Identification of Carbonate Reservoir Prospective Zones Using Rock Physics Approach and Extended Elastic Impedance (EEI) in “BAP” Field, South Sumatera Basin

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Abstract. One type of reservoir that has a large enough potential is the carbonate reservoir. Carbonate reservoir has heterogeneity in relation to pore shape, so it is necessary to apply a specific rock physics approach and seismic inversion which takes into account the elastic parameters of the rock in order to know the prospect zone of the carbonate reservoir. The rock physics approach taken is to estimate the modulus of the matrix and the estimation of the aspect ratio shows that the prospect carbonate has an aspect ratio range of 0.10 - 0.30 dominated by the pore shape of the Stiff Pore. Seismic inversion shows using extended elastic impedance shows carbonate porous (Mu-Rho < 33 GPa*g/cc) and saturated hydrocarbons (Lambda-Rho < 40 GPa*g/cc) are in the middle area (around the well) where the lateral spread is getting thinner with a thickness of up to 10 ms. The prospect zone analysis from rock physics modeling and extended elastic impedance shows that reef Baturaja Formation carbonate is a zone that has a good reservoir quality dominated by a pore shape that develops is stiff pore.

1. Introduction
The identification of prospect areas in a carbonate reservoir is not very easy because the carbonate reservoir has heterogeneous properties related to various pore shapes (Mavko et al., 2009). Therefore, it is necessary to do rock physics modeling with various approaches so that the modeling of the elastic properties of the rock in the P-wave and S-wave data closer to the actual geological conditions and used as a reference in identifying the heterogeneity of carbonate rocks (Dvorkin, 2007). An interpretation stage is carried out on the seismic data using seismic inversion model-based by carrying out the process in extended elastic impedance order to strengthen the results of the identification of the carbonate reservoir distribution pattern in the "BAP" field. In the case of the “BAP” field. The Telisa Group is located in the Baturaja Formation, which is a formation formed from the transgression phase where the composition of the Baturaja Formation consists of Limestone (Limestone) or platforms and reef (De Coster, 1974). The thickness of the lower part of these formations varies, but averages 200-250 feet (about 60-75 m). With the age range in this formation it is equivalent to the fauna (foraminifera planktonic) in the N5-N6 (Early Miocene) age range formation as shown in Figure 1.
2. Research Methodology

2.1. Data
In the field research "BAP" the identification process was carried out on the "BAP" well. The field consists of wells BAP-1, BAP-2, BAP-3, and BAP-4. The process of identifying carbonate reservoirs is carried out in two stages, the first stage is identification with the rock physics approach, which requires sufficient data, namely the BAP-1 well. Then at the identification stage by inversion is carried out on wells BAP-2, BAP-3, and BAP-4 which are covered by seismic data. The seismic data used in the “BAP” field are three-dimensional (3D) seismic data partial angle-stack which is limited by in-line 1100-1500 and x-line 1001-2000. With information partial stack with angles near (4-140), mid (14-220), far (22-380). Seismic data in the "BAP" field has 3 horizons, namely Baturaja, Pendopo, and Basement horizon. Research area in the field "BAP" is shown in Figure 2.
2.2. Method

Data processing carried out in the "BAP" field uses two approaches, namely the approach with rock physics modeling in the BAP-1 well which aims to determine the heterogeneity of carbonate rocks to suit the actual geological conditions. Then the approach with seismic inversion aims to identify the validated prospective zone of the carbonate reservoir from the modeling results. The data processing flow is shown in Figure 3.

2.2.1. Cut Off V-shale more than 0.25. The data is sorted with a cut off V-shale > 0.25. This is done so that this modeling is actually carried out on carbonate rocks and void the presence of claystone lithology inserts in it.

2.2.2. Density Estimation. Determination of density matrix and fluid density obtained from linear line equations is very important to determine the elastic modulus of solid rock. The equation $y = -1.8448x + 2.7044$ is obtained where $y$ is the value bulk density and $x$ is the porosity data. Then the matrix density value obtained is 2.7044 g/cc in Figure 4.
2.2.3. Estimation of Modulus of Elastic Fluid. Estimation is performed using the Wood equation (1955). In the absence of pressure, temperature, and salinity data, the assumptions used in determining the value of fluid elastic parameters are K-brine = 2.2 GPa, K-oil = 1.1 GPa, ρ-brine = 1 g/cc, and ρ-oil = 0.8 g/cc.

