

STUDY OF ROCK PHYSICS AND SEISMIC ATTRIBUTES OF HYDROCARBON RESERVOIRS IN SABAH BASIN

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Abstract. Elastic moduli are known to discriminate fluid and lithology for effective reservoir characterization. However, in some cases, the elastic modulus can also show the same response for different type of fluid and lithology. In our study area, a few elastic moduli were used to evaluate the hydrocarbon sands, water sand and shale as identified based on well log response. Seismic attributes such as Relative Acoustic Impedance attribute and RMS amplitude attribute are also applied to confirm the well log analysis and investigate the seismic response. Based on the results, the effective elastic moduli for our study area is the Lambda-Mu-Rho, Velocity Ratio (V_p/V_s), Poisson's ratio and Scaled Inverse Quality (Q) Ratio. The seismic attributes such as the Relative Acoustic Impedance highlights the impedance difference between the formations while RMS amplitude shows the hydrocarbon presence. The workflow of this study is applicable for other areas for effective fluid and lithology delineation.

1. Introduction

Acoustic impedance (AI), which is the the product of velocity and density [1], is affected by different lithology type. Seismic inversion of acoustic impedance is usually done to get the 3-D elastic modulus volume that can be used for interpretation of a hydrocarbon field. High acoustic impedance interval is interpreted as shale and the low acoustic impedance as hydrocarbon-bearing sand in most clastic reservoirs. The acoustic impedances' differences are also used as an expression for the reflection coefficient to make the synthetic seismograms that can be seen on the seismic cross-section [1]. Other elastic modulus such as velocity ratio and Lambda-Mu-Rho are also commonly used to distinguish different fluid and lithology. Elastic properties therefore are very important in ensuring an effective interpretation of reservoir.

2. Study Area and Objectives

Our study area has two wells in the Sabah basin which are Well UTP-1 and Well UTP-2. Well UTP-1 has oil, gas and water sand while Well UTP-2 has gas sand. The Sabah basin is known to have soft shale which complicates the seismic interpretation as they have the same seismic amplitude response [2]. Therefore, this paper aims to compare the response of these two wells and determine the best parameter used for 1) well that penetrates all hydrocarbon and water sand, and 2) well that penetrates gas sand only with possibility of soft shale.



3. Methodology

Figure 1 shows the whole workflow of this study. Literature review was first conducted to understand the background of the elastic modulus and seismic attributes followed by Petrel and Rockdoc software familiarization. The well log and seismic data were loaded into Petrel and Rokdoc software. Petrophysical analysis were then carried out using Rokdoc software on the well log data such as generating volume of shale, porosity, and water saturation. Elastic modulus such as acoustic impedance (AI), velocity ratio (Vp/Vs), Lambda-Mu-Rho (LMR), and scaled inverse quality (Q) ratio were also generated during well log analysis. Based on the well log response and the elastic modulus, the hydrocarbon sands and shale cap rock intervals were identified and cross-plotted.

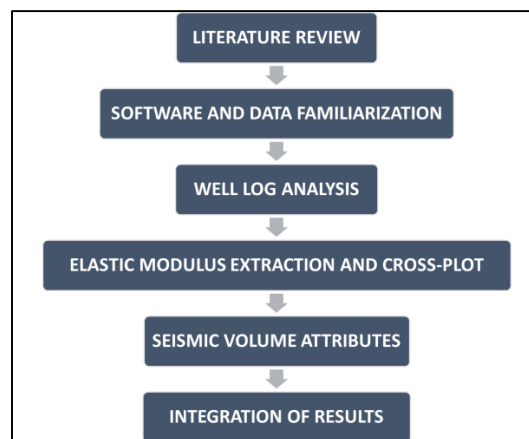


Figure 1. Workflow of Study

The wells were then correlated with the seismic volume of the area using Petrel software. Seismic volume attributes such as Relative Acoustic Impedance and RMS Amplitude attributes were applied to the seismic. Relative Acoustic Impedance attribute is chosen to evaluate the impedance of the area while RMS Amplitude attribute highlights the hydrocarbon anomaly at the well location and further from the well. Results were interpreted, compared and discussed for both wells.

