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Elastic and Electrical Properties Evaluation of Low Resistivity Pays in Malay Basin Clastics Reservoirs

Luluan Almanna Lubis[1,2], Deva P. Ghosh[1,2], Maman Hermana[2]
[1] Geosciences Department, Universiti Teknologi PETRONAS, Malaysia
[2] Centre of Excellence in Subsurface Seismic Imaging and Hydrocarbon Prediction, Universiti Teknologi PETRONAS, Malaysia

E-mail: luluan.lubis@petronas.com.my

Abstract. The elastic and electrical properties of low resistivity pays clastics reservoirs in Malay Basin are strongly dependent on the complex nature of the clay content, either dispersed or laminated/layered. Estimating the hydrocarbon pore volume from conventional electrical log, i.e. resistivity log, is quite a challenge. The low elastic impedance contrast also found as one of the challenge thus create a problem to map the distribution of the low resistivity reservoirs. In this paper, we evaluate the electrical properties and elastic rock properties to discriminate the pay from the adjacent cap rock or shale. Forward modeling of well log responses including electrical properties are applied to analyze the nature of the possible pays on laminated reservoir rocks. In the implementation of rock properties analysis, several conventional elastic properties are comparatively analyzed for the sensitivity and feasibility analysis on each elastic parameters. Finally, we discussed the advantages of each elastic parameters in detail. In addition, cross-plots of elastic and electrical properties attributes help us in the clear separation of anomalous zone and lithologic properties of sand and shale facies over conventional elastic parameter crossplots attributes. The possible relationship on electrical and elastic properties are discussed for further studies.

1. Introduction

For the last forty years, the Malay Basin has been a prolific setting for oil and natural gas explorations in south east asia which focused on several plays: structural play, stratigraphic play and basement plays (Ghosh et.al., 2010). In the Malaysian Basins, the economical important of low resistivity pay sands just recently demonstrated. Riepe et.al. (2012) and Kantaadmadja et.al. (2014) are few authors who reveal the important of these pays in the Malaysian Basins. These pays may revealed ten to hundreds million barrels of hydrocarbon (Kantaadmadja et.al., 2014). The similar problems of bypassed pays also mentioned as one of the geophysical challenges by the other authors (Ghosh et.al., 2010).

[1] Geosciences Department, Universiti Teknologi PETRONAS, Malaysia, Bandar Seri Iskandar, 32610, Tronoh, Perak Darul Ridzuan, Malaysia

The low resistivity pays are generally documented, due to the low resistivity and low contrast reading from the resistivity log. There are several factors associated to the low reading of the resistivity log fresh formation water or low salinity micro- porosity, conductive mineral as part of the minerals in the rock and very thin inter-bedding of sand and shale formation. (Worthington, 2000)

The formation parts for instance lithology, fluid and pore space of the rock influence by the depositional and geological setting, thus directly affect the responses of resistivity log and seismic data. Because of the complex nature of low resistivity pay triggering the geophysical experimental, interpretation and numerical studies turn out to be extremely challenging. Therefore this problem has mystified petrophysicist, geologist as well as geophysicist to solve the problems.

The solution of the problems requires integrated rock properties analysis, both electrical and elastic, to tackle complex mineralogy and poor understanding of anisotropic conditions to reexamine the current understanding of the reservoir properties of low resistivity pays. In this study an integrated rock properties analysis on electrical properties forward modeling and elastic rock properties analysis to discriminate the pay from the adjacent shale are tested through a rigorous workflow, started from well log interpretation, forward modeling of the well log responses to the elastic rock properties analysis.

2. Literature Review

2.1. Low Resistivity Pay Zone

Several numbers of technical papers described on the possibility of finding the low resistivity pays. These pays are possible to find in almost all major siliciclastic depositional environments (Kantaadmadja et.al., 2014). The most general causes of low resistivity pays are the clay minerals. The clays which filled by water in its microporosity can be acted to exchange cations within the pore fluids which caused the suppression of the electrical logs reading (Worthington, 2000).

