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Is the Qp/Qs Attribute Better for Hydrocarbon Prediction?

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Abstract: The objective of this study is to evaluate the performance, the attribute of inverse quality factor ratio of P-wave and S-wave (inverse Qp/Qs) as hydrocarbon indicator. To evaluate these performances, this attribute was compared with other hydrocarbon indicators; Poisson Ratio (PR), Lamda Rho ($\lambda\rho$), Lamda over Mu (λ/μ) and Bulk modulus (K). The testing were performed on well data from Malay basin field. Based on our study in the well domain, the log and trend of Qp/Qs is more close to the hydrocarbon saturation than Poisson ratio and Lamda over Mu. In the scenarios of geological model data, the contrast of Qp/Qs is also highest than others in all reservoir model. Even in low acoustic impedance contrast condition where is the shale and sand is difficult to be distinguished, the Qp/Qs still has highest contrast. This testing shows that the inverse Qp/Qs attribute is consistent with resistivity and hydrocarbon saturation log from well. Hence, it was concluded that the Qp/Qs, qualitatively has potential to be used to delineated hydrocarbon, however the quantitative interpretation of inverse Qp/Qs for hydrocarbon prediction still need further testing and investigations.

Key words: Qp/Qs, acoustic impedance, seismic wave, lithology and fluid effect, Poisson ratio

INTRODUCTION

Discrimination between pore fluid and lithology effect is one of the ultimate goal in the hydrocarbon prospecting. Interpretation based on seismic amplitude by extracting some elastic properties to distinguish the lithology and pore fluid have been proposed such as fluid factor (Smith and Sutherland, 1996), orthogonal Lame Constant (Goodway *et al*., 1997), Poisson ratio and AVO rotation (Connolly, 1999) and others including the success of the use of that attributes. However, in certain conditions, that attribute still difficult to distinguish pore fluid from lithology, the pitfalls still be generated. It is well known because the amplitude of seismic wave is affected by some factors such as divergence or spreading, angle dependent reflection and transmission losses, angle dependent ghosting in marine situation, inelastic absorption, internal peg-leg multiple energy loss, scattering and mode of wave conversion. Hence it is understandable an ambiguity still remain when we interpreted the amplitude.

In some cases such as in Malay basin field, a poor reservoir containing gas may have the same amplitude response as relatively better quality sand with an oil pore fluid. Also the highly porous sand with brine could yield a bright spot as well as gas sand. This ambiguity remains an added complication in AVO and amplitude analysis and several false anomalies have been drilled. The lithology and fluid effect is hard to be distinguished in amplitude analysis.

This study was directed to find out a new attribute that can represent only pore fluid rather than combination of both lithology and pore fluid effect. This attribute are based on attenuation mechanism theory.

Indication of attenuation mechanism as hydrocarbon indicator has been reported by some authors. Castagna *et al*. (2003) reported that there is shadow zone beneath gas reservoir, they used the Instantaneous Spectral Analysis (ISA) method to detect the low frequency shadow. Korneev *et al*. (2004) explained the low frequency is associated with low quality factor of medium due to the fluid flow which is agreed with diffusive-viscous theory. They used the frequency-dependent amplitude and phase-reflection properties to detect and monitor fluid saturated layers.

The effect of fluid flow in the pore during elastic waves propagation has been predicted analytically in the Biot's theory for low and high frequency (Biot, 1956). The squirt flow effect of unbounded fluid during wave propagation will produce new wave field due to the fluid movement. This squirt flow can absorb a part of initial wave energy irreversibly hence the propagated wave will be attenuated significantly. Not only P wave, but also S-wave undergoes the attenuation when it is propagated in the dispersive medium. The degree of

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attenuation in the medium is representing in the quality factor of P wave (Qp) and S-wave (Qs).

In this study, the inverse ratio of Qp/Qs performance and correlated it with hydrocarbon presence in the reservoir were evaluated.

