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Rock Type Identification Based on the Critical Porosity Value in Sandstone; Case Study from Kutai Basin

Suryo Prakoso
Lecturer, Petroleum Engineering, Faculty of Earth and EnergyTechnology,
Universitas Trisakti, Jakarta, Indonesia
Sonny Winardhi
Lecturer, Geophysical Engineering, Faculty of Mining and Petroleum Engineering,
Institute Teknologi Bandung, Indonesia

Abstract:
The quality of rock type is highly influenced by detail pore geometry of rock. However, detail pore geometry is influenced by rock texture such as grain size, grain sorting, and degree of angularity. These factors cause variation in the quality of rock. Every rock types have similar pore geometry and pore structure, thus it can be assumed that each sample data in a single rock type have similar packing and critical porosity values. In this paper, the pore geometry, pore structure and critical porosity were used for rock grouping.
The concept of pore geometry and pore structure which refer to Wibowo and Permadi (2013) and the concept of critical porosity which refer to Nur (1995) were used to identify the rock type. A mathematical relationship in the form of power law model between pore geometry and pore structure (Wibowo and Permadi, 2013) is used to describe the element of rock volume which have similar characteristics of the fluid flow and namedas rock type. Nur et al. (1995) stated that critical porosity value is influenced by both lithology and internal characteristics of rock. The critical porosity herein is defined as the value of porosity that border the sedimentary rock and suspesion.Therefore, it can be shown that good quality of rock type will have greater range of critical porosity values.
About 314 sandstone samples from Kutai Basin were used for this study. The physical properties of rocks were measured in the laboratory, including porosity, permeability, P and S wave velocity (V_p and V_s). It can be shown that each rock type which is characterized by similar of microscopic geological feature have a different range of critical porosity values. The result of rock grouping using critical porosity values is not significantly different from the result which is identified using rock type chart that refer to Wibowo and Permadi (2013). Based on the value of the critical porosity, rock samples can be grouped properly for each rock type.

Keyword: *Pore Geometry, Pore Structure, Critical Porosity, Rock type*

1. Introduction

One of the problems found in reservoir modelling is the approach which is used to estimate the rock type. Rock typing is needed to get the relationship of porosity and permeability. Permeability is the most important physical properties of rocks on the contrary its variable has a high degree of uncertainty, and the most difficult to predict in porous media. Several studies have been conducted to define the rock type. Amaefule et al., 1993 composing the method to identifying of rock types using hydraulic unit (HU). Where one HU will have a similar value of FZI. Wibowo and Permadi, 2013 using the power law model to define the rock type based on the similarity of pore geometry and pore structure. Rocks that have similar por geometry and pore structure will have linear trend that is different from the other groups.

These methods evidently accurate to define the rock type based on the core data. However, the method does not explain how to determine the rock type in the wells which have no core data. Some researchers arrange a method in order to obtain rock type on the wells or into the interval which have no core data with statistical approach (Abbaszadeh et al., 1996). Rock type is estimated by statistical methods using log data and FZI or HU obtained from the core data so it has a fairly high degree of uncertainty.

This paper shows another simple approach to estimate the rock type. Rock types estimation was conducted using the critical porosity approach (Nur et.el., 1995). The critical porosity values were calculated based on the bulk modulus that can be derived from the P-wave velocity. A good quality rock types tend to be composed by simple pore geometry and pore structure, so it will have greater critical porosity value than the low quality rock type. Therefore it can be used to estimate rock types.

2. Problem Statement

An understanding of the pore geometry and pore structure complexity is needed to describe the reservoir. The complexity of pore geometry and pore structures are influenced by variations in depositional environments and the diagenetic process that control the pore geometry and pore structure. The variation of pore geometry and pore structure will lead to the formation of a specific zone in a reservoir rock that have similar characteristics of fluid flow.The variation of pore type and pore size provides a description of the pore geometry and pore structure. Spheres are often used to idealize the pores and grain. A packing variation of grains will provide different pore geometry properties of rock such as pore size and porosity. Packing will also lead to different grain contact.Thus, affecting the pore structure where the pore structure will control the hydraulic conductivity of rock. Therefore the rock quality is strongly influenced by pore geometry and pore structure of rocks. The rocks which have a similar of pore geometry and pore structure will form a different certain group (rock type) from another. According to that statement it can be said that one rock type has similar packing so it will have maximum porosity that differ from another rock type. The maximum porosity is equal to critical porosity value of sedimentary rock before it transformed to suspension (Nur,1995). By assuming that each core sample has a different complexity, the critical porosity value can be calculated using an approach of Nur (1995), thus it can be used to define the rock type.

