Linking Between Sedimentary Facies and Petrophysical Rock Type: A Case Study

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Abstract. Rock typing is a technique of grouping rocks that have similar properties, which properties can be in the form of sedimentary, petrophysical, and reservoir parameters. Classification based on sedimentary parameters is called sedimentary rock type (SRT), while grouping based on petrophysical parameters is called petrophysical rock type (PRT). The purpose of this study is to determine the relationship between SRT and PRT in the research area. The method used to determine sedimentary rock type is to use the facies concept approach, while the method used to determine petrophysical rock type is the Hydraulic Flow Unit Method, Global Hydraulic Element, Winland R35, and Pore Geometry Structure. In this study, determined the relationship between sedimentary rock type with petrophysical rock type, where some facies that have certain characteristics will have a certain type of petrophysical rock type pattern. Thoroughly bioturbated mudstone facies which have low porosity and permeability have two petrophysical rock types with initial sequence (RT 1 and RT 2) with the HFU, GHE, and Winland R35 methods, while with the PGS method there are RT 4 to RT 7. These facies have low rock type variations, it can be concluded that these facies are homogeneous.

1. Introduction
One very important step in characterizing reservoirs and modeling is rock typing. This technique is a technique of grouping rocks that have similar properties, which properties can be in the form of sedimentary, petrophysical, and reservoir parameters [1]. Sedimentary parameters are guidelines in determining sedimentary rock typing (SRT), while petrophysical (electrofacies) and parameters are a reference in petrophysical rock typing (PRT) [1]. The SRT technical approach is an approach with the concept of facies. The facies is a general term used to classify rocks based on the same property owned by these rocks, such as mineralogy, texture, fossil content, and depositional environment [1]. Determination of facies can be done by observing outcrops or by observing cores. In the field of petroleum geology, more often determine facies by describing cores. The petrophysical rock typing (PRT) technique is a technique for grouping rocks based on the physical properties of rocks. The physical properties of these rocks include porosity and permeability. The porosity and permeability values are obtained from routine core analysis, where the analysis is a core analysis activity that is often done during the drilling process. Not only from routine core analysis, porosity and permeability can also be obtained from well logs. The petrophysical rock typing method has been developed since 1993 [2] and continues to grow, recorded research on petrophysical rock typing has experienced rapid progress in 2018.
Along with the development of technology, petrophysical rock typing methods began to emerge with various advantages that refines the previous method. Nevertheless, some recent research shows that it is precisely the method that emerged at the beginning of research on rock typing that is suitably applied to the reservoir. Therefore, this study will reveal the relationship between sedimentary facies with petrophysical rock typing in the study area in the Bass Basin, Australia.

2. Material & Methods

2.1. Geology setting and samples
This research was conducted in the Yolla Gas Field that produces oil and gas from the Eastern View Coal Measures (EVCM) reservoir. Stratigraphically, EVCM overlaps the Otway Group with volcanic rocks. Nonetheless, the EVCM lithology is a very thick succession of sandstones, siltstones, shale, and coal [7] deposited in the fluvio-lacustrine environment [8]. EVCM can be divided into 3 units based on its age, the uppermost Eocene sandstone, in the middle of the alternation between coal and Eocene shale, while the lowest part is dominated by siltstone and thick sandstone [8]. The uppermost part of the sandstone in EVCM is identified with TEV4 and this is a gas and oil-bearing based on data from the Yolla-3 well.

The Yolla-3 well is located in the Bass basin, Australia. This basin is located 150 km south of Wonthaggi, to be precise in the Bass Strait. This basin is divided into two sub-basins, the Cape Wickham Sub-Basin to the west and the Durroon Sub-Basin to the east. In the Cape Wickham Sub-Basin there are several oil and gas wells that are actively producing and in the sub-basin there are several blocks. One of the gas producing blocks is T / RL 1 where the Yolla-3 well is located. This well produces gas from the EVCM reservoir.

2.2. Petrophysical rock typing method
To determine the petrophysical rock type (PRT), routine core analysis and well log data can be used. Routine core analysis data are preferred because they may be more accurate. However, not all intervals are taken for core analysis because of the high cost. In addition to using core analysis routine data, well log data can also be used. The use of well log data must be validated with a routine core analysis data. By considering the accuracy of the data, this study uses routine core analysis data from the Yolla-3 well.