2.2.4. Estimation of Elastic Modulus Solid Rock. Absence of XRD data and the elastic modulus of solid rock for each depth, an estimate of the elastic modulus of carried out solid rock is using the approach single value and Krief (1990) and Dvorkin (2007). The results of the validated equations are used to estimate the modulus value for shear solid rock at each depth point and furthermore, it can estimate the aspect ratio value of each depth point.

2.2.5. Determination of Aspect Ratio Value. Determination of the aspect ratio value is obtained based on the experimental modification of Kumar and Han (2005). This experiment aims to obtain the aspect ratio value of each depth point and can be used to identify the heterogeneity of carbonate rocks in the target zone. The model for determining the aspect ratio value based on the upper limit (Hashin Shtrikman Upper Bound), middle limit (Wyllie), and lower limit (Hashin Shtrikman Lower Bound) is shown in Figure 5.

2.2.6. Kuster-Tokoz Velocity Validation. After obtaining the value aspect ratio based on the experimental modification Kumar and Han (2005). The next step is to validate by modeling the P and S velocities of saturated rock using the Kuster-Toksoz model. The results of the validation of the maximum correlation and error were minimum used in the analysis stage of the pore properties of the carbonate rock. Correlation and results were obtained error in the initial experiment using the elastic modulus of solid rock single value and the final experiment using the modulus shear solid rock model Krief (1990) is shown in Table 1.

| No | Zone | Information | Initial Experiment | Final Experiment |
|----|------|-------------|--------------------|-----------------|
|    |      |             | RMSE   | R²    | RMSE   | R²    |
| 1  | Stiff| Vp          | 0.0492 | 0.9930| 0.0264 | 0.9938|
|    |      | Vs          | 0.1180 | 0.8974| 0.0938 | 0.8938|
| 2  | Soft | Vp          | 0.0689 | 0.9508| 0.0512 | 0.9499|
|    |      | Vs          | 0.0749 | 0.9050| 0.0563 | 0.8958|
| 3  | All Zone | Vp  | -       | -     | 0.0424 | 0.9694|
|    |      | Vs  | -       | -     | 0.0747 | 0.8945|

Figure 5. The relationship between velocity-p and the pore shape of the rock

Table 1. Error and correlation coefficient
2.2.7. **Analysis Tuning Thickness.** In the seismic data processing, process analysis is necessary tuning thickness to determine the minimum thickness of a layer so that it can be resolved by seismic data. The obtained average P-wave velocity ($V_p$) around the target formation is 4872,091 m/s. With a dominant seismic frequency of 18 Hz. Thus, with a value tuning thickness around the target area of 67,667 m while the thickness of the target reservoir is around 77.75 m and above the value tuning thickness, the seismic data can resolve the target reservoir.

2.2.8. **Logging Derivative.** In this process, the production of derived logs is obtained from existing well data. Such as $V_p$, $V_s$, and density data. Logs derivatives such as P-Impedance, S-Impedance, Lambda-rho, Mu-Rho, Lambda/Mu, $V_p/V_s$. In this case, the log data that can be processed with the derivative log is the well data "BAP-4". Meanwhile, for data from wells "BAP-2" and "BAP-3", the log derivatives were carried out to obtain the P-impedance value which was used as inversion validation for the well "BAP-4".

2.2.9. **Sensitivity Analysis.** Sensitivity analysis is carried out to find elastic parameters that are sensitive to the presence of changes in lithology and fluid in the target area carried out by the inversion process.

2.2.10. **Extended Elastic Impedance.** This stage aims to determine the volume of extracted seismic reflectivity based on the reflectivity of the P wave and the reflectivity of the S wave which represents certain elastic parameters according to the correlation angle $\chi$ with the elastic parameters of the well data carried out by the EEI process.

2.2.11. **Well Seismic Tie.** This process aims to tie seismic data and well data. Considering the difference in the data domain between time domain seismic data (domain-two-way time) and depth-well data.

2.2.12. **Seismic Inversion.** An inversion process is carried out using a model based, which begins with the process of creating a model at low frequency controlled by well data. Furthermore, pre-inversion analysis is carried out in order to determine the inversion parameter which gives the optimal inversion result. The optimal inversion results can be identified from the inversion results that approach log data and seismic data with a value error minimum. The inversion process stage is carried out for each EEI reflectivity which corresponds to a certain elastic parameter.

