Identifying the Distribution of Alteration Zone Using Very Low Frequency Method in Candi Gedong Songo, Ungaran, Semarang, Central Java

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Abstract. The alteration zone could be a key link and a proof to know where the paleo heat source was previously located. An electromagnetic survey to identify and to map the lateral and vertical distribution of alteration zone had been done at geothermal area Candi Gedong Songo, Ungaran, Central Java, from 9th – 19th of June 2014, using VLF method. The survey consisted of 6 profiles, with NW – SE direction, which were located nearby the fumaroles spots and then went down to the observed alteration zone. Each profile was 600 m long and the distance between each profile was 20 m. The space between each measurement point of a profile was 20 m. In this study, tilt and ellipticity data with frequency of 19.8 kHz (Japan) and 24 kHz (Panama) were used. First, the data was processed to get the cross features anomaly between tilt and ellipticity data on the chart. Then, the derivative fraser and the relative current density pseudosection were also made to support the cross features anomaly. The interpretation of this data was done qualitatively using fraser and relative current density pseudosection. The result shows that the alteration zone gives high response of conductivity compared to its surrounding area. This is supported by the anomaly cross features between tilt and ellipticity data on the chart, also by high value of fraser and relative current density. Thus, the alteration zone are located in meter 150 – 250 in V1 and V2 profiles, also in meter 180 – 250 in V5 and V6 profiles. This result indicates that the ancient heat source was previously located nearby the fumaroles area and it is physically shown by the presence of sulphuric clay mineral content at the alteration surface area.

1. Introduction

Many techniques and efforts are being developed to fulfill the needs of energy these days. One of the many efforts is through the exploitation of geothermal resource. Geothermal has proven to be a fulfilling energy resources that has many advantages compared to fossil energy resources. It is renewable, produces almost zero pollution, and of course environmental-friendly.

Geothermal potencies spread from West to East of Indonesia. Java Island has many geothermal potencies spread along the mountains, one of them is located in Gedong Songo, Ungaran, Semarang, Jawa Tengah (Middle Java). The geothermal type of Gedong Songo is volcanic which has many visible manifestation such as fumarole, steaming ground, hot spring, and alteration zone. In this work, the VLF
method was used in order to identify the alteration zone as it allows fast fieldwork measurements, low cost, and can detect conductive zones easily.

This kind of work is a final-year field work activity of Geophysics sub-Department, Universitas Gadjah Mada. The acquisition process took up to 8 days which has been done by all of student of Geophysics sub-Department, Universitas Gadjah Mada (Class of 2010). The other 2 days were needed to complete the processing and interpretation step to finalize the result. So, as the total, this work has been done in 10 days (from 10th to 19th June 2014).

2. Regional geology
Gedong Songo is a part of Ungaran Mt. Which located on East of Serayu Highlands. Ungaran Mountain bordered by alluvial land on North, quarter volcanic route (Sindoro, Sumbing, Telomoyo, Merbabu Mt.) on South, and Kendeng Highlands on East. North of Java is consist of geosyncline with West-East orientation (Van Bemmelen, 1949) [1].

According to Bemmelen, the measurement area is occupied by alluvial and young Ungaran deposition. This formation consisted of volcanic breccia which lies over Damar Formation series (tuffaceous marls and tuff limestone) and developed on Upper Pleistocene.

Java Island is an area of basin subsidence, fault system, folding system and volcanism under the influence of different stress regime on different time. There are three structural pattern namely Meratus pattern (North East – South West), Sunda pattern (North – South) and East – West Pattern.

Tectonic system in Ungaran is dominated by stress regime of Sunda pattern. This pattern created mainly extensional geology structure. On this area, it was found many collapse structure with West – South East orientation. This situation leads to graben which exist on South and horst on North of Ungaran Mountain

3. VLF method
The VLF method is one of many geophysics method that used electromagnetic wave on its acquisition. The aim is to measure electrical conductivity of the target by capturing secondary electromagnetic wave. Secondary electromagnetic wave is generated from induction of primary electromagnetic wave to a medium. The induction of a conductor by the primary electromagnetic wave resulting in Eddy current and causing secondary magnetic field to occur which is captured by VLF receiver. This general concept on how VLF method works is shown on Figure 1.

![Figure 1](image-url)  
*Figure 1. Principle of electromagnetic method induction (Grant, F.S. and West, G.F., 1965 [2])*
VLF method studies the target using a certain designed survey in a shape of line by line. The parameters as a result of VLF survey along the line are the values of tilt angle (θ) and ellipticity (ε) (or known as I/P and Q) at each measurement point (Karous and Hjelt, 1983) [3]. The illustration and formulas of tilt angle (θ) and ellipticity (ε) are shown in Figure 2 and equation (1) and equation (2).

\[
\varepsilon = \frac{b}{a} = \frac{H_z H_x \sin \phi}{[H_x e^{i\theta} \sin \theta + H_x \cos \theta]}
\]

\[
\tan(2\theta) = \frac{2 \left( \frac{H_z}{H_x} \right) \cos \phi}{1 - \left( \frac{H_z}{H_x} \right)^2}
\]

4. Data
Data used on this study are tilt and ellipticity (%) with frequency of 19800 KHz (Japan) and 24000 KHz (Panama) based on measurement using T-VLF Iris Instrument.

5. Methods
VLF is an effective method to map some targets of geothermal area, it is cheap and fast. This fieldwork aims to map the alteration zone distribution of geothermal area Candi Gedong Songo. VLF data acquisition which covering the whole survey area was done in 10 days (from 10th to 19th June 2014). The complete workflow of this fieldwork is shown in Figure 3.

