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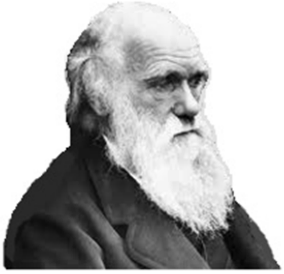

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Pore Fluid and Lithology Discrimination of a Well in the Niger Delta Region using Elastic Parameters

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ABSTRACT

With respect to the high uncertainties associated with methods of determining lithology and pore fluid using well logs, quantitative rock physics analyses was used to determine the lithology and pore fluid of a reservoir in the Niger Delta. Inaccurate prediction of lithology and pore fluid results in the inaccurate determination of other petrophysical properties and parameters such as porosity, permeability, net pay, etc. The primary objective of this research is to predict lithology and pore fluid using rock physics analysis. However, reservoir zones were also predicted. Density, compressional wave velocity and shear wave velocity logs were used as input to calculate elastic parameters such as velocity ratio, Poisson's ratio and Bulk Modulus. The calculated velocity ratio log was used to differentiate between sand and shale. Poisson's ratio and velocity ratio using the Goodway interpretation template was carried out and used to delineate pore fluid content; gas sand, oil sand and sandstone formation from cross-plot analysis.

***Keywords*:** Pore Fluids, Lithology, Elastic Parameters, Poisson's ratio, Velocity ratio

1. INTRODUCTION

Lithology basically refers to the type of rock in the Earth crust. Different kinds of rocks exist in the subsurface but not all are conducive for hydrocarbon accumulation. For a subsurface rock to be a good hydrocarbon storage, the rock should be sedimentary with pore spaces. These pore spaces can be filled with hydrocarbons (Schlumberger, 1989). Knowledge obtained from the lithology of a well can be used to determine a range of parameters

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including the much needed pore fluid content. Lithology and pore fluid prediction are vital for reservoir characterization, these are very important aspects of exploration and production such as geological studies, reservoir modeling, formation evaluation, enhanced oil recovery processes, and well planning including drilling and well completion management.

Accurate determination and understanding of lithology, pore fluid, pore shapes, and sizes are fundamental to other petrophysical analysis. Accurate prediction of lithology and pore fluid is, and will continue to be, challenges for hydrocarbon exploration and development (Kupecz et al., 1997). The accurate determination of lithology and pore fluid aids in the accurate determination of porosity, saturation and permeability. The economic viability/importance of a hydrocarbon field is also reliant on the quality and accuracy of lithology and pore fluid (Hami-Eddine et al., 2015). The growing difficulty in convention (reservoir that uses the natural pressure gradient for hydrocarbon extraction) and unconventional (reservoir that requires special recovery operations outside the conventional operating practices) reservoir has made precise lithology and pore fluid prediction very essential (Hami-Eddine et al., 2015).

Lithology and pore fluid can be unambiguously determined using core samples obtained from underground formation. Core sample analysis for lithology and pore fluid prediction are expensive and usually involves vast amount of time and effort to obtain reliable information (Chang et al., 2002). Hence, this method cannot be applied to all drilled wells in a field. Also, different geoscientists may obtain inconsistent results based on their own observations and analyses (Akinyokun et al., 2009; Serra and Abbott, 1982). Cuttings obtained from drilling operations can also be used to determine lithology and pore fluid. The disadvantage of using cuttings from drilling operation to determine lithology and pore fluid is that the retrieval depths of the cuttings are usually unknown and the samples are generally not large enough for precise and reliable determination of lithology and pore fluid (Serra and Abbott, 1982). There has been a growing interest in determining lithology and pore fluid using well log data which is cheaper, more reliable and economical. Well logging also offer the benefit of covering the entire geological formation of interest coupled with providing general and excellent details of the underground formation (Serra and Abbott, 1982). Brigaud et al. (1990) observed that well logs offers a good representation of in-situ conditions in a lithological unit than laboratory measurements mainly because well logs sample finite volume of rock around the well and delivers uninterrupted record with depth instead of sampling of discrete point.

Despite well log being the best form of lithology and pore fluid prediction, uncertainties in measurements, complexities of geological formation, and many other factors result in the unforeseen complication in lithology and pore fluid prediction. Some traditional well log interpretation techniques such as combining and cross-plotting of log data have been established using well log data. These methods are recently used for quick evaluations (Ellis and Singer, 2008). The efficiency of these traditional methods is minimal when considering large heterogeneous reservoir data. To make lithology prediction of a heterogeneous reservoir with large dataset possible, different approaches have been presented. These approaches include petrophysical and rock physics analysis for lithology and pore fluid prediction.