3. **Result and Discussion**

3.1. **Target Zone Analysis**

The target zone in the field well “BAP” is in the Baturaja formation. Where this target zone is identified by lithology of carbonate types saturated by hydrocarbons. From a reading volume-shale low, the result of cross-over between low neutron porosity and density with a low change in value water saturation.

3.2 **Prospect Zone Analysis**

For the hydrocarbon prospect zone analysis based on petro-physical parameter data and the results of rock physics modeling. Figure 6 shows the prospect zone analysis carried out on BAP-1 well which is divided into 3 zones, namely zone A, zone B, and Zone C. So that the three zones are in one Baturaja Formation, for zone A and zone B shows the existence of a good type of reservoir quality as indicated by the high values of porosity and hydrocarbon saturation. And if it is compared with the results of the related rock physics model, the result of the aspect ratio value which is relatively large compared to the elastic parameters shows that the best reservoir quality is in zone B because it has a developed rock pore type, namely types vuggy and moudic porosity (stiff pore). This pore type produces small Lambda-Rho and K/\mu dry values when porosity > 0.20 and large Lambda-Rho and K/\mu dry when porosity < 0.20. In accordance with the geological review of the Baturaja Formation, it is developing due to the existence of a platform which is a relatively zone tight with low porosity and hydrocarbon saturation values. in accordance with the results of the modelling shown by zone C is dominated by rock types soft pore. And the part of reef the Baturaja Formation which is a relatively zone porous indicated by the porosity and
high hydrocarbon saturation values in Zone A and Zone B are zones that have good reservoir quality with pore types that develop in the zone dominated by types reference pore + stiff pore.

Figure 6. Prospect zone based on log data and aspect ratio value.

3.3 Sensitivity Analysis

From the results of the cross-plot preliminary on the well "BAP-1", it was found that the target formation area between baturaja and pendopo horizon found that the majority of rock lithology types were carbonate rock types. And in determining the cut-off between the carbonate porous and tight the value was Mu-Rho cut-off 33 GPa* g/cc. Where the carbonate with high porosity is below Mu-Rho 33 GPa* g/cc while the carbonate with low porosity is above Mu-Rho 33 GPa* g/cc. Then by using the fluid sensitive parameter, namely lambda-rho, from the results of the analysis cross-plot, the cut-off value for carbonate saturated with hydrocarbons or low SW is at a value Lambda-Rho small of 40 GPa* g/cc. Meanwhile, the carbonate that is saturated with water or high SW is at a Lambda-Rho value of 40 GPa* g/cc which is shown in Figure 7.

Figure 7. Sensitivity Analysis Baturaja Formation
3.4 Extended Elastic Impedance

The optimal correlation on sensitive log parameters is lambda-rho corresponds to log EEI (-30°) and mu-rho corresponds to log EEI (71°). The result of reflectivity Mu-Rho on the horizon of the Baturaja horizon is dominated by a positive color (red), this is related to changes in lithology. The results of EEI analysis and changes in reflectivity, which lambda-rho are dominated by negative colors (blue) in the Baturaja horizon, are associated with changes in fluid content as shown in Figure 8 and Figure 9.

![Figure 8. Correlation analysis and error EEI log on rock elastic parameters](image1)

![Figure 9. (a) EEI reflectance volume (330°), (b) EEI reflectance volume (71°)](image2)

3.5 Inversion Results.

In the initial process of inversion, well seismic tie was carried out. Parameters that were carried out by well seismic tie were sensitive parameters in the reservoir identification process, namely Lambda-Rho and Mu-Rho. The time-depth relationship is obtained in the correlation process around the target formation so that it can be matched between the well data and the seismic data in Table 2.

| No | Sensitivity Parameter | Wavelet       | Correlation |
|----|-----------------------|---------------|-------------|
| 1  | Lambda-Rho            | Ricker 16 Hz -15° | 0.680       |
| 2  | Mu-Rho                | Ricker 16 Hz +15° | 0.762       |

The results of the inversion Mu-Rho of the Baturaja formation are in the yellow-red color zone with a range of values in Mu-Rho between the values < 33 GPa*g/cc around the horizon of the Baturaja formation which is estimated to be carbonate lithology with high porosity and Lambda-Rho < 40 GPa*g/cc is a type of carbonate saturated with hydrocarbons as shown in Figure 10. Therefore, from the inversion analysis in the “BAP” field around the horizon of the Baturaja formation, it is a type of carbonate rock, reef build-up relatively porous saturated with hydrocarbons. It is also in line with the geological review that the identification of carbonates in the baturaja formation is widely distributed,
consisting of platform relatively tight carbonates. Carbonates build-up and and reef relatively porous under the Baturaja horizon.

