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# Identification of Hot Water Pathway in Jatimulyo Village, South Lampung Using Magnetic Methods

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**Abstract**

Geothermal energy originates from Earth's core heat, creating a hydrothermal system. Surface manifestations, like hot water, hold potential for geo-tourism. Detecting this system underground necessitates a comprehensive study. Geophysical methods, such as magnetics, can be used to predict hot fluid pathways and identify structural and alteration zones. This study aims to use the magnetic method to locate the outflow pathway in the Jatimulyo village, Jati Agung sub-district, South Lampung. Results reveal an anomaly in the form of a fault structure acting as a pathway for hot water. The distant hot spring lacks pluton granite and exhibits lower temperatures. The findings suggest a low magnetic anomaly along the outflow path, attributed to the loss of magnetic properties in heated rocks. Geological data indicates a northwest-southeast fault in the western part of the area, which may influence the fluid pathway.

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## 1. INTRODUCTION

Geothermal is heat originating in the bowels of the earth which then heats the fluid above it to form a hydrothermal system. The heated fluid will then be pushed to the surface through the cracks in the rock and due to the high pressure, which is then characterized by manifestations [1]. Indonesia is a country that has enormous geothermal potential. This capacity can occur as a result of the many volcanic and high tectonic activities. Those activities are caused because Indonesia is a confluence of 3 active tectonic plates, namely the Indo-Australian plate subducting the Eurasian plate from the south, the Pacific plate subducting the Eurasian plate from the east, and the Eurasian plate in the north [2]. As a result of the confluence of these three plates, a series of volcanoes was formed in Indonesia which caused volcanoes to emerge from magma intrusions from beneath the earth's layers [3]. In addition, the result of the movement of these tectonic plates causes the formation of faults which can become fluid pathways to the surface so that hot springs form on the surface. Generally, hot water from geothermal manifestations in Indonesia is used for tourism purposes. One of them is located in Jatimulyo Village, Jati Agung District, South Lampung. This area has been used as hot spring area that was accidentally obtained from a groundwater well. Geologically, this area is in the Lampung Formation which is dominated by tuff rocks [4]. From the results of temperature measurements, the hot springs in this area have a low temperature indicating the water is far from the heat source. This feature is usually identified as an outflow heat flow path. To detect the path of this heat flow, the measurements using the geophysical method is conducted using the magnetic method.

Geophysics studies can be used to interpret rock structures and subsurface areas that have geothermal potential. The method used for geothermal surveys is the magnetic method [5]. The magnetic method is used to determine the alteration zone. This method detects variations in the rock magnetic field within a geothermal system which generally has a lower magnetization than the surrounding rock. This is due to the demagnetization process by the hydrothermal alteration process which will change the existing minerals into minerals that have lost their magnetic field [6]. In addition, the low magnetic anomaly is caused by the presence of structures [7] which result in physical changes in the bed. This anomaly can be identified based on the value of the magnetic susceptibility around it [8].

## 2. MATERIALS AND METHOD

Geologically, the study area is dominated by normal fault structures of the horst graben type which were formed before the Lampung Formation (QTl) was formed. The rocks found in this formation consist of tuffaceous claystone, tuffs, clay, tuffaceous sandstones, and conglomerates which have a thickness of about 200 meters and were deposited in terrestrial-fluvial and brackish water environments [9]. Based on the geological map [9], the direction of the main fault in the study area is trending Northwest -Southeast (Figure 1). Previous studies near study area, using the gravity method showed that there was a structure perpendicular to the main fault trending East-Northwest Southwest [10]. This fault is indirectly part of the extensional tectonics of the Sunda Strait [11].

Geothermal sources come from magma chambers or the bowels of the earth due to a loading process [11]. The heat-conducting medium can be formed in hot fluid (hot water) or hot steam (steam) [12]. In a geothermal system, the heated water can flow in two different way called outflow and upflow zones. The upflow zone is a zone with geothermal potential that has a higher permeability and temperature gradient than the outflow zone [13,14], while the outflow zone is a zone where lateral geothermal flows occur characterized by a lower temperature compared to the upflow zone [13,14]. In geothermal exploration, the geophysical method, such as the magnetic method, commonly is used in preliminary surveys. The magnetic method can be able to determine the alteration zone which is measured based on geomagnetic anomalies with magnetic susceptibility values around them [10].

