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RESEARCH ARTICLE

RESERVIOR MODELING AND ROCK PHYSICS ANALYSIS OF "ADE'' FIELD OFFSHORE NIGER DELTA

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ABSTRACT

Rock physics has been used to create a link between geophysical observable parameters and geological parameters and this makes it to be a part of reservoir characterization. Even though various rock physics models have their own benefits and limitations in reservoir formation. Set of data used were check shot, well logs and 3D seismic volume. The study aimed at modeling and analysing reservoir properties with rock physics properties to build a structural models and to understand potential hydrocarbon within study area. Twelve (12) reservoir sand units were identified and analyzed for petrophysical parameters and rock properties from well log data for four (4) wells. Rock physics templates (RPTs) was used by plotting acoustic impedance (AI) versus Vp/Vs ratio) to discriminate fluid and lithology for reservoir zones.Prospectivity of thereservoir units was inferred and confirmed from elastic and estimated rock physic parameters such as velocity_ratio, shear impeadance and Acoustic impedance. These were crossploted and the following respective reservoir properties (porosity, water saturation and shale volume) were used as colour indicators. The quality and distribution fluid type within sands and shale was observed from 3D structural models.These further explain the lateral extent of the known reservoirs unit.

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INTRODUCTION

A good reservoir is one that is commercially productive; it produces enough oil or gas to pay back its investors for the cost of drilling and leaves a profit. Rock physics is an indispensable tool for an efficient interpretation, providing the basic relationship between the lithology, fluid, and geological deposition environment of the reservoir (Chi and Han, 2009). Rock Physics describes a reservoir rock by physical properties such as porosity, rigidity, compressibility; properties that will affect how seismic waves physically travel through the rocks. It is used to establish relations between these material properties and the observed seismic response, and to develop a predictive theory so that these properties may be detected seismically Abe *et.al.,* 2018. Rock Physics provides a good link between petrophysics, geomechanics, seismic data and the internal reservoir rock properties such as porosity, mineralogy, pore space, pore fluid that are valuable information to hydrocarbon prospect.

Aim and Objectives of the Study: The aim of this project is to evaluate hydrocarbon eservoir using rock physics and logs to help improve the understanding of reservoir formation within the study area "Kola's" Field, Niger Delta.

The objectives are to:

i. Delineate the reservoirs and discriminate the fluid type within the reservoir zone through well correlation
ii. Analyzethe elastic and rock physic properties of hydrocarbon reservoirs.
iii. to establish the trends of elastic and rock physic parameter in shales and sands and how they affect lithologies
iv. build reservoir and rock physics properties models to facilitate optimal hydrocarbon recovery

Justification of the Study: The Niger Delta is a prolific hydrocarbon basin, known for its vast reserves of oil and gas. Reservoir delineation and rock physics in the Niger Delta is justified due to its economic significance, potential for resource optimization, exploration success, and regulatory compliance. By studying the properties such as porosity, permeability, fluid saturation, and rock properties

- it addressed the challenges associated with accurate estimation, this research can provide valuable insights and contribute to the sustainable development of the region's oil and gas industry

Geology and Location of the Study Area: The Niger Delta is situated on the Gulf of Guinea in the southern part of Nigeria. It covers an area between longitude 05^{0}41'27E to 05^{0}42'05E and latitude 05^{0}51'55N to 05^{0}52'03N. The study area is the "Kola's" Field which is within Niger Delta Basin in Nigeria with three distinct Formations Akata Formation, Agbada Formation and the Benin Formation. The base map is shown in Figure 1.1, the Niger Delta basin is bounded to east and west by the Calabar Flank and Benin Flank respectively, the Gulf of Guinea to the south and in the north by older (Cretaceous) tectonic structures like Anambra Basin, Abakiliki uplift and Afikpo Syncline. It has a thickness of more than 10 km that is composed of overall regressive clastic sequence, and a delta which prograde southwestward to form major active depobelts.This field containsfour offshorewells. The Niger Delta is rated amongst the productive hydrocarbon tertiary deltas in the world and covers an area of 75,000 km2 (Akinsete et al., 2020).

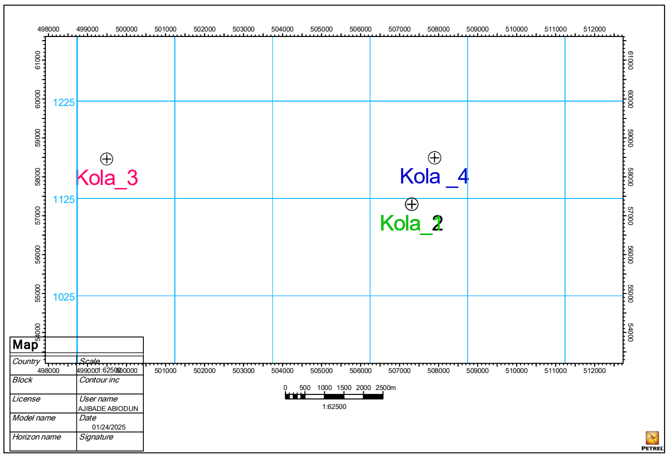

Figure 1. Location and Base Map of the Study Area

Previous Work: David et al., (2016) carried out work on rock physics assessment of reservoir potential in the Montney in the development of unconventional energy resources requires an in-depth understanding of various subsurface conditions to properly characterize the reservoir by performing an AVO inversion to estimate elastic properties from seismic data followed by a rock physics inversion to estimate porosity and mineral fractions in the reservoir to assist in the identification of optimal zones for hydrocarbon production. Several works by Aigbedion et al (2017), Nwankwo et al (2017) and Merriouset al (2013), characterized reservoir based on petrophysical parameters and attempted modelling these properties, without determining the presence of tight oil. Tight oil is a petroleum that occurs in a free or adsorbed state in source rocks or tight reservoir rocks (e.g sandstone and carbonate rock) interbedded with or close to source rocks, and has not experienced large-scale long-distance migration. Avseth (2011) used 4D sesimic to determine a reservoir area's elastic properties and lithology. The models describe these rock physic properties; the friable sand, cement, intial sand pack. The effect of these three physical properties on the formation can be described by the slope of the trend line from the on bulk modulus (K) and porosity (Φ). If the sandstone pore structure of a reservoir formation changes after a CO_2 flood, a rock physics diagnostic should be able to measure the changes with acoustic data. This shows the correlation between acoustic and pore structure properties is not only applicable from well log data, but also 3-D seismic which spans the entire field.

