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Magnetic Anomaly Model Interpretation of Geothermal Area in Air Putih Region, Lebong Regency, Bengkulu Province

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Abstract

Lebong Regency is located in the Sumatra Fault Zone, a relatively long dextral shear fault, causing unique structural and morphological changes around the fault zone. The Air Putih area, Lebong Regency, has geothermal manifestations in the form of hot springs that gush and flow from river banks and cliffs. In determining the subsurface structure model, magnetic anomalies were interpreted from direct measurements using two sets of Proton Precession Magnetometers (PPM) as the base and rover. The magnetic method was used to identify the subsurface structures displayed in a 2D model. The results of magnetic anomaly mapping in the study area show that 2D modelling can provide an overview of objects or rocks that cause anomalies at the study site. Based on subsurface modeling at the research site, four incisions were made, namely incisions A-A’ with a susceptibility contrast value of 0.516042 SI with hematite mineral type; in incisions B-B', it is suspected that is a mineral, namely gneiss with a susceptibility value of 0.164160 SI; incision C-C' has a susceptibility value of 0.172010 SI with gneiss rock type; and incision D-D' has a susceptibility value of 0.060604 SI, which is suspected to be a pyrite mineral. The rock types in the study area are mainly thought to be gneiss igneous rocks and the magnetic minerals quartz, pyrite, and calcite, which have different susceptibility values.

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INTRODUCTION

Lebong Regency is one of the regencies in Bengkulu Province, Indonesia. Based on geological information, Lebong Regency is located in the Sumatra fault zone, a relatively long dextral shear fault that runs from north to south of Sumatra Island. This condition causes changes in the shape of the derived structure and morphology around the fault zone (Mukazairo et al., 2020). These geological conditions have the potential to provide abundant geothermal resources in the Lebong Regency area (Lestari et al., 2022). One of the geothermal characteristics of Lebong Regency is the hot springs that gush and flow from the banks of rivers and cliffs, making Lebong Regency one of the famous tourist attractions with a hot spring area in Air Putih Village.

Hot springs in Air Putih Village, Lebong Regency, occur due to magma's intrusion into the lithosphere. This intrusion causes the heat to spread in the rock, so that the high temperature causes fractures in the rock. The high heat continues to propagate in all directions to the reservoir layer. Areas with geothermal prospects are characterized by the presence of hot springs (spring water), fumaroles (hot steam), hot mud, sublimated sulfur, and altered rocks due to increased temperature (Farid et al., 2023). In addition, a hydrothermal system has a reservoir to accumulate heat and a cap rock layer (Basid et al., 2014).

Geothermal energy is generated by magmatic processes that occur during volcanic eruptions, resulting in changes in rock temperature and magnetic properties of rocks. The magnetic properties of the rock will decrease when heated by magma. Some stones near hot springs (geothermal) have lower magnetic susceptibility values than surrounding rocks. The low magnetic susceptibility values of rocks convert minerals in geothermal systems into paramagnetic and diamagnetic minerals, called the demagnetization process. The low magnetic susceptibility values of the rock can also interpret the potential zone as a heat source and reservoir (Lestari et al., 2022). This is one of the reasons why magnetic methods can be used in geothermal prospecting.

The potential of geothermal energy is observed through the appearance of steam and hot water rising to the surface through fractures in the rock. These occurrences are observed using various geophysical methods. The most common geophysical methods used to examine the earth's subsurface structure include gravity, magnetic, and seismic. This research used the geomagnetic method to determine and collect information on the earth's subsurface structure regarding the distribution of magnetic anomalies in the geothermal source area. This method has advantages, including a high level of accuracy, simplicity and the quick identification of minerals that are close to the Curie temperature (Farid et al., 2023). Therefore, this method is very effective in observing areas or regions that have geothermal potential.

