Volcanostratigraphic Analysis Using Fault and Fracture Density (FFD) Method for Geothermal Potential Assessment: A Case Study of Rajabasa Volcano, South Lampung, Indonesia

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ABSTRACT

Nowadays, conventional energy production has decreased, so that the development of alternative energy is needed, one of which is geothermal energy. Geothermal potential can be produced by volcanic and non-volcanic processes. Until now, several geothermal areas that have been explored are the result of volcanic processes. One of them, the volcanic area that has geothermal energy potential is Rajabasa Volcano. Rajabasa Volcano in South Lampung District, Lampung Province. The method in this study is the study of literature using quantitative approaches, volcanostratigraphic analysis, and Fault and Fracture Desinty (FFD). Volcanostratigraphy analysis is done by identifying topographic maps, geological maps, geological data, and FFD methods using ArcMap, Global Mapper, and Surfer software. Studies on volcanostratigraphy and FFD can support geothermal exploration in a preliminary survey. Volcanostratigraphy and FFD identification aims to predict manifestations, volcanostratigraphic units, and geothermal prospect areas in the region. Based on volcanostratigraphy analysis, there is two crowns and one hummocky. The crowns consist of Rajabasa and Tangkil. The presence of the crown reflecting a long lived geothermal system. The results of FFD data processing show three zones, namely dark green-moss green (0-1.1 km/km²), light green-young orange (1.1-2.2 km/km²), and orange-red (2.2-3.3 km /km²). The red zone represents a high fracture density value in the region. This is evidenced by the discovery of manifestations of hot springs and fumaroles on the surface. Hot springs indicate the influence of geothermal and magma gradients that increase the temperature of the water from below the surface to the surface. Fumarole indicates the presence of magma at shallow depths, so that the water has boiled before reaching the surface. The existence of these two manifestations is based on FFD and the results of the correlation with volcanostratigraphy indicate that the research area has the potential to be carried out by geothermal exploration development.

Keywords : Fault and Fracture Density, Geothermal, Rajabasa, Volcanostratigraphy

INTRODUCTION

Geologically, Sumatra Island was formed due to a encounter between two plates, namely the Eurasian plate and the Indo-Australian plate. The encounter between the plates results in tectonic activity which results in several active volcanoes. Some active volcanoes produce geothermal energy potential. According to Pusat Sumberdaya Geologi (2017), the potency of geothermal energy in Indonesia reaches 29 GWe. One area that has the potential to have geothermal energy is in Rajabasa Volcano. Rajabasa Volcano is located in South Lampung District, Lampung Province. Knowing that there is a potential for geothermal energy requires further investigation to explore and exploit the area. One of important factor in geothermal exploration associated with volcanoes is identifying the volcanostratigraphy of the area.Volcanostratigraphy is the science of stratigraphy related to volcanism and its products (Bronto et.al., 2016). The volcanostratigraphic system layer is based on volcanic sources, deposite types, and relative time sequences. Volcanostratigraphic interpretation is done by integrating topographic maps, geological maps, and geological data. The Fault and Fracture Density (FFD) method is also carried out in geothermal exploration and exploitation to determine the high value of structural density by interconnection between faults and fractures in the study area (Suryantini and Wibowo, 2010). Fracture can be formed during tectonic activity to form rock deformations, such as folds and faults. Fracture can also be formed around the body's intrusion which develops during intrusion of igneous rocks into surrounding rocks. In geothermal systems, the presence of faults and fractures can act as permeable zones for the migration of fluid from the reservoir to the surface and become hot springs or fumaroles. This study aims to describe volcanostratigraphic units, identify FFD, and geothermal manifestations. After carrying out these steps it can be predicted that areas with the potential to have geothermal energy for further exploration surveys.

