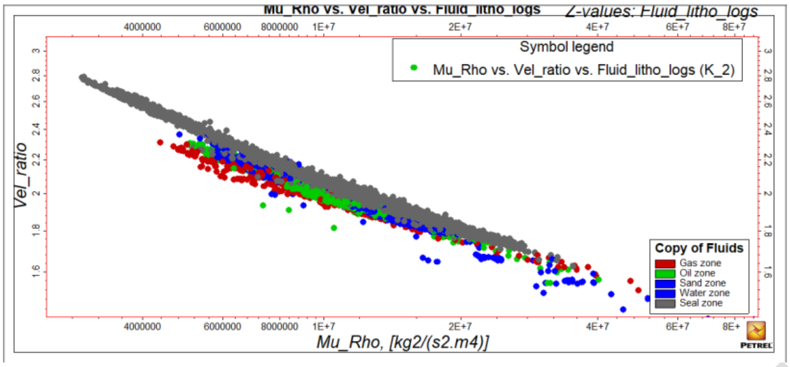

Figure 5b: Velocity_Ratio versus Mu_Rho Crossplots Model

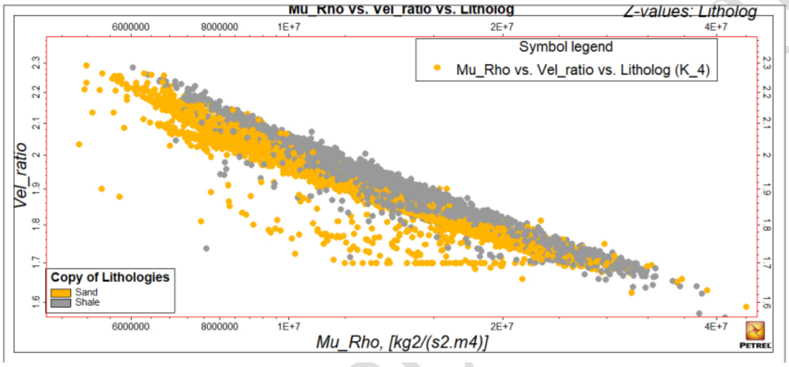

Figure 6a: Velocity_Ratio versus Mu_Rho Crossplots Model

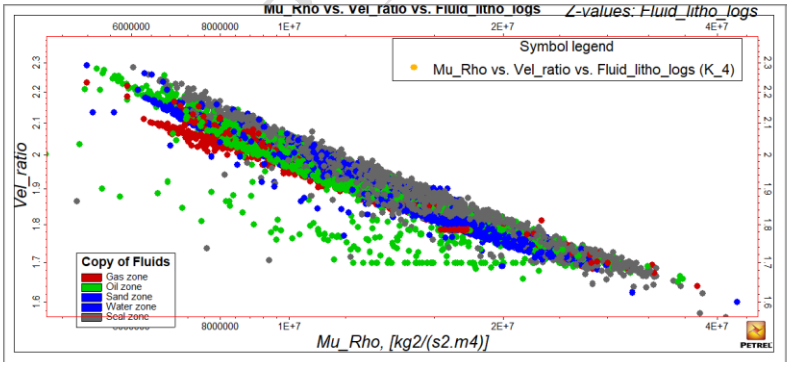

Figure 6b: Velocity_Ratio versus Mu_Rho Crossplots Model

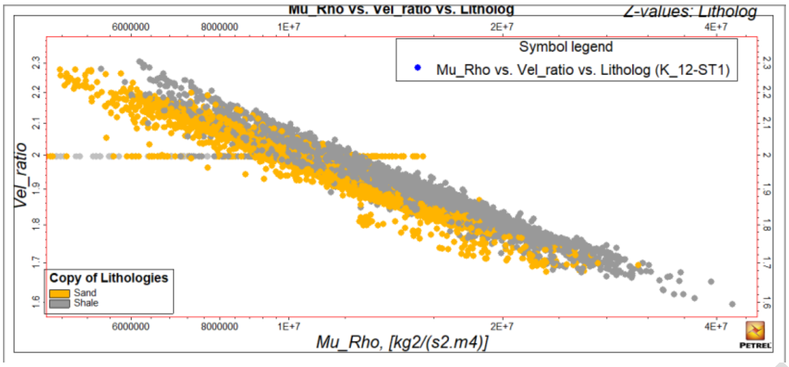

Figure 7a: Velocity_Ratio versus Mu_Rho Crossplots Model

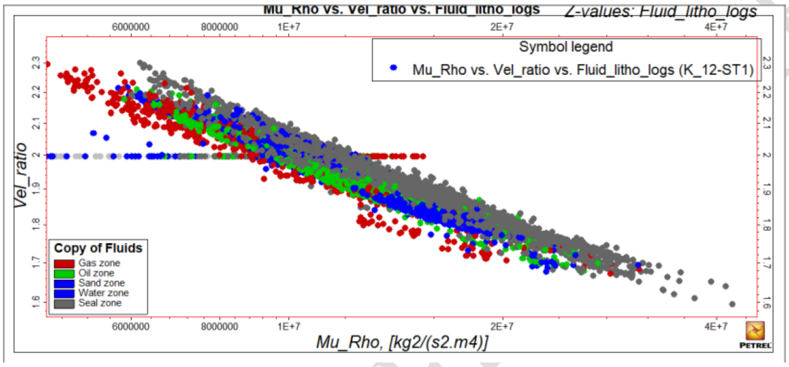

Figure 7b: Velocity_Ratio versus Mu_Rho Crossplots Model

4.3 Incompressibility and Rigidity Analysis

In other to characterize the incompressibility and the rigidity of the rocks with respect to fluids in the pore spaces. Lambda-Rho (λρ) versus Mu-Rho (λρ) cross-plot shows positive relationship that implies the higher the lambda-rho values, the higher the Mu-rho values indicating icreased incompressibility. provides lithological and fluid information within reservoir sand. In the hydrocarbon zones, the Lambda_Rho values increases while MuRho tends to decrease in reservoir zones (Fig. 8). Lambda-Rho (λρ) versus Mu-Rho (λρ) colour coded with resistivity showed that the zone with the lowest Lambda-Rho values has the highest resistivity response, indicating hydrocarbon-charged zones. There are four cluster zones shown that were defined as Shale (gray sphere), Brine (Blue sphere) Oil-charged (Green sphere) and Gas-charged sand (red sphere) lithology (Fig. 8). This implied, that water filled sands unit has high level of incompressibility than oil and gas-filled sand units, also that shale increases in rigidity and incompressibility than reservoir sands. This was as a result of low density of hydrocarbons compared to that of water zone and higher acoustic impedance of sand than shales (Oyetunji, 2013).

In the hydrocarbon zones, as shown in Figure 8a, 8b and 8c, the Lambda_Rho and Mu_Rho values is low compared to water zones as revealed from the logs signatures most especially in gas. This is due to higher density and velocity encounter water zones are higher than that of hydrocarbons. Even though Mu_Rho should reveal higher values in reservoir sands zones as a results of have higher acoustic impedance than shales but the presence of the hydrocarbon within the pore space has altered the rock property across the wells.

Cluster analysis of elastic rock properties further helped to discriminate fluid fills in the reservoirs with gas-oil saturation and wet sand. Oladele, *et al.,* (2019). This revealed a distinct trend in distribution of fluid types present within the reservoir sand units on cross-plots. The cross-plots reveal that clusters with the least water saturation correspond to high resistivity, which implies highly charged hydrocarbon saturation sand that confirmed the presence of gas/oil in the reservoirs sand and showed lower Lambda_Rho values confirming its low incompressibility within the sand unit.

