GEOLOGY FAULT NETWORK OF HULULAIS GEOTHERMAL SYSTEM, BENGKULU, INDONESIA

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Keywords: *Hululais Volcanic Complex (HVC), Suban Agung Fault (SAF), Hululais Geothermal Field (HGF).*

ABSTRACT

The Hululais geothermal field in Bengkulu, Indonesia is one of the geothermal fields developed by Pertamina Geothermal Energy (PGE), situated on the western side of an overlapping Ketahun and Musi Segment, which is part of Great Sumatera Fault. Morphologically, the Hululais field stand within in Hululais Volcanic Complex (HVC) consisting entirely of Quaternary volcanic rocks. The orientation of structural geology is predominantly northwest-southeast (NW-SE). These structural trends are consistent among surface and subsurface data, fault network, determined from map lineament interpretation, geologic mapping, gravity data and borehole data. The most significant structural features are the Suban Agung Fault (SAF), this master fault strikes northwest through HVC. The northwest trending SAF plays an important role in this system, affect a zone of extension recent volcanism and controls the fluid circulations of Hululais geothermal system.

Ascertain of the fault network in Hululais Geothermal Field (HGF) will assist to define the most productive parts of the zone. Similar fault studies can be applied in other geologic structures to define the most permeable areas in the field.

1. INTRODUCTION

Hululais field in RejangLebong, Bengkulu Province, Indonesia is one of the geothermal working areas developed by Pertamina Geothermal Energy (PGE). Hululais field could be reached by 5-6 hours' drive towards the mountainous Barisan Range in the North of Bengkulu City (Figure 1). Due to its location that is close proximity to the Sumatran Fault Zone (SFZ), a segmented major NW-SE strike-slip fault along the Sumatra Island, Hululais' structural development and volcanism are influenced by SFZ activity. These two factors play the role to the existence of geothermal system beneath the Hululais field. Surface indicators of the geothermal reservoir we include in this study are fumarole, solfatara, mud pool, hot springs, and surface alteration.

Geoscience Studies in Hululais and surrounding areas have been carried out by Pertamina and other institutions since 1992. The earliest publication in the study area focuses on the regional geological mapping of Bengkulu with a scale of 1:100.000 (Gafoer, et al., 1992). The more detailed geological mapping in the study area was done internally by Pertamina (Budiardjo, 1994) which led to the earliest geothermal resource assessment of Hululais. Since then, various geoscience publications have been made but few that discuss the structural and volcanism aspect in Hululais. These two topics are the main discussion latter in this paper.

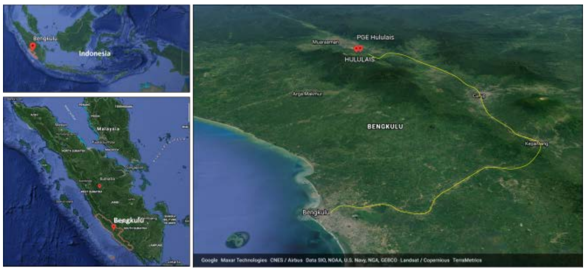

Figure 1: Location map of the study area (Topographic taken from Google Maps, 2020)

2. STRUCTURAL GEOLOGY

2.1 Regional Geological Structure

Sumatra Island is influenced by the convergence of two plates, the northward movement of Indian Plate beneath the Eurasian Plate. The convergence of these two plates is accommodated by oblique subduction. The result of oblique subduction is depicted on the surface by the NW-SE dextral strike-slip of Sumatra Fault Zone (SFZ). The fault zone forms the NW-SE Barisan Range of Sumatra Island that separates the back-arc basin to the east and forearc basin to the west (Muraoka, et al., 2010, Barber, et al., 2005, Darman &Sidi, 2000, Sieh &Natawidjaja, 2000).

Along its 1900-km long, the Sumatra Fault Zone has 20 major segmentations separated mostly by valleys and lakes that form as stepovers. The stepovers length might vary from about 35 km to 200 km (Natawidjaja, 2018). The movement of SFZ also provides pathways for magma that is resulted from partial melting as the product of the oblique subduction. Therefore, most major volcanoes in Sumatra Island is spatially located parallel to SFZ and not far from the fault zone.

