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Subsurface Interpretation of the Panjang Fault Area, Lampung, Based on Geomagnetic Method

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Abstract

Research on the area along the Panjang Fault - Lampung, the area from the Teluk Betung to Tanjung Karang Barat area using the 19-T GSM PPM tool with base rover acquisition on 2 tracks 2 kilometers apart obtained 40 acquisition points with a spacing of 0.3 kilometers. This study aims to determine the type of lithology and subsurface rock structure by utilizing the susceptibility value of rocks from magnetic anomalies. In the process of processing magnetic anomaly data, upward continuation is carried out as high as 350 m which is intended to reduce the total anomaly with the upward anomaly results so that a residual anomaly is obtained. Next, make a 2D subsurface model on the incision A - B in the residual anomaly map. Based on the results of qualitative interpretation, the total magnetic anomaly of the research area illustrates positive to negative anomaly values with a tighter contour pattern that indicates the presence of a fault structure. While based on quantitative interpretation, the 2D modeling in incision A - B shows a susceptibility value of 0.100 cgs which can be identified as breccia tuff rock, a susceptibility value of 0.0391 cgs is thought to be rhyolitic tuff rock, pumice tuff rock, and sandstone tuff, and a susceptibility value of 0.150 cgs is a rock from the intrusion of Mount Betung in the form of andesite-basalt lava. In addition, rocks with a susceptibility value of 0.0024 cgs are metamorphic rocks. The correlation between 2D modeling and regional geology is seen in the research area, which is in the Tarahan Formation (Tpot), which is suspected to be a fault structure in the Bumi Waras area with a strike direction of NW - SE which is the course of geothermal manifestations or minerals.

Keywords: local magnetic anomaly; magnetic susceptibility; Panjang Fault.

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Introduction

Faults are areas of interest for mineral, geothermal and oil and gas exploration, because they are the pathway for hydrothermal fluids to the surface, and the pathway for oil and gas migration to the reservoir. Bandar Lampung City is a densely populated area located at the southern tip of Sumatra Island (Mangga et al., 1993). Based on the geological map of Tanjungkarang Sheet, Bandar Lampung City is affected by several active faults. One of them is the Lampung Fault with a northwest-southeast direction, which is one of the faults located in the Bandar Lampung area in Panjang District, Bandar Lampung City to Natar District, South Lampung Regency. Lampung Fault also divides Bandar Lampung City with morphology along the fault in the form of slopes to steep hills.

The magnetic method is a geophysical method that works to utilize the magnetic properties of rocks and materials under the earth's surface. The data measured in this method is the value of the magnetic field in each area. Through IGRF correction and daily variation correction, anomalous magnetic field values will be obtained. This anomalous magnetic field value is then mapped in the magnetic anomaly contour. From the mapping results, the geological structure of the survey area can be identified (Fashihullisan et al., 2014). Therefore, based on this, the fault structure in the Bandar Lampung area can be identified by the magnetic method. For many years, magnetic prospecting has been used to investigate the subsurface structures associated with mineral deposits (Ben et al., 2021).

Magnetic method is a geophysical method based on the measurement of magnetic field intensity variations (Abdullah & Sunaryo, 2014). Magnetic surveying is a geophysical technique that can provide valuable insight into the Earth's crust by detecting differences in magnetization (Nicolosi et al., 2016). The source of the earth's magnetic field is generally divided into, (i) the intensity of the earth's main magnetic field (main field); (ii) the intensity of the external magnetic field (external field) and (iii) the intensity of the anomaly magnetic field (Nuha ABA et al., 2014; Rasimeng et al., 2020).

The magnetic anomalies are always superposition of potential fields from sources of different depths and scales. The potential fields can be decomposed in the spatial or frequency domain to give more specific geological interpretations, and this process is generally termed as the potential field separation (Yang & Li, 2023). The source of the magnetic anomaly is a dipole field that produces positive and negative anomaly pairs. The reduction process to the polar direction refers to changes in the magnetic field in the vertical direction, as seen from the North Pole of the Earth to facilitate qualitative interpretation (Setiadi et al., 2016). So, the author uses this method to produce more accurate modeling of subsurface structures and can show the rock layers as well. The total magnetic field anomaly data at the measurement location is still in the form of magnetic dipoles. Therefore, it is necessary to make a reduction correction to the pole. This dipole anomaly is transformed to the earth's magnetic north pole by changing the direction of the anomalous magnetic field slope to 90˚. After reduction to the poles, the total magnetic field anomaly value becomes monopole (Hiden et al., 2023). Prominent magnetic field anomalies are often referred to as local magnetic fields (crustal fields) because these magnetic fields are generated from rocks with strong magnetic mineral content in the earth's crust (Heningtyas et al., 2020).

Magnetic anomaly characteristics, such as direction of maximum extension and gradient, can reveal information about the direction, dip, and strike of tectonic structures, such as faults and dike swarms (Hinze et al., 2013; De Ritis & Chiappini, 2023). In addition, magnetic anomalies can also reveal the location, extent, and depth of crustal volumes with very low or fully demagnetized magnetization (Bouligand et al., 2014; Tontini et al., 2019). The magnetic anomalies obtained still contain two regional and residual anomalies, so they need to be separated (Ilapadila et al., 2019). Regional – residual anomaly separation is a very important step. Therefore, an appropriate data filter is needed to obtain accurate data results for better interpretation. There are several methods used to separate the two anomalies. However, the most used method is the upward continuation method. Previous research using the upward continuation method such as Hiskiawan (2016) and Nurdin et al. (2017).

