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Esomchi Nwokoma[1]
ORCID: 0000-0002-0680-0469

Okechukwu Ebuka Agbasi[2]
ORCID: 0000-0001-5649-0107

Obinna Christian Dinneya[3]
ORCID: 0000-0002-2024-6863

PREDICTION OF LITHO-POROSITY USING INCOMPRESSIBILITY AND RIGIDITY, OFFSHORE NIGER DELTA, NIGERIA

[1] Department of Physics, College of Physical Science, Michael Okpara University of Agriculture, Umudike, Nigeria
[2] Department of Physics, College of Physical Science, Michael Okpara University of Agriculture, Umudike, Nigeria;
Geophysics Unit, Geookan Nigerian Limited, Eket, Nigeria
agbasi.okechukwu@gmail.com
[3] Department of Physics, College of Physical Science, Michael Okpara University of Agriculture, Umudike, Nigeria

Abstract

The computed velocity ratio and Poisson's ratio were used to calculate the pore fluid and lithology content. The gas sand, oil sand, and brine sand were identified using velocity ratio and Poisson's ratio analyses. The velocity ratio and Poisson's ratio study supported the gas sand anticipated by the rock physics analysis using lambda-mho and mu-rho. The velocity ratio and Poisson's ratio analyses were used to better define the wet sand anticipated by the lambda-mho and mu-rho rock physics analyses. Lithology and pore fluid determination are very essential for the exploration and production of hydrocarbons. The wet sand from the rock physics analysis of lambda-mho and mu-rho was predicted to comprise oil sand and brine sand. The value of lambda-mho is between 21.74 and 25.67; for mu-rho is between 16.34 to 23.21; for Poisson's ratio is between 0.25 to 0.29; and for V_p/V_s ratio is between 1.74 to 1.83. These confirm the presence of oil sand in all the seven (7) reservoirs studied in two (2) wells. All the reservoirs fall between the Agbada region (10212.50 – 11741.00 ft) and have a very good net pay zone ranging from 41.50 ft to 193.00 ft in the Niger Delta region, Nigeria. The obtained velocity ratio and Poisson's ratio were used to calculate the pore fluid content. The gas sand, oil sand, and brine sand were identified using velocity ratio and Poisson's ratio analysis. The velocity ratio and Poisson's ratio studies supported the gas sand anticipated by the rock physics analysis using lambda-mho and mu-rho. The velocity ratio and Poisson's ratio analyses were used to better define the wet sand anticipated by the lambda-mho and mu-rho rock physics analyses. The moist sand anticipated by the rock physics studies of lambda-mho and mu-rho was oil sand and brine sand.

Keywords*:* density, lambda-rho, mu-rho, velocities

PRZEWIDYWANIE POROWATOŚCI SKAŁ NA PODSTAWIE BADAŃ NIEŚCIŚLIWOŚCI I SZTYWNOŚCI W DELCIE RZEKI NIGER, NIGERIA

Abstrakt

Do obliczenia zawartości płynu porowego i zbadania litologii zastosowano współczynnik prędkości i współczynnik Poissona. Piaski gazonośne, roponośne i solankonośne zidentyfikowano na podstawie analizy współczynnika prędkości i współczynnika Poissona. Badania w oparciu o współczynnik prędkości i współczynnik Poissona potwierdziły występowanie piasku gazonośnego, na co wskazywała analiza właściwości fizycznych przy użyciu lambda-mho i mu-rho. Analizy współczynnika prędkości i współczynnika Poissona zastosowano dla lepszego zdefiniowania piasku mokrego przewidzianego przez analizy właściwości fizycznych skały za pomocą lambda-mho i mu-rho. Określenie litologii oraz zawartości płynu porowego jest bardzo ważne w procesie poszukiwania i pozyskiwania węglowodorów. W wyniku analizy właściwości fizycznych skały za pomocą lambda-mho i mu-rho przewidziano, że piasek mokry zawiera piaski roponośne i solankonośne. Wartość lambda-mho waha się pomiędzy 21,74 a 25,67; a wartość mu-rho wynosi 16,34 – 23,21; współczynnik Poissona ratio wynosi 0,25 – 0,29; a V_p/V_s waha się pomiędzy 1,74 a 1,83. Potwierdza to obecność piasku roponośnego we wszystkich siedmiu (7) złożach badanych w dwóch (2) odwiertach. Wszystkie złoża znajdują się w regionie Agbada (10212,50 – 11741,00 stóp) i mają bardzo dobrą strefę opłacalności netto – 41,50 do 193,00 stóp w rejonie delty Nigru (Nigeria). Otrzymane współczynniki prędkości i Poissona wykorzystano do wyliczenia zawartości płynu porowego. Piaski gazonośne, roponośne i solankonośne zidentyfikowano na podstawie analizy współczynnika prędkości i współczynnika Poissona. Badania za pomocą współczynników prędkości i Poissona potwierdziły występowanie piasku gazonośnego, przewidzianego przez analizę właściwości fizycznych skały, przy użyciu lambda-mho i mu-rho. Współczynniki prędkości i Poissona wykorzystano dla lepszego określenia piasków mokrych, przewidzianych przez analizy właściwości fizycznych skały, przy użyciu lambda-mho i mu-rho. Najwięcej piasków przewidzianych przez badania nad właściwościami fizycznymi skały, przy użyciu lambda-mho i mu-rho stanowiły piaski roponośne i solankonośne.

Słowa kluczowe: gęstość, lambda-rho, mu-rho, prędkości

1. INTRODUCTION

A well's lithology may be used to calculate a variety of factors, including the critical pore fluid volume. Lithology is the study of the types of rocks found in the Earth's crust. A sedimentary rock with pore space is required to be a suitable hydrocarbon storage rock. Determining lithology and pore fluid is critical for efficient hydrocarbon exploration and production [1, 2]. A hydrocarbon field's economic viability is also dependent on the quality and accuracy of its lithological investigation. The increasing difficulties in conventional (reservoirs requiring operations outside standard operating methods) and unconventional (reservoirs requiring operations outside conventional operating practices) reservoirs have made precise forecasting critical. The proper determination of lithology aids in the decision-making process in petroleum engineering [3, 4].

Using core samples acquired from subsurface formations, lithology and pore fluid may be identified clearly. Core sample analysis is costly and normally requires a significant amount of time and effort to acquire good results. This approach cannot be used on all of the drilled wells in a field. Based on their individual observations and analyses, different geoscientists may derive contradictory results [5, 6]. Well logging has the additional benefit of covering the entire geological formation of interest as well as providing extensive and detailed data about the subsurface formations.