REGIONAL GEOLOGY

Stratigraphically, Rajabasa Volcano Complex consists of Tangkil, Taman Pematang, Balerang, and Rajabasa Volcano. According to Suswati et.al. (2001), volcanic products from the Rajabasa

Volcano Complex are divided into five periods from old to young, namely (1) Old Tangkil Volcanic Products, consisting of Old Tangkil (Tv) Volcanic Product Units that are Pliocene aged, (2) Old Taman Pematang Volcanic Products , consisting of a Pleistocene Old Volcanic Product Unit (PTv), (3) Balerang Volcano Products, consisting of a Balerang (Bl) Pyroclastic Unit and Lava Balerang (Ba) Unit that are Pleistosen aged, (4) Side Eruption Products (845 Hill) , consisting of Lava 845 (845l) units in Pleistocene age (Figure 1).

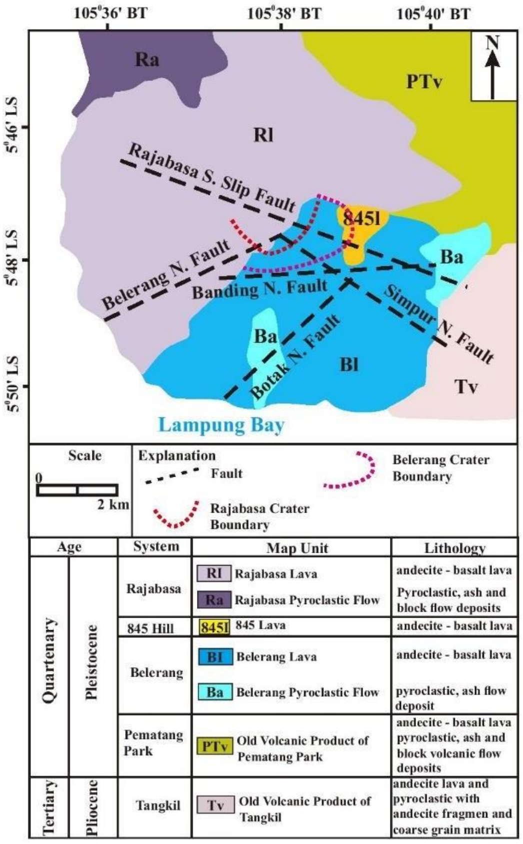


Figure 1: Stratigraphy of Rajabasa Volcano Complex (Suswati et.al., 2001)

Based on the Geological Map of Tanjungkarang Sheet (Mangga et al., 1993), in the study area there were three volcanic rock units of varying ages, from Tertiary to Quaternary, Andesite Unit (Tpv), Lampung Formation (QTl), and Rajabasa Volcanic Rock (Qhv) (Figure 2). The Andesite Unit Unit composed of andesitic lava as a product of tertiary volcanism spread with direction from the western to the southeastern part of the Rajabasa Volcano. The Lampung Formation consists of ryolitic tuff, pumiceous tuff, clay, and tuffaceous sandstone. The Rajabasa Volcanic rock belongs to the young (quaternary) volcanic deposits consisting of basaltic-andesitic lava, breccias, and tuffs forming the Rajabasa volcanic cone body (Table 1) . Rock composition indicates that Rajabasa Volcano is a composite type or Strato cone. According to Bronto et.al. (2012), based on the characteristics of the current lava flows on Mount Rajabasa, this Andesite Unit is predicted to have grown not far from the source of the eruption. The history of eruptions in Rajabasa Volcano was recorded by Van Padang (1951) in (Budiarjo et al, 1995) who said that in 1863 and 1892 there was an increase in volcanic activity, but no eruption had occurred.