Based on research conducted by Heningtyas et al. (2017), it states that knowing the arrangement of rock formations around the fault line and knowing the fault line based on geomagnetic modeling of magnetic field anomaly distribution patterns. Furthermore, research by Sulandari et al. (2023) conducted in the Lampung - Panjang Fault can be identified using magnetic methods with the separation of regional and residual anomalies and the Filter Horizontal Derivative (FHD) process for the interpretation process. Then the Bandar Lampung area is categorized as a landslide-prone area because the constituent rocks have many fractures that make the slope unstable. The Bandar Lampung area also has many faults that cause many hills with steep morphology (Agustina et al., 2020). Based on the results of the research that has been done before, this research uses geomagnetic method which aims to determine the variation of magnetic field and subsurface interpretation in Lampung Fault area, especially around Teluk Betung to Tanjung Karang Barat, Bandar Lampung City. By utilizing the physical properties of rocks in the form of susceptibility values, to find out types of lithology or rocks are under the surface of the Lampung Fault area. Geophysical data from the results of research using magnetic methods in the form of rock susceptibility anomaly values that can be a target object to determine what types of minerals are in the subsurface and can determine the structure or lithology below the surface of the research area.

Materials and Methods

Geographical Location

Geographically, the research location is in the Bandar Lampung area between 50º20'-50º30' N and 105º28'-105º37' E, precisely in Teluk Betung District to Tanjung Karang Barat District, Bandar Lampung, Lampung Province.

Geological Setting

Geologically, the research location generally has rock outcrops along the Lampung fault area in the form of andesitic-basaltic rocks shown in Figure 1.

The lithological contact of rock units and formations exposed on the surface along the Lampung fault consists of the Tarahan Formation (Tpot), Campang Formation (Tpoc), Waygalih schist rock unit (Pzgs), Young Volcanic deposits of G. Betung (Qhv(b)) and Lampung Formation (QTl). While the lithology of each formation or rock unit is; Lampung Formation (QTI) in the form of stony tuff, rhyolitic tuff, solid tuff, tuffaceous claystone, and tuffaceous sandstone; G. Betung Young Volcano Unit (Qhv(b)) in the form of lava (andesite-basalt), breccia and tuff; Alluvium (Qa) in the form of crusts, pebbles, sand, clay, and peat. Tertiary rocks are composed of volcanic products and intrusive rocks. It consists of the Campang Formation (Tpoc) with the lower part being a mixture of mudstone, shale and compact tuff, the upper part is a breccia of various materials with sandstone and siltstone inserts; Tarahan Formation (Tpot) in the form of compact tuff, breccia with lentil inserts; Pre-Tertiary rocks are composed of bedrock in the form of metamorphic rocks of the Inseparable Kasih Mountain Complex (Pzg) in the form of Pelitan schist and a little gneiss; and the Waygalih Schist rock unit (Pzgs) in the form of green amphibole schist, diorite orthogenes amphibolite (Mangga et al., 1993; Mulyasari et al., 2018).

Data Acquisition

Acquisition with a line system where magnetic field measurements at each location on the surface consist of two tracks with about 300 meters between each measurement point, and the number of measurement data is 40 measurement points (Figure 2).

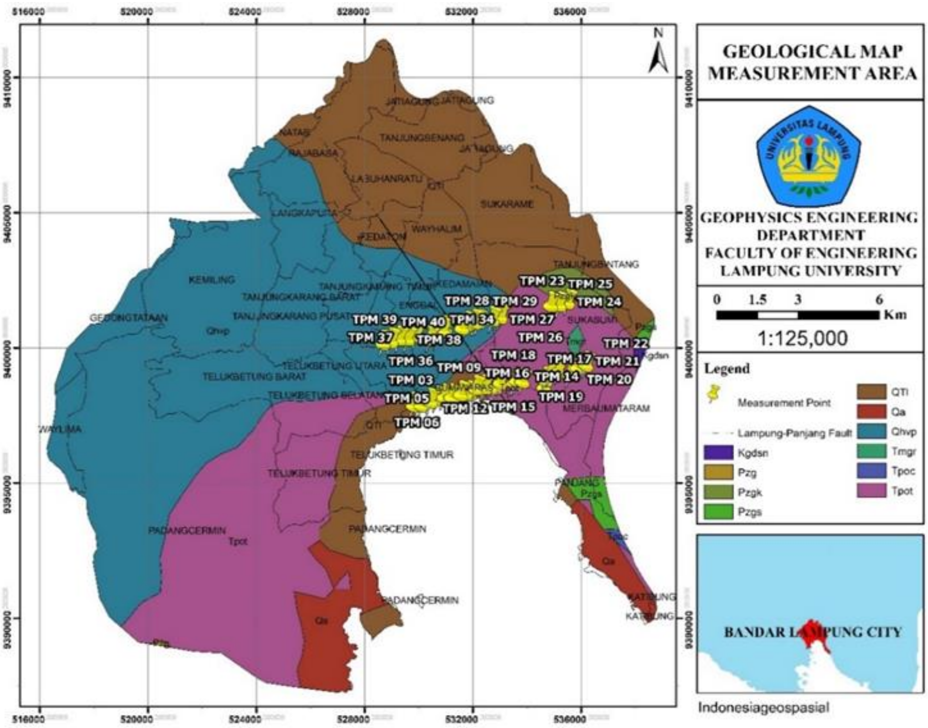

Figure 1. Geologic map of Bandar Lampung and surrounding areas (modified form Mangga et al., 1993; Mulyasari et al., 2018).