Well logging is a technique for continuously documenting the physical properties of a geological formation as they change over time or depth. The hydrocarbon industry's first loggers were Marcel and Conrad Schlumberger. Well logs may be used to identify the hydrocarbon bearing zone, compute the number of hydrocarbons, measure porosity and permeability, identify lithology, and so on. The lithology and pore fluid composition of hydrocarbon reservoirs have been effectively predicted using well logs. Ogungbemi [7] predicted the lithology of Nigeria's „Benin River Field" using the ratio of compressional and shear wave velocities and their travel durations. Despite the effectiveness of identifying gas sand, brine sand, and shale using well logs, rock physics analysis cannot be used to detect oil sand.

To minimise improper petrophysical parameter estimation, an effective method of assessing lithology and pore fluid should be adopted [8]. In a conceivable scenario, a clean formation will not be encountered, in which case this assumption might be made, but the attributes derived will be inaccurate. Well logs have been used to develop standard ways of well log interpretation, such as merging and cross-plotting log data. These conventional methodologies are ineffective when dealing with massive volumes of different reservoir data. This method combines petrophysics and rock physics studies to forecast lithology and pore fluids [9].

Petrophysics is largely used in the hydrocarbon sector to investigate reservoirs. Methods for estimating a single attribute at a time are used in petrophysical analysis [10]. The pores can range in size from sub-microns in tight sandstones to centimetres in vuggy carbonate rocks [11]. The study's major goal is to forecast the lithology and pore fluid of a reservoir in the Niger Delta Region using density, compressional, and hear wave velocity logs as input.

2. LOCATION AND GEOLOGICAL SETTING OF THE STUDY AREA

The Niger Delta basin is a passive continental margin extensional rift basin found along Nigeria's western coast, between the Niger Delta and the Gulf of Guinea, with documented access to Cameroon, Equatorial Guinea, and Sao Tome and Principe. The basin is incredibly complex, and it is economically significant due to its abundant hydrocarbon system. The Niger Delta basin is a large subaerial basin in Africa. It has a subaerial area of approximately 75,000 km^2, a total area of 300,000 km^2, and a sedimentary fill of 500,000 km^3. The depth of the sediment fill ranges from 9 to 12 kilometres [12]. It is composed of several geologic formations that demonstrate how this basin formed as well as regional and large-scale tectonics in the area. It is surrounded by numerous other basins formed by similar processes [13]. It is located in the Benue valley's southernmost section, which is bounded by the Cameroon volcanic line and the transform passive continental margin.

During oil exploration and production, the stratigraphy of the Niger Delta clastic wedge has been recorded; nevertheless, most stratigraphic schemes remain exclusive to the major oil firms active in the Niger Delta region. The Niger Delta's composite tertiary sequence is made up of the Akata, Agbada, and Benin formations in increasing order [14]. They are made up of an estimated 28,000 ft (8,535 m) segment of the delta's approximate depocenter in the centre [15]. The age of the basin ward decreases, indicating the general regression of depositional conditions inside the Niger Delta clastic wedge, which is stratigraphically comparable to these three formations in eastern Nigeria.

The formations are the result of a gross coarsening upward progradational clastic wedge deposited in marine deltic and fluvial settings. The distribution of strata in the majority of the Niger Delta's hydrocarbon accumulations have been identified in Agbada formation sandstones and are largely confined to roll-over anticlines fronting growth faults [16]. The amount of accumulation may or may not be limited by judgement growth faults or antithetic faults cutting the anticline. The Akata formation is the largest source rock in terms of volume, and its burial depth is commensurate with the depth of the oil window.

3. METHODOLOGY

3.1. Data Acquisition

The logging process can be done during or after the well is drilled. Below, there is a description of the data collection procedure. Well log data can be a source of essential information capable of defining and describing reservoirs and other important parameters. Ten wells have been considered for this thesis. This well was chosen because of the compressional wave velocity log, shear wave velocity log, and density log present were in good condition.

The methodology employed for this research is listed below:

1. loading of the input logs (density, compressional, and shear wave logs),
2. conditioning, editing, and reconstruction of input logs,
3. developing a programme to compute velocity ratio, Poisson's ratio, and Lamé parameters,
4. data analysis for petrophysics and rock physics.

These steps were carefully carried out to avoid or reduce errors. The research methodology in chronological order is presented above.

3.2. Data loading from well logs

The density, compressional wave velocity, and shear wave velocity logs of the wells were imported and displayed using the Interactive Petrophysics Software. The Kelly bushing elevation, log type, and unit were specified prior to the display of the log data.

3.3. Log conditioning and modification

Well log data is often regarded by geophysicists as „hard data" because the probing instruments take the measurements from a very close range to the rocks under in-situ conditions. Hence, well logs are not exposed to the same rigorous editing and conditioning as seismic data. This can be a source of error because log data is exposed due to geological complexities, uncertainties in measurement, etc. Almost all well log data needs to be edited and corrected before interpretation of the log. These corrections are applied to eliminate or reduce errors such as: mud filtrate invasion, gaps, deficient log data, etc. Editing and conditioning of well logs is usually generalised if not ignored prior to rock physics application and geophysical modeling. Frequent editing of well log data would require depth shifting, estimation of pseudo-data to replace bad log data, and invasion corrections (if necessary) [17]. The editing process is often oversimplified by geophysicists because these edits are below seismic resolution [18]. However, prior to any log-based seismic models, log editing should be executed carefully to avoid inaccurate assumptions and seismic amplitude response. The density and compressional wave velocity logs used for the study were of good quality. However, the shear wave velocity log had a gap. The error due to the gap (the red line in the Vs log) was corrected using the spline interpolation technique. One gap was identified; however, the quantity of unrecorded data can be estimated.

4. RESULTS AND DISCUSSION

4.1. Sand and shale discrimination using velocity ratio

The fundamental purpose of well log analysis is to use log data as a baseline to identify clean sand from shale and to indicate zones of interest, i.e., hydrocarbon-filled clean sand [19]. Lithology was determined using the velocity ratio and gamma ray logs. V_p logs may be used to assess lithology, porosity, and pore fluid. Despite their importance, V_p logs are impacted by three unique properties of rocks, namely density, mass, and shear moduli, making V_p difficult to estimate for lithology. In contrast, the V_p/V_s ratio is density independent and may be used to construct Poisson's ratio, a significantly more diagnostic lithological indication [20]. An imaginary line was drawn to distinguish sand from shale using a shale baseline of 1.80. The gamma ray values in discerning our sand-shale interface correlate to deflection to the right of the baseline representing shale and deflection to the left of the baseline representing sand. Figures 1 and 2 depict sand and shale strata using the velocity ratio log (from the velocity panel).