Lithostratigraphy of Niger Delta: The Cretaceous section has not been penetrated beneath the Niger Delta Basin, the youngest and southern most sub-basin in the Benue-Abakaliki trough (Reijers and others, 1997). Lithologies of Cretaceous rocks deposited in what is now the Niger Delta basin can only be extrapolated from the exposed Cretaceous section in the next basin to the northeast--the Anambra basin. From the Campanian through the Paleocene, the shoreline was concave into the Anambra basin (Hospers, 1965) resulting in convergent longshore drift cells that produced tide-dominated deltaic sedimentation during transgressions and river-dominated sedimentation during regressions (Reijers and others, 1997). Shallow marine clastics were deposited farther offshore and, in the Anambra basin, are represented by the Albian-CenomanianAsu River shale, Cenomanian-Santonian Eze-Uku and Awgushales, and Campanian/Maastrichtian Nkporo shale, among others (Nwachukwu, 1972; Reijers and others, 1997). The distribution of Late Cretaceous shale beneath the Niger Delta is unknown.Figure 2.shows the principal types of oilfield structures in the Niger Delta with schematic indications of common trapping configurations (after Tuttle *et al.* 1999).

MATERIALS AND METHODOLOGY

Materials: The datasets available for this study are geophysical well logs for four (4) wells, consisting of sonic, resistivity, density, neutron and gamma ray logs, Checkshot and 3-D seismic volume data. Schlumberger Petrel 2014 software was used in the data analysis.

METHODOLOGY

Rock Physics and Elastic Property Models: In other to adequately model rocks behavior with respect to fluids types occupying pore space in a reservoir rock, some rock physics properties were determined to observe reservoir attributes in terms of rock physics and reservoir characterization. The properties are P-wave velocity (v_p), P to-S-wave velocity, Acoustic Impedance ($\boldsymbol{Z_p}$) and Shear Impedance ($\boldsymbol{Z_s}$) and velocity ratio.

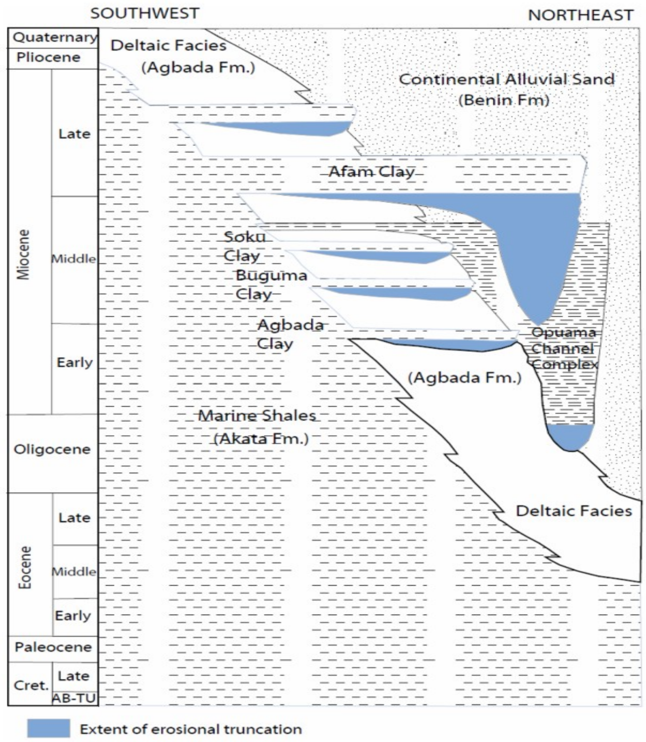

Figure 2. Stratigraphic column showing the 3 formations of the Niger Delta (Kalu *et al.*, 2020)

P-wave and S-wave Velocities: Sonic interval travel time from the sonic log was used to estimate compressional velocity or P-wave velocity (V_p). Using (Ziet *al.*, 2021) equation.

$$V_p = \frac{1000000 \times 0.305}{\Delta t_p} \qquad \text{.................................1}$$

In order to compute the shear velocity (v_s) from P-wave velocity (v_p), P to-S-wave velocity transform (GC) by Greenberg and Castagna (1992), was used, this is near to the mudrock equation of Castagna et al. (1985) in water-saturated siliciclastic rocks,

$$v_s = 0.862\ v_p - 1.172 \qquad \text{.................................2}$$

Where $\Delta t_p$the interval transit times in$\mu sec/ft$,

Acoustic Impedance (Z_p) and Shear Impedance (Z_s): They are properties that describe how much a medium resist the propagation of both an acoustic wave and shear waves as it passes through that medium. When both wave encounters a boundary between two media with different impedances.

$$Z_p = \rho \times V_p \quad \text{.....................................(3)}$$

$$Z_s = \rho \times V_s \quad \text{.....................................(4)}$$

RESULTS AND DISCUSSIONS

The result of this work is presented in derived logs, crossplots, maps, model, and tables. It covers all area of the data analysis from rock physics, petrophysics and seismic interpretation.

Lithology Delineation and Correlation of Reservoirs: Two types of lithostratigraphicwere delineated across the four well locations, Sand and shale lithologies were identified. Twenty four (24) hydrocarbon prospects sand units were marked and correlated across the four wells in the study area. (Sand-1, Sand-2 to Sand-24.), these were reservoirs zones of interest. The well correlation panel reveals the stratigraphy of the study area as shown in Figure 3.

Fluid Type Identification: The presence of water and hydrocarbon (oil and gas) was observed in the reservoir sands based on the resistivity, density and neutron porosity signatures revealing fluid types in the study area. This was observed vertically along the well in Figure 3 and Figure 4.