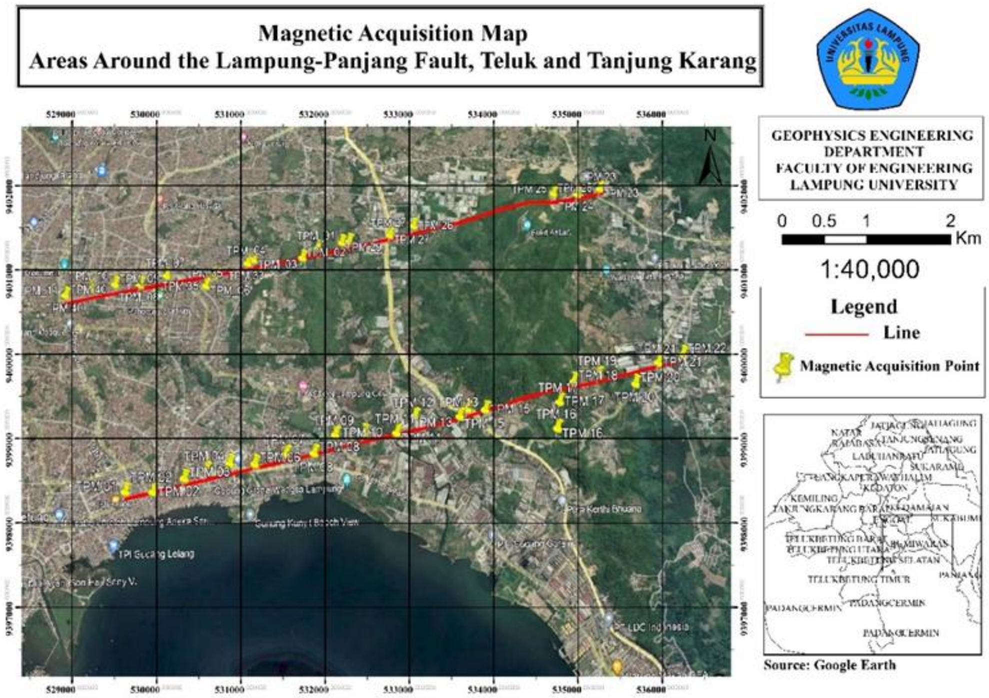

Figure 2. Location map of measurement points.

The line-type acquisition system will get data that has a regular and fixed distance. Magnetic field measurements use the GSM-19T Proton Precession Magnetometer (PPM) tool for the rover and base station respectively. Base station data measurements are placed in a noise-free area to get the optimal tool reading value. While the rover measurement data is carried out mobile in accordance with the acquisition design that has been made as shown in the magnetic acquisition map. The reading value of the tool obtained from the acquisition in the field is then calculated to obtain the magnetic anomaly value.

Data Processing and Analysis

Data processing in this study goes through several stages, the first of which is making IGRF (International Geomagnetic References Field) through the BMKG website https://www.bmkg.go.id/geofisika-potensial/kalkulator-magnet-bumi.bmkg and correction of daily variations. The second stage calculates magnetic anomalies from total magnetic field data in the research area. With the following equation:

$$HA = H_{total} - H_{IGRF} \pm \Delta H_{\text{diurnal}} \quad (1)$$

Description:
HA : Magnetic Anomaly
$\Delta H_{diurnal}$: Diurnal Variation Value
H_{total} : Total Magnetic Field Value
H_{IGRF} : IGRF Value

The next stage is the upward continuation process where this process is carried out to eliminate residual anomalies by looking at the tendency of the contour pattern of the continuation results (Fikar et al., 2019). Continuation is carried out as high as 350 m which is used to eliminate local magnetic effects and can facilitate the interpretation process if a separation is made between regional and residual anomalies (Regita et al., 2022). To get the residual anomaly using the following equation:

$$\text{Res} = T_{Anomaly} - T_{Upward} \quad (2)$$

Description:
Res : Residual Anomaly
$T_{Anomaly}$: Total Anomaly
T_{Upward} : Anomaly of Upward Result

Then the Reduce to Pole process localizes the residual anomaly results which are transformed from dipole to monopole form for further analysis of magnetic patterns using 2-dimensional modeling. This modeling is seen based on the high-low value of magnetic anomalies in the study area so that areas with anomalies with drastic high-low changes can be seen to determine fault and intrusive areas (Fashihullisan et al., 2014). Based on the magnetic field anomaly contours, quantitative interpretation can be done using 2D modeling, by matching the residual anomaly curve based on the trajectory data selected from the residuals. magnetic field anomaly map with the model curve which is done iteratively (Efendi et al., 2016). This processing stage can be seen through the following flowchart: (Figure 3).