The pay zones that produce low resistivity or low-contrast log responses are inclined by a variation of aspects related with anisotropy, conductive mineralogy, water salinity or fresh water formation in addition to microporosity, dip and bed thickness. There are several measurements can be done to resolved bed thickness effect. One of the technology are the use of borehole image logs and triaxial induction resistivity (Claverie et al., 2010). The summary of the log responses of the formations in the Malay Basin are well reported by Kuttan, M. (1980). Most of the cases related to the low resistivity pay are the reservoirs with high silt even though it is low clay content and very fine grained sand. The fresh water formation affect the log responses as well.

2.2. Electrical and Elastic Properties Relationship

In normal condition, the pay zone can be easily distinguish from the adjacent shale and the water-bearing zone by using resistivity log. The good illustration from http://www.spec2000.net is shown below:

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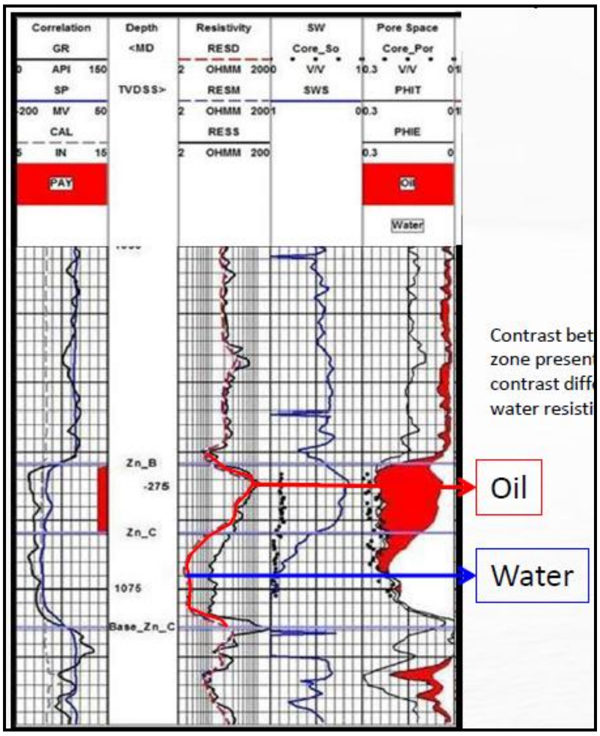

Figure 1: Contrast between oil and water zone presents because of the contrast difference between oil and water resistivity (from http://www.spec2000.net)

Contrast between oil and water zone presents because of the contrast difference between oil and water resistivity. The tool works by conducting electric current, and the readings are depending on the type of lithology and pore fluids.

Generally, the velocities depend on the ratio rock moduli to density. The moduli and density effects generate velocity variations which depend on the rock properties such as porosity, fluid saturation, and texture. The seismic (P- and S- wave) velocities – Vp and Vs respectively – of an isotropic rock material can be estimated using known rock moduli and density as follows:

$$V_P = \sqrt{\frac{K_{sat} + (4/3)\,\mu_{sat}}{\rho}},$$

$$V_S = \sqrt{\frac{\mu_{sat}}{\rho_{sat}}},$$

where K is bulk modulus, μ is shear modulus, and ρ is the bulk density.

The physics of elastic and electrical properties in conducting a porous media share no physical parameter. Thus this make the velocity and resistivity cannot be directly related (Carcione, 2007). Rock physics information is usually used to link the elastic and electrical properties data through porosity. This link is not exact (Werthmuller, 2014).

Some of the recent approaches are by developing joint inversion for CSEM and seismic data through rock physics and structural links (Abubakar, 2012). The step they have done is to first determine porosity and saturation of the formation. The results of the inversion was claimed to be better than a single dataset inversion, seismic or CSEM data. Werthmuller (2014) used background resistivity model which derived from velocities data. However the weaknesses concluded from the paper are the model is isotropic and having no resistivity calibration outside well logs data location. The approach by Abubakar, 2012, was adopted by Gao using crosswell synthetic data. Dell'Aversana, P., G (2012) used velocity, resistivity and density measurement from crosswell and involving bayes to link electrical and elastic properties. Kwon and Snieder (2011) investigate uncertainty in the combination of CSEM and seismic data. The approach is by using a synthetic and Bayesian. They consider several type of sources of uncertainty, from well log are seismic wave velocity and electrical resistivity. Seismic and CSEM data are the other data consider for the sources of uncertainty.

