Identification of natural fractures and in situ stress at Rantau Dedap geothermal field

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Abstract. Rantau Dedap Area is a geothermal field which is located in Great Sumatra Fault (GSF). The fault and fracture are main factor in the permeability of the geothermal system. However, not all faults and fractures have capability of to flow the fluids. Borehole image log is depiction of the borehole conditions, it is used to identify the natural fractures and drilling induced fracture. Both of them are used to identify the direction of the fracture, direction of maximum horizontal stress ($S_{H\text{max}}$), and geomechanics parameters. The natural fractures are the results of responses to stress on a rock and permeability which controlling factor in research area. Breakouts is found in this field as a trace of drilling induced fracture due to in situ stress work. Natural fractures are strongly clustered with true strike trending which first, second, and third major direction are N170°E – N180°E (N-S), N60°E – N70°E (NE-SW), and N310°E – N320°E (NW-SE), while the dominant dip is 80°–90°. Based on borehole breakout analysis, maximum horizontal stress orientation is identified in N162°E – N204°E (N-S) and N242°E (NE-SW) direction. It’s constantly similar with regional stress which is affected by GSF. Several parameters have been identified and analyzed are $S_{H\text{max}}$, $S_{H\text{min}}$, and $S_y$. It can be concluded that Rantau Dedap Geothermal Field is affected by strike-slip regime. The determination of in situ stress and natural fractures are important to study the pattern of permeability which is related to the fault in reservoir of this field.

1. Introduction

In situ stress, active fault, and natural fractures are known as the determinant factors for permeability. Fault is the manifestation of active deformation that caused by changes in regional stress pattern. Active deformation associated with the fault movement lead to the formation of fracture and disruption to in situ stress [1]. Distribution of permeability around the fault affected the formation of fracture due to in situ stress. This causes a difficulty in determining fluid flow system of fracture.
Rantau Dedap Field has fractured reservoir since it is a fault controlled system. Fracture reservoir is located on areas with complex geological fault structure. The fault affects distribution of permeability on the area. Reservoir that has low permeability of matrix, would not have no significant fluid flow if they are not fractured [2].

2. Geomaterial and Structural Setting
Rantau Dedap Area is a geothermal field located in Great Sumatra Fault (GSF). The oblique convergent is resulted by N-S regional compression and possible dextral strike-slip faulting. The dextral transcurrent Sumatran Fault runs in the entire length of Sumatra, from Banda Aceh to the Sunda Strait. The fault is coincident with the Sumatran volcanic arc and parallel to the offshore trench [3]. The Island of Sumatra is an island arc produced by subduction of the Indian-Australian Plate beneath the Southeast Asia Plate. The relative 7.7 cm a NNE-directed motion of the Indian Ocean results in oblique (c. 45°) subduction at the Sunda Trench (see figure 1) [4].

The tectonic phase from the field data suggest the extensional tectonic regime work at Rantau Dedap field from central area through Bukit Besar area, while a compressive phase located more to the south seemed to be the limit of opening zone [5].

![Figure 1](image_url)  
*Figure 1. Regional Rantau Dedap structure framework [1]. Vectors show rates of movement relative to a stable Southeast Asia. They imply stress accumulation in parts of the subduction region.*
Bukit Besar area was inferred as a morpho-tectonic that has main effect to Rantau Dedap structure since it is denote as part of a sinistral fault’s evident trending NE-SW toward higher elevation of Bukit Besar itself. Rantau Dedap is likely under influence of two major structures, i.e. Manna Fault (GSF) and Kikim Fault as shown in figure 2. Kikim Fault as normal fault with striking NE-SW to Bukit Besar area. Even though, no clear expression at surface (see figure 1). These structures control the locations with respect of thermal manifestation distribution more likely bound by such faults configuration [4].

The structural map of study area is shown in figure 2. The oldest tectonic phase of WNW-ESE compressional stress probably produced the Manna Fault and mostly recorded in the pre-Besar volcanic in the southeastern area [5]. The next phase was sinistral movement of Kikim Fault that had produced the N-S compressional stress and generated Cawang Fault. Subsequent phase of NW-SE extensional stress that possibly acted as releasing period of previous compressional stress have opened most of the Cawang Rift structures. As the Cawang Fault was cut and superimposed by a series of lateral collapse structures striking NW-SE and sliding toward WSW direction (see figure 2). The distribution of thermal manifestations in this field is controlled by strike slip faults and their associated fractures particularly in NE-SW, NW-SE and N-S trends [6].

Figure 2. Structural Map of Rantau Dedap project. The circle data (stress orientation) and the red lines shows distribution of structural data measurement [5].

3. Geological and Structural Setting

3.1. Natural Fracture

The natural fracture in the borehole image consists of conductive and resistive fracture. Conductive fractures have a low resistivity because it is filled by drilling mud which gave a conductive respond. Partial fracture is part of conductive fracture which is formed partially sinusoidal in wellbore. A
resistive fracture will have high resistivity due to the minerals, while the surrounding of wall formation has a low resistivity value. Conductive natural fractures which as basis for determining the direction of current working stress at the moment. Sometimes these fractures are filled with conductive minerals and would appear darker even though they are closed (see figure 3).