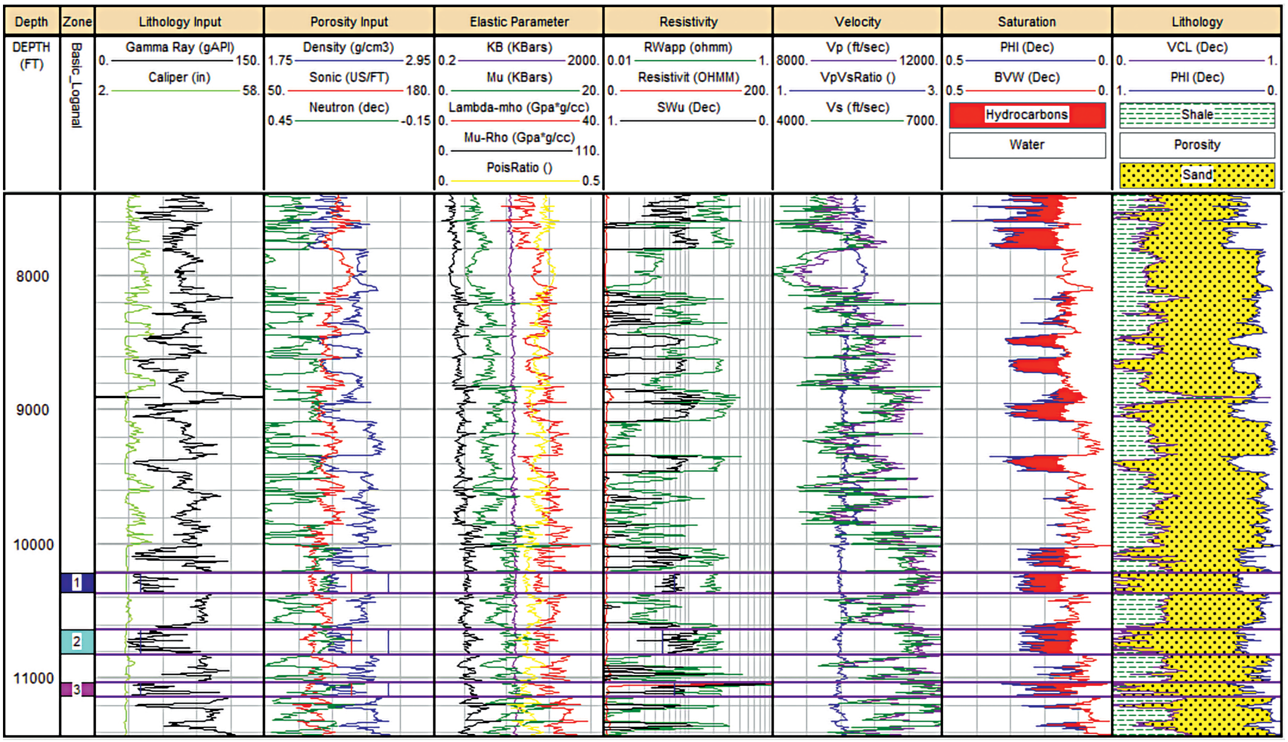

Fig. 1. Composite log suite for well AG 60. (Velocity Panel V_p/V_s Blue line)
Ryc. 1. Złożony pakiet log dla odwiertu AG 60. (Panel szybkości V_p/V_s linia niebieska)

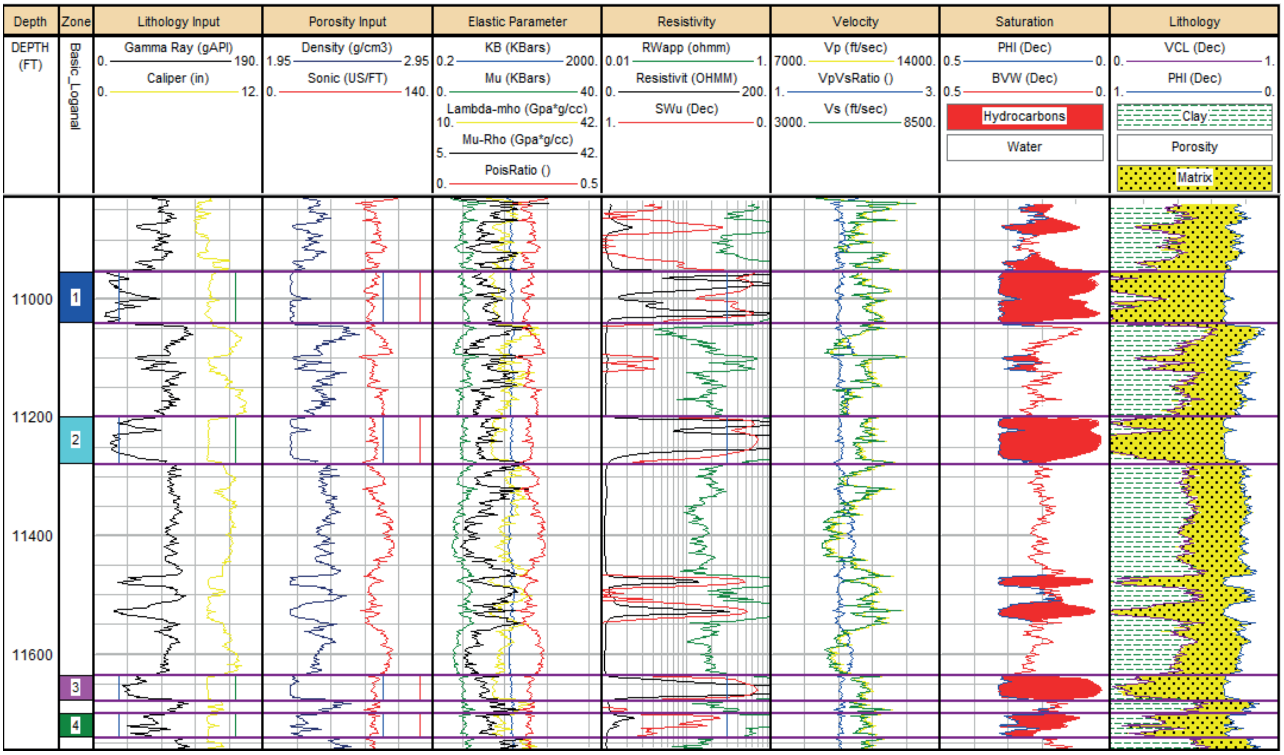

Fig. 2. Composite log suite for well AG 10. (Velocity Panel V_p/V_s Blue line)
Ryc. 2. Złożony pakiet log dla odwiertu AG 10. (Panel szybkości V_p/V_s linia niebieska)