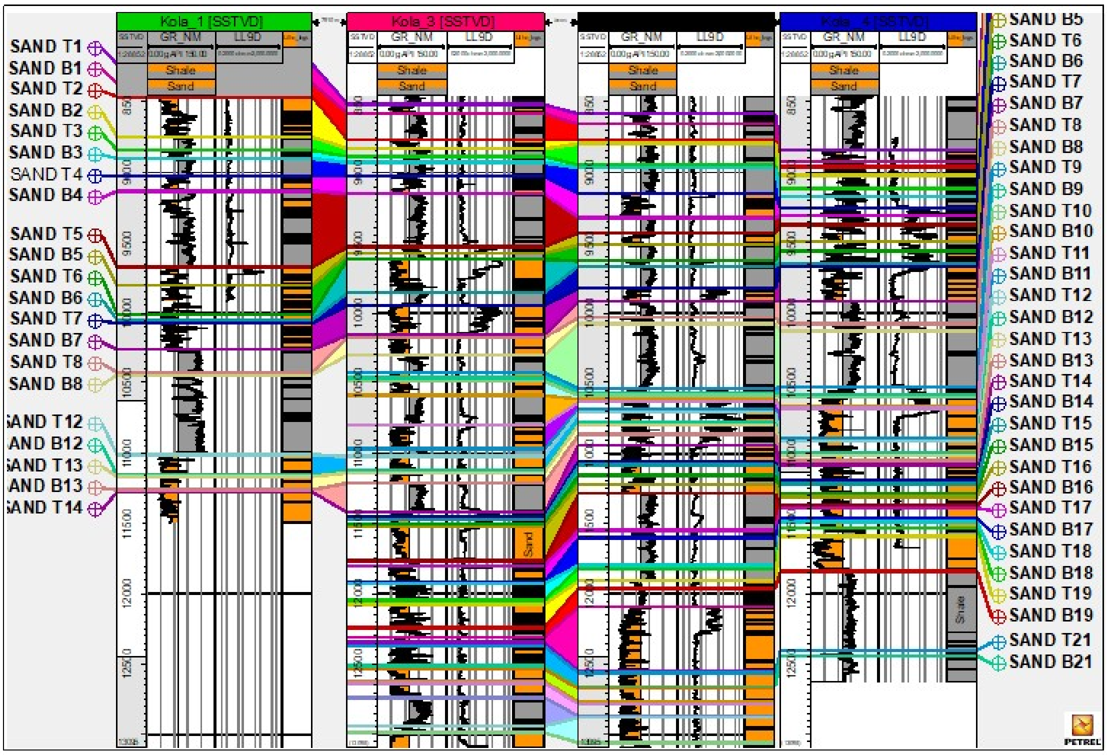

Figure 3. Stratigraphy Well Logs Correlation Panel for the wells

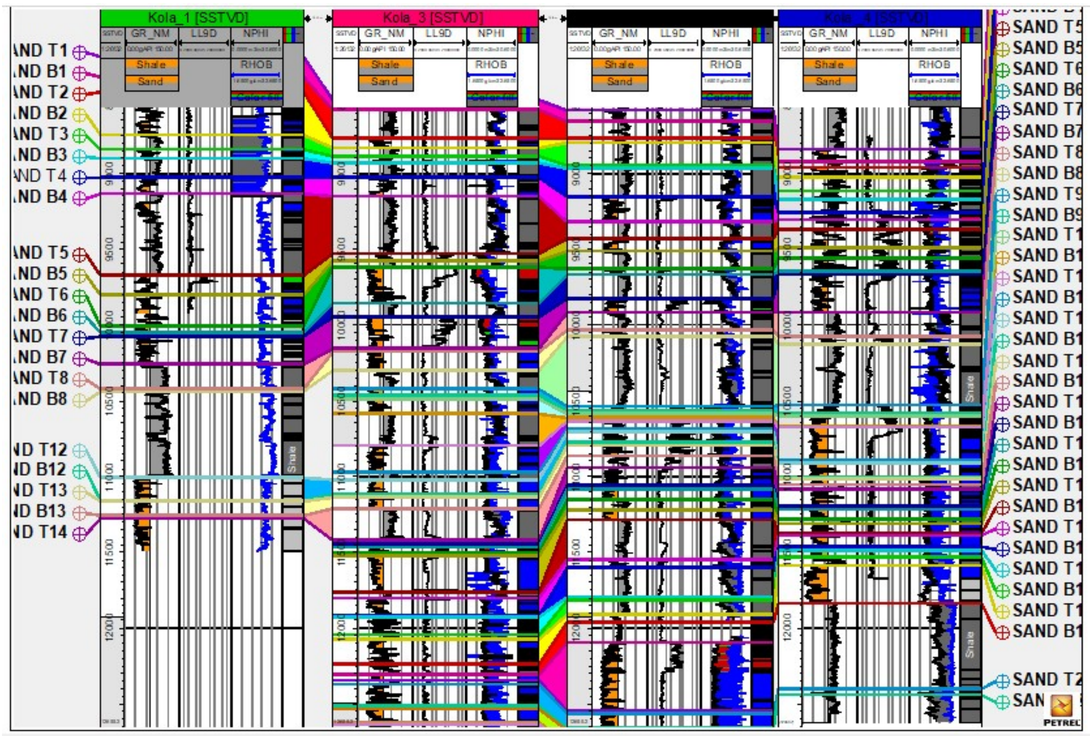

Figure 4. Reservoir Fluid and Analysis

Very high resistivity showed the reservoir sand with gas zone followed by oil prospective zones then water. The parameters revealed the prospective of the reservoirs with respect to oil and gas in place (Olowokere, 2009a, 2009b). The gas is designated with red color, oil with green and water with blue, Figure 4.

Reservoir Properties and Rock Physics Models

Shear Impedance and P_Impedance crossplot: The reservoir sands is characterized by low IP and low IS with water saturation as good reservoir indicator as shown in Figure 5. Shear Impedance and P_Impedance crossplot revealed reservoir quality in terms of good porous medium, permeable and low amount of water saturation together with fluids in place within the sand units pore space.This implies, potential hydrocarbon reservoir with low water saturation. Whereas some sand unit with high Shear Impedance and P_Impedance including shale counterpart, reveal the possibly ofhigh impedance minerals such as calite and dolomite and it could lead to generation of hydrocarbon and storage (Ojo and Olowokere, 2010).