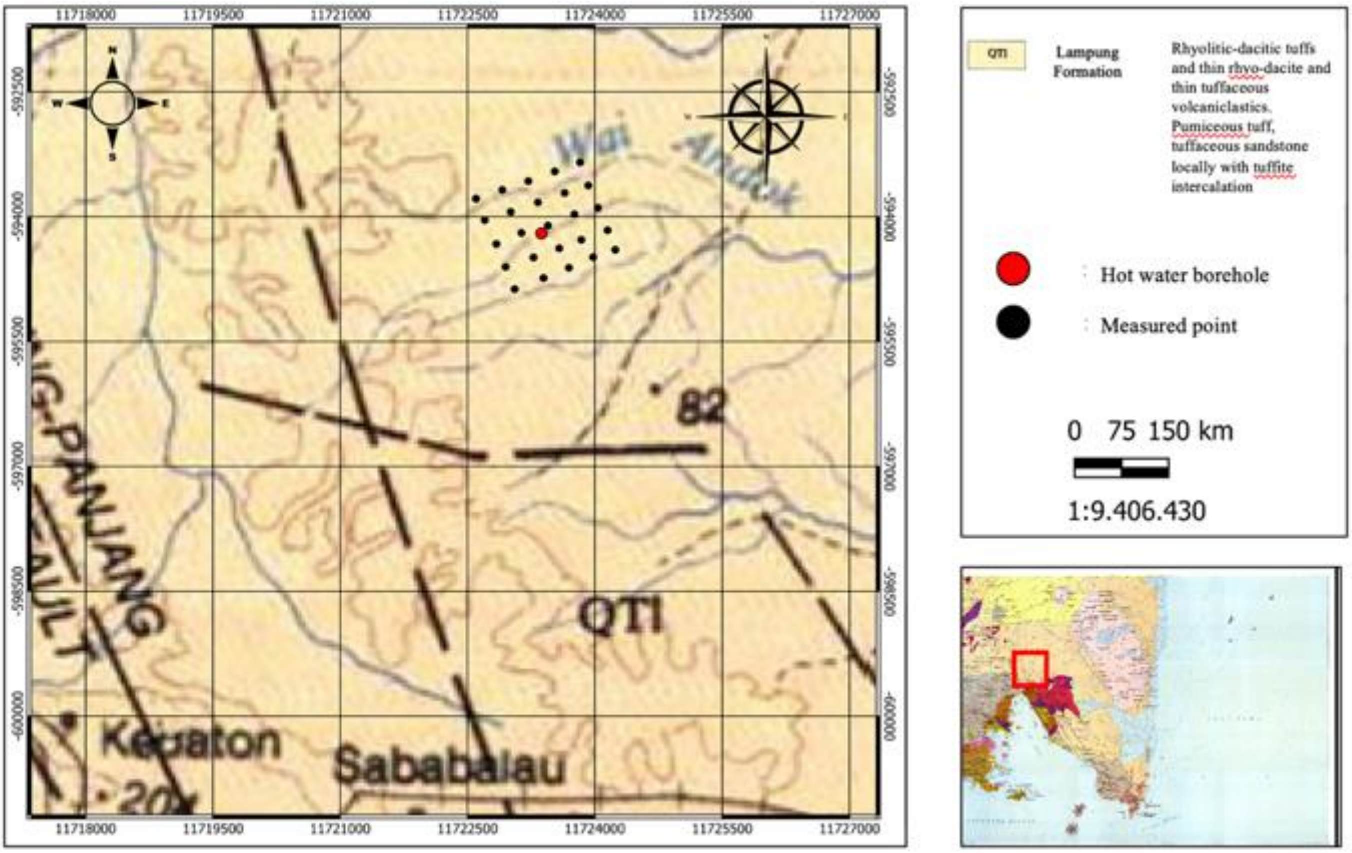



**Figure 1.** Geological map of the study area showing he main structure in West-North-East direction, and several other minor structures which are almost perpendicular to the main structure [9].