4.2. Lithology prediction using Lamé parameters

The velocity ratio can be used to tell sand from shale. The disadvantage of lithology discriminating using velocity is compensated for by lithology prediction using the Lamé parameter. For the well's thorough lithology forecast, the Lamé parameter, which is fluid and lithology sensitive, was applied. Goodway [21] recognised the use of the Lamé parameter in determining reservoir properties. Goodway [21] encouraged the use of relationships between Lamé parameters λ (incompressibility) and μ (rigidity), and ρ (density) and how they can be used to differentiate lithology and identify gas sand. Lambda (λ) and mu (μ) are very sensitive to pore fluid and rock matrix, respectively. Lamé parameters help interpreters better understand rock physics. Mu-rho (μρ) referred to as rigidity, is the „resistance to strain resulting in shape change with no volume change" [22]. Mu-rho (μρ) is very useful for discriminating lithology. The fact that sand has a higher mu – rho than overlying shale is a unique result of this methodology. Lambda-mho (λρ), usually referred to as incompressibility, is useful for fluid detection and discrimination.

Research has shown that hydrocarbon-filled sandstone is less dense than water-filled sandstone. Hence, hydrocarbon-filled sandstone has low Lambda-mho (λρ) values. Pore fluid and mineral properties affect the lithology of a formation. From the Lamé parameters calculated, a cross plot of the difference between Lambda-mho-Mu-Rho and density was carried out and analyzed. The bulk modulus (KB), shear modulus (Mu), Lambda-mho (λρ) and Mu-Rho (μρ) are shown in the elastic parameter panel in figures 1 and 2.

The crossplot of Lambda-mho-Mu-Rho and density for the wells are shown in figures 3 to 6, alongside with the crossplot of Lambda-mho-Mu-Rho and density, in the reservoir identified in each of the wells.

From the crossplot analysis, the various lithologies and fluids were detected and mapped as gas sand, wet sand, and shale. The sandstone reservoir in all the wells corresponds to a low incompressibility (lambda) but high rigidity (mu). This affirms the fact that, λ, μ, and ρ are good for detecting gas-filled sand, wet sand, and shale.

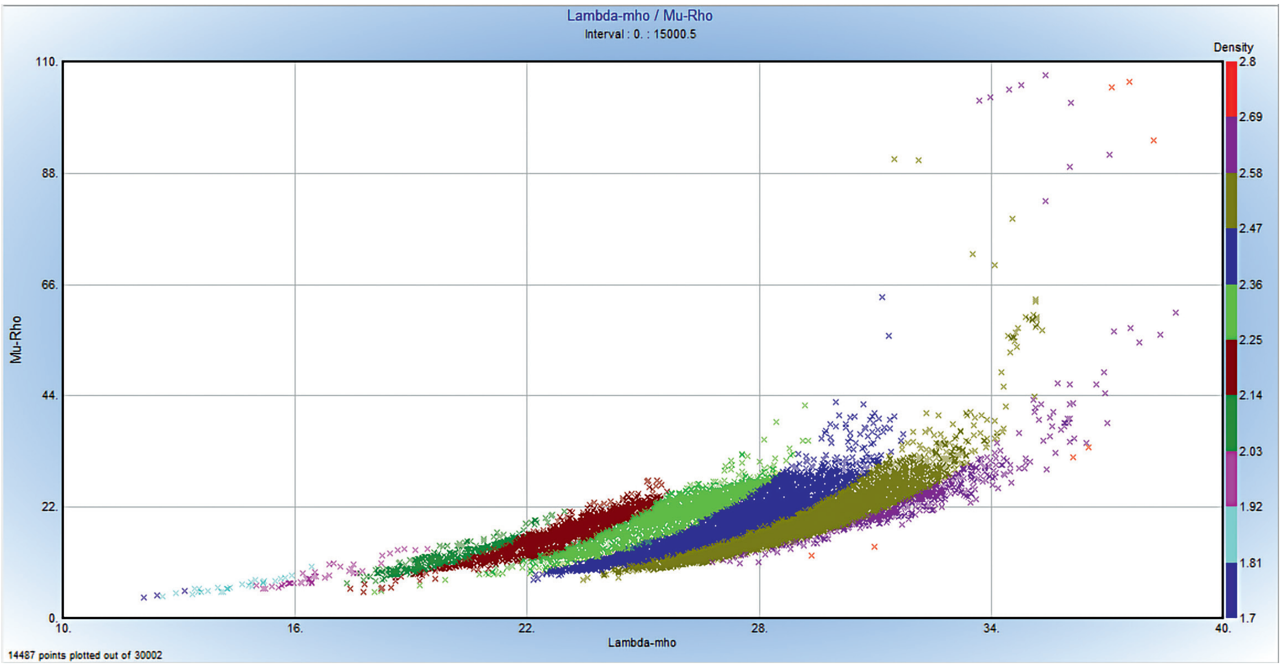

Fig. 3. Crossplot of Lambda-mho-Mu-Rho and density well AG 60
Ryc. 3. Wykres Lambda-mho-Mu-Rho i gęstości, odwiert AG 60

