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# Subsurface Rock Modeling with Half Slope Inversion of Reduce to the Pole Geomagnetic Anomaly in Hot Spring Natar-Lampung Area

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### Abstract

The research in South Lampung's Natar area assesses geothermal heat source potential using the magnetic method with 89 measurement points along the Lampung-Panjang Fault line in a 3 km^2 area. Reducing to the Pole filtering enhances magnetic data accuracy. The Peter Half Slope method is employed, revealing depth ranges for different underground indicators (82.63 m to 144.25 m for very thin bodies, 61.97 m to 108.19 m for intermediate bodies, and 49.57 m to 86.55 m for very thick bodies). Geological analysis of the Lampung-Panjang fault area correlates with the Tanjungkarang Sheet Map, indicating various rock types within the Lampung Formation. The study underscores the Peter Half Slope method's effectiveness in determining subsurface anomaly depth through magnetic data.

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## 1. INTRODUCTION

Geothermal energy is one of the abundant energy sources in Indonesia and is an environmentally friendly renewable energy source. The main characteristic that is known to exist in a particular area is the manifestation of geothermal heat such as hot springs, mud pools, fumaroles, warm soil, and others [1]. There are areas that have geothermal hotspots, where this area is located in South Lampung Regency, Lampung Province. Its existence is well known because of its geothermal surface manifestation in the form of hot springs that have benefits for bathing places. The hot spring is divided into two, namely Natar hot spring and Cisarua hot spring [2].

Geologically, the hot springs in Natar occur in a relatively flat area far away from the volcanic hills that are the source of the heat. However, geothermal energy has the potential for regeneration if one of its elements is optimally managed. The hot spring in Natar is one manifestation of a geothermal potential that can be sustained as long as the water supply in the reservoir is maintained [1].

From the analysis of morphology and groundwater basins, the geothermal system located in Natar is the Metro-Kotabumi Groundwater Basin (CAT), where the catchment area is in the western part around the foothills of Bukit Baran and in the south of Gunubg Betung and Pesawaran [1]. The emergence of hot water can be expected to be controlled by the presence of fault structures that affect the level of secondary permeability.

The Natar area is one of the areas passed by the Lampung-Panjang Fault. The Lampung-Panjang Fault, which is a horizontal fault, stretches from the Tarahan area to Tanjung Karang [3]. The sign of the Lampung-Panjang Fault can be seen from the morphology of the area, which is characterized by the presence of hills with steep slopes. The prospect of geothermal resources in the Natar area is caused by the activity and energy generated from the Lampung-Panjang fault.

Geomagnetic surveys aim to determine underground geology based on magnetic field anomalies caused by magnetic minerals in underground rocks [4]. Evaluation of magnetic source model parameters such as location, depth, thickness, inclination, size, shape, range and magnetic susceptibility is very important in the interpretation stage. In general, structural model parameters are often analyzed and estimated using spectral methods, inversion and modeling techniques, graphical methods, and other numerical methods [5].

Magnetic methods are commonly used in geophysical methods to identify and image subsurface targets. The difficulty in interpreting magnetic anomalies is due to the dipolar nature of the magnetic field, the superposition of multiple magnetic sources and the presence of noise. Reduction to Pole (RTP) is an operator that takes a magnetic anomaly and transforms the asymmetric shape into symmetric and reproduces the magnetic anomaly with vertical magnetization [6].

In geophysics, magnetic surveys on ocean ridges provide an important clue, leading to the theory of plate tectonics and revealing the history of the Earth's magnetic field polarity since the Early Jurassic. In magnetic surveys, there are three things that must be done such as (1) measuring the magnetic field at predetermined points, (2) correcting the measurement results to determine the changes, and (3) comparing the value of the results from the field with the estimated value of each measurement, this value is called the IGR (International Geomagnetic Reference Field). And the difference between the measurement value and the IGRF is called a magnetic anomaly [7]. In addition, determining the depth of the magnetic anomaly source is an important thing to do. Determination of depth in geophysics usually uses spectrum analysis, such as in research on determining curie point depth in geomagnetic anomaly data conducted by [8].