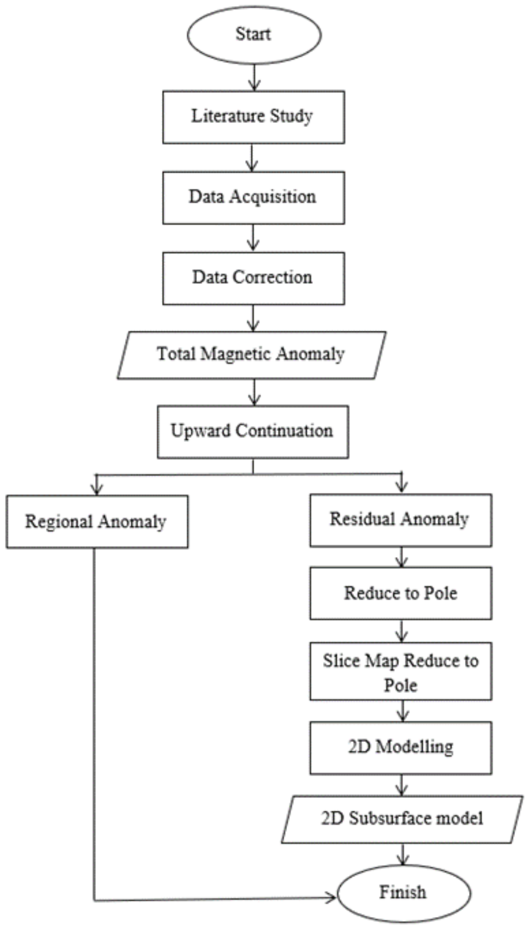

Figure 3. Research flowchart.

Results and Discussion

This study began with an acquisition in the Bandar Lampung area, Lampung. Magnetic acquisition was carried out with the help of PPM (Proton Precession Magnetometer) GSM-19 T Magnetometer tool and assisted with Garmin GPS tool to determine and plot the acquisition point. Acquisition points were made as many as 40 points with line acquisition technique, this acquisition area stretches from Teluk to Tanjung Karang which cuts the Panjang Fault area - Lampung.

Data processing after the acquisition process is carried out by finding the value of the magnetic field anomaly by carrying out the correction process of the magnetic data obtained. However, before that, it is necessary to correct the daily variation using the time interpolation method from the rover and base station where the base measurements are made with a time interval of 900 seconds or 15 minutes. So that the results of the magnetic field can be seen in Figure 4.

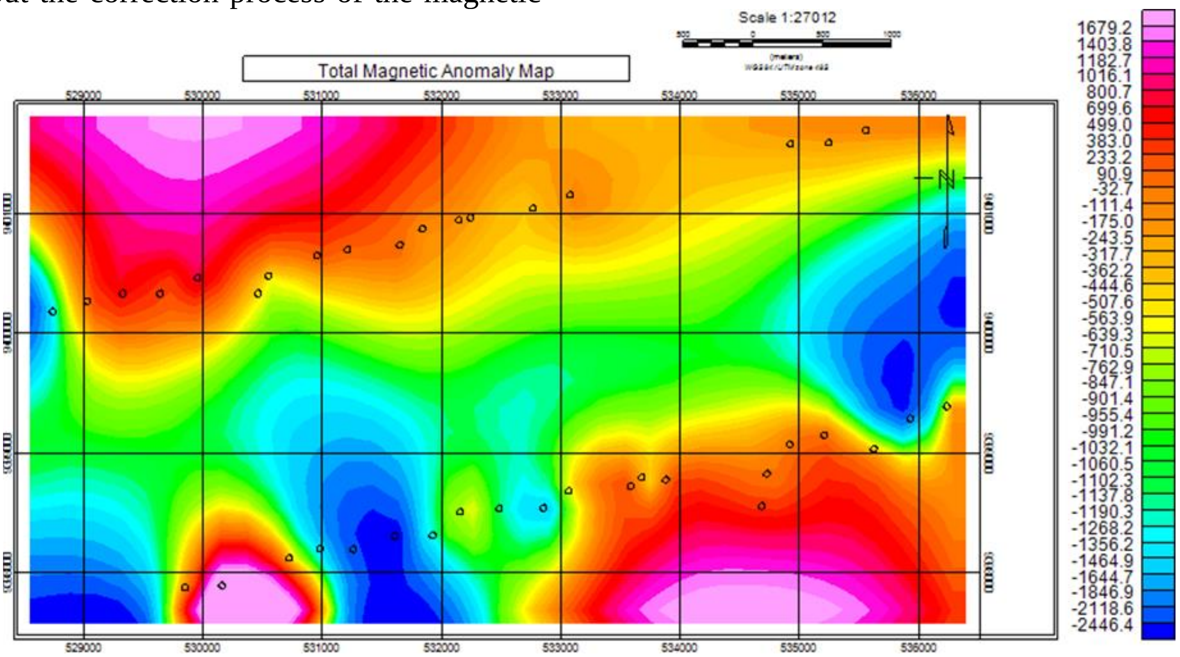

Figure 4. Contour map of the total magnetic field anomaly of the study area.

