Resistivtiy Structure in Tangkuban Parahu Area Drived from CSAMT Data

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Abstract. Tangkuban Parahu is located in Bandung, West Java, one of a volcano area. Controlled-source audio frequency magnetotelluric (CSAMT) survey has been conducted in the area using transmitter located in 3-5 km from the survey area. The objective of the survey was to determine a subsurface resistivity structures that may correlate to a geothermal reservoir in unknown geothermal potential area. In the paper, we applied a two-dimensional (2D) inversion scheme to interpret of the CSAMT data to obtain several resistivity sections describing the subsurface resistivity structures. The results of 2D inversion indicated several subsurface low resistivity anomaly (1-10 ohm.m) in the depth of 1000-1500 meter that may correlate to the existing a geothermal reservoirir confirmed by several surface manifestations in the area.

1. Introduction

Tangkuban Parahu is located in a volcanic region in Bandung, West Java, Indonesia. The area is geographically situated in the South latitude of 06^{o}7'17"– 6^{o}7'17" and in the East longitude of 107^{o}36'12"- 107^{o}40'16". The topographic elevation of the field is ranging from 800 to 2200 m above sea level. A Controlled-source audio frequency magnetotelluric (CSAMT) measurement, in the operating frequency range of 0.25 Hz to 8192 Hz, has been carried out in the area to acquire 42 soundings with the irregular space stations, varied from 200 to 500 m between sounding, covering the Tangkuban Parahu and its environs. The location of transmitter was about 3 – 5 km in the south from the survey area (Figure 1).

The objective of the survey was to demonstrate the capability of the CSAMT method to determine a subsurface resistivity structures in the deeper part and to delineate it that may correlate to a geothermal reservoir in unknown geothermal potential area. Further more, if it is possible in the future, the area can be exploited to produce a geothermal energy for generating the electricity after doing several geophysical, geological and geocemical exploration. For the reason, the geothermal energy is one of the alternatives in Indonesia.

The configuration of CSAMT measurement is shown in Figure 2. The CSAMT method utilizes a grounded electric dipole generating electromagnetic (EM) wave source has been developed by Goldstein and Strangway [1]. The EM wave polarization of the fields can be selected by the orientation of the transmitting antenna and the signal strength. The CSAMT measurement must be carried out at a distance greater than 3-5 skin depths from the transmitter site where the plane wave approximation is valid. Since the measurements were made using the electric field along the transverse, we assumed that the data correspond to the transverse magnetic (TM) mode [2].