3. Method of Approach

3.1. Approach of Rock Typing

Wibowo and Permadi (2013) developed an approach to estimate the rock type based on the relationship of pore geometry and pore structure of rocks sample. Pore geometry and pore structure can be simple written as combination of porosity and permeability. An approach on pore geometry and pore structure is carried out by applying the equation of capillary tubes model by Kozeny (1927). For capillary tube, the relationship of pore geometry and pore structure can be approximated by applying Kozeny equation (1927) as follows:

$$\left(\frac{k}{\phi}\right)^{0.5} = \phi\left(\frac{k}{\phi^3}\right)^{0.5} \qquad (1)$$

where$k$ is the permeability andϕ isporosity. The $(k/\phi)^{0.5}$ is depicts the pore geometry while (k/ϕ^3)constitutethe pore structure that can be writtenas$1/F_s\tau S_b^2$.Where$F_s$is the shape factor, $\tau$is tortuosity, and $S_b$is specific surface area per unit bulk volume. Equation 1 shows the relationship of pore geometry and pore structure for the capillary tube with the value of pore structure exponent 0.5. As for the natural porous media equation 2 can be written in the form of power law as follows:

$$\left(\frac{k}{\phi}\right)^{0.5} = a\left(\frac{k}{\phi^3}\right)^{b} \qquad (2)$$

A constant a is a volumetric efficiency of pores, b is the exponent of pore structure with maximum value is 0.5. The lower the quality of rock types will have a smaller exponent value of pore structure b. One rock type has similar pore architecture where their similarities can be shown similar on microscopic geological feature. Plot $(k/\phi)^{0.5}$ on the Y axis and (k/ϕ^3) on the X axis on a log-log graph shows linear straight line with maximum slope of$b$ 0.5. The lower value of exponent pore geometry b shows the poorer quality of rock type, so it will also have a lower value of pore efficiency a. A linear data is a group data from porous media that entirely has similar relationships of pore geometry and pore structure as represented by the similarity of pore architecture and resulted from the same geological processes.

3.2. Modelling of Rock Solid Framework and Critical Porosity

The rock matrix within the natural porous media is composed by several minerals. The approach of Hashin Shtrikman (1963) can be used to model the bulk modulus of a rock that consists of more then 1 mineralogy as follows:

$$B_{hs} = B_1 + \frac{f_2}{\dfrac{1}{(B_1 - B_2)} + \dfrac{f_1}{(B_1 + 4/3\,\mu_1)}} \qquad (3)$$

$$\mu_{hs} = \mu_1 + \frac{f_2}{(\mu_2 - \mu_1)^{-1} + f_1\left[\mu_1 + \dfrac{\mu_1}{6}\left(\dfrac{9B_1 + 8\mu_1}{B_1 + 2\mu_1}\right)\right]} \qquad (4)$$

where B_{HS} is Hashin Shtrikman mineralbulk modulus, μ_{HS} is Hashin Shtrikman mineral shear modulus, $B_{1,2}$is mineral bulk modulus 1 and 2, $\mu_{1,2}$ is mineral Shear modulus 1 and 2 while $f_{1,2}$ is the fraction of mineral 1 and 2.
The value of critical porosity of rock can be approximated by the equation of Nur et al. (1995). Nur et al. (1995) developed the equation which is modifiedfrom Voigt bound equation. The critical porosity is defined asdomain limit of consolidated sediment and suspension as follows:

$$B = \left(1 - \frac{\phi}{\phi_c}\right) B_m \quad (5)$$

B is *bulk modulus*, B_m is *bulk modulus* mineral, ϕ is porosity and ϕ_c is critical porosity.

4. Results and Analysis

4.1. Data Description

The data used in this research included routine core analysis consisting of permeability, porosity, lithology description and sedimentology analysis, such as petrographic (thin section) and XRD. Acoustic wave velocity data is obtained from the laboratory measurement of rock sample using SonicViewer-Sx that equipped with pizoelectric transducer for measuring the P and S-waves velocity. These datas were obtained from the publication of Prakoso etal. (2016). Sandstone samples were obtained from the Kutai Basin, with total of 430 core plug a diameter of 1 - 1.5 inches and 1.6 to 6.5 cm long. The sandstones are belonging to Balikpapan Formation, Middle Miocene - Late Miocene age and were deposited in deltaic plain - deltaic front in association with fluvial sediment, distributary channel and mouth bar. The lithology of Balikpapan Formation is dominated by fine to coarse grained sandstone, thick, deposited as an alternating with claystone, shale, and coal. All samples are composed of predominant quartz mineral. The range of porosity values from 4.5 to 36.9%, while the permeability range from 0.05 to 4504 mD. The range of V_p value is 1527 - 4396 m/s whereas V_s is 946 - 2837 m/s.

