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Prediction of Caprock and Structure of Candi Gedongsongo Geothermal System from AMT Data

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Summary

Geophysical investigation with AMT method conducted based on the existence of the surface manifestations on Candi Gedongsongo area and appear to identify the structure of the suspected fault as a weak zone both as recharge area and the emergence of the manifestation zone. This investigation was done on the post volcanic belt of older subduction zone that have significant geothermal gradient by the depth AMT data acquisition was done with Stratagem Unit 26716-01 Rev D by Geometrics that calculate true resistivity with its inversion then modeled on 2D model to identify the fault structure and 3D model to shows the caprock geometry. As a result there are 2 faults shows that has strike and dip of N350oE / 60o that continues from north to south and the second fault shown on P1 but the strike and dip can not be known. The caprock identified on high resistivity value ranges between 1000 -100,000 ohm.m with andesite lithology lying under elevation of 1000 m.

Introduction

Indonesia is the biggest country having 40% of geothermal energy potential in the world. This condition happens because Indonesia lies inside the ring of fire which is the result of interaction between Indo-Australian oceanic crust subducted beneath Eurasian continental crust. As a result, Indonesia has 331 points of geothermal prospecting (*Center of Mineral Resources, Coal, and Geothermal, Ministery of Energy and Mineral Resources*), along with the older volcanic belt from Sumatera to Maluku. As we know that geothermal energy offers brighter solution as renewable energy, hence Indonesian government is taking advantage of this geothermal energy prospets for electric generator project to 35,000 MW necessary.

In encouraging this project, this study was done with geophysical method to identify geothermal system of Candi Gedongsongo, Ungaran, Semarang, Central of Jawa. Surface manifestations such as fumarole, steaming ground, alteration, and geyser are our first feature to perform geophysical investigation. The method used in this study is AMT (Audio Magneto-Telluric) method which take advantage from propagation of electro-magnetic wave to identify geothermal system based on the electric resistivity response.

Signal source from magneto-telluric method is magnetic field from outside of earth, it's magnetic field that made in atmosphere and magnetosphere. Both of the components have a variation value to the time and it can be used for magneto-telluric exploration. Based on the existence of the surface manifestations then conducted geophysical investigation by using AMT method, appear to identify the structure of the suspected fault as a weak zone both as recharge area and the emergence of the manifestation zone, as well as to know the cap rock of this geothermal system.

Method and/or Theory

1. Audio Magneto-telluric Method

Audio Magneto-telluric is electromagnetic passive method which count fluctuation of natural electrical field (E), and natural magnetic field (B) on the orthogonal direction to surface to knowing electrical properties of rock (Daud, 2012). In this method, range of frequency that can be catched is 0.1 Hz to 10 Hz. High frequency comes from thunder activity in ionosphere, and low frequency comes from magnetosphere. The equation that used in this method is Maxwell equation. It comes from magnetic- electrical phenomenom in nature that that has been studied by Faraday, Ampere, Gauss, Coulomb, and Maxwell. 4 equations are below this.

$\nabla \times H = i+(\partial D)/(\partial t)$	Ampere equation	(1)
$\nabla \times E = -(\partial B)/(\partial t)$	Faraday equation	(2)
$\nabla .D\, E = \rho$	Coulomb equation	(3)
$\nabla . B = 0$	Magnet's flux equation	(4)

With E is an electrical field (Volt/m), B is a flux or magnetic induction (waber/m^2 or Tesla), H is magnetic field (Ampere/m), ρ is electrical charge density (Coulomb/m^3), s as a conductivity (S/m), and e is a dielectrical constants (F/m^3).

2. Skin Depth

If we use smaller frequency, we can get deeper penetration (Simpson, 2005). Skin Depth is value of depth where electromagnetic waves amplitude has been induced become 1/e from amplitude on surface. Skin depth equation with permeability value $\mu = \mu 0$ = 1,256 x 10-6 H/m, and frequency ($\omega = 2\pi f$), is :

$$\delta = 503\sqrt{\frac{\rho}{f}} \qquad (5)$$

With δ is a skin depth (m), ρ is a resistivity of homogeneous medium (Ω.m), and f is a electromagnetical waves frequency (Hz).