METHOD

The regional geology of the study area in Figure 1 shows that the study site is located on the Ketaun Fault Segment, which is affiliated with the Sumatra Fault. The research site is tectonically located in the Paleogene basin of Bengkulu, whereas the South Sumatra Basin is located in the same basin and entered the Neogene period (Zikri & Hastuti, 2019). Figure 1 shows that Lebong Regency has several rock formations: Tomh, Tmgr, Toms, and Tmba. Regionally, the Hulusimpang Formation (Tomh) was deposited in line with the Seblat Formation (Toms) due to the Eocene to Early Oligocene phase of volcanism. In the Early Miocene, the basin experienced a decline, resulting in the rising water table, and sedimentary material from the Seblat Formation (Toms) was deposited until the Middle Miocene (Oktarina & Sutriyono, 2022). The Hulusimpang Formation (Tomh) is an Oligocene to Miocene-aged volcanic rock formation composed of lava, volcanic breccia (volcano), and tuff with sulfide mineralization and quartz veins (Damanik., 2022). The Seblat Formation (Toms) consists of a mixture of claystone, siltstone, and siltstone with sandstone and conglomerate inserts. This formation is Middle-Early Miocene in age. In addition to sedimentary rocks, there are igneous rocks in the form of deep extrusive rocks, such as granite, which is middle Miocene in age. The Granite Formation (Tmgr) and Bal Formation (Tmba) are composed of granite rocks and volcanic rocks with andesite, volcanic breccia, and tuff (Purwanto et al., 2024).

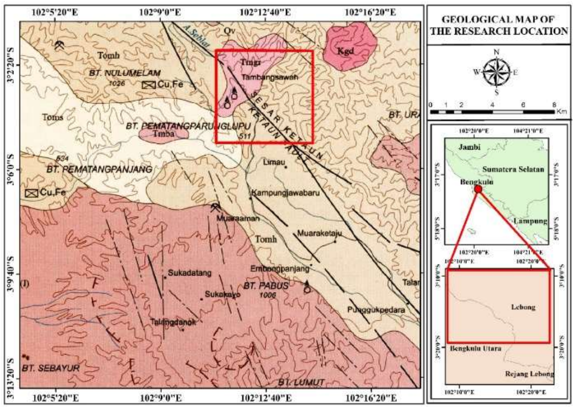

Figure 1. Regional geologic map of Lebong Regency

Research on geothermal potential in the Air Putih area, Lebong Regency, using the base and rover method, used two sets of proton precession magnetometers (PPM) consisting of sensor tubes and aluminum rods. Before taking measurements at the research location, a field survey is necessary to assess the environmental conditions and determine the measurement points that are not close to objects that produce noise, such as roads, bridges, and electric poles. At the time of measurement, one magnetic device is placed at the base to record data on daily magnetic field variations, and other devices measure predetermined measurement points (Rohim et al., 2020). In addition, a workbook is also needed to record the day, date, time, coordinate points, and total magnetic field strength value, as well as a geological compass and Global Positioning System (GPS) as the north direction of the earth's magnetic field and PPM sensor.

The research data were collected in an area of 16,000 m^2 at the coordinates 3°3'0.981 S 102°10'58.048 E, which can be seen in Figure 2. The research area is a forest area that passes through a river with a fairly steep topography. The study area is 16,000 m^2, with a spacing between points of 100 to 200 meters and 49 magnetic stations. Data collection includes latitude, longitude, altitude, time, and geomagnetic variation in nano-Tesla (nT).