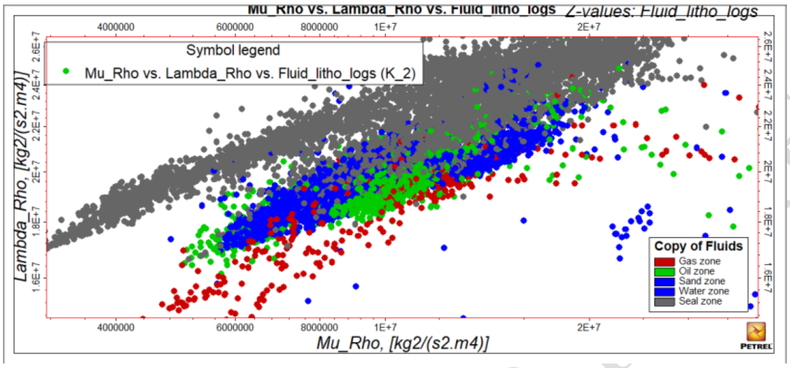

Figure 8a: Lambda_Rho versus Mu_Rho Crossplots Model

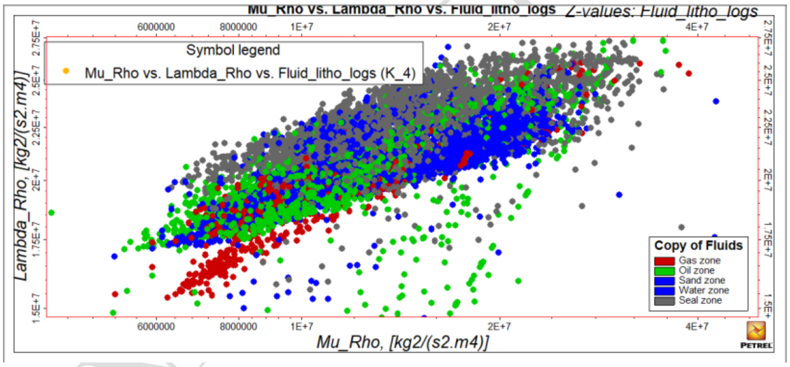

Figure 8b: Lambda_Rho versus Mu_Rho Crossplots Model

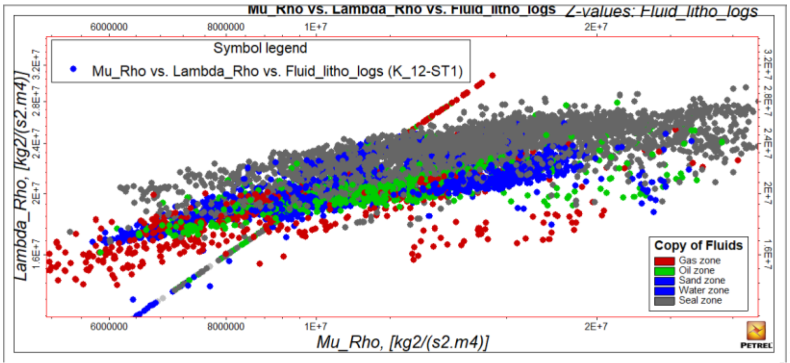

Figure 8c: Lambda_Rho versus Mu_Rho Crossplots Model

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CONCLUSION

Reservoir lithology and fluid discrimination were done using rock physics cross-plots of P–Impedance, Lambda-Rho, Mu-Rho, and VP/VS ratio seismic attributes. The analysis of elastic and rock physics parameters from the field of study have revealed pore-fluid types, distinguishing hydrocarbon-bearing sand units and shale as counterpart on lithology within the study area. The effect of porosity, mineral composition, and fluid saturation on the subsurface was observed in the variations of elastic properties of the sediments. P-sonic and density logs which provide an insight about the porosity trend and density information for the different lithology. Having realized that the porosity in the reservoir unit is moderately good and the water saturation is low. The models explained the general behavior of the rock in terms of poor, moderate and good qualities. This is helpful to note that the reservoir is good and economical.

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