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The Feasibility Study of Reservoir Geomechanics from Brittleness Evaluation

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Abstract
A detailed understanding regarding the rock Brittleness Index is useful in oil and gas exploration as upfront information to determine the rock fracture gradient. Researchers have proposed several methods to estimate the rock Brittleness Index. However, different methods may yield different results and, hence, lead to varying interpretations regarding the Brittleness Index classification. This paper estimates the Brittleness Index of an Indonesian gas well using three approaches based on the log data and Rock Physics Modeling and to assess the consistency of the methods. In this study, the rock's brittleness is estimated based on the elastic parameters obtained from the log data as well as the rock physics method and mineralogical data. In the case that the acoustic data is unavailable, the acoustic log data was first estimated using Rock Physics Modeling using Voigt-Reuss-Hill, Kuster-Toksöz, and Biot-Gassman methods. These elastic property-based methods were then compared with the Brittleness Index obtained from the mineralogical method. The results obtained in this study suggest that the elastic property-based and the mineralogical-based methods produced a consistent Brittleness Index. However, they are different in terms of their vertical resolution. It is observed that the Brittleness Index estimated using the actual log data produced a higher resolution index as compared to the one estimated based on the mineralogical data. The Brittleness Index estimation based on the elastic parameters from the log data suggests that the rocks can be classified as less ductile to less brittle, while the Rock Physics Modeling suggests a generally less ductile type of rocks. To optimize the hydraulic fracturing design and planning, it is advised that the TOC data be combined with the Brittleness Index to identify the most suitable depth for an effective and optimum hydraulic fracturing. For further investigation in the future, it is necessary to log geomechanical and direct sample tests in the laboratory from the sample/core to obtain the best geomechanical model of the hydrocarbon shale formation in the study area.

Introduction
A detailed understanding regarding the rock Brittleness Index is significant in oil and gas exploration as upfront information to determine the rock fracture gradient. Brittleness of the shale formation plays an important role in evaluating the interval potential area for hydraulic fracturing. Brittleness, a measure of rock's ability to fracture, is a complex function of lithology, mineral composition, TOC, effective stress, reservoir temperature, diagenesis, thermal maturity, porosity, and type of fluid (Wang and Gale 2009). Therefore, brittleness is one of the key mechanical properties of rocks, and is included in most of petrophysical reports of unconventional shale reservoirs (Hucka and Das 1974). However, the absence of a universally accepted definition and measurement of brittleness has led to various methods or models for its quantification (Göktan 1991).
One of the key parameters in shale gas exploration are brittle and fracture. The shale should have contained more quartz than clay minerals to keep the fractures open during the production process. We estimated the Brittleness indicator of gas-saturated shale interval which are Poisson's Ratio and Young's Modulus. Both of them are affected by the kerogen content (high TOC), the maturity of kerogen, and also the fluid type saturated within the pore space.
In this case, we observed that our TOC were about 2-3% and within immature and early mature level of maturity according to the vitrinite reflectance plot analysis. Thus, the brittleness indicators in this work are estimated from mineral composites of shale intervals and assumed to be fully gas-saturated. This work aimed to be the feasible study for evaluating the sweet spot the gas shale layers using the integrated analysis of petrophysical and also estimated elastic properties from rock physics model of shale intervals by utilizing limited data source.

Data and Method
We classify the Rock Brittleness Index into four categories according to their interval values of rock mechanical properties, mineral composition, TOC and others (Perez Altamar and Marfurt 2014), this classification is similar to review wells included in shale formations as below:

- Ductile = < 0.16
- Less ductile = 0.16 - 0.32
- Less brittle = 0.32 - 0.48
- Brittle = > 0.48

Minerals acted as the most significant factor in controlling brittle rock behavior (Ye, Tang and Xi 2020). The most brittle area has abundant quartz and the least brittle has abundant clay mineral (Jarvie, et al. 2007). According to that, we estimated the brittleness of our area using the following equation [1] by incorporating the information of mineral composition and TOC.

$$BI_{modification} = \frac{F_{Quartz}}{F_{Quartz}+F_{Clay}+F_{TOC}+F_{Composite}} \quad [1]$$

Next, we evaluate the average value brittleness using the combination of Poisson's Ratio and Young's Modulus as the controlling mechanical properties (Grieser and Bray 2007) using the following equation [2]-[4].

$$E_{brittleness} = \frac{E - E_{min}}{E_{max} - E_{min}} \quad [2]$$

$$v_{brittleness} = \frac{v - v_{max}}{v_{min} - v_{max}} \quad [3]$$

$$BI_{average} = \frac{E_{brittleness} - v_{brittleness}}{2} \quad [4]$$

Finally, we incorporated the complex information of porosity, mineral composition, TOC, and type of fluid to get the best estimation of brittleness index using the rock physics model. The modified of our rock physics schemes (Fig. 1) aims to discriminate the ductile and brittle interval layers using the information of elastic wave parameters which are transformed into mechanical properties of Poisson's Ratio and Young's Modulus.