Crossplot of Velocities against Porosity: Velocity and porosity crossplot color coded with gamma ray shows moderate separation between sand and shale base on the porosity values but some overlapped was observed from the velocity which makes it difficult to discriminate lithology from velocity-porosity model as shown in Figure 6. The cross plot reveal evidence of fluid saturation and lower rock density in both lithologies due to high porous media.The velocity of sand is relatively lower compare to that of shale and high porosity which suggests makes it apotential reservoir rock. This confirmed the presence of hydrocarbon in the reservoirs sand units.

Crossplot of Velocities ratio against Acoustic Impedance: The possible saturation of hydrocarbon in the study area is analyzed on cross plot of Vp/Vs ratio against Acoustic Impedance using porosity, volume of shale and fluid types as indicators shown in Figure 7a and 7b respectively. These show clusters of good reservoirs sand in the crossplot with high porosity and lower shale volume distribution. Vp/Vs ratio is one of the fluid indicator properties within rock units because it help to analysis sensitivity of compressional waves to fluid changes.

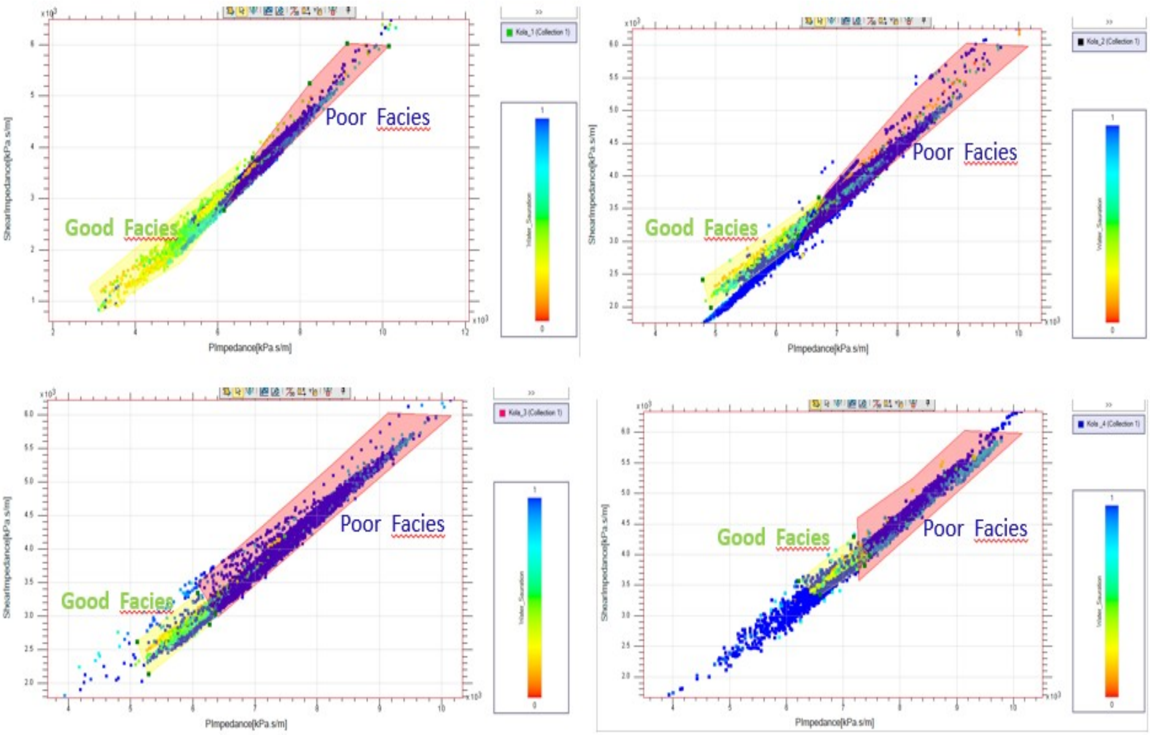

Figure 5. Acoustic Impedance against Shear Impedance Cross plot with water saturation as indicator in "Kola" 1, 2,3 and 4

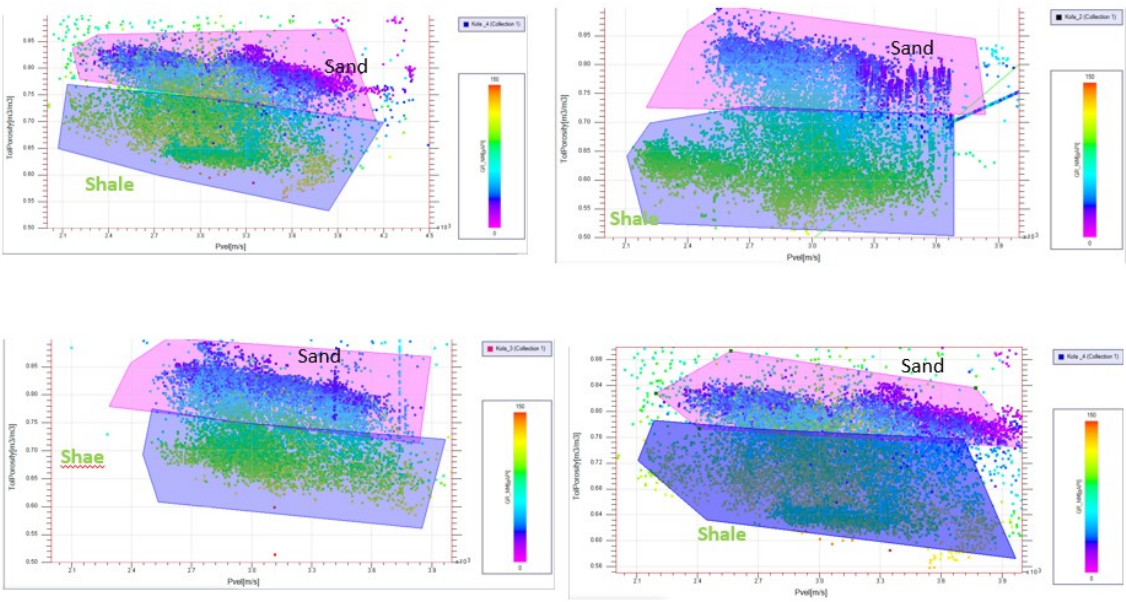

Figure 6. Crossplot of Velocities against Porosity color coded with gamma ray for ADE wells