The magnetic field anomaly map made is lifted by the upward continuation method as high as 350 meters with the help of the Ms Fortran PS 4.0 program by entering the script that has been made, but before that changes are made to the nodes on the magnetic field anomaly map which n2 for the Fortran program to be used, n2 is made on the nodes which is 64x64 grids and the data obtained is 4,096 nodes on the anomaly map so that the level of accuracy on the map increases and the X space used is 119.015 and the Y space is 60.730, then a magnetic field anomaly map will be obtained that has been lifted at an altitude of 350 meters from the height of the starting point of measurement which can be seen in Figure 5.

In the upward continuation transformation process transformation process causes anomalous sources with short wavelength responses will experience significant attenuation compared to the length of anomalous sources with large wavelengths (Blakely, 1996). Upward continuation is done to remove residual or local effects from the measurement area which will then only leave local effects because it is lifted 350 m high. However, lifting with the upward continuation method is done to create local or residual magnetic field anomalies which will be used to make subtractions or differences to obtain local anomalies.

The upward continuation filter operation allows transformation of data measured at one surface to several higher surfaces (Amigun et al., 2012) and tends to smooth the original data by attenuating anomalous short wavelengths relative to the wavelengths of their counterpart. The upward anomaly results are included in the regional anomaly so that regional effects are obtained and require residual effects for further processing. The processing to get the residual anomaly effect is done by entering both maps and then doing math to subtract and will get a residual or local anomaly map like Figure 6 below.

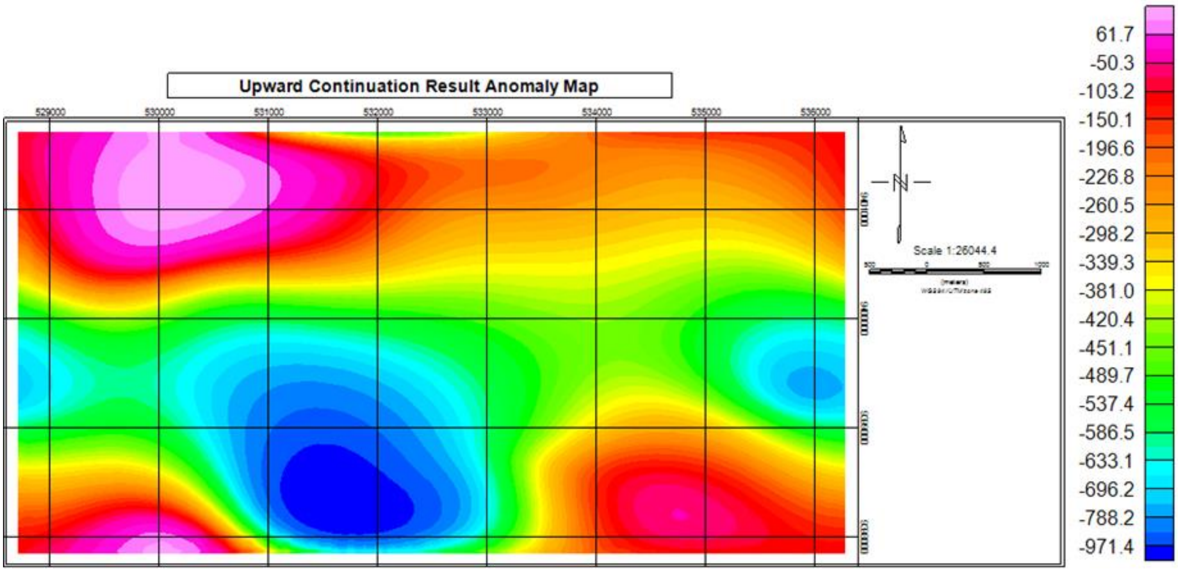

Figure 5. Contour map of total magnetic field anomaly upward continuation 350 m height.

