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# Subsurface Structure Mapping Using Geophysical Data in Candi Umbul-Telomoyo, Magelang, Central Java, Indonesia

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Abstract. Candi Umbul warm spring is one of the manifestations in the Telomoyo geothermal prospect area. A geophysical survey had been conducted using VLF (Very Low Frequency) EM, VLF R and magnetic methods in the Candi Umbul-Telomoyo. VLF EM, VLF R and magnetic data were aimed to image the conductivity and magnetic anomalies distribution of the subsurface beneath the Candi Umbul-Telomoyo. VLF EM data had been mapped with Karous-Hjelt filter and analysed by tipper analysis, VLF R data had been modelled using 2layinv and analysed using impedance analysis. On the other hand, magnetic data processing was done with upward continuation. The Karous-Hjelt filter and 2layinv models show the highest conductivity distribution that located at 4800-5000 m were correlated with tipper and impedance analyses. In addition, the high-low magnetic contrast from the quantitative magnetic data interpretation indicates a fault (which could be a fluid pathway) which is closed to the Candi Umbul warm spring manifestation.

#### Introduction

Indonesia is a country with high geothermal prospect potential [1]. Telomoyo volcano, as one of geothermal prospect area locates in Magelang, Central Java, Indonesia. One of geothermal manifestation is the Candi Umbul warm spring, temperature of  $(35 - 36)^0$  C [2]. Warm spring indicates that there are fluids beneath the earth. A conductivity distribution of VLF data and susceptibility distribution of magnetic data are able to map the fault.

Previous study found that upflow zone located around the Telomoyo caldera [3]. In the contrary, the outflow zone was interpreted around the Candi Dukuh, Candi Umbul and Pakis Dadu manifestations [4]. A previous magnetic model showed a normal fault with strike N  $60^{\circ}$  E/45° [5]. Stratigraphy of research area consists of Kaligetas Formation, Gunungapi Gilipetung rock, Gunungapi Andong and Kendil rock, Gunungapi Telomoyo rock, Gunungapi Merbabu rock, Kerucut Gunungapi sedimentation and alluvium [6]. Four main structures in Candi Umbul-Telomoyo has direction N 100-110° E/N 280-290° E, N 60-70° E/N 240-250° E, N 20-30° E/N 200-210° E, and N 150-160° E/N 330- $340^{\circ}$  E, where the major direction of the structures are northwest-southeast and north-south [2]. Whereas, VLF and magnetic data were aimed to identify the major structure which controls Candi Umbul warm spring.

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**Figure 1.** The research area was located in Candi Umbul-Telomoyo, Magelang Regency, Central Java, Indonesia. The Candi Umbul warm spring manifestation is one of the three warm springs manifestation of Telomoyo geothermal area. The Candi Umbul is located on the west side of Telomoyo volcano.

#### Method

Acquisition of VLF EM data was performed on March 18-19, 2017 while VLF R data acquisition conducted was on March 25-26, 2017. Magnetic data, acquisition was done on April 6-9, 2017. Based on geological map Magelang-Central Java [7], the direction of the main structure is north-south. For that reason, VLF's line had west-east direction using the transmitter from NWC (19800 Hz) and VTX3 (18200 Hz). VLF data consist of 54 points in a line of 10.3-kilometres length. Magnetic data acquisition consist of in 3 lines (105 points).

VLF EM data were processed using spline and moving average. Tilt data also filtered using Fraser equation [8]. In order to get the current density distribution of VLF EM, the data were also filtered using Karous-Hjelt [9]. The presence of conductor is indicated by low resistivity [10]. The relation between magnetic field represented by tipper (A, B) which used as VLF EM data analysis. Tipper A is parallel to x coordinate (east), while tipper B parallel to y coordinate (north) and transmitter direction [11]. The ratio of the horizontal magnetic field and the orthogonal magnetic field (called impedance) were used in VLF R data analysis [12]

On the other hand, magnetic data processing started with diurnal and IGRF correction. The result from the total anomaly magnetic field was reduced to pole and upward continuation 1500 m. Upward continuation is a process that transforms anomalies measured on a surface to those that have been measured on some higher surface [13].