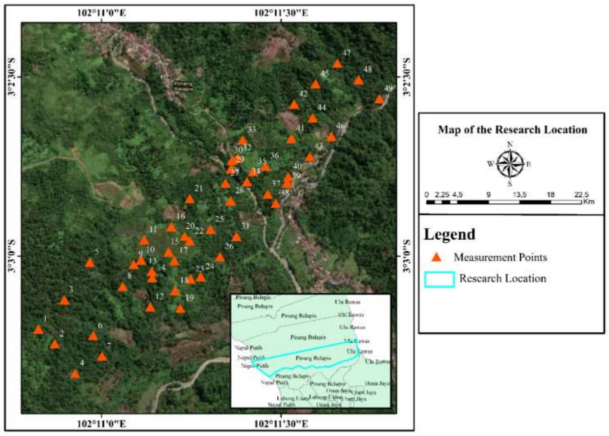

Figure 2. Map of the research location

RESULTS AND DISCUSSION

Interpretation of Total Magnetic Anomaly

The total magnetic anomaly data in the study area was corrected by adjusting the daily variation and International Geomagnetic Reference Field (IGRF) values with average measurement data. These values were then mapped to determine the distribution of magnetic anomalies in the study area. Figure 3 shows the contour pattern of the total magnetic anomaly with positive and negative clusters. The anomaly contour map formed is a magnetic field that is still mixed between local and regional anomalies. This indicates that the magnetic anomaly is a dipole, and it appears that the local anomaly still affects the total anomaly in the topography. Figure 3 shows significant differences in magnetic intensity values characterized by positive and negative anomalies. Positive signs indicate high and adverse signs indicate low magnetic anomaly values at the measurement location. The lowest magnetic field anomaly value is -320 nT, marked in dark green, while the highest is 529 nT, marked in red. The opposing magnetic anomaly value is due to heat sources, reservoirs, and demagnetization effects on rocks. When there is an increase in temperature, the ferromagnetic minerals in the rock layer will lose their magnetic properties. As a result, negative magnetic anomalies often occur in geothermal case studies (Hidayat et al., 2021). The total magnetic field anomaly contour map is in a state where the topography is uneven and still influenced by local anomalies. Therefore, residual and regional magnetic field anomalies must be separated using MagPick software (Junaedy et al., 2016).

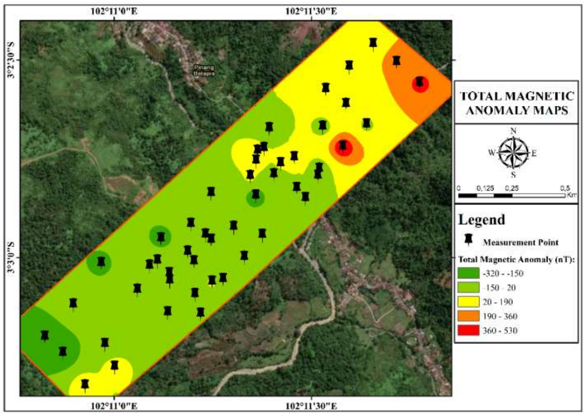

Figure 3. Map of magnetic anomaly distribution

Upward Continuation

The upward continuation process is carried out to distinguish and separate between residual (local) anomalies and regional anomalies, and to determine the condition of the subsurface structure and the influence of the total magnetic field at a certain depth based on the measurement results at the research site. The upward continuation process can be done by increasing the elevation value of the observation field or measurement location (Susanto et al., 2017). In the upward continuation process, the reduction results values and regional effect at the study site. The upward continuation used a trial-and-error method from 100 meters to 500 meters above sea level. The result of the experiment shows that the elevation value or height that shows the local anomaly pattern tends to be stable at an altitude of 300 meters above sea level. At this altitude, there is no sign of weakned magnetic dipole pairs.

The residual magnetic anomaly value ranges from -240 nT to 387 nT. Different rocks can cause this variation in the anomaly value under the surface. Meanwhile, the regional magnetic anomaly measured in the research area is -98 nT and 117 nT. The results of the residual and regional magnetic anomalies are in Figure 4.