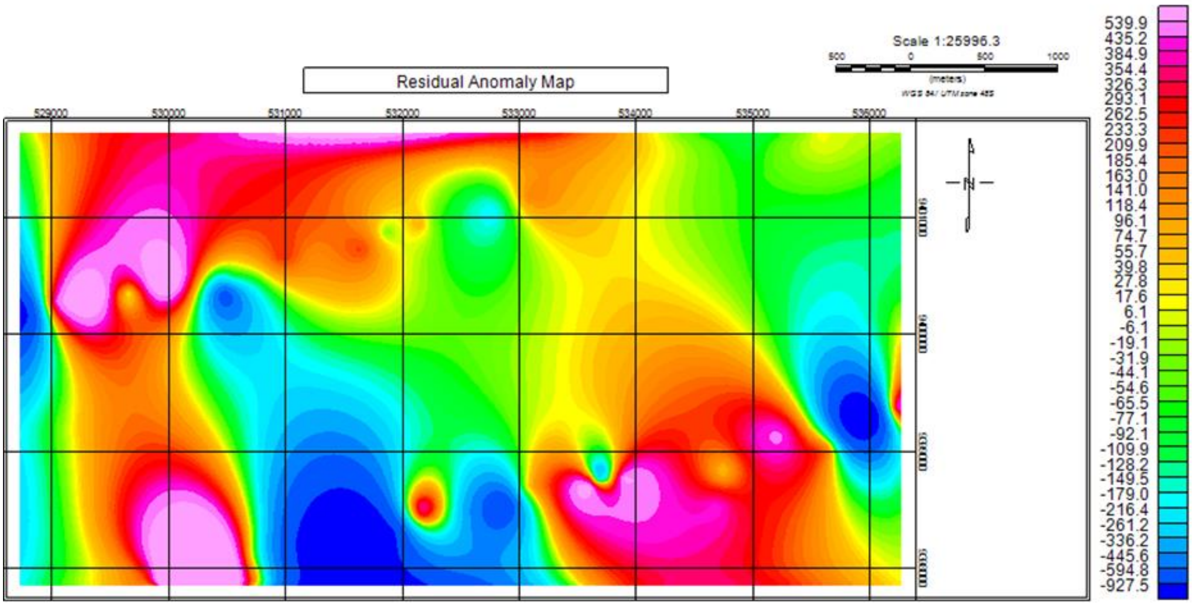

Figure 6. Total magnetic field residual anomaly contour map.

The residual anomalies obtained are still under the influence of the dipole effect or two poles. The north and south poles of the subsurface object, so that for the purposes of a more definite and clear interpretation, a transformation is carried out to change the dipole effect to monopole. The transformation carried out is RTP (Reduce to magnetic pole) which will result in the assumption that the anomalous object is below the surface right with the highest anomalous value.

The result of the RTP transformation is shown in Figure 7 below. To produce higher resolution magnetic maps the downward continuation method of Tran & Nguyen (2020) has been applied to the magnetic data. Small amplitude anomalies are shown more clearly on the continuation map (Abdelrahman et al., 2024).

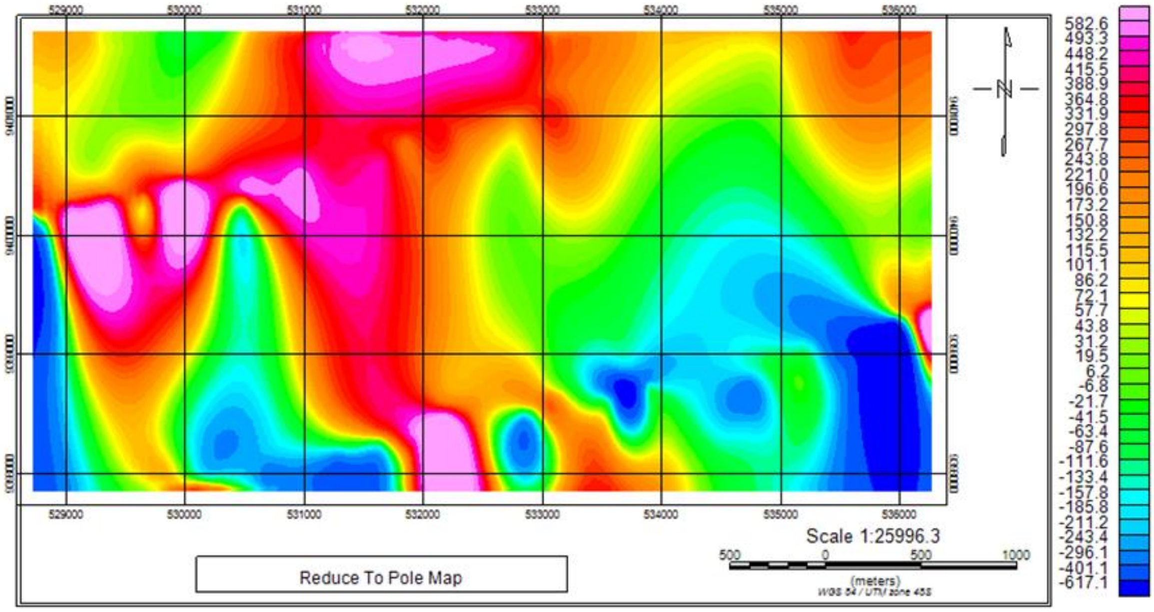

Figure 7. Contour map of total magnetic field anomaly reduce to the pole.

