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The Evidence Used in Targeting Wells in a Geothermal Reservoir Using Fracture Zones and Erratic Structure at Lumut Balai and Tompaso Geothermal Area, Indonesia

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ABSTRACT

The most useful surface and subsurface data would concentrate precision orientations to optimize future well design and development strategy. Abundant open fractures are concentrated in more brittle rock at the reservoir. A number of faults were identified through the fractures zone. This is the best evidence for the future development strategy for Lumut Balai at South Sumatra and Tompaso at North Sulawesi.

Three wells at Lumut Balai area and two at Tompaso area have been drilled successfully at a depth of 1,800-2,200 mMD. FMI logging and spinner logging have been done at both areas. Evaluation of spinner data from LMB well indicate an erratic structure at the depth of 800–1,000 mMD that showed the means of how some turbulent fluid flow through narrow fractures to the biggest fractures in reservoir during fluid injection in hole. The fracture zone has been separated at the interval 1,000–1,700 mMD for LHD well at Tompaso area and most of the fracture zones form potential production zones. Both data fully support the next targeting of wells in the surrounding areas.

1. INTRODUCTION

The geothermal areas of Lumut Balai at South Sumatra and Tompaso at the North of Sulawesi are newly developed and being expanded to fulfill the national electricity needs that must be online at 10,000 MW by year 2012 (***Figure 1***). These are at the early stage of development according to the long range commitment of the Pertamina Geothermal Energy planning strategy. Lumut Balai has two power plant units with a total power output of 110 MW, requiring 9 production and 11 injection wells. Tompaso is in one working area group with Lahendong at the North of Sulawesi, being an extension development area from existing production of the Lahendong Area. It is currently producing electricity at a total of 60 MW from three power plants units. At the Tompaso area, four exploration and development wells have already been drilled. All developments are on schedule to achieve their target.

Following are the logging activities implemented to address the objective of finding potential zones in reservoir: a).Taking subsurface data in the form of stratigraphic geobore, b).Identification of geothermal mineralogy, c).Identification of micro fractures shaped in vein, Veinlet, Open fractures and Sealed fractures, d)Taking core sample, e)Running logging FMI (formation Micro Image) and FMS (Formation Micro Scanners), f).Spinner logging, g).Running Kuster temperature and pressure, h).Well completion, i).Gross permeability test and j).Production test.

This paper will be focused on the analysis and examination of fractures and fluid injectivity during drilling as a way of finding potential zones at the reservoir that can be made principal targets in development drilling. This is to achieve the production target to fulfill the need for 10,000 MWe electricity for the nation from the geothermal areas of Sumatra and Sulawesi.

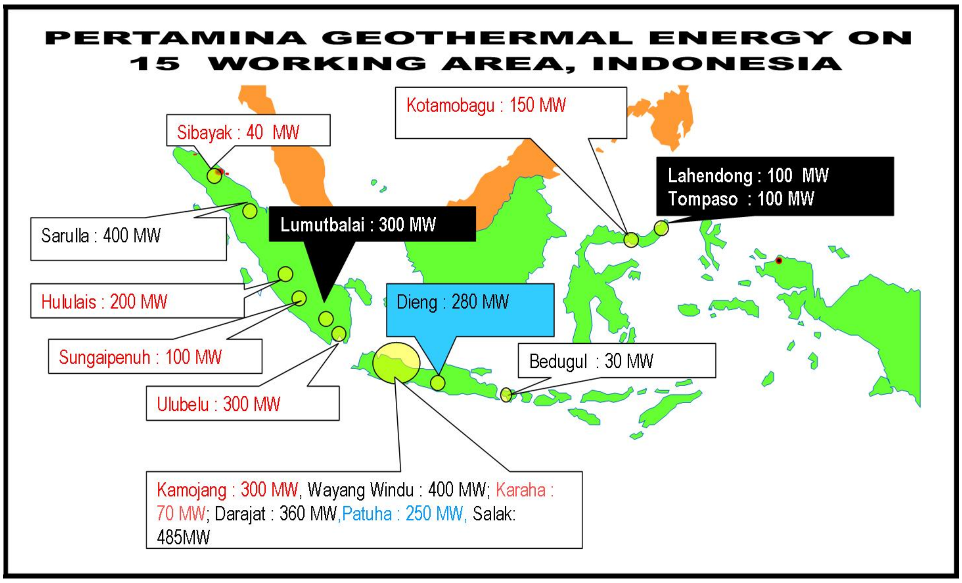

Figure 1: The Locations of Lumut Balai and Tompaso Geothermal Area, showing resources. Both areas at ongoing developing stage, Indonesia