Survey design is the initial step that should be done before starting acquisition. Survey design was made based on the geological information of the geothermal manifestations location and the topography map of the survey area. Data acquisition was performed with the final survey design which comprises of 6 profiles (each profile was 600m long), the distance between each measurement point and between each profile were 20m. Each profile was measured in N 165° E direction. Two transmitters at 19.8 kHz (Japan) and 24 kHz (Panama) were used in this survey. These profiles layout can be found in Figure 4.
Figure 3. Workflow

The profiles were designed perpendicular to the regional structure and to the transmitters. VLF survey was performed using T-VLF from *Iris Instrument* with three receiver components (*Hx*, *Hy* and *Hz*). The measurement recorded tilt and ellips respond. During the acquisition, we also needed to do simple geological sampling and mapping which associate with the existence of geothermal manifestations. Furthermore, the elevation of each measurement point should be noted. That will give benefit in creating geological profiling along the measurement profile as shown in Figure 5. This geology profiling along the line measurement helps us to interpret and analyze the processed data.
Figure 4. Design survey map (black dotted) and survey map (yellow dotted) VLF measurement with azimuth direction N165°E

Figure 5. Geology profiling of line V1 in Geothermal area, Gedong Songo. Alteration zones found around in meter 20, 150 and 400 along the track measurement line V-01

The data obtained from acquisition was processed to get anomaly chart by plotting tilt & ellips versus distance along profile measurement. This anomaly chart was used to identify conductive zones. Derivative fraser calculation and equivalent current density model were made to support the anomaly chart. The result shows alteration zone gives high response on conductivity than its surrounding area.
This is supported by cross feature between tilt and ellipticity data on anomaly chart, also by high value of fraser and equivalent current density. The result of these plots and the equivalent current density model can be seen in Figure 6.

![Figure 6](image)

**Figure 6.** An example of Line V1 processing which resulting in plot of real & imaginary component, also fraser filtered data. This line graph plot was combined with the 2D pseudodepth relative current density value.

As can be seen on Figure 6, the original data of real (blue dotted line) and imaginary (orange dotted line) components were plotted along with the value of fraser filtered data (grey dotted line) using the real component along with the model of relative current density of six profiles. The relative conductive zones are shown on the original plots as crossing value of real and imaginary part, with high value of fraser filtered data, and high relative current density value.

The equivalent current density was created by calculating the tilt value as real component in electromagnetic field. In its calculation, there was distance correction every six measurement points. The maximum pseudodepth of equivalent current density distribution was 4n, where n is the distance between each measurement point. This means that with 20m measurement distance, the pseudodepth penetration was 80m, as shown in Figure 6.

The result of relative current density was then used to make interpretation of the measurement area. Furthermore, the slicing model of each profile in pseudodepth of 20m and 40m was made to get lateral equivalent current density. The slicing result was overlaid on contour maps and were plotted on each measurement point. The alteration zone distribution was interpreted using the lateral current density model, plots of tilt, ellips, and fraser (which shown anomaly area), with the aid of geological profile over the measurement area.
6. Discussion
Plots of the original and filtered of real and imaginary components (using Japan transmitter 19.8 kHz) was produced for each profile (V1, V2, V3, V4, V5, and V6) and they were interpreted in view of the existence of conductive zones that could be related to the alteration zones. As a first step, the original data of real (blue dotted line) and imaginary (orange dotted line) components are plotted along with the value of fraser filtered data (grey dotted line) using the real component. The crossing value of real and imaginary component and high value of fraser was interpreted as conductive area.

In Figure 6, plots of the original and filtered of real and imaginary part along with the model of relative current density of six profiles are presented. As we can see from this figure, the relative conductive zones are shown on the original plots as crossing value of real and imaginary part, with high value of fraser filtered data, and high relative current density value. In this picture, there is correlation between the plots of data and high relative density current that related to the conductive zone in meter 150 in line V1 as alteration zone.

Figure 7. Correlation of relative current density of each profile.
As a final step, the models of relative current density of each profile are produced then we make a correlation. **Figure 7** shows a continuity conductive zone along line V2, V1, V6, and V5. It can be interpreted that the conductive zone shown in **Figure 7** are related to the alteration zones. There is a continuity conductive zone in meter 150 – 250 along line V-02, V-01, V-06, and V-05 also in meter 450 in along line V-01 and V-02. The conductive zone are related to the alteration zone.

The slicing of relative density current of all profiles is also produced. The slicing is made in order to show the lateral view of the measurement area. The red area shown in **Figure 8** has higher density current value rather than the surrounding area. This correlates with red zone in line V1 until V6. This can be interpreted as an area of alteration zone.

**Figure 8.** Slicing of line V1, V2, V3, V4, V5 and V6. (a) Slicing in apparent depth 20; (b) Slicing in apparent depth 40. The red area shown in this figure has higher current density value rather than the surrounding area. So that we interpreted this area as alteration zone.
Conclusions

The alteration zones as surface manifestation of geothermal field in Gedongsongo, Ungaran, Central Java are shown in plots in original data as crossing value of the real and imaginary parts, with high value of fraser filtered data, and high relative current density value.

Those alteration zones are located in meter 150 – 250 in V1 and V2 profiles. Also in meter 180 – 250 in V5 and V6 profiles. There is another relative conductive zone in meter 450 in V1 and V2 profiles that could be related to the flow of sulphuric water around the measurement area.

This alteration zone distribution provides us an information about the paleo heat source of this geothermal field. Thus, by interpreting and analyzing the lateral and vertical pseudodepth of equivalent density model with the aid of geological and geochemical information found on the surface area (steaming ground and relic manifestation), we can assume that the paleo heat source was located nearby the fumarole and hot spring area.

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