In this study, depth determination uses a different method, namely the Peter Half Slope method. The Slope method is one of the earliest magnetic depth estimation techniques [9]. The Peter Half Slope method [10] estimates depth by finding the horizontal distance between two parallel lines that pass through the maximum and minimum anomalies and have a slope equal to half of the maximum horizontal gradient of the anomaly.

The half slope method has previously been used in a study related to magnetic surveys for magnetic investigations on minerals in a village in Nigeria by [11] where half slope was used to estimate the depth of the anomaly source. In addition, research conducted by [12] related to aeromagnetic anomaly analysis and structural alignment for mineral and hydrocarbon exploration in Ikom and around Southeast Nigeria, where in his research the half slope method was used to estimate the depth of the anomalous source as well. From the previous studies that have been done, most of them are used in mineral exploration, so in this study the authors use the half slope method in a different case, namely to estimate the depth of subsurface rocks in hot springs in Natar-Lampung.

## 2. MATERIALS AND METHODS

This research utilizes primary data taken directly from geomagnetic acquisition in the field. In this geomagnetic acquisition, the magnetic intensity of the research area was obtained. Geomagnetic acquisition was carried out in the Natar area, South Lampung using a grid system acquisition. With a total of 89 research points and coverage outside the research area of 3 km$^2$.

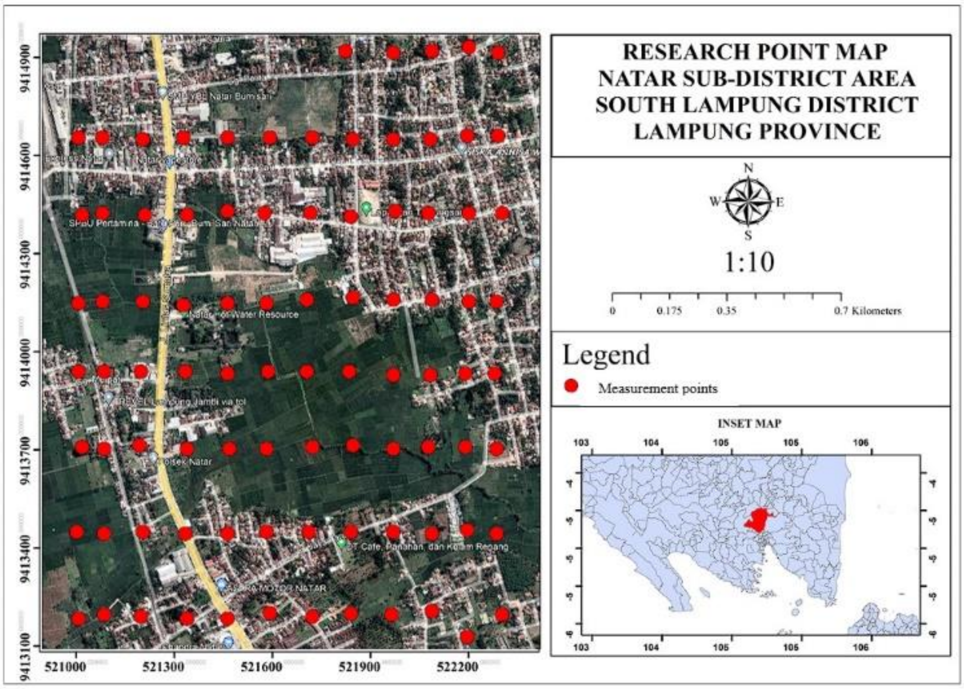

**Figure 1**. Geomagnetic data measurement location in the Natar hot spring area, Lampung Province (modified from Google Earth)

The creation of magnetic anomaly contour patterns in this study uses Oasis Montaj software which is then carried out RTP filtering (reduce to pole) to reduce the influence of one of the poles of the earth's magnetic field which is done by correcting declination and inclination [13]. Basically, the RTP filter changes the magentic anomaly somewhere at the earth's magnetic north pole. So, the magnetic field anomaly is right above an object that causes the anomaly, and the magnetic anomaly becomes monopole [14].