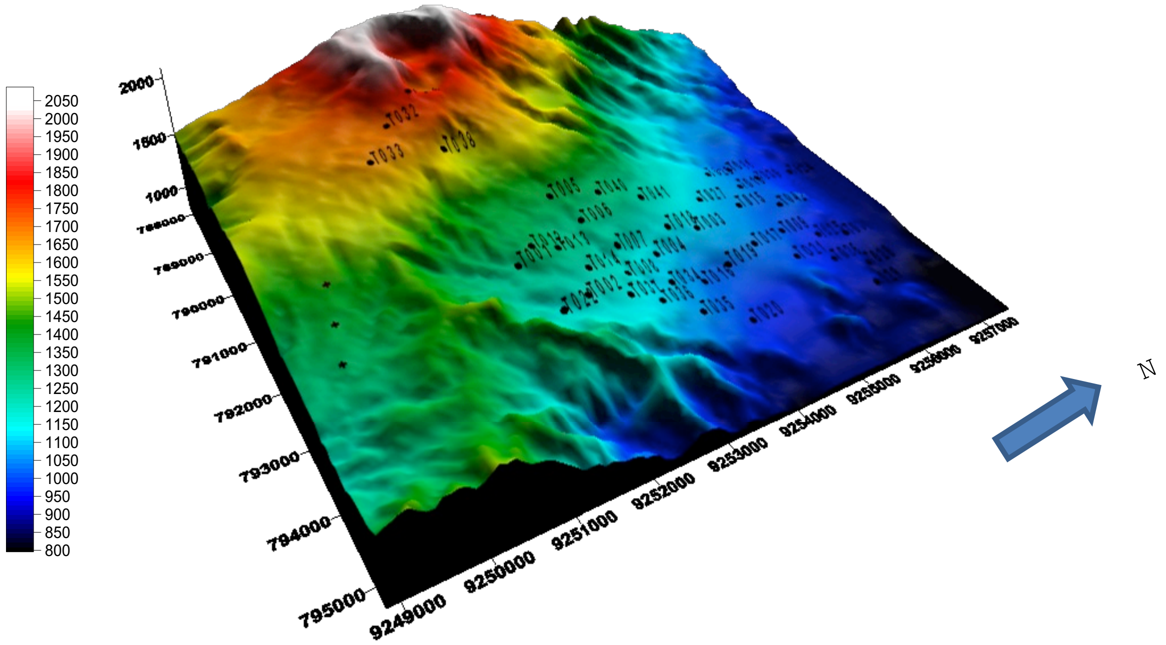

Figure 1. Map of Tangkuban Parahu area

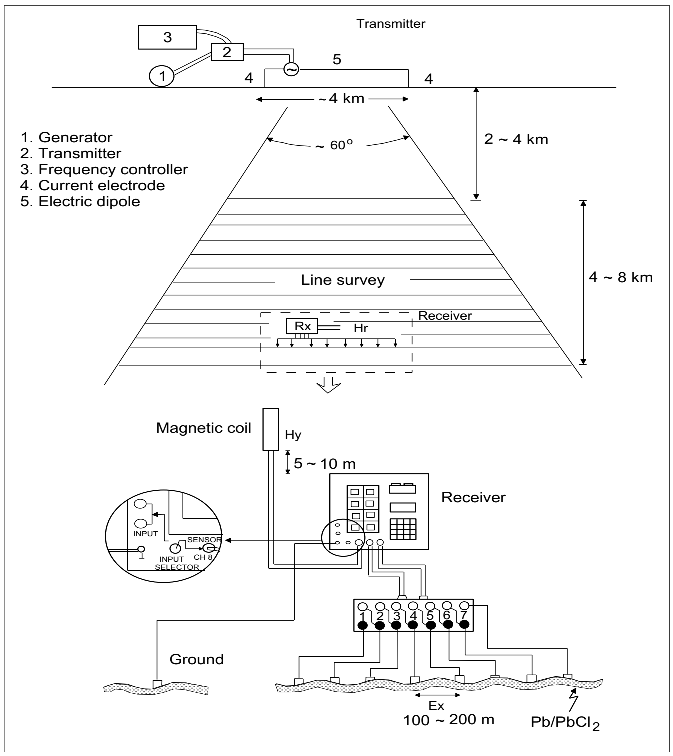

Figure 2. Configuration of CSAMT measurement

The location of the sounding sites of the CSAMT survey in Tangkuban Parahu is shown in Figure 3. The transmitter (Tx) was located about 3 to 7.5 km in the South from the sounding site area that was in Cikole, Lembang. The orientation of the electric field was parallel to the electric current dipole in every sounding site. On the other hand, the magnetic coil is located about 7 meters from the receiver and perpendicular to the electric field (TM mode).

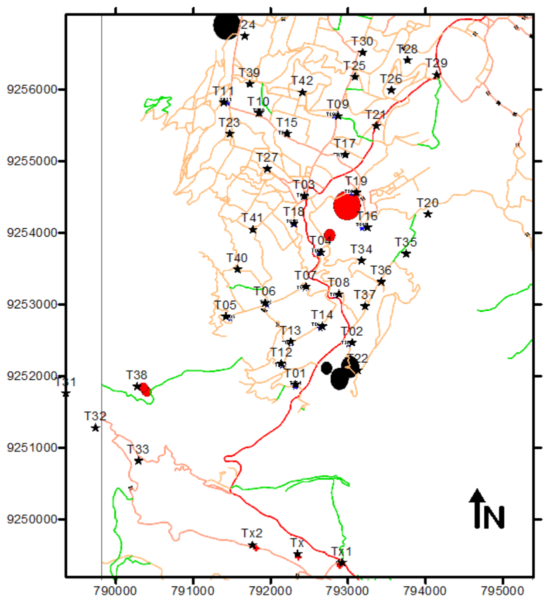

Figure 3. Location of the sounding sites of the CSAMT survey

The typical structure of geothermal system is schematically presented in Figure 4. The cooler upper zones are characterized by alteration of electrical conductive layer that is formed at temperatures above 70 ^{o}C. At higher temperatures, illite of less conductive layer becomes interlayered with smectite. The proportion of illite increases with the temperature, forming about 70% of the mixed-layer clay at 180 ^{o}C. Above this temperature, the smectite content continued to decrease, and pure illite commonly appears at greater than 220 ^{o}C[3]