Table 1: Stratigraphy of volcanic rocks in Rajabasa Volcano with description (Modified from Mangga et al., 1993)

Age	Rock Unit Name	Description
Quaternary	Rajabasa Volcanic Rocks (Qhv)	Lava (andesite-basalt), breccias, tuff, spread out locally in the Rajabasa Volcano, southern part of Kalianda City.
Quaternary-Tertiary	Lampung Formation (QTl). Previous name Lampung Tuff (van Bemmelen, 1949)	Pumiceous tuff, rhyolitic tuff, tuffite, welded tuff, tuffaceous claystone, tuffaceous sandstone, distributed widely from Bakauheni to northern Kalianda till northern part of Bandar Lampung City. Pumiceous tuff, yellowish grey-greyish white, medium- to coarse-grained, poorly sorted, mainly comprising pumice and rock fragments. Rhyolitic tuff, brownish white, slightly jointed, hard. Tuffaceous sandstone, yellowish broken white, subrounded, partly pumiceous, somewhat soft, often shows cross bed structure, generally of dacitic composition.
Tertiary	Andesite (Tpv)	Andesitic lava, light-dark grey, hard, porphyritic; plagioclase, amphibole, and pyroxene phenocrysts embedded in aphanitic groundmass; outcrop relatively fresh, strongly/sheeting jointed; cropping out in the eastern part of Rajabasa Volcano; unconformably overlain by the Lampung Formation.

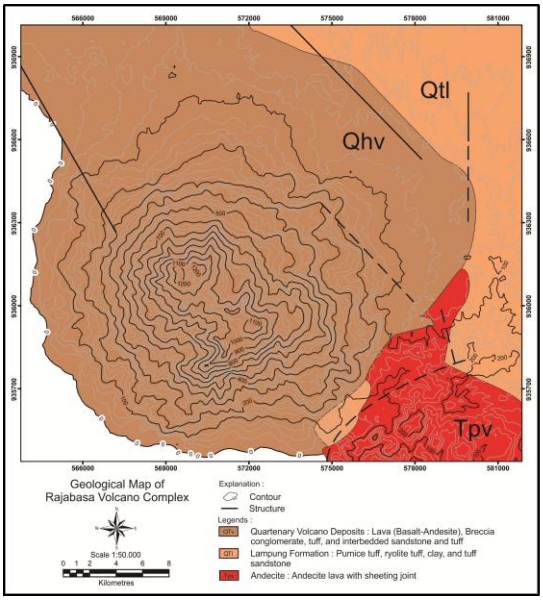


Figure 2: Geological map of Rajabasa Volcano Complex (modified from Mangga et.al., 1993)

Quaternary volcanoes along the Sunda and Banda arc of Indonesia is a famous example of subduction-related volcanism. The Sunda Strait located in the southeastern part of Sumatra island marks the transition region from orthogonal to oblique subduction and interpreted as an extension area and as the result of a northwestward motion of the arc slices located between the trench and the Sumatran Fault System (Barber et.al., 2005). According to Ninkovich (1976) in Barber et al. (2005) the aperture of the Sunda Strait is the result of a Sumatra clockwise rotation along 20° around the axis located near the Sunda Strait since the Late Miocene. Based on the geological map of Tanjung Karang (Mangga et. al., 1994), the pattern of alignment and fault structures that develop is directed towards NW-SE and N-S. The structural pattern trending NW-SE is an extension pattern from Sumatran Fault (Katili, 1975). The trending fault pattern N-S is indicated as a basement structure pattern commonly found in the Java sea (Martodjojo, 2003)

South Lampung is divided into three blocks, namely Bengkulu Block, Central Block, and Sekampung Block (Van Bemmelen, 1934 in Nazarwin 1994). The Bengkulu and Central Block blocks are separated by Semangko Fault while the Central Block and Sekampung Block are separated by Lampung Fault. This Lampung Fault continues to the south and cuts off the Rajabasa Volcanic complex and Mount Balerang. The Lampung Fault has a northwest-southeast direction and local faults that are northeast-southwest. Lampung Fault is a strike-slip fault and preficted controlling the geothermal system in the north and southeast of Mount Rajabasa (Amin, 1988 in Nazarwin, 1994). In addition to faults, other geological structures that developed is a crater which also acts as a geothermal controller. The crater is the Balerang Crater which is located on the summit of Mount Balerang and the Rajabasa Peak Crater which is located at the top of Rajabasa Volcano. The Rajabasa Peak Crater and the Balerang Peak Crater formed steep slopearound the crater. These slopes is a product of an eruption followed by destruction phase along with the process of forming the crater morphology in Mount Rajabasa (Suswati, et al., 2001).