The following are some petrophysical rock typing methods that is used in this study:

2.3. Hydraulic Flow Unit Method (HFU)
HFU method was discovered in 1993 [2]. Before, to describe the reservoir, “correlation method” based on log data is used [2]. However, this “correlation method” cannot be applied globally because several factors influence it, including high shale volume values due to K-Feldspar, high water saturation values due to kaolinite, and the presence of siderite, pyrite, and smectite which will affect the yield value calculations on resistivity, density and neutron log [2]. To determine the rock type using the hydraulic flow unit method, the initial step is to determine the flow zone indicator (FZI), formulated with Equation (1) below.

\[
FZI = \frac{1}{(F_s)^2 \tau S_v} = \frac{RQI}{PGR} = \frac{0.0314 K (\Phi_e)^{1/2}}{\Phi_e (1-\Phi_e)} \quad (1)
\]

Where \(F_s\) is shape factor infraction, \(\tau\) is tortuosity infraction, \(S_v\) is the surface area of each grain volume in \(\mu m^{-1}\), \(RQI\) is Reservoir quality index in \(\mu m\), \(PGR\) is Pore geometry radius, \(k\) is permeability in millidarcy \(\Phi_e\) is effective porosity infraction. With this FZI value, it can be determined rock type in the reservoir by making a semilog graph between probability and FZI. The probabilities plotted are
based on the normal distribution of the FZI values. Determination of rock type is based on changes in slope on the graph, as in figure 1 below.

![Figure 1. Cumulative probability plot of log FZI [3]](image)

2.4. *Global Hydraulic Element Method (GHE)*

This method was discovered by Corbett & Potter [4]. This method is the development of the HFU method which is realized in the rock type classification based on the lowest FZI value. The following table classifies the type of rock method based on the lowest FZI value.

| FZI  | GHE |
|------|-----|
| 48   | 10  |
| 24   | 9   |
| 12   | 8   |
| 6    | 7   |
| 3    | 6   |
| 1,5  | 5   |
| 0,75 | 4   |
| 0,375| 3   |
| 0,1875 | 2 |
| 0,0938 | 1 |
The advantages of this method include: grouping rock type is quite easy, based only on the value of FZI and GHE; A template from GHE is available to save time; it is easier to choose the data that will be used to predict reservoir quality because it is already contained in the template [4].

2.5. Winland R35 Method
Winland R35 method was discovered by Winland in 1980 through his experiments in determining the empirical relationship between permeability and pore throat with mercury injection (MICP test) to determine the net pay cut-off in a clastic reservoir. Rock type grouping with this method uses the pore opening radius at the 35th percentile (R35) whose equation can be seen in Equation (2) below.

$$\log r_{35} = 0.732 + 0.588 \log K_{air} - 0.864 \log \varphi_{core}$$

(2)

Where $r_{35}$ is the radius of pore opening at the 35th percentile, $K_{air}$ is uncorrected air permeability in milidarcy, $\varphi_{core}$ is porosity in %. The determination of rock type with this method is done by grouping data based on gradient similarity on the serial number graph with the value of r35 as in Figure 2 below.

![Figure 2. The graph used to determine each rock type based on Winland R35 Method [5]](image)

2.6. Pore Geometry Structure (PGS)
PGS method was developed by Wibowo & Permadi in characterizing the carbonate reservoir [6]. This method is used to examine the relationship between microscopic geological characteristics of carbonate rocks and the porous system of carbonate rocks. The pore geometry equation produced from this method is with equation $(k/\Phi)^{0.5}$ and pore structure with equation $(k/\Phi)^3$. After pore geometry and pore structure are obtained, they can then be plotted on the base map log graph in figure 3 below.
Figure 3. The graph that used to determine each rock type based on PGS Method [6]
The advantage of this method is that it can be applied to heterogeneous reservoirs (carbonate reservoirs), and is easy to apply because there is already a rock type template.

3. Result and Discussion

According to data from the Yolla-3 well, on TEV4 sandstones, there are four facies, which are Thoroughly bioturbated mudstone, Laminated sandstone, and mudstone, Flaser bedded sandstone, and Thoroughly bioturbated sandstone and mudstone [8]. The uppermost facies is thoroughly bioturbated sandstone and mudstone facies. These facies consist of mudstone and sandy siltstone, which have been homogenized by bioturbation [8]. This process causes vague sedimentary structures, however, some sedimentary structures can still be observed, such as relic wavy parallel laminae [8]. These facies are deposited in a lower shoreface setting environment that may be associated with distal storm events [8]. The core photograph can be seen in Figure 4 below.
Figure 4. Interpreted core photograph to determine thoroughly bioturbated sandstone and mudstone facies and flaser bedded sandstone facies [8].

Below the thoroughly bioturbated mudstone facies, there is a flaser bedded sandstone facies consisting of silty to very fine-grained sandstone with mudstone occurring as laminations, which is interpreted as being deposited in a tidal environment. The core photograph can be seen in Figure 5 below.
Figure 5. Interpreted core photograph to determine flaser bedded sandstone facies [8].