Rock physics establishes a bond between elastic properties (V_P/V_S, bulk and shear modulus, etc.), reservoir properties (permeability, porosity, lithology, etc.), and architecture properties (fractures) (Saberi, 2013).

In determining lithology, gamma ray log are used to differentiate sand from shale and calculating the volume of shale (Fens, 2000). The presence of sand and other rock layers are difficult to be detected using gamma ray and spontaneous potential logs. Pore fluids are also usually predicted traditionally either using resistivity logs or a crossplot of porosity logs (density and neutron porosity). In the absence of resistivity logs, the porosity log can only be used to determine wet formation. Determining which fluid made the formation wet using porosity logs is impossible. It is therefore paramount to analyze log data using petrophysical and rock physics analysis to predict lithology and pore fluid content with less uncertainties.

Lithology and pore fluid determination are very essential for the exploration and production process and are also fundamental to reservoir characterization. Understanding the lithology and pore fluid of a reservoir is the foundation from which other petrophysical parameters are determined. Porosity, permeability and water saturation are physical properties that make it possible to evaluate a hydrocarbon reservoir. However, these physical parameters/properties can be determined accurately only when lithology and pore fluids are determined accurately.

2. MATERIAL AND METHODS

The materials used for this study are wire line logs which include the following; Gamma (GR), Resistivity (RT), Neutron (NPHI), Density (RHOB) and Sonic (Sonic). Log data acquisition for these wells spans three decades and exhibit a wide range of data quality due to advancements in wireline tool engineering, drilling techniques, and mud systems. The procedure of well logging data preparation and analysis are as follows, log plots of caliper, gamma, resistivity, neutron, density and sonic were plotted using Interactive Petrophysics v.4.2, with these plots estimation of Porosity, Volume of Shale and Lithology were obtained.

The Gamma ray log is useful for defining shale beds when the spontaneous potential log is distorted. The GR log reflects the proportion of Shale and in many regions, can be used qualitatively as a Shale indicator. The bed boundary is picked at a point midway between the maximum and minimum deflection of the anomaly. There are many different ways of determining the volume of Shale (Vsh) in a Shaly formation (Schlumberger, 1987). In a Shaly porous and permeable zone, the volume of Shale (Vsh) can be estimated from the deflections of the GR curve.

$$I_{GR} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}} \qquad 1$$

$$V_{sh} = 0.08(2^{(3.71 I_{GR})} - 1) \qquad 2$$

Porosity was calculated from sonic logs using the Wyllie Time Average

$$\phi_w = \frac{\Delta t_{\log} - \Delta t_{\max}}{\Delta t_{ft} - \Delta t_{\max}} \qquad 3$$

Wyllie Time Average Porosity equation

$\Delta t_{\log}$ = is the reading on the sonic log in μs/ft

$\Delta t_{\max}$= is the transit time of the matrix material (about 55.5 µs/ft)

Δt_{ft} = is the transit time of the saturating fluid (about 189 µs/ft for fresh water)

The effective porosity is given by

$$\phi_e = \phi_w (1 - V_{sh}) \tag{4}$$

There are several empirical equations (for example, Han et al., (1986) and Castagna et al., (1993)) to predict V_s from other logs. Most formations give transit times between 40µsec/ft and 140 µsec/ft, so these values are usually used as the scale. The reciprocal of velocity is the specific acoustic time, which is recorded on the Acoustic log in µsec/ft. The conversion equation between velocity and slowness is given as:

$$V_s = \frac{304878}{\Delta T_s} \tag{5}$$

where: ΔT_s is in microseconds per foot, and the velocity, V_s is in feet per second).

The modulus of elasticity is the ratio of stress to strain. The elastic moduli are:

Distances between adjacent molecules increase in order from solids to liquids to gases. Because of this, solids have little compressibility as compared to liquids and gases. In fact, the bulk modulus is the reciprocal of compressibility and is therefore sometimes referred to as the coefficient of incompressibility (Dresser Atlas, 1982).

In terms of well logging parameters and in practical units, the relationship between Sonic wave Velocities and Elastic constants are established. The four elastic constants are expressed as:

Shear Modulus $G = \dfrac{a\rho_b}{\Delta T_s \upsilon}$ 6

Bulk Modulus $K_b = a\rho_b \left(\dfrac{1}{\Delta T_c^2} - \dfrac{4}{3\Delta T_s^2} \right)$ 7

Young's modulus $E = 2G(1+\upsilon)$ 8

Poison's Ratio $\upsilon = 0.5\left(\dfrac{V_p}{V_s}\right)^2 - \dfrac{1}{\left(\dfrac{V_p}{V_s}\right)^2} - 1$ 9

The shear modulus is the most important elastic parameter in comparing the strength of the different formations. A combined modulus of strength has been defined as:

$$K = K_b + \frac{4}{3}G \qquad 10$$

Which is same as $K = a\rho_b\left(\frac{1}{\Delta T_c^2} - \frac{4}{3\Delta T_s^2}\right) + \frac{4}{3}\frac{a\rho_b}{\Delta T_s \upsilon}$ 11

This combined modulus compares favorably with known conditions of formation strength. Corrections to the log data for hydrocarbon effects are required before calculating the combined modulus values.

