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Interpretation of Subsurface Structure Based on the Magnetic Data at Semurup Geothermal Area Kerinci

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ABSTRACT

The interpretation of subsurface structures in Semurup geothermal area has been carried out using the geomagnetic method. Data were collected in an area of 1500 m × 1400 m consisting of 160 points. The magnetic anomaly value obtained was derived from the total magnetic induction value that has been corrected by IGRF and diurnal variation, then transformed by reduction to equator and upward continuation to remove noise and separate local and regional anomalies. The results of data processing showed the total magnetic field values in the study area ranged from -1730.4 nT to 1909.0 nT. Magnetic anomalies in this study area are dominated by negative values that may be caused by demagnetised rocks (a result of hydrothermal alteration). The results of 2D modeling, it has 5 rock layers that can be classified into 3 main parts of the geothermal system The first and second layers are caprock with a depth of up to 850 meters consisting of sedimentary rock, clay, and sandstone. The third layer is indicated as a reservoir with a depth from 850 to 1450 m and is dominated by sandstone and clay alteration Hot rock in the fourth and fifth layers is dominated by basalt igneous rock and the presence of dacitic lava intrusion from the northeast of the study area at depths below 1450 m, and the Siulak fault as a outflow zone for geothermal fluid. The presence of the caprock, reservoir, hot rock, and fault zones indicates that the Semurup area has geothermal potential and is suitable for further exploration.

1. INTRODUCTION

Geothermal energy is natural heat energy originating from within the earth which then propagates to the surface by conduction and convection. Geothermal energy produces clean and renewable energy. This energy source has great potential as a solution to the national energy crisis from the use of fossil fuels (Royana, 2013).

One of the geothermal prospect areas in Indonesia is in Semurup, Kerinci Regency, Jambi. It is marked by the presence of surface manifestations in the form of hot springs which are predicted to have considerable geothermal potential, namely Semurup Hot Spring. It is also supported by the estimated reserves of 158 MWe (KESDM, 2017) and the reservoir temperature based on the geothermometer calculation results between 117^{o}C-251^{o}C which is categorized as relatively high temperature (Rezky et al., 2010). Based on measurements in the Semurup hot spring pool, the surface temperature ranged from 80^{o}C to 90^{o}C with a pH of 7 (neutral) and had great potential for development. Semurup geothermal manifestations are in the Bandan geological formation which is predicted to be dominated by volcanic sedimentary rocks and is related to the Lumut volcano in the northeast of the hot springs. (Shancharlo et al., 2020). According to the findings of earlier research investigations, the Semurup geothermal area contains geothermal energy potential that can be harnessed. However, from all these results, it is not enough to explain the geothermal system in detail. In this study, a further preliminary survey was conducted to obtain additional information in the form of rock layers and fractures causing the emergence the manifestations and subsurface structures which became important indicators in further exploration such as the drilling stage with the ultimate goal of building a geothermal power plant (DiPippo, 2016).

As a preliminary study to interpret the structure of geothermal subsurface rocks, geophysical studies are needed in areas that have surface manifestations. The geomagnetic method is one of the geophysical methods that is often used for preliminary surveys in geothermal exploration. This geomagnetic method is sensitive to vertical changes in rock layers based on rock susceptibility, namely the ability of rocks to be magnetized. Geomagnetic methods are also used to determine subsurface geological structures such as faults, folds, igneous rock intrusions, and geothermal reservoirs (Santosa, 2013). Therefore, this method is very useful in mapping surface volcanic rocks which are quite related to geothermal exploration. In addition, magnetic methods can determine geothermal prospects including mapping of hydrothermal alteration zones that show a reduction in magnetization relative to the source rock (Rusli, 2009). Based on research that has been done by Moghaddam et al. (2012), Afandi et al. (2013), Lestari et al. (2016), Hidayat et al. (2021), Mawarni et al. (2018) and Mahmudi et al. (2019) by using the geomagnetic method, the potential in the area around the geothermal prospect can be identified from negative magnetic anomalies, so this method is suitable for detecting geothermal potential as a preliminary survey. Based on these results, it can be used as supporting data and consideration for further surveys, namely complex geophysical surveys and drilling.