4. Results and Discussion

Figure 2 shows the interpretation of Well UTP-1 and Well UTP-2. Based on gamma ray, resistivity and neutron-density well log response, the hydrocarbon, water and shale intervals were identified and then cross-plotted. The thickness of the investigated intervals are shown in Figure 2.

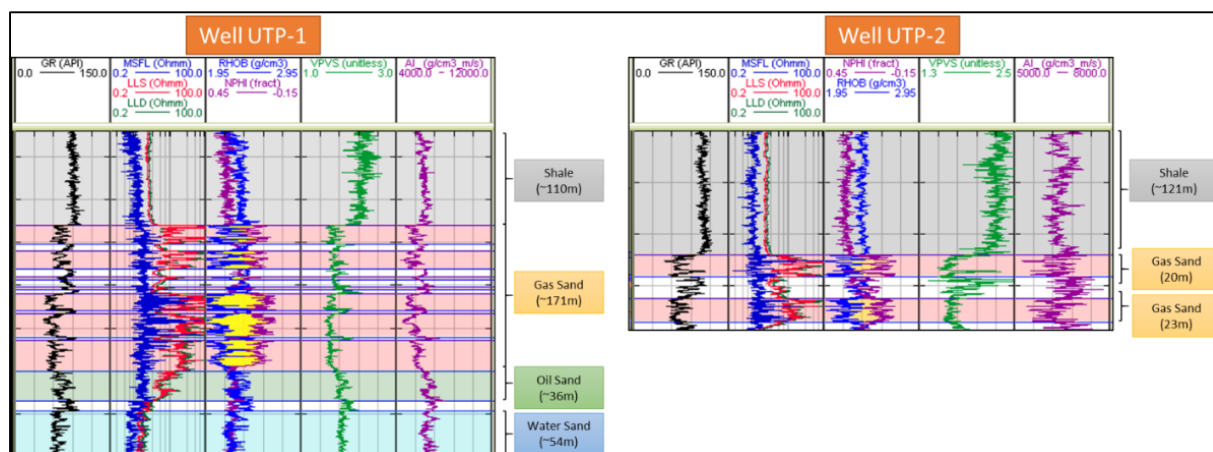


Figure 2. Interpretation of Shale and Gas Sand of Well UTP-1 and Well UTP-2

4.1. Elastic Properties Cross-plot Analysis

4.1.1. Acoustic Impedance (AI) vs. Velocity Ratio (V_p/V_s) cross-plot [3]. Based on the acoustic impedance vs. velocity ratio (V_p/V_s) cross-plot for Well UTP-1 in Figure 3a, the acoustic impedance of the shale and the reservoir rocks are slightly similar. The acoustic impedance values between the oil sand and the water sand overlap. The acoustic impedance value of the gas sand and the shale in Figure 3b which is Well UTP-2 is almost similar which attribute to the case of soft shale. The AI vs. V_p/V_s cross-plot thus is not efficient in separating the fluid and lithology as the acoustic impedance value for the soft shale overlaps with the acoustic impedance value of hydrocarbon sands.

4.1.2. Lambda-Rho vs. Mu-Rho cross-plot [4]. Based on the Lambda-Rho vs. Mu-Rho cross-plot in Figure 4, the Lambda-Rho values for gas sand in both wells are the lowest while the shale has the highest Lambda-Rho values. This is because the gas sand is more compressible than shale. The oil sand and water sand in Figure 4a shows that the oil sand and water sand for Well UTP-1 overlaps. Thus, in our study area, the Lambda-Rho and Mu-Rho parameters are not advisable to use for wells with oil and water sand but more effective for well with gas sand reservoir only.