METHODOLOGY

Extracting the inverse Qp/Qs ratio from rock physics relation: The attenuation and phase velocity of plane wave propagation in the viscoelastic medium is govern by Kramers-Kronig relation (Mavko *et al*., 2009) and maximum of quality factor can be estimated using by following equation:

$$\frac{2Q^{-1} = \dfrac{M_{\infty} - M_0}{P\sqrt{M_0 M_{\infty}}}}{2Q_s^{-1} = \dfrac{G_{\infty} - G_0}{P\sqrt{G_0 G_{\infty}}}} \tag{1}$$

where, M and G are compressional and shear modulus and the indexing is representing the relaxed and un relaxed condition. Equation 1 shows that inverse quality factor can be predicted from high and low frequency condition. By adopting the Hudson crack theory for isotropic model the Qp/Qs is determined as (Mavko *et al*., 2005):

$$\frac{Q_P^{-1}}{Q_S^{-1}} = \frac{5(M/G-2)^2}{4(M/G-1)} / \frac{2[M/G+M/G]}{(3M/G-2)3(M/G-1)} \tag{2}$$

This equation showing that the inverse Qp/Qs can be predicted from M and G. We used this equation to estimate the inverse Qp/Qs ratio.

Evaluation of inverse Qp/Qs on well data: In the well data the inverse of Qp/Qs is estimated using Eq. 2 where, M and G are derived from well log. The curve and the trend of this attribute are compared with hydrocarbon saturation log. The similarity was measured by calculating the correlation coefficient between these curves with water saturation/hydrocarbon saturation log. Also the comparison between Qp/Qs and other hydrocarbon attribute; Lamda over Mu and Poisson ratio are performed to know the performance of the Qp/Qs attribute.

Evaluation of contrast of inverse Qp/Qs: The contrasts of inverse Qp/Qs are calculated by generating the simple geological model consist of shale in the top and sand in the bottom. The contrasts are calculated as interface properties which are representing the ratio of difference and average of these models. Twelve scenarios consist of combination of hard shale, soft shale, hard sand and soft sand for every type of fluids (brine, oil and gas) were generated. Evaluation was also performed by compared the contrast of inverse Qp/Qs with Lamda over Mu and Poisson ratio contrast. The data was used here is the data from Malay basin field.

RESULTS AND DISCUSSION

Evaluation of inverse Qp/Qs on well data: Figure 1 shows the well log data from Malay Basin field where is

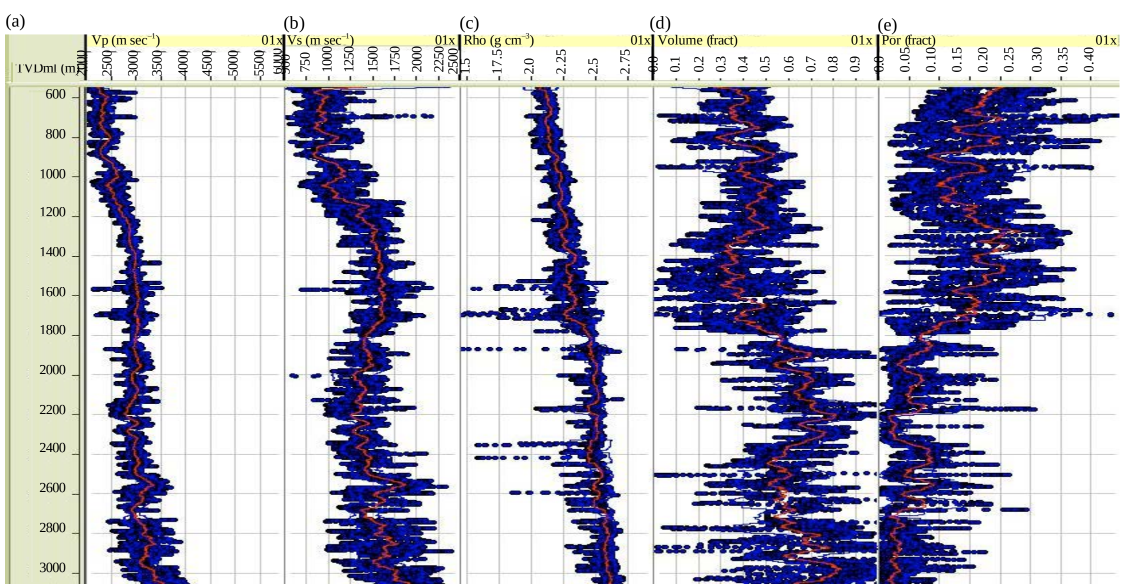

Fig. 1(a-e): Well log data from Malay basin field, from (a) P-wave velocity, (b) S-wave velocity, (c) Density, (d) Shale volume and (e) Porosity log