This implies that the sand is highly porous and serve as good medium for high hydrocarbon accumulation. Increases in impedance revealed the presence of gas-saturated sands to brine sands due to consistent decrease in bulk density values (Abe et.al, 2018).For emphasis in Figures 7cgas sands is observed at relatively high Vp/Vs ratio, with very low impedances. Meanwhlie, shale show lower Vp/Vs and high acoustic impedance values than sand, therefore acoustic impedance and Vp/Vs ratio are suitable for identifying the fluid type within a reservoir unit, (Olowokere and Ojo, 2010) These two (Acoustic impedance and Vp/Vs ratio) reveal cluster of gas-sand, brine-sand and wet shale.This also established the fact that in high porous medium cause acoustic impedance decreases. Hence, the result showed that areas with low porosity correlate with high acoustic impedance values, while areas with high porosities revealed low acoustic impedance.Dorcas et.al., (2020).

Structural model provide detail information about the subsurface geologic of the zone of interest with respect rock physics properties within the study area. The interpretation is based on d 3D grid cell which show several vertical layers as main horizon in to the pillar gridding, and this revealed thickness of each lithologic layers. The distributions of different estimated rock properties within the zones of interest(reservoirs rocks) in the study is observed in 3D models for few rock physic properties (Acoustic Impedance and Shear Impedance) and reservoir properties (Shale Volume, Porosity, and Water saturation) Figure 8 and 9. This explained both lateral and vertical distribution of the rock physics properties in response to fluid type within the reservoir rock.

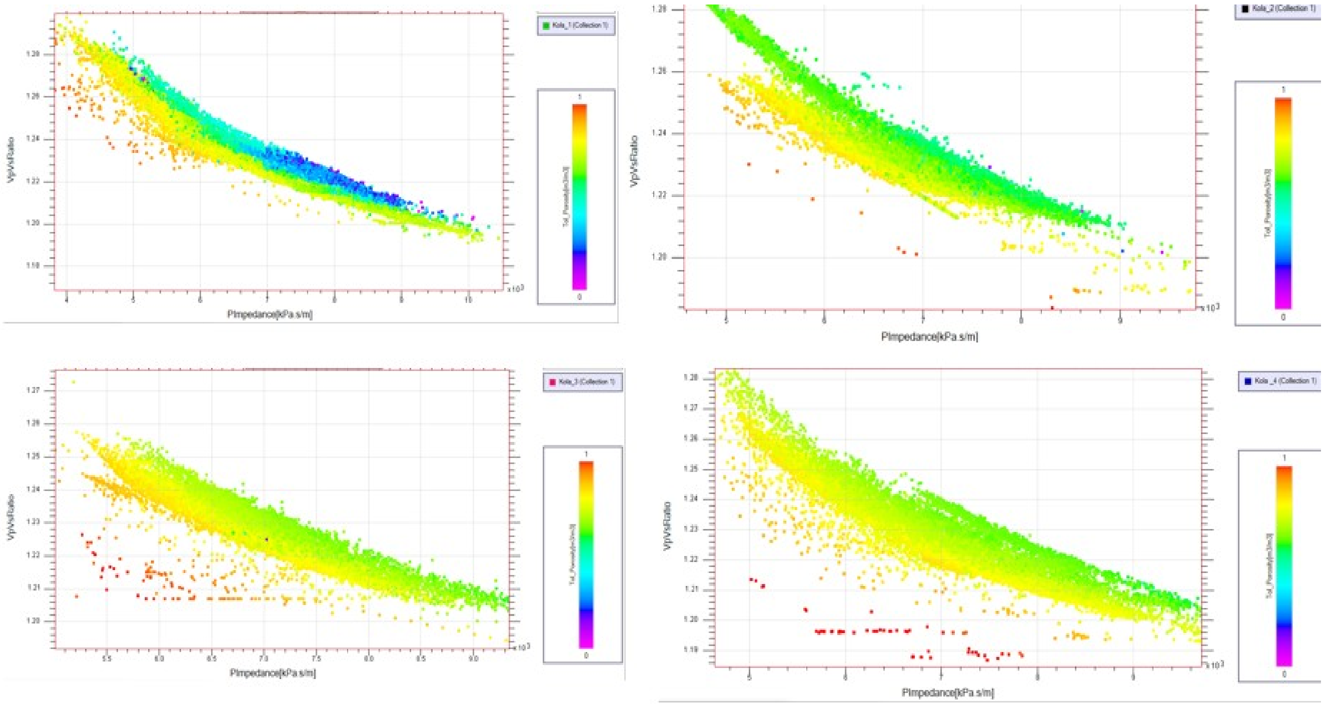

Figure 7a. Cross plot of Vp/Vs ratio against Acoustic Impedance with Porosity as indicator in "Kola" 1, 2 4 and 10

