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CORRIGENDUM TO:

Magnetotelluric Investigations in the Way Umpu Geothermal Prospect Area, Lampung Province, Indonesia

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Figures 1 (page 229) and 4 (page 235) are modified as follows:

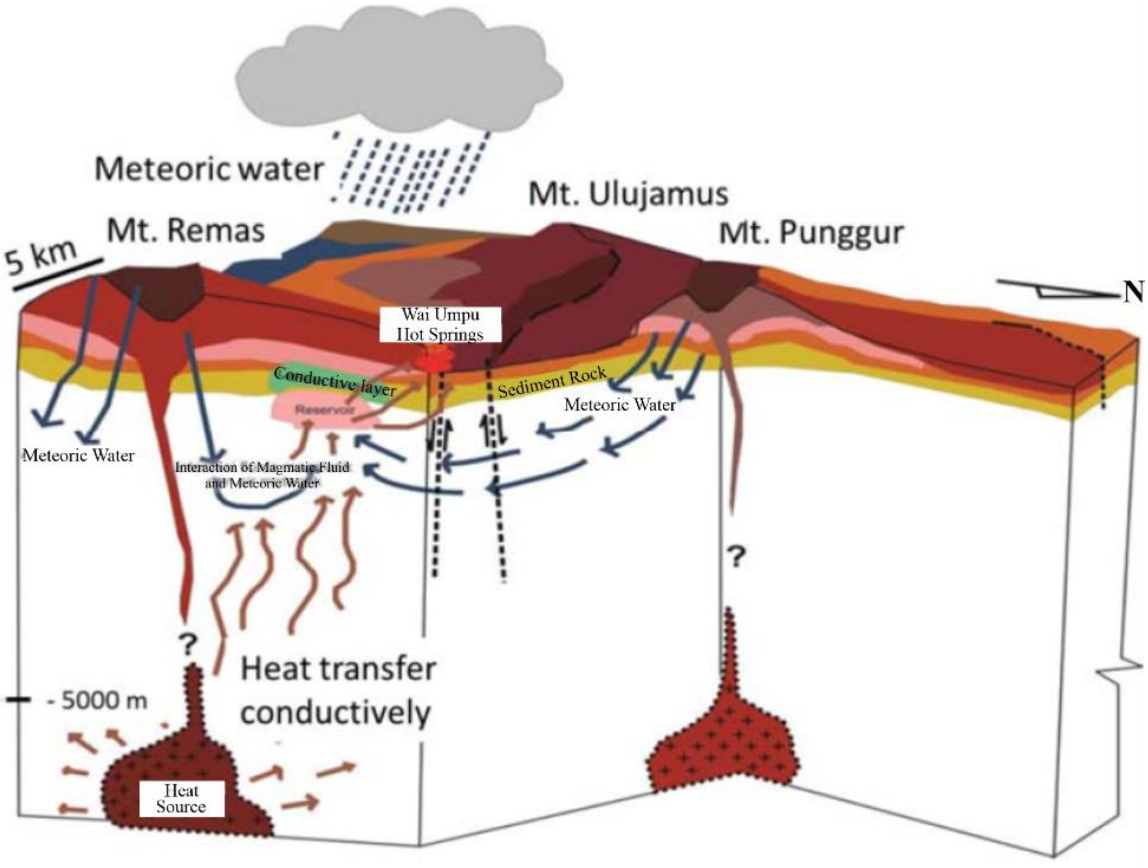

Figure 1 Schematic model of the tentative Way Umpu geothermal system (Integrated Team Survey PSDG, 2012)

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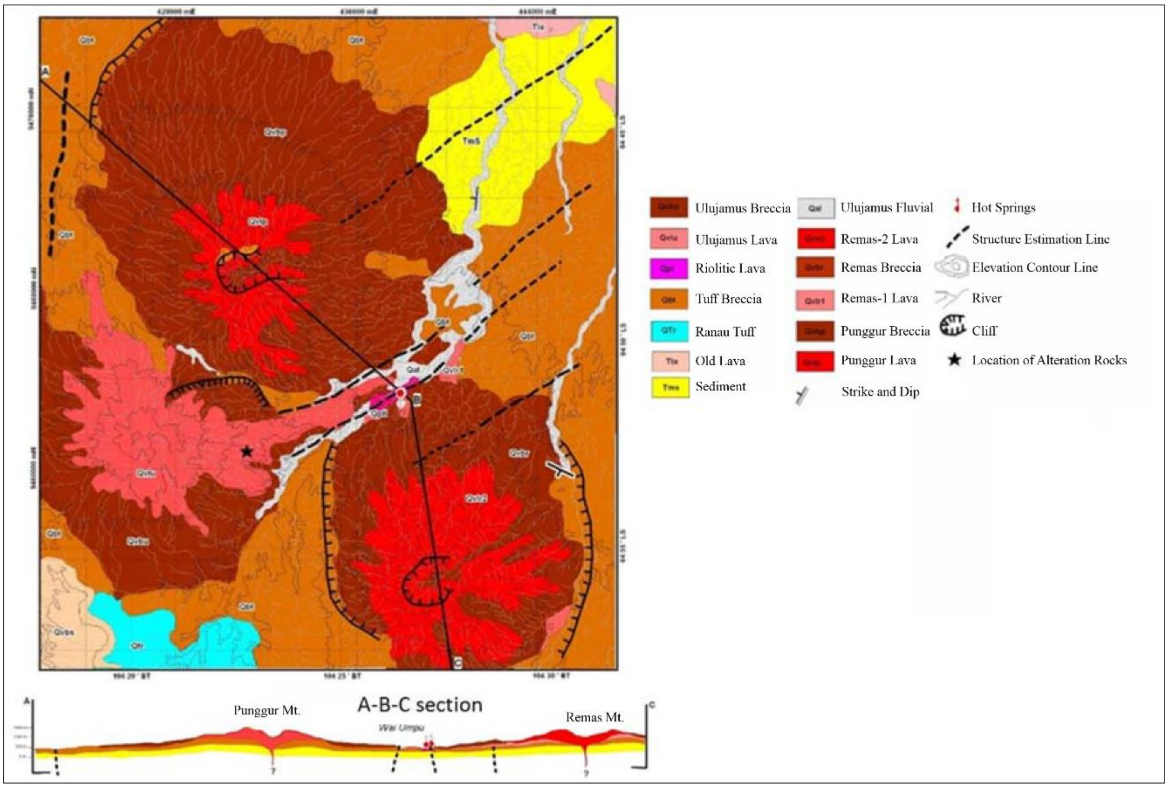