The velocity ratio of different lithologies proposed by Castagna et al. (1985) using velocity ratio are found in Table 1 below. Pore fluid and mineral property affect the lithology of a formation.

Table 1. Velocity ratio for different rock types (Castagna et al., 1985).

Range of V_p/V_s	Rock type
0.10 – 1.20	Fine grained sand
1.20 – 1.45	Medium grained sand
1.46 – 1.60	Coarse grained sand
1.60 – 1.80	Sandstone
Above 2.00	Shale or Clay

Source: Castagna et al., 1985

3. RESULTS OF ANALYSIS

The principal step of well log analysis is to differentiate clean sand from shale using baseline on the log data and to delineate zones of interest, i.e. hydrocarbon filled clean sand. Gamma log and Elastic Parameters such as Velocity ratio, Poisson’s ratio and Bulk Modulus used to determine the lithology. V_P logs can be used to determine lithology, porosity, and pore fluid. Despite V_P logs been valuable, they are influenced by three separate properties of rocks, i.e. density, bulk and shear moduli, which make V_P ambiguous for lithology prediction. The V_P/V_S ratio, however, is independent of density and can be used to derive Poisson’s ratio, which is a much more diagnostic lithological indicator (Kearey et al., 2002).

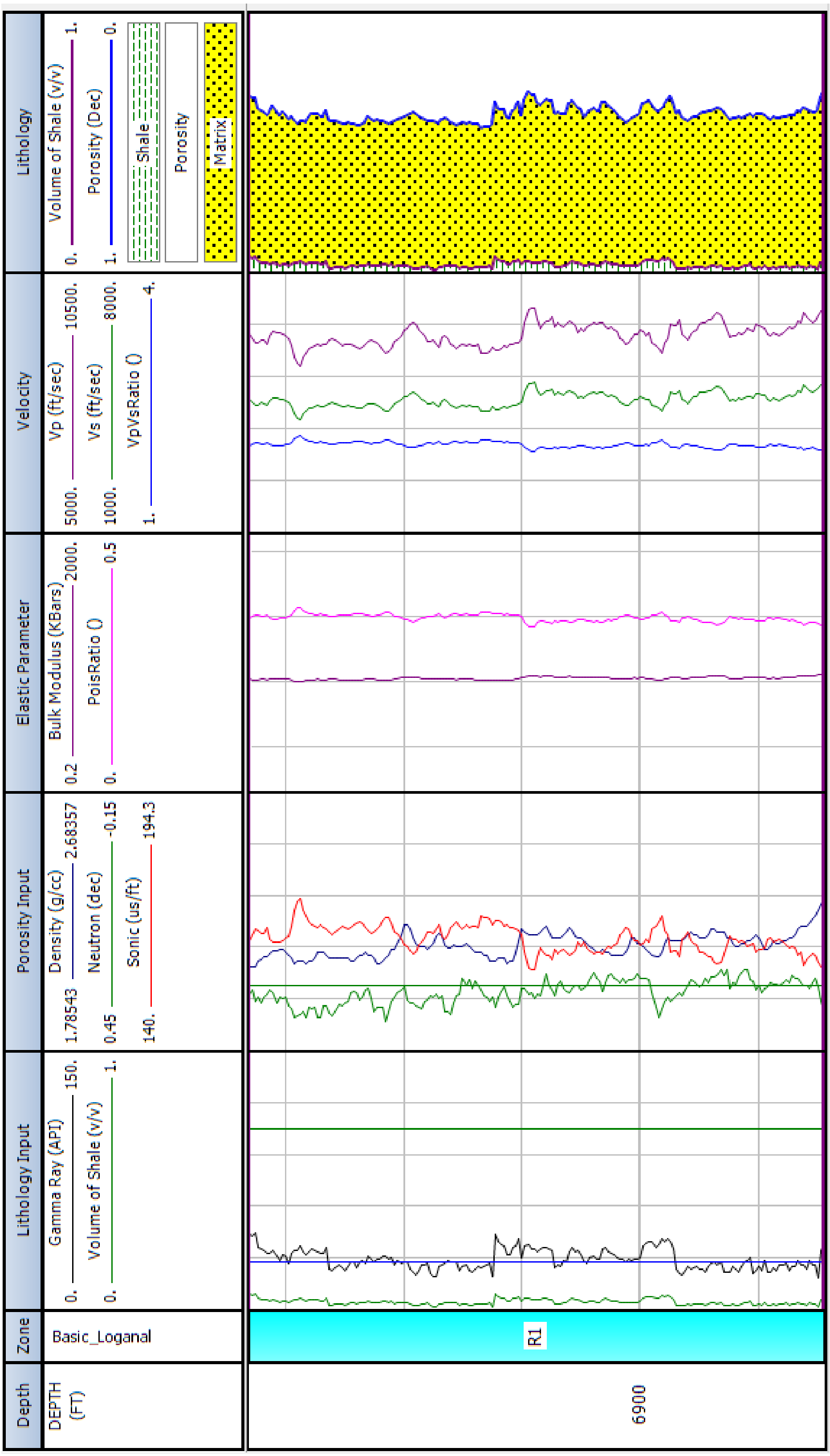

Figure 1. Elastic parameters of Reservoir 1

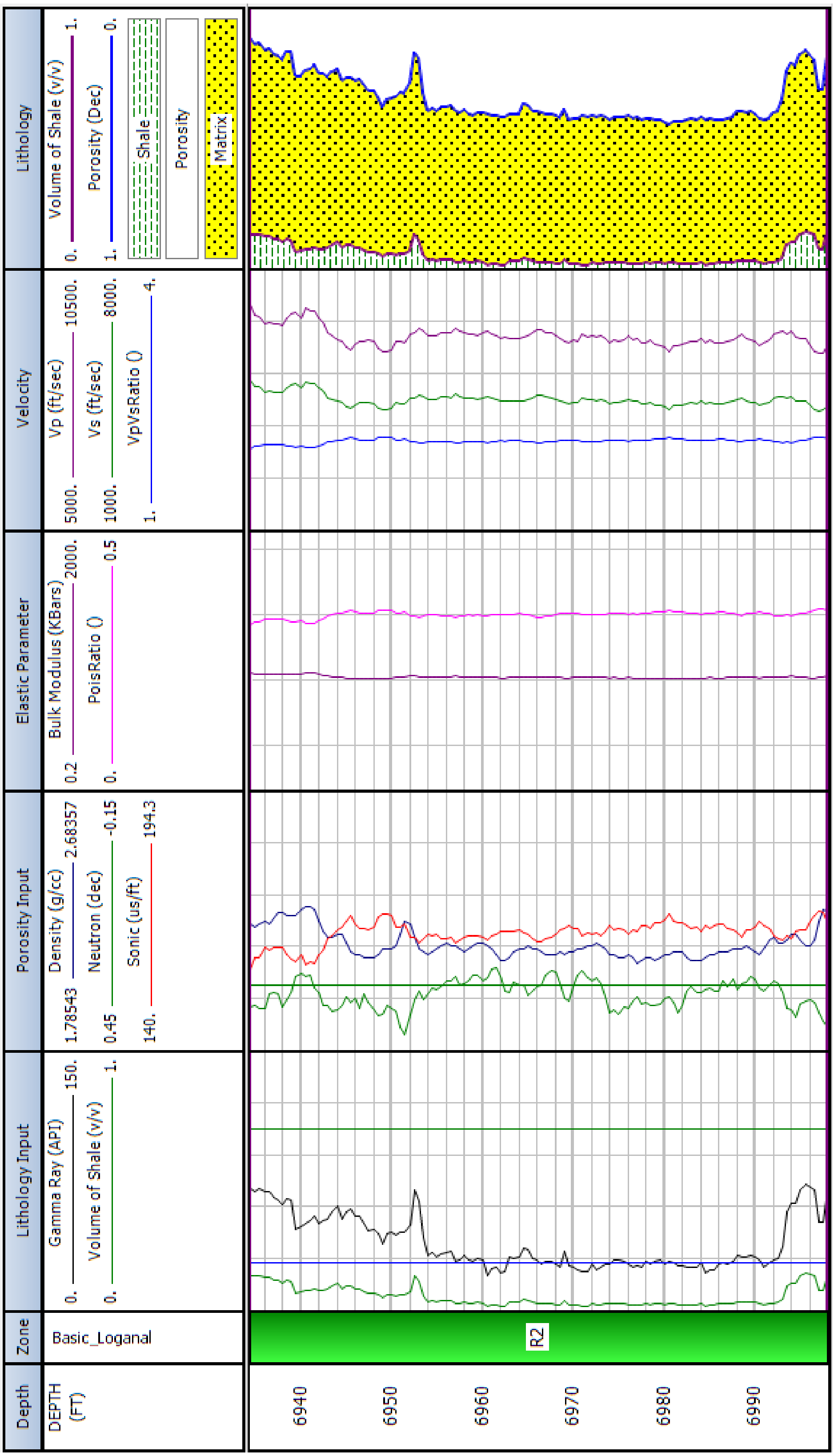

Figure 2. Elastic parameters of Reservoir 2

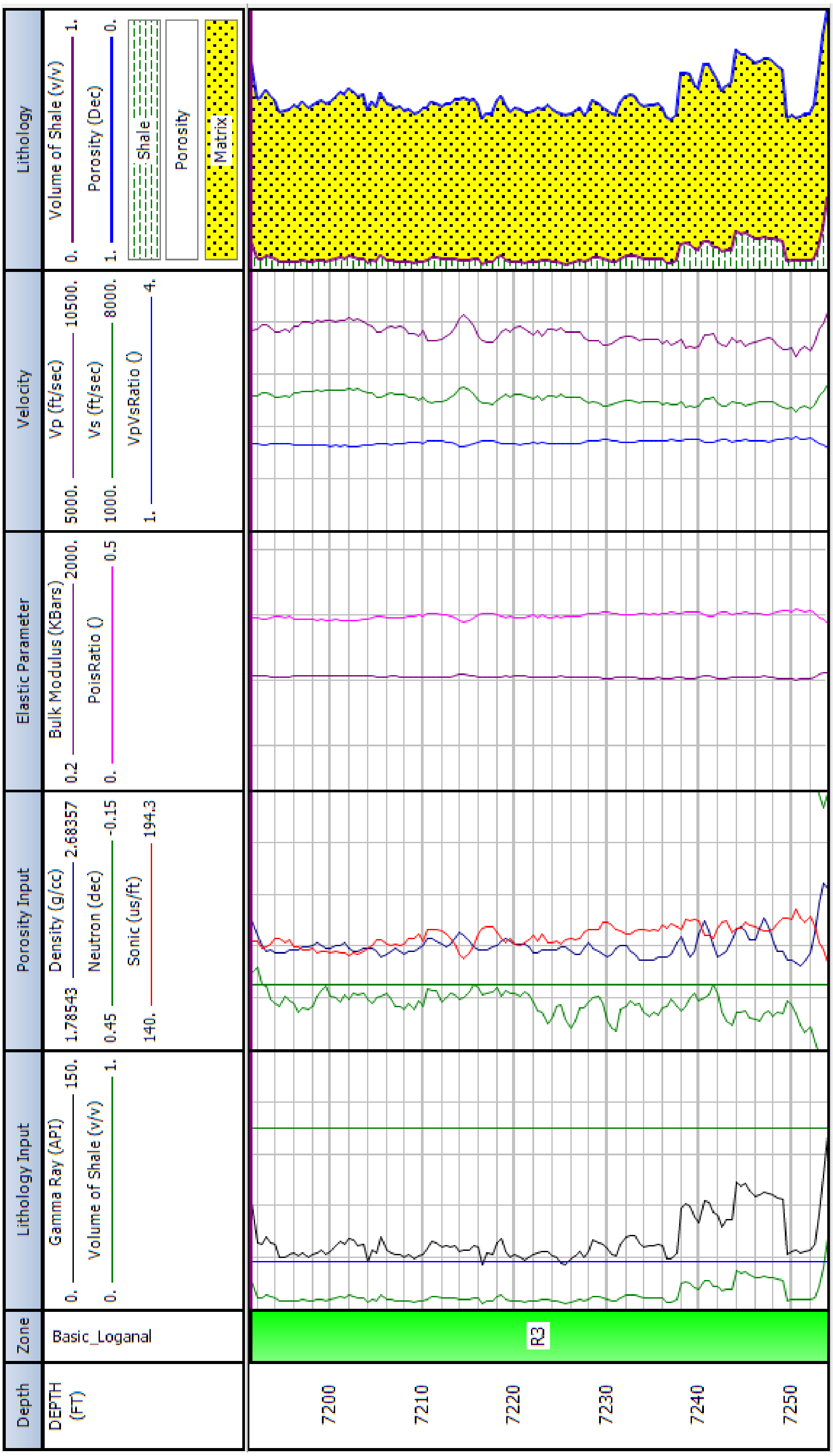

Figure 3. Elastic parameters of Reservoir 3

A crossplot of velocity ratio and Poisson’s ratio was carried out and analyzed. From the pore fluid prediction guideline shown in Figure 5 below, the various pore fluid content was predicted.