The purpose of RTP is to take the observed total magnetic field map and create a magnetic map that will show the surveyed area at the magnetic pole, assuming all fields in the observed area are due to induced magnetic effects which can be calculated using the equation below [9].

$$RTP(\theta) = \frac{1}{\sin(I)\cos(I)\cos{(D-\theta)^2}} \qquad 1)$$

where:

$\theta$ : Wave number
$I$ : Geomagnetic inklination
$D$ : Geomagnetic declination

Estimating the depth of the source of anomalous variation is done using the Peter Half Slope method which estimates the depth by finding the horizontal distance between two parallel lines that pass through the maximum and minimum limits of the anomaly and have a slope equal to half of the maximum horizontal gradient of the anomaly [9]. The Peter Half Slope method is a half slope method whose technique uses the hypotenuse of the profile to estimate the depth to the magnetic source or basement depth (sediment thickness) in sedimentary basins [15].

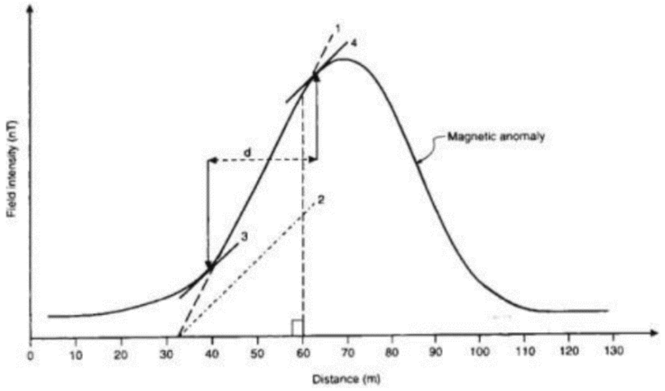

**Figure 2**. Illustration of Peter's half slope method [7]

This method requires several curve parameters on the magnetic anomaly profile such as maximum slope, half-maximum slope, tangent point and the distance between them [16]. Where the distance is proportional to the depth of the source [17]. The application of this method is done using the Matlab program by entering the upper limit, lower limit and displaying the curve profile.

## 3. RESULTS AND DISCUSSION

### Total Magentic Field Anomaly

In Figure 3, the total magnetic anomaly contour illustrates the relationship between the measurement position and the total magnetic field value. The total magnetic anomaly contour clearly shows that the contour is a dipole containing pairs of negative and positive clusters, this is because the anomaly source is assimilated between shallow and deep anomaly sources so that it can be interpreted that the area has anomalous objects. The total magnetic anomaly contour also shows the difference in magnetic intensity marked by negative and positive anomaly values, from -1500 nT marked in purple to +1140 nT marked in orange. On the anomaly contour, it can be seen that the Natar manifestation point is in the magnetic intensity range of -1260 nT to -780 nT marked in blue.