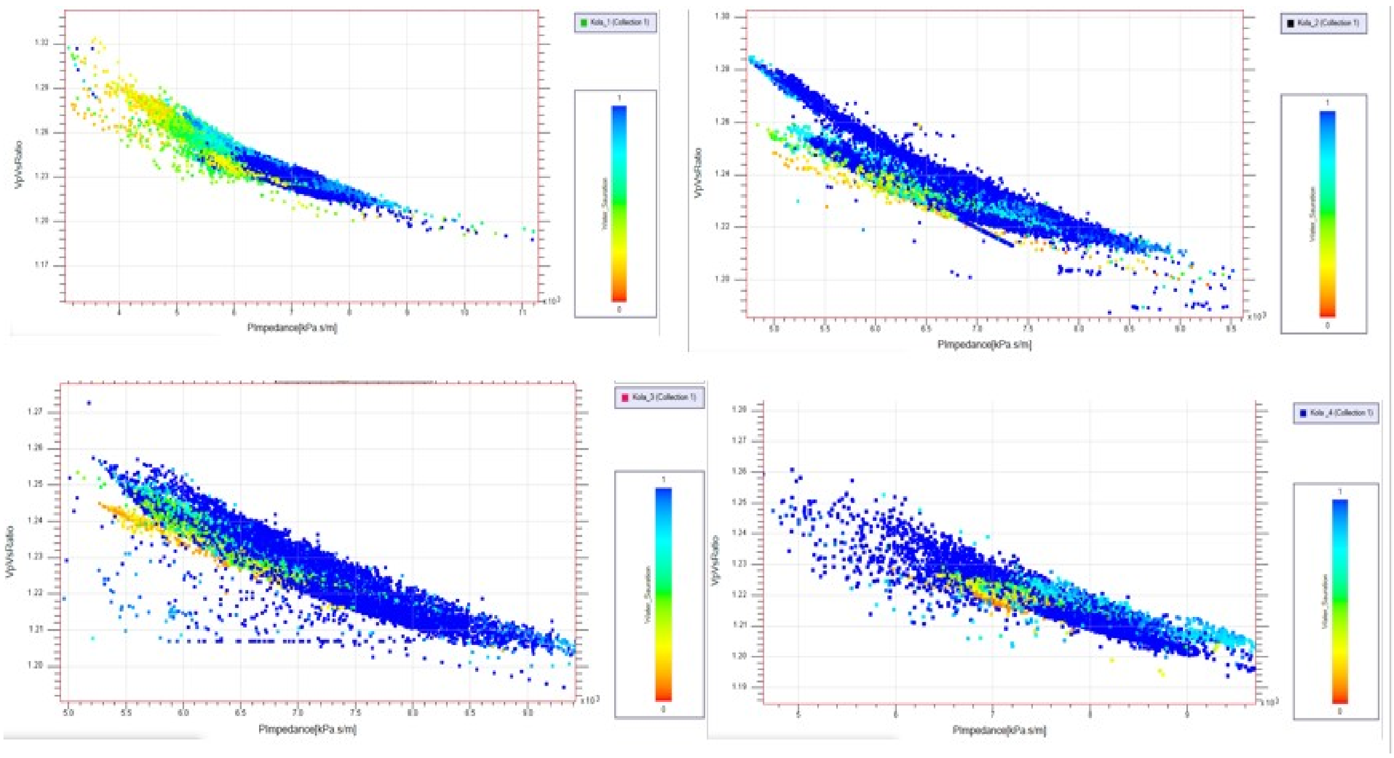

Figure 7b. Cross plot of Vp/Vs ratio against Acoustic Impedance with Water saturation as indicator in "Kola" 1, 2 4 and 10

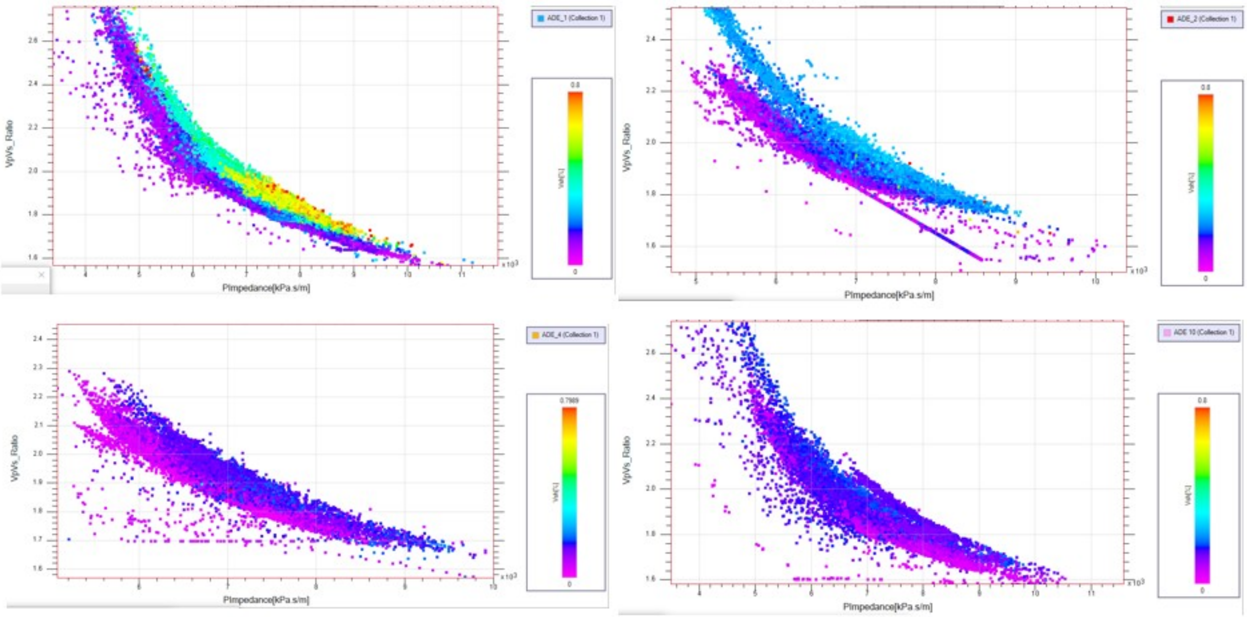

Figure 7b. Cross plot of Vp/Vs ratio against Acoustic Impedance with shale volume as indicator in "Kola" 1,2 4 and 10