2. FRACTURE AND INJECTIVITY ANALYSIS

2.1 Fractures in Geothermal Borehole

Fractures in geothermal borehole can be classified based on the model and cause of the event (Netherwood R. et al, 2008) as follows: 1. Layered boundary shaped layer of formation contact or contact between different lithologies or facies; 2. Structural dips shaped or minor continuous conductive fractures area, planar features cutting bedding and major open or filled minerals clay, minor discontinuous conductive fractures some as major or minor fractures but is not connected to each other, resistive fractures shaped in resistive planar features cutting bedding but resistive cement healed and fault fractures as continuous planar features cutting bedding with a sense of offset like drag or facies or lithology change; 3. Breakout and induced fractures from drilled damage looking like irregular conductive features due to borehole damage on opposing sides of and paralleling borehole not crossed it while induced feature indicated by fractures that is track vertically down but do not cross the borehole or appear as discontinuous gashes on opposing sides of the borehole.

By using the Schmidt Net of analysis, Roset shaped diagram can be determined as well as strike and dip azimuth from the model and classification above so that the grouping of fractures is known and the location of potential zonation as a reference for the next well.

2.2 Injectivity Flow Test in Geothermal Borehole

The injectivity flow tests are grouped into 2 (two) kinds depending on their use - injectivity tests done in a spinner logging job and well completion. Fluid used in both types of jobs is water with the purpose of indirectly cooling the formation and measuring properties and capacity of fractures at the reservoir. The fluid also increases the fluid reserves in the reservoir so that the quantity of fluid has increased when steam is produced from the reservoir.

In the spinner logging job, the quantity of fresh water that is used is based on borehole dimension. At Lumut Balai present holes have a dimension of 9 5/8" casing and 7" liner at interval 800–2,250 mMD. During the spinner logging run, the rate of injection of fresh water is 10,300–23,000 BWPD (Barrels Water Per Day). At Tompaso hole dimensions are 9 5/8" casing and 8 1/2" liner in the depth interval of 1,000–1,750 mMD. Maximum fresh water rate injected is about 33,350 BWPD. In the injectivity flow test during the well completion test, tools is set at the representative depth then hypodermic fresh water is gradually injected at certain varying quantities. The aim of the injectivity test is to measure fracture properties at the reservoir and fluid acceptance.

3. RESULT AND DISCUSSION

3.1 Fractures Analysis

Fractures that appear in the electrical borehole images at the Lumut Balai well were conductive open fractures invaded by drilling fluid or clay. They are abundant and concentrated in more resistive and therefore more brittle rock. Resistive fractures are healed by electrically resistive minerals such as quartz or calcite are less extensively developed and maybe concentrated in both resistive and conductive rocks. Faults were identified based on evidence of movement that includes truncation of bedding and changes in lithologic or facies or lithology across a fault plane. A high angle fault was observed in the image with borehole enlargement at the depth of around 1,000-1,100 mMD. This zone indicates a potential major production zone. Depths of 1,100-1,600 mMD were absent of any major conductive open fractures and dominance of resistive healed fractures, and depths of 1,600-2,200 mMD were abundant of open fractures, particularly at the depth interval 1,600–1,800 mMD. Azimuth of all fractures and faults was dominantly oriented, striking NNW-SSE and NW-SE and dipping to the NE. This closely corresponds with the regional fault of Sumatra Semangko Fault along Bukit Barisan Moutaint.