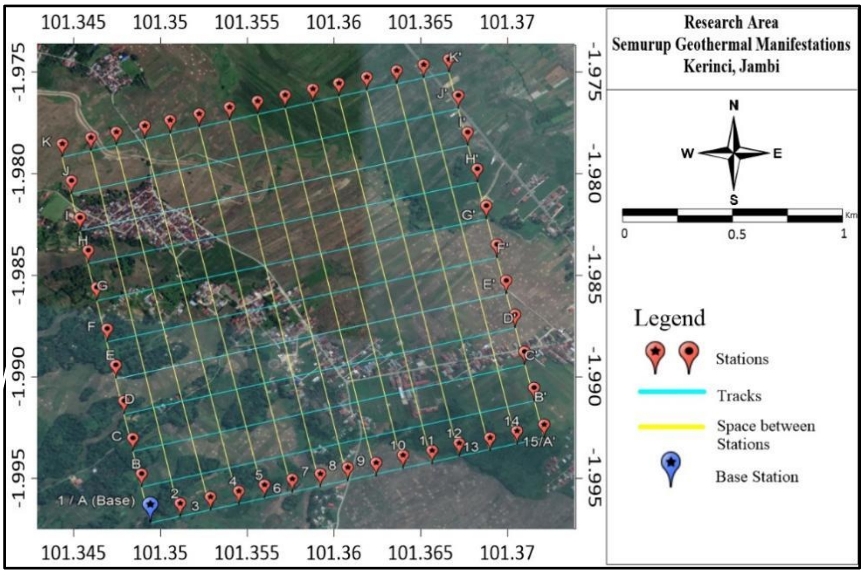

Figure 1 Data collection map

2. METHOD

2.1 Data Collection

Data collection was carried out in an area of 2.14 km^2, which has 11 tracks with a distance of 150 meters each tracks and has 14 to 16 points with a space of 100 meters as shown in Figure 1. Data retrieval used Precision Milligauss Meter GU-3001 with looping method which starts and ends at the same point (base station) on each track. Measurements at each point were repeated 4 times with the sensor facing north. Data collection was done by recording hour, longitude, latitude, elevation which is read on GPS and the total magnetic field value that appears on the magnetometer at each data collection point and base station.

2.2 Data Processing

Data processing begins with making a contour map of the total magnetic field induction obtained from the acquisition of magnetic data, then the IGRF (International Geomagnetic Reference Field) and diurnal variation correction was carried out to obtain the total magnetic field anomaly value using Equation (1).

$$\Delta H = H_p - H_{IGRF} \pm H_d \tag{1}$$

where ΔH is the magnetic anomaly, H_p is the measured magnetic field, H_{IGRF} is the theoretical magnetic field of IGRF correction, and H_d is the diurnal correction. The total magnetic anomaly value is interpreted in the contour map, then followed by the transformation of the magnetic field process. The first transformation is reduction to the equator to eliminate the magnetic dipole effect and the inclination effect. The second transformation is an upward continuity to reduce the influence of local magnetic anomalies and emphasize the influence of regional magnetic anomalies on the contour map. The regional magnetic anomaly contour map resulted from the separation of the anomaly is then sliced. The slice results are described by 2D modeling using Oasis Montaj.

3. RESULT AND DISCUSSION

3.1 Data Processing Results

3.1.1 Magnetic Anomaly

Figure 2 shows the magnetic field anomaly values ranging from -1730.4 nT to 1909.0 nT. Based on these results, it can be seen that low anomalies is in blue to green with anomaly values between -1730.4 nT and -684.5 nT, medium anomaly in yellow to orange with anomaly values between -684.5 nT and 511, 7 nT and high anomaly, namely red to pink with anomaly values from 511.7 nT to 1909.0 nT. The tendency of negative magnetic intensity is thought to be caused by heat sources, reservoirs and demagnetization of volcanic rocks below the surface. This negative magnetic intensity always occurs in geothermal studies because ferromagnetic minerals present in rock layers will lose their magnetic properties when there is an increase in temperature (Telford et al., 1990).