Figure 4 Geological map of Way Umpu (Integrated Team Survey PSDG, 2012)

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MAGNETOTELLURIC INVESTIGATIONS IN THE WAY UMPU GEOTHERMAL PROSPECT AREA, LAMPUNG PROVINCE, INDONESIA

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ABSTRACT
The Geological Research Center's (GRC) or Pusat Sumber Daya Geologi (PSDG) previous research estimated that the Way Umpu 1 Hot Springs in the Way Umpu geothermal prospect area reflects a reservoir temperature of 160°C–195°C. From geological observations, the main fault structure in that area is the Way Umpu Fault, which has a strike direction of NE–SW and the area is dominated by volcanic rocks. Many joints are also found along the fault line. The Way Umpu-1 Hot Springs is controlled by these geologic structures. The previous research and field observations lead us to carry out continuing research in this area, which is aimed at determining its resistivity structure to a depth of 4 km. For this purpose, we carried out field measurements using Audiomagnetotelluric (AMT) and Magnetotelluric (MT) methods. The work presented in this paper is the result of 1-D and 2-D inversion modeling from 8 MT soundings. We compared inversion models using the 1-D Bostick transformation scheme, 1-D Occam model, and 2-D Nonlinear Conjugate Gradient (NLCG) algorithms. The study results reveal the existence of a strike as indicated from the geological data and a low resistivity zone at a shallow surface to a depth of 2 km that is most probably associated with partial melting and intrusion at a greater depth.

Keywords: 1-D model; 2-D model; Geothermal; Magnetotelluric, Nonlinear Conjugate Gradient

1. INTRODUCTION
Indonesia has many potential geothermal resources. In the tectonic setting known as the "Pacific Ring of Fire", Sumatra Island has the largest geothermal potential. This area is part of the subducted Indo-Australian oceanic plate located in the south of the Eurasian continent to the north. Renewable energy requirements as well as knowledge of the geologic conditions trigger the exploration of geothermal conditions. The Geological Resource Center's or Pusat Sumber Daya Geologi (PSDG) previous research in the Way Umpu Geothermal Area, Lampung suggested investigation using the Magnetotelluric method (MT).

In order to explore a geothermal system, researchers require information related to the presence of a reservoir cap rock, which is generally clay. The detection of the presence of clay was made by physical parameters, such as the relatively low resistivity values, which range from 1–100 ohm.m (Mussett & Khan, 2000). In this case, the existence of the conductive layer can be obtained by using the MT method.

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This method gives structural information of subsurface resistivity variations in the form of natural electric and magnetic fields of the earth, due to the sun activity which is the source of electromagnetic waves below 1 Hz and lightning for electromagnetic waves above 1 Hz (Vozoff, 1991). In addition, the MT method has a wide frequency range, so that it can be used to investigate the basis of overburden pressure at a depth of over 1000 m (Cumming, 2009).

Furthermore, modeling MT data requires data inversion stages. Inversion is done by applying an algorithm that can reconstruct the subsurface condition from observation data. Models produced from 1-D inversion are variations of resistivity values with depth values. Inversion of the 1-D Occam model searches allows for the smoothest solution model that fits the data (Constable et al., 1987). Meanwhile, 2-D modeling will present variations of resistivity with depth and lateral measurements. The inversion algorithm of a 2-D Nonlinear Conjugate Gradient (NLCG) algorithm finds the solution to minimize the object function on the data residuals and the second spatial derivative of the resistivity (Rodi & Mackie, 2001).

In order to obtain data corresponding to conditions in the field, researchers need knowledge of the local geological conditions, the presence of manifestations, and possible causes of noise in the data. Therefore, in this paper we are not only discussing the models of 1-D and 2-D MT data, but also the MT acquisition in Way Umpu, Lampung, Indonesia.

2. THEORETICAL BACKGROUND

2.1. Geothermal System

The geothermal system is a natural heat transfer in a given volume in the earth's crust (Hochstein & Browne, 2000). Geothermal systems can be found in areas with a normal geothermal gradient or higher, such as the boundary between the plates, where the geothermal gradient can be higher than the average value (Dickson & Fanelli, 2004). There are three main elements in the geothermal system, which are permeable reservoir rocks, water to carry heat from the reservoir to the surface of the earth, and the heat source (Goff & Janik, 2000).

Geothermal systems in the world are classified into four groups based on geological and tectonic relationships: volcanism and tectonics, continental collision zones, the continental rift system and active volcanism (Chandraskharam & Bundschuh, 2008). The geothermal system in Indonesia belongs to a group associated with volcanic and tectonic activity, which is commonly found in subduction zones. The volcano-tectonic geothermal system is defined as a system that is associated with other graben and volcanic cones, which are generally found in Sumatra, especially along the Sumatra fault system (Kasbani, 2009).