In the zone of fracture that appears in the representative borehole for Tompaso Geothermal Area, overall conductive fractures show dominant NE-SW, ENE-WSW, and ESE-WNW strike in agreement with share maximum that indicate reverse geometry and compressional regime. Seven zonation of fractures have been classified at depth interval of 900-1,800 mMD. Three of seven fractures zonations show clearly well corresponding faults, particularly at the interval depth of 900-1,100 mMD, 1,300-1,400 mMD and 1,400-1,650 mMD (***Figure 2***). Unfortunately, the representative well for this case has a total depth of around 1,800 mMD, and it is still a big question mark at the deeper section until 2,500 mMD. Local fractures in the reservoir were controlled by faults trending above, mainly corresponding to regional faults affected by subduction at the North along SW-NE strike. The subduction is still active due to the presence of active volcanoes of Soputan, and Lokon Mahawu.

3.2 Injectivity Flow Analysis

Production logging identified a number of discrete flow events both into and out of the formation fractures. The potential production zones are associated with specific geological features, including faults, isolated large fractures and fracture zones (Richard E.N. et al., 2008).

In the case of Lumut Balai wells with 12 ¼" open hole, 23,200 BWPD (Barrels Water Per Day) were injected at the section below 800–2,270 mMD. At around 1,100 mMD there was a major increase in flow rate. Flow into the borehole from reservoir fractures is calculated at 8,900 BWPD, indicating the main potential production zone. At the depth of 1,180-1,550m MD, the fluid loss is minor, about 2,100 BWPD into the reservoir fractures. However, below 1,550-1,800 mMD, there is a total flow of 21,100 BWPD into the reservoir fractures (***Figure 3***). At the lower openhole 8 ½" interval 1,800-2,270 mMD, injection flowing from overflow at the upper 12 ¼" borehole is calculated at 8,900 BWPD. At the depth of around 1,900 mMD, the spinner rate indicates injection flowing at 4,760 BWPD into the reservoir associated with a high angle fault. Near the total depth of the well at 2,100-2,270 mMD, a decrease in spinner flow rate indicates injection of 2,335 BWPD into the reservoir fractures associated with a conductive lithology containing faults and major angle fractures.

Tompaso geothermal area is a case of reservoir fractures zone. Overall the interval 900-1,800m MD, there is variable fractures density and local zones but only the major flow event according to the spinner flow rate result of 33,350 BWPD injection over the interval around 1,000 mMD corresponds to a reservoir fractures zone. This zone is probably associated with one major open fracture represented by a fault.