4.1.3. Velocity Ratio (V_p/V_s) vs. Poisson's ratio cross-plot [5]. Based on the velocity ratio (V_p/V_s) vs. Poisson's ratio cross-plot in Figure 5a, the gas sand has the lowest values of velocity ratio (V_p/V_s) and Poisson's ratio values, followed by the oil, water sand and the shale.

4.1.4. Scaled Inverse Q_s (SQ_s) vs. Scaled Inverse Q_p (SQ_p) [6]. Based on the scaled inverse Q_s (SQ_s) vs. scaled inverse Q_p (SQ_p) cross-plot in Figure 6, the SQ_s values of the gas sand and the shale for both wells are different. The gas sand has the lowest SQ_p values. The values of SQ_s values for the oil and water sand can be seen overlapping. However, the SQ_p can discriminate the oil and water sand for Well UTP-1.

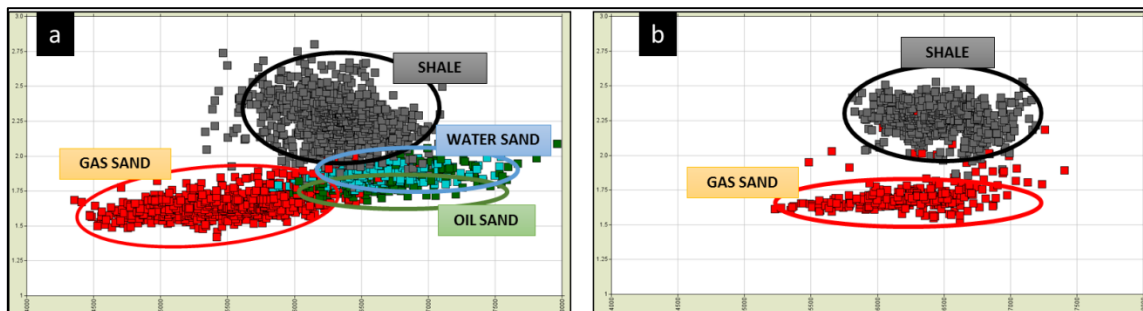


Figure 3. a) AI vs. V_p/V_s cross-plot for Well UTP-1 and b) AI vs. V_p/V_s cross-plot for Well UTP-2

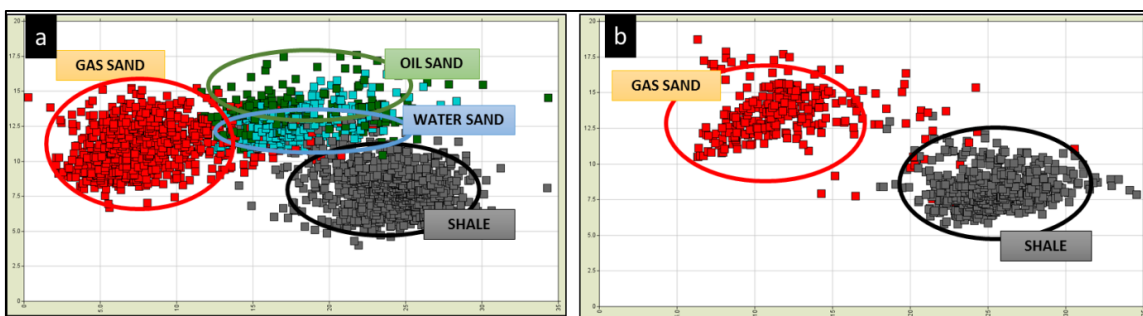


Figure 4. a) Lambda-Rho vs. Mu-Rho cross-plot for Well UTP-1 and b) Lambda-Rho vs. Mu-Rho cross-plot for Well UTP-2