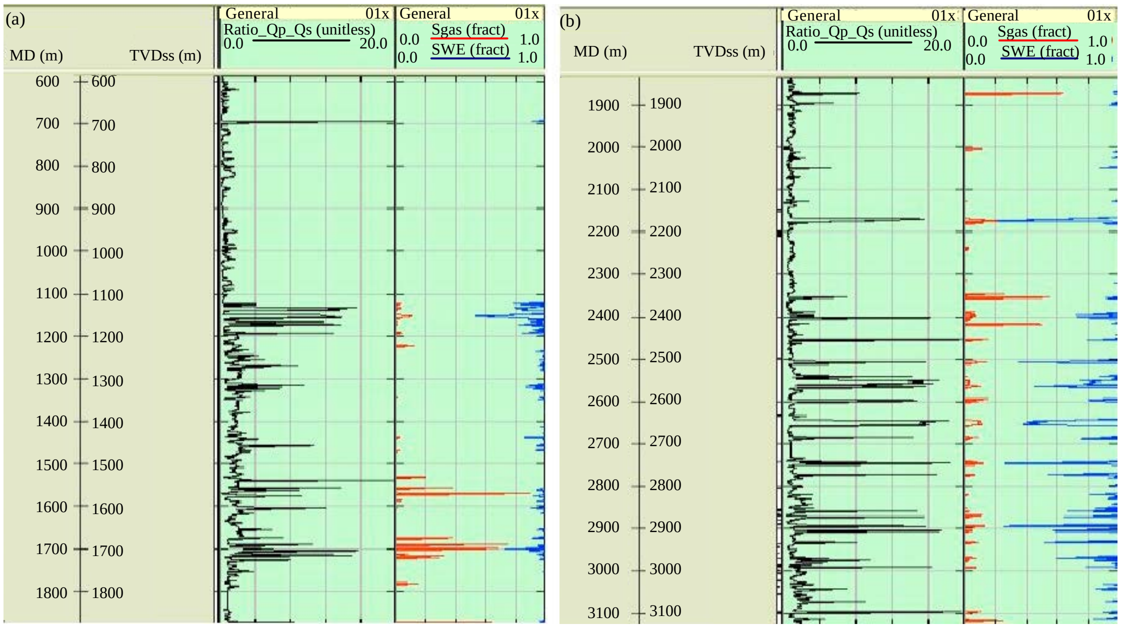

Fig. 2(a-b): The Qp/Qs (first coulumn), water saturation log (blue) and gas saturation (red) in the second coloumn at (a) Group 1 and (b) Group 2

the elastic properties (P-velocity, S-velocity and density) increase with depth, but the porosity decrease. Up to 1800 m of depth the porosity is high but after that the porosity is relative low. For some purposes the analysis was grouped based on the porosity value. Hence the zone of interest is grouped into two group. The group 1 is a zone below 1800 m and group 2 is a zone with depth more then 1800 m. The group 1 has porosity average around 20% and group 2 has porosity avarege around 10%.

Figure 2 shows the Qp/Qs curve that extrated from data in the Fig. 1 compared with water saturation log and gas saturation log.

In the Fig. 2 it is clear that anomaly of Qp/Qs curve is macth with high saturation of gas and low saturation of water log either on group 1 or group 2. Even we separated the analysis based on porosity variation, but here we know that the porossity is not effect on Qp/Qs curve. This fact tell us that the Qp/Qs is not sensitive with lithology variation, the Qp/Qs only related with the saturation in the rock as shown in detail in the Fig. 3.

Figure 3 shows the lithology variation with shaly sand (a) and clean sand (b) condition. Here we can see that the shale formation and sand formation is not distinguished by in the Qp/Qs curve. Shale as well as brine sand will give low Qp/Qs, sand only will give high Qp/Qs if the water saturation is low. The summary of the relation between lithology-pore fluid filled with Qp/Qs are summerized in the Table 1.