Because of volcanic formation on the active plate boundary zone, most of Indonesia's geothermal system comes from hydrothermal systems. The hydrothermal system is a type of geothermal system where heat transfers from a heat source (often a cooling pluton) to the surface by free convection, involving meteoric fluids with or without traces of magmatic fluids (Hochstein & Browne, 2000). There are 5 essential components of the hydrothermal system. These are: a heat source, a permeable reservoir, the water supply, a cap rock, and the mechanism of water absorption (Dipippo, 2005).

Based on the classification systems in geology, geophysics, hydrology, and engineering, the types of geothermal systems, known as tectonics, igneous young, and geo-pressured are commonly called a hydrothermal system (Goff & Janik, 2000). Tectonic systems associated with high heat flow, occur in the back arc, crustal extension, collision zones, and along the fault zones. This system has a reservoir temperature ≤ 250°C and a depth of ≥ 1.5 km. Meanwhile, young igneous systems, associated with Quaternary volcanism and the intrusion of magma, are generally located in the reservoir at a depth of ≤ 1.5 km with a temperature < 370°C. Geo-pressured systems can be found in sedimentary basins, with a depth of 1.5–3 km and a temperature of 50–190°C.

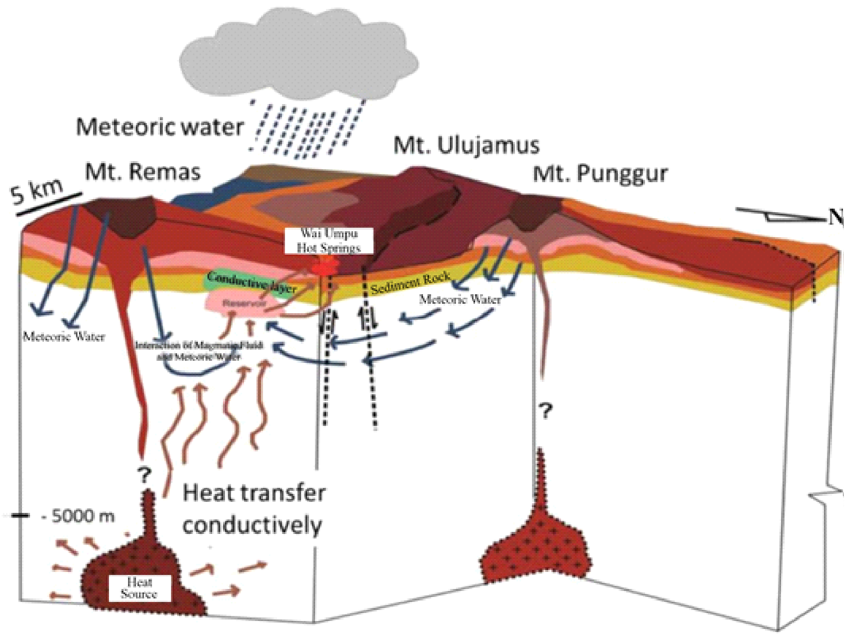

Figure 1 Schematic model of the tentative Way Umpu geothermal system
(Integrated Team Survey PSDG, 2012)

The hydrothermal system in the Way Umpu area is shown in Figure 1. The heat source is estimated in the body of young volcanic cones of Quaternary age, with the youngest body at the top of Mt. Remas. This is reinforced by the manifestations of crap gas in the Way Umpu-1 Hot Springs shown in Figure 2.

Figure 2 Way Umpu-1 Hot Springs

Manifestations in this area are generally derived from the magma body which still has the potential to store heat. Reservoir lithology in the case study area is thought to be sedimentary rocks. The reservoir layer is probably formed due to the activity fault structures or the pores of sediment layers. Recharge zones are spread over the peaks of mountains, such as on Mt. Remas, Mt. Punggur, and Mt. Ulujamus. Previous research indicated that a cap rock is located on the slope of Mt. Remas, which is dominated by altered clay.

2.2. MT Method

In geothermal exploration, the MT method is used to describe the distribution of resistivity in the subsurface. The source of MT is natural sources from solar wind and lightning activity with 0.001-104 Hz frequency range (Vozoff, 1991). MT utilizes time variation of geomagnetic field measured at the earth's surface. Then, fluctuations of magnetic field induce electrical currents. Variations of the electrical conductivity of lateral and vertical directions in the crust are caused by the presence of ions or solid conductive objects (Zhdanov, 2002). Ions present in the form of geothermal fluid circulation in the upper crust, or as partial melting in the lower crust or mantle. Solid objects in this context is the rock, if heated it will be highly conductive.

In order to find the response of earth, the calculation of MT method is based on the concept of electromagnetic fields. An electromagnetic field in a medium can be described by Maxwell's equations:

$$\nabla . D = \rho_e \quad (1)$$

$$\nabla . B = 0 \quad (2)$$

$$\nabla \times E = -\partial_t \mathrm{B} \quad (3)$$

$$\nabla \times H = J + \partial_t D \quad (4)$$

where D is electric displacement (in Cm^{-2}), ρ_e is electric charge density (in Cm^{-3}), B is the magnetic induction (in T), E is electric field (in Vm^{-1}), H is magnetic field (in Am^{-1}), J is electric current density (in Am^{-2}), and ∂_t is partial derivative of time.

Maxwell's equations consist of Gauss's Law for electricity that states the electric field diverges from the electrical charge (Equation 1); Gauss's Law for magnetism that states there is no magnetic monopole (Equation 2); Faraday's Law for electricity that states the circulation of the electric field produced by the magnetic field varies with time (Equation 3); and Ampere's Law that states the circulation of the magnetic field is generated by the vector sum of currents and electric fields that vary with time (Equation 4).

Vector components in Maxwell's equations are related to the linear constitutive equations:

$$D = \varepsilon E \quad (5)$$

$$B = \mu H \quad (6)$$

$$J = \sigma E \quad (7)$$

where $\varepsilon = \varepsilon_0 \varepsilon_r$ is the dielectric permittivity (in Fm^{-1}), $\mu = \mu_0 \mu_r$ is the magnetic permeability (in Hm^{-1}), and σ is electrical conductivity (in Sm^{-1}).

