Magnetotelluric 1D-Based Lithological Study of Geothermal Prospect Near Bogor Fault, Kepahiang

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Abstract *- Kepahiang Regency, Bengkulu Province has significant geothermal potential due to its location on the subduction line and the Sumatra Musi segment fault. This research aims to identify the subsurface lithology of the geothermal zone using the Magnetotelluric method. This method measures the response of natural electric and magnetic fields to determine subsurface resistivity values. Inversion of 1D Magnetotelluric data at six pointsv (MT5, MT6, A6, A5, A1, A4) showed three classes of resistivity values of low (0.21-4.0 Ωm), medium (31-80 Ωm), and high (≥200 Ωm). Low resistivity zones are found at MT6 and A6, indicating the presence of geothermal reservoirs in the form of sandstone, limestone, and igneous rocks. Medium resistivity at MT5 and A5 indicates a clay layer as caprock, while high resistivity at A1 and A4 indicates hot rocks in the form of granite and metamorphic rocks. These results provide a preliminary picture of geological conditions for geothermal exploration in the area.*

Keywords*: Geothermal; Kepahiang; Magnetotelluric; Resistivity.*

INTRODUCTION

Indonesia is one of the countries with abundant geothermal natural resource potential, this is due to Indonesia being located at the confluence of three plates, namely the Indo-Australian plate, Eurasia and the Pacific plate which is characterized by an active ring of fire (Bahri & Ramadhan, 2022). Indonesia itself has a total geothermal energy potential estimated at 29,000 MW, which is one of the largest geothermal potentials in the world (ESDM, 2016). Based on data collected by the Ministry of Energy and Mineral Resources, no less than 256 geothermal prospect areas in Indonesia have been identified (Nurdiyanto et al., 2014). Meanwhile, the utilization is only 8.9% or 2,130 MW based on the latest records of the geological agency (Humas E, 2020). Geothermal energy can be the main choice of energy sources to meet energy needs in Indonesia, Indonesia itself requires a large additional energy supply to meet industrial and household needs (Farid et al., 2021). Geothermal energy is proven to be able to reduce dependence on fossil energy whose reserves are increasingly depleting, meaning that the energy crisis that has hit this country and the whole world can be seriously overcome through the use of geothermal energy (Farid et al., 2023).

Geothermal is a renewable energy that can be utilized sustainably at a low cost and affordable by all levels of society (Farid et al., 2021). Geothermal as one of the energy sources that has enormous potential in meeting national and international energy needs (Hadiwijoyo, 2011). In addition, geothermal is also heat energy that comes from within the earth naturally and is stored in rocks and fluids that fill the fractures and pores in the earth's crust (Rybach, L. ; Muffler, 1981). The utilization of areas containing geothermal energy can be done, in areas around plate tectonics caused by active tectonic activity that produces geothermal heat (Simbolon et al., 2020).

Kepahiang Regency, located in Bengkulu Province, is one of the areas with potential geothermal energy reserves in Indonesia. The Kepahiang area is on a subduction line located in the magma arc area of Sumatra in the western part of the Indonesian tectonic system, known as the Barisan lane. This lane is an area of magma activity in the Tertiary and Quaternary periods (Pamungkas, 2023). Kepahiang Regency is located in the area around the Musi segment, which allows for geothermal heat caused by the movement of the Musi fault, causing fractures in the rock, which produce fluid pathways below the surface (Iswahyudi et al., 2019). Geothermal manifestations that appear on the surface include hot springs, altered rocks, and fumaroles. This research needs to be conducted to determine the subsurface lithology of geothermal zones around the Musi segment to the Bogor fault of the Musi sub-fault. One of the passive Geophysical methods often used in the identification of geothermal areas is the Magnetotelluric (MT) method because it is considered capable of detecting subsurface structures to a depth of approximately 8,000 m (Wulandari & Eddy Z. Gaffar, Siti Zulaikah, 2014). The use of the MT method is also based on using low frequencies so that it is able to detect to a greater depth than other methods (Rahmawati et al., 2024).

