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Resistivity Structures Of Bonjol Geothermal Prospect, Indonesia, Derived from Magnetotelluric Data

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ABSTRACT

The Bonjol geothermal area is situated on a segment of the Sumatran fault zone (SFZ), Indonesia. During 2009 magnetotelluric (MT) measurements were carried out on the area with the aim of extracting resistivity features related to geothermal reservoirs of the area. MT data were collected from 25 measurement stations along 4 lines trending SW – NE and processed using robust algoritms. Processed MT data were computed with Non Linear Congugate Gradient Method to produce two-dimensional models of electrical resistivity. The resistivity models show pronounced resistivity contrasts elongated to SFZ trending NW-SE. The resistivity models revealed the presence of shallow low resistivity zone to depth of about 800 m due to low-temperature clay minerals as indicated by shallow drillings. This low resistivity is followed by moderate to high resistivity zone, which may indicate high-temperature geothermal system at depth.

1. INTRODUCTION

Indonesia is blessed with abundant geothermal energy resources. Most of them are associated with quaternary volcanic like in Sumatra, Java, and Nusa Tenggara. Bonjol area is one of them which is located in West Sumatra Province and situated on a segment on Sumatra Fault Zone (SFZ) (figure 1). Geothermal prospect of this area is indicated by hot springs and altered rocks. Integrated survey (Geology, Geochemist, Gravity, Magnetic, and DC Resistivity) had conducted by Center for Geological Resources (CGR) of Geological Agency of Indonesia in 2007. Result of this survey had published by Kusnadi (2007), Mustang (2007), Bakrun (2007), and Kholid (2007). Result of this survey shown that the geothermal prospect is associated with young volcanic in Bukit Binuang and Sumatran Fault activities.

During 2009 magnetotelluric (MT) measurements were carried out on the area with the aim of extracting resistivity features related to geothermal reservoirs of the area. Resistivity is one of rock physical properties that can be used for guiding subsurface structure analysis. In geothermal prospect especially in volcanic area the altered rocks as clay cap is commonly shown by low resistivity (<10 Ohm-m) that is very different with the volcanic environment which has high resistivity anomalous (Ushijima, 2000 and Jonhston, 1992).

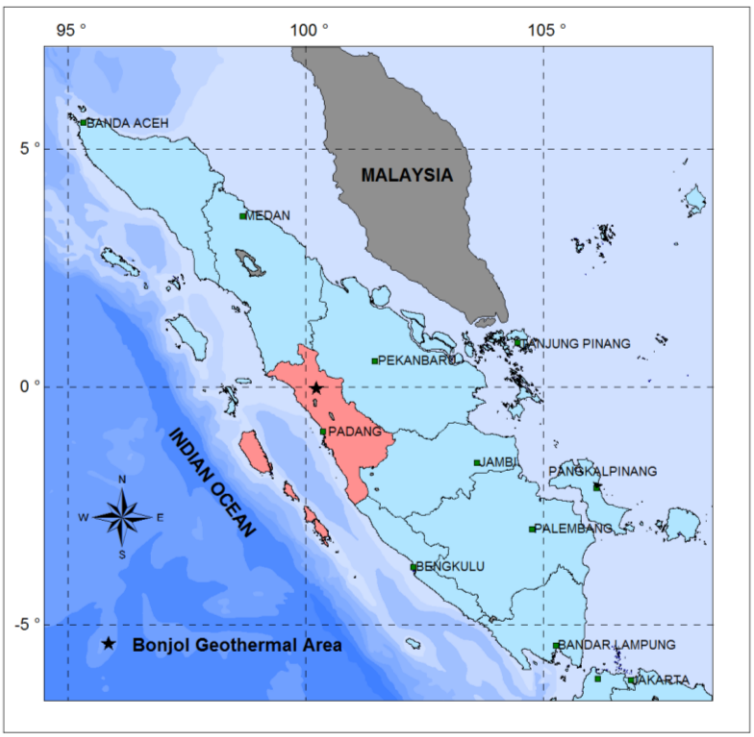

Figure 1. Location of Bonjol Geothermal Area

2. GEOLOGY AND SURFACE THERMAL MANIFESTATION

Bonjol area is mainly covered with Tertier and Quaternary volcanic rocks as lava and pyroclastic flow and sediment (figure 2). The oldest volcanic rock is old andesite lava and Malintang dacitic Lava (Tertier) exposed in the central and eastern part of the area. The quaternary volcanic rocks is mainly an andesitic lava covered most of the area. The youngest lava (Plistosen) is situated in Bukit Binuang and indicated that this area is associated with volcanic rock.