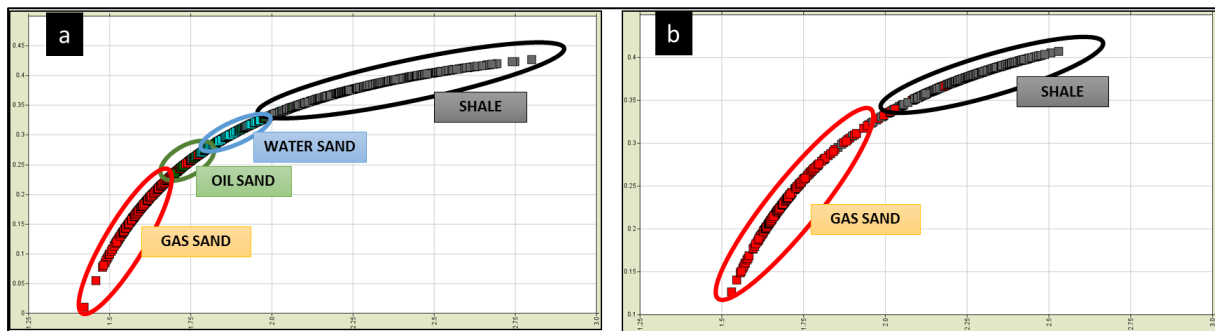


Figure 5. a) V_p/V_s vs. Poisson's Ratio cross-plot for Well UTP-1 and b) V_p/V_s vs. Poisson's Ratio cross-plot for Well UTP-2

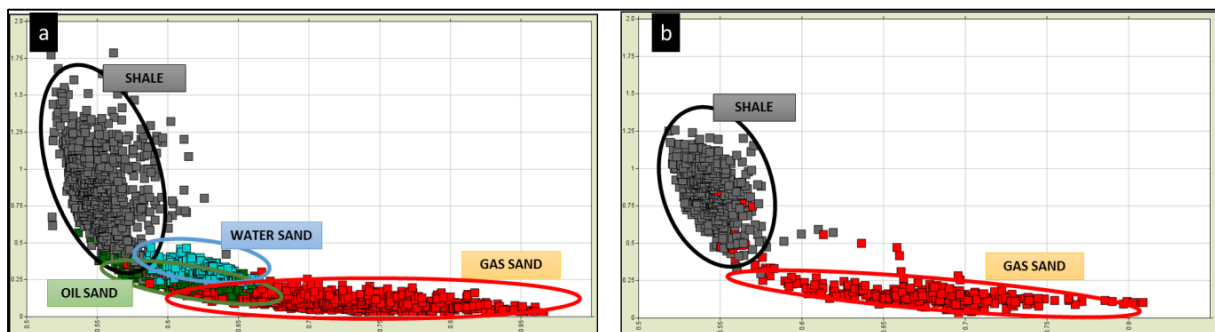


Figure 6. a) SQ_s vs. SQ_p cross-plot for Well UTP-1 and b) SQ_s vs. SQ_p cross-plot for Well UTP-2

4.1.5. *The summarized values of the elastic modulus.* Based on the cross-plots, the elastic modulus range of values for each fluid and lithology were summarized and shown on Table 1.

Table 1. Elastic Modulus Values for Well UTP-1 and Well UTP-2

Fluid and Lithology	Acoustic Impedance ((g/cm ³)/(m/s))	Velocity Ratio	Poisson's Ratio	Lambda-Rho ((GPa)/(g/cm ³))	Mu-Rho ((GPa)/(g/cm ³))	Scaled Inverse Qs	Scaled Inverse Qp
Well UTP-1 Gas Sand	4355 - 6936	1.4 - 2.0	0.0 - 0.35	0-22	6 -15	0.55 - 0.86	0.0 - 0.55
Well UTP-1 Oil Sand	5990 - 7962	1.6 - 2.0	0.20 - 0.35	11-34	10-17	0.53 - 0.66	0.14 - 0.56
Well UTP-1 Water Sand	5841 - 7543	1.7 - 2.0	0.25 - 0.35	12-28	10-16	0.56 - 0.66	0.20 - 0.46
Well UTP-1 Shale	5333 - 7159	1.7 - 2.8	0.25 - 0.42	14-34	4 -13	0.50 - 0.64	0.22- 1.78
Well UTP-2 Gas Sand	5220 - 7410	1.5 - 2.3	0.10 - 0.38	6-30	7-18	0.54 - 0.80	0.0 - 0.90
Well UTP-2 Shale	5810 - 7200	1.8 - 2.5	0.30 - 0.4	18-34	5-13	0.50 - 0.62	0.25- 1.25

