Journal of Engineering and Applied Sciences 15 (6): 1481-1486, 2020
ISSN: 1816-949X

Determination of Geothermal using Parameters Resistivity and Phase in the Two-Dimensional Magnetotelluric Data Modeling Technique in Central Sulawesi, Bora Area

[1]Sunaryo, [2]Tasya Andini Sastrianti, [2]Mutia Delina and [3]Ahmad Zarkasyi
[1]Departement of Educational Physics, Faculty of Mathematics and Natural Science,
Universitas Negeri Jakarta,
Jl. Rawamangun Muka No. 1, 13220 Jakarta Timur, Indonesia
[2]Departement of Physics, Faculty of Mathematics and Natural Science, Universitas Negeri Jakarta,
Jl. Rawamangun Muka No. 1, 13220 Jakarta Timur, Indonesia
[3]Subsurface Research Groups, PSDGESDM. Jl,
Soekarno-Hatta No. 444, 40254 Bandung, Indonesia

Abstract: Geophysical research was carried out by using the Magnetotelluric (MT) method on X geothermal exploration to determine the distribution of resistivity and geothermal reservoir zones. The data included nine measurement points with TE-TM invariant mode from two-dimensional modeling. Data were processed by using secondary data from the acquisition process and then utilizing SSMT2000, MTEditor and Win Glink Software. The results shown in this study were in the form of resistivity and subsequent phases with the North-South trending geological conditions. From the analysis obtained in the two-dimensional modeling, there were three distribution zones of resistivity including low, medium and high resistivity distributions. Low resistivity distribution zones of 4-14 Ωm was estimated to be clay cap, the zone of moderate resistivity distribution of 19-159 Ωm was estimated to be reservoir rock which controls the appearance of hot water manifestations and the zone of high resistivity distribution >216 Ωm was estimated to be rock (basement) which is a geothermal source of the Bora area.

Key words: Magnetotelluric, geothermal, resistivity, TE-TM, SSMT2000, Bora area

INTRODUCTION

Indonesia has 120 active volcanoes that can provide benefits for the use of natural sources. One of the natural sources that can be utilized is geothermal energy. The geothermal energy is a source of heat energy stored on the surface of the earth and has several contents including hot water, water vapour and rocks along with minerals and other gases that cannot be separated in a geothermal system. The geothermal system is controlled by the existence of 5 components including heat sources, reservoir, cap rocks, geological structures and water catchment areas. According to Ministry of Energy Mineral Resources, Indonesia is a country that has enormous potential for the geothermal exploration activities because Indonesia's location lies in the tectonic position of the world.

Based on the geological map, Bora area lies in a non-volcanic environment, namely in the environment of metamorphic rock, sedimentary and granite rocks. The geothermal manifestations along the depression zone of the Bora region are controlled by the North-South and Northwest-Southeast cesarean activity trendings. These potentials become essential for geothermal exploration activities using geophysical methods.

The most effective geophysical method is the Magnetotelluric method (MT). The magnetotelluric method is a geophysical method that utilizes the natural electromagnetic fields. The source of natural electromagnetic fields is the interaction between the solar wind with the magnetosphere at the low frequencies (<1 Hz) and the meteorological (Chave and Jones, 2012) activity in the form of lighting at high frequencies (>1 Hz). In this case, the frequency range of natural electromagnetic fields lies from 10^{-4}-10^{4} Hz. The Magnetotelluric (MT) method uses measurements involving magnetic field (H) and Electric field (E) fluctuations, the purpose of which is to determine the resistivity and conductivity of rocks on the Earth's surface from shallow depths up to 10 km (Simpson and Bahr, 2005).

From this study, we will report the results of modeling two-dimensional magnetotelluric data whose purpose is to analyze the Bora geothermal area based on the distribution of resistivity and phase. Resistivity distribution is one of the physical properties that can describe the geothermal prospect zone. This study also presents the stages such as processing, modeling and analysis of the magnetotelluric method for geothermal exploration in Central Sulawesi, Bora area.