Research using the Magnetotelluric method was conducted by Suhendra et al., to find the rock lithology of the geothermal reservoir zone and estimate the depth of the geothermal reservoir rock zone in the Hululais geothermal field area, Lebong Regency. The results of the research conducted by Suhendra et al. successfully identified the presence of geothermal reservoirs in the study area. Based on the data obtained, the reservoir zone began to be detected at a depth of about 400 meters from the surface. This finding indicates the potential for shallow geothermal systems in the area, which can be a target for further exploration and development (Suhendra et al., 2024). Research by Hardiansa et al., in the Kepahiang area, Bengkulu, used the Magnetotelluric (MT) method to determine the geothermal potential around the Bogor segment. The modelling results showed the presence of geothermal reservoir zones at a depth of 2-3 km, with low resistivity values between 0.14-1 Ωm (Hardiansa et al., 2025). This research aims to identify the lithology in the geothermal reservoir zone in Kepahiang Regency. It is expected that the results of this study can provide comprehensive information about the subsurface lithological conditions in the geothermal zone in the area.

Regional Geology and Geothermal

Based on the detailed geological map of the study area (Figure 1) Kepahiang is surrounded by hills to steep hills and partly plains to undulating plains. The hills to steep hills are composed of young volcanic rocks of Quaternary age, consisting of lava, volcanic breccia and tuff. While the plains to undulating plains are composed of Quaternary age deposits in the form of river alluvial deposits, alluvial deposits resulting from weathering of young volcanic rocks (Sihombing et al., 2024). Geological formations in the Kepahiang area include the Quaternary Volcano Formation, Diorite, Gumai Formation, Hulusimpang Formation, Seblat Formation, and Kaba Volcano Formation found in the area (Firdasari, 2018). The geological structure also shows that the Kepahiang area is dominated by faults. In general, the faults found in the Kepahiang area are active faults that follow the structural pattern of the island of Sumatra, which is northwest-southeast orientated. Some other faults are north-south and northeast-southwest orientated. The geological structure pattern was formed due to previous tectonic activity (Supartoyo et al., 2019). One of the faults that affect the geology of the Kepahiang area is the

Sumatra Musi segment fault that runs north-south and is located right in the Kepahiang area (PUSGEN, 2017).