Scalar quantities, ε , μ and σ describe the intrinsic properties of the material when the electromagnetic field is propagating in an homogeneous isotropic medium. Ohm's Law (Equation 7) explains that the Earth behaves as a conductor, where J is the total electric current density (in Am-2). In the MT study, variations of σ , ε and μ in rocks can be ignored.

Derivations of Maxwell's equations and linear constitutive equations produce the Telegrapher's equation (Equation 11) to describe the process of diffusion and wave propagation in a homogeneous medium. It is obtained from using the identity vector (Equation 8), adding the curl operator (Equation 9) and assuming an homogeneous earth model (Equation 10). Then, Telegrapher's equation solution can be expressed by a periodic sinusoidal function (Equations 12-13).

$$\nabla \times \nabla \times V = \nabla(\nabla \cdot V) - \nabla^2 V \tag{8}$$

$$\nabla \times (\nabla \times E) = \nabla \times \left(-\frac{\partial B}{\partial t}\right) \tag{9}$$

$$\nabla \cdot E = 0 \tag{10}$$

$$\nabla^2 (E,H) - \mu\sigma \frac{\partial (E,H)}{\partial t} - \mu\varepsilon \frac{\partial^2 (E,H)}{\partial t^2} = 0 \tag{11}$$

$$E(r,t) = E_0(r) e^{-i\omega t} \tag{12}$$

$$H(r,t) = H_0(r) e^{-i\omega t} \tag{13}$$

where r is position, t is a function of time, E_0 is amplitude of the electric field, H_0 is amplitude of magnetic field, and ω is the frequency of electromagnetic (EM) wave.

Furthermore, the first and second derivation of the solutions of Telegrapher's equation and the substitution identify other vectors that will yield the Helmholtz equation (Equation14):

$$\nabla^2 (E,H) + k^2 (E,H) = 0 \tag{14}$$

$$k^2 = \mu\varepsilon\omega^2 \left(\frac{\sigma}{\varepsilon\omega} i + 1\right) \tag{15}$$

where k^2 is the square of the complex wave number. This equation describes conduction and displacement currents.

The effective skin depth (Equation 16) of the electromagnetic waves is obtained from the real component of k. Skin depth is defined as the distance where the wave amplitude is reduced by a factor of e^{-1} (Zhdanov, 2009). From this equation, the dependence of attenuation on frequency can be used as a tool to control the depth of the resistivity measurements.

$$\delta = \frac{1}{\alpha} = \sqrt{\frac{2}{\mu_0 \sigma \omega}} \tag{16}$$

where δ is skin depth (in m) and $\rho = 1/\sigma$ is resistivity in a homogeneous medium (in Ohm.m).

From the relationship between E and B in Equation 3, the plane wave assumption states that an induced magnetic field only has a horizontal component as a result of the large distance to the source. Thereafter, we can derive the following equation:

$$(E,B)=(E_0,B_0)e^{-i(kz-\omega t)} \tag{17}$$

where $e^{-i\alpha z}$ is the exponential decay with depth, $e^{-i\alpha z}$ are the sinusoidal variations in depth, and $e^{-i\omega t}$ is the sinusoidal variation in time (Vozoff, 1991). Furthermore, from the ratio of orthogonal components obtained from field measurements, apparent resistivity is obtained:

$$\rho_{a_{xy}} = \frac{1}{\mu\omega}\left|\frac{E_x}{H_y}\right|^2 \tag{18}$$

Apparent resistivity can be considered as an average resistivity of the earth with a radius equal to the skin depth (Bera & Rao, 2012). The time lag of the magnetic field from the electric field is expressed by:

$$\varphi_{xy} = Arg\left(\frac{E_x}{H_y}\right) \tag{19}$$

The ratio of E_x / H_y on the surface is very important because the frequency can be determined accurately from the time that precision must be maintained in data collection (Vozoff, 1991; Bostick, 1977; Integrated Team Survey PSDG, 2012). Impedance, introduced by Tikhonov (1950) and Cagniard (1953), is associated with a model in which the primary field is uniform in the horizontal direction. The main purpose of the Tikhonov–Cagniard impedance models respectively is to determine the impedance of the layered medium and how the model applies the impedance tensor factor to a relatively high frequency (Berdichevsky & Dmitriev, 2002). The impedance tensor equation is:

$$Z_{xy} = \frac{E_x}{H_Y} \tag{20}$$

In 1- D models, the conductivity only varies with depth, so the condition assumed as being:

$$[Z] = Z\begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \tag{21}$$

while, in 2-D models, the conductivity varies along the vertical axis z and one horizontal axis, x or y, perpendicular to the strike of the model. Therefore, we assumed the following conditions:

$$[Z] = \begin{bmatrix} 0 & Z_{xy} \\ Z_{yx} & 0 \end{bmatrix} \tag{22}$$

In the 2-D model, the magnetotelluric (MT) field is divided into two modes, the TE mode and TM mode. The TE mode describes the current flow as being parallel to the strike. This mode can identify anisotropy and narrow conductors that are not yet defined by the TM mode (Grandis, 2009). Meanwhile, the TM mode describes the current flow perpendicular to the strike. This mode is more sensitive to lateral resistivity changes and is generally less affected by 3D effects (Grandis, 2009).

2.3. Inversion Method

Inversion theory is a collection of mathematical techniques to reduce the data in order to obtain information about the physical earth based on observations (Menke, 1989). Inversion modeling also is referred as fitting the data for the model parameters to search a response that fits the observational data (Grandis, 2009). The inversion problem can be written as:

$$m = A_s^{-1}(d) \tag{23}$$

where m is the model parameter, A_s^{-1} is the inverse of the forward operator on the source, and d is the data (Zhdanov, 2002).

