Estimation of Existence Geothermal Manifestation Using Very Low Frequency (VLF) Method in the Pagerkandang Vulcanic, Dieng, Central Java

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Abstract. Very Low Frequency (VLF) measurement has been done at Pagerkandang Volcanic, Dieng Volcanic Complex (DVC) to examine the possible existence of conductive zones that related with geothermal manifestation. VLF – EM survey used tilt mode with T-VLF BRGM Iris Instrument operated with two frequencies, they are 22200 Hz from Japan (JJI) and 19800 Hz from Australia (NWC). There are five lines with distance between lines is 50 m, and distance between measure points is 20 m. The parameters measured from VLF method are tilt angle (%) and elliptisity (%). Data processed by tilt angle value with Fraser and Karous – Hjelt filter used WinVLF program. Karous – Hjelt filter resulted current density contour to estimate lateral location from conductive and resistive zones. The conductive zone is interpreted as the area which have high current density value. This area located at eastern dan western of Pagerkandang Volcanic. The conductive zone related to geothermal manifestation as like as fumarol that appeared because presenced of normal fault. Whereas the resistive zone is interpreted as the area which have low current density value. This area spread almost in the middle of the Pagerkandang Volcanic. The resistive zone was caused by the high weathering in claystone.

Keywords : Very Low Frequency, Pagerkandang Volcanic, geothermal manifestation

1. Introduction
Dieng Volcanic Complex (DVC) is one of the productive geothermal fields in Indonesia. Dieng geothermal systems have a high temperature and liquid-dominated. High temperatures in geothermal systems can be caused by the age and composition of the heat source (Wohlez and Heiken, 1992; Muffler and Duffield, 1995 in Harijoko A et al. 2016). The total potential of geothermal energy in Dieng is estimated at 355 MW but only 60 MW which has been utilized as a source of power plant. Pagerkandang volcanic is one area that has a geothermal prospects associated with Sileri Crater. Geothermal manifestations can be fumaroles, acid sulfate spring, mud pools, steaming ground and rock alteration (Harijoko A et al. 2016).

VLF method utilizing electromagnetic wave induction can be used to determine the continuity of conductive regions geothermal area based on their surface manifestation. Control of the fault structure largely determines the location of these manifestations. Open fractures formed by the structure used as the hydrothermal fluid flow path and carries with her metallic minerals. In this paper conducted qualitative interpretation of the value of the tilt angle using Fraser filter and Karous – Hjelt filter. Karous – Hjelt filter will generate value for the current density equivalent (RAE) to estimate the distribution of the resistive and conductive zones.
2. Geological Setting
Dieng Volcanic complex had being formed by volcanic stratocones, explosion craters, parasitic vent, and also hydrothermally active which originated at the junction of two major fracture zones. The fracture is an east-west trending zone, extending due west from the Dieng Mountains 50 km to the Mount Slamet and the one consist of a row of young cones including Mount Sindoro-Sumbing which extend southeast of the Dieng Mountains for 25-35 km (Zen M T, 1971; Dan Miller C et al., 1983).

Dieng Volcanic Complex also consist of three episodes, there are pre-caldera episode, post-caldera episode and the present episode. The research area located in Pagerkandang Volcanic which included in the post-caldera episode where volcanic activity develops in the caldera. Pagerkandang Volcanic has a crater on the northern part, and there are geothermal manifestations (solfatara and fumarol) scattered along the inside and outside of the crater. Most of the hydrothermal activity are associated with explosion crater, tectonic lineament, or fracture zones in the Dieng Volcanic Complex. According Jacobson (1970) in Zen M T (1971), based on electrical geophysical survey, the thermal areas outlined by surface manifestations and the belt of anomalously low resistivity that related to the northwest-southeast trending lineament. The thermal belt coincides with the zone of volcanic lineament which extends from Pakumadja to Pagerkandang. The research area is dominated by material of post-caldera eruptions, such as olivine andesite, hornblende andesite, and biotite andesite (Dan Miller C et al., 1983).

Alteration process changes volcanic rocks into clay minerals which have high conductivity (low resistivity). The altered rocks are layered by sulfur minerals and are founded surrounding the manifestation. This minerals give important information types and locations of Dieng geothermal heat source system.