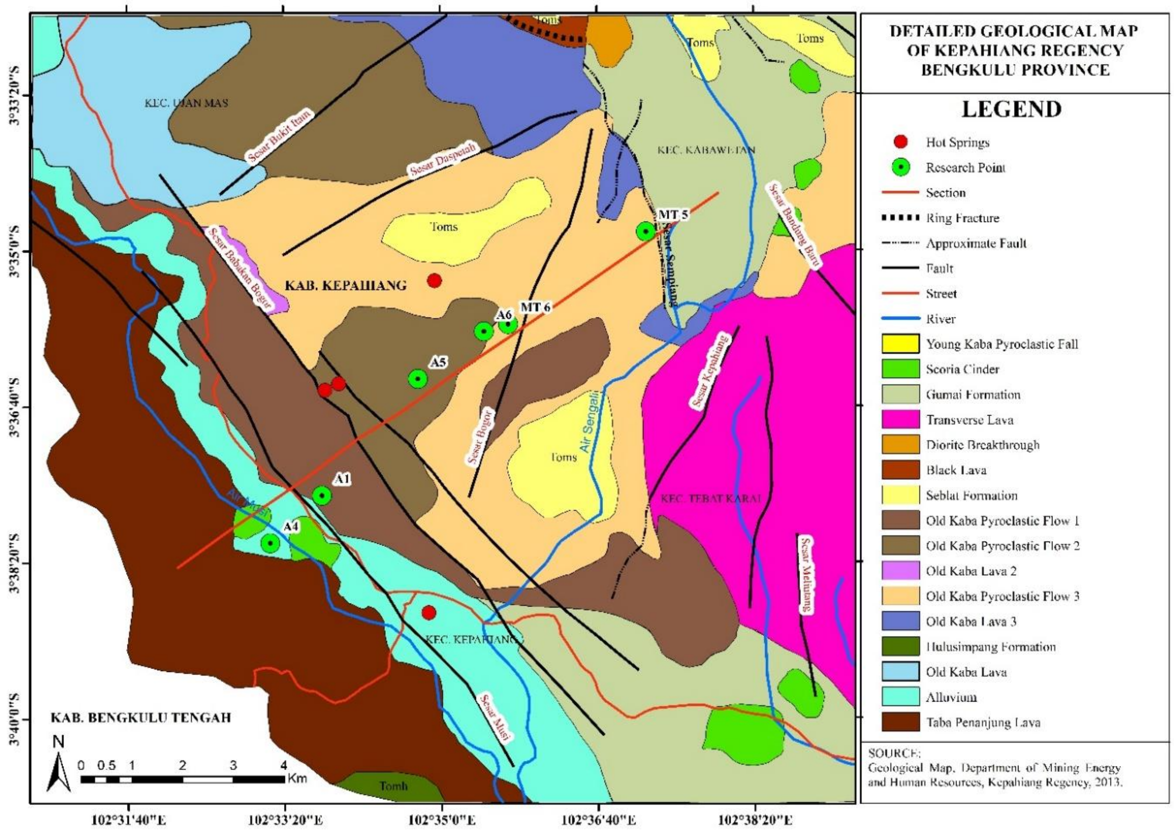

Figure 1. Detailed Geological Map (modified from (Gafoer et al., 2007) and (Irwanto et al., 2004)).

In general, an important component of a geothermal system is the heat source. A heat source is magma trapped below the surface that is directly connected to rocks that are denser than the surrounding rocks (Hardiansa et al., 2025). Kepahiang itself has geothermal potential that is very interesting to study, which is found in several places, namely Mount Kaba and Bukit Itam which are Tertiary-Quaternary volcanoes (S. Gafoer, T. C. Amin, 1992). Proven by the emergence of geothermal manifestations in the form of hot springs, fumaroles, alteration rocks, solfatara, and teralterated rocks that indicate the presence of geothermal reserves in the subsurface (F. Landung et al., 2022). Various rock types in Kepahiang Regency are altered as a result of hydrothermal activity (Hardiansa et al., 2025).

RESEARCH METHODS

This research was conducted in Kabawetan District, Kepahiang Regency with 6 measurement points with a distance interval of approximately 1 km (Figure 2). This research aims to determine the subsurface lithology and depth of the geothermal reservoir rock zone in the area around the Musi fault and Bogor fault using the 1D inversion approach of the magnetotelluric method. This method is often used to determine the distribution of resistivity in the subsurface using measurements of electric and magnetic fields at the surface. The magnetotelluric method measures the orthogonal or perpendicular components of the electric field (Ex, Ey) and magnetic field (Hx, Hy, Hz) at the Earth's surface in the time domain (Setyani, 2017). The magnetotelluric method has a penetration value that is deep enough to reach 8,000 metres so that it can be used to determine the subsurface structure (Rizal et al., 2019).