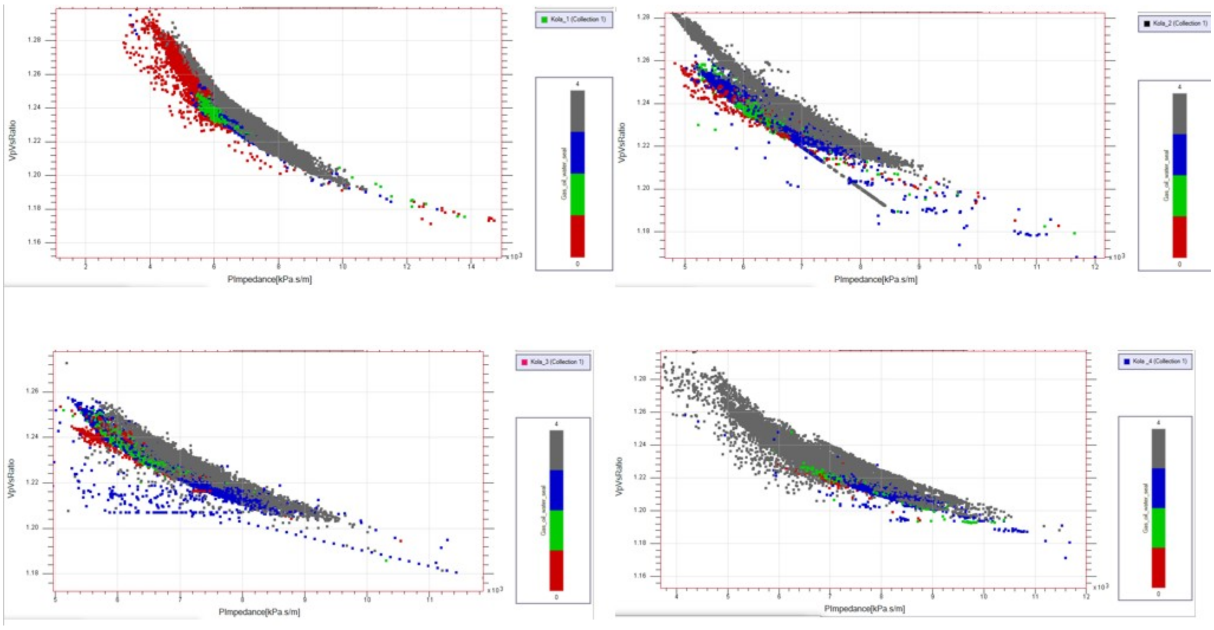

Figure 7c. Cross plot of Vp/Vs ratio against Acoustic Impedance with fluid type as indicator in "Kola" 1, 2 4 and 10