3. Very Low Frequency (VLF) Method
VLF method uses electromagnetic waves of radio waves having a frequency ranging from 15 – 30 kHz. Primary electromagnetic field of the transmitter has components vertical electric field and horizontal magnetic that perpendicular to the direction of propagation (the x axis). If a conductive medium exists in the subsurface, the magnetic component of the electromagnetic waves would induce the medium caused induced currents or Eddy currents. Eddy currents would product secondary electromagnetic field (Hs), which has horizontal and vertical components. Interference between the primary magnetic field and secondary magnetic field generates a magnetic field which is resultant polarization ellipse. The components are measured in the VLF method is a tilt angle (α) and ellipticity (ε).

Qualitative interpretation of VLF method data can be performed with fraser filter and Karous-Hjelt filter (linear filter). Data used in the process of filter is the tilt angle (%). In fraser filter large amplitude can be estimated as conductive zones (Sundararajan N et al., 2006). The highest of fraser filter graph shows the increase of the signal conductive medium, where in the conductive anomaly is considered appropriate under the peak graph fraser filter (Santos et al., 2006). The filter divides tilt angle data with 90° to transform zero-crossing into peak, and a low pass smoothing operator to reduce noise, such as topographic effect.

\[ f_{2,3} = (M_3 + M_4) - (M_1 + M_2) \]  

\( f_{2,3} \) is filter fraser value that plotted midway between \( M_3 \) and \( M_4 \) tilt angle data.
Figure 1. Ellips polarization because of existence conductive object in electromagnetic field (Bahri A S).

Figure 2. Synthetic Data VLF-EM and fraser filter data that is correlated with the 2-D resistivity models (Monteiro Santos F A et al., 2006).

Karous - Hjelt Filter used to determine the value of the current density equivalent. Lower values of current density shows a resistive zone and vice versa (Benson et al., 1997 in Monteiro Santos F A et al., 2006). Karous - Hjelt filter using linear filter theory to solve the integral equation in the current distribution. The linear equation obtained current density values for various depths along the line from vertical magnetic field each measure point. The formula used is:

$$\frac{\Delta z}{\pi} \left( \frac{I}{A} \right) \frac{\Delta x}{2} = -0.102 H_3 + 0.059 H_{-2} - 0.561 H_{-1} + 0.561 H_1 - 0.059 H_2 + 0.102 H_3$$

with $\Delta z$ is the depth (m), $(\frac{I}{A})$ is the current density (%), $\Delta x$ spaced measurements (m), and $H$ is the tilt angle of the data (%). Current density $(\frac{I}{A})$ is the flow of the charge current ($I$) in a cross-sectional area ($A$) at a certain point conductor. The position of current dencity can used to interpret the wide and dip of anomaly in certain of depth.

4. Methodology

VLF – EM survey has been done at Pagerkandang Volcanic, DVC. VLF – EM survey used tilt mode with T-VLF BRGM Iris Instrument operated with two frequencies, they are 22200 Hz from Japan (JJI) and 19800 Hz from Australi (NWC). There are five lines with distance between lines is 50 m, and distance between measure points is 20 m. Data processing for Fraser and Karous – Hjelt filter used WinVLF program by Mufaqih A A (2015).

5. Result and Discussion

Based on dissemination of tilt angle at location of VLF measured, the high tilt angles are located at the edge of Pagerkandang Volcanic, with tilt angles are 30 – 80 % (red colors). Whereas in mid Pagerkandang Volcanic has tilt angles ranging from 25 – (-40) % (green colors). The tilt angle related
to horizontal and vertical magnetic field, and indirectly can be used to determine conductive zone from high tilt angle value.

Tilt angle values obtained in the field are still influenced by external noise that has a high frequency. Because of the assumption of the waves received by VLF - EM is a wave with a low frequency, the high frequency noise to be removed, one of them uses a moving average filter. Qualitative interpretation on VLF - EM method is using Fraser filter and Karous – Hjelt filter of tilt angle values. Karous – Hjelt filter will generate value for the current density to estimate the lateral location of the resistive and conductive zones. Conductive zones are estimated to be below the chart fraser filter with high amplitude (peak chart). While the linear filter (Karous–Hjelt filter) current density value is a predicted high conductive zone.