There are several researchers documented the relation between electrical and elastic properties. Soldal (2015), CO2 flooding experiment of reservoir sandstones-monitoring changes in acoustic and electric properties. Cheng, (2015), Building a Model of Coupled Elastic and Flow Properties of Porous Rock. Ong, O, et.al., (2015), Seismic anisotropy and elastic properties of a VTI medium. Tang, X, et.al., (2015), Assessing rock brittleness and fracability from radial variation of elastic wave velocities from borehole acoustic logging.

3. Methodology

3.1. Data set

The principal data sources for electrical forward modeling and elastic rock properties analysis are the well logs data and core information. Log data includes compressional and shear sonic logs, density, gamma ray, and resistivity. We incorporated the core and petrophysical study that has already been done by PETRONAS (Malaysia) which contains a series of petrophysical properties interpretation that are the key for calibrating and improving the electrical forward modeling and elastic rock properties analysis.

3.2. Quick-look Well log Interpretation

The objective of well log interpretation to locate and define a given reservoir and also quantitatively the thickness of the reservoir, porosity and water saturation.

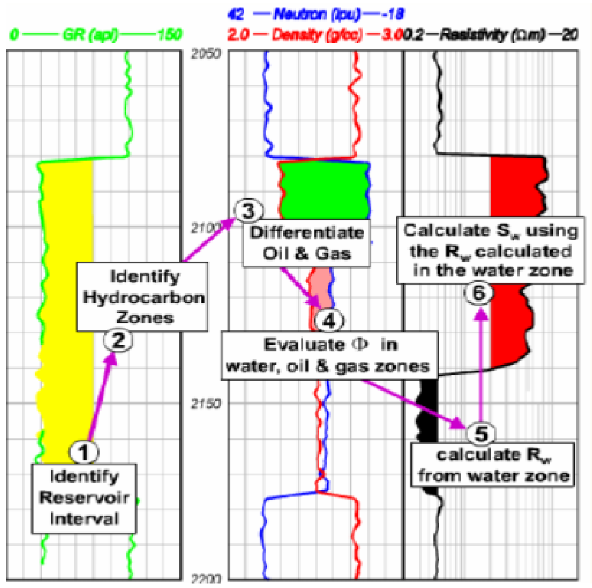

Figure 2: Steps to identify the pay zone using well log data

Figure 2. shows the steps to identify the pay zone. The first step is to identify the reservoir interval through GR log readings. Low GR usually represent sand, or for some cases coal and carbonates. Next step is to identify the hydrocarbon zones by interpreting the resistivity and neutron – density data. The crossover on neutron – density logs represent gas reservoirs with resistivity reading is high. The evaluation of the porosity of the reservoir can be calculated from neutron and density logs. The last step for quick-look interpretation is to calculate the water saturation of the pay zone.

3.3. Electrical Properties Forward Modeling

The forward modeling is constructed based on the specific petrophysical properties of the Malay Basin field example. The input for the forward modeling are water saturation (Sw), N/G, porosity, m and n value (cementation and saturation exponents respectively), GR cutoff for sand and resistivity of sands and shales end member. The electrical properties responses are simulated by applying a convolution filter to the beds conductivity.The neutron-density calculated from porosity input. The GR responses correspond to the beds created from the simulations.