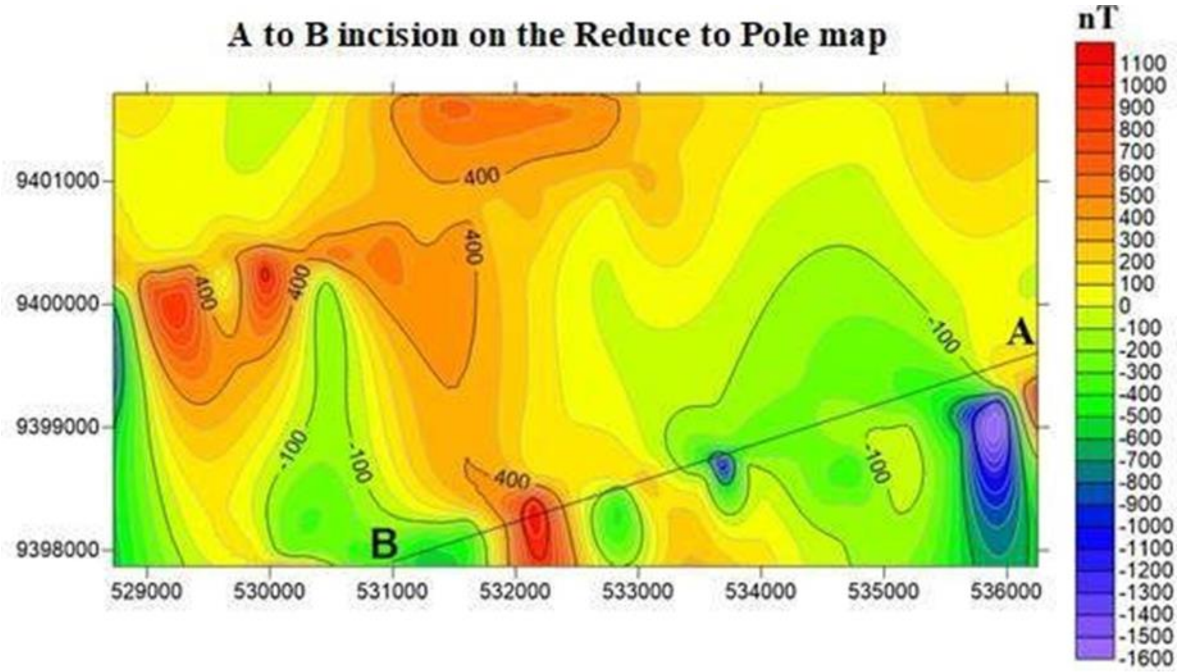

Figure 8. Incision AB on the contour map of magnet total field anomaly reduce to the pole.

The transformed anomaly map can be interpreted with the assumption that the anomalous object is in the area with the highest susceptibility anomaly value, but to interpret it, an incision or slice must be made to clarify and carry out further processing.

The slice was done with an incision line or slice from A to B cutting the Panjang Fault area - Lampung which is the target area in the study. The incision made on the RTP map from A to B can be seen in Figure 8.

After the incision or slice is made, further modeling is carried out using the help of Mag2DC software. This modeling process is known as forward modeling, where this modeling already has a susceptibility value graph from the incision results that have been read files in the software so that it only needs to make a model that produces the same line (fit) with the line of the incision results. The modeling carried out must adjust to the formation on the geological map and see the cross section of the incision results on the geological map and for the susceptibility value in the rock adjusts to the type of rock that exists in the geological formation of the measurement area and refers to the rock susceptibility table according to experts and research that has been done before.

Qualitative Interpretation

Qualitative interpretation is based on the contours of the total magnetic field anomaly resulting from upward continuation by analyzing the anomaly pattern correlated with geological conditions such as rock structure and susceptibility variations below the earth's surface. In the interpretation, a reduction map to the pole is needed to determine the pole pair. Because qualitatively the anomaly map describes the distribution of contour pairs, the tendency of the grid direction of each closed pattern contour pair and those that appear to have a sharper anomaly gradient than the surrounding area is the basis for determining the polar pair.

The total magnetic anomaly in the study area can be divided into several magnetic anomaly clusters. The first group of high positive total magnetic anomalies at values of +500 nT to +1100 nT. Second, moderate positive total magnetic anomalies at values of +500 nT to 0 (zero) nT. Then the low total magnetic anomaly group with values of -800 nT to 0 nT and finally the very low total magnetic anomaly group which has values of -800 nT to -1600 nT. The study area illustrates positive to negative magnetic anomalies. Negative and positive anomaly values and contour patterns appear close together, indicating the presence of fault structures in the area, because fault structures are characterized by anomalous lines, contour density, bending anomalies, and twin anomalies (negative and positive) (Titi, 2016; Aufia et al., 2019). Geologically, it is a manifestation that subsurface there are non-magnetic rocks which are interpreted to be a manifestation that subsurface there are rocks that have been strongly to weakly altered. According to Aktaş et al. (2023), geophysical and geological data can display the tectonic structure of the bay. an area with depth estimation analysis applied to magnetic data to identify anomalies caused by geological structures, and the boundaries or edges of subsurface resources. caused by geological structures, and the boundaries or edges of the subsurface resources. resources. These methods include reduction to polar (RTP), slope derivative, source edge detection (SED), SF, and slope derivative of the total field horizontal gradient magnitude filter (TAHG). and the Euler deconvolution method to determine depth and boundaries.

Quantitative Interpretation

Quantitative interpretation is done by creating a geomagnetic model using Mag2DC software by entering data on the earth's magnetic field parameters in the study area. Numerical modeling requires IGRF parameters, declination angle, inclination angle, and maximum depth needed in the analysis of the research area as shown in Table 1.

Table 1. Earth magnetic field parameters of the research area.

No	Parameters	Value
1	IGRF	44326.3 nT
2	Declination	0.411286°
3	Inclination	-27.8929°
4	Maximum depth	500 m

In addition to the parameters of the earth's magnetic field, the modeling process requires additional data in the form of stratigraphic maps and geological maps of the research area. With the help of geological information, modeling of anomaly-causing objects is carried out. Qualitative interpretation uses the results of qualitative interpretation incisions.