Result and Analysis

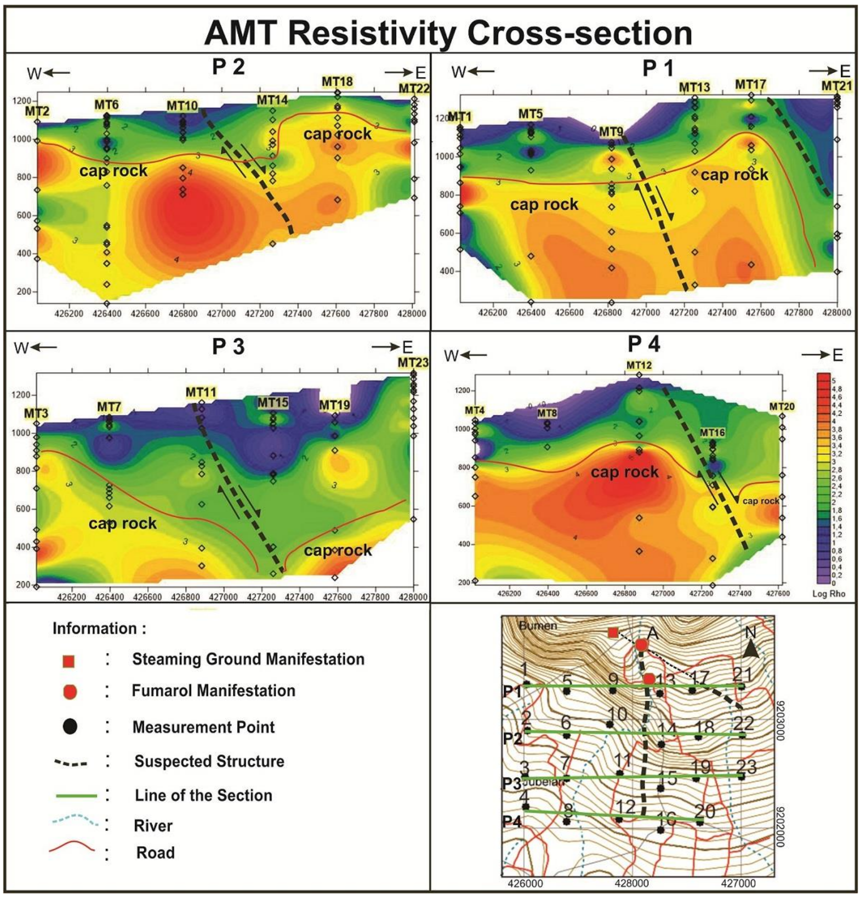

Figure 1. *The structures of Candi Gedong Songo geothermal system correlated with survey design and geological surface data of the measurement area.*

The AMT data acquisition was done with Stratagem main unit of *Geometrics* version 26716-01 Rev D that calculate true resistivity with it's inversion. As a result, the true resistivity 2D model as the function of depth shows as **figure 1.** The AMT resistivity section shows the contrast of resistivity changes that crosses anomaly with high resist value which that predicted as a fault structure. This fault controls geothermal system in the area of Candi Gedongsongo. The estimation is done because almost all of the fault zone in the research location is the hot discharge zone that caused the alteration process with low resistivity value (membrane polarization effect). In addition, low resistivity values around the fault zone are also caused by relatively high of fluid concentrations. The estimation of the fault structure is reinforced by the presence of several paths of geothermal manifestation that are the result of the formation of the fault structure and supported by some surface data. The existence of a normal fault intersecting at the point of manifestation of fumarole "A" with the position of each structure is N 342 ° E / 56 ° and N 356 ° E / 83 °.

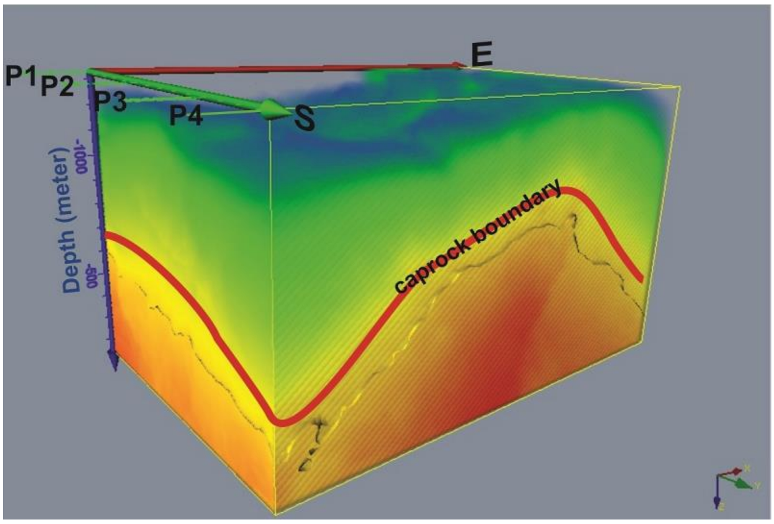

Figure 2. *3D Model of caprock in Candi Gedongsongo geothermal system.*

From the 3D resistivity model above can be seen the pattern of distribution of high resistivity value (color scale: orange - red) which is marked by the red line on the cross section (**figure 1** and **figure 2**) with a range of values between 1000 - 100,000 ohm.m at elevation below 1000 m. The anomaly is thought to be an andesitic lava and breccia that serves as a caprock in the geothermal system of the Candi Gedongsongo area. This is because the nature of igneous rocks that are impermeable and have interlocking minerals that can serve as caprock. This statement supports the research of Eddy Z. Gaffar et al. (Geotechnology Research Center, 2007) in the area of Candi Gedongsongo which mentions the existence of a surface layer of nearly 400 m thickness occupied by a highly resistive layer with high-resistance value> 1000 ohm-m allegedly lava and breccia andesitic products of Ungaran mountain and serves as a cover layer (cap rock) geothermal system. Caprock in this area has a relatively varying depth with a range of 200 - 300 m below the measurement point.

Conclusions

Through interpretation of log rho values of the true resistivity P1-P4 combined with the geologic background of Candi Gedongsongo, we found that the low resistivity anomaly that crossing the high resistivity anomaly indicated a fault. Thus, there are 2 faults shows on the model. First fault has strike and dip of N350ºE / 60º that continues from north to south as shown on section P1- P4. Second fault shown on P1 but the strike and dip can not be known. The high resistivity value ranges between 1000 -100,000 ohm.m considered as the caprock of Candi Gedongsongo geothermal system. The caprock might be lava and breccia andesitic that lying under elevation of 1000 m.

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