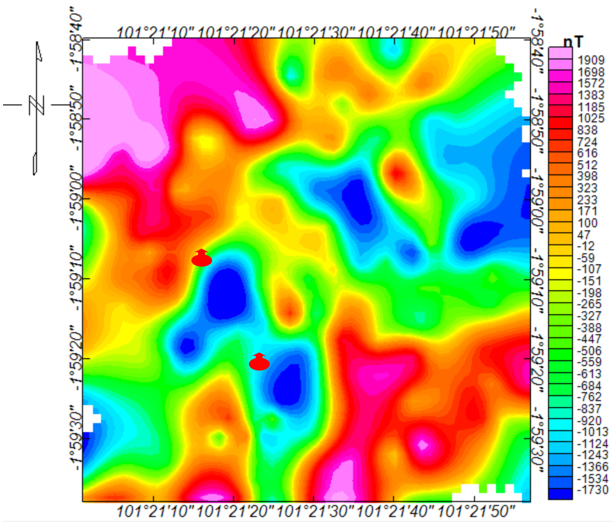

Figure 2 Magnetic anomaly contour map

The magnetic field anomaly obtained still has the influence of magnetic dipole-dipole pairs which are described in the form of positive magnetic value closures with negative magnetic value closures. Magnetic dipoles are anomalies originating from one object that is formed due to the influence of declination and inclination angles that change the direction of rock magnetization. To eliminate the influence of the magnetic dipole, it is necessary to perform reduction to equator (RTE) transformation.

3.1.2 Reduction to the Equator (RTE)

Magnetic field anomaly data after RTE process is shown in Figure 3. Low magnetic anomaly is located in the northeast, center, and southeast part of the study area. The low anomaly position moves slightly to the north after reduction to the equator. This movement is due to the research area being in the 47s UTM zone or at the geographical south latitude of the earth. The result of reduction to the equator causes changes in the value of the magnetic anomaly range from -1730.4 to 1909.0 nT to -1258.1 to 1524.7 nT. There was a decrease in the range or data range from 3639.4 nT to 2782.8 nT. The decrease in the data range is caused because after reduction to the equator the dipole effect turns into a monopole and the dominance of the anomaly value becomes negative so that the anomaly will decrease (Leu, 1982).

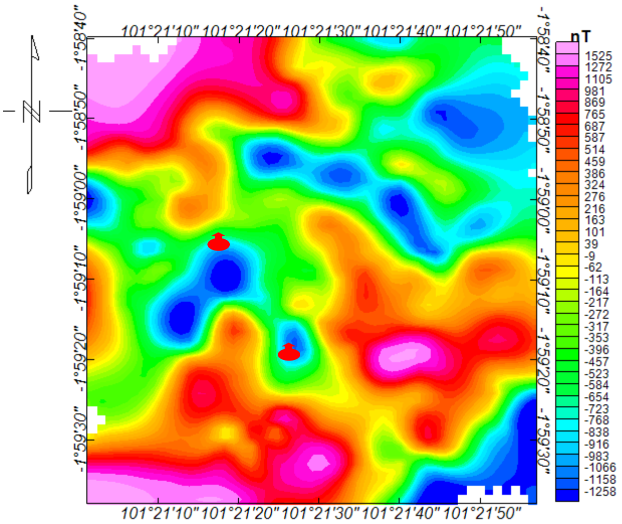

Figure 3 Reduction to equator contour map

3.1.3 Upward Continuation

Magnetic anomalies used to interpret the indications of geothermal potential are regional magnetic anomalies. This anomaly aims to depict the overall condition of the geothermal system below the surface. To reduce the influence of local magnetic anomalies and emphasize regional magnetic anomalies on the contour map, it is necessary to operate upward continuation.