Table 1: The order of Qp/Qs related to lithology variation

Lithology	Qp/Qs
Clean sand hydrocarbon filled	↑↑↑↑↑
Shally sand hydrocarbon filled	↑↑↑↑
Brine sand	↑↑
Shale	↑

The Qp/Qs was compared with others elastic properties(Poisson ratio(PR), Lamda Rho ($\lambda\rho$), Lamda over Mu (λ/μ) and Bulk modulus (K)) which are representing the water saturation. The result is shown in the Fig. 4.

From Fig. 5 we can see that the caracteristic of Poisson ratio at high porosity zone decreases with depth which is contrary at low pororosity zone, the Poisson ratio increases. It is clear that Poisson ratio is sensitive with porosity of medium, in the other word the lithology still give high impact on Poisson ratio value. Meanhwile the properties of Lamda Rho has high value at high porosity zone and low at low porosity zone, here the porosity proporsionally affect the lamda rho properties. The bulk Modulus is not too efected by difference porosity, however the value of bulk modulus is increse with depth. All of these properties relation with depth will more clear if we analysis as trend as shown in the Fig. 5.

Evaluation of contrast of inverse (Qp/Qs): Fluid content detectability using Qp/Qs also was evaluated on the

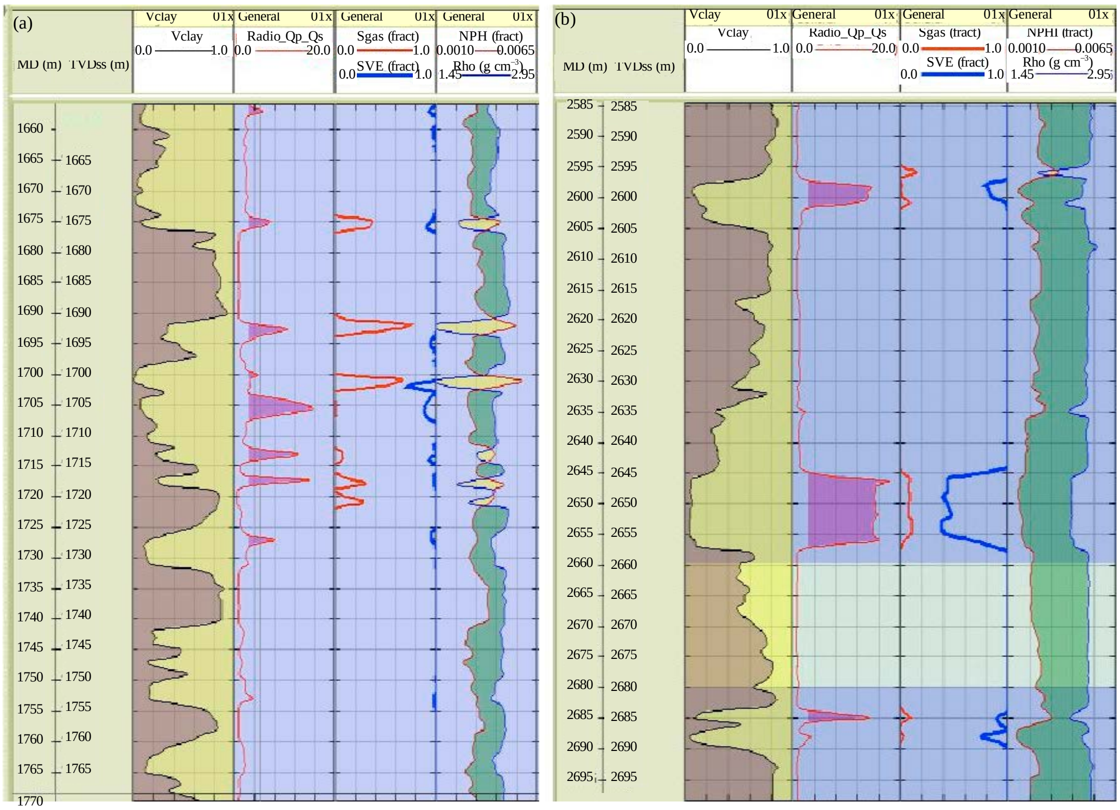

Fig. 3(a-b): The Qp/Qs curve (second coulumn) compared with Vclay (first coloumn), saturation log (third coloumn) and Neutron porosity and density log (forth coloumn) for (a) Shaly sand and (b) Clean sand

