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TWO-DIMENSIONAL INVERSION FINITE ELEMENT MODELING OF MAGNETOTELLURIC DATA: CASE STUDY "Z" GEOTHERMAL AREA

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Abstract: Two-dimensional resistivity analysis of magnetotelluric data has been done at "Z" geothermal area which is located in southern part of Indonesia. The objective is to understand subsurface structure beneath reasearch area based on 2-D modeling of magnetotelluric data. The inversion finite element method were used for numerical simulations which requires discretization on the boundary of the modeling domain. The modeling results of magnetotelluric data shows relativity structure dissemination: 0-10 ohm.m in a thickness of 1 km (*Clay Cap*), 10-100 ohm.m with 1-2 km depth respectively (*reservoir zone*), and on a scale of 100-1000 ohm.m in a depth of 2-3 km (heat source zone). The result of relativity structure can be used to delineate an area with geothermal prospect around 12 km^2.

Keywords: magnetotelluric; finite element; geothermal potential;

INTRODUCTION

Geothermal area "Z" is located in active geothermal complex source which lies between subduction zone where Indo-Australia plate and Eurasia plate collide. Geothermal system is composed by many subsurface structures, such as reservoir, caprock, or fracture. To determine its geothermal characteristics, varied geophysical methods can be employed. Obtaining physical parameters of Earth's layers which has prospect for geothermal utilization. One of that parameter is namely resistivity. The resistivity variation inform about the existence of weak zone, such as fault by higher conductivity anomaly reaching surface and lies around more resistive blocks. This constant is primary physical property of Earth which is strongly influenced by hydrothermal processes presents in geothermal reservoirs [1]. Because of it's sensitivity in conductivity change due to magma existency , partial melt, hydrothermal or alteration layer, structure, and or water saturated zone, thus MT is a prominent tool for investigation. Especially, when fault and hydrothermal zone are exist, resistivity distribution will be shown as low resistivity features [2][3][4].

MT has widely spread been successful in geothermal exploration [1][5][6]. Alteration and fracture zones when filled by thermal fluid will produce resistivity change then be higher conductive. Furthermore, Making model of geothermal system should reveal major geological structure of the area and the properties of the geothermal conceptual model. By this research, we did Magnetotelluric (MT) campaign, particulary to image subsurface resistivity distribution then prospectus geothermal field, with high temperature and permeability can be estimated.

MAGNETOTELLURIC METHOD

Magnetotelluric is one among pasive geophysical methods, where electric field and magnetic field are measured at Earth's surface in orthogonal direction. Originally, EM field is generated from geomagnetic variation from solar activity that induces telluric (electric field) current in the earth. The propagated telluric current depends on resistivity distribution beneath and its response is in frequency domain. The amplitude and phase are relying on variation of subsurface resistivity as well. An equation (1) describes perpendicular ratio of Electric field and magnetic field [7][8][9]

$$\vec{Z} = \frac{\vec{E}}{\vec{H}} \qquad (1)$$

Where $\boldsymbol{Z}$ is complex valued of 2 x 2 impedance tensor (equation 2), obtained for each MT station as a frequency function; $\boldsymbol{E}$ is horizontal electric field $\boldsymbol{E} = [ExEy]^T$ and $\boldsymbol{H}$ is horizontal magnetic field, given as

$$\boldsymbol{H} = [HxHy]^T$$

$$\boldsymbol{Z} = \begin{bmatrix} Z_{xx} & Z_{xy} \\ Z_{yx} & Z_{yy} \end{bmatrix} \qquad (2)$$

Z contains information of amplitude and phase $\boldsymbol{\varphi}$ thus represented as apparent resistivity ρ_a,as presented at equation (3)

$$\boldsymbol{\rho}_{aij} = \frac{|Z_{ij}|}{\mu_0 \; \omega} \qquad (3)$$

Where $\boldsymbol{\omega}$ is angular frequency $\boldsymbol{\omega = 2\pi f}$ and *i, j = x, y* then phase component is given by equation (4)

$$\varphi = \arg(Z_{ij}) = \tan^{-1}\left(\frac{ImZ_{ij}}{Re\,Z_{IJ}}\right) \qquad (4)$$

A common criterion for electromagnetic waves penetration is called *skin depth*, the distance where the signal amplitude is reduced to 1/e, that is 37 % of its surface as estimated by equation (5) [9],

$$\delta \; \approx 500 \; \sqrt{\rho T} = 500 \; (\rho f)^{1/2} \qquad (5)$$

where ρ is average resistivity over an appropriate depth range, T and f are period.

In order to investigate subsurface structure, 2D inversion is choosen. It performs well in some geothermal research, speciality to analyse near surface structure, such as fault [2][10. So it can produce a result of apparent resistivity and phase below surface area. Inversion step as MT data processing tool calculates resistivity distribution beneath survey sites. It depth coverage can reach from meters to hundreds kilometers[11]

GEOTHERMAL

Geothermal system is the thermal energy transfer phenomena, from deep-seated Earth's layer then ascends to the top.

