1D and 2D Occam’s Inversion of Magnetotelluric Data Applied in Volcano-Geothermal Area In Central Java, Indonesia

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Abstract. One-dimensional (1D) and two-dimensional (2D) magnetotelluric data inversion were conducted to reveal the subsurface resistivity structure beneath the eastern part of a volcano in Central Java, Indonesia. Fifteen magnetotelluric sounding data spanning two lines of investigation were inverted using Occam’s inversion scheme. The result depict that there are extensively conductive layer (2-10 ohm meter) below the volcanic overburden. This conductive layer is interpreted as the clay cap resulted from thermal alteration. A higher resistivity layer (10-80 ohm meter) underlies the clay cap and is interpreted as the reservoir whose top boundaries vary between 1000 m above and 2000 m below sea level.

1. Introduction

The 1D and 2D Occam’s inversion is one way for interpreting the geophysical data. The 1D Occam’s inversion of electromagnetic sounding data was first suggested by Constable et al. (1987) followed by the 2D Occam’s inversion introduced by Hedlin and Constable (1990). Since then the Occam’s inversion has been widely used to interpret electromagnetic data including magnetotelluric (MT) data. This inversion scheme produces a smooth model that fits a data set within certain tolerances. By using smoothness constraint, an inverted model might not yield the best fit to the data but it is still acceptable.

Magnetotelluric is one of the electromagnetic methods which is used to investigate resistivity distribution of subsurface. The capability of magnetotelluric method describe the resistivity contrast of subsurface suitable be used for volcano or geothermal area e.g Ghaedrahmati (2013), Srigutomo et al. (2008), Pellerin et al. (1996), and Spichak and Manzella, (2009). In addition, the penetration depth of the magnetotelluric method is begun tens until hundreds kilometer, so that it to be standard tool in geothermal exploration (Hersir & Flovenz, 2013).

The study case is conducted in the province of Central Java, Indonesia. The magnetotelluric survey conducted for total 15 stations and divided into two lines that extend from northwest to southeast. The first line has seven sounding site with total length 8.28 km. While the second length has eight sounding site with the total length 12.51 km. The area of measurement is located in the western flank of a volcano. Meanwhile, there are geothermal manifestations such as hot springs and alteration zones, yielding a high possibility that this area has prospective geothermal reservoir.
2. **Occam’s Inversion**

The 1D Occam’s inversion uses the roughness factor. Electromagnetic problem in Occam’s inversion is a non-linear case. In general, the forward problem of 1D MT problem that relates the observed data and the sought model parameters is expressed as:

\[
d = F[m]
\]

where \(d\) is the data matrix and \(F\) is forward functional, whereas \(m\) is the matrix of model parameters. At \(k\)-th iteration, the estimated model parameters are obtained by solving the following equation:

\[
m_{k+1}(\mu) = \left[ \mu \partial^T \partial + (WJ_k)^T WJ_k \right]^{-1} (WJ_k)^T Wd_k
\]

where \(\mu\) is a Lagrange multiplier, \(W\) is weighted diagonal matrix \(M \times M\), and \(J\) is the Jacobian matrix.

The 2D Occam inversion is an expansion of 1D Occam inversion. At \(k\)-th iteration, the estimated model parameters are obtained by solving the following equation:

\[
m_{k+1} = \left[ \mu (\partial_x^T \partial_y + \partial_z^T \partial_z) + (WJ_k)^T WJ_k \right]^{-1} (WJ_k)^T W
\]

where \(\partial_x\) is roughness matrix to describe different model parameter laterally and \(\partial_z\) is roughness matrix to describe model parameter vertically.

3. **Result and Discussion**

The 1D and 2D Occam’s inversion schemes have been carried out. The Figure 1 shows resistivity profiles resulted from 1D inversion for the first section. It is seen that from northwest to southeast the section exhibits variation in resistivity value. Beneath the first five stations MT45, MT40, MT34, MT27 and MT20 resistivity values tend to decrease with depth while the other two sounding points (MT13 and MT06) shows resistivity values that tend to increase with depth.

Generally in a geothermal area, clay cap layer possesses low resistivity value of 10 ohm meter or below (Pellerin et al., 1996), whereas reservoir typically exhibits higher resistivity value of about 10-60 ohm meter. From Figure 1, it can be concluded that shallow layer beneath this section has high resistivity value that varies from tens to hundreds ohm meter beneath MT45, MT40, MT34, MT27 and MT20 representing a volcanic overburden. Below this layer, very low resistivity layer (2-10 ohm meter) exists from depth of 500 until 2000 meter below sea level representing the clay cap resulted from mineral alteration (Pellerin et al., 1996). Below the interpreted clay cap, resistivity values tend to increase at interval 10-80 ohm meter which is interpreted as zone of reservoir whose elevation of its top boundary varies from 1500 to 0 meter above sea level.
The second section is depicted in Figure 2. Relatively resistive overburden layer is found in all stations. Below this layer, low resistivity layer exists whose top boundary varies at elevation of 1000 to -1000 meter having resistivity of about 5 to 10 ohm meter. This layer may represent the expected clay cap beneath the MT line. Below this low resistivity layer, an intermediate resistive layer (10 to 80 ohm meter) representing a geothermal reservoir zone is found having top boundary that varies a elevation about -1500 to -2000 meter.
Then resistivity sections resulted from 2D Occam’s inversion schemes are shown in Figure 3 and Figure 4.

Figure 3. (a) Distribution sounding magnetotelluric area section one, (b) Resistivity section resulted from 2d Occam’s inversion scheme section one.

Resistivity section shown by Figure 3 indicates shallow low resistivity layer regarded as clay cap beneath thin resistive volcanic overburden. Below the clay cap an intermediate zone exists from MT45 to MT13 representing reservoir having thickness that varies from 500 to almost 2000 meter. The continuation of resistivity distribution describes the geometry and dimension of the clay cap as well as the reservoir.

Figure 4. (a) Distribution sounding magnetotelluric area section two, (b) Resistivity section resulted from 2d Occam’s inversion scheme section two.

The second resistive section resulted from 2D inversion is depicted in Figure 4. Thin clay cap and reservoir are estimated to be present beneath MT49, MT43, MT38 and MT32 in the center of the MT line. The clay cap thickens in the southeastern part of this section particularly beneath MT25 and MT11.
4. Summary
Based on the results, we can make several summaries as follows:
- the 1D and 2D Occam’s inversion models shows a tendency of resistivity to decrease with depth until about 1000 meter from the surface and then it tends to increase again,
- depths of top boundary of the reservoir vary between elevation of 1000 – 0 meter above sea level,
- thicknesses of reservoir can be estimated to be about 500 to 2000 meter,
- 2D Occam’s inversion scheme describe subsurface resistivity structure better in terms of geometry and dimension than that of 1D scheme.

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