2.2Hululais Geological Structure

Hululais area is bounded by two dextral strike-slip faults of Ketahun Segment to the north and Musi Segment to the south (Figure 2). These two segments are part of the Sumatra Fault Zone. Musi Segment lies 70 km northwest of Air Keruh pull-apart basin and has slip rate of 11 mm/yr (Sieh and Natawidjaja, 2000). It is also interpreted to continue beneath the Hululais and Bukit Lumut mountain. Ketahun Segment has 85 km in length and at the southern tip of the segment, it ends at the 6-8 km wide dilatational step over onto the Musi Segment (Sieh and Natawidjaja, 2000). As a result of the movement of two right stepping dextral strike-slip faults, the overlap area is the extensional overstep that is known as the pull-apart basin. Juanda, et al., (2015) interpreted that these two segments exist within the study area based on the recorded microearthquake data (Figure 3).

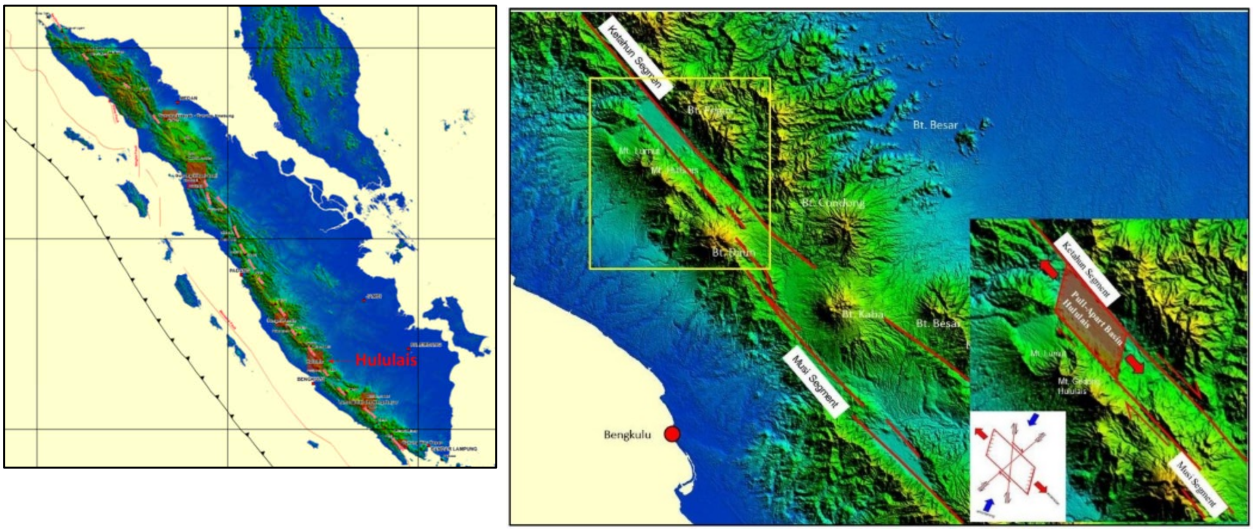

Figure 2. Tectonic map of Sumatra showing the relative location of Hululais at the clustered volcanoes within the Sumatra Fault Zone (SFZ) (modified from Muraoka, et al., 2010, Barber, et al., 2005, Darman&Sidi, 2000, Sieh&Natawidjaja, 2000).

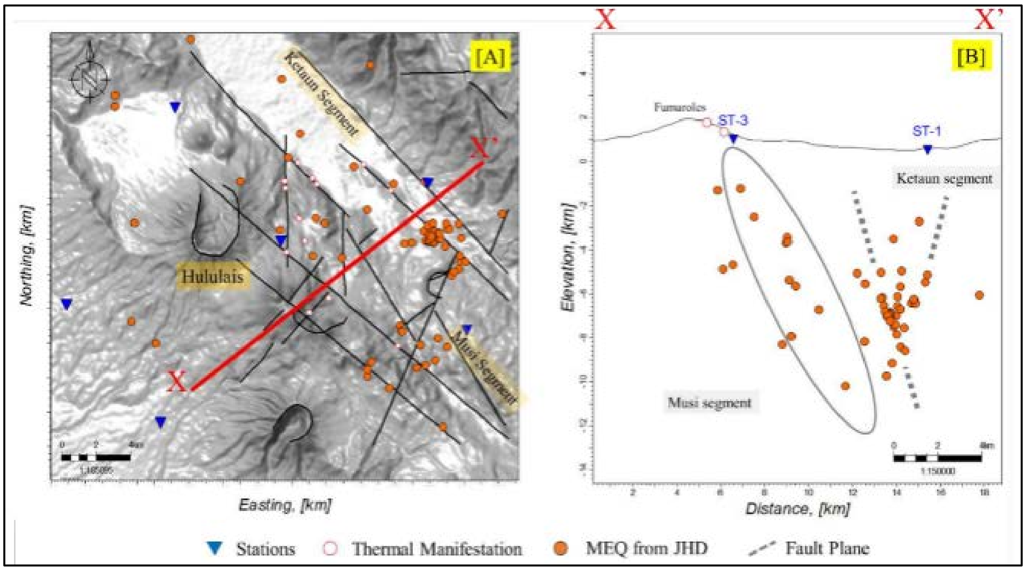

Figure 3. Microearthquake epicenter distribution on surface (left) and its hypocenter distribtution on vertical section. Microearthquake data cluster depict a faultzone of Ketahun and Musi Segment (Juanda, et al., 2015).