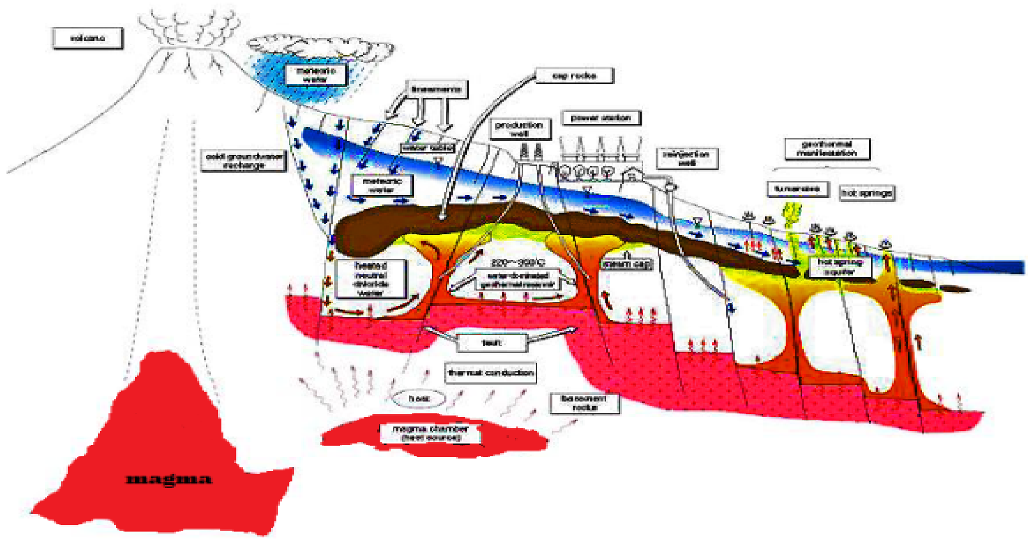

Figure1. Geothermal conceptual model [13]

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Some evidents of this occurence are volcanic eruption , hotspring manifestation, fumarole and steaming ground[12]. Heath source, reservoir and clay cap or caprock are the main components of Geothermal to be existed. Magma which cooled far in bottom, roles as heat source. The magma cooling process produces igneous rock that induces thermal energy conductively to its surrounding[13]. When the heath is spreading, it boils fluid flowing in reservoir. The warmed fluid move upward as thermal fluid through vents. Consequently as it meets clay cap, the cap will trap this aqueous material [4]. Because of fluid occupancy, that is underlying cap rocks, the pressure located below the cap is increasing. Therefore, this case trigers fracturing structure, to release thermal fluid into surface as manifestation. Furthermore, underneath sustainable heating mechanism appears as low resistivity region and by MT sensitivities to resistivity change, this measurement technic is properly utilized to investigate geothermal potencial field[14]

METHOD

We analyzed secondary data from Pertamina Geothermal Energy Ltd. Consisted of *DEM (Digital Elevation Model)* data that give information about sites and lines of targeted survey in topographyc map (Figure 2). As well as the main research data, magnetotelluric data containing apparent resistivity and phase, as seen on Figure 3. A number of MT sites is 63 with modeling profiles are 10 lines. We constructed *mesh* modeling as long as 25 km resulting 60 elements of model as we can see at Fig. 3. This mesh. That *mesh* is used for inversion process upon *finite element* numerical work subsequently.