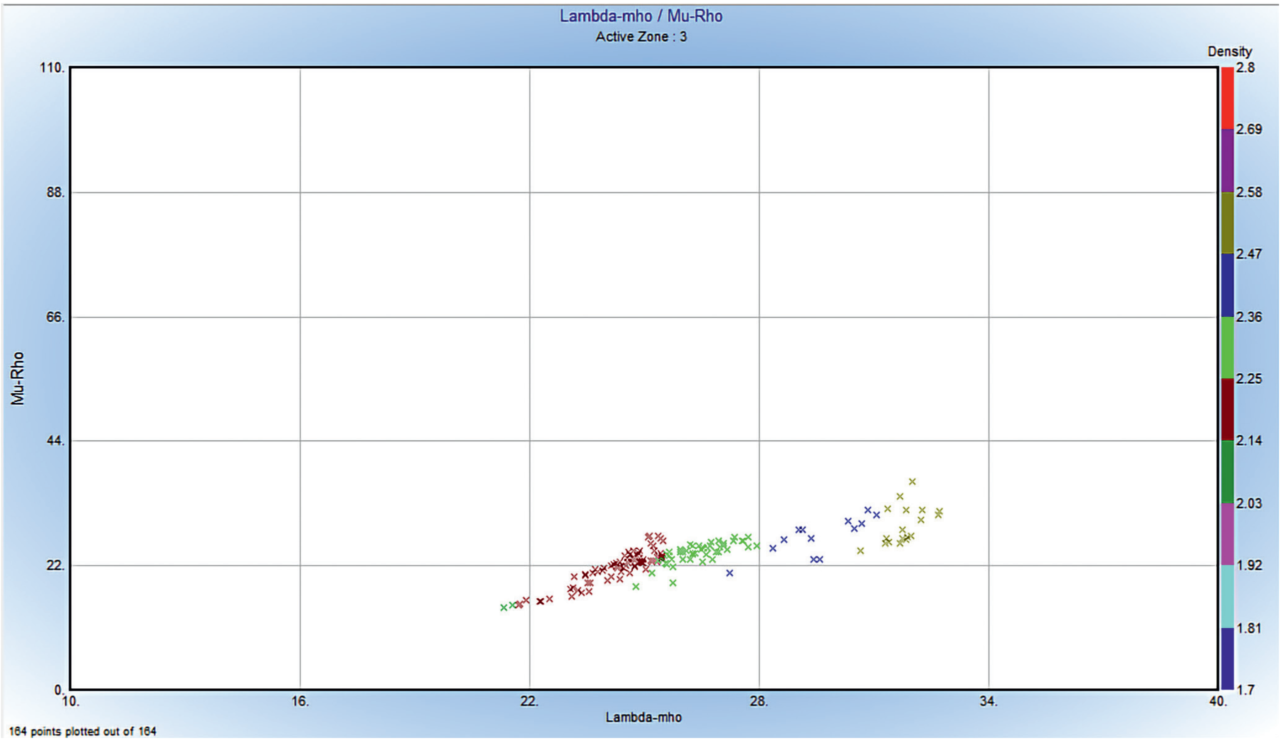

Fig. 4. Crossplot of Lambda-mho-Mu-Rho and density well AG 60 for reservoir 3
Ryc. 4. Wykres Lambda-mho-Mu-Rho i gęstości, odwiert AG 60 dla złoża 3

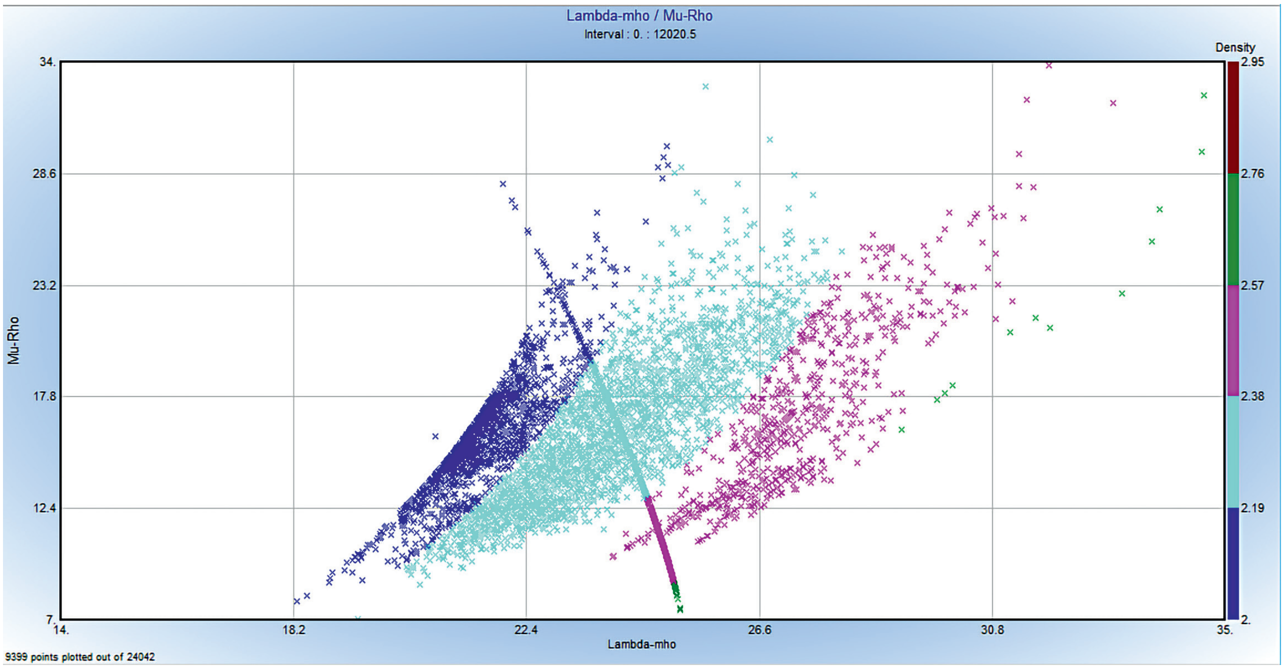

Fig. 5. Crossplot of Lambda-mho-Mu-Rho and density well AG 10
Ryc. 5. Wykres Lambda-mho-Mu-Rho i gęstości, odwiert AG 10