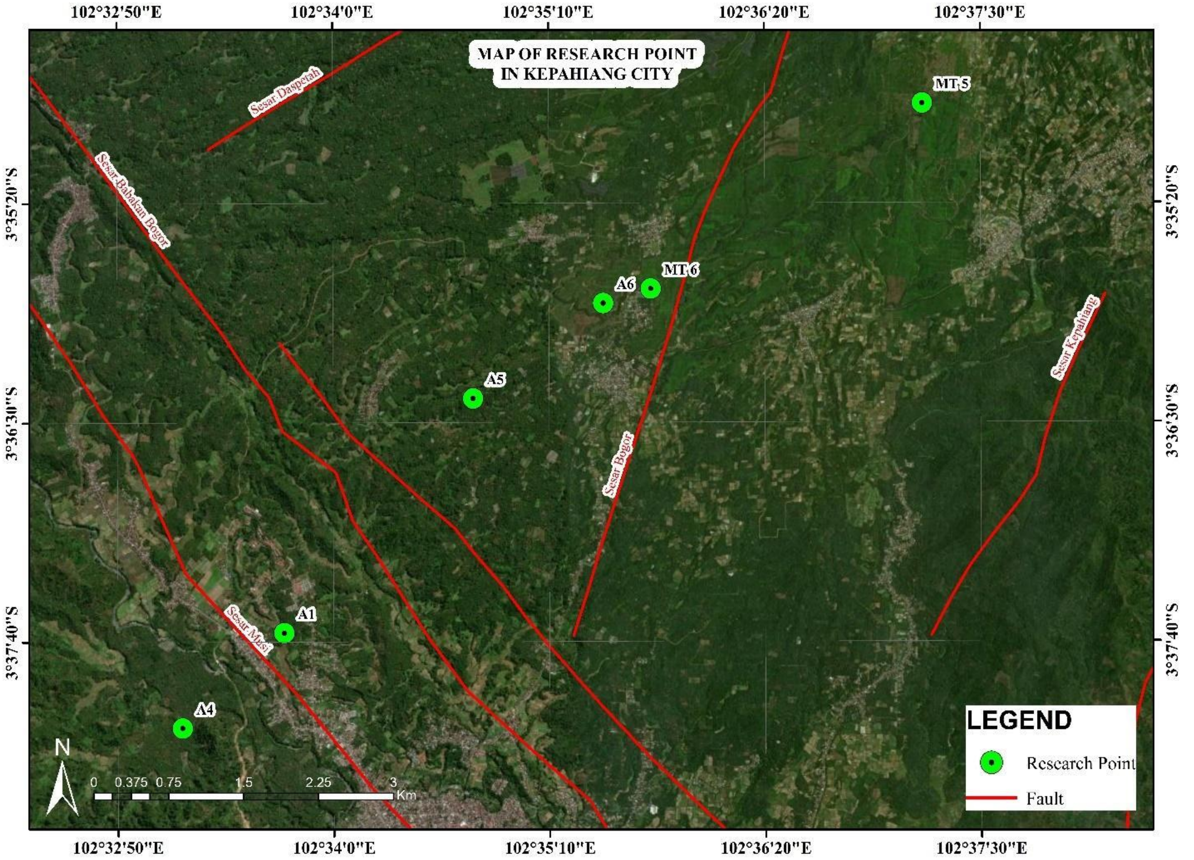

Figure 2. Map of Research Point

The magnetotelluric method also utilises natural electromagnetic fields to determine the Earth's subsurface structure based on the electrical properties of rocks at relative depths (including the Earth's mantle) within the Earth (Hidayat et al., 2016). Figure 3 shows a typical magnetotelluric setting. Naturally generated variations in the Earth's magnetic field are the source field, providing a broad and continuous spectrum of electromagnetic waves that induce currents within the Earth. These induced currents contribute to the magnetic field match measured at the surface and retain, information about the subsurface conductivity structure ranging from a few tens of metres to hundreds of kilometres deep. The internal coordinate system measures electric fields horizontally orthogonal and magnetic fields vertically and horizontally orthogonal (Al Ansory et al., 2023).

The electrical conductivity structure of the earth can be known using natural electromagnetic fields. In the magnetotelluric method that has a frequency above 1 Hz is a thunderstorm, while for most signals below the frequency of 1 Hz due to the magnetosphere system by solar activity. The frequency used in the magnetotelluric method ranges from 10-5 Hz - 103 Hz (Fitrida et al., 2015).

The general equation, to determine the nature of electromagnetic waves, is Maxwell's equation (Fitzpatrick, 2008):

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad (1)$$

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \quad (2)$$

$$\nabla \cdot D = q \quad (3)$$

$$\nabla \cdot B = 0 \quad (4)$$

Description:

$\vec{E}$: Electric Field (Volt/m)
B : Magnetic or Induced Flux (Weber/m^2)
H : Magnetic Field (Ampere/m)
J : Current Density (Ampere/m^2)
D : Electric Displacement (Coulomb/m^2)
q : Current Charge Density (Coulomb/m^3)
t : Time (s)