3.4. Elastic Properties Cross-plot

The cross-plot of elastic properties can be used to interpret the lithology and pore fluid. Odegaard and Avseth (2003) introduced the rock physics templates (RPT) where the common elastic properties information used for RPT are velocity ratio which is compressional and shear velocity (Vp/Vs) ratios and acoustic impedance (AI). The used of different rock physics models combined with RPT also can be used for different type of lithology, such as carbonate (Lubis and Ghosh, 2014). Elastic properties cross-plot analysis is the first step to efficiently differentiate the lithology and pore fluids. The results of this analysis later on can be used as an input for AVO inversion. These elastic properties calculated and derived using the information from compressional and shear log data. The common quantitative analysis from the calculated elastic parameters (Vp/Vs and AI) indicated that the hydrocarbon pay sands, especially gas sands will have lower values compare to the adjacent shales and brine sands. The tabulated information for elastic properties cross-plots is shown on Table 1.

Table 1. Elastic properties and its derivation

Elastic Properties	Descriptions
Vp – Compressional Velocity	Compressional sonic log
Vs – Shear Velocity	Shear sonic log
AI – Acoustic Impedance	AI = ρ*Vp
SI – Shear Impedance	SI = ρ*Vs
Vp/Vs – Velocity ratio	Compresional sonic log/Shear sonic log
LambdaRho - Lame parameter*density	LambdaRho = AI^2 - $2SI^2$
MuRho - Shear modulus* density	MuRho = SI^2
inverse Qp	$SQp^{-1} \equiv \frac{5}{6}\frac{1}{\rho}\frac{(M/G-2)^2}{(M/G-1)}$
inverse Qs	$SQs^{-1} \equiv \frac{10}{3}\frac{1}{\rho}\frac{(M/G)}{(3M/G-2)}$

4. Result and Discussion

The results obtained in this study can be divided into 3 parts, 1) quick-look well log interpretation, 2) electrical forward modeling and 3) Elastic properties cross-plot analysis. Figure 3 illustrates the basic well log interpretation from one of the well in Malay Basin. On Figure 2, Formation B 100 and D 35 are typical log responses of gas pay reservoirs. The main log responses to note is that over the sand interval at B100 and D 35, the Gamma Ray (GR) is low GR and having cross-over on the density and neutron responses. The resistivity showing high readings compare to the adjacent shale. Based on a standard log analysis the high GR on formation B 100 and D 35 would be interpreted as sand formation with high clay content. However, the interpretation with cautions should be considered since the work by Kuttan, M., (1980), reported the response can be from sand reservoirs with very fine grained and have high silt and low clay content. The elastic logs, AI and Vp/Vs showing low readings, typical gas sand reservoirs.

