Magnetotelluric method application for conceptual modelling of geothermal system Pariangan West Sumatera

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Abstract. Geological structures on Pariangan is influenced by the tectonic activities of the Sumatera Fault System, volcanic arc of Complex Mt. Marapi and Central Sumatera Basin. stratigraphy of this area was dominated by andesitic-basaltic lava and pyroclastic rocks (Quaternary). This study purpose to determine of geological structures, and heat source location of geothermal system in this area using Magnetotelluric Method (MT). 2-D resistivity model from MT method was combined with geological map for the conceptual models of geothermal system. Based on conceptual model, geothermal system in area was controlled by a couple of main fractures. These fractures are associated with faults in the northwest-southeast and southwest-northeast directions on geological map. It’s also influenced the surface manifestation (e.g hot springs) and alteration mineral zone. Heat source was composed by metamorphic rock (slite rock and granit rock) at 1500-4000 musl as based rock. This heat source associate d with activities of MT. Marapi.

1. Introduction

Pariangan geothermal area is a influenced by a Sumatera fault system (SFS). It’s also following the radial fault pattern from Mt. Marapi [1]. In administration it is located in District Tanah Datar, province of West Sumatera, Indonesia [1]. This area has fractures and faults which order northwest to southeast and southwest to northeast [2]. Some product from Mt. Marapi activities (e.g malihan rock, granite, pyroclastic flows, pyroclastic fall-out) are exist in this area. the other lithology are sedimentary rock and surface sediments (Perm-Carbon to Tertiary). Surface manifestation on this geothermal system is hot spring and warm spring (Sopandidih and Kotabaru), and the mineral alterations [3]. Some mineral alteration exist in this area is secondary quartz, carbonates mineral, epidote, chlorites, sericites, illites, kaolinites, dickites, montmorillonites, hallosites, paragonites, phengites, and nontronites [3].

Conceptual models are descriptive or qualitative models based on geological information. It can used data from geophysics survey, geological mapping, geospatial mapping, geochemical information and also well log data [4]. In this study, the conceptual modelling was reconctrued only based on Magnetotelluric data analysis.

2. Data Analysis and Methods

Required information system in geothermal exploration was related to a reservoir and cap rock (e.g. Clay). this information detected using a physics parameter like resistivity (1-100 Ωm) [5]. MT method
was obtained a conductive layer based on resistivity values. MT method give an information about a structure existence in subsurface from resistivity variations. It is cause of natural electromagnetic wave fields of the earth which comes from activity of the sun at 1 Hz. Source of electromagnetic waves comes from the lighting [6]. Range frequency was recorded from MT method is very wide. So, it’s can used for investigate the overburden pressure with depth over 1000 m [7].

MT modelling requires a data inversion stages with applying an algorithm. The algorithm chosen must can using for design the condition of subsurface based on data observation. 1-D inversions model of MT give an information about resistivity to depth values. 1-D inversion model used in this study is Occam inversion. this model used because give a model with smoothest solution [8]. The characteristic of Occam's inversion is 1D modeling like a thin film. In Occam's inversion, very complex models produced from number of geo-electricity number models [9]. Occam inversion uses the Roughness parameter which is first derivative and second derivative of resistivity value to depth (eq. 1)

\[ R1 = \int \left( \frac{dm}{dz} \right)^2 dz \]

\[ R2 = \int \left( \frac{d^2m}{d^2z} \right)^2 dz \]

where m (z) is resistivity. The principle in this inversion was similar with interpolation of data using modern methods. It was how find the best solution with measurement which a smallest possible roughness [10].

Resistivity variation to depth and measurements laterally obtained by using 2-D inversion model. this study used Nonlinear Conjugate Gradient (NLCG) algorithm (eq. 2). This algorithm used to reduce function of object on residuals data and then minimize of resistivity from second spatial derivative value [11].

\[ d = F (m) + e \]

\[ d, m \text{ is a vector data and vector model. } e \text{ and } F \text{ are a vector of error, and a function of forward model. If } d = [d^1 d^2 \ldots d^M]^T, d^i \text{ is log amplitude or log phase of } \rho_{app} \text{ (eq. 3) for TE or TM polarization, site of observation, and also corner frequency (ω). } m = [m^1 m^2 \ldots m^M]^T \text{ are vector parameters for determine function of resistivity model.} \]

\[ \rho_{app} = \frac{i}{2\omega} \left( \frac{\langle E_x \rangle}{\langle H_y \rangle} \right)^2 \]

\[ \langle E_x \rangle \text{ show the value of site observation from } E_x, \text{ usually at a point it is being } E_x \text{ and average of spatial value of the } E_x \text{ field. } \langle H_y \rangle \text{ is an analogous field function of the } H_y. \text{ Inversion problem solve by solution of ill-posed problems [11]. For minimize function of object } \psi \text{, we can use the solution of regularized being a model, defined by eq. 4. [12].} \]

\[ \psi (m) = (d - F (m))^T V^{-1} (d - F (m)) + \lambda m^T L L^T m \]

if λ, is a positive parameter and V is a definite positive matrix for determine of error vector e variance. \( \psi \) is also defines a function of stabilizing on the spacing model. Matrix L can simplified use operator of second-difference such that and make a uniform grid blocks of model. \( L m \) approximates the Laplacian of log ρ [12].