Corresponding Author: Sunaryo, Departement of Educational Physics, Faculty of Mathematics and Natural Science, Universitas Negeri Jakarta, Jl. Rawamangun Muka No. 1, 13220 Jakarta Timur, Indonesia

MATERIALS AND METHODS

This research uses the secondary acquisition results of Subsurface Research Group (PSDG) in Bandung, West Java. The data as many as nine measurement points with several stages such as the pre-processing stage are processed by using the Geophysics Phoenix SSMT2000 Software to perform Fourier transformation. Then, we determine the value of cross power to be used as well as robust processing using MTEditor Software and the last step is to make the static correction and two-dimensional modeling inversion using Win Glink Software.

The measurement of the Magnetotelluric (MT) method uses the Maxwell equation because it is a synthesis of magnetic, electric phenomena. The following is a description of Maxwell's equations in a differential form and a frequency domain can be written in the form (Telford *et al*., 1990).

$$\nabla\times E = -\frac{\partial B}{\partial t} \tag{1}$$

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

$$\nabla . D = \rho_f \tag{3}$$

$$\nabla . B = 0 \tag{4}$$

where, E is the Electric field (Vm^{-1}), B is the magnetic induction (Tesla), H is the magnetic field (Am^{-1}), j is the electric curent (Am^{-2}), D is the electricity transfer (Cm^{-2}), dan ρ_f is the electrical charge (Cm^{-3}) and ∇ is an operator in vector calculus.

The electromagnetic signal which is capable of penetrating the Earth is so-called the skin depth. In this case, the electromagnetic waves have a dependence on the magnitude and frequency of electrical conductivity for the penetration depth of the media being passed (Kearey *et al*., 2002). The following is skin depth equation formulated by Vozoff (1991):

$$\delta = 503\sqrt{\frac{\rho}{f}} = 503\sqrt{\rho T} \tag{5}$$

Where:

δ : The electromagnetic skin depth (m)
T : The period (s)
f : The frequency
ρ : The resistivity (Ωm)

Based on the placement of the magnetic field receiver and the electric field in measuring MT data, the electromagnetic propagation produces two measurement modes, namely TE mode and TM mode. However, for this research, a joint mode was carried out, i.e., the TE-TM mode which can comprehensively describe the conductivity information of the Earth. The following is an explanation of the TE-TM mode equation (Cumming and Mackie, 2010):

$$\frac{\partial \vec{B}_z}{\partial y} - \frac{\partial \vec{B}_y}{\partial z} = \mu\sigma \vec{E}_x;\ \frac{\partial \vec{B}_x}{\partial z} = \mu\sigma \vec{E}_y;\ -\frac{\partial \vec{B}_x}{\partial z} = \mu\sigma \vec{E}_z \tag{6}$$

$$\frac{\partial \vec{E}_z}{\partial y} - \frac{\partial \vec{E}_y}{\partial z} = -i\omega \vec{B}_x;\ \frac{\partial \vec{E}_x}{\partial z} = -i\omega \vec{B}_y;\ -\frac{\partial E_x}{\partial z} = -i\omega \vec{B}_z \tag{7}$$

In the Fourier transformation step, it functions to convert the time series data into series frequencies in order to calculate the impedance value and measurement time used from the beginning to the end of the measurement for 16 h. After the cross-power selection process is done, the robust processing step selects the most suitable data eliminates the trend to be smoother than the resistivity curve and phase. Moreover, then, the two-dimensional modeling inversion is processed by using Win Glink Software with TE and TM mode invariant according to geological information in the area.

RESULTS AND DISCUSSION

Data from the acquisition in the form of time series are shown in Fig. 1. Based on Fig. 1, it can be analyzed for the E_x and E_y electric field responses and the magnetic fields H_x, H_y and H_z. The time-series data can change from the time domain to the frequency domain with the selection of the right time because it will affect the quality of the data.

Before the robust process, we must determine the cross-power value that will be used, so that, the partial data set is more precise and produces good data quality. This robust process is good because it can eliminate outliers or points that deviate from the trendline data and can prevent the amount of noise generated from measurements. Figure 2 shows the results of the robust process of the resistivity curve obtained by the MTEditor Software. The following is a comparison of the image of the apparent resistivity curve of the robust process.

Figure 2a shows the results of a robust process that has not finished the editing process and still shows much noise. Figure 2b shows the auto edit process in the MTEditor Software that can make it easier for us to know the pattern of resistivity. Figure 2c is an advanced result (edit) of the auto edit process to create a smoothly form pattern of apparent resistivity. Figure 2d shows the apparent resistivity the pattern equation in Win Glink Software. We can see that the up and down trendlines tend to be stable which causes ρ_{xy} and ρ_{yx} coincide.