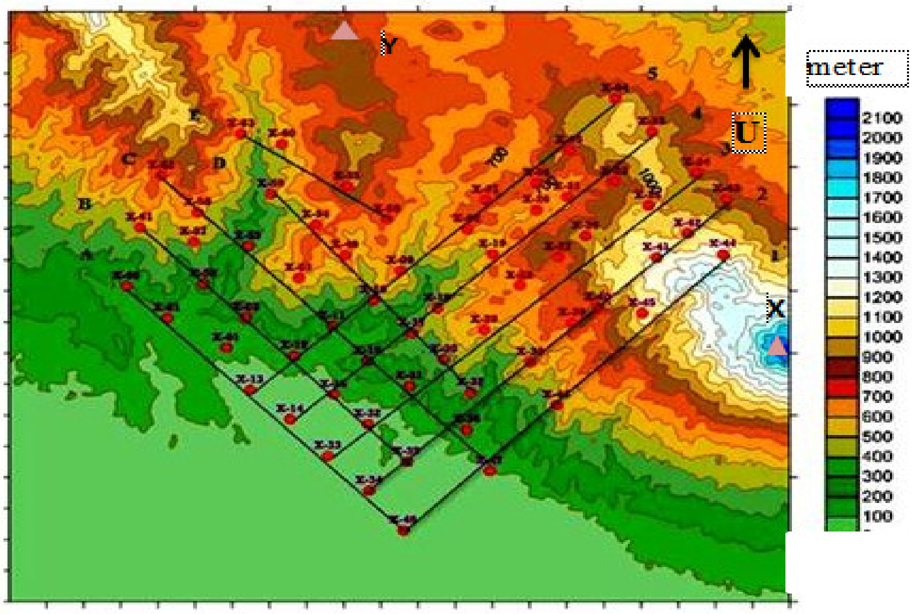

Figure 2. Sites and lines distribution of research area

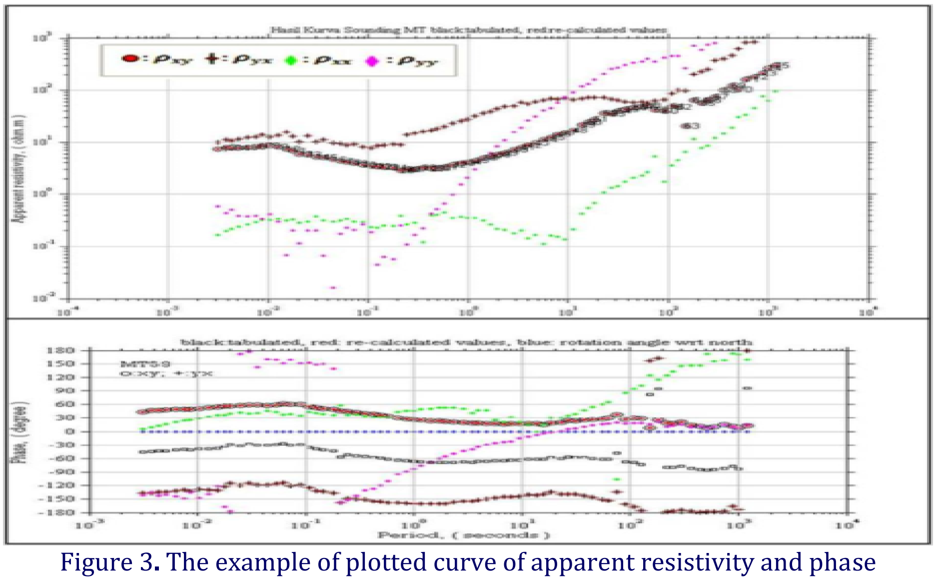

Figure 3. The example of plotted curve of apparent resistivity and phase

MT response function presents resistivity and phase are achieved from above inversion step computed in matlab software. The particular numerical scheme solves differential equation in electromagnetic field. This program only needs deiscretization at constraint fields of model[15]. Once noise is removed, we assume 2 dimensional model based on finite element inversion result. Data result we earned from this operation later we projected it into 3D visualization.

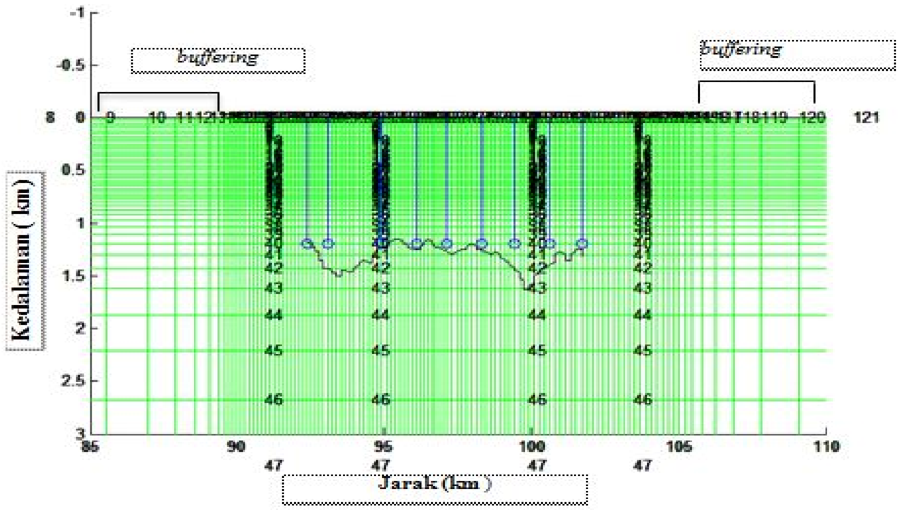

Figure 4. Mesh model example

RESULT AND DISCUSSION

We received subsurface resistance distribution profile of MT data of the "Z" area that has been inverted computationally. From resistivity spreading below line 2 as seen at Figure 4, generally it informs conditions of survey area, scoping elevation between 80 m to 1200 m a.s.l. Apparent resistivity and phase as main MT output were originally resulted from employing a frequency band 1000 Hz to 0.01 Hz.