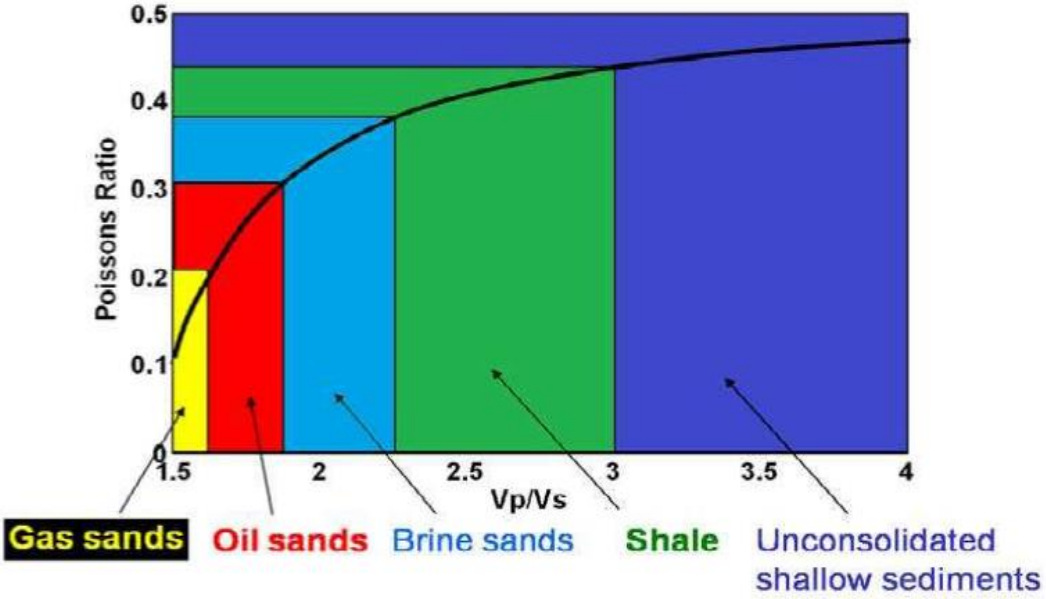

Figure 4. Guideline for pore fluid prediction using Poisson’s ratio and velocity ratio

Pore fluid prediction is possible by analyzing the relationship existing between Poisson’s ratio and velocity ratio. The crossplot of Poisson’s ratio and velocity ratio is shown in Figure 5. From the interpretation guide, it can be observed that gas and oil sand have lower Poisson’s and velocity ratio compared to brine sand and shale. The gas sand, oil sand, brine sand, and shale was selected on the crossplot.

Table 2. Analysis of three reservoirs for fluid prediction analysis using Elastic Parameters

		Top: 6834ft Bottom: 6931ft R1 Net: 97.5ft			Top: 6934.5ft Bottom: 6993ft R2 Net: 64ft			Top: 7191.5ft Bottom: 7254ft R3 Net: 63ft		
Curve	Units	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Bulk Modulus	KBars	9.876	13.06	11.256	10.401	12.82	11.116	10.117	13.078	11.175

Density	g/cc	2.079	2.310	2.152	2.089	2.280	2.154	2.079	2.361	2.146
Porosity	%	0.301	0.440	0.387	0.111	0.439	0.343	0.000	0.419	0.334
Effective Porosity	%	0.229	0.410	0.326	0.048	0.390	0.275	0.000	0.361	0.261
Gamma Ray	API	18.611	44.685	29.18	20.398	72.602	38.986	25.667	101.370	40.550
Neutron	dec	0.261	0.382	0.315	0.259	0.412	0.320	0.259	0.489	0.346
PoisRatio		0.319	0.355	0.335	0.319	0.349	0.338	0.322	0.350	0.336
Sonic	us/ft	102.600	117.600	109.162	102.8	114.7	110.17	104	115.2	109.461
Volume of Clay	Dec	0.000	0.217	0.038	0.000	0.579	0.154	0.000	0.953	0.164
Volume of Shale	v/v	0.012	0.062	0.030	0.015	0.145	0.054	0.024	0.282	0.056
V_p	m/sec	2591.836	2970.760	2794.063	2657.367	2964.980	2767.929	2645.833	2930.769	2785.726
V_s	m/sec	4030.090	5029.812	4563.630	4202.980	5014.562	4494.678	4172.551	4924.302	4541.633
V_p/V_s		1.938	2.110	2.010	1.940	2.074	2.021	1.953	2.080	2.013