The magnetic method utilizes the magnetic properties of the rocks caused by differences in the composition of the minerals making up the rocks [15]. In geothermal it is used to interpret the subsurface layer based on the intensity of the magnetic field measured in the magnetic anomaly, based on the magnetic anomaly it is obtained that there are differences in the value of rock susceptibility based on the composition of the area [16]. Susceptibility is a value that provides information about the ability of an object or rock to be magnetized. In geothermal manifestations, an anomaly with a negative value can be indicated and the rock in that area has a low susceptibility value due to an alteration process [8]. Rock susceptibility can be expressed in the following equation:

$$k = \frac{M}{H} \qquad (1)$$

where M is the magnetic intensity (A/m) and H is the magnetic field strength.

In the magnetic method, the data obtained from the acquisition contain the distortion from the noise, so that the raw data needs to make several corrections such as daily corrections and IGRF corrections. Daily correction can be written in the following equation [17]:

$$T_E = \left[\frac{T_{base2}-T_{base1}}{t_{base2}-t_{base1}} \times (t_{obs} - t_{base1})\right] + T_{base1} \qquad (2)$$

where TE is the daily magnetic field magnetization value (T), Tbase2 is the magnetic field magnetization in T at the tbase2, Tbase1 is the magnetic field magnetization at the base at time base 2 (T), tbase2 is the observation time 2 at base (s), tbase1 is the observation time 1 (s), and tobs representative the observation time in the field (T). IGRF correction is applied to eliminate the influence of the Earth's main magnetic field which can affect the value of the total anomaly magnetic field [18]. The main magnetic field of the earth always changes over time so that IGRF corrections are needed [19]. The results of the two corrections produce the distribution of magnetic anomalies in the form of total magnetic intensity (TMI).

To eliminate the influence of the magnetic inclination angle, a reduction process is carried out to the poles [20]. This will change the anomaly that was originally a dipole into a monopole. From the resulting RTP map, the process of separating residual and regional anomalies is then carried out by spectral analysis (Figure 2). From the spectral analysis, the relationship curve between the amplitude and the wave number k is obtained.