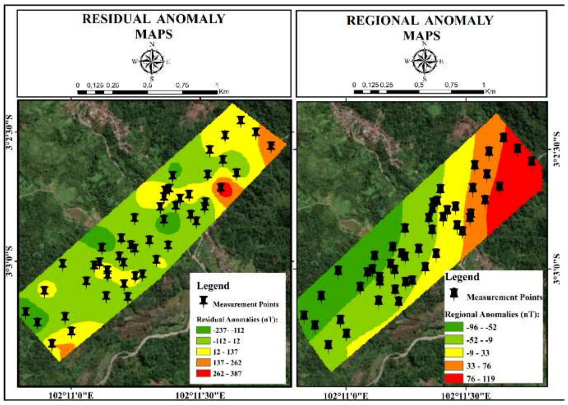

Figure 4. Map of residual and regional magnetic anomalies at 300 m height

Reduction to the Pole

The magnetic field anomaly at the measurement location is still a magnetic dipole. Therefore, to facilitate qualitative interpretation, a reduction correction to the poles must be made so that the earth's magnetic field is not dipole (Rohyati et al., 2019). Using MagPick software, we reduce the residual anomaly contour map to the polar direction, which minimizes the resulting magnetic field anomaly map and turns the magnetic field anomaly value into a monopole (Ariani et al., 2013) . When the reduction process is complete, there is a significant difference between the local magnetic anomaly values before the reduction to the polar direction. The magnetic value increases to a very high value of 707 nT, and the lowest magnetic anomaly value is -689 nT. Then, the anomaly contour map obtained from the reduction to polar transformation was created using ArcGIS software. The contour map was used for the digitization and slice process in Surfer13 software (Figure 5).

The digitization process aims to determine the boundaries of the initial and final coordinates of the sliced contour map. Meanwhile, the slices cut from the results of the digitization process are used to identify rock types and subsurface structures. Furthermore, modeling is done using Mag2dc software by entering the inclination, declination, coordinates of the research location, and the magnetic anomaly value of the measurement location (Abdullah et al., 2014). This modeling is carried out using the trial-and-error method, which requires researchers to test several times while modeling the structure of rock layers (Ahmad et al., 2019), namely by matching two curves: the curve of the observed magnetic anomaly value in the form of a green dotted line, and the calculated anomaly curve, in the form of a solid black line (Zulfitrah et al., 2018).

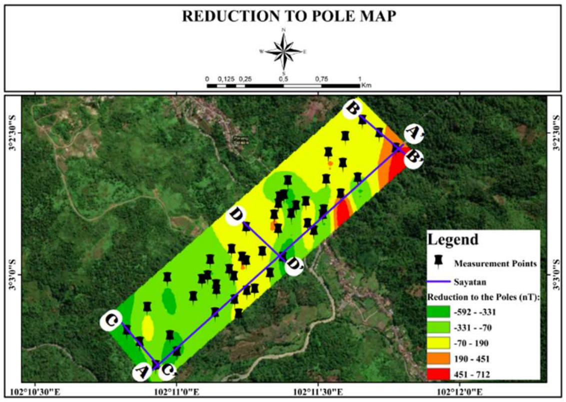

Figure 5. Magnetic anomaly contours after reduction to poles

2D Modeling

The magnetic anomalies are interpreted by profiling the A-A' incision, as seen from the processing results in Mag2DC, which obtained five bodies and a misfit value of 139.96, as shown in Figure 6. For this 2D modeling, three types of rocks are used, each with different susceptibility values. Based on Table 1, the rock mineral obtained from Body 1 is considered the hematite mineral, estimate to reach a depth of 30 meters and with a susceptibility value of 0.516042 SI.

Table 1. Magnetic susceptibilies of various rocks and minerals (Telford, Geldart dan Sheriff, 1990).

Type	Susceptibility x 10^3 (SI)		Type	Susceptibility x 10^3 (SI)	
	Range	**Average**		**Range**	**Average**
Sedimentary			*Minerals*		
Dolomite	0-0.9	0.1	Graphite		0.1
Limestones	0-3	0.3	Quartz		-0.01
Sandstones	0-20	0.4	Rock salt		-0.01
Shales	0.01-15	0.6	Anhydrite, gypsum		-0.01
Av. 48 sedimentary	0-18	0.9	Calcite	-0.001- -0.01	
			Coal		0.02
Metamorphic			Clays		0.2
Amphibolite		0.7	Chalcopyrite		0.4
Schist	0.3-3	1.4	Sphalerite		0.7
Phyllite		1.5	Cassiterite		0.9
Gneiss	0.1-25		Siderite	1-4	
Quartzite		4	Pyrite	0.05 - 35	1.5
Serpentine	3-17		Limonite		2.5
Slate	0-35	6	Arsenopyrite		3
Av. 61 metamorphic	0-70	4.2	Hematite	0.5-35	6.5
			Chromite	3-110	7
Igneous			Franklinite		430
Granite	0-50	2.5	Pyrrhotite	1-6000	1500
Rhyolite	0.2-35		Ilmenite	300-3500	1800
Dolorite	1-35	17	Magnitite	1200-19200	6000
Augite-synite	30-40				
Olivine-diabase		25			
Diabase	1-160	55			
Porphyry	0.3-200	60			
Gabbro	1-90	70			
Basalts	0.2-175	70			
Diorite	0.6-120	85			
Pyroxenite		125			
Periodite	90-200	150			
Andesite		160			
Av. Acidic igneous	0-80	8			
Av. Basic igneous	0.5-97	25			