The robust process step is carried out repeatedly in order to get the apparent resistivity and phase curve patterns to be smooth and less affected by noise. Figure 3a shows the results of robust processes in the

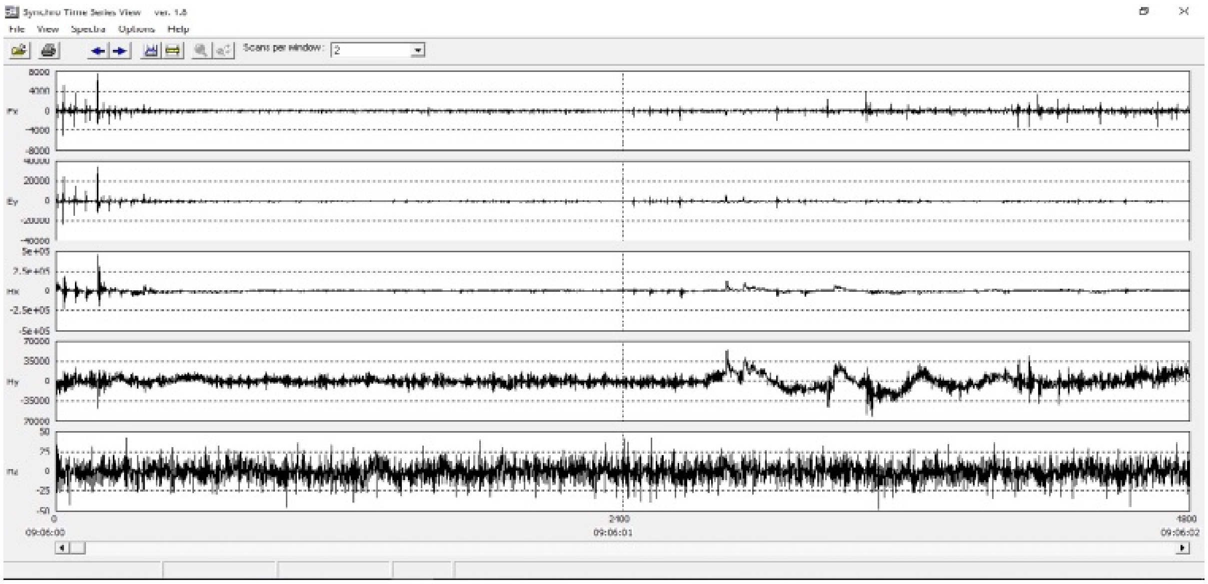