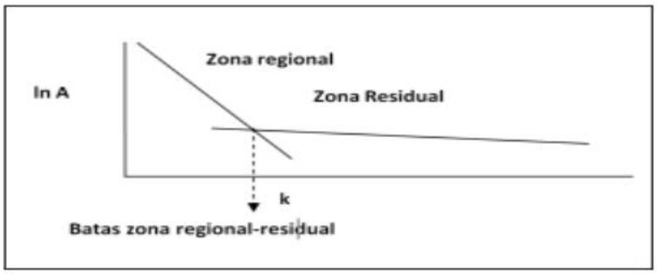


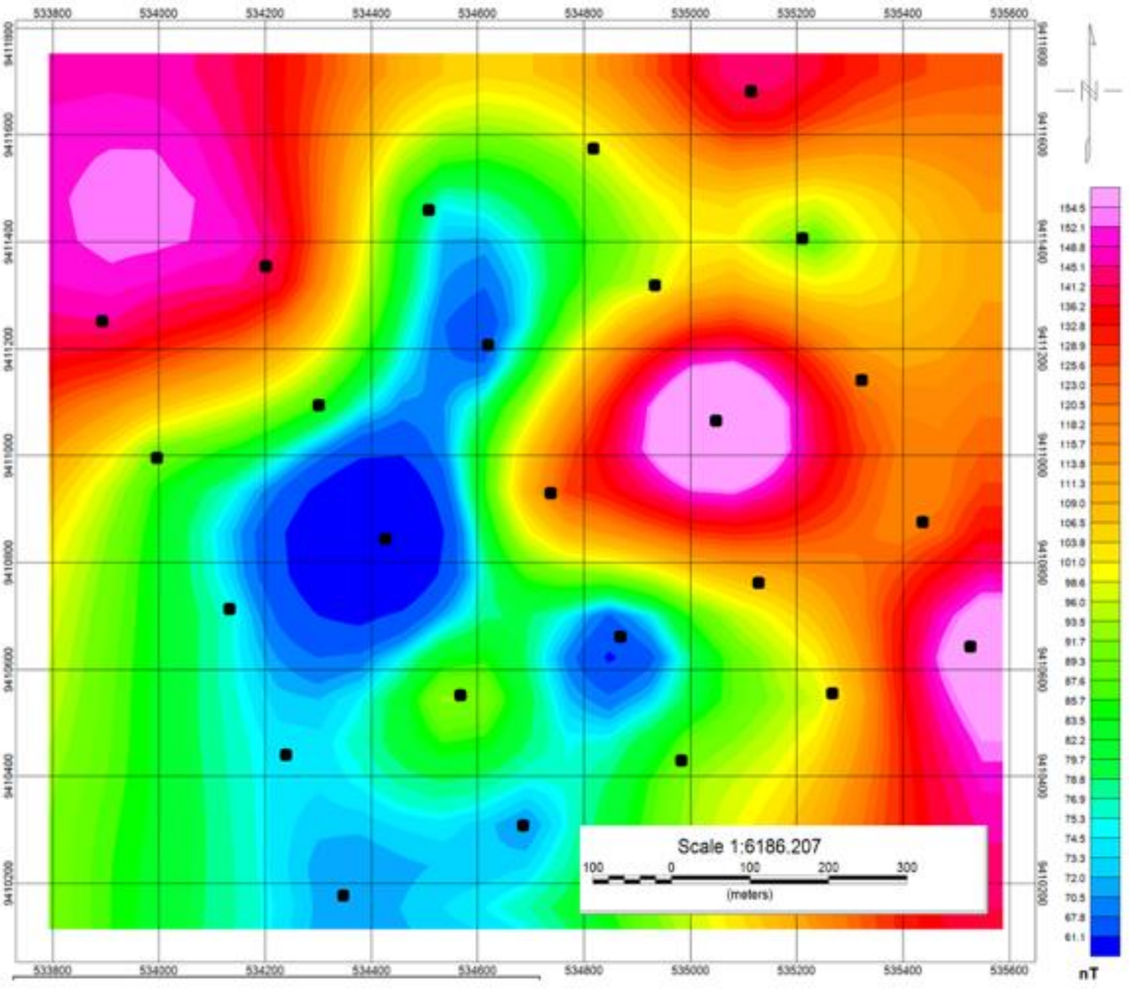

**Figure 2.** Spectral analysis curve which is the relationship between the ln A value and the wave number k [21].

To increase the resolution, especially small anomalies originating from shallow depths that are faintly visible due to strong magnetic field disturbances from inside or outside the earth, a Second vertical derivative (SVD) analysis is carried out [22]. On the SVD map the closed curve of the maximum and minimum values is able to show secondary structure information in the form of faults [23].

In this study, two stages of interpretation were carried out, namely qualitatively and quantitatively. Qualitatively the interpretation was carried out by analyzing the contour maps of the total magnetic field anomaly so that the results were obtained in the form of anomaly areas that cause magnetic anomalies. Furthermore, to see the shape of the geothermal distribution at the study site, based on the magnetic anomaly data obtained, a quantitative interpretation is carried out with 2D modeling, namely matching the residual anomaly curve based on the slicing data that has been selected from the residual magnetic field anomaly map with the model curve which is done iteratively until the smallest error is obtained [24].

## 3. RESULTS AND DISCUSSION

The TMI map has been corrected is displayed in map form (Figure 3). The corrections made to the magnetic data function to obtain magnetic anomaly values that are no longer affected by the presence of magnetic values from within the earth or outside the earth. The total magnetic intensity (TMI) map is a result of a combination of regional and residual anomalies, besides that the TMI map still has a dipole effect due to the influence of the inclination and declination angles.