Underneath flaser bedded sandstone facies, laminated sandstone, and mudstone facies were deposited in the subtidal environment with the influence of waves and tidal current [8]. These facies consist of mudstone, silty sandstone, and very fine grained sandstone [8]. The core photograph can be seen in Figure 6 below.
Figure 6. Interpreted core photograph to determine laminated sandstone and mudstone facies [8].

Below the laminated sandstone and mudstone facies, there are thoroughly bioturbated mudstone facies that have not been able to observe their sedimentary structures due to the influence of high-level bioturbation [8]. These facies are interpreted as being deposited in the offshore marine/wave influenced prodelta environment [8].
Figure 7. Interpreted core photograph to determine thoroughly bioturbated mudstone facies [8].

Based on the description and photographs above, rock type at this region can be summarized (see Table 2 below) as follow:

| Facies                        | Depositional Environment               |
|-------------------------------|---------------------------------------|
| Thoroughly bioturbated mudstone | Transitional offshore/wave-influenced prodelta |
| Laminated sandstone and mudstone | Wave influenced proximal delta front |
| Flaser bedded sandstone       | Tidal flat/sandy embayment            |
| Thoroughly bioturbated sandstone and mudstone | Distal lower shoreface |
So, there are four facies (sedimentary rock type) on TEV4. Porosity and permeability graphs for each facies can be seen in Figure 8 below.

![Porosity and permeability plot on each sedimentary rock type](image)

**Figure 8.** Porosity and permeability plot on each sedimentary rock type

After determining the sedimentary rock type, the next step is to determine the petrophysical rock type that starts with the HFU method. The petrophysical rock type grouping graph with the HFU method can be seen in Figure 6 below.

![HFU Method petrophysical rock type determination](image)

**Figure 9.** HFU Method petrophysical rock type determination
From it can be seen that with the HFU method, six petrophysical rock types are distinguished based on the gradient on the graph (Figure 9). After the HFU method, from the FZI value using the GHE method, four petrophysical rock types were obtained. With the Winland R35 method, five petrophysical rock types are obtained which are distinguished based on the gradient on the serial number graph with the r35 shown in Figure 10.

![Figure 10. Winland R35 Method petrophysical rock type determination](image1)

The last method used is PGS, resulting in the grouping of seven petrophysical rock types from the pore geometry and pore structure values plotted on the log graph, as shown in Figure 11.

![Figure 11. PGS Method petrophysical rock type determination](image2)
A semi-log graph between porosity and permeability on each petrophysical rock type is shown in Figure 12.

**Figure 12.** Porosity and permeability plot of each petrophysical rock type based on the method used in this study.

Petrophysical rock typing methods can be classified into various types of petrophysical rock (Figure 8). This occurs due to the different assumptions in each petrophysical rock type grouping. In general, similar patterns occur in porosity and permeability charts in 3 methods, namely the HFU, GHE, and Winland R35 methods and the number of petrophysical rock types is not much different. Different patterns are shown by the PGS method (Figure 11), wherethis method found the most type of petrophysical rock, totaling 7.

When combined with the concept of sedimentary rock type with petrophysical rock type, it will be seen that the Thoroughly bioturbated mudstone facies have a Petrophysical Rock Type range with the HFU, GHE and Winland R35 methods ranging from Rock Type (RT) 1 and Rock Type (RT) 2, whereas the PGS method produces RT 4 to RT 7 RT range that is not too far away is due to the homogeneity of this facies. The small RT in the HFU, GHE, and Winland R35 methods is due to the low porosity and permeability values of the mudstone.

In the Laminated sandstone and mudstone facies, RTs are found to be diverse and range from RT 1 to RT 5 in the HFU and Winland R35 methods, and RT 1 to RT 4 in the GHE method. In the PGS method found RT 1 to RT 4. The diversity of RT found in this facies is caused by the presence of mudstone lamination on the sandstone, which is seen in the facies above, the presence of mudstone will make RT 1 and 2 (low) in the HFU, GHE, and Winland R35. Sandstone which has good porosity and permeability will be reflected from high RT (RT 4, RT 5, and RT 6) on the HFU, GHE, and Winland R35 methods.

In the Flaser bedded sandstone facies, RTs are generally seen uniformly, and range between RT 4 to RT 6 in the HFU method, RT 3 and RT 4 in the GHE method, and RT 4 and RT 5 in the Winland
R35 method. A uniform and high RT indicates that this facies is homogeneous and is the best to be a reservoir. This is because these facies have reliable porosity, permeability, and homogeneity for storing petroleum.