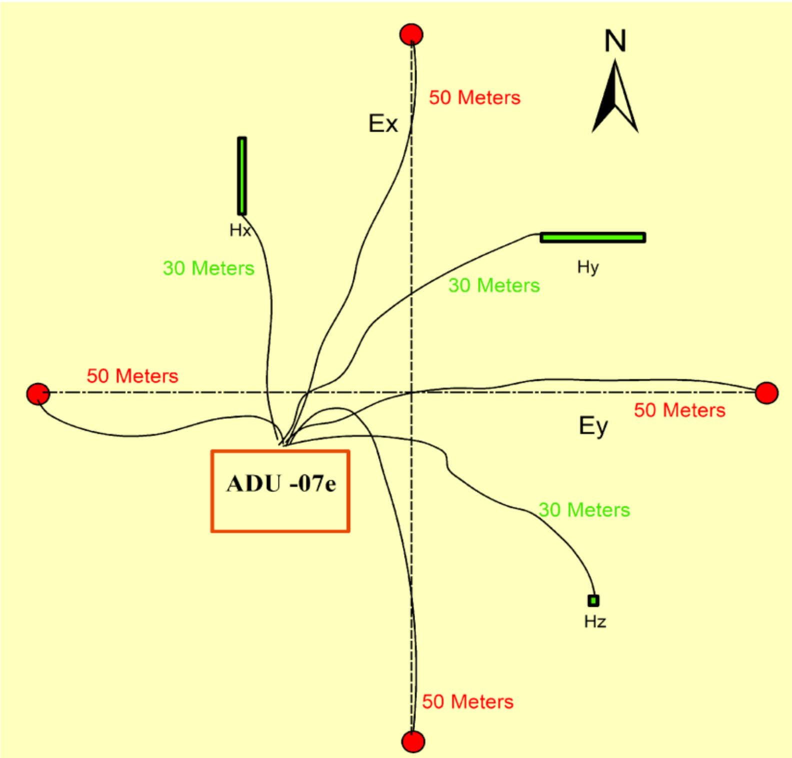

Figure 3. Magnetotelluric Arrangement in Internal Coordinate System (Al Ansory et al., 2023).

Data processing was carried out using Mapros and ZONDMT1D software. The measurement results with the ADU-07e Magnetotellurik tool are in the form of electric field time series data that have good quality with regular time intervals (Figure 4). Figure 4 shows the results of 16 hours of measurements taken with a low frequency (128 Hz) with a recording time of 13 hours because small frequencies are more susceptible to noise so that the recording time is longer, medium frequency (1024 Hz) with a recording duration of 2 hours, high frequency (4096 Hz) with a recording time of 1 hour because the frequency used is large.

Processing begins with processing on mapros software by converting survey time series data into formal edi files on mapros. Moving the time series data into a special folder, followed by importing with the "easy ats import file" command, data that is still in time format must be converted or transformed into the frequency domain using fast fourier transform (FFT) by monitoring the sampling time, and filtering the data and exporting it into edi data (Figure 5). Figure 5 shows the results of data processing using Mapros, which transformed the data from the time domain to the frequency domain. The results show three main frequency ranges: a low frequency bandwidth that ranges from 10-2 to 102 Hz, a medium frequency bandwidth that is around 103 Hz, and a high frequency bandwidth that exceeds 103 Hz. Each of these frequency bandwidth ranges is represented by the points seen in Figure 5. Then, processing the edi file data in the ZONDMT1D software to produce a model of the relationship between resistivity values (specific resistance) and depth using the correlation of resistivity values with ground surface depth.