Fig. 1: Time-series data

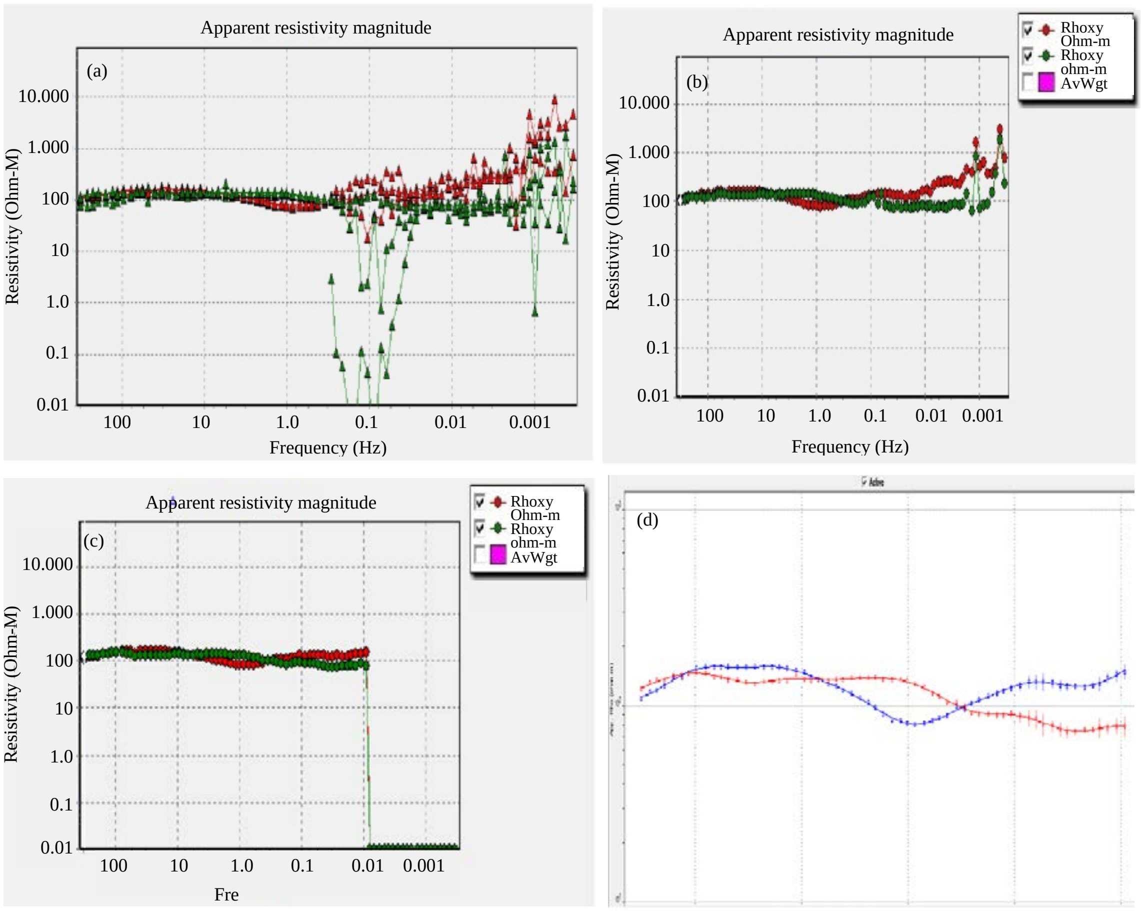

Fig. 2: Apparent resistivity: (a) The results of a robust process, (b) Auto MTEditor, (c) The result of edit MTEditor and (d) Sounding Win Glink