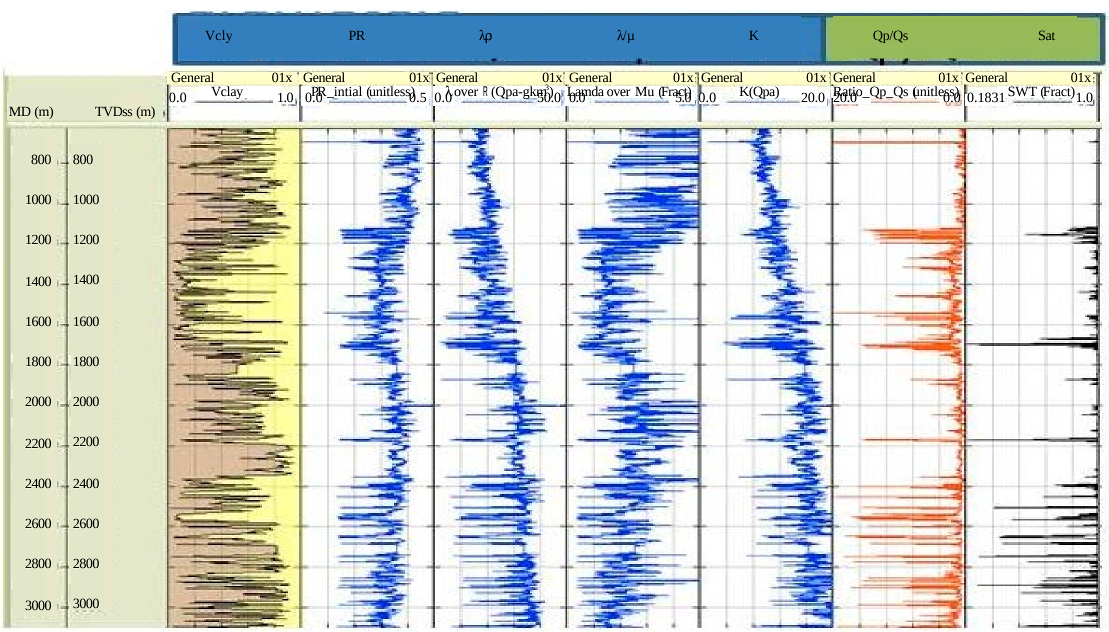

Fig. 4: The Qp/Qs (red) compared with Poisson ratio (PR), Lamda Rho (λρ), Lamda over Mu (λ/μ) and Bulk modulus