Due to limited data in modelling our gas-saturated shale rock, we had carefully done several steps to get the best model in delineating the sweet spot according to brittleness index from the targeted well. Firstly, estimating the bulk modulus of matrix mineral (Km) which mostly composed of quartz, clay, and several minor minerals from SX-ray Diffraction (XRD) Dataset. The value of Km plays significant role in calculating saturated bulk modulus later. Therefore, this part should be handled properly depicting the real condition of our rocks. Then, putting the matrix minerals bulk modulus together with the aspect ratio of rocks into the bulk modulus of dry rock (Kdry) calculation using Kuster-Toksöz approach. Finally, we obtained Vp and Vs of gas-saturated rock from Gassmann equation and calculated two mechanical properties of rock, which are Poisson's ratio and Young's Modulus. Both of properties obtained were assumed to be the best fit parameters in the model which represents the condition of minerals composing rock, fully gas-saturated rock, and pore space of rock.

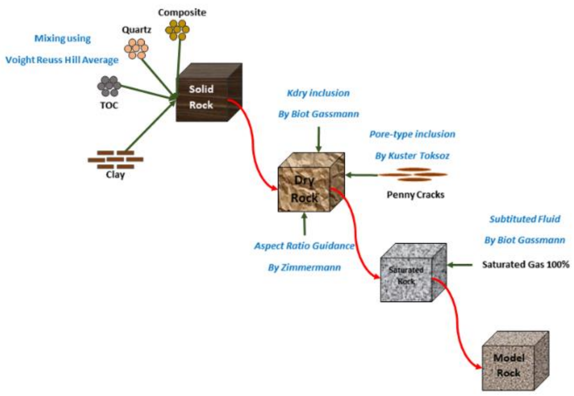


Figure 1 Rock physics Modeling scheme in research

Result and Discussion

Herein this paper, we discussed the rock Brittleness Index from three approaches in order to get the best technique of which should be used as the quick look when delineating the brittleness index of rocks from such limited resources.

<u>Brittleness Index Based on Elastic Property Data Log.</u>

Based on the modulus of elasticity information from the log data, the corrected Brittleness Index value is in the range of 0.001 - 0.795 where the brittleness of the rock in the research well has a ductile to brittle type. Where rock brittleness is dominated by rocks that are less ductile to less brittle with an average Britleness Index value of 0.294 (Fig. 2). The potential location of the maximum fracture zone is localized at 7 depth points with different thicknesses with the level of rock brittleness from less brittle to brittle with an average Brittleness Index of 0.425. The maximum brittleness of rocks tends to have high seismic wave velocities, high Young's modulus, and low Poisson Ratio (Fig. 3). This indicates that the potential zone as the maximum fracture point tends to have high seismic wave velocities associated with its excellent ability to penetrate rock layers with high brittleness.

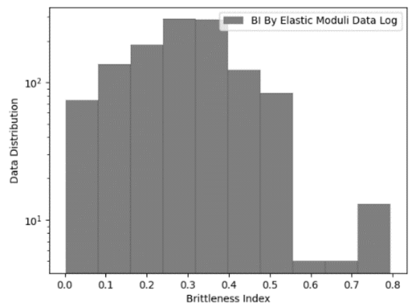


Figure 2 Histogram of Brittleness Index Data log

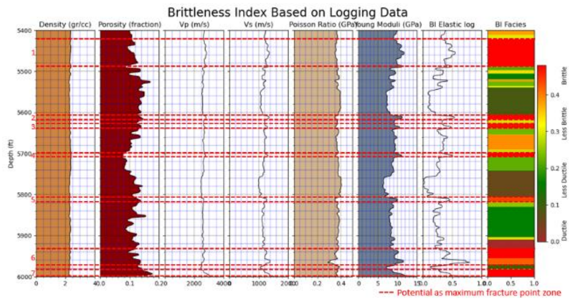


Figure 3 Brittleness Index Interpretation Based on Elstic Properties of Data Log with Maximum Fracturing Point Location

<u>Brittleness Index Based on Elastic Property Rock Pyhsics Modeling.</u>

In this paper, Rock Physics Modeling is proposed to reconstruct seismic wave velocity based on modeling rock physical parameters and mineralogy distribution information (XRD Mineral) at some depth points which is used as a seismic velocity validator from well log data. Applying the Voigt-Reuss-Hill and Kuster-Toksoz Boundary Method, we propose that the rock matrix has a soft pore type (Fig. 4a), This is related to the mineral composition which is dominated by low density mineral composition (composite mineral), with a flat pore geometry seen from the ratio of the longest pore axis to the shortest pore axis of rock porosity with a penny crack inclusion shape represented by the Zimmerman aspect ratio distribution (Fig. 4b) so that it is very representative of the condition of the research well is dominated by shale lithology, and the fill pore fluid which is composed of gas fluid.