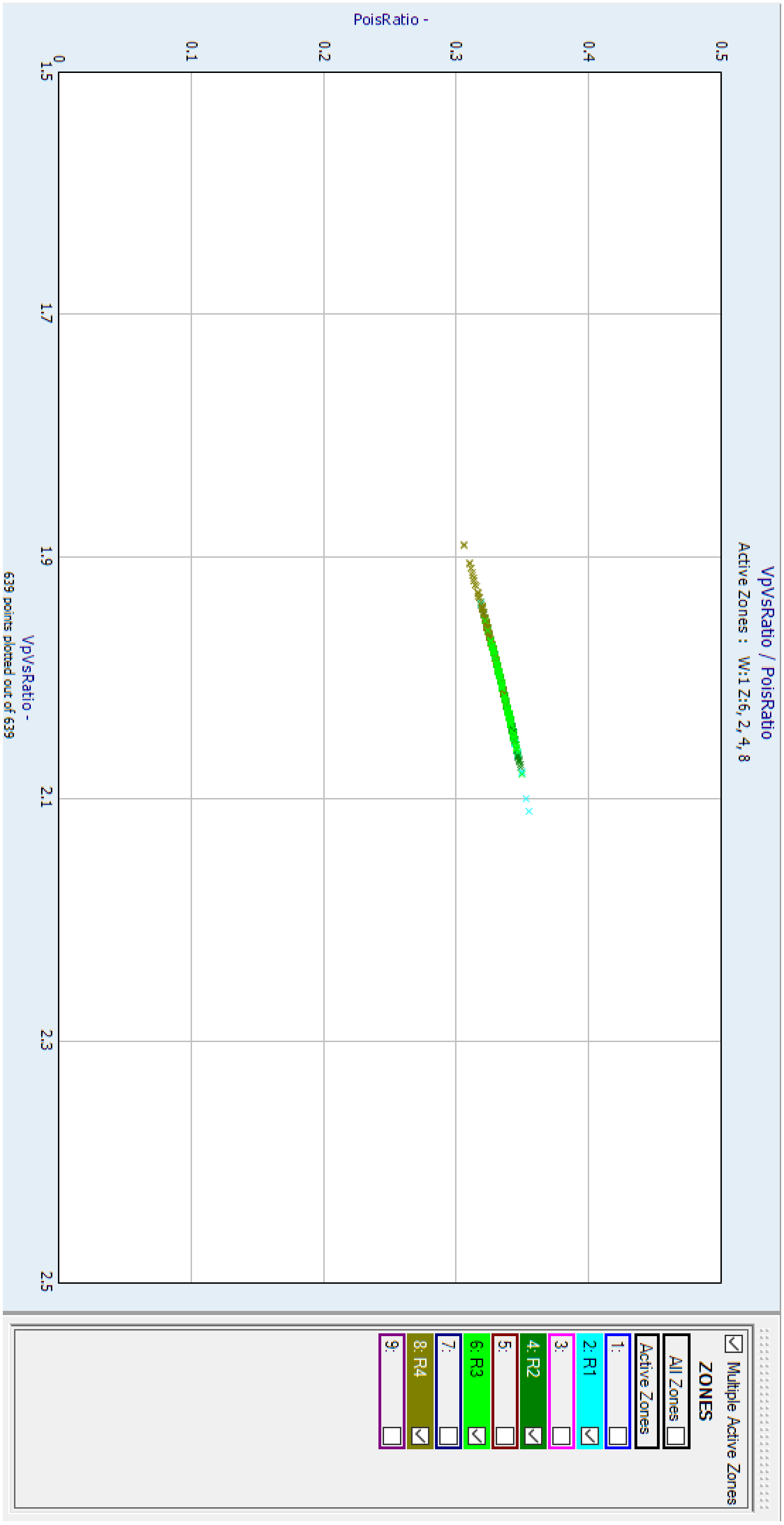

Figure 5. A crossplot and interpretation of Poisson’s ratio and velocity ratio

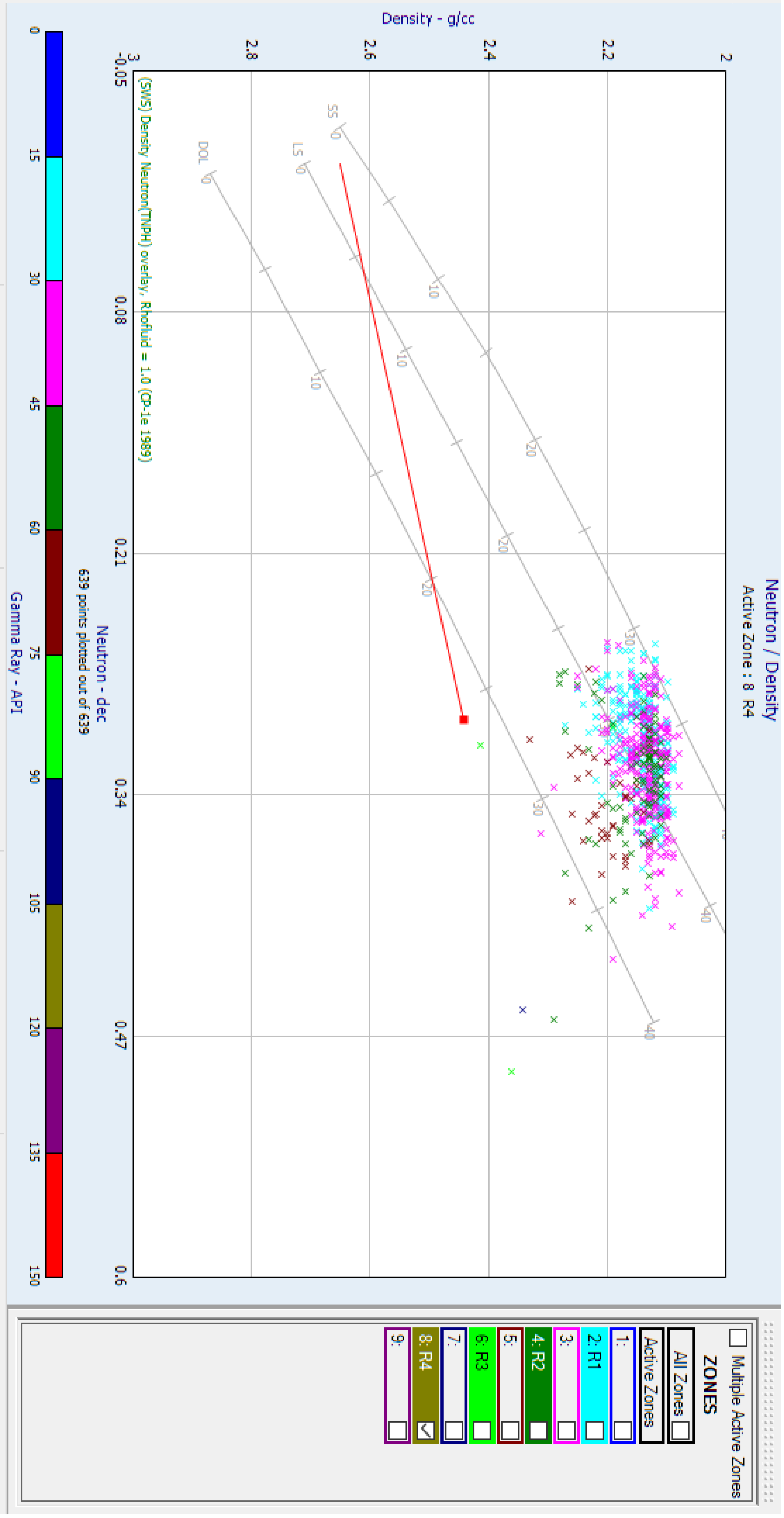

Figure 6. Neutron Density Crossplot for Lithology prediction

4. DISCUSSION

The velocity ratio was not only used to deduce lithology but also to detect the presence of hydrocarbons in pores. Velocity ratio is very sensitive to pore fluid of sedimentary rocks. In an oil layer, compressional wave velocity decreases as shear wave velocity increases (Bahremandi et al., 2012). Tathan (1982) realized that the velocity ratio is much lower in hydrocarbon saturated environment than the liquid saturated environment. The reduction and increase in compressional and shear wave velocity respectively with an increase of hydrocarbon, make velocity ratio more sensitive to fluid change than V_p and V_s individually. Velocity ratio decreases in hydrocarbon layers because density decreases in the shear wave velocity while bulk modulus decreases in compressional wave velocity. This is very crucial in determining fluid and oil water contact. This anomaly is due to the fact that the compressional and shear wave velocities are propagated from an oil layer into a water layer. The boundary where the rapid velocity contrast is observed is the oil-water-contact (O.W.C) which occurs in medium to coarse grained sandstone.

5. CONCLUSION

Well log data provide useful parameters to determine lithology and pore fluid. Petrophysical and rock physics analyses of log data were successfully applied to well log data. Density, compressional velocity and shear wave velocity logs were used as input for this research. Gamma Ray log and Velocity ratio log was used to differentiate sand from shale to understand the general overview of the distribution of sandstone in the well. Castagna et al. (1985) empirical values of velocity ratio for rock types was used. Using Goodway (2001) interpretation technique, gas sand, wet sand, sandstone, and shale were predicted from the crossplot. Pore fluid content was determined using the calculated velocity ratio and Poisson's ratio. From the analyses of velocity ratio and Poisson's ratio, the gas and oil sand was mapped out.

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