At the lowest facies, namely, Thoroughly bioturbated sandstone and mudstone, RT 1 to RT 3 were found by the HFU, GHE, and Winland R35 methods, and RT 3 through RT 5 by the PGS method. In general, the RT pattern found in this facies is similar to the RT pattern found in the thoroughly bioturbated mudstone facies, but because the dominant lithology in this facies is sandstone, so it is more dominated by RT 2 in the HFU, GHE, and Winland R35 methods. Whereas the PGS method is dominated by RT 4. In summary, petrophysical rock type-based sedimentary rock type can be seen in Table 3.

| Facies                      | HFU Rock type | GHE Rock type | Winland R35 Rock type | PGS Rock type |
|-----------------------------|---------------|---------------|-----------------------|---------------|
| Thoroughly bioturbated mudstone | 2             | 2             | 1                     | 4             |
|                             | 2             | 2             | 2                     | 4             |
|                             | 1             | 1             | 1                     | 7             |
|                             | 1             | 1             | 1                     | 7             |
|                             | 1             | 1             | 1                     | 5             |
|                             | 1             | 1             | 1                     | 6             |
|                             | 1             | 1             | 1                     | 5             |
|                             | 1             | 1             | 1                     | 6             |
| Laminated sandstone and mudstone | 4             | 3             | 4                     | 3             |
|                             | 4             | 3             | 4                     | 3             |
|                             | 4             | 3             | 4                     | 2             |
|                             | 2             | 2             | 4                     | 2             |
|                             | 2             | 2             | 3                     | 3             |
|                             | 5             | 4             | 4                     | 2             |
|                             | 5             | 4             | 4                     | 2             |
|                             | 4             | 3             | 4                     | 3             |
|                             | 3             | 3             | 4                     | 3             |
|                             | 2             | 2             | 3                     | 3             |
|                             | 6             | 4             | 5                     | 1             |
|                             | 5             | 4             | 4                     | 2             |
|                             | 5             | 3             | 4                     | 2             |
|                             | 3             | 3             | 3                     | 3             |
|                             | 4             | 3             | 4                     | 2             |
|                             | 2             | 2             | 2                     | 3             |
|                             | 3             | 3             | 4                     | 3             |
|                             | 4             | 3             | 3                     | 3             |
4. Conclusion

Thus it can be concluded that, in general, the HFU, GHE and Winland r35 methods have the same rock type ordering, where the core samples which have high porosity and permeability will be in the lower order rock type (RT 4, 5, 6). This is in contrast to PGS where the core sample which has high porosity and permeability will be in the first order (RT 1, 2).
In particular, only the thoroughly bioturbated mudstone facies were imply to RT 1, while the other facies had a random RT pattern. Thus, it cannot be concluded that the SRT controls PRT.

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**References**

[1] Kadkhodaie-Ilkhchi, A., & Kadkhodaie-Ilkhchi, R. (2018). *A review of reservoir rock typing methods in carbonate reservoirs: relation between geological, seismic, and reservoir rock types*. Iranian Journal of Oil & Gas Science and Technology, 7(4), 13-35.

[2] Amaefule, J. O., Altunbay, M., Tiab, D., Kersey, D. G., & Keelan, D. K. (1993). *Enhanced reservoir description: using core and log data to identify hydraulic (flow) units and predict permeability in uncored intervals/wells*. SPE Annual technical conference and exhibition. Society of Petroleum Engineers.

[3] Enaworu, E., Ajana, L. O., & Orodu, O. D. (2016). *Permeability Prediction in Wells Using Flow Zone Indicator (FZI)*. Petroleum and Coal, 58(6), 640-645.

[4] Corbett, P. W. M., & Potter, D. K. (2004). *Petrotyping: A base map and atlas for navigating through permeability and porosity data for reservoir comparison and permeability prediction*. International Symposium of the Society of Core Analysts (Vol. 5, No. 9).

[5] Haikel, S., Rosid, M. S., & Haidar, M. W. (2018, November). Study comparative rock typing methods to classify rock type carbonate reservoir Field “S” East Java. In Journal of Physics: Conference Series (Vol. 1120, No. 1, p. 012047). IOP Publishing.

[6] Wibowo, A. S., & Permadi, P. (2013, March). *A type curve for carbonates rock typing*. In IPTC 2013: International Petroleum Technology Conference (pp. cp-350). European Association of Geoscientists & Engineers.

[7] Boral Energy (1998). Yolla 2 Well Proposal T/RL1.

[8] Origin Energy (2005). Yolla 3 T/L1 Offshore Bass Basin Well completion report: interpretive data.