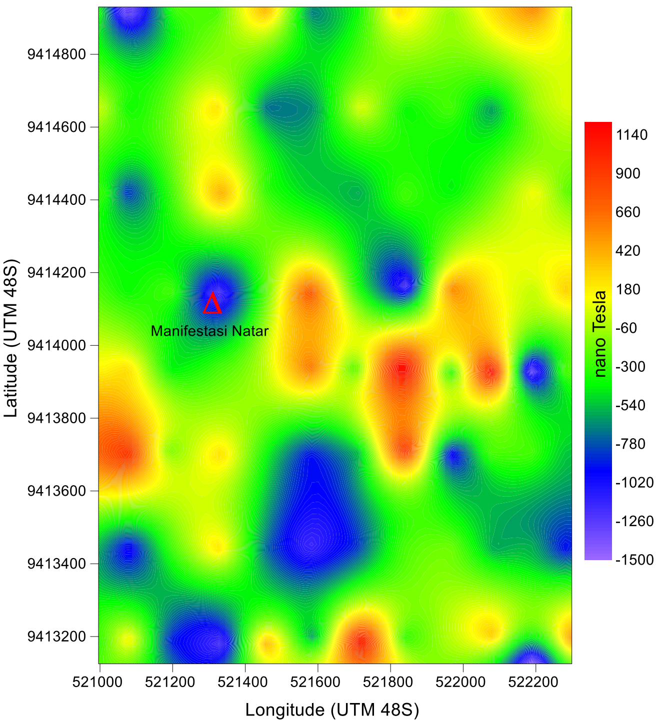

**Figure 3**. Total magnetic field anomaly contour map of the Natar hot spring area, Lampung province

### RTP Magentic Field Anomaly

Figure 4 shows the contours of the total magnetic field anomaly that has been reduced to the pole (Reduce to Pole). According to [17], RTP is a magnetic data processing filter used to remove the influence of the magnetic inclination angle, needed because of the nature of the magnetic dipole which can make it difficult to interpret field data which is generally asymmetrically patterned. The RTP magnetic field anomaly contours above have magnetic intensity values ranging from -2400 nT to +2550 nT. The purple to blue colored section shows low magnetic intensity of -2400 nT to -1300 nT. The green section shows moderate magnetic intensity of -750 nT to -200 nT, and the yellow to orange section shows high magnetic intensity of +350 nT to +2550 nT.

After obtaining the magnetic field anomaly from RTP, the next step is to make an incision cutting the low closure with the high closure to obtain a solid model based on the rock susceptibility value. The incision of the RTP magnetic field anomaly is shown in Figure 5, it can be seen that the magnetic intensity is in the range of +15 nT to +135 nT.