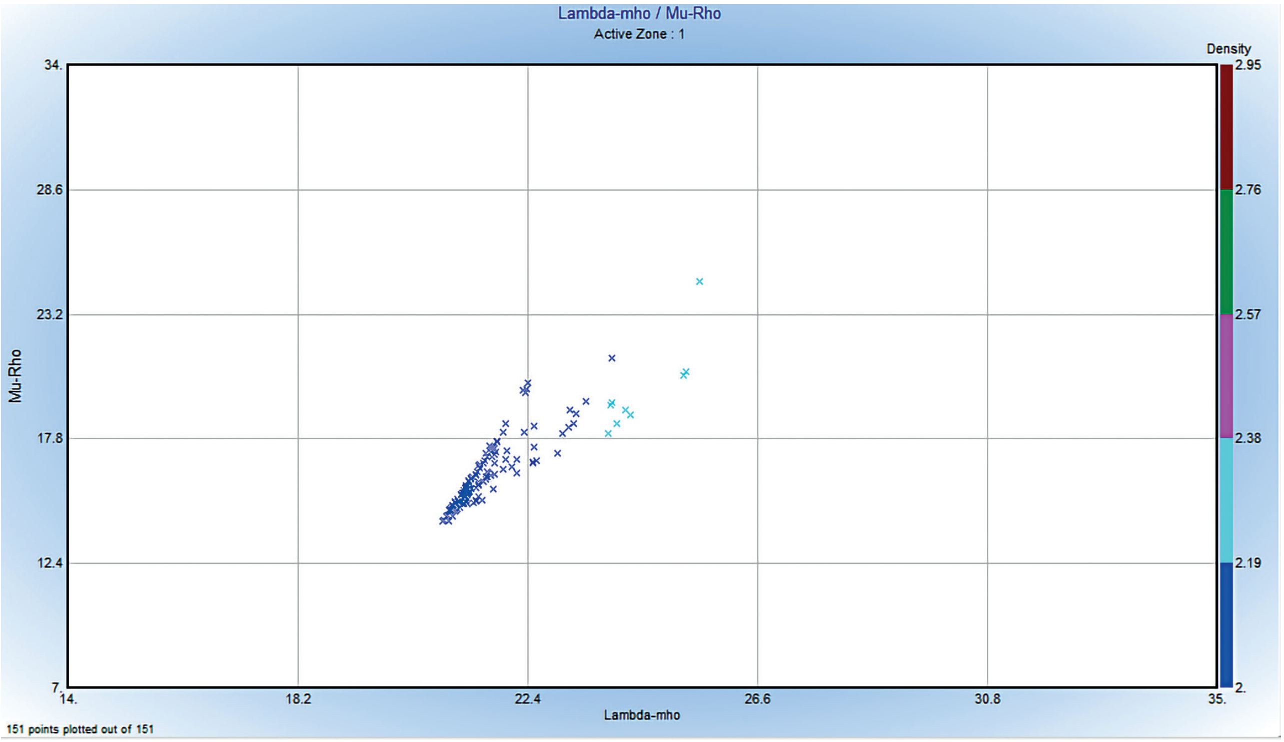

Fig. 6. Crossplot of Lambda-mho-Mu-Rho and density well AG 10 for reservoir 2
Ryc. 6. Wykres Lambda-mho-Mu-Rho i gęstości, odwiert AG 10 dla złoża 2

4.3. Pore fluid prediction using Vp/Vs and Poisson's ratio

A velocity ratio and a Poisson's ratio crossplot were created and evaluated. Pore fluid prediction can be accomplished by examining the link between Poisson's ratio and velocity ratio. Figures 7 and 8 show a crossplot of Poisson's ratio and velocity ratio. According to the interpretation guide, gas and oil sand have lower Poisson's and velocity ratios than saline sand and shale. The crossplot was used to choose the gas sand, oil sand, and brine sand for the reservoirs indicated in each well.

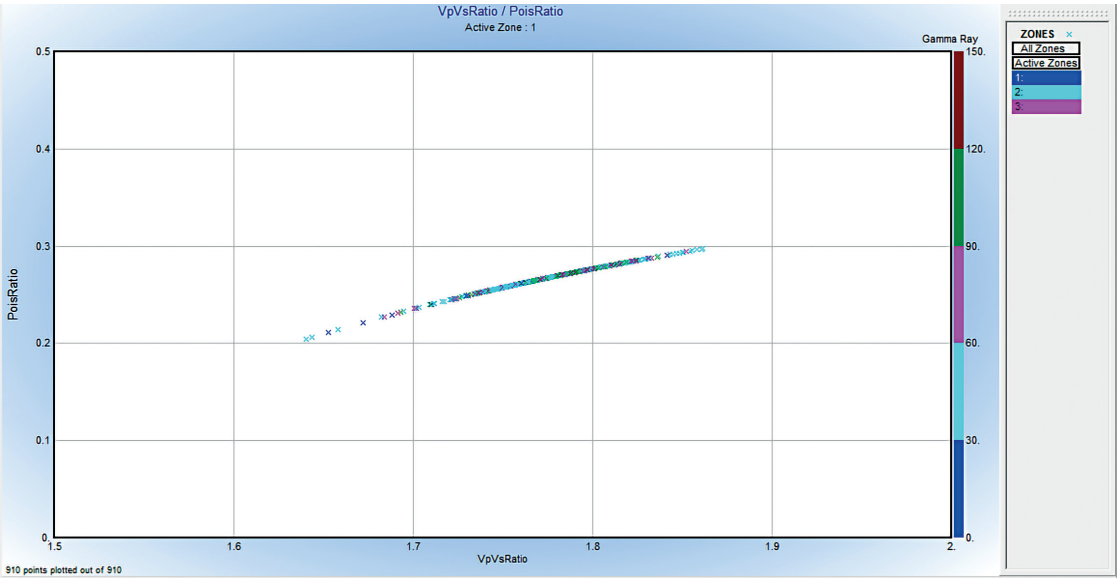

Fig. 7. A crossplot of Poisson's ratio and velocity ratio for reservoirs AG 60
Ryc. 7. Wykres współczynnika Poissona i współczynnika prędkości dla złoża AG 60