Geological structure is mainly trending Northwest-Southeast similar with the Sumatra Fault Zone. This structure is normal fault and made graben Bonjol. Another structure is normal fault with trending southwest-northeast.

Surface thermal manifestation is appear as hot springs with temperature range from 73.4 ^{o}C until 87.9 ^{o}C and normal pH. This hot springs is associated with Takis normal fault. In the southern part of the area appear another hot spring with lower temperature about 49.7 ^{o}C and normal pH (figure 3).

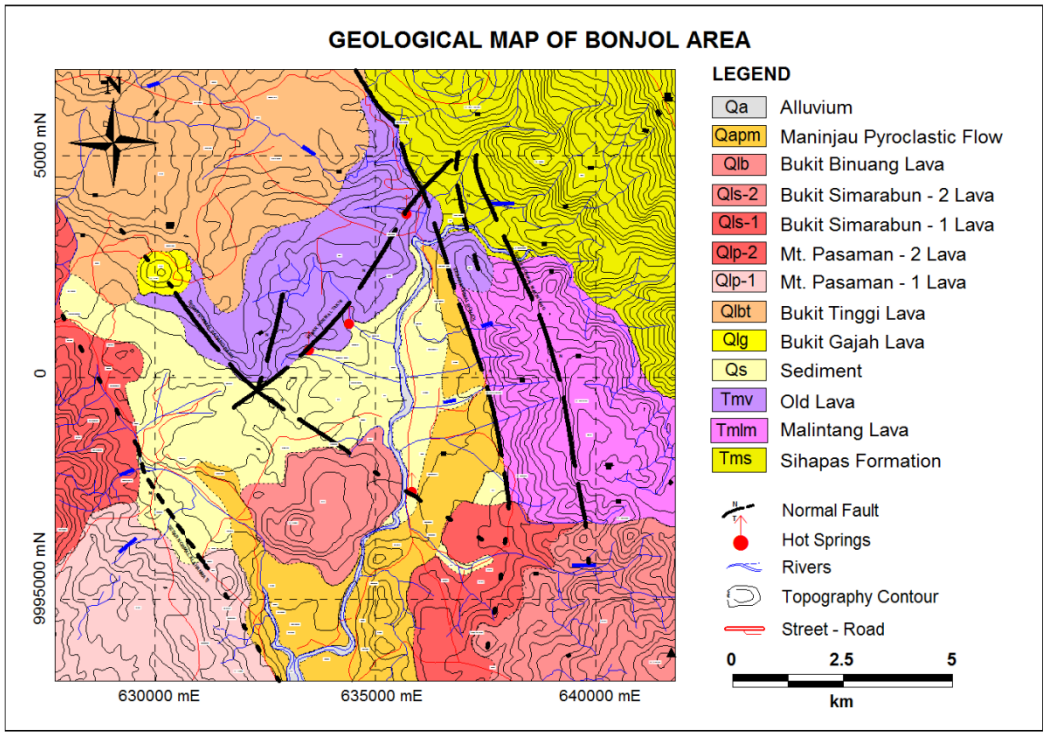

Figure 2. Geological map of Bonjol area

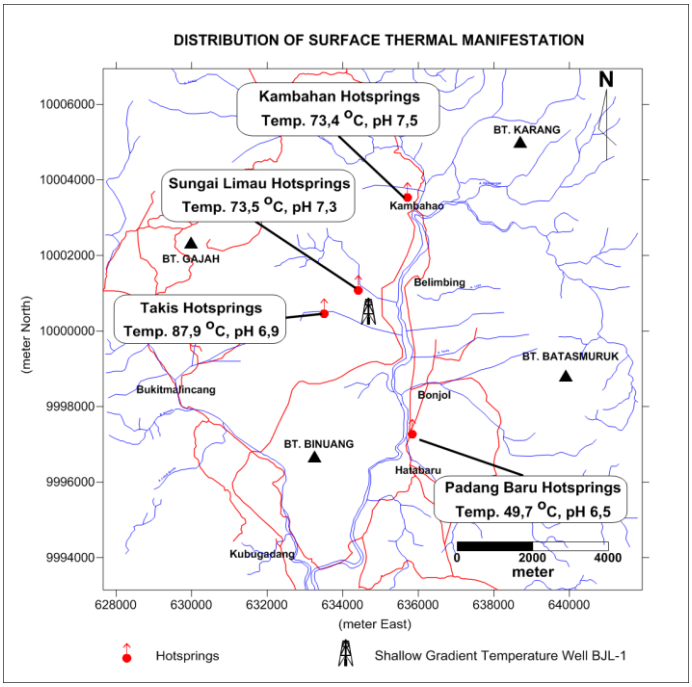

Figure 3. Distribution of surface thermal manifestation

3. MT SURVEY

MT measurement had conducted on 25 measurement stations along 4 lines trending SW – NE with single site measurement technique (figure 4). Interpretation of the MT data is used 2-D inversion modeling with Non Linear Conjugate Gradient algoritm as described by Rodi and Mackie (2001). This method is provided by WinGlink Software.