The result of the 1-D model is an horizontal layered earth model, in which resistivity varies only with depth (Grandis, 2009). The Bostick transformation scheme produces the depth resistivity distribution of a continuous or near-continuous condition (Bostick, 1977). In this study, we estimated resistivity using pseudo-resistivity and phase factors:

$$\rho(z) = \rho_a(\omega)\left(\frac{\pi}{2\phi(\omega)} - 1\right) \tag{24}$$

$$z = \left(\frac{\rho_a(\omega)}{\mu\omega}\right)^{1/2} \tag{25}$$

where the nominal depth z is in accordance with the skin depth in the half-space. Then we compared the 1-D Bostick transformation scheme to the Occam model. The Occam inversion model is an inversion to get a smooth model, which is derived from the model parameters with the smallest roughness (Constable et al., 1987). These algorithms are used in the 1-D modeling software WinGLink® licensed by PSDG:

$$R_1 = \sum_{i=2}^{N}(m_i - m_{i-1})^2 \tag{26}$$

$$R_2 = \sum_{i=2}^{N-1}(m_{i+1} - 2m_i + m_{i-1})^2 \tag{27}$$

For 2-D resistivity, models vary in the horizontal direction and in terms of depth (Grandis, 2009). The Non-linear Conjugate Gradient (NLCG) algorithm is used in the 2-D inversion software package WinGLink® (Geosystem, 2007). The NLCG computational algorithm is relatively efficient and effective in relation to the regularization solution of the 2-D MT inversion to minimize the objective function (Rodi & Mackie, 2001).

$$\Phi = \Phi_d + \tau.\Phi_m \tag{28}$$

The regularization parameter τ is a weighting factor between the data norm and the mode norm (Widodo, 2012). Optimal norm weighting between the model and the data can be obtained from the determination of the L-curve (Hansen & O'Leary, 1993). The L-curve is a log plot of the data norm (Φ_d) and the mode norm (Φ_m). The parametric selected regulation lies at the point in the corner of the vertical part of the curve, where the curvature reaches its maximum value.

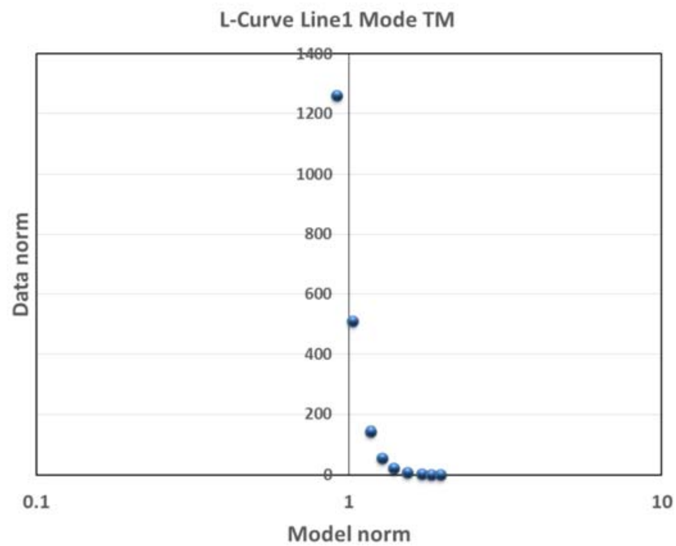

Figure 3 L-Curve application in Line 1 of this study

The quality of the inversion results can be obtained in the form of the Root-Mean Squared (RMS) value from the calculation of the difference between the measurement data (d_j) and the data models (d'_j):

$$RMS\ (\%) = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\frac{\left(d_j - d'_j\right)^2}{{d_j}^2}} \times 100 \tag{29}$$

3. GEOLOGICAL SETTING

3.1. Regional Geology

The geothermal potential of Wai Umpu lies in the district of Way Kanan (104°17'–105°04' BT and 04°12'–04°58' LS), which is in the northern part of Lampung, Indonesia.

As seen in Figure 4 the main fault structure in the area of investigation is the Way Umpu Fault, in the northeast-southwest direction. It is estimated as a block of normal faults, of which there are relatively speaking more blocks located from the southeast down to the block in the north-west. The fault line is indicated by the straight alignment of the sedimentary rock units in the north-east to the south-west orientation of the hot springs. In addition, at some point along the fault, intensive joints are readily apparent as being the geological structure that controls the Way Umpu Hot Springs.