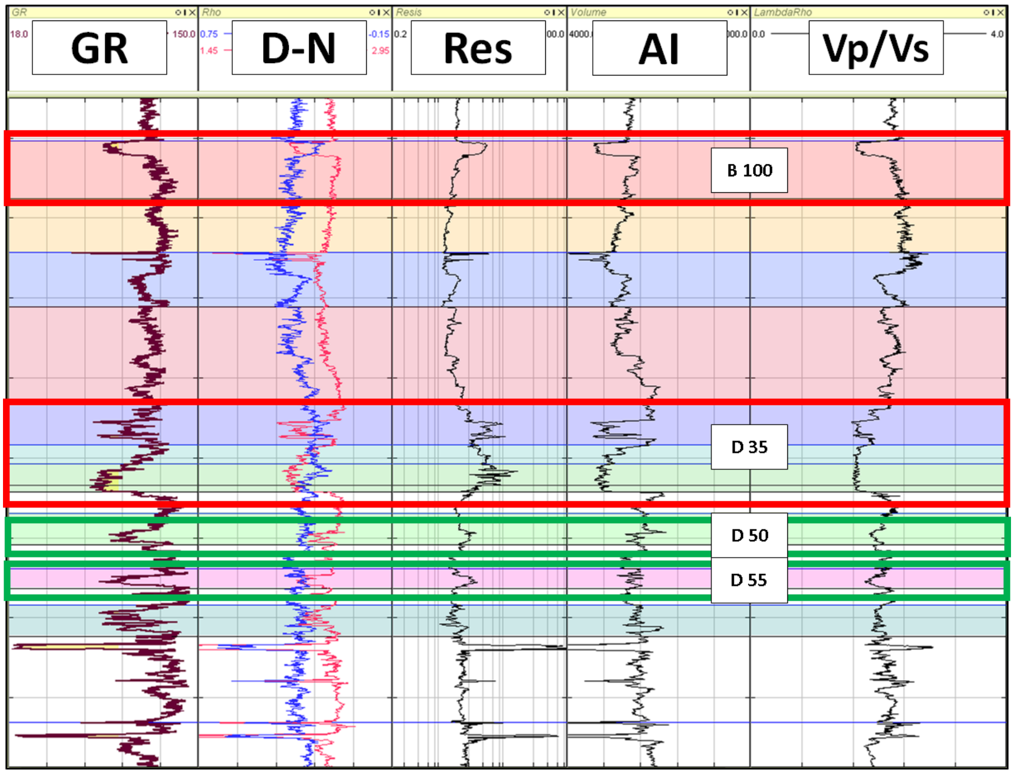

Figure 3. Quick-look interpretation on formation B and D in a field in Malay Basin.

Formation D 50 and D 55, are the oil bearing section (petronas report). This reservoir is atypical of low resistivity pay, where the resistitiy contrast with the adjacent shale are not having high contrast. The GR values show low readings for sand formation. The formation would be interpreted as shaly sandstone or another possibility as very fine grained sandstone with high silt and low clay content. The formation waters if it is fresh can cause the low contrast between the oil bearing reservoir and the adjacent shale.

Figure 4. shows forward modeling of electrical properties and other log responses for possible pay zones at B and D formation which interpreted from Figure 3. The yellow and green color in the track between GR and resistivity curves are the sands and shales, respectively. The blue color on GR track is showing the GR responses on each scenarios. The dashed red line on GR track is the cutoff used to determine the net to gross (N/G). The dashed line is halfway between clean-sand and shale end points. The result of net sands are shaded in tan yellow in GR tract. The electrical properties response, in these tracts on resistivity log responses, simulated by applying a convolution filter to the thin-bed conductivity values which is shown in Track 2. Track 3, simulated the responses of density and neutron logs. The forward modeling on Figure 4.a, simulated the log responses on formation B 100, where the GR, resistivity and density-neutron log responses are typical of gas sand reservoirs. The input for the forward modeling are 10% water saturation (Sw), 90% N/G, 30% porosity, m and n value are 2 (cementation and saturation exponents respectively), GR cutoof sand 60 GAPI, resistivity of sands and shales end member are 44 and 1 ohmm. The forward modeling results of the resistivity is around 13 ohmm.