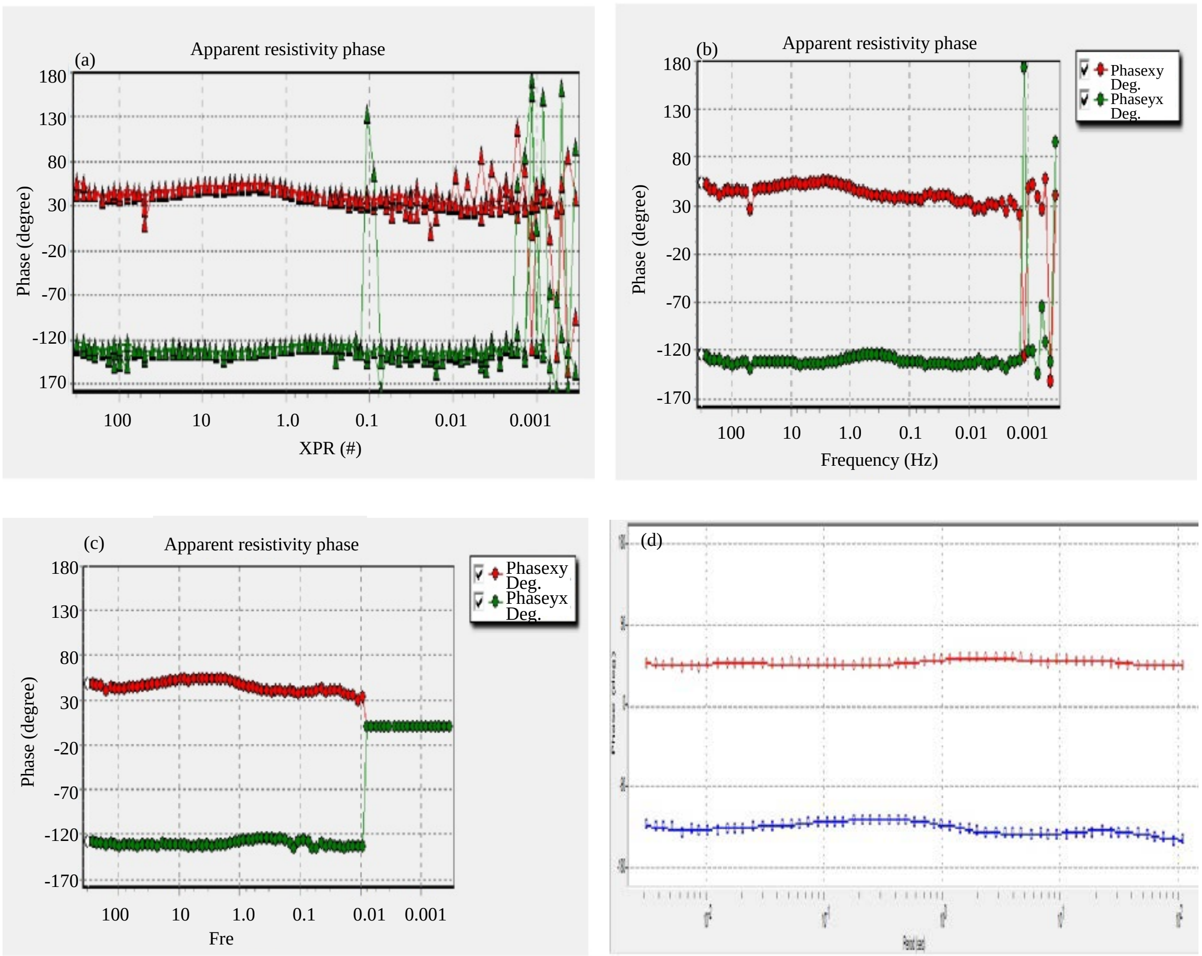

Fig. 3: Phase: (a) The results of robust process, (b) Auto MTEditor, (c) The result of edit MTEditor and (d) Sounding Win Glink

phase that have not finished the editing process yet and there is still much noise generated. Figure 3b shows the auto edit process in the Editor Software that can make it easier for us to know the pattern of the phase. Meanwhile, Figure 3c is an advanced result of the auto edit process, so that, it can more smoothly form a phase pattern. Figure 3d shows the existence of the phase pattern equation in the Win Glink Software.

The processing data obtained from the MTEditor needs to be converted to obtain a lower surface structure model. Then, you can do the two-dimensional modeling using Win Glink Software. First, the model obtained is in the form of a Maps model that is presented in the elevation contour and the location of the MT measurement point as shown in Fig. 4.

The maps model in Fig. 4 is a map that shows the entire measurement point with a depth of 4000 m. It also can determine the profile of the track that will be made.

Then, the sounding model is shown in Fig. 5. The sounding model is a model that can describe resistivity to depth and also make a one-dimensional structure model at each measurement point by determining the resistivity value and can edit the thickness of the inner layer. The following is an example of a sounding model in Fig. 5.

Compared to the two-dimensional resistivity modeling, one-dimensional resistivity varies only with depth because it only shows the resistivity distribution roughly from below the Earth's surface, so, this study uses two-dimensional resistivity modeling with two measurement modes, TE (Transverse Electric) and TM (Transverse Magnetic). The results of the two-dimensional resistivity cross-section is shown in Fig. 6.

In the resistivity cross-section with Southwest Northeast direction and nine measurement points, there is color contrast in the distribution of resistivity. In