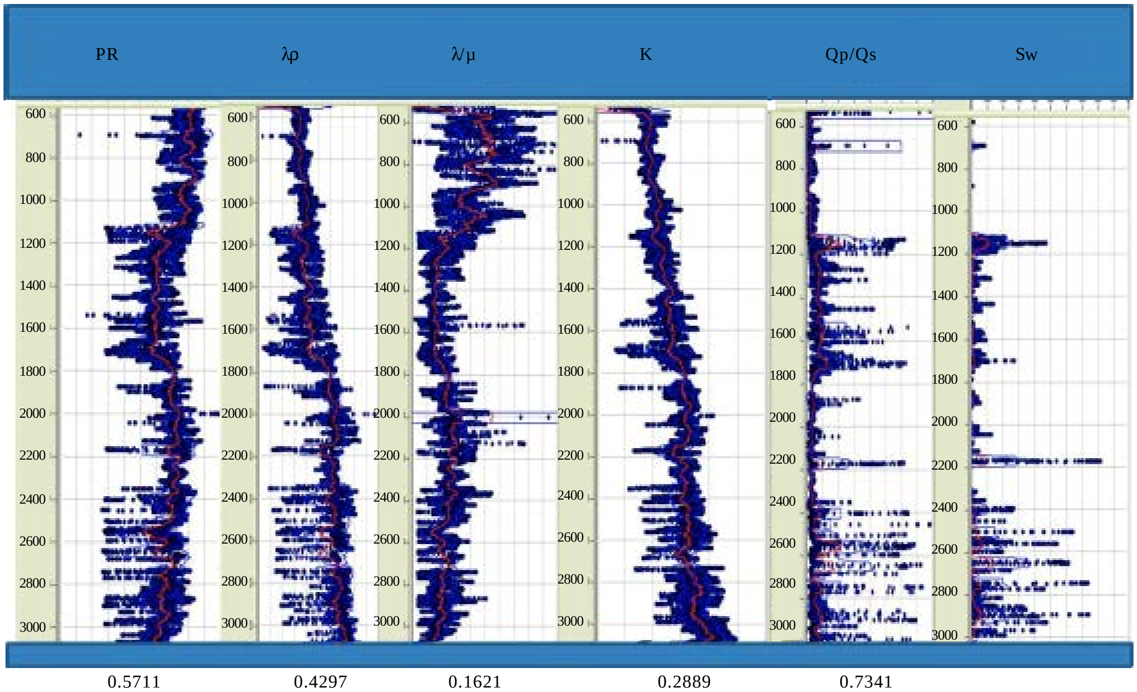

Fig. 5: The trend analysis of Qp/Qs compared with Poisson ratio (PR), Lamda Rho (λρ), Lamda over Mu (λ/μ) and Bulk modulus and its coefficient correlation with water saturation

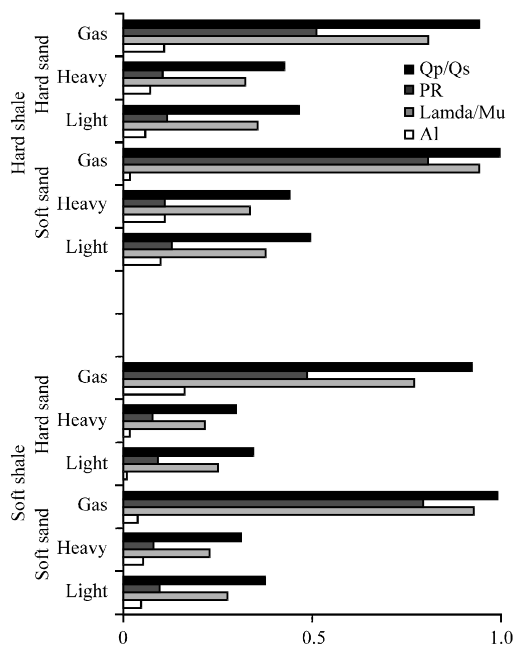

Fig. 6: Contrast of Qp/Qs compared with Poisson ratio (PR) and Lamda over Mu (λ/μ) for different geological model

contrats of Qp/Qs. Figure 6 shows the value of Lamda over Mu, Poisson ratio and Qp/Qs and its contrast for different scenarios of lithology and pore fluid. From Fig. 6, it can be seen that gas sand contrast is very high in Qp/Qs followed by Lamda over Mu and Poisson ratio for every scenario of lithology and pore fluid. The effect of lithology still high in in Poisson ratio follows by Lamda over Mu and very weak effect on Qp/Qs. Gas sand contrast always high and consistent on Qp/Qs in all different lithology interfacing. Gas in soft sand still gives high contrast in soft and hard shale on Qp/Qs compared with Lamda over mu and Poisson ratio. In this analysis, the Qp/Qs is more powerful than lamda over mu and Poisson ratio to detect the hydrocarbon.

CONCLUSION

The present study shows that the Qp/Qs is an effective attribute for hydrocarbon identification. The curve and the trend of Qp/Qs is more similar to the hydrocarbon saturation compared with other hydrocarbon indicator such as Poisson ratio, Lamda Rho, Lamda over Mu and Bulk Modulus. Meanwhile based on testing on various geological model, the contrast of Qp/Qs is more effective and powerful to identify the hydrocarbon in all condition of interfacing of shale on sand. The Qp/Qs attribute has potential to be used for better hydrocarbon prediction.

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