The Attribute for Hydrocarbon Prediction Based on Attenuation

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Abstract. Hydrocarbon prediction is a crucial issue in the oil and gas industry. Currently, the prediction of pore fluid and lithology are based on amplitude interpretation which has the potential to produce pitfalls in certain conditions of reservoir. Motivated by this fact, this work is directed to find out other attributes that can be used to reduce the pitfalls in the amplitude interpretation. Some seismic attributes were examined and studies showed that the attenuation attribute is a better attribute for hydrocarbon prediction. Theoretically, the attenuation mechanism of wave propagation is associated with the movement of fluid in the pore; hence the existence of hydrocarbon in the pore will be represented by attenuation attribute directly. In this paper we evaluated the feasibility of the quality factor ratio of P-wave and S-wave (Qp/Qs) as hydrocarbon indicator using well data and also we developed a new attribute based on attenuation for hydrocarbon prediction -- Normalized Energy Reduction Stack (NERS). To achieve these goals, this work was divided into 3 main parts; estimating the Qp/Qs on well log data, testing the new attribute in the synthetic data and applying the new attribute on real data in Malay Basin data. The result show that the Qp/Qs is better than Poisson’s ratio and Lamda over Mu as hydrocarbon indicator. The curve, trend analysis and contrast of Qp/Qs is more powerful at distinguishing pore fluid than Poisson ratio and Lamda over Mu. The NERS attribute was successful in distinguishing the hydrocarbon from brine on synthetic data. Applying this attribute on real data on Malay basin, the NERS attribute is qualitatively conformable with the structure and location where the gas is predicted. The quantitative interpretation of this attribute for hydrocarbon prediction needs to be investigated further.

1. Introduction
The main challenge in the seismic exploration is to predict hydrocarbon prospecting. Many seismic attribute have been proposed such as fluid factor (Smith, 1996), orthogonal Lame Constant (Goodway, Chen, & Downton, 1996), Poisson ratio (Verm & Hiltemnn, 1995) and AVO rotation (Connolly, 1999) and others. However, these attributes were based on the amplitude analysis. Interpretation based on amplitude still has an ambiguity because of the amplitude as seismic response is determined by many factors such as wave field 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. The interpretation based on amplitude is non-unique; it means that there are a lot of conditions that can produce the same seismic responses.
In case of 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. Hence there is a need to find out a new attribute that can representing only pore fluid rather than combination both of lithology and pore fluid effect.

Indication of attenuation mechanism as hydrocarbon indicator has been reported by some authors. Castagna et. al [1] 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 [2] explain the low frequency is associate with low quality factor of medium due to the fluid flow which is agree with diffusive-viscous theory. They used the frequency-dependent amplitude and phase-reflection properties to detect and monitor fluid saturated layers.

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 [3]. The squirt flow effect of unbounded fluid during wave propagation will produce new wave field that can absorb a part of wave energy irreversibly. As consequence, the transmitted 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 attenuation in the medium is representing in the quality factor of P wave (Qp) and S-wave (Qs).

This paper discusses the possibility of Qp/Qs for hydrocarbon prediction especially in the Malay Basin field. For comparison, the Qp/Qs was compared with the Lamda over Mu and Poisson ratio and the performance of them in determining the hydrocarbon have been examined. In the other part of this work, a new attribute for hydrocarbon prediction which is based on attenuation has been developed and it was tested on synthetic and real data.

2. Background theory

2.1. Attenuation mechanism and definition

In the damped harmonic oscillation theory, the solution of wave propagation is represented by a complex number in wave number, where the imaginary part of that complex number is representing the attenuation. The solution of damped harmonic oscillation is:

\[ A(x,t) = A_0 e^{i(k'x - \omega t)} \]

where the A is amplitude with complex wavenumber \( k' = k + i\alpha \), hence the equation (1) can be formulated as:

\[ A(x,t) = A_0 e^{-\alpha x} e^{i(kx - \omega t)} \]  

(2)

In equation (2), we can see that amplitude decay by \( \alpha \) factor. The \( \alpha \) is defined as the absorption or attenuation coefficient. In term of energy, the attenuation coefficient is defined as loss energy per cycle of wavelength. By defining the quality factor (Q), attenuation can be formulated as: (Toksoz, Johnston, Seismic Wave Attenuation, SEG publication), 1981.

\[ \frac{1}{Q(\omega)} = \frac{1}{\pi} \frac{A_0}{A_0(1 - e^{-\alpha L})} \approx \frac{\alpha L}{\pi} \]

or

\[ Q(\omega) \approx \frac{\pi}{\alpha L} \]

(3)

Equation (3) is showing that the attenuation of medium can be represented in term of quality factor (Q). The term of attenuation in this context is associated with intrinsic attenuation which is properties of medium.