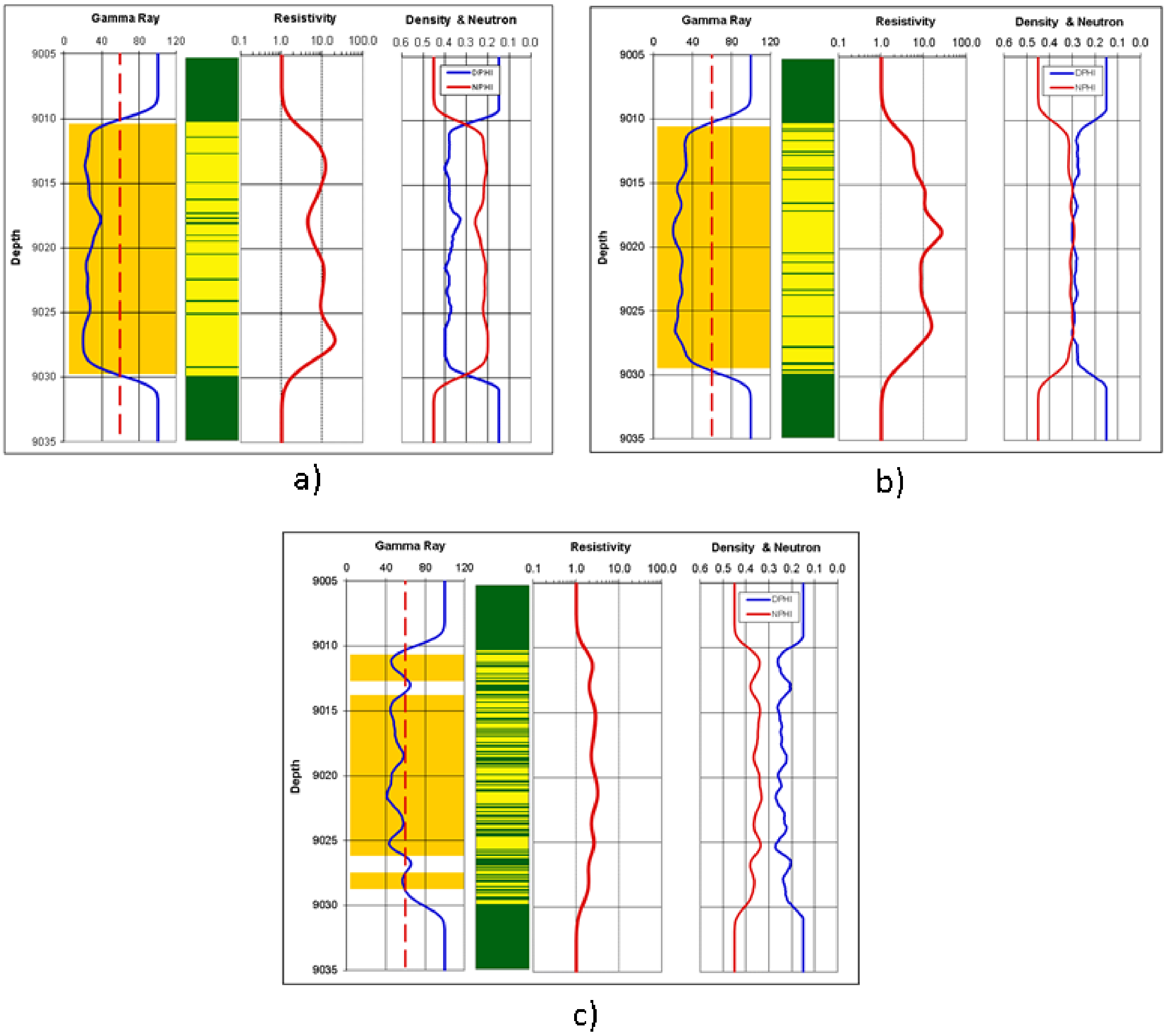

Figure 4. Forward modeling on well log responses, a) gas sand, b) oil sand and c) low resistivity pay.

The forward modeling on Figure 4.b, simulated the log responses if having a formation with oil sand pay. The input for the forward modeling are 90% Oil saturation (So), 90% N/G, 30% porosity, m and n value are 2 (cementation and saturation exponents respectively), GR cutoof sand 60 GAPI, resistivity of sands and shales end member are 44 and 1 ohmm. The forward modeling results of the resistivity is around 11 ohmm. The forward modeling on Figure 4.c, simulated the log responses on formation D50, for low resistivity pay with lower N/G. The input for the forward modeling are 10% water saturation (Sw), 60% N/G, 30% porosity, m and n value are 2 (cementation and saturation exponents respectively), GR cutoof sand 60 GAPI, resistivity of sands and shales end member are 44 and 1 ohmm. The forward modeling results of the resistivity is around 2 to 3 ohmm, typical low resistivity pay on the evaluated field.

The sands and shales are shown in yellow and green, respectively, in the track between the GR and resistivity curves. Track 1 shows the gamma ray in blue. The cutoff used to determine net sand is the red dashed line halfway between the clean-sand and shale endpoints. The resulting calculated net sand intervals are shaded tan. The electrical properties response, resistivity log, simulated by applying a convolution filter to the thin-bed conductivity values, is shown in Track 2; the simulated density and neutron logs are in Track 3.