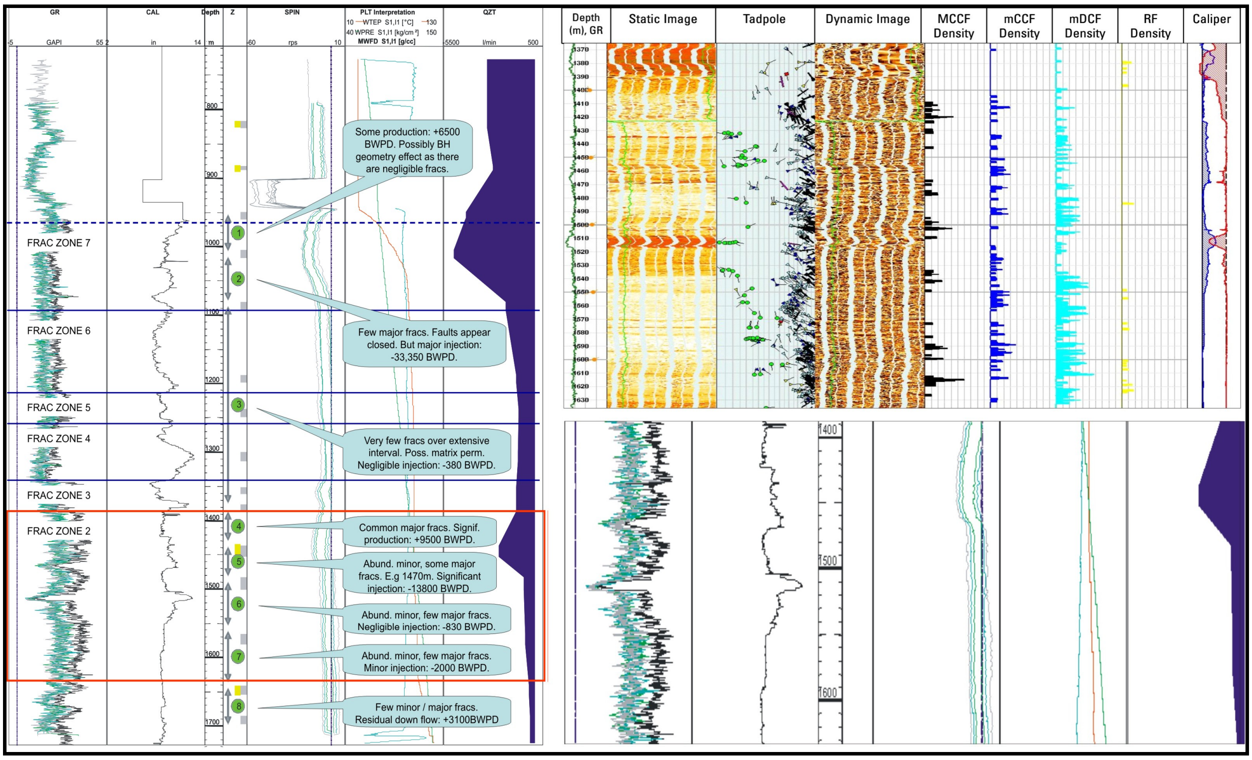

Figure 2: Fracture Zone (900 – 1,800 mMD). At the top of this fracture zone there is significant production associated with a number of major conductive fractures. Below this producing interval, three intervals of minor to significant injection occur. This fracture zone is characterized by abundant minor, but also significant major conductive (open fractures) throughout (Source Netherwood,R,. et al, 2008)

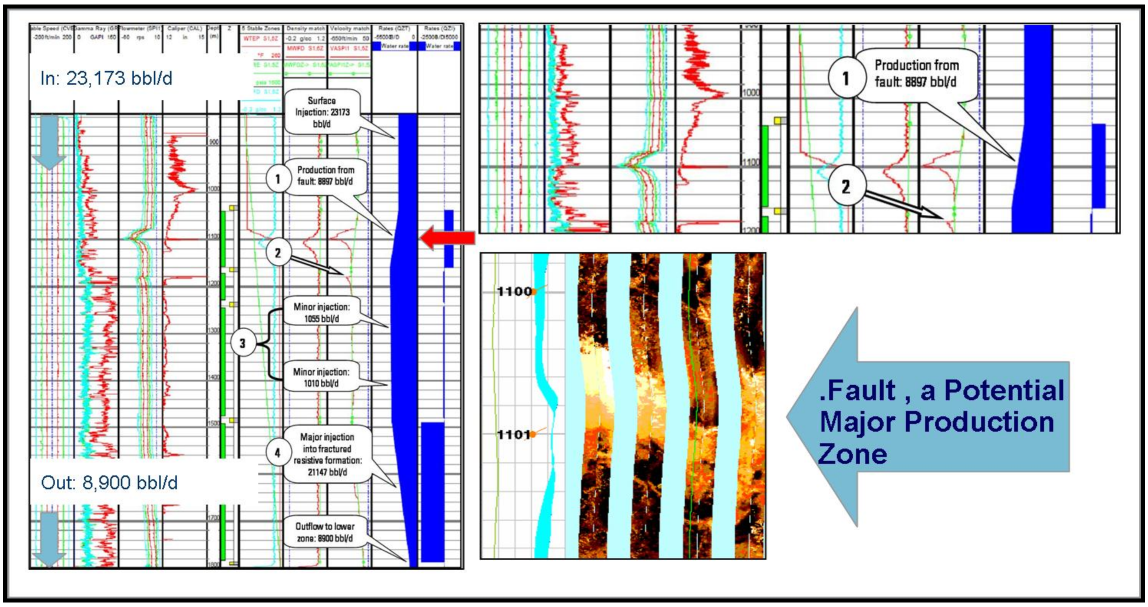

Figure 3: At interval depth 900 - 1,100 m with injected 8,897 BWPD flow into wellbore, high angle fault observed on image with borehole enlargement. Example from Lumut Balai well (Source : Netherwood,R,. et al, 2008

