Study comparative rock typing methods to classify rock type carbonate reservoir Field “S” East Java

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Abstract. Challenges in the characterization of the carbonate reservoir are related to rock type and porosity. The permeability cannot be determined only by porosity. So the method that can be used to classify rock type and estimates the permeability is rock typing method. This study uses several rock typing methods that are Flow Zone Indicator (FZI), Winland R35, Pore Geometry Structure (PGS), and Lucia method. Core data from three wells have been applied in this study as reference wells. The objective is comparing those four methods and choose the best method for this study. There are two assessments in comparing. First, comparing the core permeability with predicted permeability on each method of rock typing. The result is the Winland R35 method has a better correlation between predicted permeability and core permeability, which have the value of the gradient is 0.9772, \(R^2\) is 0.9369 and RMS error is 62.14 mD. Second is by spreading the seismic parameters data to see the separation of each class in each method of rock typing. From this assessment, Lucia has a better distribution of seismic parameters. This assessment is more important than the first assessment. Therefore, Lucia is the best rock typing method in this study.

Keywords: Rock type, Carbonate, Permeability, Impedance

1. Introduction

Carbonate reservoir has a high level of heterogeneity than clastic reservoir, which is relatively only controlled by depositional facies. It is because of the facies variation vertically and laterally that more intensive [1], as well as intensive diagenesis. That is the reason why this study need accurate methods that can make hydrocarbons development more effective and efficient.

Challenges in the characterization of the carbonate reservoir are related to rock type and porosity [2]. The permeability of rocks cannot be determined only by porosity. The method that can be used to determine rock type and estimates the permeability of rocks is the rock typing method. That method very appropriately applied to the carbonate reservoir that tends to be very dynamic to change (diagenesis). It is believed can predict and optimize carbonate reservoir better. Core data can be used to determine rock type based on geology (lithotyping) or petrophysics (petrotyping) characterization [3].

There are many rock typing methods, which are Lucia, Flow Zone Indicator (FZI), Winland R35, and Pore Geometry Structure (PGS) method. Those methods use different principles in classify rock type and have their respective advantages and disadvantages.
Several models of rock typing methods have been developed by many researchers, but most of them are not consistent to determine rock type in carbonate reservoir rocks based on both geological and engineering features. So there is a need to look at the level of consistency and suitability of a method of rock typing that applied to a field [4].

Therefore, it is important to do a study of the rock typing methods comparison. By knowing the results, it can be known the accurate and suitable rock typing method to be used in characterizing the reservoir of carbonate rocks.

2. Methodology
This study classifies rock type and estimates permeability of rocks in carbonate reservoir using the combination of rock typing and classifier modelling methods. Besides that, it also makes the comparison of several rock typing and classifier methods that are Lucia, Flow Zone Indicator (FZI), Winland R35, and Pore Geometry Structure (PGS) method.

There are three wells which have core data at a certain depth interval, so those are used as reference wells. Those wells are also made as target wells for permeability estimation at depth intervals that don’t have core data. There is also a well that doesn’t have core data at all. Those core data are permeability and porosity. Those two parameters are used to classify rock type using FZI, Winland R35, and PGS methods.

Beside core data, the result of Differential Effective Medium (DEM) method is used as input to classify rock types based on rock typing Lucia method. A parameter that needed is interparticle porosity. It is also used seismic parameters such as acoustic impedance (AI), shear impedance (SI), and lambda mu rho as the parameter to see the separation of each class in each method of rock typing. Four rock typing methods that used in this study are:

2.1. Lucia method
Lucia method divides rock into three classes based on rock fabric and grain size (figure 1). Equation (1), can be used to classify rock type [5,6].

\[
\log(k) = (A - B \log(rfn)) + \left( (C - D \log(rfn)) \log(\Phi_{ip}) \right)
\]

(1)

where \(A = 9.7892, B = 12.0838, C = 8.6711, D = 8.2965, \) and \(rfn\) is the rock fabric number with range from 0.5 until 4, and \(\Phi_{ip}\) is the fractional interparticle porosity.

Figure 1. Lucia classify rock type based on rock fabric [7,8].
2.2. **Flow Zone Indicator (FZI) method**

This method uses the flow unit concept in segmenting the reservoir. Flow Zone Indicator (FZI) is a parameter that will be used to determine rock type class boundaries. Equation (2) can be used to get FZI value [9].

\[
FZI = \frac{1}{\left(\frac{F_s}{S_{sv}}\right)^{1/2}} = \frac{RQI}{PGR} = \frac{0.0314 \left(\frac{k}{\Phi_e}\right)^{1/2}}{\Phi_e} \left(1 - \Phi_e\right)
\]  

where \(k\) is the rock permeability in milidarcy (mD), and \(\Phi_e\) is the fractional effective porosity.

Normal probability analysis can be used to classify rock type [10], that is by using a graph of normal probability on log FZI, where the x-axis is log FZI and the y-axis is the probability of FZI. Determination of class boundaries is determined by looking at the slope changes on the line, where each change in the slope indicates the difference in rock type (figure 2).