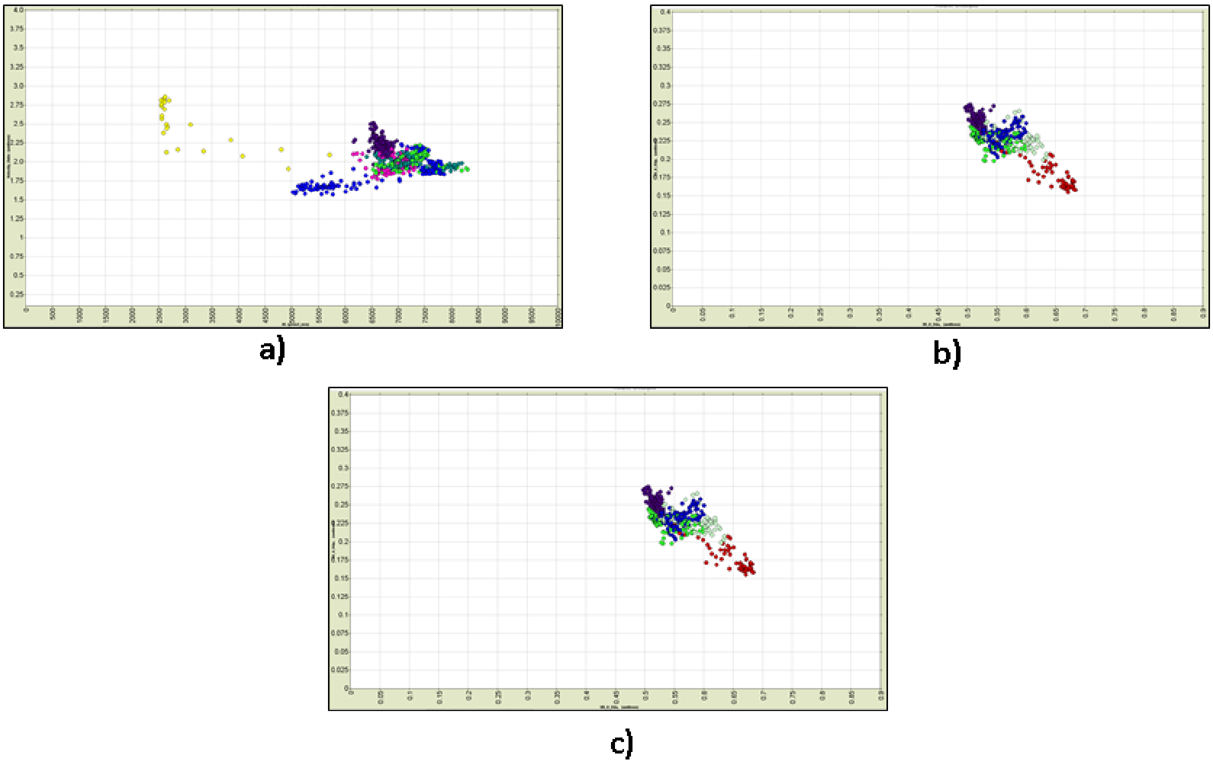

Figure 5. Elastic properties cross-plot analysis a) Vp/Vs vs AI, b)LambdaRho-MuRho and c)Sqp vs Sqs.

5. Conclusion

The integrated study on electrical and elastic properties analysis are presented and discussed in details. The objective of this study is to provide an interpretation of several pays in a field of Malay Basin, with focus on the low resistivity pay anomalies on elastic and electrical properties. Inverting the results directly to seismic data must be done with cautions due to the scale and dispersion effect. Thus this integrated analysis provides a preliminary study on transforming the elastic to electrical properties. The effect of different lithology and fluid types was separated from SQp domain and SQs domain respectively. The plots of lithology and fluid types effect are orthogonal on each domain axis. This approach can be used initially to model the resistivity from seismic velocity. The workflow can be started from the isotropic modeling the will be extended to anisotropic modeling for the velocity to resistivity transform. In our case the media is vertical transverse isotropy (VTI) for laminated sand shale sequences. The rock physics link can be used to develop the resistivity trend. SQs show potential inversion for resistivity modeling since its having similar responses with resistivity.

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