METHODS

The methods in this study are literature studies, vulcanostratigraphy analysis, and Fault and Fracture Desinty (FFD) (Figure 3). Literature studies are needed by using a quantitative approach. Volcanostratigraphic identification requires basic volcanic understanding, such as volcanic geology, genetic volcanism, variation of volcanic rocks, volcanic facies, paleovolcanoes, and super-imposed volcanism. Volcanostratigraphy analysis is done by identifying the top of the volcano on topographic maps. Interpretation is based on topographic maps and geological data in the research area to determine the relative age of volcanoes in the region. This information will help in evaluating geothermal potential in the study area. Interpretation of the volcanic eruption center into some smaller volcano stratigraphy units. A volcanic eruption center can be devided into a hummock, several types of creating a crown, a group crowning a brigade, some brigades and super brigades form an arc. The FFD method used in this study uses Digital Elevation Model (DEM) data issued by the Geospatial Information Agency (BIG) to analyze remote sensing images. The data is processed using GlobalMapper software to get the alignment pattern. The shadow feature of the DEM image is used in straightness analysis. Line identification is needed to support the analysis and estimation of line level at the macroscopic scale. Azimuth lighting direction is divided from several angles, namely 0°, 90°, 135° and 315° with the same lighting height. Visible lineaments were then recorded by using ArcGIS 10.5. Then, a grid is created to determine the density and total line length of lines for each grid. In addition, the exact value corresponding to the total length of the line is added to each center of the grid and contours are made. Contour maps are made using Surfer 12 software to reflect fracture density. The high density contour shows that high density cracks can be interpreted to correlate with high permeability. The results of vulcanostratigraphic interpretation and FFD analysis can be used as a reference to support geothermal exploration in the preliminary survey.