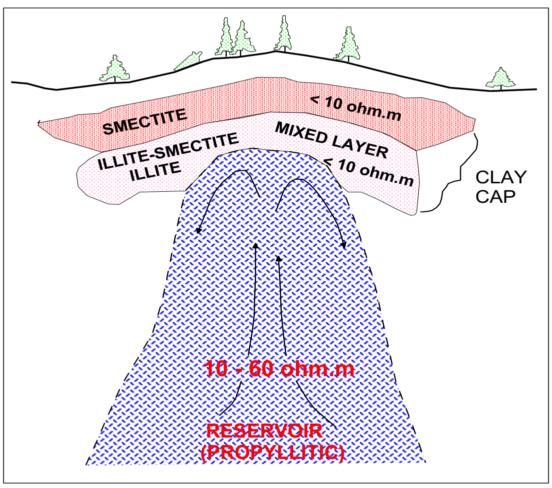

Figure 4. A generalized geothermal system [3]

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2. Basic theory

The basic concept used in the CSAMT method can be derived from the solution of Maxwell's equations, these are

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \tag{1}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial \mathbf{t}} \tag{2}$$

$$\nabla \cdot \mathbf{D} = 0 \tag{3}$$

$$\nabla \cdot \mathbf{B} = 0 \tag{4}$$

where **E** is the electric field intensity (V/m), **B** is the magnetic induction (tesla), **H** is the magnetic field intensity (A/m), ω is the angular frequency, μ_o is the magnetic permeability (H/m).

The general solutions of a tangential component of electric field (E_ϕ) and a radial component of magnetic field (H_r) are expressed in cylindrical coordinates as [4]

$$E_\phi \approx \frac{Idl \sin \phi}{\pi \sigma r^3} \tag{5}$$

$$H_r \approx \frac{Idl \sin \phi}{\pi \sqrt{\mu \sigma \omega r^3}} e^{\frac{-i\pi}{4}} \tag{6}$$

The apparent resistivity on the earth surface derived from Maxwell's equation in a far-field zone is

$$\rho_{axy} = \frac{1}{\mu\omega} \left| \frac{E_x}{H_y} \right|^2 \tag{7}$$

Although the CSAMT measurements were carried in a far-field zone, the data still contain some near field and transition zone data when the frequency from transmitter signal is low (deep survey). Therefore, it needs to make a correction technique for a near-field and transition effect to use the CSAMT data before applying the MT interpretation scheme [5].

3. Interpretation of CSAMT data

A 2D inversion technique based on a non-linier conjugate gradient method [7] was applied to invert the selected CSAMT data. Since the measurements were made using the electric field along the transverse and the magnetic field normal to the traverse, it is assumed that the data correspond to the TM-mode.

Employing a 2D inversion scheme to the CSAMT data in Tangkuban Parahu, we constructed the 2D resistivity section for several profiles. The resistivity section obtained from 2D inversion of Line-2 indicates that the distribution of the low resistivity anomaly (<10 ohm.m) in the depth of 700-1000 m is distributed in the northeast from t-19 to t-28 (Figures 5). This anomaly is may considered as hydrothermal alteration zone in a geothermal reservoir structure. On the contrary, the low resistivity anomaly is not found in the southeast. From the figure also shows that the electrical discontinuity is found below the sounding site t-07, it may correspond to the existing fault in the area.

It is identified from the 2D resistivity section of Line-8 of NW-SE direction (the position of line shown in the left of the Figure 6) that the distribution of the low resistivity anomaly is also found below sounding sites t-17 to t-35. It is also considered as the hydrothermal alteration zone. Furthermore, the electrical discontinuity also discovered below the sounding site t-10, it is considered as a fault in this zone.