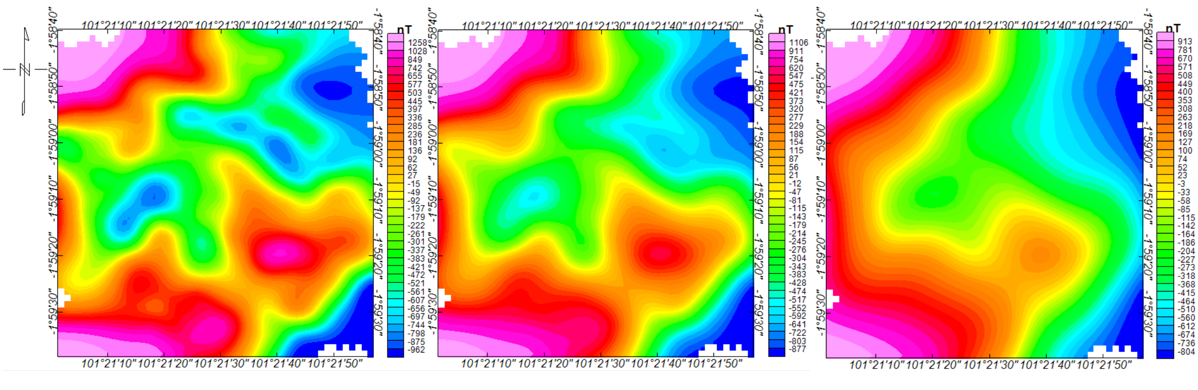

Figure 4 Upward continuation at 50 m, 100m and 200 m

The 50 m upward continuity contour map, the anomaly does not look different from the contour of the magnetic anomaly so that it does not show regional magnetic anomaly. Contour map of upward continuation with a height of 100 m describes the rock composition in the study area. The continuity contour shows a regional magnetic anomaly to interpret, besides that the local effect has not been completely eliminated. Then the results of the continuation upwards of 200 m already seem to be too dominant for regional effects, without the influence of local effects at shallow depths, so that the original anomalies on the contour map are no longer visible. Based on the results of the upward continuation in Figure 4, the continuity contour map at height of 100 m was used for 2-dimensional modeling.

3.2 Two-Dimensional Modeling

3.2.1 Slices on the contour map of an upward continuation

On the upward continuation contour map with a height of 100 meters, slices are made to describe the subsurface structure. The intensity of the magnet that has been discontinued is taken into 2 slices (A-A' and B-B') as shown in Figure 5. These two slices were chosen because they intersect the positive contour pattern and the negative contour pattern with a path length of 2075 meters and 2120 meters, respectively. These two slices also pass through surface manifestations and the main Siulak fault which is indicated by the dotted line and also based on geological data.