From the justification of these parameters, we proceed to the Biot-Gassmann Modeling stage and get the view that the gas fluid substitution carried out in the research well does not provide a very significant change between the primary wave velocity of the modeling data and the log data. Meanwhile, a very significant change was confirmed in the relationship between the secondary velocity of the modeling data and the log data due to the limitation of the static saturation properties of the modeling fluid on the dynamic properties of the secondary wave velocity of the log data (Fig. 5). Bulk modulus and shear modulus of saturated rock conditions to the seismic velocity of the results of the saturation conditions in the wells of this study have a directly proportional relationship. Overall, we found a positive relationship between the modeling seismic wave velocity (V_P and V_S) and the log data, with the view that the seismic wave velocity of the saturated rock will be greater than the seismic wave velocity of the log data.

Based on the velocity model, we return to the relationship between the elastic properties of the rock brittleness distribution. Based on the modulus of elasticity information from the modeling results, the corrected Brittleness Index value is in the range of 0.241 – 0.502 where the brittleness of the rock in the research well has a ductile to brittle type. Where the rock brittleness is dominated by less ductile rocks with an average Brittleness Index value of 0.294 (Fig. 6). The potential location of the maximum fracture zone is localized at 4 depth points with different thicknesses with the level of rock brittleness from less brittle to brittle with an average Brittleness Index of 0.384. The maximum brittleness of rocks tends to have high seismic wave velocities, high Young's modulus, and low Poisson Ratio (Fig. 7). This shows that the potential zone as the maximum fracture point tends to have high seismic wave velocities associated with its excellent ability to penetrate rock layers with maximum brittleness.

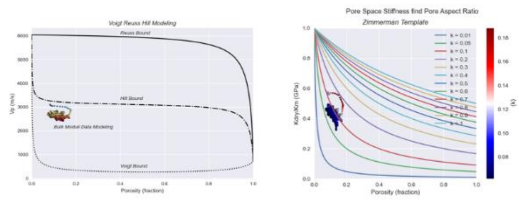


Figure 4 (a) Voigt Reuss Hill Modeling (Mavko, Mukerji and Dvorkin 2020), (b) Pore aspect ratio distribution using Zimmerman's constant pore space stiffness (Russell and Smith 2007)

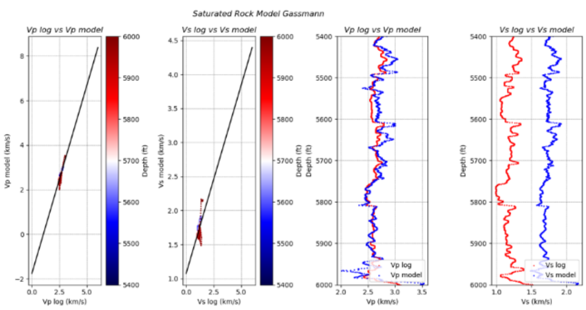


Figure 5 Seismic velocity Modeling Results with Biot Gasmann Modeling

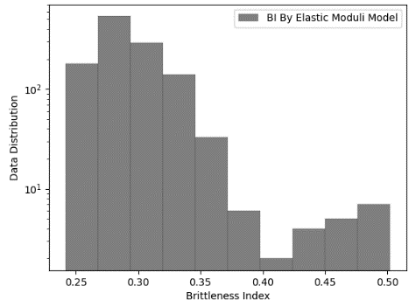


Figure 6 Histogram of Brittleness Index Rock Physics Modeling

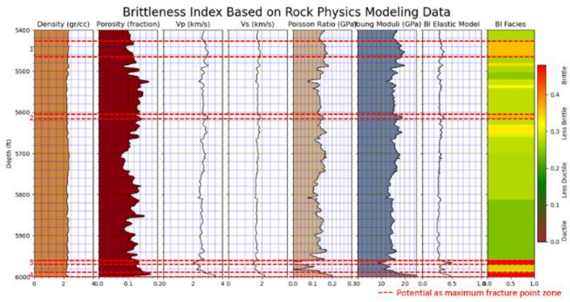


Figure 7 Brittleness Index Interpretation Based on Elstic Properties of Rock Physics Modeling with Maximum Fracturing Point Location