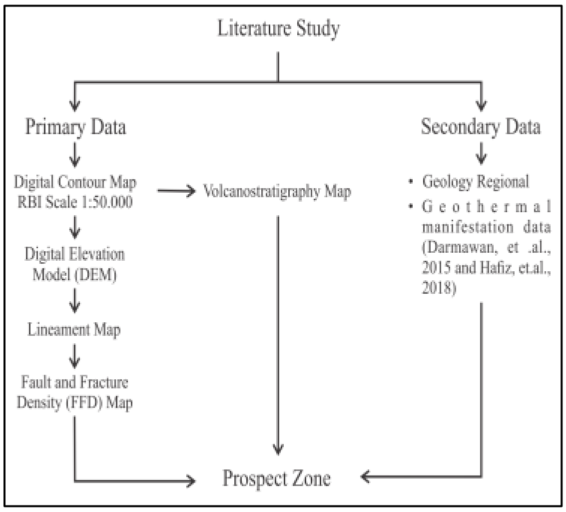


Figure 3: The workflow of research

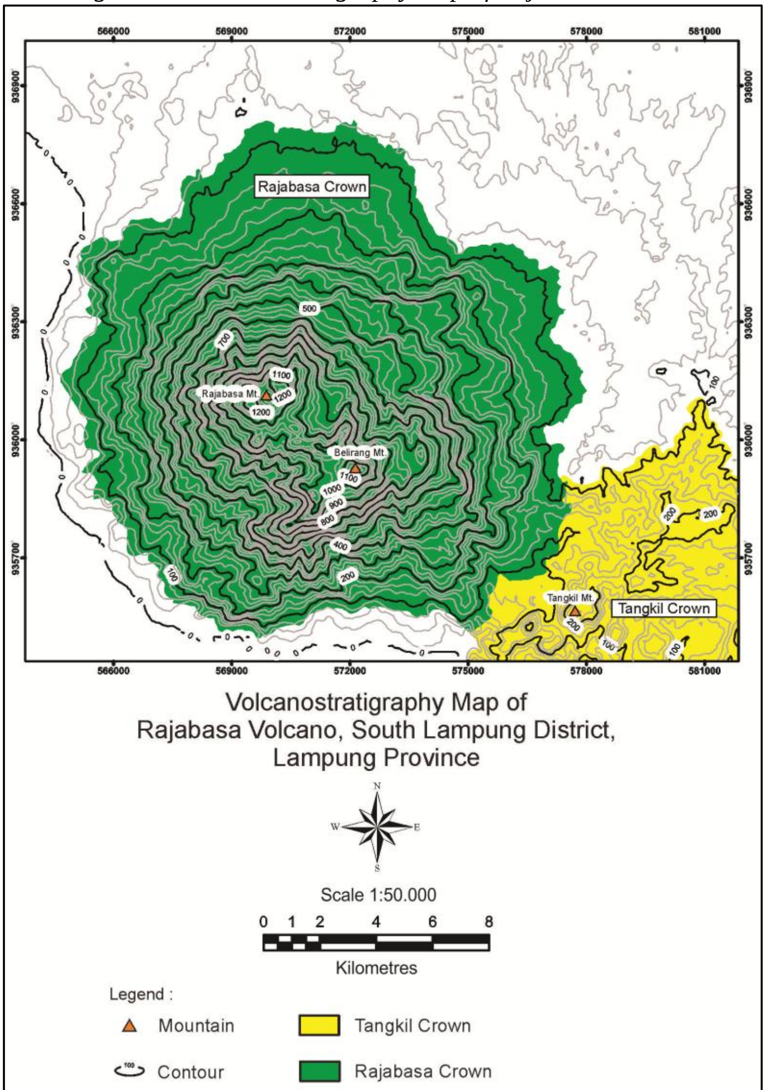
RESULTS

In this study, using volcanostratigraphic analysis with fault and fracture methods as primary data, while field data such as geological and geochemical data based on Darmawan et.al. (2015) and Hafiz et.al., (2018) as secondary data.

Volcanostratigraphy

Volcanostratigraphy identification can be used regionally and locally in an area. Regionally, it is generally applied if it includes more than one volcano, while the local area is used for a single volcano. The levels of volcanostratigraphic units from small to large are Hummock (Gumuk), Crown (Khuluk), Brigade (Bregada), Super Brigade (Mangala), and Arc (Busur). Based on vulcanostratigraphy analysis using topographic maps with a scale of 1: 50.000, it was identified that in the study area is formed two crowns and one hummock. The volcanostratigraphic unit formed consists of Rajabasa Crown and Tangkil Crown (Figure 4). Rajabasa Crown consisting of basaltic-andesitic lava, breccias, and tuffs. Tangkil Crown consisting of andecite lava with sheeting joint (Mangga et.al., 1993). According to Bronto et. al., (2016), the presence of hummock distributed in very large areas or as monogenetic cones can be long live geothermal systems. The appearance of Rajabasa Volcano based on remote sensing illustrates several composite cones. This is because the eruption center moves from the SE direction to the NW, each of which develops its own volcanic cone. According to Bronto et al., (2012), there is volcanic activity that occurs on the sides and feet of Mount Rajabasa which is referred to as the phenomenon of monogenetic volcanism. Therefore, all cones in the Rajabasa Volcanic Complex with eruption points on the sides and feet are estimated as Pre-Rajabasa Caldera. Thus, the presence of monogenetic cones in Rajabasa Volcano shows the long life of the geothermal system