. **Figure 3.** The total magnetic intensity map shows high anomaly (light red) and low anomaly (dark blue)

From the TMI map, low and high anomaly values indicating the data has two poles with a low anomaly value range of 61.1 nT marked in blue and high anomaly values are in the range of 154.5 nT. Furthermore, the RTP process is carried out to change the anomaly which was originally a dipole convert into a monopole as shown in Figure 4.

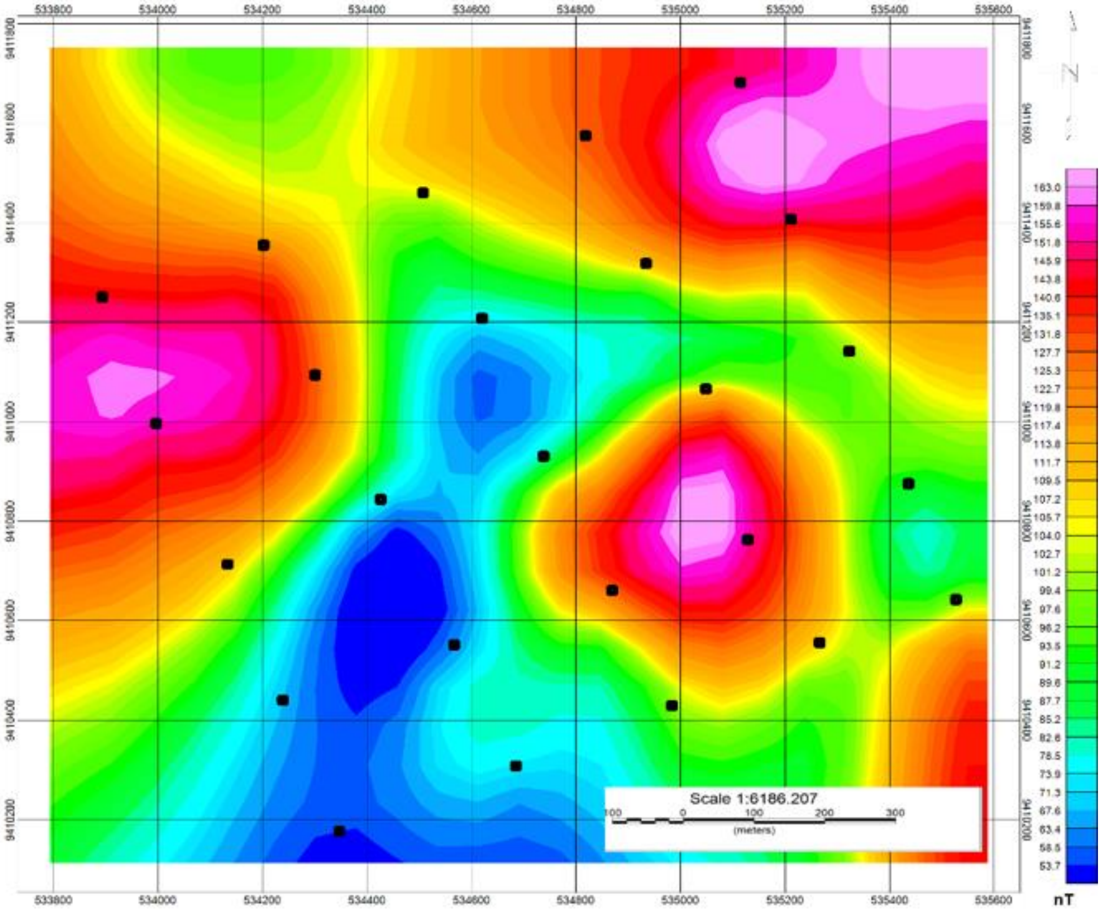



**Figure 4.** The pole reduction map shows high anomaly (light red) and low anomaly (dark blue).

Separation of regional and residual anomalies in the frequency domain is principally carried out for the separation of anomalies due to the presence of objects that are below the surface which will give rise to geomagnetic responses obtained spatially with low frequencies [25]. Separation of residual and regional areas by performing spectral analysis as shown in Figure 6 for depth estimation to obtain regional and residual depth estimates. The results of the estimated depth will be used as a reference for depth in magnetic modeling, namely for a residual depth of 152.112337 meters.