#### **Result and Discussion**

Tipper analysis was done by calculating the ratio between the value of the vertical magnetic field and the horizontal magnetic field. The horizontal magnetic field is the primary magnetic field derived from the transmitter. While the vertical magnetic field is a secondary magnetic field resulting from induction of the primary magnetic field. The variation of the tipper value shows variations in lateral conductivity beneath the surface [14]. Based on tipper analysis result, the existence of conductive anomaly was indicated by the increasing tipper values at distances of 1200 m, 3200 m, 4200 m, 5600 m and 8250 m in local coordinate (from west direction of the profile line survey).

The first processing on VLF EM data was the interpolation of tilt data using a spline to make the same measurement spacing (100 metres). Karous-Hjelt filter gave the result of high current density

distribution in red colour which associated with the conductive zone. The conductive zone found at distance of 4000 m to 5600 m of local coordinates. While the resistive zone (blue colour) appears at 5700 m-7000 m of local coordinates. In VLF EM data, a consistent conductive anomaly appears at 5600 metres distance (shown in Figure 2). The conductive anomaly is estimated to be a fault. While the fault at distance of 5600 metres is a relatively north-south fault that indicated as a river.



**Figure 2**. Current density distribution map. The conductive zone was characterized by a high current density (red colour). The conductive zone was at distance of 4000 m to 5600 m local coordinates. While the resistive zone showed at a distance of 5700 m-7000 m local coordinates.



**Figure 3**. The result of the sorted impedance log data versus distance at frequency 18200 Hz. The approximate location of the conductive anomalies was at a distance of 1000 m, 5200 m and 8750 m.

For VLF R, the impedance log data were sorted based on the quality bar of electromagnetic signal that received and the transmitter signal direction. Since the apparent resistivity value is proportional to the impedance value, the existence of the conductor was also characterized by the small impedance value measured. Based on Figure 3, the approximate location of the conductive anomaly shown by the decrease of impedance which located at distances of 1000 m, 5200 m and 8750 m local coordinate.

The input for VLF R modelling were apparent resistivity, phase and distance. Weighting data was also used to get the fit model. Weighting parameter was quality bar and noise (electric noise, magnetic noise and magnetic electric noise). The higher quality bar and the absence of noise would give the higher data weight. Based on the result of 2layinv modelling, the conductive zone of the model was found at distances of 1000 m-2500 m that indicated by red colour The green colour in the east of survey area showed a resistive zone which correlated to andesite-basaltic rock in Telomoyo volcano.

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**Figure 4.** Resistivity model of Candi Umbul-Telomoyo volcano using the 2layinv software. The conductive zone is shown at distance of 1500 m-3000 m (red colour) while the resistive zone located in the east of survey area represented by green colour.

In magnetic processing, total magnetic field anomaly which got from diurnal and IGRF correction had the distribution value of -681 nT to 271 nT. The wide range of this anomaly caused by variation of lithology in the survey area. In order to change dipole effect become monopole, total magnetic field anomaly was reduced to pole. The reduce to pole map still consisted of local anomaly and regional anomaly which should be separated with upward continuation. Upward continuation made the anomalous feature clearer. Figure 5 has a high anomaly with red to pink colour while the low anomaly has the blue colour. The presence of high-low anomaly indicated the structure beneath the surface.



**Figure 5.** Map of magnetic field anomaly from 1500 m upward continuation of geothermal prospect area of Candi Umbul-Telomoyo volcano. The number 1 anomaly pattern was identified as the normal fault structure and the number 2 anomaly pattern was identified as the lithologic contact between the Gilipetung andesite rocks and the Merbabu volcano pyroclastic deposits.

# Conclusion

A geophysical survey can be a brief method to reveal a structure beneath Candi Umbul-Telomoyo geothermal prospect area. A geophysical survey using VLF and magnetic method show the fault structures which control Candi Umbul warm spring located at distance of 1500 m and 5600 m. At distance of 1500 m, the fault has northwest-southeast direction while at distance of 5600 m, the fault has north-south direction.

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