Figure 3. Distribution of tilt angle value at survey area.

On the graph of Fraser filter and Karous-Hjelt filter look anomalous responses that are interrelated. On Line A conductive zones are located at a distance of 120-240 m or on the eastern side of the Pagerkandang Vulcanic assuming depth (skin depth) up to 100 m. Conductive zones on Line A have a value of current density between 8–25%. While the resistive zones on Line A are spread between 300-600 m, with a value of current density between (-5) - (-20)%.

The conductive area on Line B is at a distance 500 m (east) and 680-1180 m or on the western side of the Pagerkandang Vulcanic has a value of current density between 10-50% if the skin depth is up to 200 m. High resistivity area in the middle of the Pagerkandang Vulcanic has a value of current density between -10 - (-30)%.

The conductive zones on Line C is between 160-220 m and 560-800 m which has a continuity with the conductive zones on Line B that located on the western side of the Pagerkandang Vulcanic. The value of current density on Line C is between 8–40% including a conductive area. High resistivity area is located at 380–480 m which is also located in the central part of the Pagerkandang Vulcanic, with a value of current density between (-12) - (-28)%.

High conductivity zones on Line D are located at a distance of 180-360 m (east) and 600-700 m (west) with current density between 6-20%. High conductivity area in the western side predicted still associated with Line B and Line C in the south. While the resistive area is located at a distance of 120 m - 180 m (east) and 380-560 m (east) with current density between (-4)% - (-20)%, and the skin depth reaches 120 m.

The measurements on Line E was began on the western side of the Sileri Crater bordering the east side of the Pagerkandang Vulcanic. High conductivity zones are located at a distance of 80-260 m or in transition from Sileri Crater and Pagerkandang Vulcanic with current density between 20–50%. High
resistivity areas are located at a distance of 270-620 m, or scattered in the central part of the Pagerkandang Vulcanic with a value of current density between 10 - (10)% and the skin depth reaches 100 m.

The existence of high conductivity area can be influenced by the presence of geothermal manifestations such as fumaroles, fracture structure, and igneous body (intrusion). Fumaroles discovered in the eastern side of Line A and Line C, which is associated with the normal fault as a result the area has high permeability that allows the upwards flow of the thermal fluids, so the geothermal manifestations may appear on the surface. Fumaroles is also located in the western Pagerkandang Vulcanic, indicated by high conductivity values are constantly on the western side of Line B, Line C, and line D.
FIGURE 4. (a) Fraser Filter Result from tilt angle data line A and Pseudosection Result from Karous – Hjelt Filter line A. (b) Fraser Filter Result from tilt angle data line B and Pseudosection Result from Karous – Hjelt Filter line B. (c) Fraser Filter Result from tilt angle data line C and Pseudosection Result from Karous – Hjelt Filter line C. (d) Fraser Filter Result from tilt angle data line D and Pseudosection Result from Karous – Hjelt Filter line D. (e) Fraser Filter Result from tilt angle data line E and Pseudosection Result from Karous – Hjelt Filter line E.

Igneous rocks are found in research area, like outcrop and boulder. Igneous rock outcrops are found andesite and andesite-dasitic with massive structures and porfiro-afanitic texture. The large outcrops of igneous rock are founded on Line E in the eastern side of the Pagerkandang Volcanic adjoin with Sileri Crater. While the high resistivity area is expected due to the high weathering in claystone. Resistive zones are spread almost in the middle of the Pagerkandang Volcanic.

FIGURE 5. (a) Andesite – dasitic rock (b) Fumarol that founded in survey area
6. Conclusion
Based on data analysis, data processing result and interpretation, Very Low Frequency (VLF) method is used to estimate conductive zones and resistive zones are influenced by current density value that related to surface manifestations. The conductive zone is interpreted as the area which have high current density value. This area located at eastern dan western of Pagerkandang Volcanic. The conductive zone related to geothermal manifestation as like as fumarol that appeared because presenced of normal fault. Whereas the resistive zone is interpreted as the area which have low current density value. This area spread almost in the middle of the Pagerkandang Volcanic. The resistive zone was caused by the high weathering in claystone.

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