3. Result and Discuss
1-D inversion modelling was performed as a comparison or a controller for 2D inversion model. 1-D inversion model in form resistivity variation form depth soundings. This model was operated In WinGLink software. This software using Bostick and Occam inversion model. Bostick model used to estimate variations resistivity to depth from sounding curve of pseudo section apparent resistivity [13].
3.1. MT Method Modelling

Figure 1 show the average resistivity values of the TE and TM modes at sounding line 1. There are four layers with different resistivity which is different rock. It’s means there are 4 layers of rock at this line. The model resembles to drill log data which shown the resistivity to depth. Depth penetration of resistivity in this line was 800 means above sea level (masl) to 14000 means under sea level (musl). Range resistivity variation was 5-1200 Ωm. Every sounding point in the line give a different information of resistivity variation. It’s difficult to investigate the stratigraphy of subsurface all of area study because 1-D inversion model only give an information at sounding point. So, for identification stratigraphy in this area we to used 2-D inversion model. This model can reconstruction geothermal system in the area (Figure 2).

![Figure 1. 1-D model result of Magnetotelluric data](image)

2-D inversion model used an invariant mode from combination of TE and TM modes. 2-D model on this study using τ=1, rms = 3,13 %. 2-D inversion model give geothermal system information, such as cap rock, reservoir, heat source and also structure which exist in the area. Generally, low resistivity (< 10 Ωm) is associated with an increase in the amount of clay that associated to cap rock location. Based on Figure 2, low resistivity zone (5-30 Ωm) which indicated cap rock shown by red to yellow color. It was corresponding to thickness about 800 meters. This layer was associated with young volcanic rocks of Mt. Marapi products consisting of Marapi lava and pyroclastic flows. Cap rock indicated by the formation of rock alterations with argillic type around hot water and the reservoir is thought to be in the environment pre-Marapi and volcanic rocks metamorphic.

Geologically, the low type of resistivity was indicated by clay rocks. It was impermeable zone from geothermal system. The next layer is reservoir with resistivity value 30-300 Ohm-m with thickness about 1000 m. The reservoir rock was interpreted to a metamorphic rock which is influenced by fault structures. The highest resistivity value was (>300Ωm) located on 1500-4000 musl. This zone was interpreted as basement rock. It also indicated as heat source which form by metamorphic rock such as Slite rock or granite. Figure 2 also shown there is fault was form with the northwest-southeast and southwest-northeast. It was a couple Strike-slip fault which opposite each other. This fault was control surface manifestation on this area. From 1-D and 2-D inversion model above we have designed a conceptual model for geothermal system on Pariangan field area based on MT method (Figure 3).
3.2. Geothermal System on Pariangan Area

Geothermal system in this area is a plateau and a part of Mt. Marapi as active volcano type A [14]. Manifestation in this system is presence of fumaroles and solfatara in active craters. Geothermal cycle begin with infiltration of meteoric water in permeable zones and then trap in subsurface. It’s heated by a heat source (reservoir) at at the 800 m musl. Heat source in this area was dominated by granite rock and also metamorphic rocks. Heat was transfer from the magma chamber of Mt. Marapi. Geological activity in this volcanic area was form a cap rock at 300 masl - 800 musl. It was made heat water trap in a reservoir area and then heat the rock around it. A heat water going to surface as manifestation of geothermal through fault system around the reservoir area.

Figure 2. 2-D model result of Magnetotelluric data

Figure 3. Conceptual modelling of Geothermal System based on Magnetotelluric data
Low resistivity on this area is thought to be the up-flow zone of Mt. Marapi geothermal system where deep heat water held by alteration rocks around Pariangan and flowing westward to form Kotabaru hot springs and to southeast forms Sopandih hot springs [14].

4. Conclusion
Geothermal system on this area located on up-flow zone of MT. Marapi. The system was controlled by a couple of fracture in the northwest-southeast and southwest-northeast side of system. This fracture associated to local geology structure on this area. Heat source identify from Mt. Marapi activities with granite and metamorphic rock dominated.

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