3.3 Corresponding Reservoir Fracture Zone and Injection Flow

3.3.1 Lumut Balai Geothermal Area

There is close correlation between fracture zones in the reservoir with capacity injection from fluid flow. In the reservoir's fracture at Lumut Balai at the depth around 1000-1100 mMD, this zone indicates a high angle fault with borehole enlargement and a potential major production zone. This fault trending NW-SE, strikes parallel to the regional Semangko Fault. The second reservoir targets fracture zones at 1,500-1,800 mMD. The spinner reading indicates a total flow of 21,100 BWPD into the formation down to a depth of 1,780 mMD. This flow decrease is associated with highly resistive and heavily (open) fractured lithology over the two intervals 1,546–1,554 and 1,660-1,780 mMD. At the lower 8 ½" inch interval at 1,865-2,270 mMD, outflow from the upper 12 1/4 inch borehole section into the lower 8.5 inch section is calculated at 8,900 BWPD. Again, spinner and temperature events were interpreted in conjunction with the borehole image data (Pertamina Geoth. Energy, 2008).

3.3.2 Tompaso Geothermal Area

Seven zonations of fractures were classified at the depth interval of 900-1,800 mMD based on combining FMI and spinner data from three of seven fractures zones clearly corresponding to faults, particularly at the interval depth of 900-1,100, 1,300-1,400 and 1,400-1,650 mMD. The depth interval at around 900-1,100 mMD is characterized by very few conductive fractures and some faults. The base of the zone, however, represents the major flow zone in the well taking injection of 33,350 BWPD. Below this zone at a depth interval 1,100-1,400 mMD, there are a few minor conductive fractures and some discontinuous conductive fractures. Injection flow rate is around 380-400 BWPD through these few fractures. In the last of the deepest interval at 1,500-1,800 mMD, at the top of this zone is significant production associated with a number of major conductive fractures. Below this producing interval, there are three intervals too minor for significant injection occur. This fracture zone is characterized by abundant minor and major conductive open fractures throughout. Even the matrix of rocks is resistive, indicating poor matrix permeability. As explained before, unfortunately, total depth of the well is around 1800 mMD, since deepening to 2,500 mMD would be a big technological and economic challenge.

3.3.3 Reservoir Targeting

In the reservoir of Lumut Balai, the main zone targeting for the next production wells are at the depth of around 1,000-1,100 mMD. This zone indicates a high potential major production zone due to fault fractures trending NW-SE parallel to the regional Semangko Fault. Around the main production zone, about 30-35 % of the fresh water injected entered the formation, more or less 19,000 BWPD of the total injected 56,000 BWPD. This zone presents an erratic structure which indicates some water moving turbulently during injection through a small open fracture at the top and continuously down to a big fracture zonation at the deeper section. The second reservoir targets fracture zones at the interval 1,500-2,270 mMD. The productivity in this zone is less than the above and is calculated at around 8,900 BWPD. This is roughly because the maximum entry of injection is too small as a residual from the above entry zone at the interval < 1100 mMD (***Figure 4***).

Tompaso's reservoir mainly has the presence of three out of seven fractures zones clearly well corresponding to faults, particularly at the interval depth of 900-1,100, 1,300-1,400 mMD and 1,400-1,650 mMD. The depth interval 900-1,100 mMD and surrounding is controlled by a few conductive fractures and some faults with potential production of more or less 33,350 BWPD. Below this zone at depth interval 1,100-1,400 mMD contains a few minor conductive fractures with approximate potential production of around 380-400 BWPD. In the last of the deepest interval 1,500-1,800 mMD, at the top of this zone is significant production associated with a number of major conductive fractures. This fracture zone is characterized by abundant minor and major conductive open fractures and the same way projected to the deepest 2.500 mMD (***Figure 5***).

CONCLUSIONS

1. In the reservoir of Lumut Balai, the main target for the next production wells are at the depth of around 1000-1100 mMD, which is a high potential major production zone due to fault fractures. There is an entry of about 30-35% of the injected fresh water flow. There is an erratic structure indicating the presence of some narrow open fractures at the top, continuously down to a big fracture zone at the deeper section. The second reservoir is targeting fracture zones at the interval 1,500-2,270 mMD. The productivity in this zone is calculated at around 8,900 BWPD.