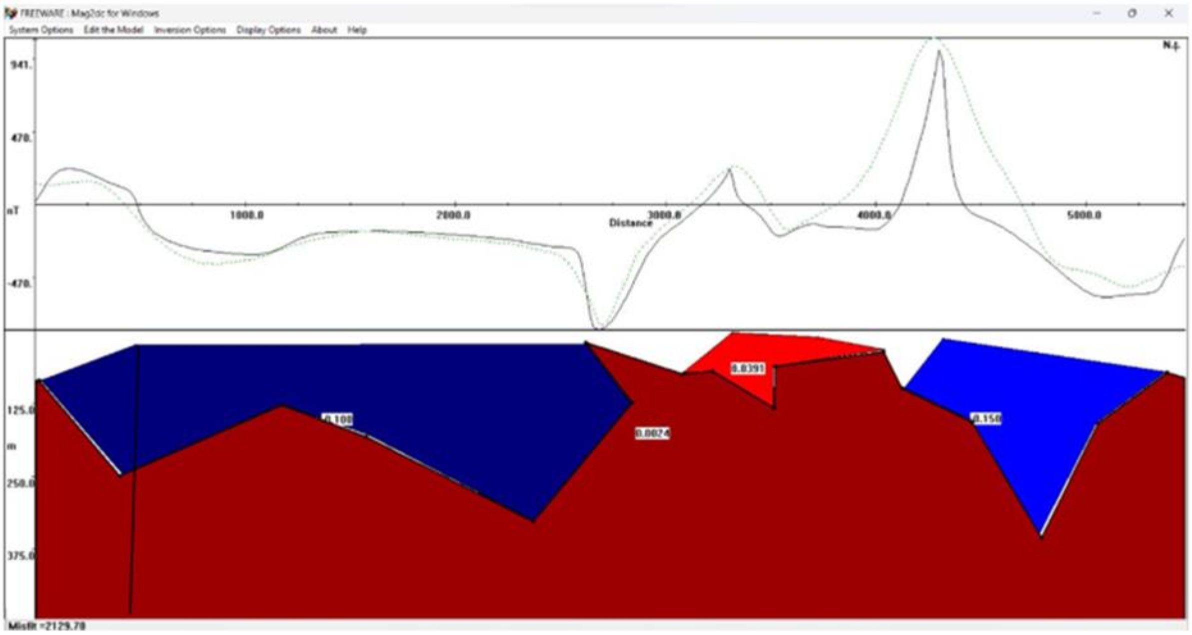

Figure 9. Modeling of the A-B incision.

The incision will show a subsurface cross section to explain the existing rock structure. The results of the A-B incision modeled in Mag2DC different susceptibility contrasts with the surrounding rocks so that it can be interpreted that there are 4 anomaly-forming rocks in the model as shown in Figure below. In the A-B profile modeling based on the reference susceptibility value of Telford et al. (1990) shows a susceptibility value of 0.100 cgs for the first body (dark blue color) estimated to be a tuff breccia rock covering the southern layer with a thickness of 25 meters to 300 meters from the surface.

At a susceptibility value of 0.0391 cgs for the second body (red color) with a depth of between 5 meters to 120 meters from the earth's surface, it is estimated to be rhyolitic tuff, claystone tuff and sandstone tuff. In the third body (blue color) with a susceptibility value of -0.150 cgs and with a depth of 15 meters to 350 meters from the earth's surface then bedrock depths to more than 300 meters are estimated to be andesite - basalt lava from the intrusion of Mount Betung. The fourth body (dark red color) and a susceptibility value of 0.0024 cgs with a north-south direction is a metamorf schist rock.

In modeling cross-section A – B (Figure 9) is tolerated with the geological conditions and surface appearance in the study area. Based on the regional stratigraphic column, there are three layers of Tertiary to Quaternary age and the fourth layer is Paleozoic aged schist malachite rock. The three layers near the surface are Tarahan Formation (Tpot) in the form of solid tuff, breccia with lentil inserts, Lampung Formation (QTi) in the form of stony tuff, rhyolitic tuff, solid tuff tuff, tuffaceous claystone, and tuffaceous sandstone then Young Volcano Formation (Qhv) in the form of lava (andesite-basalt), breccia and tuff and the lower layer is malleable rock as the base or parent rock. The fault structure is estimated to exist in Bumi Waras area with strike direction NW - SE (Northwest - Southeast) in Tarahan Formation. The fault is thought to be the course of geothermal or mineral manifestations.

Conclusion

From the results of magnetic anomaly data modeling, high positive (+500 nT to +1100 nT), medium positive (+500 nT to 0 nT), and low negative (-800 nT to -1600 nT) magnetic anomalies were identified, indicating the presence of fault structures in the area. The positive and negative anomaly values of contour density in the study area are suspected to be fault structures with coordinates 5º26' 0.819" S -111º19' 25.863" W and depth 25 meter until 500 meter. Based on the regional geology, the study area tracks through three formations, among others: Tarahan Formation (Tpot), Lampung Formation (QTi), and Young Volcano Formation (Qhv), so that from the magnetic anomaly value, it is known that the lithology of the research area with a susceptibility value of 0.100 cgs is breccia tuff rock, a susceptibility value of 0.0391 cgs rhyolite tuff rock, a susceptibility value of -0.150 cgs intrusive rock (andesite-basalt), and a susceptibility value of 0.0024 is metamorphic rock.

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Author Contribution

Rasimeng, S. and Rafied, F. conducted a literature study and created a research survey design. Then the authors Valentin, F., Aurora, T.G., and Nurlaili, J. carried out acquisition, data processing and 2D modeling, as well as analysis and interpretation of the results.

Conflict of Interest

The authors declare no conflict of interest.

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