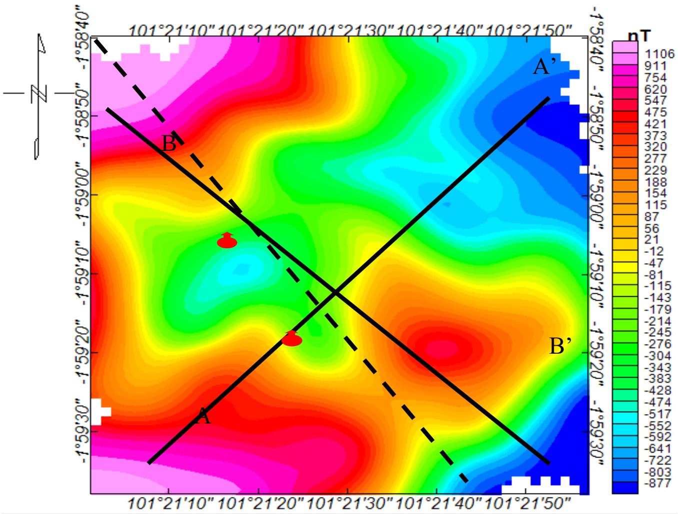

Figure 5 Slices on the contour map of upwards continuity results to 100 m

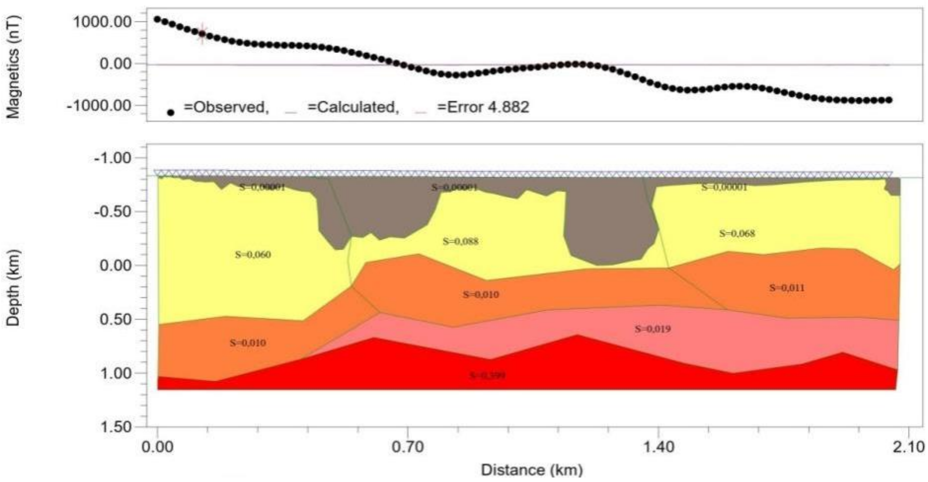

Figure 6 Subsurface 2D Model on A-A' slices

3.2.2 A-A' slice modeling

In the A-A' slice, it passes through the negative contour pattern located in the northeast to the positive contour pattern in the northwest. The parameters used in this modeling are IGRF value of 43167.76 nT, declination angle of -0.0194 degrees, inclination angle of -21.4091 degrees, maximum depth of 2000 m from ground level, and track length of 2075 m.

The modeling result in Figure 6 shows that there are 5 different layers. For the type of rock in each layer, it is necessary to add additional data in the form of geological data to reduce the high ambiguity. Table 1 can be used to describe rock conditions in geothermal areas with rock susceptibility in SI units (10^{-6}). The parameters shown are susceptibility, thickness, and geometry.

Table 1 Interpretation of the results of the A-A' slice modeling

Anomaly Geometry	Geological Data	Thickness Estimate (m)	Susceptibility Value (SI)	Interpretation
Layer 1	Alluvium	150	0.00001	Sand, silt, clay
Layer 2	Tuff sandstone	650	0.060 - 0.088	Sediment, sandstone, pyroclastic
Layer 3	Sandy tuff	600	0.010 - 0.011	Alteration of clay, sandstone, pyroclastic
Layer 4	Dacite intrusion	350	0.019	Dacitic lava
Layer 5	Basalt lava	-	0.399	Basalt igneous rock

3.2.3 B-B' slice modeling

The 2-dimensional modeling on the B-B' slice has a path length of 2120 m. This trajectory passes through a negative contour pattern in the north to a positive contour pattern in the south and also passes through a positive closure pattern in the middle.

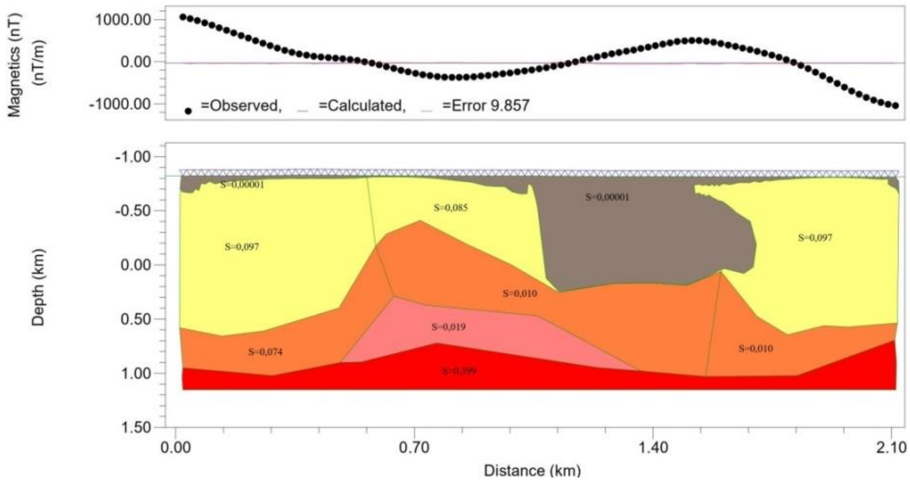

Figure 7 Subsurface 2D Model on B-B' slices

Based on the geological data and the susceptibility value of the modeling results in Figure 7, the structure of the Semurup geothermal subsurface rock can be interpreted in Table 2.