2.2. Attenuation and rock physics relation

The attenuation and phase velocity of plane wave propagation in the viscoelastic medium is govern by Kramers-Kronig relation [4] and maximum of quality factor can be estimated using equation:
\[ 2Q_p^{-1} = \frac{M_p - M_r}{\sqrt{M_p M_r}} \]
\[ 2Q_s^{-1} = \frac{G_p - G_r}{\sqrt{G_p G_r}} \]  
(4)

where the \( M \) and \( G \) are compressional and shear modulus, the indexing is representing the relaxed and unrelaxed condition. The equation (4) shows that inverse quality factor can be predicted from high and low frequency condition. By adopting the Hudson crack theory for isotropic model the \( Q_p/Q_s \) is determined as \( [4] \):

\[ \frac{Q_p^{-1}}{Q_s^{-1}} = \frac{5}{4} \frac{(M/G-2)^2}{(M/G-1)} \left[ \frac{2M/G}{3(M/G-1)} + \frac{M/G}{3(M/G-1)} \right] \]  
(5)

3. Methodology

The main objective of this study is to find out a new attribute for hydrocarbon detection based on attenuation mechanism. In general, this work is divided into two part; feasibility study of \( Q_p/Q_s \) as hydrocarbon indicator in the well data and the development of new attribute based on attenuation for hydrocarbon prediction purposes.

3.1. Feasibility study on well data

In the first part, a \( Q_p/Q_s \) is estimated from well data using equation (5), where the \( M \) and \( G \) are derived from well log. To correlate this \( Q_p/Q_s \) parameter with hydrocarbon content, a well data from Malay Basin field has been examined. Crossplot, trend analysis and the contrast have been analysed to showing the performance of \( Q_p/Q_s \) in determining the hydrocarbon. Finally, the performances of this parameter were compared with the existing fluid indicator; Poisson’s ratio and Lamda over Mu.

3.2. Normalized Energy Reduction Stack

In the second part, the new attribute Normalized Energy Reduction Stack (NERS) was defined. This attribute are operated on gather data to get the stack of energy reduction due to the attenuation. Assumption was made that in the gathers, the spectral energy of far offset will be reduced more than the near offset if the medium contain the hydrocarbon. Hence the stacking over gather of this energy reduction will represent the attention. If the existence of hydrocarbon in the pore is directly can be represented by attenuation, the NERS attribute hopefully can be used as direct hydrocarbon indicator. The gather with hydrocarbon will has high NERS and vice versa. Normalized are taken by divide the spectra with its maximum value, this technique are performed to minimize the effect of amplitude hence the different lithology will not affect too much on this attribute.

Mathematically the NERS attribute is formulated as:

\[ \text{NERS} = \sum_f \left[ \frac{\left( A_{\text{ref}}(f^2 - A_{\text{ref}}) \right) (A_{\text{av}}(f^2 - A_{\text{av}}))}{\sum_f A_{\text{av}}(f^2 - A_{\text{av}})} \right] f \]  
(6)

where the amplitude spectral are normalized using the maximum value in each windows target. Schematic of this definition is illustrated in the Figure 1:
The steps to calculate NERS from gather consist of; windowing of reflection target, performing the time frequency analysis, normalizing the spectral using its maximum value, calculating the integral of the spectra over all frequency, subtraction the value for every trace by zero offset trace and finally the summation all the residual for all offset are calculated. Before this technique is applied into real data, this method was tested using synthetic data using AVO class 2 model. In the final testing, a set of partial stack data from Malay Basin field was used to test the NERS attribute.

4. Result and discussion

4.1. Feasibility of Qp/Qs as hydrocarbon indicator in Malay Basin Field
In well domain, the values of Qp/Qs were calculated based on Vp, Vs and density logs. The curve is shown in Figure 2a. Compared with water saturation log, the Qp/Qs curve is tie similarly. High value of Qp/Qs associates with low water saturation log and vice versa. This result showing that the Qp/Qs is effectively can be associated with hydrocarbon saturation. Comparing with other pore fluid indicator (Lamda over Mu and Poisson ratio), the Qp/Qs has highest correlation value with water saturation curve. The coal bed formation is shown as low value in Qp/Qs log unlike in Lamda over mu and Poisson ratio curve. This fact indicated that coal will not be identified as hydrocarbon on Qp/Qs analysis. The ambiguity between coal and gas sand will be solved in the Qp/Qs analysis.

Figure 2. (a) Qp/Qs curves compared with Lamda over Mu, Poisson ratio and water saturation, and its trends (b)

Trend analysis of Qp/Qs is performed by plotting the Qp/Qs value over depth and it’s spectral. Using the water saturation trend as reference, the Qp/Qs trend was compared with Lamda over Mu and Poisson ratio trend, the result shown that Qp/Qs trend is more close to water saturation trend rather than Lamda over Mu and Poisson ratio trend as shown in the Error! Reference source not found.2b. In this figure, we can see that the Lamda over mu and Poisson ratio still has trend over depth not like Qp/Qs trend; it might be that both of them still effected by other factor such as compaction and
porosity that is embedded as lithology factor. In the spectral analysis also, the Qp/Qs spectral is more similar with water saturation spectral than Lamda over Mu and Poisson ratio.