Based on Table 1, the values of the acoustic impedance for different fluid and lithology in both wells are almost in the same ranges. This would complicate the interpretation of the inversion product if seismic inversion of the modulus is carried out for the area as similar values of acoustic impedance

represent different formation. The values of velocity ratio discriminate the gas sand and shale better than the acoustic impedance values for both wells, which suggest that it would be an effective modulus for a gas field. The Poisson's ratio values are slightly overlapped, but the trend is clear between reservoir and shale interval where shale has a higher Poisson's ratio value than reservoir rocks. For Lambda-Rho modulus, the values of different intervals for both wells almost overlap and thus it advised to be coupled with Mu-Rho modulus for better interpretation. The SQs values for the formation in both wells almost overlap, but is more effective when combined with SQp. These values and the trend of the elastic moduli, such as low or high values for certain fluid and lithology, can be the reference if seismic inversion is carried out on our study area.

4.2. Seismic Attributes Analysis

Seismic volume attributes were applied to our study area by using Petrel software in order to evaluate the formation penetrated by the wells and the formation further from the wells. The results of the attributes were compared with the realized seismic amplitude attribute.

4.2.1. Relative Acoustic Impedance Attribute [7]. Based on Figure 7b, 7e and 7f, the yellow and red colours show the highest impedance change between the formations while the blue colour shows the lowest impedance changes. Figure 7b shows the blue outline of the accretionary prism and the impedance difference inside the prisms. Figure 7e displays the blue outline of the prism shape and internal formation penetrated by Well UTP-1 which can't be seen clearly on the realized seismic amplitude section. Figure 7f shows the red and yellowish outline of the formation penetrated by Well UTP-2.

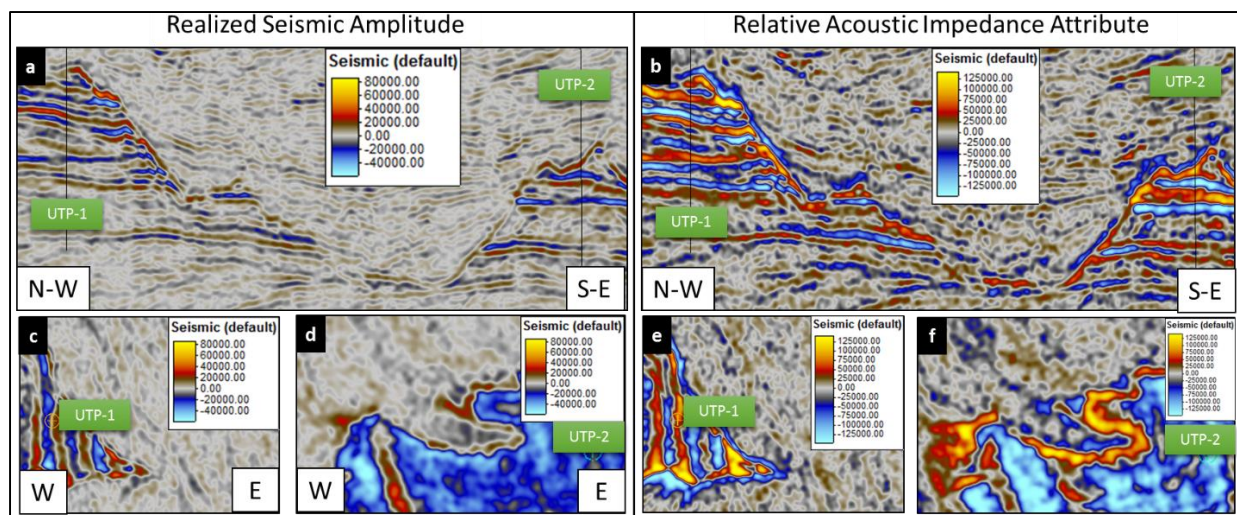


Figure 7. a) Cross-section of realized seismic amplitude, b) Cross-section of Relative Acoustic Impedance, c) Time-slice of realized seismic amplitude for Well UTP-1, d) Time-slice of realized seismic amplitude for Well UTP-2, e) Time-slice of Relative Acoustic Impedance for Well UTP-1, f) Time-slice of Relative Acoustic Impedance for Well UTP-2