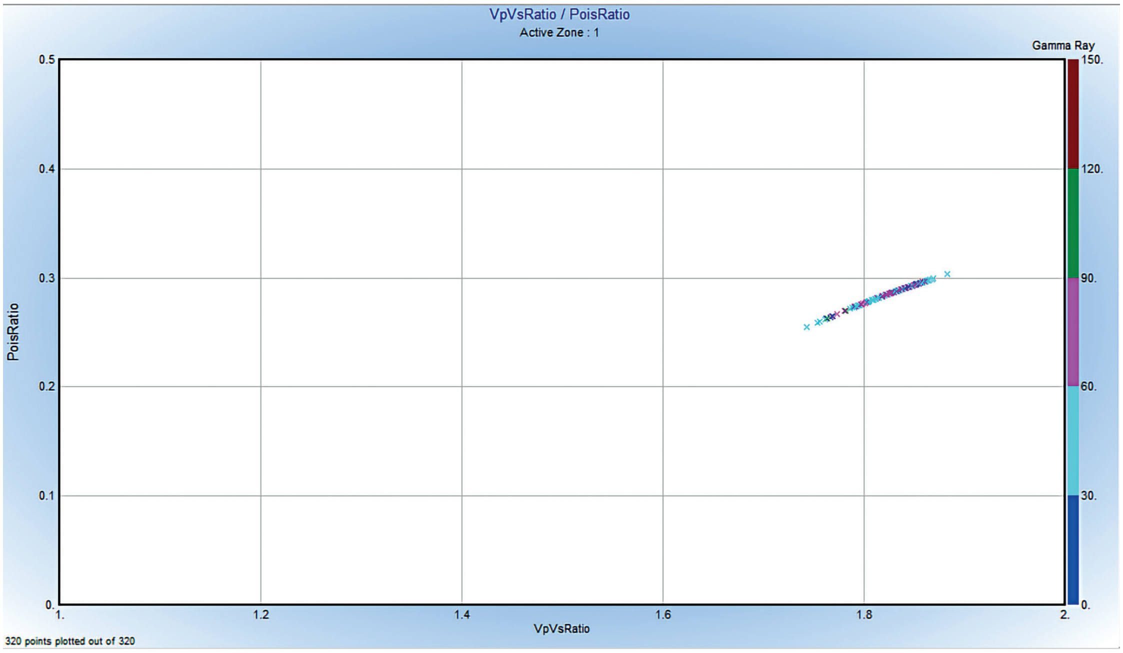

Fig. 8. A crossplot of Poisson's ratio and velocity ratio for reservoirs AG 10
Ryc. 8. Wykres współczynnika Poissona i współczynnika prędkości dla złoża AG 10

4.4. Pore fluid and lithology prediction using lambda-mho and Poisson's ratio

A lambda-mho and Poisson's ratio crossplot were created and analyzed. Pore fluid prediction can be accomplished by examining the link between Lambda-mho and velocity ratio. Figures 9 and 10 show a crossplot of Poisson's ratio and velocity ratio.

Lambda-mho (λρ), also known as incompressibility, is important for fluid detection and differentiation; hydrocarbon-filled sandstone is less dense than water-filled sandstone. Hence, hydrocarbon filled sandstone has low Lambda-mho (λρ) values. Pore fluid and mineral properties affect the lithology of a formation.

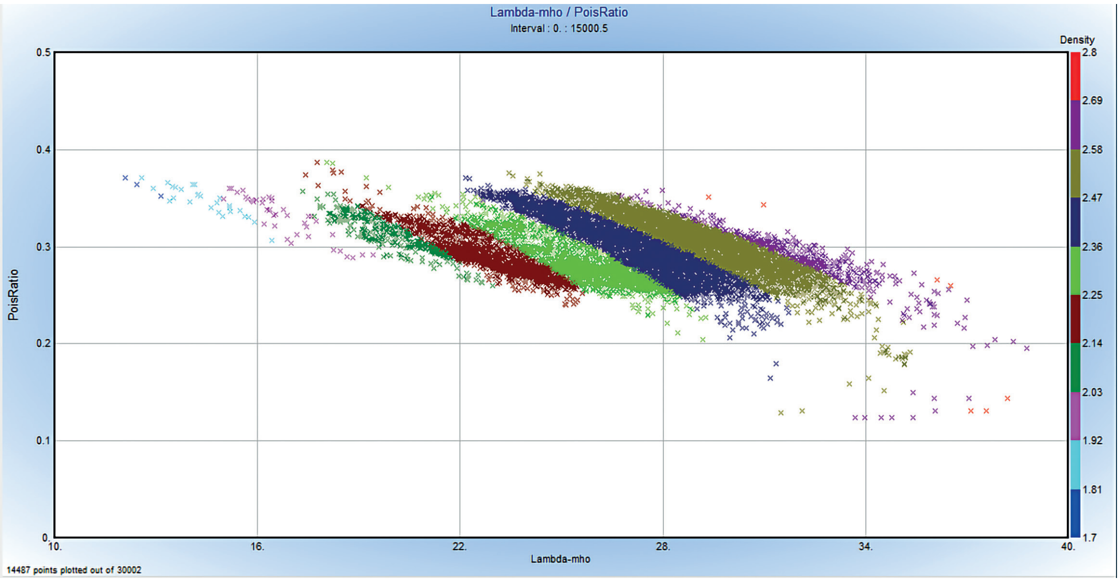

Fig. 9. Crossplot of lambda-mho-PoisRatio and density well AG 60
Ryc. 9. Wykres współczynników lambda-mho-Poisson i gęstości, odwiert AG 60

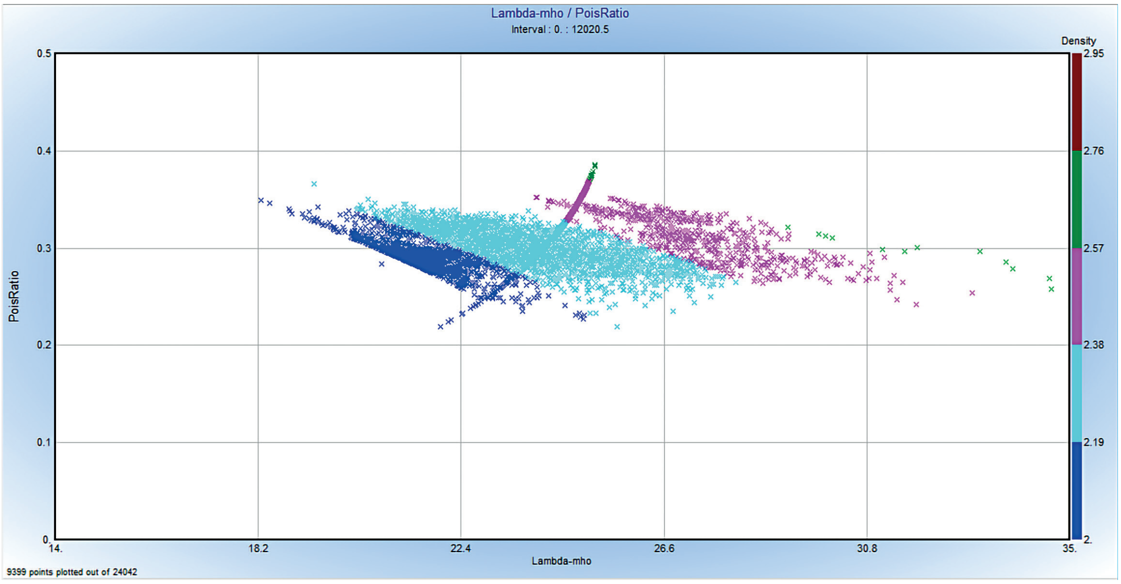

Fig. 10. Crossplot of Lambda-mho-PoisRatio and density well AG 10
Ryc. 10. Wykres współczynników lambda-mho-Poisson i gęstości, odwiert AG 10