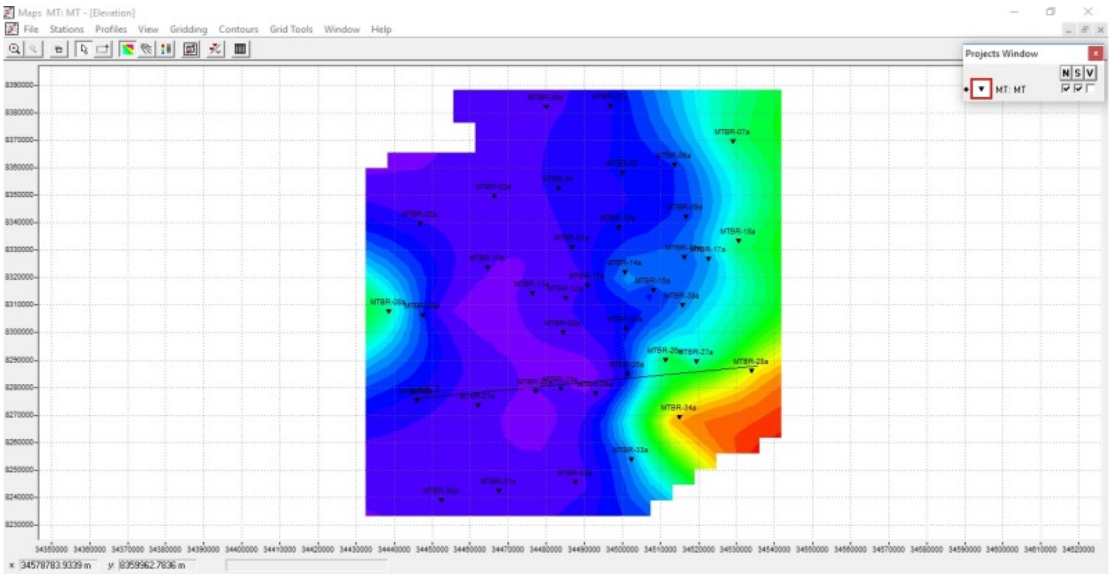

Fig. 4: Model maps

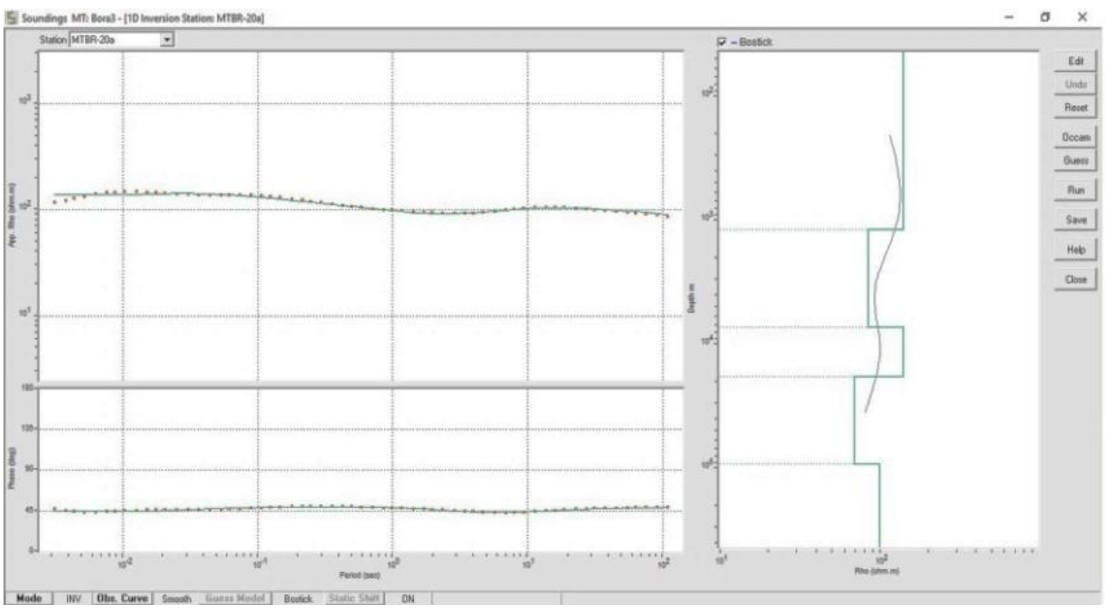

Fig. 5: Sounding model1D

general, it is divided into three distribution zones, low resistivity distribution of 4-14 Ωm shown by red-yellow color, medium resistivity distribution of 19-159 Ωm shown by the green-blue color and high resistivity distribution of >216 Ωm shown by the blue navy purple.

Low resistivity distribution is at the center of the MTBR 24, MTBR 25 and MTBR 26 points below the surface known as the region's depression zone. This is usually related to a layer that is waterproof. This rock can be interpreted as a clay cap for geothermal systems. Under the low resistivity distribution zone, there is a moderate resistivity zone which is thought to be a geothermal reservoir rock. The reservoir rock is thought to be a metamorphic rock that is influenced by a fault structure which makes it possible to store hot fluids.