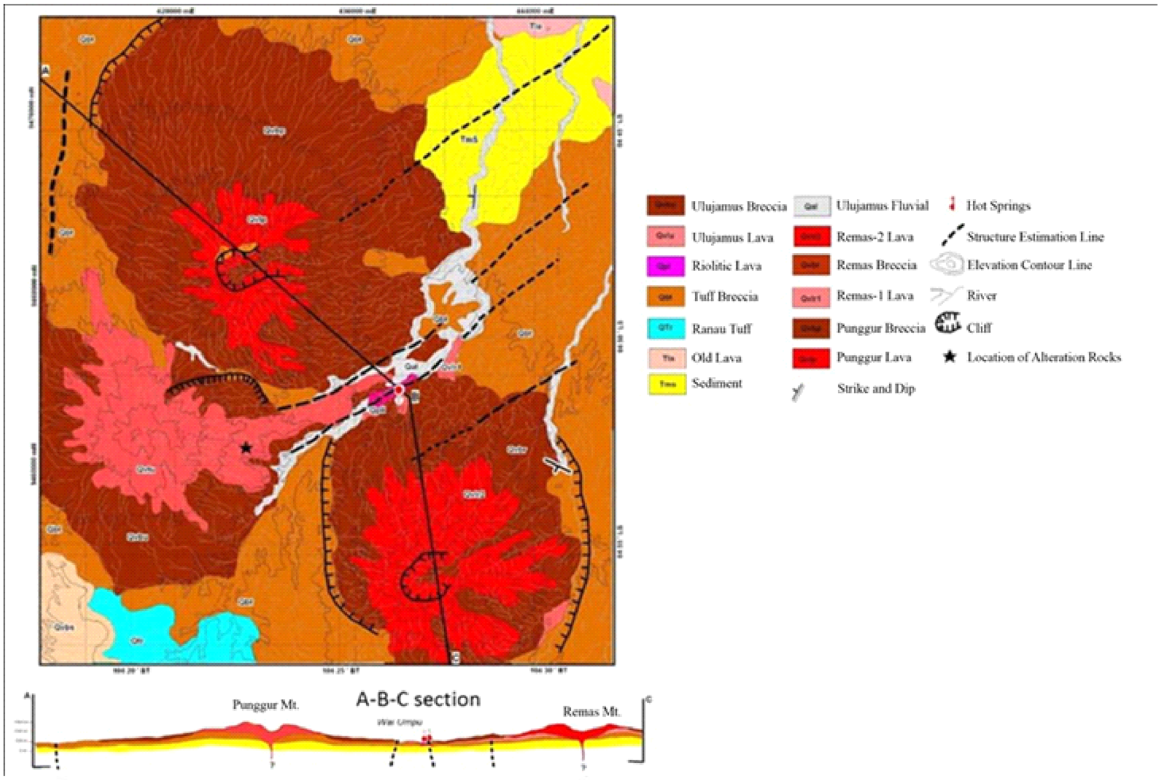

Figure 4 Geological map of Way Umpu (Integrated Team Survey PSDG, 2012)

3.2. Geomorphology

Geomorphology in the study area can be grouped into four geomorphological units (GU): Cone volcano GU, wavy steep hills GU, Medium wavy hills GU and Plain GU.

The cone volcano geomorphology unit forms the bodies of volcanic cones that are inactive, which in this case includes Mount Remas, Ulujamus, and Punggur. The cone shapes have slopes varying between 30° to 60°, but in some places the slopes reach 90°. The geomorphological unit is composed of lava rock and volcanic breccias products, each composing the geomorphology of the volcanic cones. The wavy steep hills geomorphology unit is a transition typology. The slopes in this region range between 30° to 70°. In the case study area, this unit is composed of tuffaceous breccia rocks and volcanic breccias. The medium wavy hills geomorphology units have slopes varying between 10° to 30°. In the investigation area, the unit is composed of sedimentary rock morphology composed of tuffaceous breccias. Plain geomorphology units have slope ranges from less than 10°. In the study area, these units have a lithology composed of loose materials which have been deposited by rivers or alluvial flows.

3.3. Stratigraphy

The previous survey shows that the Way Umpu area is dominated by volcanic rocks scattered from the center to west, from the north to the west, and then from the sedimentary rocks in the eastern part. The oldest rocks in this area are sedimentary rocks that appear in the northeast area of the investigation (Figure 4). Based on field observations and from the analysis of topographic maps and satellite imagery or DEM (Digital Elevation Mode) data, we obtained the sequence stratigraphy ranging from the youngest to the oldest (Integrated tim survey terpadu PSDG, 2012): Sedimentary rock unit (Tms), Old Andesite Lava Unit (Tla), Lava Riolitik Unit (QPL), Tuffaceous rocks breccia unit (QBT), Pyroclastic fallout Ranau unit (Qtr), Breccia Mt.

Subhanallah unit (Qbs), Lava Flow Mt. Ulujamus unit (Qvlu), Volcanic Breccia Ulujamus unit (Qvbu), Lava Mountain Punggur Unit (Qvlp), Volcanic Breccia Unit Mt. Pugur (Qvbp), Volcano Lava Remas Unit-1 (Qvlr1), Volcanic Breccia Remas unit (Qvbr), Volcano Lava Remas Unit-2 (Qvlr2), Alluvial Deposition Unit (Qal) and Rock alterations.

4. DATA ACQUISITION AND PROCESSING

4.1. MT Acquisition

Location of the MT measurement is shown in red dots (Figure 5). There are 40 MT soundings. The MT data acquisition in Way Umpu was conducted in about a month, from mid-April to May 2013. The location of measurement points is determined by topographical team. In this study, we only discussed one (1) measurement line consisting of eight (8) MT soundings. The distance between measurement points is about 1.5 km.

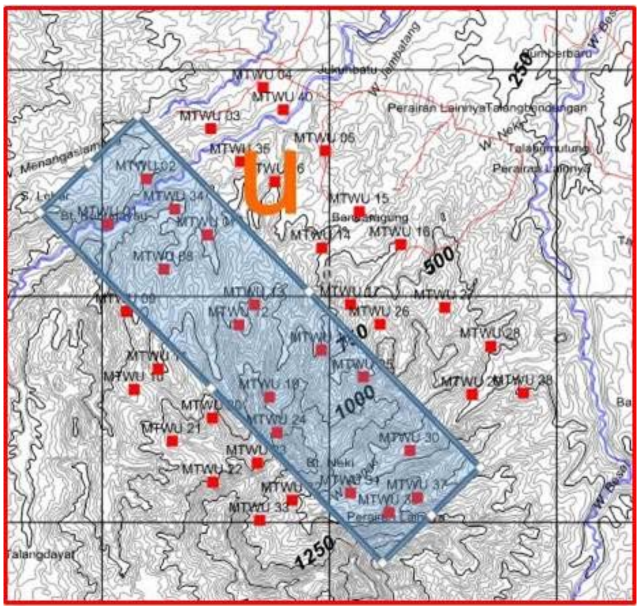

Figure 5 Topographic map and distribution of MT measurement in Way Umpu; the blue box is area of our discussion