The geologic structure of Hululais is analyzed from various surface and subsurface data. Remote sensing data, surface measurements on several fair to good exposed outcrops were taken (extension fracture, shear fracture, sheeting joint, and possible fault surfaces), gravity data, fracture orientation from borehole log data in 12 wells and feed zone depth of 24 wells were integrated to the lineament analysis. The limitation of surface measurements in HGF are constrained by dense jungle and intense weathering, so the surface data is limited in the proximal area

Hundreds of fractures were picked each borehole image log and about 329 surface observations of faults and fractures obtained. When the fault and fracture orientations are plotted on a stereonet, there are three dominant sets of orientations at Hululais (Figure 4):

1. NNW-SSE or relative N-S
2. NE-SW
3. NW-SE

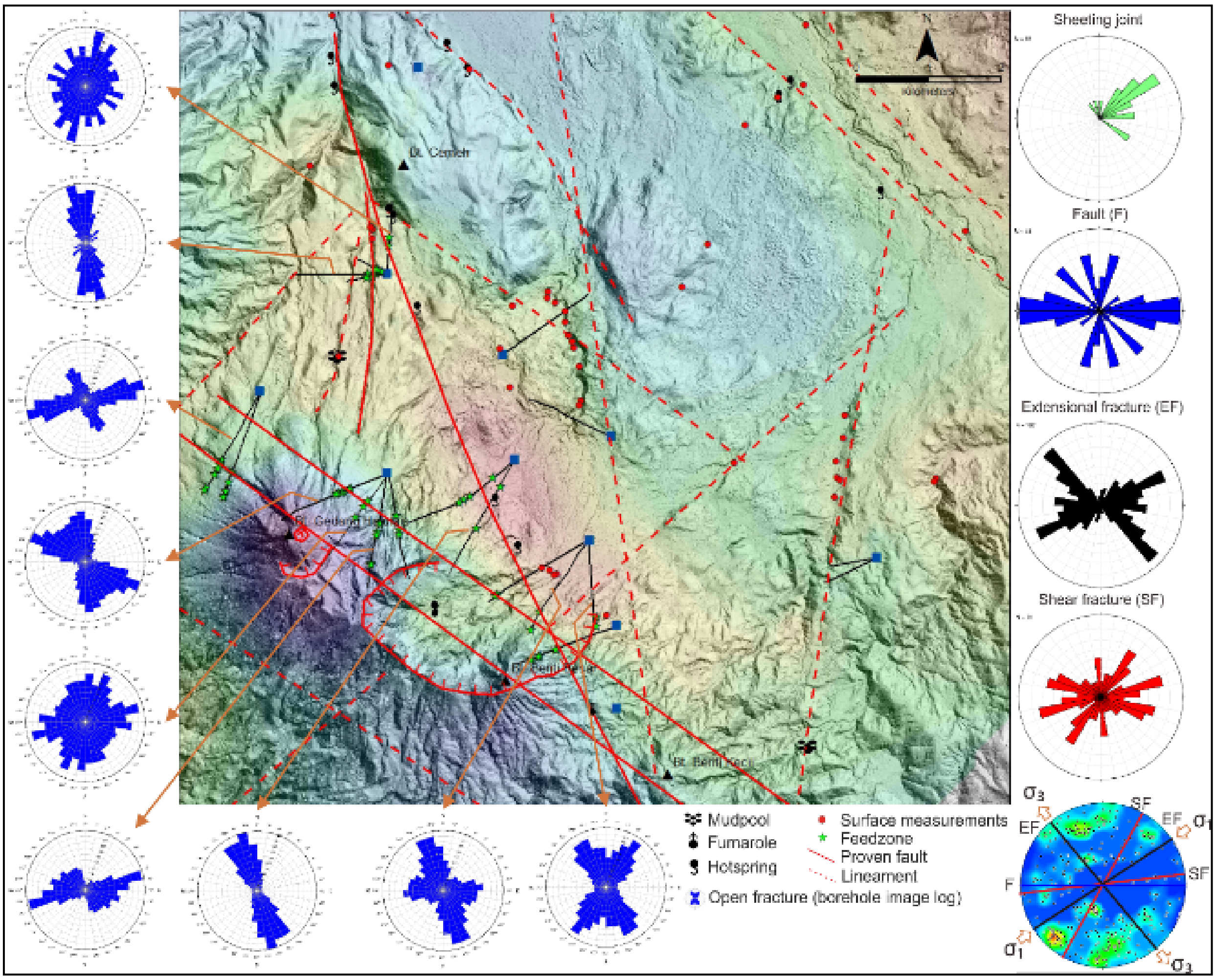

Figure 4. Geologic structure map of Hululais showing three main structure orientations based on open fracture orientation from borehole image log (blue stereonet, left and bottom section) and field measurements (Sheeting joint, fault, extensional fracture and shear fracture). A contoured plot of 329 both plane and line geological structures from field measurements with its dominant structure direction are shown on the right bottom. A transparent rainbow color in the background of the map is the residual gravity anomaly used to delinate lineaments in conjunction with the LiDAR data. Nevertheless, nearby geologic structures influence the recorded data in specific location in wells and also on surface.

