Fracture characterization with fieldwork data and its implication for basement fracture reservoir at Muaro Silokek Granitic Outcrops

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Abstract. The Muaro Silokek Area is a location that is quite complex in geological structure and consists of granitic rocks which vary in mineral composition, so it’s fit to do fieldwork for fracture characterization for analog basement fracture reservoir. This research was continuance of previous study about granitic basement fracture at around Sumatra, now especially with fieldwork data. The aim of the study is to determining fracture characteristics like fracture spacing, fracture aperture, fracture length by using fieldwork data to determine fractal analysis and relate it to fracture reservoir. Those research conducted by using scanline and windows scan method with total 2700 cm scan line and 490000 cm² area of widows scan in five location damage zone. The result shows generally shear fracture have three main orientations, there were NE – SW, NNE – SSE, ENE – WSW and NNE – SSW, W – E, NW – SE for joint orientation. Cumulative distribution of fracture spacing, fracture aperture, fracture length at five location scan line and window scan following power law. Statistically, fracture porosity and permeability result shows linear data distribution with cubes calculation methods. This fracture permeability has exponential distribution relationship with fracture aperture, and fracture porosity has power distribution relationship with fracture spacing.

1. Introduction

Basement fractured research in Muaro Silokek previously has been conducted by Toreno [1] and Sapiie et al [2] who conducted a study of natural fracture characteristics in basement rocks including granitic rocks in Muaro Silokek which stated that natural fracture characteristics in outcrops and subsurface shows lithology factors was strongly affects the density of natural fractures, and Koesmawardani, et al [3,4], make another approach by using photogrammetric analysis to perform natural fracture characteristics at the macro scale and micro fracture analysis to determine the relationship of mineral composition to fracture characteristics. However, the research doesn’t explain the fracture characteristics by direct measurement in the field on granitic rocks in Muaro Silokek related to natural fracture reservoir. So to follow up previous researchers, this theme becomes interesting to perfect the study of fracture characteristics in granitic rocks which are related to natural fractured reservoirs.

The Muaro Silokek area is located in the Ombilin Basin, especially basement rocks, according to Silitonga and Kastowo in Koning [5], granite rocks in the Muaro area have an age of 206 ma or Upper Triassic age. Ombilin Basin is a type of pull apart basin [5]. Based on geographical location, the Ombilin
Basin is located between the Barisan Mountains, but based on the structure geology and tectonics, this basin is located east of the volcanic arc recent, and states that the Ombilin Basin is known as inter mountain basin [6].

2. Methodology

To complete Koesmawardani’s research, natural fracture analysis was carried out on the meso scale by measuring fracture data directly in the field with scanline and windows scan methods to determine the characteristics of the fractures which include fracture type, fracture orientation, fracture aperture, fracture spacing and fracture length of natural fractures at the damage zone and different granitic rocks characteristics (figure 1) [3,4]. The measurements were carried out at five observation location that have different granite characteristics using a geological compass, measuring tape ropes, rulers, and calipers. That fieldwork were made at five granitic rock locations with a total of 2700 cm linear scan line and 490000 cm² windows scan.

Figure 1. Direct fracture data measurement using scan line (SL) and windows scan (WS) methods to find out the fracture characteristics such as fracture length (L), fracture aperture (A), and fracture spacing (S).

Those fracture characteristics in each granitic type data then separated based on type of fracture which are shear fracture and joint. And the orientation of shear fractures and joint then confirmed by fracture orientation analysis on a macro scale based on DOM data by Koesmawardani to determine its relationship with the main regional fault [3].

The other fracture characteristics such as fracture spacing, fracture aperture, and fracture lengths are measured to determine the fractal analysis by making cumulative distribution table at each fracture characteristics. The fracture spacing is measured from the distance between the fractures, the fracture aperture is the opening distance in each fracture measured, and the fracture length is measured on each fracture until the fracture stops or is interrupted by another fracture. This analysis was using to confirm that each fracture characteristics has power law distribution data [7].

To connect the fracture characteristics with fracture reservoir, we calculate fracture porosity and fracture permeability at each location. The estimated permeability value in this study uses the Aguilera equation using two calculation methods namely Match Sticks and Cubes [8]. The porosity value is calculated using the Aguilera equation with the Cubes Method. Fracture porosity (ϕf) estimation with Cubes Method, are using variable fracture spacing (D) in centimeter (cm) and fracture apetture (W) in centimeter [8]:

\[
\text{Cubes, } \phi_f = 3 \times \frac{W}{D}
\]

Aguilera defines permeability as a property of porous media and capacity of the media to transmit fluids [8]. Reservoir rocks can have primary and secondary permeability. Primary permeability is also referred to as matrix permeability. Secondary permeability can be form of open fracture and caves in rocks. To calculate the fracture permeability value, the Match Sticks and Cubes Method is used with the equation:

\[
\text{Cubes, } K_2 = \frac{2}{3} \left( K_f \times \frac{W^2}{D} \right)
\]
3. Results and discussion