4.2. Identification of Rock Quality Based on the Pore Geometry and Pore Structure (PGS)

Data grouping is carried out based on the relationship of pore geometry $(k/\phi)^{0.5}$ and pore structure (k/ϕ^3) using porosity and permeability data that obtained from routine core analysis (Figure 1). Data grouping is performed using a rock type chart Wibowo and Permadi (2013). Any data that have similar microscopic geological features is on the same line, therefore, it is called as one rock type. Similarity on microscopic geological features is identified based on the petrographic data. The dominant geological attributes affect each rock type, such as the rock texture (including grain size, grain sorting, degree of angularity, hardness), volume of clay, type of cement will also determine the quality of the rock types (Prakoso et. al., 2016). A good quality rock type denoted by small number of rock type and tend to be composed by coarse grain size, well sorting, low hardness and low clay volume.

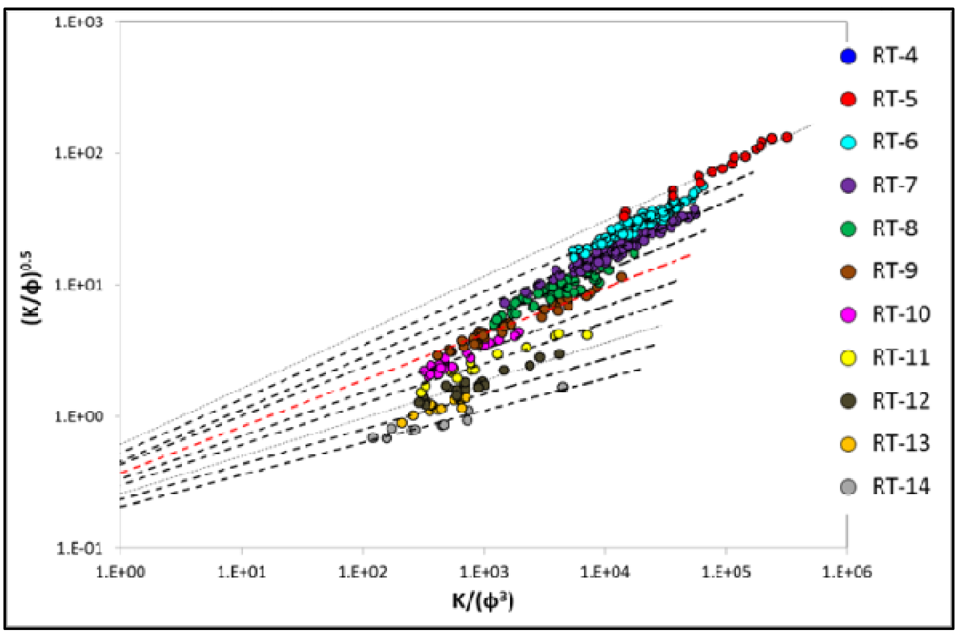

Figure 1: Identification of rock type based on PGS method

4.3. Identification of Rock Quality Based on the Critical Porosity

As previously discussed, the critical porosity value can be approximated using equation of Nur (1995) where it is a function of bulk modulus and porosity. Porosity were obtained from rountine core analysis while the value of bulk modulusis calculated from the P and S wave velocity data.Based on XRD analysis, in general, the rock sample is mainly composed by quartz and clay (Figure 2).The XRD data shown that each rock type is composed by predominant quartz mineral, about up to 98% for rock type 5 which has the most excellent quality (Figure 2). Sandstone samples which are used in this study are relatively clean as indicated by total clay volume is lesser than 10 % for the lowest quality of rock type. However, it can be seen that the volume of clay tend to increase in equal with the decreasing of rock type quality