4.2.2. RMS Amplitude Attribute. Based on Figure 8b, 8e, and 8f, the 'warm' red yellowish colour indicates hydrocarbon and both wells has penetrated hydrocarbon sands. The RMS amplitude shows the anomaly which can't be seen on the realized seismic amplitude alone. Figure 8b shows hydrocarbon sands, which are displayed as the red yellowish colour, penetrated by Well UTP-1 and Well UTP-2 and thus confirms the well log interpretation. Based on the result, most of the hydrocarbon anomalies are found to be inside the accretionary prisms.

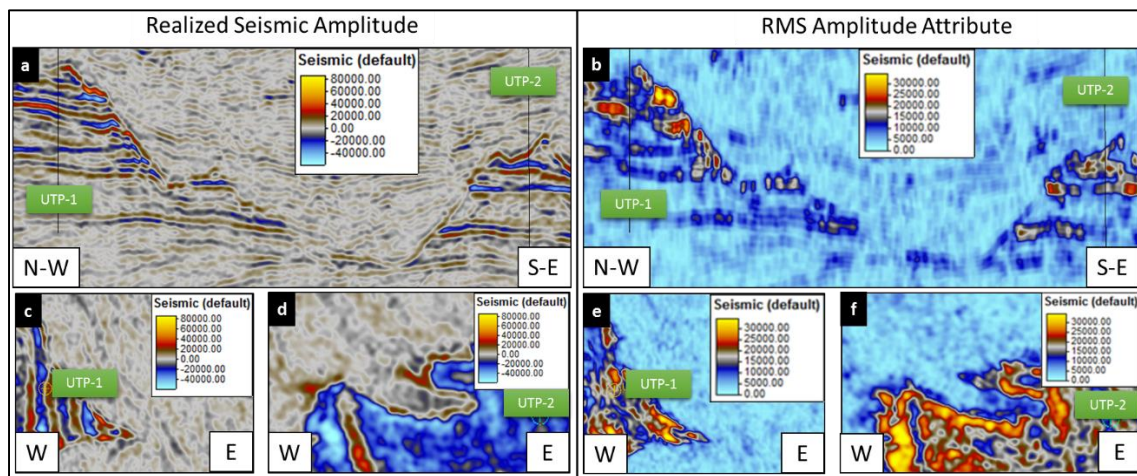


Figure 8. a) Cross-section of realized seismic amplitude, b) Cross-section of RMS Amplitude, c) Time-slice of realized seismic amplitude for Well UTP-1, d) Time-slice of realized seismic amplitude for Well UTP-2, e) Time-slice of RMS Amplitude for Well UTP-1, f) Time-slice of RMS Amplitude for Well UTP-2

5. Conclusion

In conclusion, for our study area, the effective elastic moduli for well with oil, gas and water sand and shale are Velocity Ratio (V_p/V_s), Poisson's ratio and Scaled Inverse Quality (Q) Ratio while the effective elastic moduli for well with soft shale and gas sand is the Lambda-Mu-Rho (LMR), V_p/V_s , Poisson's ratio and Scaled Inverse Quality (Q). The Relative Acoustic Impedance seismic attribute displayed the outline of formation which cannot be seen on the realized seismic amplitude section while the RMS amplitude confirms the hydrocarbon presence. For future study, seismic inversion can be conducted to further study about the formation. This study workflow is applicable to other areas and can help in fluid and lithology discrimination.

6. Acknowledgement

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