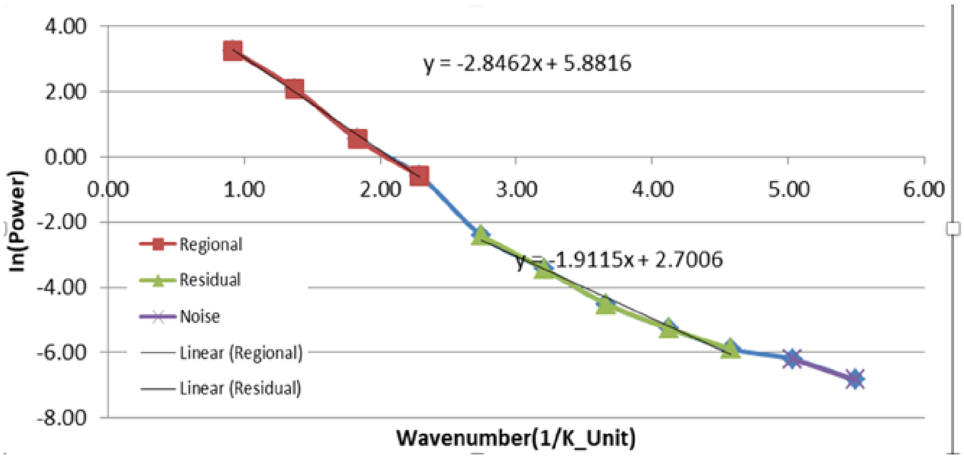



**Figure 4** Spectral analysis curve to separate regional anomaly, residual and noise from RTP data.

The separation of the anomalies will result in regional anomalies and residual anomalies, with a range of values for regional anomalies of 62.7 nT to 154.4 nT (Figure 7) and values for residual anomalies of -18 nT to 18 nT (Figure 8a). On both maps, the distribution of low anomalies tends to be in the southern and central parts of the study area where there are hot springs.

On the residual anomaly map the magnetic anomaly is seen more clearly and the distribution of low anomalies is more visible. It is suspected that the low anomalous distribution is a rock alteration zone caused by the influence of heat which weakens the magnetic properties of the rock. From the residual map it is suspected that there is a structure that controls the flow of hot fluid in the study area. This can be seen from the low anomaly pattern which indicates that the rock loses its magnetic field due to heat. Furthermore, the Second Vertical Derivative (SVD) process is carried out to see a clearer indication of the structure using Elkins filter showing clearer contras anomaly values as shown in Figure 6b. Indication of a structure in the form of a fault is characterized by the contrast of high anomaly and low anomaly.