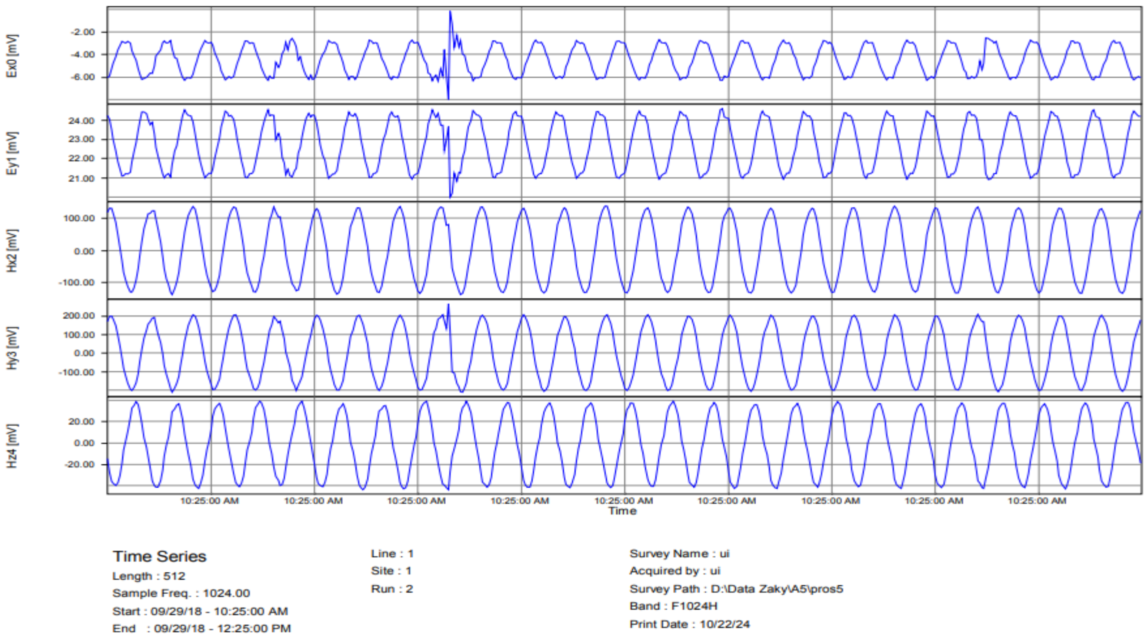

Figure 4. Time series data.

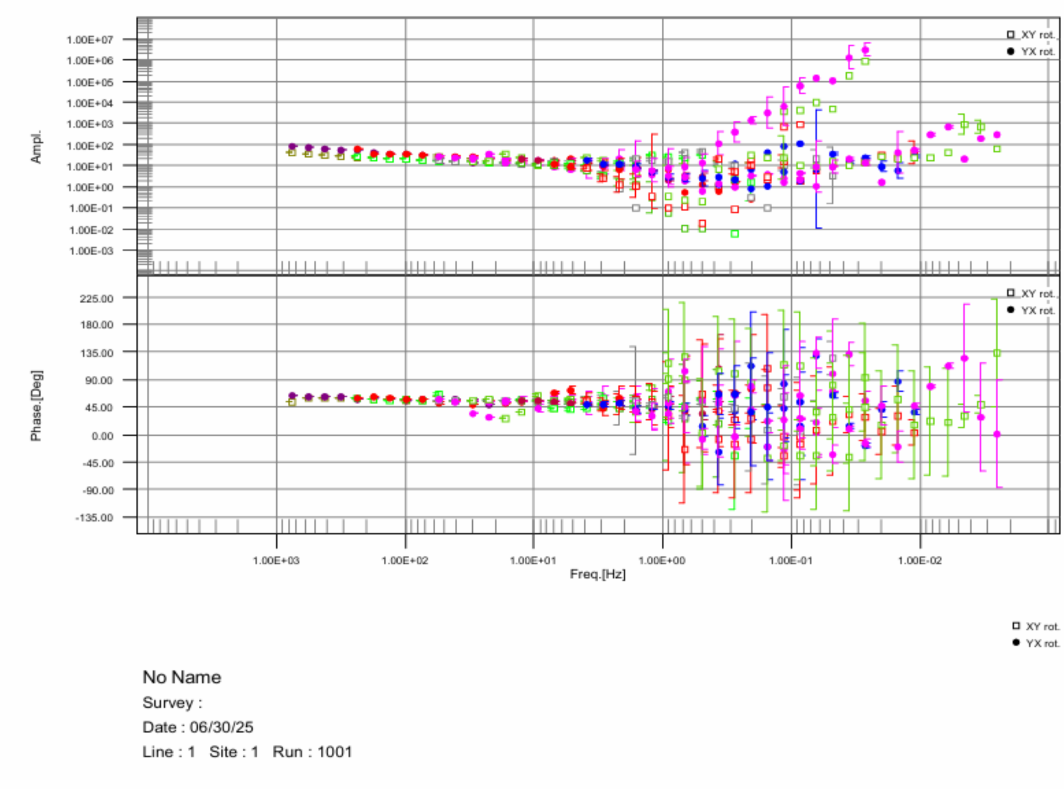

Figure 5. EDI data.

