Subsurface structure identification uses derivative analyses of the magnetic data in Candi Umbul-Telomoyo geothermal prospect area

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Abstract. Telomoyo geothermal prospect area is located in Central Java, Indonesia. One of the manifestations around Telomoyo is a warm spring, called Candi Umbul. The hydrothermal fluids from the manifestation could be from the subsurface flowing up through geological structures. The previous research about 2D magnetic modeling in Candi Umbul showed that there was a normal fault with strike/dip N60\textdegree E/45\textdegree respectively. This research aims to know the distance boundary and the kind of the geological structure in the study area. We also compared the geological structure direction based on the geologic map and the derivative maps. We used derivative analyses of the magnetic data, i.e. First Horizontal Derivative (FHD) which is the rate of change of the horizontal gradient in the horizontal direction. FHD indicates the boundaries of the geological structure. We also used Second Vertical Derivative (SVD) which is the rate of change of the vertical gradient in the vertical direction. SVD can reveal normal fault or thrust fault. The FHD and SVD maps show that the geological structure boundary has the same direction with the north west-south east geological structure. The geological structure boundary is in 486 m of the local distance. Our result confirms that there is a normal fault in the study area.

1. Introduction

Indonesia is a country that located in the ring of fire zone. This condition makes Indonesia has about 127 active volcanoes around it [1]. These volcanoes are the sources of some geothermal prospect areas in Indonesia, especially in Java Island that dominated by volcanism activities. One of the geothermal areas in Java is Telomoyo.

One of the manifestations around Telomoyo is a warm spring, called Candi Umbul. This warm spring has a chloride water type which the temperature is about 36\textdegree C and pH 7.6 [2]. Based on the research of structural lineaments satellite imagery data, the geothermal prospect area in Candi Umbul is correlated with Telomoyo activities [3]. Besides that, there were VLF-EM and 2D magnetic modeling research. The VLF-EM result showed that there was a high conductivity zone. It associated with the subsurface
structure. The high conductivity zone was located in 5600 m of the local coordinate [4]. The 2D magnetic modeling in Candi Umbul showed that there was a normal fault with strike/dip N60°E/45° respectively [5].

This research aims to know the distance boundary and the kind of the geological structure in Candi Umbul-Telomoyo geothermal prospect area. We used derivative analyses of the magnetic data, i.e. first horizontal derivative and second vertical derivative. We also compared the geological structure direction based on the geologic map and the derivative maps.

![Figure 1](image1.png)

**Figure 1.** The red rectangle map is a part of the geologic map of the Magelang and Semarang quadrangles [6]. The survey design points overlay the geologic map [7]. The yellow rectangle map is the map of Indonesia, while the green rectangle map is the map of Java Island. The black rectangle in Java Island’s map shows the research location.

2. Materials and Methods
This research is an advance part of the previous research. The method and the data are same, but we used different analyses. In this research, we used the magnetic method. The magnetic method is a potential method which measures the earth’s magnetic field intensities. The magnetic field intensities are obtained from the magnetic properties of the underlying rocks and the environment where the rocks are in it [8].

![Figure 2](image2.png)

**Figure 2.** The map shows the total magnetic field of the study area. It still has the dipole data. The largest anomalies are in the west and in the middle of the map [7].
To delineate and analyze the structures beneath the surface in Candi Umbul-Telomoyo geothermal prospect area, we used First Horizontal Derivative (FHD) and Second Vertical Derivative (SVD) to the magnetic data. Both analyses aim to know the margins of the magnetic sources [9].

Before doing FHD and SVD, the data were transformed into a Reduction to Pole (RTP) because the study area still produced dipole data (Figure 2). RTP is a filter to make the data easier to be interpreted. It provides a simple approach to improve realistic estimations of the source of anomalies [10]. The dipole data have an asymmetric pattern [11]. This asymmetric pattern depends on the shape of perturbing body, the direction of the magnetic field and the inclination angle of the study area [12].