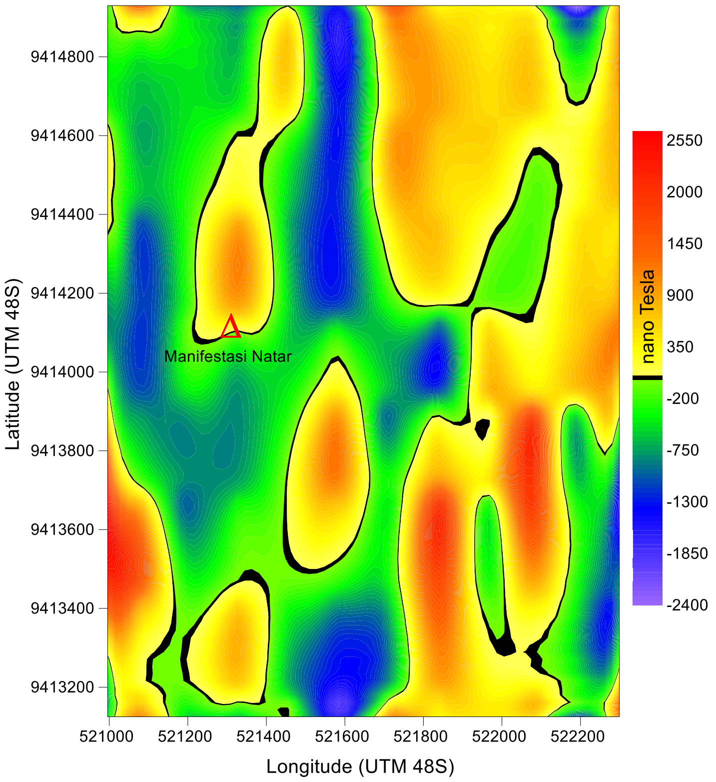

**Figure 4**. Total magnetic field anomaly contour map RTP of the Natar hot spring area, Lampung province

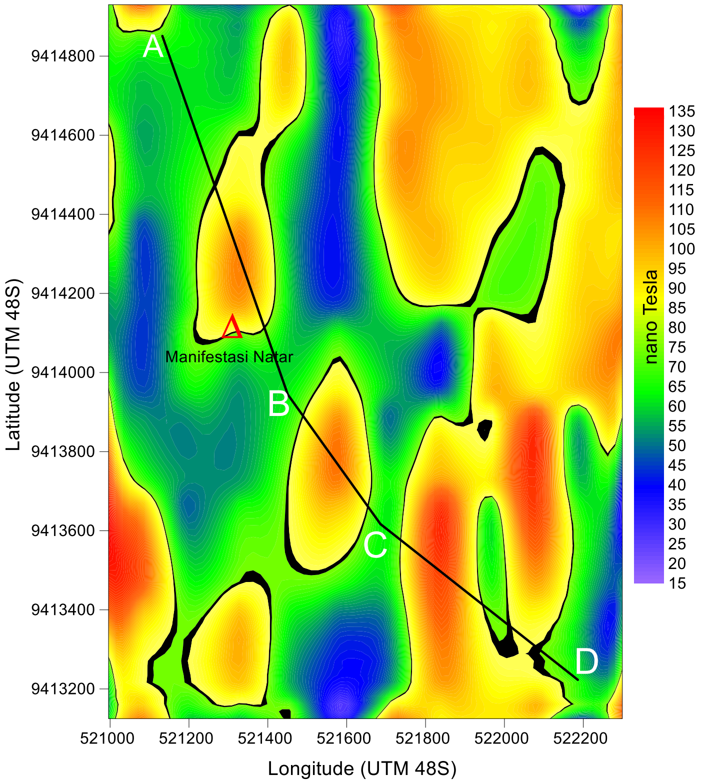

**Figure 5**. Slice ABCD trajectory on the total magnetic field anomaly RTP of the Natar hot spring area, Lampung province

In Figure 6, it can be seen that high anomalies are indicated by the presence of mounds, the higher the mound, the higher the anomalous value. Meanwhile, the low anomaly is indicated by the presence of a basin, where the deeper the basin, the lower the anomalous value.