Figure 4: Volcanostratigraphy map of Rajabasa Volcano

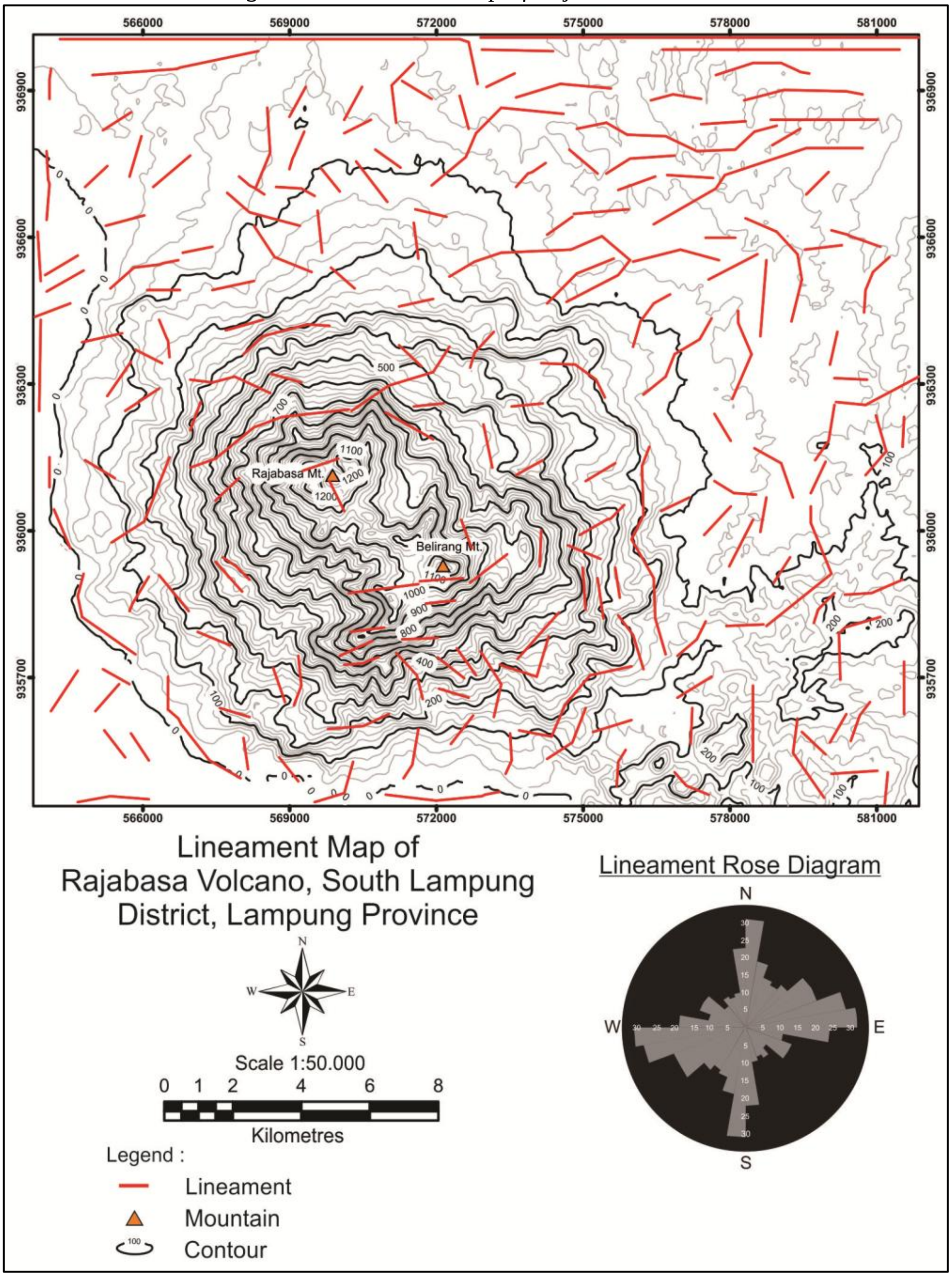


No.	Volcanostratigraphy Unit Crown	Age	Lithology
1	Rajabasa	Quarternary	Lava (basalt-andecite), breccia, conglomerate, and tuff
2	Tangkil	Tertiary	Andecite lava with sheeting joint

Fault and Fracture Density (FFD)