The First Horizontal Derivative (FHD) is the rate of change of the horizontal gradient in the horizontal direction. FHD indicates the boundaries of the geological structure. This derivative analysis is used to delineate high-frequency features clearly [13]. The gradient amplitude of first horizontal derivative can be defined by [14]:

\[
FHD = \sqrt{\left(\frac{\partial H}{\partial x}\right)^2 + \left(\frac{\partial H}{\partial y}\right)^2}
\]

while the Second Vertical Derivative (SVD) is the rate of change of the vertical gradient in the vertical direction. Theoretically, from the Laplace’s equation, if \( H \) is a potential so \( \nabla^2 H \) is equal to 0 [15]:

\[
\frac{\partial^2 (\Delta H)}{\partial z^2} = -\frac{\partial^2 (\Delta H)}{\partial x^2} - \frac{\partial^2 (\Delta H)}{\partial y^2}
\]

the SVD can reveal normal fault or thrust fault. If the maximum absolute value is greater than the minimum absolute value, we conclude it as a normal fault. Vice versa, we conclude it as a thrust fault [16].

3. Results and Discussions

Figures 3 and 4 show the geological structure boundary that causes the anomalies. The geological structure boundary in figure 3 can be correlated with 0 value in the number scale range of figure 4. Besides that, we also used the geologic map from figure 1 to determine the geological structure in the study area. The FHD and SVD maps show that the geological structure boundary has the same direction with the north-west-south-east geological structure.

![Figure 3](image)

**Figure 3.** The map shows the first horizontal derivative in the X direction with A-B slicing line. Line A-B slices the boundary of the geological structure perpendicularly.

The geological structure that appears in the FHD and SVD maps is only the west side. The other geological structures do not appear on the map because the lithology is dominated by andesite in the middle and east side. Andesite is an igneous rock that contains some magnetic minerals. Those minerals will have a strong response to the magnetic anomalies. So, the lithology response will be stronger than the geological structure response.

We made two graphs of FHD and SVD from the A-B slicing line of figures 3 and 4. The first horizontal derivative tends to have characteristics with maximum or minimum value in the area with the
geological structure. In figure 5a, the peak of the graph shows the maximum value. This maximum value indicates the geological structure boundary. From the graph, we know that the geological structure boundary is located in the local distance 486 m with the FHD value is 0.489 nT/m.

**Figure 4.** The map shows the second derivative in the vertical direction with A-B slicing line. Line A-B slices the boundary of the geological structure perpendicularly.

To determine the kind of the geological structure in the study area, we used the SVD graph in the figure 5b. In this graph, the anomaly that is caused by the geological structure will have maximum absolute value and minimum absolute value. The maximum absolute value is 0.00261 nT/m² and the minimum absolute value is 0.00239 nT/m². Since the maximum absolute value is greater than the minimum absolute value, we conclude it as a normal fault.

**Figure 5.** (a) The graph of the first horizontal derivative in the A-B slicing line. (b) The graph of the second vertical derivative in the A-B slicing line.

This research has confirmed the previous 2D magnetic modeling research. The kind of the geological structure in the study area is a normal fault. Besides that, this research has confirmed the geological map about the direction of the west side geological structure is north west-south east.

4. Conclusions

Based on the results, only the west side geological structure boundary appears in the FHD and SVD maps. The FHD and SVD maps show that the geological structure boundary has the same direction with the north west-south east geological structure. This geological structure boundary correlates with the maximum value of the FHD map and it has 0 value in the number scale range of the SVD map.

The FHD graph shows that the geological structure boundary is in 486 m of the local distance. It has maximum FHD value 0.489 nT/m. While the SVD graph has maximum absolute value at about 0.00261 nT/m² and minimum absolute value at about 0.00239 nT/m². Since the maximum absolute value is
greater than the minimum absolute value, we conclude that the kind of the geological structure in the study area is a normal fault.

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