It is observed on Figure 4 that the nearby faults influence the structure data orientation. Moreover, the orientation of the fracture from the borehole log data is mostly parallel to the nearby lineaments. When a lineament orientation aligns with the fracture orientation from the borehole image log and coincides with the occurrence of the feed zone in the well, the lineament is considered as proven. The NNW-SSE to N-S structure and NW-SE structure concede with surface manifestations and may play a role in fluid flow to surface. These two structures trend observed in Hululais has resulted from the movement of two major NW-SE dextral strike-slip faults that have N-S compressional stress creating a N-S extensional structure and NW-SE major faults.

The structures in the area are controlled by the formation of the pull-apart basin. The plot of all surface fractures shows that the NE-SW shear fracture with its conjugate and the NE-SW extension fracture follows the structural model of a pull-apart basin (Figure 5, lower right). On the other hand, the NE-SW extension fractures are the product from E-W faults. These structures are very localized as these data were obtained from several outcrops around Sungai Air Kotok. The outcrops in Sungai Air Kotok have better exposure compared to the other locations so the structure data in here is reliable to represent the E-W fault.

Based on the shape and the orientation of the structures, the pull-apart basin has rhomboidal to stretched geometry with a length-to-width ratio of 3:1 (Figure 5). This is in agreement with the average geometry of pull-apart basins that are described by their length-to-width ratio of 3:1 (Aydin and Nur, 1982 as cited in van Wijk, 2017; Dooley and McClay, 1997 as cited in van Wijk, 2017; Basile and Brun, 1999 as cited in van Wijk, 2017). Mann, et al., (1983) as cited in van Wijk (2017) assume that the geometry of the pull-apart basin is related to its geometrical stages due to fault growth. It is interpreted that the pull-apart basin stages in the study area are more mature than the other lazy S-Z shaped (spindle) pull-apart basins in the other area in Sumatra.