2. In the Tompaso reservoir, main potential zones are controlled by the presence of three out of seven fractures zones clearly well corresponding to faults with potential production of more or less 33,350 BWPD. Below these zone at depth interval 1,100-1,400 mMD contains a few minor conductive fractures with potential production of around 380-400 BWPD. In the last of the deepest interval > 1,500 to 2,500 mMD, there significant production associated with a number of major conductive fractures.

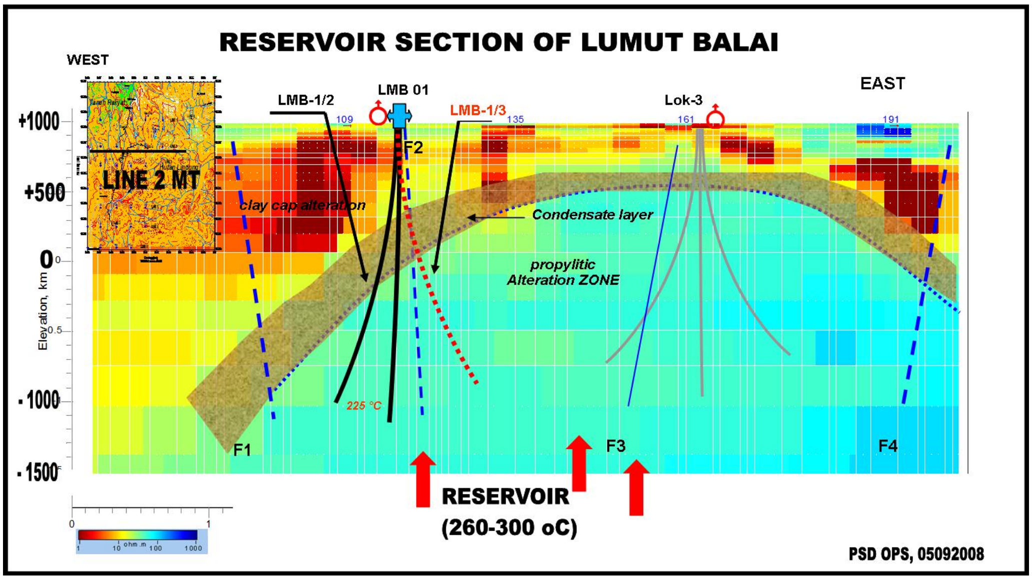

Figure 4: Reservoir geothermal model of Lumut Balai, South Sumatra, Indonesia

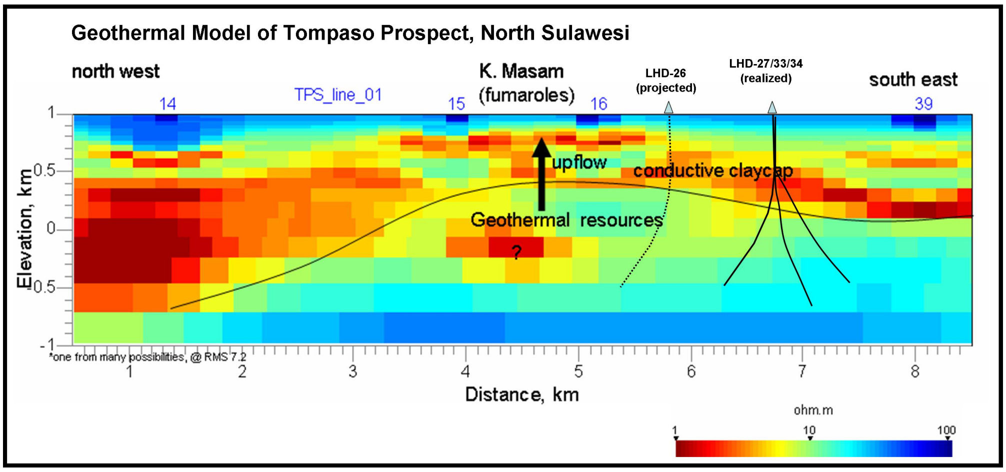

Figure 5: Reservoir geothermal model of Tompaso, North Sulawesi, Indonesia

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