Equipment used in the MT survey in Way Umpu geothermal prospect are:

1. MT tool GDP-32II, which is a product of Zonge Engineering
2. Coils (magnetic sensors) Hx and Hy, which were buried to minimize noise
3. Porous pots (electric sensors), which were embedded in north, south, east, and west directions at a distance of 50m from the MT tools, and the fifth porous pot was located near the MT tool
4. GPS-receiver
5. Multimeter, to ensure the existence of cable voltage
6. Waterpass, used to ensure that the coils were placed in a flat condition
7. Laptop to transfer data from the MT tool

Electric currents in the earth generate a signal that can be measured using the AMT/MT Zonge equipment. Frequency dependence of the amplitude and phase of the transfer function factors were used to interpret the conductivity as a function of depth. In this study, MT data acquisition is carried out using the measurement frequency range of 0.0059–8 Hz with supporting AMT data within a frequency range of 0.09–8 Hz, 3–256 Hz, and 192–8192 Hz. To measure the potential difference, electric field measurements using an electric dipole North–South and East–West within 100m were conducted. Meanwhile, the magnetic field was measured with a magnetic coil in North-South and East–West directions.

4.2. MT Processing

In this study, Zonge DATRPRO® is used for robust processing of the MT data or signal amplification. Robust Processing is an iterative process, whereby at an early stage the Least Square (LS) estimate of the impedance values is obtained for a subsequent Gaussian distribution.

MTFT is a program in Zonge DATRPRO ® that serves to process and examine the time-series data that is acquired by Zonge GDP-32^{II}. MTFT reads the time series from file *.out, calibrates the antennae of amtant.cal, calibrates the system from amtbrd.cal, and calibrates the treatment preferences of mtft.cfg. Then MTFT, using a cascade decimation for the Fourier transform of a time series, writes to the spectral coefficients file *.fft. Once the spectral data has been calculated, the program can be used to allow MTEdit to process and analyze the strong impedance and the average apparent resistivity data.

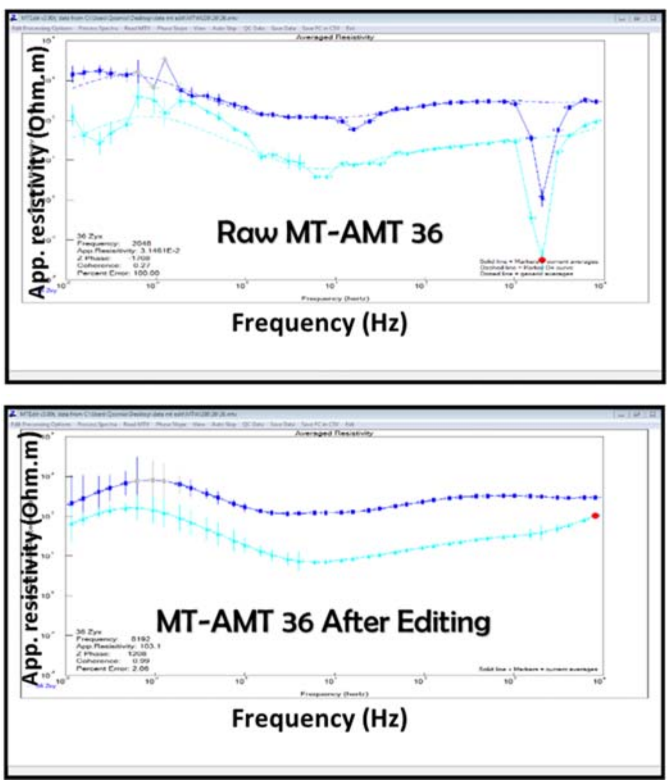

Figure 6 Quality Control data on program MTEdit

MTEdit is a program that serves Zonge DATRPRO ® for processing and analyzing MT data. MTEdit is used to calculate the impedance and the average values of apparent resistivity as unaveraged, spectral data. The QC Data menu option (Figure 6) can be used to adjust or skip flags on unaveraged impedance points shown in the plots Real (Z) versus imag (Z) and |H| versus polarization and coherence to a particular frequency. MTEdit read the Fourier coefficients for each station of the *.fft. Furthermore, MTEdit save the edited copy of the spectral data for each station in a file with the extension *.mtv.

Astatic is a program in Zonge DATRPRO ® that serves to automatically calculate the static correction and import the configuration data survey. The program is also used to convert file formats to SEG format, EDI files.

5. MODELING AND INTERPRETATION

Resistivity from 1-D model varies with depth soundings. In WinGLink software, Bostick 1-D model is shown by the green line in Figure 7, while the Occam 1-D model is shown by the purple line. The result shows that the Occam model produces a more detailed layer than the Bostick transformation scheme.