While the high resistivity distribution is at the Southwest-Northeast and below the MTBR21, MTBR27

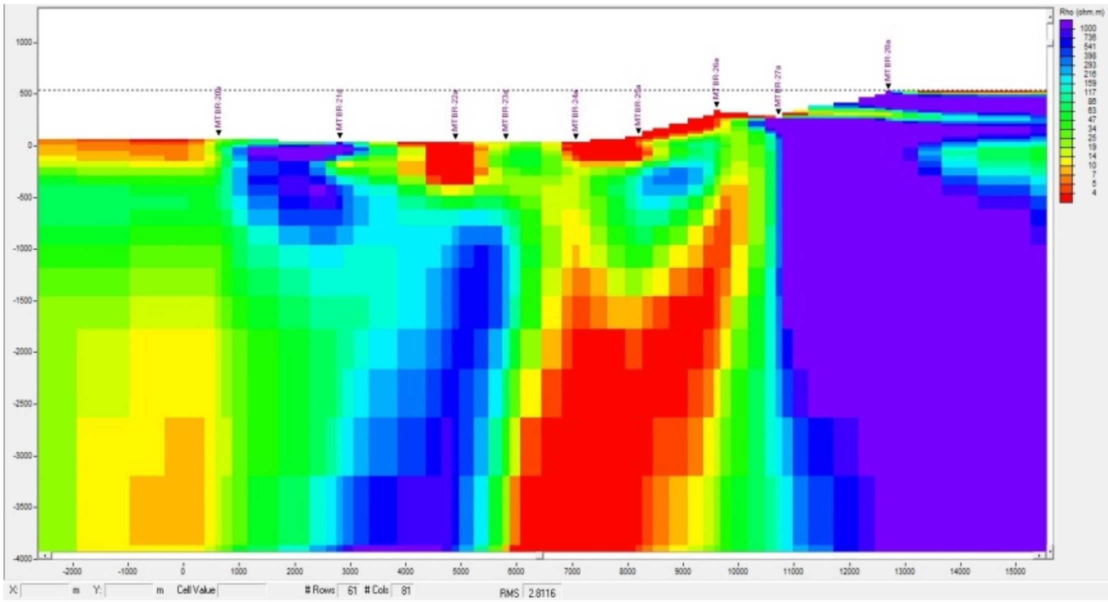

Fig. 6: Two-dimensional resisitivity cross section results

and MTBR28 measurement points can describe the depression zone. This zone is interpreted as the basement, which is a geothermal source of the Bora area.

CONCLUSION

Based on the description of the two-dimensional modeling of magnetotelluric data, it is concluded that there are several stages, namely Fourier transform, robust processing, cross-power selection to two-dimensional inversion. Data processing starts from time-series data to produce a two-dimensional resistivity modeling value including three resistivity distribution zones, namely the distribution of low, medium and high resistivity values. Low resistivity distribution zones of 4-14 Ωm is estimated to be clay cap, the zone of moderate resistivity distribution of 19-159 Ωm is estimated to be reservoir rock which controls the appearance of hot water manifestations and the zone of high resistivity distribution >216 Ωm is estimated to be rock base (basement) which is a geothermal source of the Bora area.

ACKNOWLEDGEMENTS

The researchers would like to thank the Subsurface Research Groups (PSDG) Bandung for the opportunity given to study the MT method during the final assignment and for the permission given to publish this study. We also thank the supervisor who has provided knowledge and guidance to the researchers.

REFERENCES

Chave, A.D. and A.G. Jones, 2012. The Magnetotelluric Method: Theory and Practice. Cambridge University Press, Cambridge, UK., ISBN: 978-0-521-81927-5, Pages: 552.

Cumming, W. and R. Mackie, 2010. Resistivity imaging of geothermal resources using 1D, 2D and 3D MT inversion and TDEM static shift correction illustrated by a Glass Mountain case history. Proceedings of the World Congress on Geothermal, April 25-29, 2010, Bali, Indonesia, pp: 1-11.

Kearey, P., M. Brooks and I. Hill, 2002. An Introduction to Geophysical Exploration. Wiley-Blackwell, Hoboken, New Jersey, USA.,.

Simpson, F. and K. Bahr, 2005. Practical Magnetotellurics. Cambridge University Press, Cambridge, UK., ISBN: 9780521817271, Pages: 254.

Telford, W.M., L.P. Geldart and R.E. Sheriff, 1990. Applied Geophysics. 2nd Edn., Cambridge University Press, USA., ISBN-13: 9780521339384, Pages: 792.

Vozoff, K., 1991. The Magnetotelluric Method. In: Electromagnetic Methods in Applied Geophysics, Nabighian, M.N. (Ed.). Society Exploration Geophysicist, Tulsa, Oklahoma, USA., ISBN: 9781560800224, pp: 641-711.