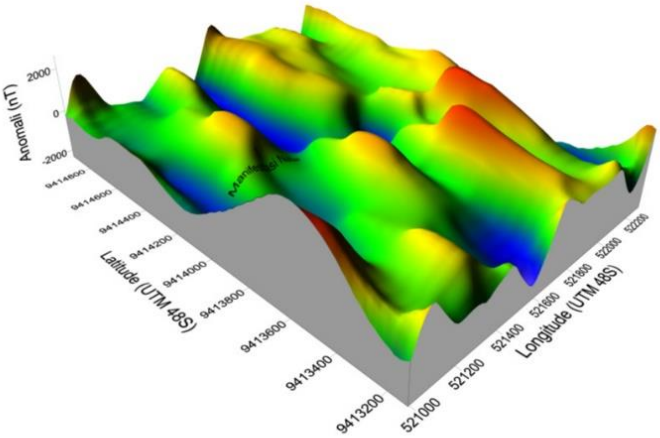

**Figure 6**. Total magnetic field anomaly contour surface model RTP in the Natar hot spring area, Lampung province

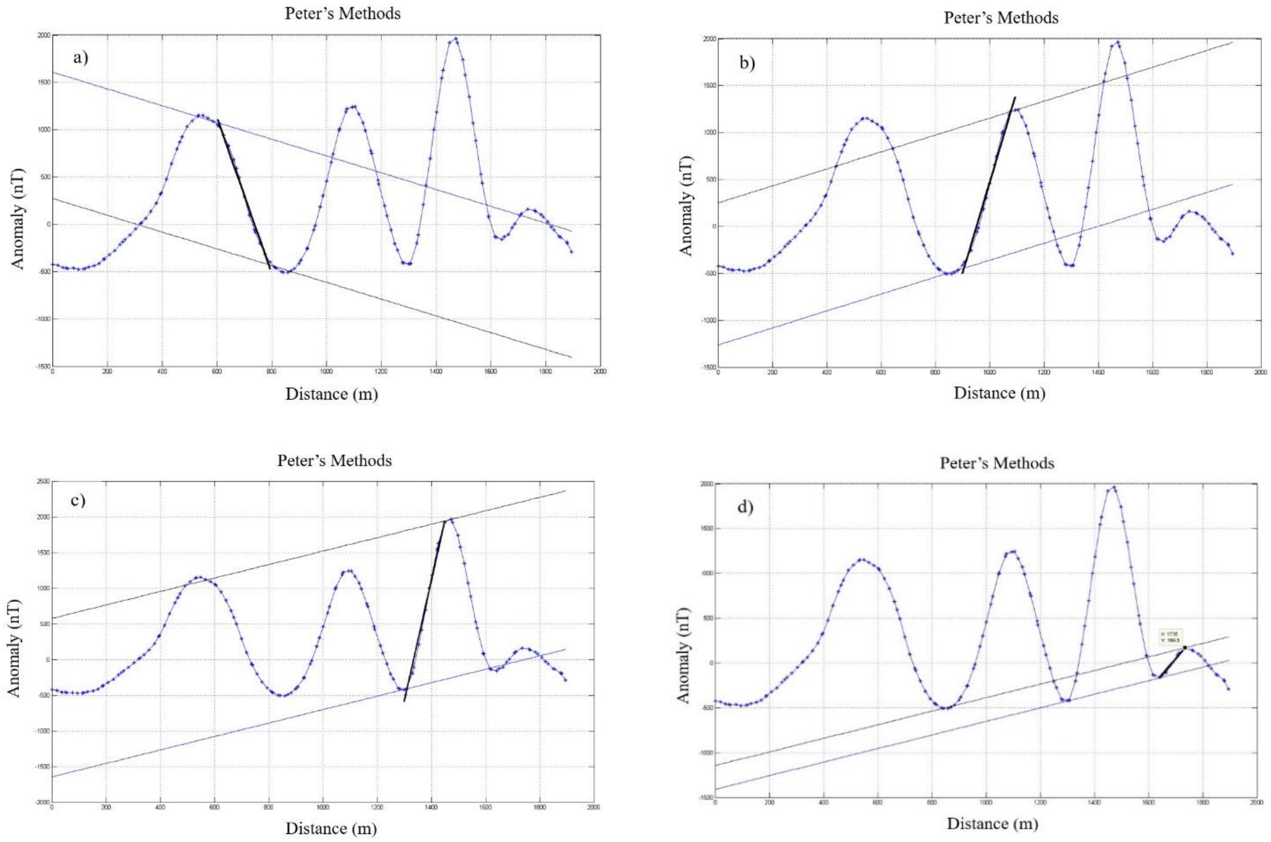

**Figure 7**. The slope of the anomaly profile curve based on the ABCD slice is shown in Figure 5. a) the peak slope of the 1st anomaly profile; b) the peak slope of the 2nd anomaly profile; c) the peak slope of the 3rd anomaly profile; d) the peak slope of the 4th anomaly profile.

Based on the calculation results using Peter's method, depth variations were obtained based on the very thin body, intermediate body, and very thick body of anomalous model approaches, as shown in Table 1 below. In the Peter Half Slope method, the depth (d) to the top of the body is reduced towards the pole, then expressed in the formula:

$$P = kd \qquad 2)$$

The horizontal distance between two parallel lines is called P, while the constant used is called k. When the value of k = 1.20, the body is classified as very thin. For a value of k = 1.60, the body is classified as medium. A value of k = 2.0 signifies that the body is very thick [9].

**Table 1**. The depth of the line ABCD geomagnetic anomaly using Peter's method in the Natar hot spring area, Lampung Province

| Body | *Very thin body* (m) $\left(d=\frac{x}{1.2}\right)$ | *Intermediate body* (m) $\left(d=\frac{x}{1.6}\right)$ | *Very thick body* (m) $\left(d=\frac{x}{2}\right)$ |
|---|---|---|---|
| Body 1 | 144.25 | 108.19 | 86.55 |
| Body 2 | 142.85 | 107.14 | 85.71 |
| Body 3 | 112.04 | 84.03 | 67.22 |
| Body 4 | 82.63 | 61.97 | 49.57 |

Figure 7 shows the modeling generated using Matlab software, resulting in four bodies with different heights and curve widths. Then, the modeling is described in Table 1, resulting in each body being differentiated based on its characteristics into three types, namely very thin body, intermediate body, and very thick body. Body 1 has a width of 173.10 m. This body is included in the very thin body category if the value of x or body width is 1.2d, then the resulting body value is 144.25m. If the x value is equal to 1.6d, then the body is included in the intermediate body category with a value of 108.19 m. However, if the x value is equal to 2D, the body will be classified as a very thick body with a value of 86.55m. Body 2 has a width of 171.42 m, and is included in the very thin body if the x value or body width is 1.2d, the resulting body value is 142.85 m. If the x value is equal to 1.6d, then the body falls into the intermediate body category with a value of 107.14 m. However, if the x value is equal to 2d, the body will be classified as a very thick body with a value of 85.71 m. In body 3, it has a body width of 134.45 m, and is included in the very thin body if the x value or body width is 1.2d, then the resulting body value is 112.04m. If the x value is equal to 1.6d, then the body is included in the intermediate body category with a value of 84.03 m. However, if the x value is equal to 2d, the body will be classified as a very thick body with a value of 67.22 m. And body 4 has a body width of 99.15 m, and is included in the very thin body if the x value or body width is 1.2d, then the resulting body value is 82.63 m. If the x value is equal to 1.6d, then the body is included in the intermediate body category with a value of 61.97m. However, if the x value is equal to 2d, the body will be classified as a very thick body with a value of 49.57m.