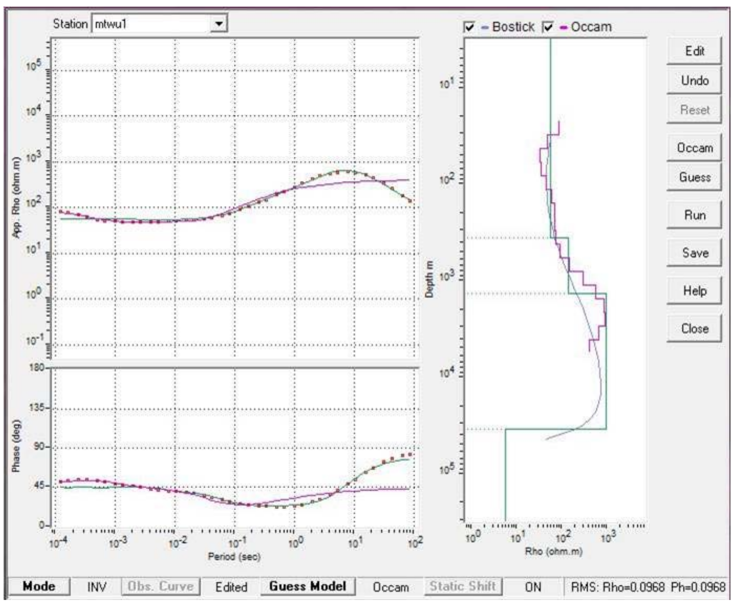

Figure 7 1-D model at MT sounding 1 in Line 1

In the 2-D model, the resistivity varies along line and depth data. From the L-curve, we use τ =3 as the regularization parameter. In this case the TE and TM modes have the same τ results. In general, the value of low resistivity (< 10 Ohm.m) is associated with an increase in the amount of clay that is associated with the clay cap position. In addition, the decrease in resistivity values can also be attributed to changes in acidity.

From the 2-D model in the TE mode (Figure 8), a low resistivity value of 13 Ohm.m exists at a zone near the surface of MT Sounding Station No. 19. From the 1-D model, we obtained information that Sounding Station No. 19 on Line 1 has a shape like a V-curve, which can be indicated as the presence of heat due to partial melting. Based on geological data, that area has Volcanic Lava Remas, so it may be possibly interpreted as a partial melt.

From the 2-D model using the TM mode (Figure 9), the contrast in low resistivity is 13 Ohm.m at a zone near the surface of the MT sounding range between 24 and 31. In this model, we can interpret the Red Zone as a zone associated with Volcanic Lava Remas, the Green Zone as being sedimentary rocks in the Volcanic Breccia Remas, while the Blue Zone as being those zones associated with magma rocks that are possibly metamorphic or igneous rocks. Based on geological data, there is a fault line located in the NE direction. Therefore, the contrast is a result of these kinds of structures. The model results show that the TM mode is better in delineating the presence of these structures, compared with the TE mode.

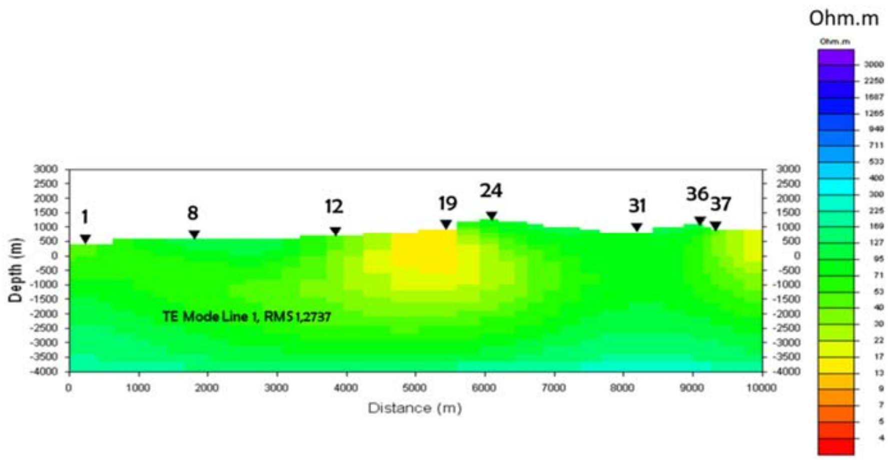

Figure 8 Resistivity model of Line 1 MT 2-D TE mode

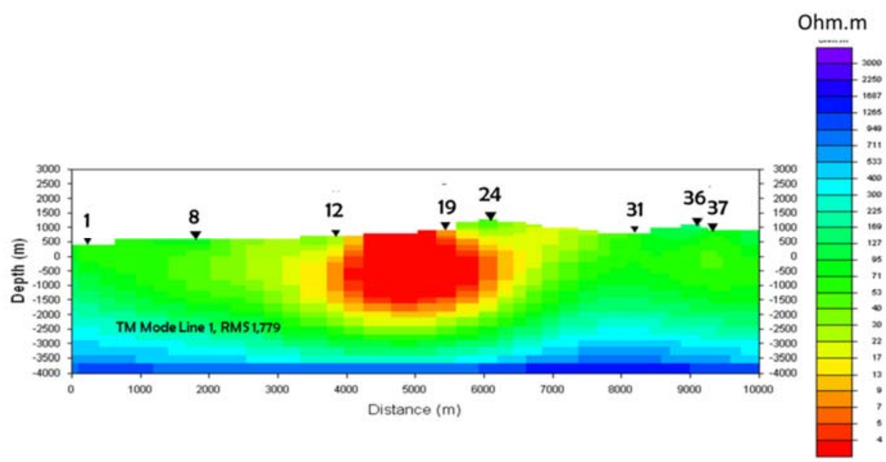

Figure 9 Resistivity model of Line 1 MT 2-D TM mode

6. CONCLUSION

From this study we obtained some important results. Firstly, factors causing noise on the measurements at Way Umpu can be minimized by burying coils and coil cables in the ground. Secondly, modeling the 1-D Occam model and the Bostick transformation scheme show relatively identical results, but the 1-D Occam model is more optimal in describing each layer. Thirdly, the model from the 2-D TM mode is better in revealing the presence of the structure compared to modeling the 2-D TE mode. We compared the inversion models using 1-D Bostick transformation scheme, 1-D Occam model, and 2-D Nonlinear Conjugate Gradient (NLCG) algorithms. Furthermore, this study reveals the existence of strike as indicated from geological data and as indicated in the zone having low resistivity value at a shallow surface to a depth of 2 km, which is most probably associated with partial melting and intrusion at a greater depth. Related to the above results, we suggest that logging data are required to calibrate measurements with the 1-D model. By modeling the resistivity structure around the Way Umpu-1 Hot Springs, the reservoir depth can be estimated.

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