One of method to determine underground manifestations that have not yet surfaced is to use delineation Fault and Fracture Density (FFD). The presence of structures facilitates fluid flow from the subsurface to surface and vice versa. The more the fracture is found, made the liquid to be easier to flow. The presence of valleys and steep slopes in the morphology of the study area shows the presence of tectonic deformations. Lineament analysis is carried out on the ridge and valley sections to find out the direction and the force that works in the study area. The resulting line is the result of the interpretation carried out based on the appearance of the line surface. Lineament calculation is done by automatic extraction of 380 lineament. Lineament data is processed into a rose diagram to analyze the direction of alignment. The results of straightness interpretation show that the main trend in the developing area of Rajabasa Volcano has a west-east direction (W-E) and north-south (N-S) (Figure 5). The direction of this lineament is interpreted as a secondary structure resulting from the movement of the Sumatran Fault System's regional primary structure with the NW-SE direction. However, a small number of regions have lineament that are in harmony with the primary structure. The developed line is indicated as local faults in the study area as fluid entry and exit lines.

Figure 5: Lineament map of Rajabasa Volcano

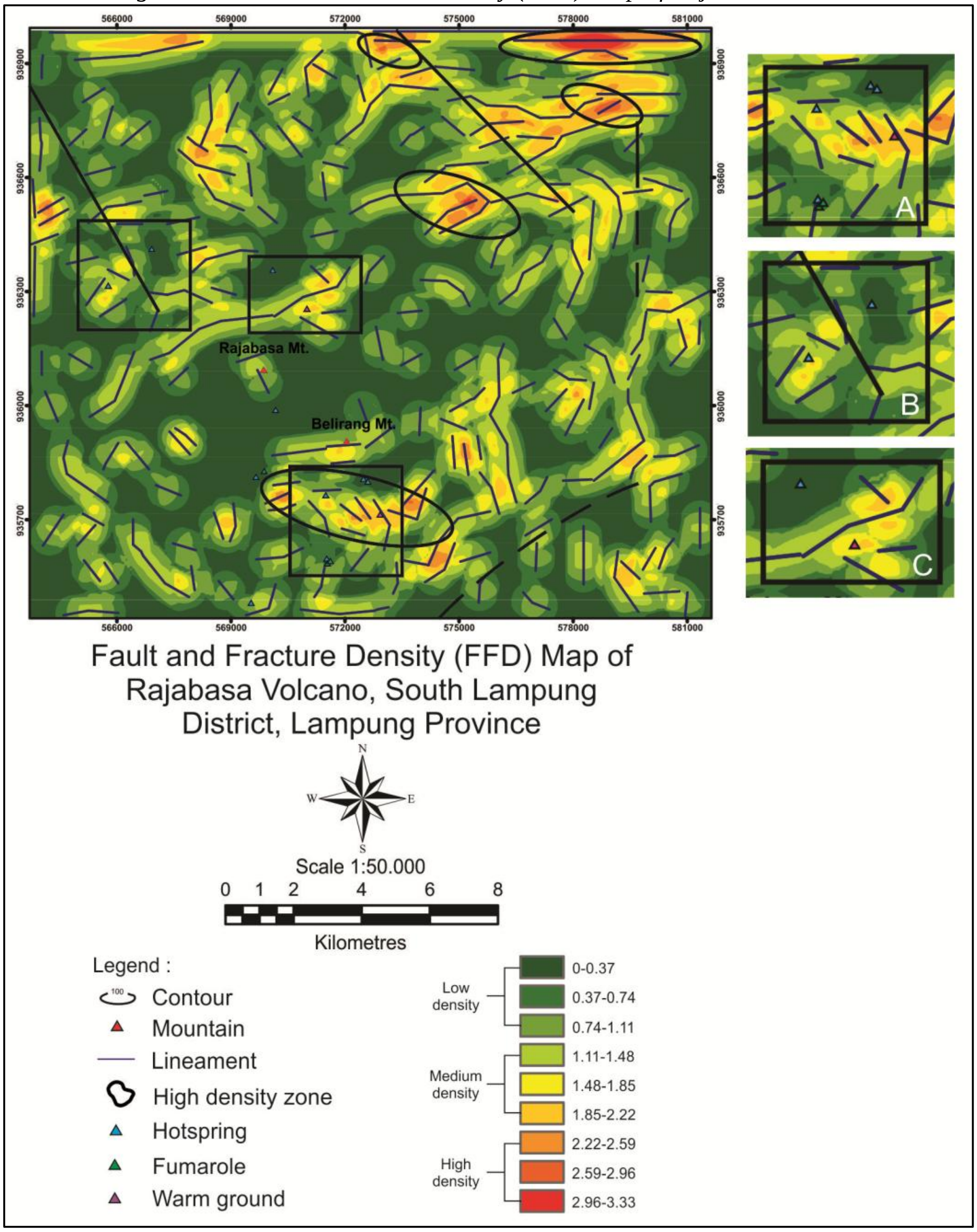


After that, lineament data associated with existing structures in the area is used to make a FFD map. The method of making FFD maps using ArcMap, Global Mapper, and Surfer software. Based on the calculation of density values using the FFD method, the Rajabasa Volcano area is grouped into three density classes, namely low density (0-1.1 km/km²) which is shown in dark green-moss green, medium density (1.1-2.2 km/km²) with light green-young orange, and high density (2.2-3.3 km /km²) indicated by orange-red color (Figure 6). High density values are in several regions, namely around Mount Belirang and in the north and northeast of Rajabasa Volcano. This area is indicated by a black oval line.

In contrast, in the western and eastern parts of Rajabasa Volcano and the western part of Mount Belirang it has a low density zone, so that geothermal manifestations are very difficult to find or far from geothermal sources.