![Normal Probability of Log FZI](image)

**Figure 2.** Normal probability of log FZI [11].

2.3. **Winland R35 method**

Winland classifies rock type using pore throat radius concept. In the Winland empirical relationship, the largest statistical correlation is when the pore throat size corresponds to a 35% cumulative mercury saturation curve, and the pore throat radius is termed R35. Equation (3) can be used to determine the R35 value [12].

\[
\log (R35) = 0.732 + 0.588 \log (k) - 0.864 \log (\Phi)
\]  

where R35 is the pore throat radius in \(\mu\)m when mercury saturation is 35%, \(k\) is the rock permeability in milidarcy (mD), and \(\Phi\) is the percentage porosity.

Semi-log plot of R35 (x-axis) and serial number (y-axis) to classify rock type [13]. R35 is displayed in logarithmic scale. R35 value is sorted from the smallest to the largest, while the serial number is a sequence of numbers starting from number 1 to the number of data. Determination of class boundaries is determined by looking at the slope changes on the line, where each change in the slope indicates the difference in rock type (figure 3).
2.4. Pore Geometry Structure (PGS) method

PGS method has a concept, which is considering the relationship between the geological aspects as well as the reservoir engineering aspects. This concept states that the pore architecture, in this case, is the pore geometry and pore structure, can be used to group rocks and also become the basis for estimating permeability. Equation (4) states the correlation between pore geometry and structure [14].

\[
\left( \frac{k}{\Phi} \right)^{0.5} = \Phi(C)^{1/2}
\]  

(4)

where \( \left( \frac{k}{\Phi} \right)^{0.5} \) is the pore geometry and \( C \) is the pore structure.

Based on equation (4), can be plotted the correlation between the pore geometry (y-axis) and the pore structure (x-axis). Rock type curve [15] can be used to classify rock type classes (figure 4).

![Figure 3. Semi-log plot of R35 based on serial number [13].](image)

![Figure 4. Rock Type Curve [15].](image)

After classifying the rock type by using those four rock typing methods, then the next step is to compare and determine the best method. There are two assessments in comparing. First, comparing the
core permeability with predicted permeability on each method of rock typing. Second is by spreading the seismic parameters data to see the separation of each class in each method of rock typing.

3. Results and Discussion
Initially, a logarithmic crossplot of core permeability against core porosity was plotted as shown in figure 5 using power trendline function. Figure 5 shows a lot of scattering, which indicates that porosity alone is insufficient to explain variation in permeability. A power correlation ($R^2 = 0.1404$) was obtained, indicating a poor linear relationship in logarithmic scale between core permeability and porosity. This poor correlation is indicating the existence of more than one group of data or rock type.

![Figure 5. Crossplot of core permeability against core porosity.](image)

Therefore, this relationship between core porosity and permeability cannot be relied upon for accurate estimation of permeability values from porosity data. To be better in estimating the permeability, then it is necessary to classify rock type using the rock typing method. The result of rock type classification based on those four rock typing methods are as follows:

3.1. Lucia method
Based on the equation (1) and varying the $rfn$ value as figure 1, then three different classes are obtained. However, since there are still many scattered data outside these three classes (figure 6a), so four classes (RT 1 – 4) are added interpretatively, which have a trend of porosity and permeability relationship (figure 6b).

![Figure 6. The results of rock type classification based on the Lucia method into (a) three classes (before modification) and (b) seven classes (after modification).](image)
3.2. Flow Zone Indicator (FZI) method
Based on the equation (2) that used to determine the FZI value and to be applied such as figure 2, there are seven different classes are obtained (figure 7a). Figure 7b shows the distribution of data for each class if plotted in the correlation between permeability and porosity.

![Figure 7](image)

(a) Normal Probability of log FZI
(b) Rock Types Based on FZI Method

Figure 7. (a) The graph of boundary determination for each rock type class based on the FZI method (normal probability of log FZI). (b) The results of rock type classification based on the FZI method in the correlation between permeability and porosity.

3.3. Winland R35 method
Based on the equation (3) that used to determine the R35 value and to be applied such as figure 3, there are eight different classes are obtained (figure 8). Figure 8b shows the distribution of data for each class if plotted in the correlation between permeability and porosity.

![Figure 8](image)

(a) Serial Number of R35
(b) Rock Types Based on Winland R35 Method

Figure 8. (a) The graph of boundary determination for each rock type class based on the Winland R35 method (semi-log plot of R35 based on serial number). (b) The results of rock type classification based on the Winland R35 method in the correlation between permeability and porosity.

3.4. Pore Geometry Structure (PGS) method
Based on rock type curve (figure 4), there are eight different classes are obtained (Figure 9a). Figure 9b shows the distribution of data for each class if plotted in the correlation between permeability and porosity.
Figure 9. (a) The graph of boundary determination for each rock type class based on the PGS method (rock type curve). (b) The results of rock type classification based on the PGS method in the correlation between permeability and porosity.