Finally, from the resistivity section of Line-9 in NW-SE direction (Figure 7) indicates that the subsurface resistivity of this line is mainly composed of 3 layers. The first layer (overburden) is high resistivity (50 to 500 ohm-m) that is between 800 to 1000 meters thick overlying the lower resistivity zone (1 – 20 ohm.m) in the second layer that is approximately 1000-1500 meters thick. These anomalous features may be due to faulting, fracturing, and hydrothermal alteration along the significant fault.

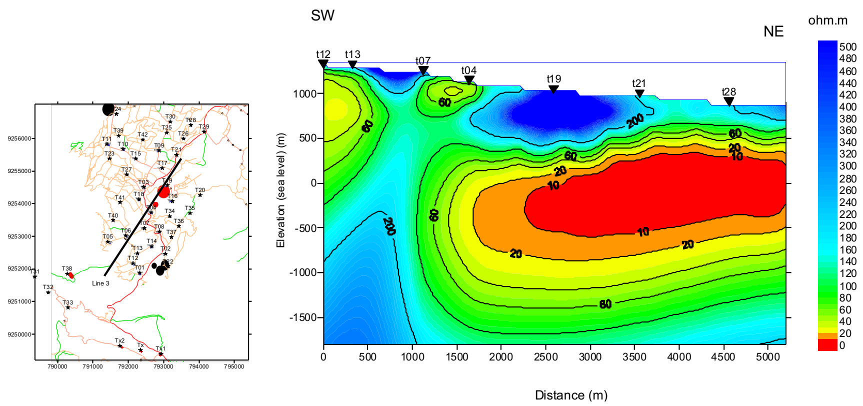

Figure 5. Resistivity section derived from 2D inversion result at Line-3

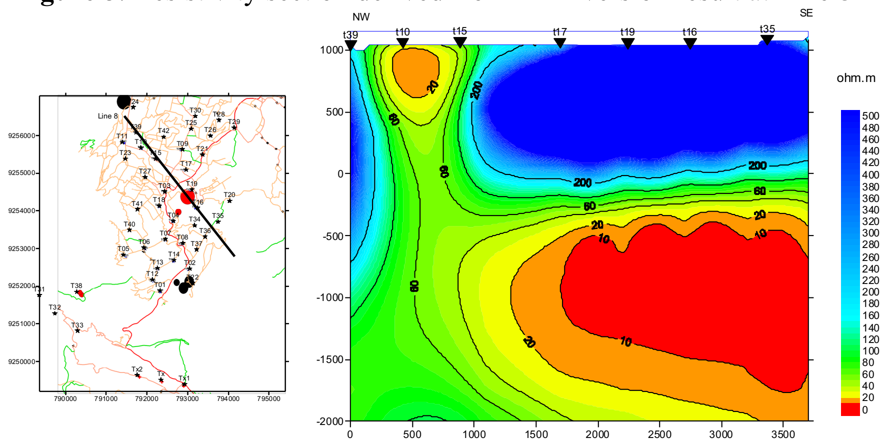

Figure 6. Resistivity section derived from 2D inversion result at Line-8

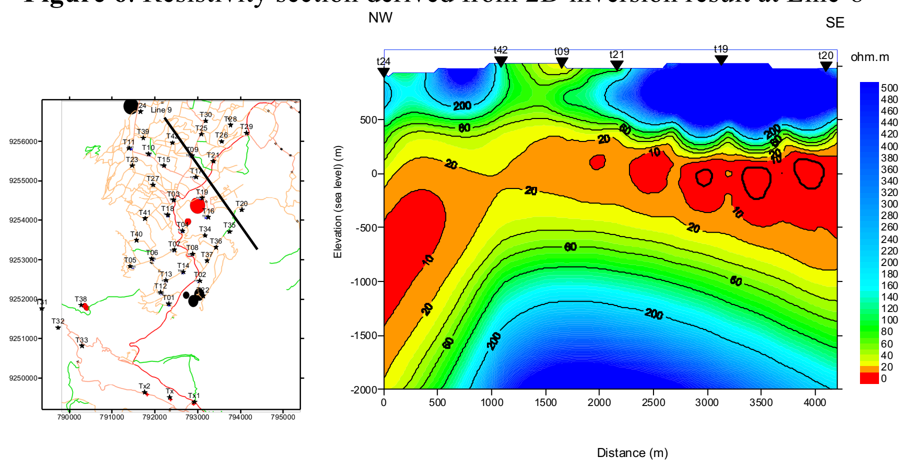

Figure 7. Resistivity section derived from 2D inversion result at Line-9

To understand the resistivity distribution in term of 3D geological structure, we constructed the 3D model of the low resistivity anomaly (<10 ohm.m) as shown in the Figure 8. The figure shows that the conductive (second) layer, which correlates to the layer of a hydrothermal alteration zone, is distributed in the northeastern part of the Tangkuban Parahu area. The region is probably a hydrothermal alteration zone where the geothermal reservoir may exist in that area.

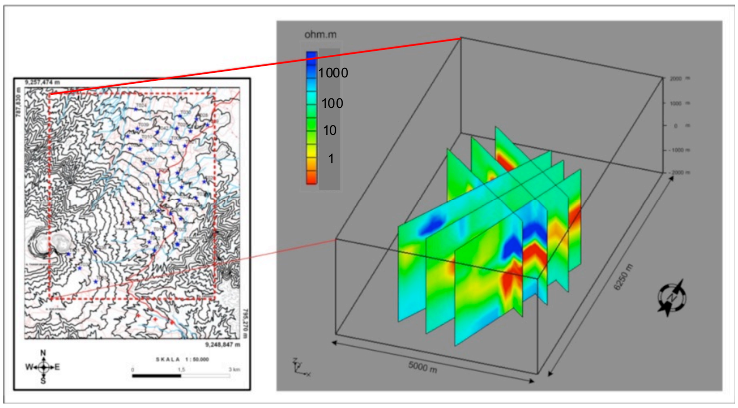

Figure 8. 3D view of resistivity structure in Tangkuban Parahu area

4. Conclusions

The CSAMT method applied at Tangkuban Parahu area was successful to locate an anomalously low resistivity zone that may indicate the existing of a potential geothermal reservoir. Employing the 2D inversion of CSAMT data generates several geoelectrical cross sections are found in the some locations that the resistivity structure is similar to a geothermal reservoir structure. The subsurface resistivity structures composed mainly by three types