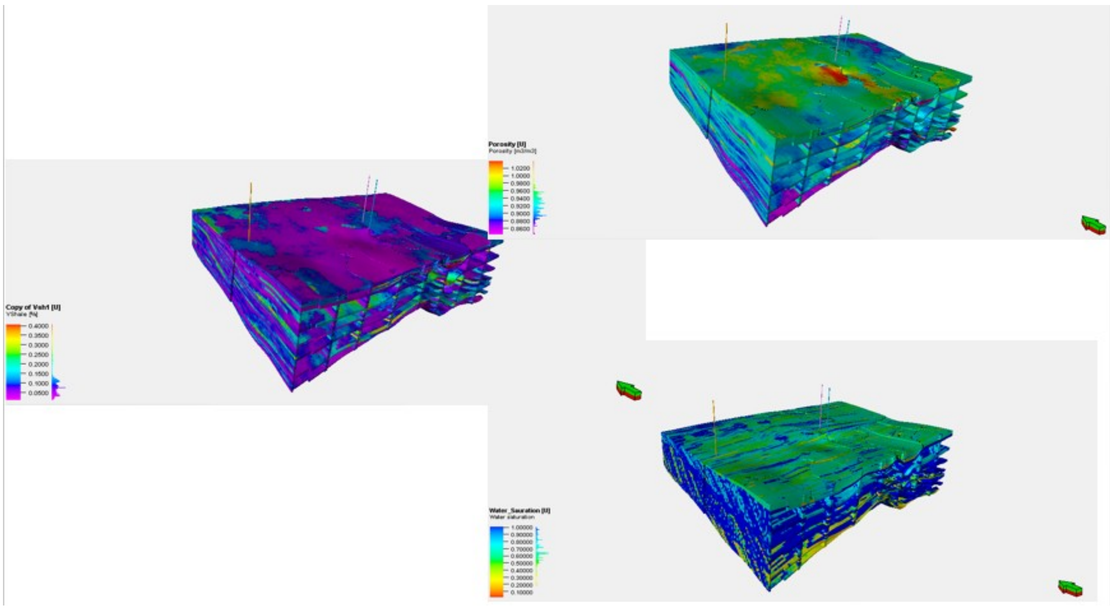

Figure 8. 3D Shale Volume, Porosity, and Water saturation Models

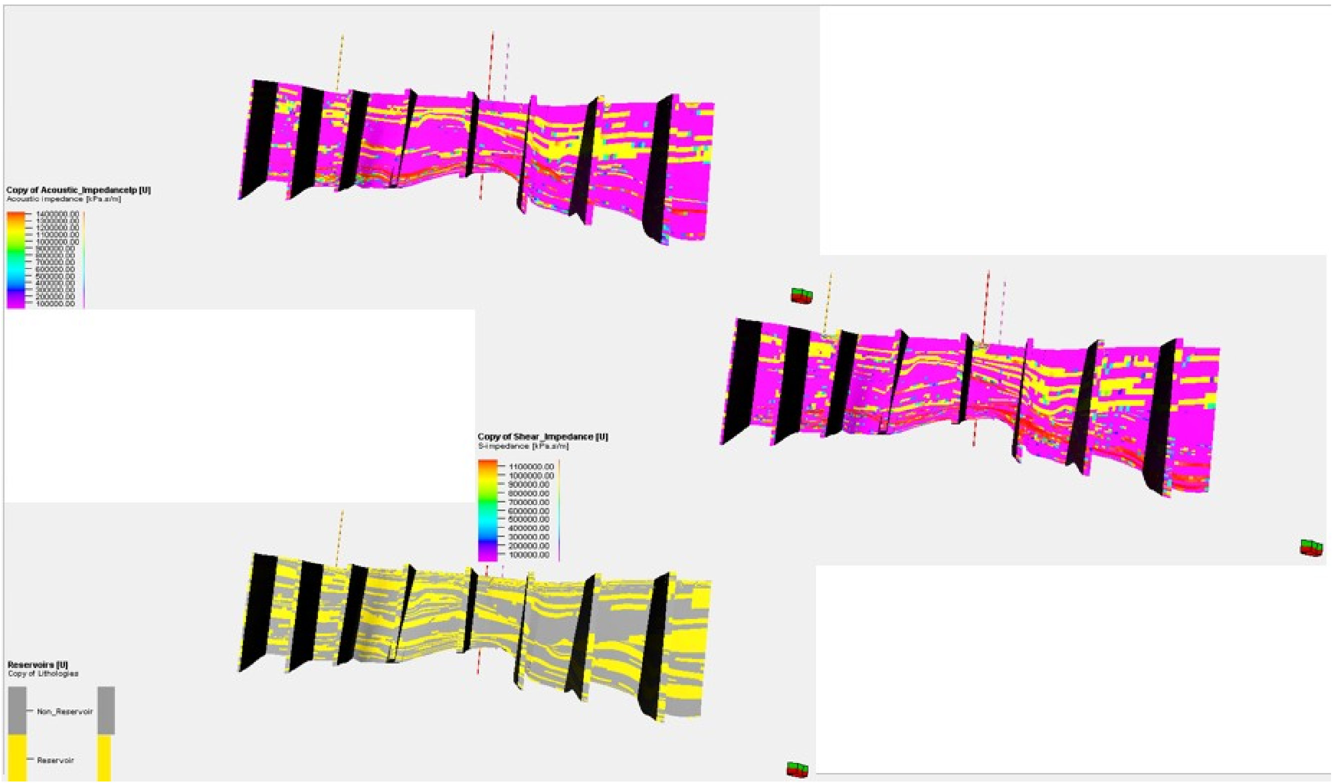

Figure 9a. 3D Acoustic Impedance, Shear Impedance and Reservoir Models

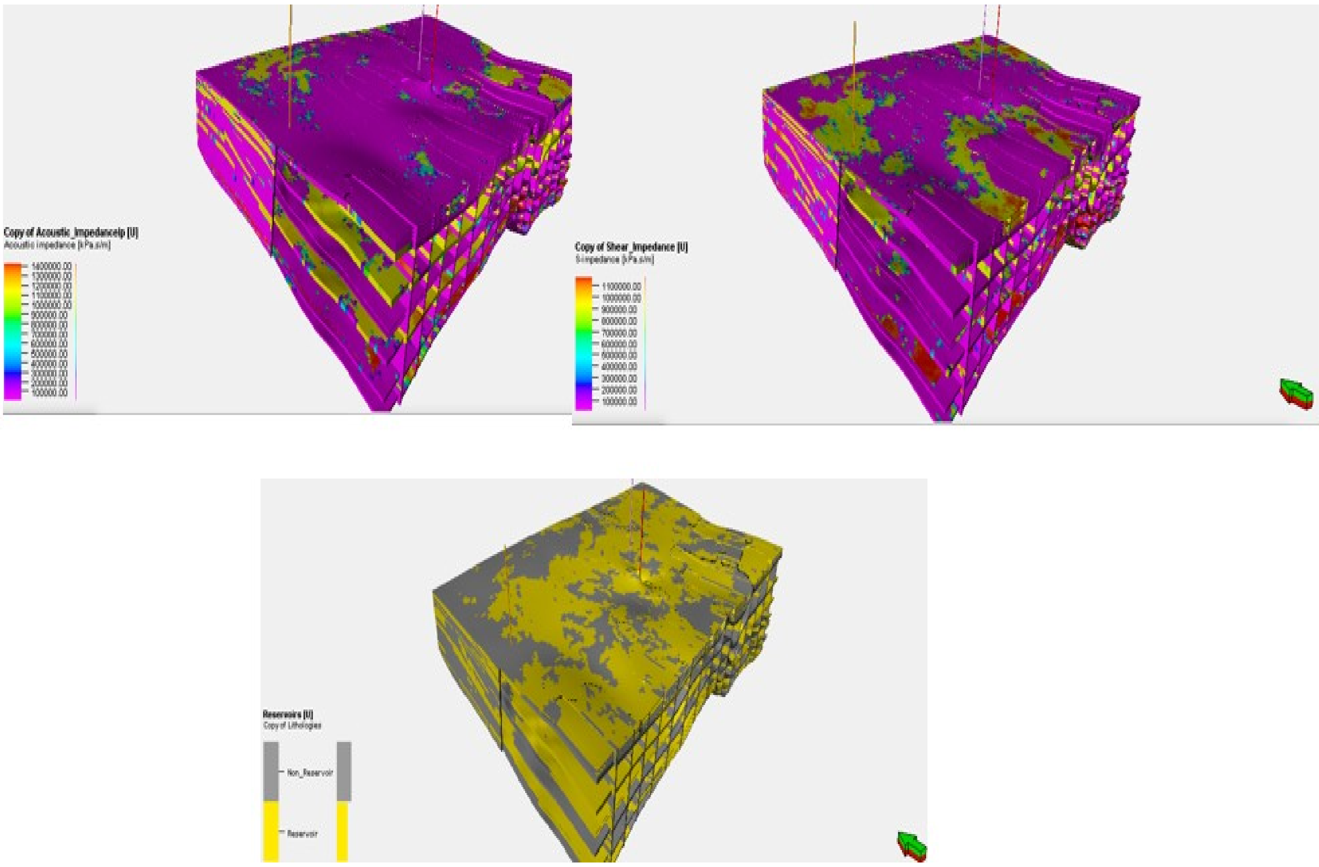

Figure 9b. 3D Acoustic Impedance, Shear Impedance and Reservoir Models

CONCLUSIONS AND RECOMMENDATIONS

Unlike compressional waves (P-waves), which can travel through both liquids and solids, shear waves (S-waves) only travel through solids because fluids do not support shear stresses. The reservoir characterization confirmed the two major lithological units, (sand and shale) within the study area as parts of Niger Delta.

Twelve (12) Reservoir sands containing hydrocarbon were identified across the four (4) wells.There is evidence of good interconnection of pores in the reservoir sands implying good porous media.It was observed that rock physic parameters cross plots of relevant properties such as porosity, P-wave velocity,Vp/Vs ratio, Acoustic Impedance, shear Impedance, revealed that the reservoir sand relatively has higher production rate in term of porous medium, water saturation shale volume, geology factors, fluid in place and entrapments by the seal. Observed response from the different rock physic properties is due to change in fluid type within the sediments.The reservoirs zones are characterized as good reservoirs body. Although, the porosity and velocity discrimination of the fluids and lithology with depth is complex, this may be due to different behavior velocity at different porous media. Vertical and spatial distribution of the geologic, elastic and rock physic properties within the zone of interest (hydrocarbon zones) were inferred from 3D structural models.

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