4.5. Reservoir zone and oil water contact (O.W.C)

The velocity ratio was used to assess the lithology of pores as well as the presence of hydrocarbons. Sedimentary rock velocity ratios are particularly sensitive to pore fluid [23]. In an oil layer, compressional wave velocity (V_p) decreases while shear wave velocity (V_s) increases. It is observed that the velocity ratio is significantly lower in a hydrocarbon saturated environment than in a liquid saturated environment. Compressional

Table 1. Interpreted values of the reservoirs in well AG 60
Tabela 1. Zinterpretowane wartości złóż w odwiercie AG 60

AG 60		**Reservoir 1**	**Reservoir 2**	**Reservoir 3**
Curve	**Units**	**Mean**	**Mean**	**Mean**
BVW	Dec	0.15	0.12	0.11
KB	KBars	16.01	16.45	16.85
Lambda-mho	Gpa*g/cc	24.61	25.42	25.67
Mu	KBars	8.67	9.04	9.50
Mu-Rho	Gpa*g/cc	20.88	22.10	23.21
PHI	Dec	0.25	0.23	0.23
PoisRatio		0.27	0.27	0.26
RWapp	ohmm	0.19	0.18	1.77
SW	Dec	0.61	0.54	0.53
Vp	ft/sec	11519.68	11622.01	11832.21
VpVsRatio		1.79	1.78	1.77
Vs	ft/sec	6455.66	6537.95	6706.98

Table 2. Interpreted values of the reservoirs in well AG 10
Tabela 2. Zinterpretowane wartości złóż w odwiercie AG 10

AG 10		**Reservoir 1**	**Reservoir 2**	**Reservoir 3**	**Reservoir 4**
Curve	**Units**	**Mean**	**Mean**	**Mean**	**Mean**
BVW	Dec	0.08	0.06	0.07	0.16
KB	KBars	14.68	14.23	14.28	14.70
Lambda-mho	Gpa*g/cc	21.89	21.74	21.90	22.94
Mu	KBars	7.64	7.12	7.14	7.42
Mu-Rho	Gpa*g/cc	17.46	16.34	16.44	17.47
PHI	Dec	0.32	0.32	0.31	0.28
PoisRatio		0.25	0.29	0.29	0.28
RWapp	ohmm	11.07	18.74	18.69	1.26
SW	Dec	0.24	0.20	0.23	0.57
Vp	ft/sec	11223.10	10946.23	10942.85	11005.39
VpVsRatio		1.74	1.83	1.83	1.82
Vs	ft/sec	6217.17	5994.51	5991.79	6042.09

and shear wave velocities drop and rise with increasing hydrocarbons, making the velocity ratio more sensitive to fluid change than V_p and V_s alone.

The velocity ratio falls in hydrocarbon layers because density decreases in shear wave velocity and bulk modulus (KB) decreases in compressional wave velocity. This is extremely important in assessing fluid and oil-water interactions.

At the reservoir, a quick fall in velocity ratio is seen, corresponding to a decrease in Vp and an increase in Vs. The compressional and shear wave velocities are transferred from an oil layer into a water layer, causing this anomaly. The oil-water-contact (O.W.C.) interface, which occurs in medium to coarse-grained sandstone, is where the rapid velocity contrast is evident.

5. CONCLUSION

The interpreter's ability to use existing data to identify and estimate the lithology and pore fluid of a reservoir is crucial. Well log data can be used to assess lithology and pore fluid. The Niger Delta Basin's well log data was effectively analyzed using petrophysics and rock physics.

This study made use of caliper, sonic, resistivity, neutron, and density logs as input. IP v.3.5 was created to calculate elastic parameters such as velocity ratio, Poisson's ratio, bulk modulus, shear modulus, shear velocity, compressional velocity, lambda-mho, and mu-rho. To gain a general understanding of the distribution of sandstone in the well, a velocity ratio log was employed to identify sand from shale. The empirical velocity ratio estimates for rock types used by Castagna et al. [24] were used. Following the separation of sand and shale using velocity ratio, rock physics analysis utilizing lambda-mho and mu-rho was performed to determine the presence of other lithology besides sand and shale. A crossplot lambda-mho and mu-rho and density were created using the calculated lambda-mho and mu-rho. Oil sand, gas sand, and brine sand were projected from the crossplot using Goodway's [21] interpretation technique.

The obtained velocity ratio and Poisson's ratio were used to calculate the pore fluid content. The gas sand, oil sand, and brine sand were identified using velocity ratio and Poisson's ratio analysis. The velocity ratio and Poisson's ratio studies supported the gas sand anticipated by the rock physics analysis utilizing lambda-mho and mu-rho. The velocity ratio and Poisson's ratio analyses were used to better define the wet sand anticipated by the rock physics analyses of lambda-mho and mu-rho. The moist sand anticipated by the rock physics studies of lambda-mho and mu-rho was oil sand and brine sand. Pore fluid content was determined using the calculated velocity ratio and Poisson's ratio. From the analysis of velocity ratio and Poisson's ratio, the gas sand, oil sand, and brine sand were mapped out. The gas sand predicted from the rock physics analysis using lambda-mho and mu-rho was confirmed by the analysis of velocity ratio and Poisson's ratio. The analysis of velocity ratio and Poisson's ratio was used to further describe the wet sand predicted by the rock physics analysis of lambda-mho and mu-rho. The wet sand from the rock physics analysis of lambda-mho and mu-rho was predicted to comprise of oil sand and brine sand.

It is therefore recommended that rock physics and petrophysical analysis of log data be carried out in the Niger Delta basin to reduce the risk of wrong prediction of reservoir parameters. Moreover, since rock physics is a link between reservoir engineering, geophysics, petrophysics, and geology, core and reservoir data should be used to enhance the interpretation.

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