RESULTS AND DISCUSSION

The results of 1D Magnetotelluric inversion data processing at six measurement points (MT5, MT6, A6, A5, A1, A4) can be seen in Figure 6. The results of one-dimensional (1D) Magnetotelluric inversion show a sounding curve that describes changes in the earth's resistivity value based on depth. This curve helps to see differences in rock types and physical conditions in the subsurface. The resistivity value at each depth can provide information about the type of rock, the presence of water or hot fluids, and the degree of heat-induced alteration. In this way, the 1D sounding curve helps to understand the underground structure and locate geothermal reservoir zones. All measurement points were inversed in 1D using 12 different rho data sets and layer thicknesses. 25 iterations were performed on the processing to get sufficient RMS values and ranged from 12% - 30%.

The resistivity value of the 1D inversion processing results obtained varies greatly, starting from 0.21 - 600 Ωm. The resistivity value can be categorised into 3 groups, including low resistivity with a value of 0.21 - 4.0 Ωm, medium resistivity 31 - 80 Ωm, and high resistivity >200 Ωm. The processing results of point MT5 (Figure 6 (T5)), show a change in resistivity value from low to high at a depth of 3.2 - 5.5 km with a medium resistivity value (31 - 80 Ωm) which is thought to be composed of clay mineral rocks (kaolinite, illite, chlorite) which are conductive and have impermeable properties. At point MT6 (Figure 6 (T6)), the resistivity value at a depth of 0 - 1.2 km shows a high resistivity value (280 - 600 Ωm) which is thought to be hot rock, consisting of granitic igneous rocks that have high temperatures but low permeability. At this point there is a prominent resistivity value observed at a depth of 2.5 - 10 km with a low resistivity value (0.21 Ωm), which is thought to be composed of sandstone, limestone, and igneous rocks, where these rocks have high porosity and permeability. At point A6 (Figure 6 (A6)), there is a striking similarity to point MT6 which is at a depth of 0.5 - 10 km with a low resistivity value (ranging from 0.21 - 0.6 Ωm), which is thought to be composed of the same rock layers, namely sandstone, limestone, and igneous rocks, where this rock layer allows the flow and of the Musi segment and the Bogor fault of the Musi sub-fault is one of the causes of the variation in resistivity values observed movement of fluids due to high porosity and permeability. Point A5 (Figure 6 (A5)), there is a change in high to low resistivity values (11 - 350 Ωm) at a depth of 2 - 7 km which is thought to be composed of clay mineral rocks, these rocks function as a cover layer or reservoir layer blocker in the geothermal system. At point A1 (Figure 6 (A1)), the resistivity value increases significantly from 240 - 600 Ωm at a depth of 2.3 - 6 km which is thought to be a hot rock layer, consisting of igneous rocks (granite) and metamorphic rocks and covered by a layer of clay mineral rocks with medium resistivity values (11 - 80 Ωm). Point A4 (Figure 6 (A4)), the resistivity value at this point has similarities with point A1 where at this point the hot rock layer is at a depth of 1 - 6 km with a high resistivity value ranging from 220 - 600 Ωm, usually composed of igneous and metamorphic rocks that have small pores and are not permeable.

The varying values in each graph arise due to differences in the reading of different resistivity values and indicate different variations in the constituent materials at each measurement location. The interaction between the Sumatra fault at various measurement sites. Geoscience in the field of geophysics is needed in the interpretation of this data with the help of other geological and geochemical data. The knowledge gained from the resistivity interpretation is expected to confirm the existence of geothermal reservoir zones that have great potential to be utilised as alternative energy sources in the future. Geoscience in the field of geophysics is needed in the interpretation of this data with the help of other geological and geochemical data.