Fluid content detectability using Qp/Qs was evaluated on Malay basin data. This parameter was compared with Lamda over mu and Poisson ratio. In the various scenarios of reservoir models, the Qp/Qs contrast in the gas sand is very high compared with Lamda over Mu and Poisson ratio. The effect of lithology on Poisson ratio and Lamda over Mu is still strong but not on Qp/Qs. In case of Gas-soft sand overlay by soft or hard shale, the Qp/Qs contrast is still highest compared with Lamda over mu and Poisson ratio. From this analysis, it can be concluded that the Qp/Qs is more powerful than Lamda over Mu and Poisson ratio for hydrocarbon detection.

4.2. Normalized Energy Reduction Stack (NERS) as Hydrocarbon Indicator

To investigate the ability of NERS method in discriminating the lithology and fluid, this method was applied into synthetic data. The synthetic model (velocity and density) were used here is the data from Malay basin field, meanwhile the Q factor is adopted from literature. The models consist of simple layering model (shale-sand-shale) with different fluid content is shown in the Figure 3. The thickness of sand bed is same for different fluid type. The wavelet source is used has dominant frequency 30 Hz.

![Simple 3-layers model (brine, oil and gas saturated), (b) AVO response and (c) NERS before stacked response.](image)

Figure 3. (a) Simple 3-layers model (brine, oil and gas saturated), (b) AVO response and (c) NERS before stacked response.

Seismic response was generated using the convolution model, the attenuation filter applied in the frequency domain. The NMO effect was neglected. The seismic response and the NERS calculated from synthetic are shown in the Figure 3a and 3b. This Figure 3 is showing that NERS attribute can be used to detect the fluid. Gas sand has highest NERS than Oil and brine sand. Oil still can be separated from brine (NERS of oil sand is larger than brine sand).

4.3 Implementation of NERS on Real Data

The seismic data from Malay Basin was used to implement The NERS analysis. Data consist of near, mid and far stack. Geologically, this area have anticline structure where is the gas potential is located in the top of these structure. The near, mid and far stack data are shown in the Figure 4.

![Section of Near stack (left) and NERS attribute data of Malay Basin Field.](image)

Figure 4. Section of Near stack (left) and NERS attribute data of Malay Basin Field.
The attribute NERS was calculated from these section using S-transform. The result is shown in the Figure 4 (right). The Gas area is very clear shown in NERS attribute (see the circle). The Gas area is representing with high NERS value (red=high, blue =low). Others gas pocket is shown as spot which are located at A and B location. These spot is not shown in the amplitude on partial stack section. This attribute is conformable with the structure which has closure area. This area is probably the prospect of gas area.

5. Conclusion
Based on the analysis on the Qp/Qs behavior, the Qp/Qs curve that was derived from elastic properties is similar with water saturation or hydrocarbon saturation curve, hence the Qp/Qs is potential to be used as hydrocarbon indicator. Applied this attribute on Malay basin data, the result showing that the Qp/Qs is potential to be used for hydrocarbon detection. On the trend and contrast analysis, the Qp/Qs also had shown the trend close to water saturation trend. It can be concluded that the Qp/Qs able to be correlated with water saturation. In the contrast test, the contrast of Qp/Qs attribute is highest than other hydrocarbon attribute such as Lamda over Mu and Poisson ratio. The Qp/Qs contrast is highest in all soft/hard shale-soft/hard sand interfacing for hydrocarbon pore filled condition then Lamda over Mu and Poisson ratio contrast. This study shown that the Qp/Qs is more sensitive with pore fluid rather than the lithology changes.

The implementation of the NERS attribute on synthetic study and real data shown that this attribute which is derived based on attenuation is able to distinguish hydrocarbon from brine. The hydrocarbon has high NERS value mean while the brine has low NERS value. The difference is significant to distinguish both of them. Implementation on real data, the result shown that the NERS attribute is able to indicate the hydrocarbon prospect. The suspected hydrocarbon area was indicated by this attribute. Hence the NERS attribute is potential to be used for hydrocarbon prediction, however the quantitative interpretation of this attribute still need further investigation.

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References
[1] J. P. Castagna, S. Shengjie, and R. W. Siegfried, “Instantaneous spectral analysis: Detection of low-frequency shadows associated with hydrocarbons,” The Leading Edge, pp. 120–127, 2003.
[2] V. A. Korneev, G. M. Goloshubin, T. M. Daley, and D. B. Silin, “Seismic low-frequency effects in monitoring fluid-saturated reservoirs,” Geophysics, vol. 69, no. 2, pp. 522–532, 2004.
[3] M. A. Biot, “Theory of Propagation of Elastic Waves in a Fluid-Saturated Porous Solid. I. Low-Frequency Range,” The Journal Of The Acoustical Society of America, vol. 28, no. 2, pp. 168–178, 1956.
[4] G. Mavko, T. Mulerji, and J. P. Dvorkin, The Rock Physics Handbook. 2009.
[5] A. R. Schoepp and G. F. Margrave, “Improving seismic resolution with nonstationary deconvolution 1998 SEG Expanded Abstracts 1998 SEG Expanded Abstracts,” in SEG Annual Meeting, 1998, vol. September, no. 1.
[6] R. G. Stockwell, “S-transform analysis of gravity wave activity from a small scale network of airglow imagers,” The University of Western Ontario, 1999.