<u>Brittleness Index Based on Mineralogical Rock Pyhsics Modeling.</u>

Based on mineralogy information from Rock Physics Modeling, the corrected Brittleness Index value is in the range 0.140 - 0.354 where the rock brittleness in the research well has a ductile type to less brittle. Where rock brittleness is dominated by less ductile rocks with an average Britleness Index value of 0.191 (Fig. 8). The potential location of the maximum fracture zone is localized at 3 depth points with different thicknesses and the level of brittleness of the rock is less brittle 0.230 (Fig. 9). The maximum brittleness of rocks tends to have a relatively high distribution of non-clay minerals (Quartz + Composite) (23.3 - 23.6 %), relatively low clay minerals (73.0 - 74.6 %), and relatively high Total Organic Carbon content (2.2 - 3.4%) as a determining factor for the optimum and economical fracturing potential zone (Fig. 10).

The results of applying the Brittleness index using the elastic properties of rocks with log data provide more complex and dynamic results, when compared to the results of the Brittleness Index modeling which is limited to several data on the constituent minerals and related physical properties (11b). This affects the vertical resolution of the brittleness of the rock facies in the study area, where the vertical resolution of the Brittleness Index using the elastic properties of log data is better than the vertical resolution of the Brittleness Index using the elastic properties and mineralogy of Rock Physics Modeling (Fig. 11a).

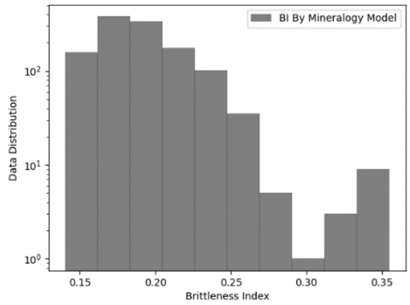


Figure 8 Histogram of Brittleness Index Mineralogy

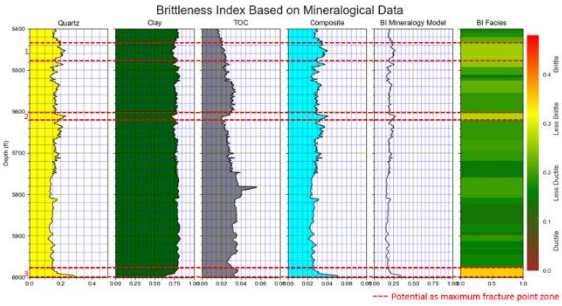


Figure 9 Brittleness Index Interpretation Based on Mineralogical Properties of Rock Physics Modeling with Maximum Fracturing Point Location

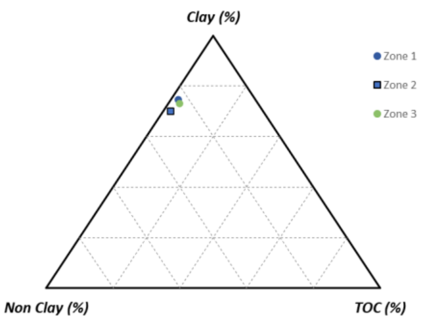
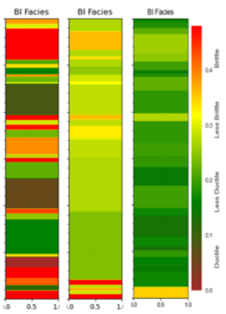
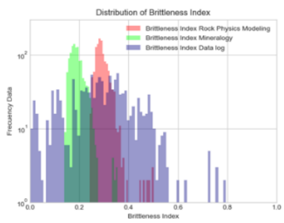


Figure 10 Mineral Composition at Maximum Fracture Point based on Mineralogical Modeling



(a) BI Elastic Properties Data Log, BI Elastic Properties RPM, BI Mineralogy RPM



(b) BI Elastic Properties Data Log, BI Elastic Properties RPM, BI Mineralogy RPM

Figure 11 Brittleness Index Interpretation

Conclusions

In this paper, the application of the 3 methods we propose provides maximum consistency to the resulting vertical resolution based on the distribution of rock brittleness index in the review wells. This estimate can be applied and becomes a quick look in seeing the potential for rock to fracture if core data is not available. To optimize the hydraulic fracturing design and planning, it is advised that the complete TOC data be combined with the Brittleness Index to identify the most suitable depth for an effective and optimum hydraulic fracturing. For further investigation in the future, it is necessary to log geomechanical and direct sample test in the laboratory from the sample/core to obtain the best geomechanical model of the hydrocarbon shale formation in the study area.

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