Table 1 shows the equation function of permeability and porosity correlation in each rock typing method. Those equations use power trendline function.

| RT | Lucia     | FZI       | Winland R35 | PGS       |
|----|-----------|-----------|-------------|-----------|
| 1  | $y = 33.023x^{0.2095}$ | $y = 101426x^{0.6648}$ | $y = 31.53x^{1.8856}$ | $y = 1.059x^{-3.645}$ |
| 2  | $y = 24.027x^{0.3966}$  | $y = 383103x^{2.9586}$ | $y = 6.9194x^{1.8365}$ | $y = 0.092x^{-3.976}$ |
| 3  | $y = 1E+07x^{4.3556}$  | $y = 133901x^{3.0326}$ | $y = 2.0548x^{1.5137}$ | $y = 0.023x^{-3.588}$ |
| 4  | $y = 7E+08x^{6.6194}$ | $y = 92696x^{3.1097}$ | $y = 0.7512x^{1.3793}$ | $y = 0.0174x^{-3.589}$ |
| 5  | $y = 6E+06x^{5.7263}$ | $y = 25560x^{3.1344}$  | $y = 0.1269x^{1.4748}$ | $y = 0.0047x^{-3.704}$ |
| 6  | $y = 290378x^{5.3967}$ | $y = 4400.7x^{3.2007}$ | $y = 0.0307x^{-1.5209}$ | $y = 0.0017x^{-2.894}$ |
| 7  | $y = 7886.5x^{4.161}$  | $y = 887.84x^{3.3047}$ | $y = 0.0111x^{1.4898}$ | $y = 0.0041x^{-1.71}$ |
| 8  | -         | -         | $y = 0.0041x^{1.097}$ | $y = 0.0004x^{-1.652}$ |

Then, using the equation function in table 1, it can be obtained the predicted permeability value for each rock typing method. The level of accuracy of the permeability predictions in each method is compared to the core permeability as shown in figure 10. To determine the best rock typing method in
predicting or estimating the permeability value, the parameters used as the valuation are the gradient, $R^2$ and RMS error.

![Crossplot of comparison of core permeability and predicted permeability based on the following methods: (a) Lucia, (b) FZI, (c) Winland R35, and (d) PGS.](image)

Figure 10. The crossplot of comparison of core permeability and predicted permeability based on the following methods: (a) Lucia, (b) FZI, (c) Winland R35, and (d) PGS.

Based on Figure 10, the four methods already have a pretty good gradient value. It can be stated that these methods can estimate permeability well. However, the Winland R35 method has the best gradient and $R^2$ values (close to 1) compared to the other three methods. Based on the gradient value which is worth 0.9772, indicating that the trendline match has been very good or close to the real condition of core data. Also, the method has very good $R^2$ value, which is 0.9369. That value indicates the accuracy of data distribution to the trendline. The Winland R35 method has the best $R^2$ value compared to the other three methods.

The RMS error of the Winland method is 62.14 mD. This value indicates the value of error or how much the difference in average results of the predicted permeability to the trendline. The RMS error of the Winland R35 method is smaller than the FZI and PGS methods, but still a bit larger than the Lucia method. It is because there are a few data that deviate far from the trend, which can be considered as noise or measurement error. Based on these results, it can be stated that the Winland R35 method is the best method for predicting the permeability of rocks.

The second assessment is doing a correlation between rock type classes in each method using seismic parameters, such as acoustic impedance (AI), shear impedance (SI), and lambda mu rho. Figure 11 shows the crossplot of acoustic impedance (AI) and shear impedance (SI) values of each rock typing method.
Figure 11. The crossplot of AI and SI based on the following methods: (a) Lucia, (b) FZI, (c) Winland R35, (d) PGS.

Figure 11 shows the distribution of AI and SI based on each rock type classes are overlapping. It happens to all four methods. However, the Lucia method has a better distribution of AI and SI. The distribution is still overlapping, but it still has a little separation between those classes if compared to the other methods. There is no data on each class which spread all over the place like the other methods. Furthermore, the distribution data from each class is separately well and fairly sequential. It shows the Lucia method is better at classifying rock type. It is the most important thing to determine the best rock typing method.

The advantage of the Lucia method is it can explain the pore type of carbonate very well, which is that method only uses the primary porosity (interparticle pore type) in classifying rock type. It is different from the other methods that pay less attention to the nature of the complexity of carbonate rocks. Furthermore, the Lucia method is also quite good and accurate in predicting permeability values (figure 10a). So it can be stated that the Lucia method is the best rock typing method in this study.

4. Conclusion

This study uses two assessments to compare four rock typing methods. The first assessment is comparing the core permeability and the predicted permeability. Second is by spreading the seismic parameters data to see the separation of each class in each method of rock typing.

Based on the first assessment, it can conclude that the Winland R35 method is the best method of rock typing in predicting the core permeability values. It is because the Winland R35 method has a better correlation between predicted permeability and core permeability, which have the value of the gradient is 0.9772, $R^2$ is 0.9369 and RMS error is 62.14 mD.
However, the second assessment shows that the Lucia method is the best method of rock typing in separating rock type classes by using the crossplot of seismic parameters, such as AI and SI. It is the most important thing and it means that the Lucia method is better at classifying rock type. Therefore, the Lucia method is the best rock typing method in this study.

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