3.1. Fracture orientation analysis

The data collected from the meso scale was carried out on the granitic rocks exposed in the Muaro Silokke area and used as confirmation from DOM data. Scanline - windows scan measurements were carried out at five locations representing different types of granitic at the study sites as follows: GT 1, GT 2, GT 3, GT 4, and GT 5 as shown in Figure 2. In Figure 2 shows that the GT1, GT2, and GT3 have the same orientation of shear fracture, consist of NNW – SSE and NE – SW with joint orientation dominantly NNE – SSW. Granitic type of GT1, GT2, and GT3 were Monzo Granite, Quartz rich Granitoid, and Syeno Granite according to Streckeisen granitic rock classification [9]. For GT4 and GT5 have ENE – WSW orientation of shear fracture with NNW – SSE and ENE – WSW orientation of joint. Granitic type of GT4 and GT5 were Syeno Granite, which is at GT5 was aplitic Syeno Granite. This study confirms that the number of fracture at each granitic with field work data as same as DOM data and being controlled by distance to fault and mineralogy control of K-feldspar and Quartz [4].

3.2. Fractal analysis

Measuring fracture attribute like fracture spacing, fracture aperture, and fracture length is done to find out fractal distribution at each scan line and windows scan. The fracture spacing is measured from the distance between the fractures, the fracture aperture is the aperture distance in each fracture measured, and the fracture length is measured on each fracture until the fracture stops or is interrupted by another fracture.

Analysis of the entire fracture attribute is done by combining the overall fracture attributes of each scan line and windows scan location. The natural fracture characteristics is concluded to be fractal that the fractal event in the 1D analysis will have a fractal dimension of 0-1 with scan line method and 2D analysis will have fractal dimension of 1-2 with windows scan method [10,11]. For example, Figure 3 is distribution data of fracture length, fracture aperture, and fracture spacing at GT2. Both fracture length and fracture aperture have range of fractal dimension (D) 1.5 which using windows scan method and for fracture spacing has value of D 0.75 which using scan line method.
Figure 2. Measurement of shear fracture and joint using scan line and windows scan methods at GT1, GT2, GT3, GT4, and GT5 outcrops.
Figure 3. Example cumulative distribution data of fracture length (A), fracture aperture (B), and fracture spacing (C) at GT2 which following power law distribution.

The fractal dimension obtained is $D = 0.62 - 0.76$ with a correlation coefficient of $R^2 = 0.96$ so that it follows the power law distribution data. For the fracture aperture and fracture length attributes were analyzed by the windows scan method. The fractal dimension value ($D$) of fracture aperture attribute obtained has a $D$ value of $1.12 - 1.99$ with a correlation coefficient of $R^2 = 0.96$ and the fracture length attribute has a $D$ value of $1.13 - 1.58$ with a correlation coefficient of $R^2 = 0.81$. So it can be concluded that fracture aperture and fracture length attribute has a power law distribution pattern because it has a $D = 1 - 2$ value with the windows scan method (2D). So with this the fractal analysis confirm that each fracture characteristics follows power law distribution according to Bonnet et al [7].

3.3. Fracture reservoir analysis

The porosity calculations with equation (1) of the Cubes Method show the estimated value of natural fracture porosity in all study sites between $0.04 - 0.22\%$. and for permeability calculations with equation (2) of the Cubes Method show the estimated value of fracture permeability in all location between $0.06 - 15.48$ darcy. For Equation (3) Match Sticks Method shows the estimated value of natural fracture permeability in all location between $0.04 - 11.61$ darcy.

Estimation of the permeability and porosity values of natural fractures from the equation are depicted in a linear cross plots showing strong correlation coefficient $R^2$ of 0.93 in the granitic basement research area. This value shows that permeability and porosity have a strong linear distribution with those equations which illustrated in Figure 4.

Figure 4. Relationship fracture permeability estimation using Cubes (A) and Matchsticks (B) method against fracture porosity estimation using Cubes Method.
3.4. Relationship fracture characteristics and fracture reservoir
Natural fractures in basement rocks can controls and provide porosity and permeability as a basement fractured reservoir [8]. Permeability and porosity of natural fractures was controlling by fracture characteristics, especially aperture and spacing. The relationship between fractures will greatly affect the value of porosity and permeability. The result of the study shows relationship between estimated permeability values with fracture aperture shows a strong exponential relationship with the value of the correlation coefficient ($R^2$) at the windows scan location is 0.97. and for fracture porosity have strong power relationship with fracture spacing which have correlation coefficient ($R^2$) at the scan line location is 0.94 (Figure 5).

**Figure 5.** Relationship fracture permeability against fracture aperture (A, B) showing strong exponential relationship, and fracture porosity against fracture spacing (C) showing strong power relationship.

4. Conclusion
So with this study, we can conclude that fracture characteristics analysis with field work data at granitic basement outcrops, have strong relationship with fracture reservoir. And with this analog study, would be a geostatistically parameter to build basement fracture reservoir model especially granitic basement rocks.

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