Then, the results of the FFD zone analysis were compared with secondary data from the field observations of Darmawan et al. (2015) and Hafiz et.al. (2018). Based on the results of field observations, geothermal manifestations were found in the form of hotspring, fumarole, and warm ground. The location of geothermal manifestations is in the area with lineament. Geothermal manifestations are traversed by faults or fractures in regions with moderate to high density values indicated by black boxes. Thus, it can be seen that a good geothermal location for exploration based on FFD is at the foot of the slopes of the Rajabasa Volcano and Mount Belirang.

Figure 6: Fault and Fracture Density (FFD) map of Rajabasa Volcano



CONCLUSION

The volcanostratigraphic unit in Rajabasa has two crowns (Rajabasa and Tangkil). The presence of the crown reflecting a long lived geothermal system. Volcanic activity that occurs on the sides and feet of Rajabasa Mountain is referred to as the phenomenon of monogenetic volcanism. With the presence of monogenic cones on Rajabasa Volcano reflect the long life of the geothermal system in the area. Lineament analysis shows that the main trend is developing, namely NNE-SSW. This is interpreted as a secondary structure that results from the movement of the primary Sumatran Fault System structure that controls the entry path of the geothermal manifestation fluid Based on the FFD method, the Rajabasa Volcano area is grouped into three density classes, namely low density (0-1.1 km/km²), medium density (1.1-2.2 km/km²), and high density (2.2-3.3 km /km²). High density values are in several regions, namely around Mount Belirang and in the north and northeast of Rajabasa Volcano. This is supported by the presence of geothermal manifestations in the form of hot spring, fumarole, and warm ground at that location. In contrast, in the western and eastern parts of Rajabasa Volcano and the western part of Mount Belirang it has a low density zone, so that geothermal manifestations are very difficult to find or far from geothermal sources. Volcanostratigraphy identification and FFD method correlated with these manifestations indicate that the research area has the potential to carry out geothermal exploration development in the foot of the slopes of the Rajabasa Volcano and Mount Belirang. However, field observations are needed to validate the geothermal prospect area from the results of the analysis that has been carried out.

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