At a depth of 9 to 36 meters, there are suspected pyrite minerals in this layer, namely in Body 2, which has a susceptibility value of 0.08619 SI, and also in Body 3, which has a susceptibility value of 0.069417 SI. Then, in Body 4, which has a susceptibility value of 0.038962 SI, it is suspected that quartz minerals are located 25 to 70 meters below the surface. In Body 5, located at a depth range of 74 meters, it is also suspected that there is a quartz-type igneous rock mineral with a susceptibility value of -0.781833 SI.

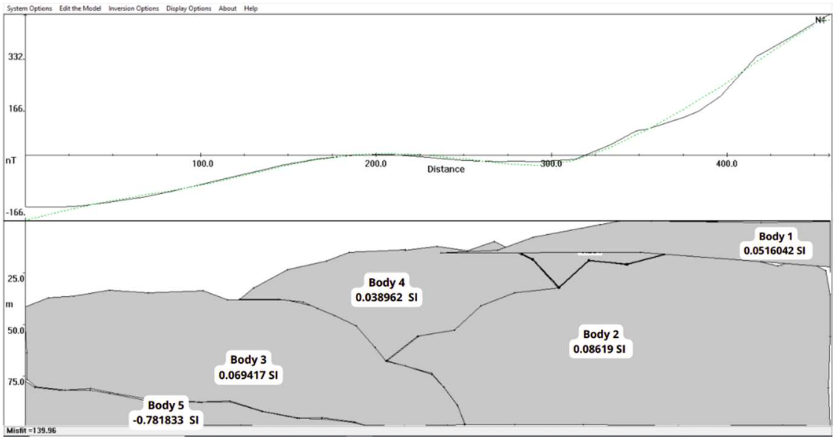

Figure 6. Modeling results of incision A-A'

The B-B incision profile modeling in Figure 7 has a mismatch of 165.54. Five bodies were obtained from the modeling. Based on the modeling results in this layer, there is a rock type in the form of gneiss, which is the result of the metamorphosis of igneous rocks in high temperatures and pressures (Irnissa et al., 2023), as indicated by Body 4, which has a susceptibility value of 0.111731 SI, and Body 5, which has a susceptibility value of 0.164160 SI, which is estimated to be at a depth of 10 meters to 76 meters below the surface. From a depth of 4 to 35 meters, it is suspected that there is a mineral in the form of calcite, with a susceptibility value of 0.069158 SI, indicated by Body 1. Body 2 and Body 3 are suspected to be quartz-type minerals estimated to be at a depth of 39 meters, with a susceptibility value range between -0.148844 SI to -0.152772 SI.

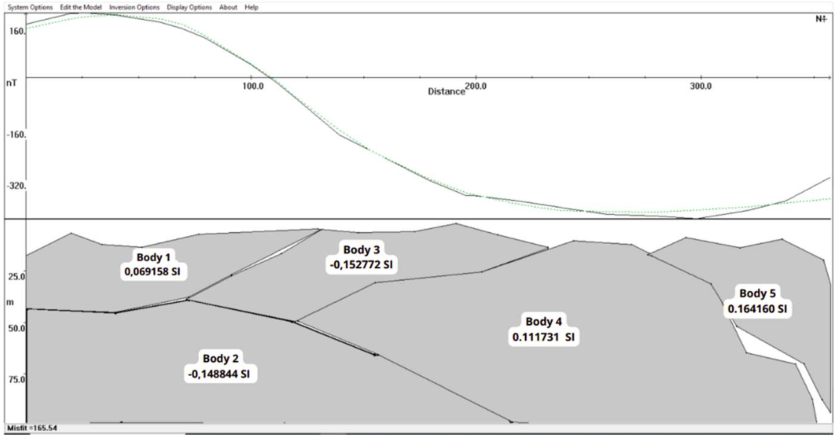

Figure 7. Modeling results of incision B-B'