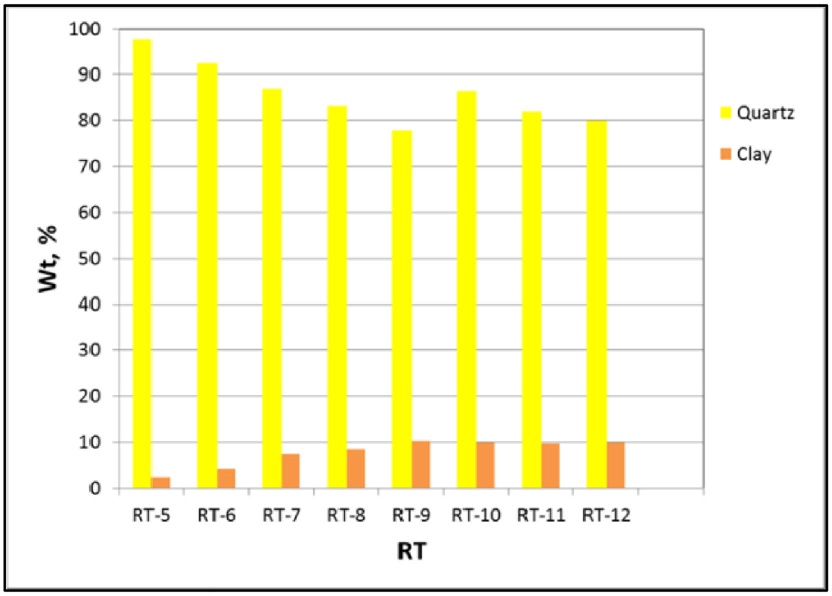

Figure 2: Histograms of quatz and clay volume for each rock type.

Therefore, bulk modulus solid frame (B_m) modelling is carried out using a model of Hashin Shtrikman (1963) by assuming the rock that only consists of two components, namely mineral 1 which is more stiff than the minerals 2. In this study, a more stiff mineral is quartz while the soft mineral is clay. Bulk modulus of quartz and kaolinite clay refer to table of elastic moduli constant, Mavko G., et al. (2009) as follows:

Mineral	***B*** **(Gpa)**	***μ*** **(Gpa)**
Quartz	37	44
Clay (Kaolinite)	1.5	1.4

Table 1: Bulk dan Shear Modulus mineral quartz dan clay (Mavko, G., et al., 2009)

Furthermore, by using equation 3 and 4 can be calculated values of bulk modulus of solid frame (B_m) for each rock sample. Value of B_m obtained is then used to calculate the critical porosity using equation 5.Figure 3is a relationship between pore geometry and pore structure overlaid with critical porosity. The color shading in figure 3 is the critical porosity value. Compared to Figure 1, it appears relatively similar that the good quality of rock type tend to have greater critical porosity than the low quality of rock type. This indicates that the critical porosity value is influenced by the quality of the rock type. Thus the critical porosity value can be used for grouping rocks based on similarity of microscopic geological features hereinafter referred to as rock type.Based on the range of critical porosity values, the rocks sample can be grouped into several rock types (Table 2).

Rock Type	**Range of Critical Porosity** (fraction)
5	0.2625 - 0.3110
6	0.2160 - 0.2625
7	0.1800 - 0.2160
8	0.1545 - 0.1800
9	0.1345 - 0.1545
10	0.1150 - 0.1345
11	0.0950 - 0.1150
12	0.0748 - 0.0950
13	0.0662 - 0.0748
14	0.0196 - 0.0662

Table 2: Range of critical porosity values for each rock type

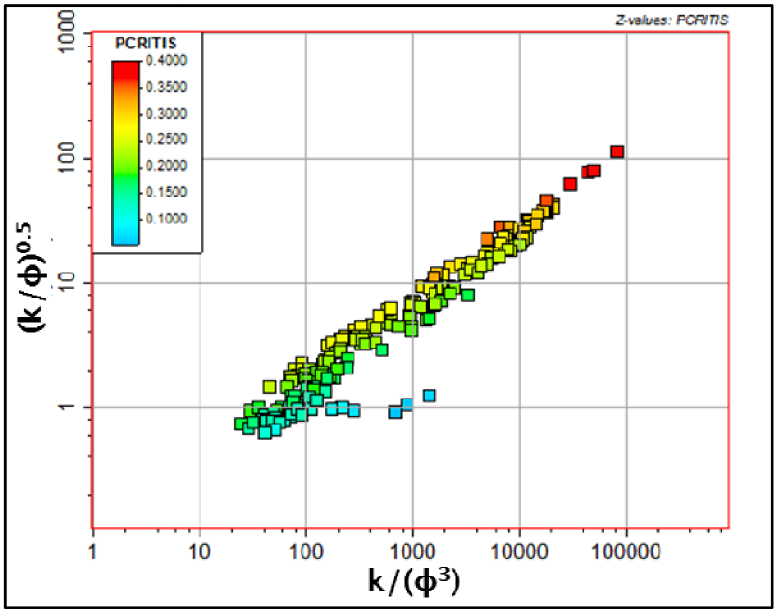

Figure 3: Relationship of pore geometry and pore structure overlaid with critical porosity values (color shading)

The critical porosity values obtained are subsequently used for the grouping data based on relationship *(k/ϕ^3)*with *$(k/\phi)^{0.5}$* (Figure 4). It can be seen that the data can be grouped properly based on the range of critical porosity values. The constant and the exponent value of the regression line of each rock type obtained by the critical porosity approach are not significantly different from those obtained from the PGS method by Wibowo and Permadi (2013) (Tabel 3).