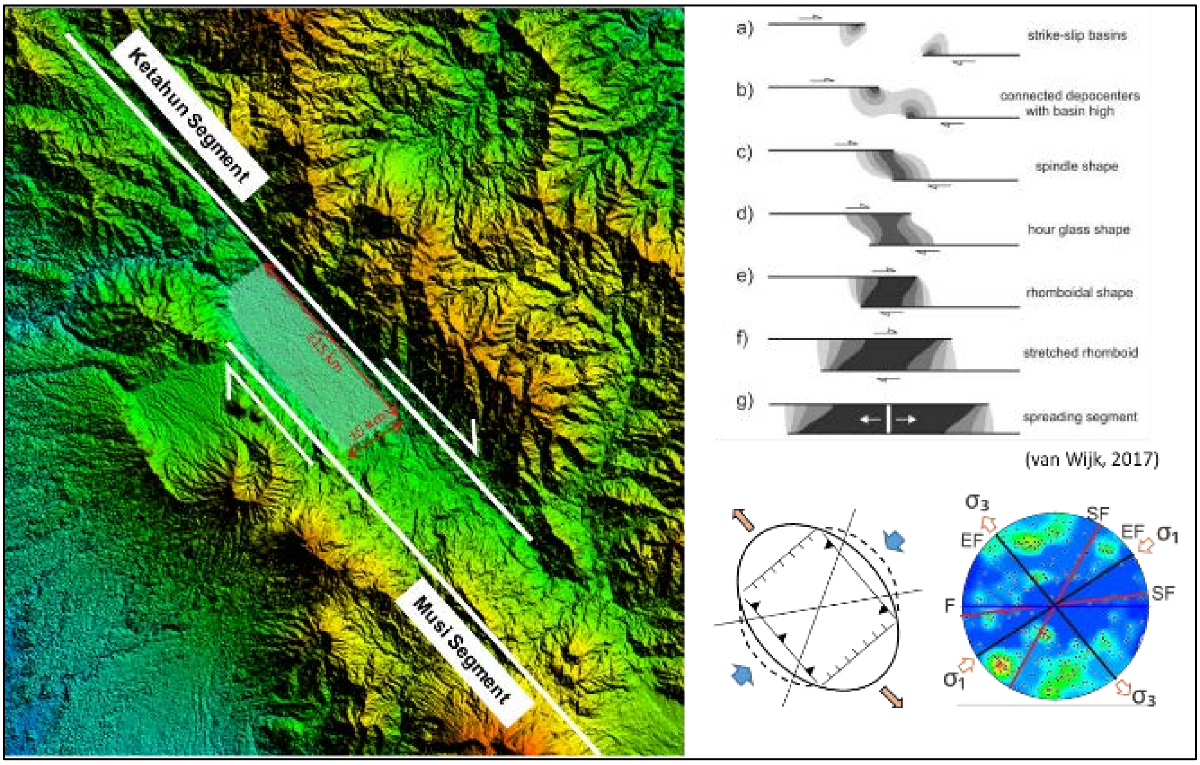

Figure 5. Simplified pull apart basin geometry in overlap area of both dextral right stepping faults of Musi Segment and Ketahun Segment (left) shows length-to-width ratio of 3:1. The pull apart basin on the map has the rhomboidal to stretched shape that reflects the geometry stages (upper right). Structures from field measurement in the study area is influenced by forces acted on pull apart basin (bottom right) as its data mainly located near and within the basin

3. DISCUSSION

By obtaining evidence of the distribution of geological structures in the Hululais area, there are at least three main trending geological structures direction, specifically North West-South East (NW-SE), North East-South West (NE-SW) and North-South (N-S) patterns. Accordingly, HGF geological structure simply can be described using Riedel Shear Model (Figure 6).

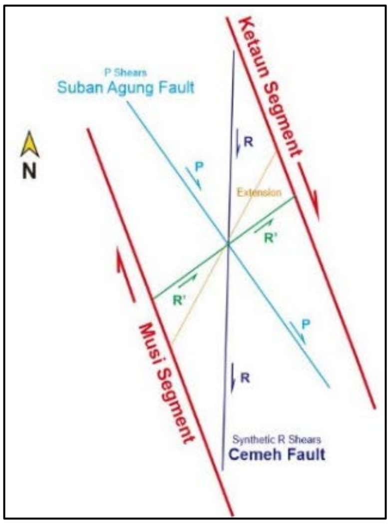

Figure 6. Geological structure model of Hululais similar with Riedel shear model

The fault network in HGF is formed between two segments of the Sumatra Fault System (SFS). It makes the structure in HGF has NW-SE (P shears) and NE-SW (Synthetic R Shears) trend that control the permeability of the HGF and lift the fluid out as a discharge in thermal manifestations on the surface and also feedzone in the well. While another directional patterns (N-S) also controlled the HGF and serve as boundary the system.

With these conditions it can explain that the structural pattern that develops in the HGF is strongly influenced by the NW-SE and NE-SW pattern i.e, Suban Agung Hulu Fault, Suban Agung Hilir Fault and Cemeh Faults.

4. CONCLUSION

Structural geology in Hululais is related to the movement of the Great Sumatran Fault in Sumatra. From the data explained above, Hululais is one of the areas where it's the field are influenced by the NW-SE structure and bounded by two segments from the GSF, namely Ketahun Segment and Musi Segment. The faults from Musi Segment provide the pathways for magma to emerge from beneath to form clustered volcanoes in the area forming the Hululais Brigade. Thus, the heatsources in Hululais may related with the activity of the NW-SE dextral major strike-slip fault. The N-S compressional forces, based on the Riedel shear model for two right stepping faults such as Musi Segment and Ketahun Segment, formed the secondary N-S to NNW-SSE structural trend that also acts as one of the major structure in the area beside the main NW-SE structural trend. These two structural trends is evidenced by the appearance of manifestation on the surface. Moreover, in the area where it is proximity with the pull-apart basin, the geologic structures recorded from the field measurement is influenced by the forces that act to form the basin.

ACKNOWLEDGEMENTS

I would like to express my deep and sincere gratitude to Exploration Geoscience team especially for all the Geologists in PT Pertamina Geothermal Energy for the cooperation with the result that field data has been analysed properly.

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