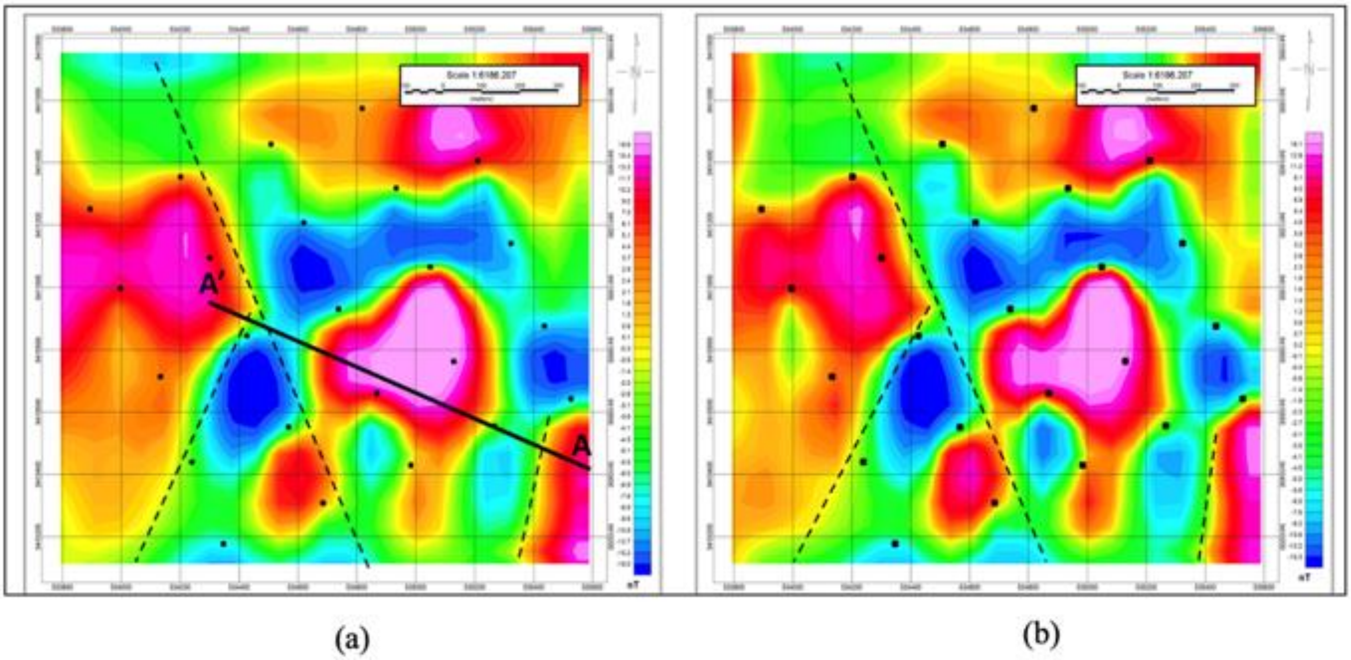



**Figure 5.** Anomaly map of (a) Residual and (b) SVD showing the possible structures around the study area that control the flow of hot fluids.