Based on data analysis, the two types of natural fractures were picked independently: 1290 strike-dips of partial fracture and 343 strike-dips of conductive fracture were measured in AA-1, AA-2 and AA-3. The data were statistically obtaining from the clustered direction of natural fracture. The first dominant direction is N170°E – N180°E (N-S), the second direction is N60°E – N70°E (NE-SW) and the third direction is N310°E – N320°E (NW-SE), while the dominant dip are 80° – 90° (see figure 4). This result is similar to surface fault of Rantau Dedap Geothermal Field (see figure 6) [5].

![Figure 3. Examples of sinusoidal trace of natural fractures (NF) intersecting the borehole wall.](image)

3.2. $S_{Hmax}$ Azimuth Modelling

Determination of the orientation $S_{Hmax}$ conducted by applying the directions orientation from induced tensile and breakouts. Unfortunately the method could not be directly applied since it was obtained from an inclined or directional well drilling. A formulation of specific equation must be constructed to resolved $S_{Hmax}$ direction (see figure 5).
The modelling of $S_{\text{max}}$ magnitudes and the azimuth are necessary to produce the breakouts of the observed width and position in the highly inclined well which was conducted using the software Stress and Failure of Inclined Boreholes (GMI-SFIB) designed by GeoMechanics International (GMI). The parameters used are the remote stress tensor onto the borehole surface, mud pressure in the borehole, thermal stress which accompanying temperature change through the coefficient of linear expansion, and the poroelastic distortion adjacent to the borehole wall through Biot’s coefficient and Poisson’s ratio [8]. Based on breakout on each well, the direction of maximum horizontal stress at each well is determined. The results indicate that the direction of maximum horizontal stress at AA-1 has N242°E azimuth direction (see figure 6), AA-2 has N204°E azimuth direction (see figure 6), and AA-3 has N162°E azimuth direction (see figure 7).

**Figure 4.** Histogram of natural fracture strikes (a) and dips (b) in Rantau Dedap well.
Figure 5. Stresses acting in the wall of a directional well [7].

a. AA-1.
Figure 6. The orientation $S_{H_{\text{max}}}$ on AA-1 (a), AA-2 (b) and AA-3 (c) are calculated based on the parameter magnitudes Geomechanics using GMI-SFIB module. The value obtained on the basis of the equation $S_{H_{\text{max}}}$ [7].
3.3. Principal Horizontal Stress Magnitudes Modelling

The maximum horizontal stress magnitudes are the most difficult parameter to be calculated. This parameter cannot be obtained specially using direct measurement. However, this parameter is adjusted by using specific calculation or using borehole breakout and frictional condition to constraint the data.

First step, $S_{\text{hmin}}$ is evaluated magnitudes ranging from critically stressed for normal faulting at a coefficient of friction of 0.8 to 1.0 in which $S_{\text{hmin}}$ approaches $S_V$, thus spanning the range of stresses consistent with normal faulting to strike-slip faulting. The 0.8 coefficient of friction is a conservative estimation based on frictional strength studies of the crust, whereas volcanic andesite is expected to have a coefficient of friction of 0.6 [9]. For this range of $S_{\text{hmin}}$ magnitudes we derived corresponding $S_{\text{hmax}}$ azimuths consistent with breakout position and width for each pair of breakouts in the borehole as a function of rock strengths (UCS).
c. AA-3.

Figure 7. Analysis of in-situ stress using stress polygon on the well AA-1(a), well AA-2 (b) and well AA-3 (c).

Next step is to combine of $S_{\text{hmin}}$ and $S_{\text{Hmax}}$ magnitudes together with $S_{\text{v}}, P_{\text{p}}$ and the wellbore conditions that could reproduce the breakout positions and widths (see figure 7). The polygon in figure 7 defines the range of principal horizontal stress magnitudes scaled to the vertical stress that can be supported by the frictional strength of the crust, conservatively estimated to be 0.8. The UCS necessary to allow the modelled breakout to form it’s contoured as a function of these principal horizontal stresses; only the ranges of $S_{\text{hmin}}$ and $S_{\text{Hmax}}$ that producing breakouts are contoured. For any given breakout, horizontal stress magnitudes scaled to $S_{\text{Hmax}}$ that are consistent with the breakout occurrence and thus is a measurement of the uncertainty in the stress magnitude model.

The analysis shows that the AA-1 has the value $S_{\text{Hmax}}$ 55.1 MPa, formed by strike slip fault regime, AA-2 has a value of $S_{\text{hmax}}$ 66.8 MPa, formed by the strike slip fault regime, and AA-3 has the value $S_{\text{Hmax}}$ 64.6 MPa, formed by the strike slip fault regime.

4. Conclusions

This detailed analysis of borehole image data recorded in AA-1, AA-2 and AA-3 well have provided a well resolved orientation of the horizontal principal stresses that agrees with other observation of the stress state at the Rantau Dedap site. Natural fracture are strongly clustered with true strike trending which the first, second, and third dominant direction is N170°E – N180°E (N-S), N60°E – N70°E (NE-SW), and N310°E – N320°E (NW-SE) respectively, while the true dip dominant is 80° –90°. The magnitude of the maximum horizontal compressive stress constrained by these data is consistent with the occurrence both strike-slip mechanisms at this site.

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