of resistivity feature obtained from 2D inversion results of CSAMT data. The overburden (first layer) has a resistivity of 30 – 150 ohm-m and thickness of 800 to 1000 m. The intermediate (second) layer has an extremely low resistivity of 3 – 15 ohm.m with 1000 – 1500 m thick. The low resistivity layer as an anomalous feature can be considered as a hydrothermal alteration zone (impermeable layer/cap rock). Finally, the basement (third) layer that is relatively more resistive than the second layer with resistivity of 30 – 100 ohm-m.

Further more, if it is possible in the future, the area can be exploited to produce a geothermal energy for generating the electricity after doing several geophysical, geological and geocemical exploration. For the reason, the geothermal energy is one of the alternatives in Indonesia.

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References

[1] Goldstein M A and Strangway D W 1975 Audio frequency magnetotelluric with grounded electric dipole source *Geophysics* vol. 40 669-683.
[2] Sasaki Y, Yoshihiro Y and Matsuo K 1992 Resistivity imaging of controlled-source audiofrequency magnetotelluric data *Geophysics* 57 952-955.
[3] E. Anderson, D. Crosby and G. Ussher, Bulls-eye! -Simple Resistivity Imaging to Reliably Locate the Geothermal Reservoir, *Poc. WGC 2000*, 909-914, 2000.
[4] Kaufman A A and Keller G V 1983 *Frequency and transient sounding method* Elsevier Science Publ. Co. Inc.
[5] Yamashita M, Hallof P G and Pelton W H 1985 *CSAMT* case histories with a multichannel CSAMT system and near-field data correction *55th SEG Annual Convention* 276-278
[6] Rodi W and Mackie R L *2001* Nonlinear conjugate gradients algorithm for 2-D magnetotelluric inversion *Geophysics* **66** 174-187.
[7] Sasaki Y, Yoshihiro Y and Matsuo K 1992 Resistivity imaging of controlled-source audio frequency magnetotelluric data *Geophysics* **57** 952–955.