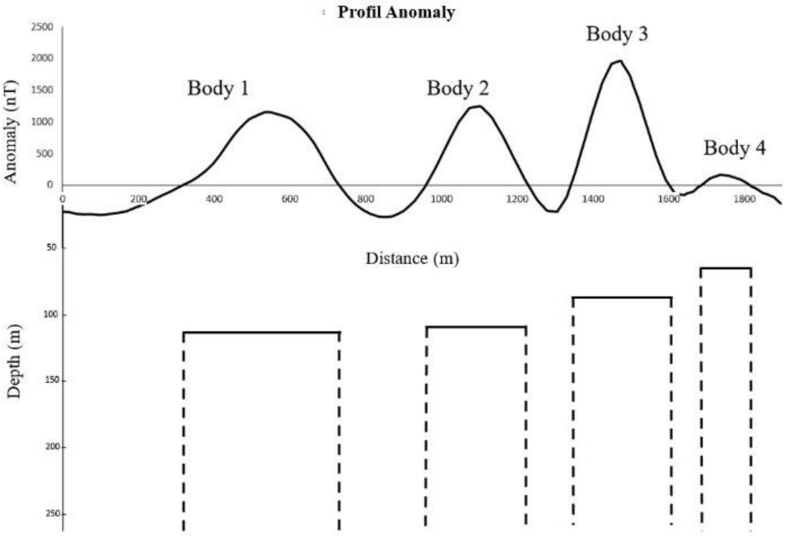

**Figure 8**. Reconstruction of the subsurface model on the ABCD slice based on the calculation results in Table 1.

Using the Peter Half Slope method, quantitative depth determination is made easier by utilizing structural indices of 1.2-2.0 of the various sizes and depths available. The results from table 1 show different depth ranges depending on the conditions at the subsurface. The depth range is 82.63 m-144.25 m for very thin bodies, 61.97 m -108.19 m for Medium thickness, and 49.57 m - 86.55 m for very thick bodies.

Figure 8 shows the condition of the subsurface rocks based on the modeling that has been made. Each body has a different shape depending on the depth and thickness of the subsurface rocks. And there is a distance between rocks that may be separated from other rocks. In Figure 8 also, the approximate location of rocks is obtained from the average depth of the three existing depth characteristics, namely very thin body, intermediate body, and very thick body. For body 1, the depth of the top body is 112.99 m, body 2 is at a depth of 111.9 m, body 3 is at a depth of 87.76 m, and body 4 is at a depth of 64.72m. By using the Peter Half Slope method, only the approximate location of the top body depth is obtained, but not to know the bottom body of an object or rock below the ground surface.

Based on the geological map of Tanjung Karang Sheet [18], most of the research area is in the Lampung Formation, which has rocky tuff, rhylotic tuff, dense tuff, tuff mudstone, and tuff sandstone. Generally, the thickness of the Lampung formation varies up to 300 meters. So the results of this study, with a geomagnetic anomaly thickness interval of 49.57–144.25 meters, have a good correlation with the geological conditions in this area.

## 4. CONCLUSION

The variation of structural index modeling has an important role in the classification of magnetic depth as a thin body with a depth range of 82.63 m - 144.25 m, an intermediate thickness with a depth of 61.97 m - 108.19 m, and a very thick body with a depth of 49.57 m - 86.55 m. The thickness of the magnetic body is inversely proportional to its depth. This shows that the thickness of the magnetic body is inversely proportional to its depth. Then, the area in this study is in the Lampung Formation which is dominated by rock types of stony tuff, ryllotic tuff, tuff solid tuff, tuffaceous claystone and tuffaceous sandstone. Conclusions can be general findings according to research problems, and can also be recommendations for the next step. Conclusions are written in paragraph form, not in list/numbering item form. Suggestions can be input for the next researcher, and can also be implicative recommendations from research findings.

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