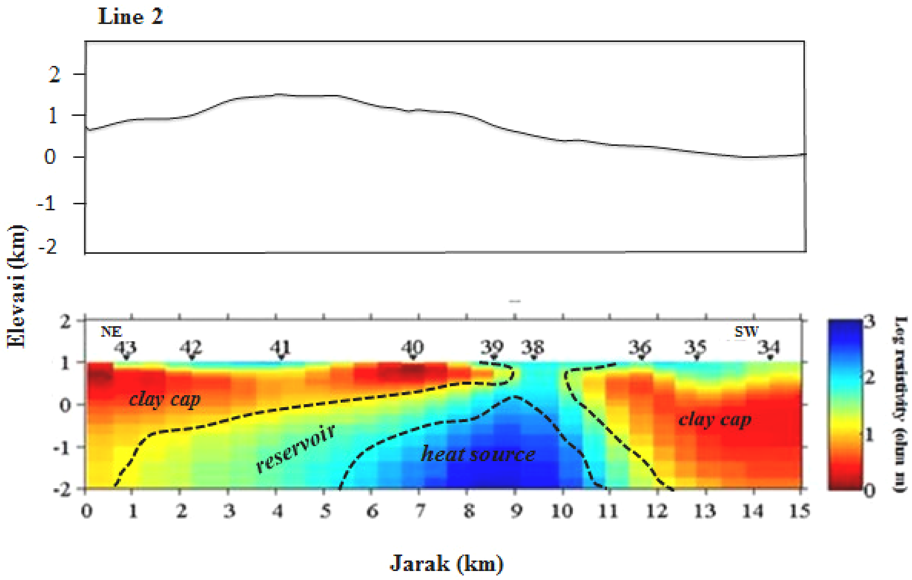

Figure5. Modeling and interpretion result of line 2

Figure 5 shows resitivity lineament under varied topography at elevation intervals 300 m to 700 m. Same as above explained line, the frequency range that we used was 1000 Hz until 0.01 Hz. Originated from distribution of rock`s resistance distribution, we could make assumption generally of three resistivity zones or blocks separation, illustrated in Figure 5 and Figure 6. The red block has low resistivity contrast compared to the other zones, ranging from 0 to 10 ohm, and it exists near to surface just reaches 1 km below top. This low anomaly is interpreted as *clay cap*.

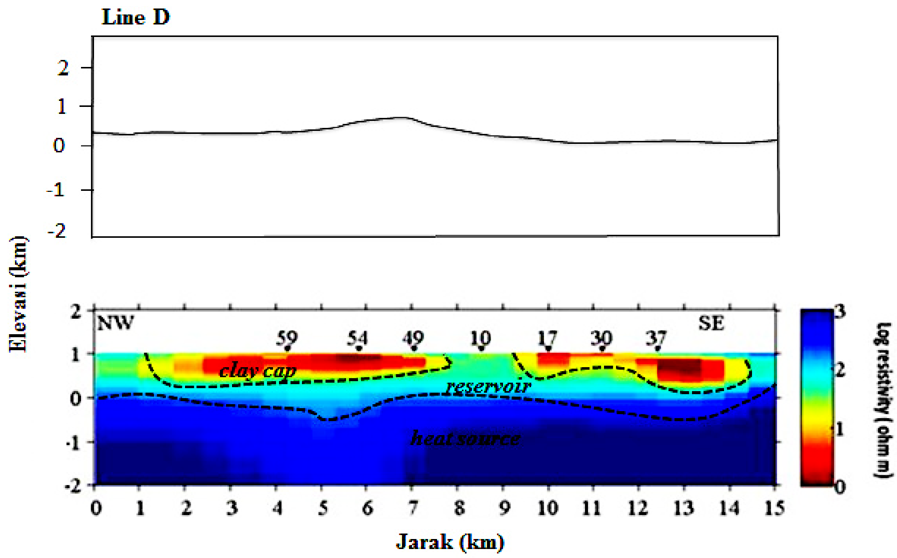

Figure 6. Modeling and interpretion result of line D

The green zone has a slight higher set between 10-100 m, appears at lower depth of 1-2 km. We considered this clay cap underlying layer as intermediet zone, roles as reservoir layer. The last resistivity contour is the highest values range 100-1000, below assumed reservoir zone. Occupies at depth 2-3 km, we estimate it as heat source. In which it induces thermal energy to overlying structures.

CONCLUSION

Based on research, we recognized some information: Clay cap has a depth 1 km b.s.l and resistivity value ranging from 0-10 ohm m. reservoir zone is located at depth 1- 2 km with resistivity range of 10- 100 ohm m, the last layer is expected to be heat source exists below reservoir at 2- 3 km, has resistivity of 100-1000 ohm m.

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