A mismatch of 120.67 is seen in the profile of incision C-C' in Figure 8. According to the modeling results, the structure of this incision is comprised of the same five bodies as the previous incision. The modelling of this incision indicates the presence of gneiss-type rocks, estimated at a depth of 29 meters below the surface. It has a susceptibility value of 0.172010 SI, as shown by Body 1. In addition, it is suspected that calcite minerals are constituents of igneous rocks, as shown by Body 4, with a susceptibility value of -0.001772 SI at a depth of 11 to 65 meters below the surface. Then, Body 2, which has a susceptibility value of -0.037085 SI, is suspected to be a quartz mineral. Body 3 has a susceptibility value of -0.053549 SI, and Body 5 has a susceptibility value of -0.026648 SI. These bodies are estimated to be between 3 to 22 meters below the surface.

Three bodies make up the modeling of the D-D incision profile in Figure 9, which has a 149.49 misfit. Modelling the incision in this layer shows that the rock in Body 1 has a susceptibility value of -0.060573 SI, per the modeling results, and is thought to contain quartz minerals located at a depth of 12 meters. Then Body 3, which has a susceptibility value of -0.011213 SI and is located at a depth of 15 meters, is also suspected to be a mineral in the form of quartz. Then in Body 2, which is at a depth of 50 meters and has a susceptibility value of 0.060604 SI, is it thought to be a pyrite mineral.

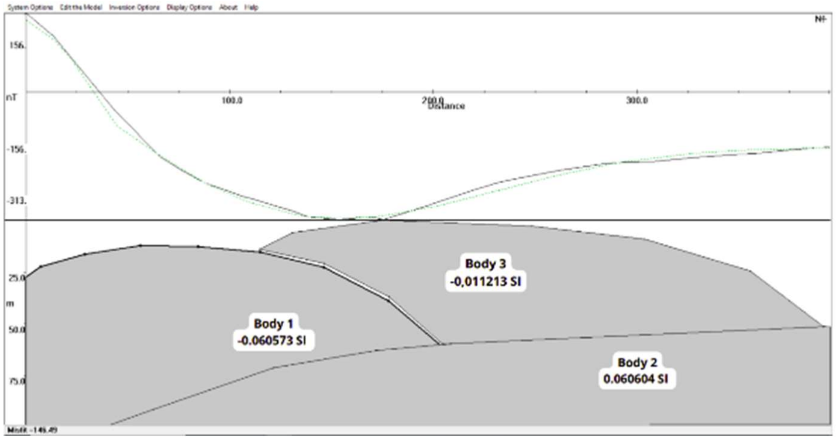

Figure 9. Modeling results of incision D-D'

The primary rock types of Lebong Regency geology include basaltic, andesite, and granite. The geological setting created by these igneous rocks facilitates mineralization from hydrothermal solutions (Lestari et al., 2022). The process of forming minerals by the interaction of hydrothermal solutions with rocks in the earth's crust is known as hydrothermal mineralization. As a result of these interactions, primary minerals are transformed into secondary minerals, a phenomenon known as hydrothermal alteration (Salaamah et al., 2014). Primary minerals are added to and weathered to create secondary minerals. Primary minerals, on the other hand, crystallize during the magma-freezing process (Bali et al., 2018). Rocks that have undergone alteration due to high pressure and temperature are said to have negative susceptibility values. These strata, considered beneath the geothermal vapor pool and geothermal host rock, have a very high ratio of secondary minerals.

CONCLUSION

The results of magnetic anomaly mapping in the Air Putih area of Lebong Regency show that 2D modeling can provide an overview of objects or rocks that cause anomalies at the research site and interpret the rock structure below the surface. Magnetic methods are used to identify underground structures displayed in 2D models. The rock types in the research area are mostly igneous rocks in the form of gneiss, and magnetic minerals of quartz, pyrite, and calcite, which have a different susceptibility values.

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