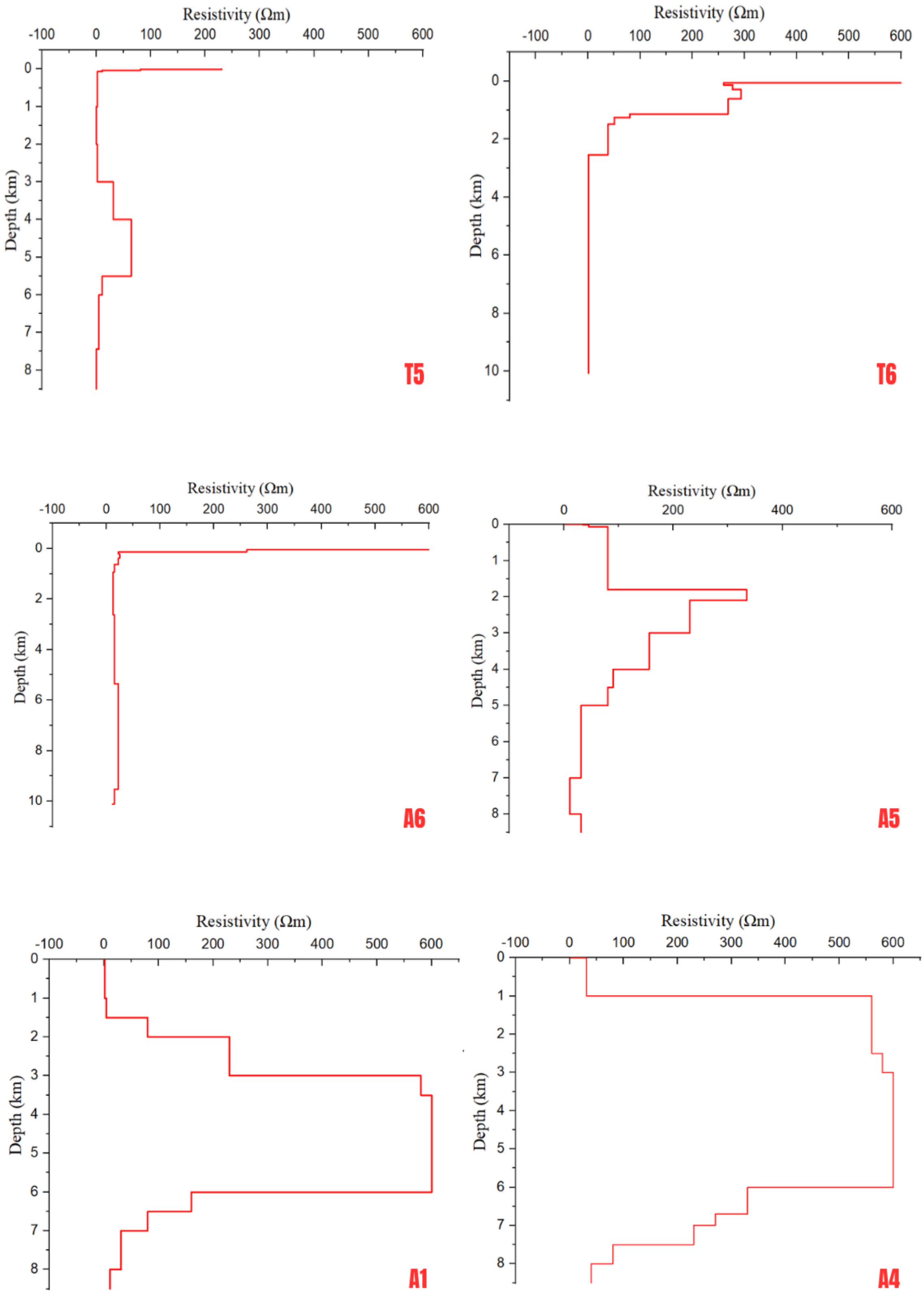

Figure 6. Inversion of 1D Magnetotelluric data (MT5, MT6, A6, A5, A1, A4).

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CONCLUSION

The results of 1D data inversion processing show the existence of varying resistivity values, including low resistivity with a value of 0.21 - 4.0 Ωm, medium resistivity 31 - 80 Ωm, and high resistivity >200 Ωm. Based on the resistivity values obtained, points MT6 and A6 show low resistivity values which indicate the presence of poros and permeable rocks such as sandstone, limestone and igneous rock. This rock layer allows fluid flow due to high porosity and permeability, so it has the potential as a reservoir zone in geothermal systems. At points MT5 and A5 have medium resistivity values indicating the presence of clay rocks that are conductive and impermeable, and limit the movement of fluids from the reservoir, which acts as a caprock in geothermal systems. At points A1 and A4 show high resistivity values indicating the presence of hot rocks, generally in the form of igneous (granite) and metamorphic rocks, which have low porosity and impermeability, usually acting as hot rocks in geothermal systems.

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