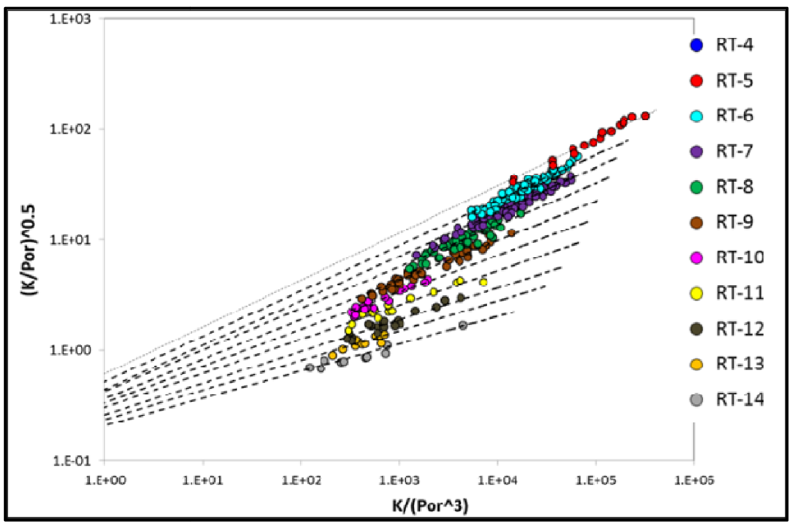

Figure 4: Grouping of rock types based on the critical porosity value

RT	Regression Formula	
	PGS	Critical Porosity
5	$y = 0.6119x^{0.4251}$	$y = 0.6119x^{0.4251}$
6	$y = 0.5279x^{0.4082}$	$y = 0.5197x^{0.4102}$
7	$y = 0.4543x^{0.3946}$	$y = 0.4419x^{0.4018}$
8	$y = 0.4317x^{0.3681}$	$y = 0.4234x^{0.3764}$
9	$y = 0.3699x^{0.3524}$	$y = 0.3639x^{0.3576}$
10	$y = 0.3333x^{0.3284}$	$y = 0.333x^{0.3338}$
11	$y = 0.3002x^{0.3082}$	$y = 0.3044x^{0.3083}$
12	$y = 0.2596x^{0.2859}$	$y = 0.26x^{0.2867}$
13	$y = 0.2345x^{0.2665}$	$y = 0.2349x^{0.2681}$
14	$y = 0.2051x^{0.2439}$	$y = 0.2072x^{0.2471}$

Table 3: Regression formula of each rock type obtained from PGS and critical porosity method

5. Discussion

Figure 3 shows that the critical porosity can be used to identify rock types based on relationship of pore geometry $(k/\phi)^{0.5}$and pore structure (k/ϕ^3). Good quality of rock types is characterized by a large grain size, well sorting and a low hardness. This rock types are likely to have relatively large of critical porosity value range. It can be described good quality rock types was characterized by a large grain size and well sorting that will have a relatively simple of pore geometry and pore structure. Group of rock sample with simple pore geometry and pore structure is certainly going to have a larger of critical porosity value. The more simple of pore geometry and pore structure will have a better packing and that it will have a larger maximum porosity value. In a rock types is have similar microscopic geological features shown by the similarity of textures and diagenetic process. Thus in one rock types have a similar pore geometry and pore structure which is characterized by a similar of tortuosity value and pore shape factor but different in pore sizes. Thus, each rock type will have a certain critical porosity value ranges (Table 2). The critical porosity value range can be used for identify rock types based on the similarity of pore geometry and pore structure. Based on the range of the critical porosity values, rock samples can be well grouped into rock types (Figure 3 and 4). The results obtained with the approach in accordance with the PGS, where rocks with simple of pore geometry and pore structure will have better rock type quality. With the approach of the critical porosity, this rock type has a greater range of critical porosity values. The results of identification of the rock types with a critical porosity have a group of data that is similar with PGS which is shown with the constant and exponential regression linesvalue relatively similar (Table 3).

6. Conclusion

1. The pore geometry and pore structure can be represented by the elastic parameters critical porosity.
2. Critical porosity can be a good indicator for the identification of rock type without looking at the cores description.
3. The good quality of rock type are indicated by a large grain size, good sorting and low volume of clay that can be represented with a large range of critical porosity value.

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