(a)

(b)

Figure 10. Inversion results (a) Mu-rho, (b) Lambda-Rho

3.6 Identification of Reservoir Prospective

From the results of slicing every 5 ms down on the horizon of the Baturaja Formation, it was identified that the lateral distribution of porous carbonate in the Baturaja Formation has a thickness of up to 10 ms (down) with a Mu-Rho value < 33 GPa*g/cc and saturated carbonate distribution The hydrocarbons laterally in the Baturaja Formation also have a thickness of up to 10 ms (down) with a Lambda-Rho value < 40 GPa*g/cc is shown in Figure 11. Where the more the porous and saturated carbonate expanse of hydrocarbons the thinner the orientation of the northwest-southeast area research. The thickening of the carbonate in the middle (the area around the well) occurs because the carbonate grows in the marine environment which has been exposed and dissolves, which is a characteristic of vuggy and mouldic porosity (stiff pore) carbonate growth. Therefore, the carbonate in the reef of the Baturaja formation has the potential to be of good reservoir quality by having high porosity and hydrocarbon saturated as evidenced by the results of rock physics modeling and EEI inversion which takes into account the elastic parameters of the rock.
4. Conclusion
According to the discussion result above, can be concluded that:

1. The identification of the quality of the carbonate reservoir in the field "BAP" from the results of rock physics modeling and EEI inversion obtained a spread of porous carbonate (Mu-Rho < 33 GPa*g/cc) and accumulated HC (Lambda-Rho < 40 GPa*g/cc) with a dominant value aspect ratio 0.10 - 0.30 (reference + stiff pore) is found on the reef part of the Baturaja formation.
2. Where in the reef part of the Baturaja formation there is a thickening of the carbonate prospects in the middle (the area around the well), the more the carbonate spread is getting thinner.
3. This shows that the carbonate grew in a marine environment that was exposed and dissolved, which is a characteristic of vuggy and mouldic porosity (stiff pore) carbonate growth which is oriented towards the northwest-southeast of the study area.

5. Recommendation
1. Pore type analysis is required in all research wells to ensure a better quality reservoir distribution (reference + stiff pore) in the spatial prospect zone.
2. It is necessary to develop research by finding the value of effective porosity in the target zone to be able to as certain the development area or location of other prospect wells that can be produced.

References
[1] De Coster G L 1974 The Geology of the central and south sumatera basin Proceeding’s 3rd annual convention IPA June 1974 Jakarta
[2] Dvorkin, J P 2007 Yet another Vs equation Geophysics Vol 73 No 2 E35-E39
[3] Krief M, Garat J, Stellingwerff J and Ventre J 1990 A petrophysical interpretation using the velocities of P and S waves (full-waveform sonic) Log Analyst Vol 31 355–369
[4] Kumar M and D Han 2005 Pore shape effect on elastic properties of carbonate rocks SEG/Houston 2005 Annual Meeting page 1477-1480
[5] Kuster G T and Toksoz M N 1974 Velocity and attenuation of seismic waves in twophase media, Part I: theoretical formulations Geophysics 39(5) 587– 606
[6] Mavko G, Mukerji T and Dvorkin J 2009 The Rock Physics Handbook (New York: Cambridge University Press)
[7] Thomas M, Ball V, Blangy J P and Tenorio L 2016 Rock-physics relationships between inverted elastic reflectivities The Leading Edge 35(5) 438-444
[8] Ursenbach C P and Stewart R R 2008 Two-term AVO Inversion: Equivalences and New Methods Geophysics 73 no 6 C31–C38
[9] Whitcombe D N, Connolly P A, Reagan R L and Redshaw T C 2002 Extended elastic Impedance for fluid and lithology prediction Geophysics 67 63–67
[10] Wyllie M R J, Gardner G H F and Gregory A R 1963 Studies of elastic wave attenuation in porous media Geophys. 27 569-589