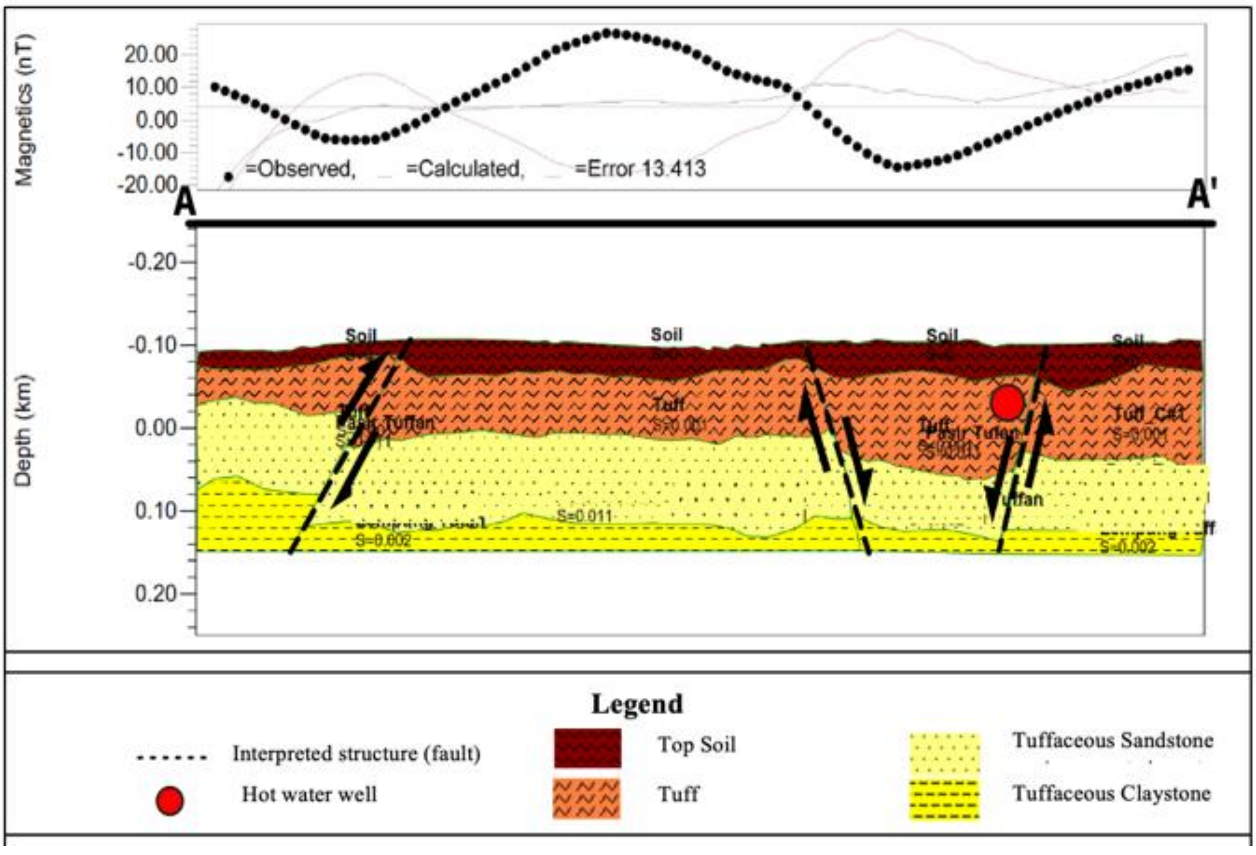



**Figure 6** 2D forward modeling map showing the presence of fractures around the study area that allow hot fluids to flow close to the surface.

Figure 7 shows an anomaly suspected to be a hot water line. There is a low anomaly which is suspected to be a hot water path. From residual map, it will be possible to estimate the existence of a structure that will be used as a reference in carrying out 2D modeling in Southeast – Northwest direction showing in Figure 6a (the solid black line from A to A'). From slicing, forward 2D modeling is carried out to produce a 2D model as shown in Figure 7. Geologically, the location of Jatimulyo hot springs consists of volcanic products which are dominated by tuff. The model consists of 4 layers with the top layer being soil with a susceptibility value of 0.0001, the second layer formed from tuff with 0.001 SI, the third layer indicating tuffaceous sandstone with 0.011 SI and the fourth layer dominated by tuffaceous claystone with 0.002 SI. In addition to obtaining the type of rock from the modeling, it was also found that there was an alleged structure that could cause the hot water flow in the study area. This also is supported by the residual and SVD anomaly results in Figure 6a and 6b. It can also be seen that in the bathing area hot water lies in a low anomaly, this is in accordance with the magnetic concept, namely when magnetic rocks are exposed to heat, their magnetic properties will get weaker and also from the residual anomaly, it can be seen that there is a flow of hot water marked in dark blue that passes through the hot spring area.

The lithology of the layers obtained from the modeling results as well as the local regional geology indicate that they are mostly consist of volcanic product. It is also seen that there are altered rocks (alteration zones) caused by the hydrothermal flow. It is suspected that the flow of hot water in the study area occurs due to tectonic activity in the form of subsurface faults because of convergent forces/pressure originating from subduction zones that subduct beneath the continental plate. Because there is no volcanic system in the study area, it can be concluded that the research area is an outflow zone where the heat source is far from the research areas. This is supported by hot water temperature in the area is less than 90 degrees.

## 4. CONCLUSION

Tectonic activity around the Lampung region greatly influences the existence of manifestations and the appearance of several hot springs in the South Lampung region. Tectonic activity in the form of faults could be possible for hot water to flow. From the results, we can conclude that the hot water that appears in Jatimulyo Village is the outflow zone with low temperatures because the area is far from heat. This can also be seen from the existence of a main structure that allows it to control the emergence of hot water in the study area. From the magnetic anomaly, a low anomaly occurs because the rocks around the hot spring have lost their magnetic field due to the heat.

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