Table 2 Interpretation of the results of the B-B' slice modeling

Anomaly Geometry	Geological Data	Thickness Estimate (m)	Susceptibility Value (SI)	Interpretation
Layer 1	Alluvium	150	0.00001	Sand, silt, clay
Layer 2	Tuff sandstone	1000	0.085 - 0.097	Sediment, sandstone, pyroclastic
Layer 3	Sandy tuff	800	0.010 - 0.011	Alteration of clay, sandstone, pyroclastic
Layer 4	Dacite intrusion	300	0.019	Dacitic lava
Layer 5	Basalt lava	-	0.399	Basalt igneous rock

3.2.4 Geothermal system interpretation based on A-A’ and B-B’ slices

The result of merging the 2 subsurface modeling slices shown in Figure 8 provides a more real and clear image of the subsurface structure. Based on this model, it can explain the existence of a fault as a place for geothermal fluid outflow in the study area and form a manifestation in the form of a hot spring pool in Semurup. Geological structure in the form of faults or fracture zones is a clue for the existence the permeable zone which is an important aspect for geothermal exploration. The fracture zone is also an indication of an outflow zone or fluid outflow to the surface as a manifestation of hot springs (Suski et al., 2010).

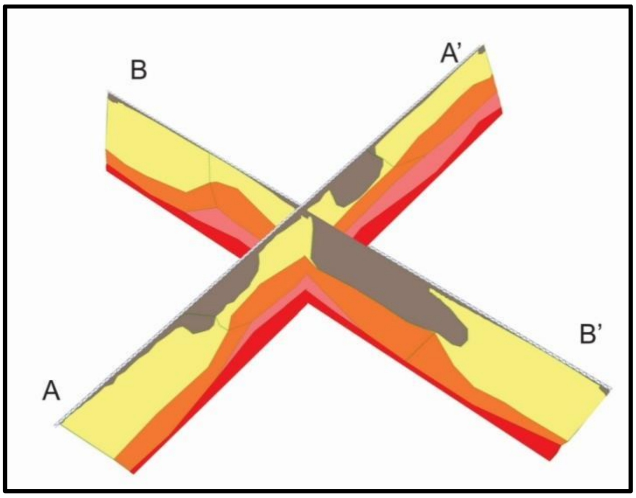

Figure 8 Combining the A-A’ and B-B’ slice models

The results of combining 2-dimensional modeling can be divided into three main parts. The first part is the near-surface layer consisting of the top two layers in the modeling AA’ and BB’ which can be interpreted as caprock. The rock structure in this layer is indicated as sand, silt, clay, sedimentary rock, and sandstone. This layer is at an average depth of 850 m. The layer below (second part) is defined as a geothermal reservoir with rocks that can be indicated as sandstone, clay alteration, and pyroclastic. In this layer there is a decrease in the rock susceptibility value as an indicator of the presence of a reservoir (Afandi et al., 2013). This layer is from 850 to 1450 m of depth, on average. The last layer that is below 1450 m depth is interpreted as hot rock consisting of dacitic lava intrusion and basaltic rock from the Bandan formation composing volcanic sedimentary rock that has a continuity with the Lumut volcano. Based on AA’ modeling, dacitic lava intrusion in this layer originates from the northeast direction so that it is closely related to the hot fluid flow from the Lumut volcano (Shancharlo et al., 2020).

4. CONCLUSION

The value of the total magnetic field anomaly in the study area ranges from -1730.4 nT to 1909.0 nT which is dominated by low anomalies. This is due to the heat source and demagnetization of volcanic sedimentary rocks. The Semurup geothermal subsurface structure is dominated by volcanic sedimentary rocks from Bandan formations and can be divided into 3 main parts, namely the cap rock in the upper layer with a depth of 850 m, the reservoir as a hot fluid to flow at a depth of 850 to 1450 m, and hot rock or igneous rock below 1450 m from the surface in the lower layer which is the source of heat. This heat source is thought to have come from the northeast in the direction of the Lumut volcano. The emergence of surface manifestations is caused by the Siulak fault that passes through the study area which functions as an outflow zone. The presence of the caprock, reservoir, hot rock, and this fault zone indicates that the Semurup area has geothermal potential and is suitable for further exploration.

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