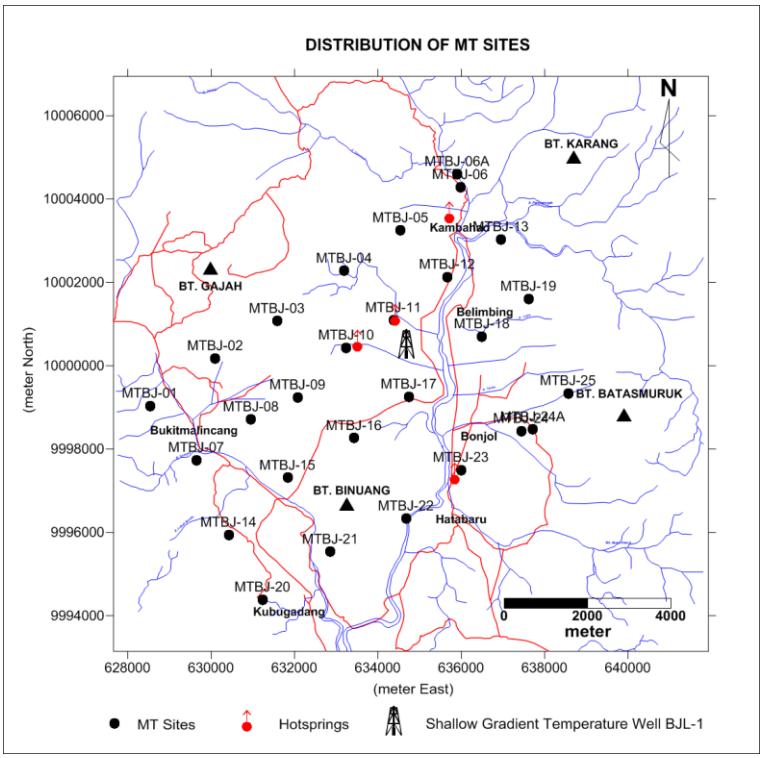

Figure 4. Distribution of MT measurement station

4. MT RESULT AND RESISTIVITY STRUCTURE

Resistivity structure derived from MT Modeling is shown by figure 5 until figure 9. Figure 5 show resistivity structure of section 1 which is situated on northwestern part of the area and cross a Kambahan hot spring. Low resistivity distributed in northeastern part of this section around Kambahan hot spring from near surface until 1000 m depth. This anomalous is in agreement with geological condition which are around this hot spring finding altered and mineralization rocks. Below this anomalous, we can see the higher resistivity (>500 Ohm-m) that interpreted as massive volcanic rocks. The southwestern part of this section show resistivity contrast (discontinuity) which associated with Alahan Mati and Padang Baru normal fault.

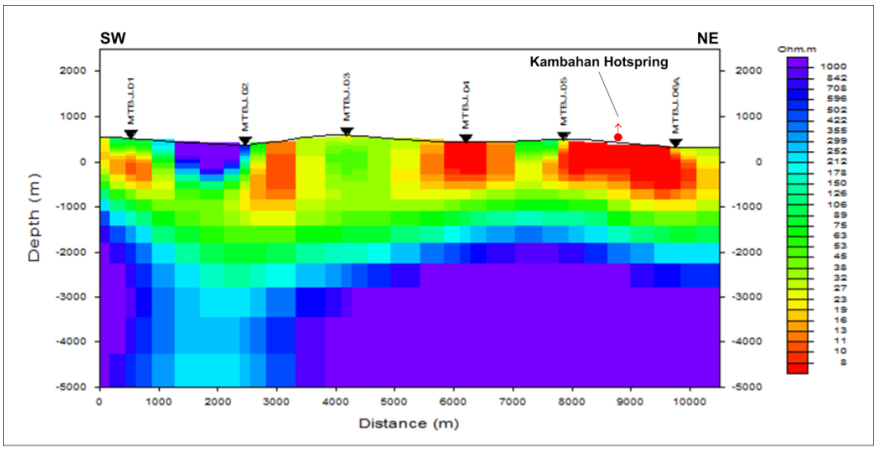

Figure 5. 2D MT model of section 1

Resistivity model of section 2 which crossed Takis and Sungai Limau hot springs is shown by figure 6. Shallow low resistivity distributed on center of this section and become deeper and thicker on southwest and northeast. This resistivity is predicted as altered rock which associated geothermal system. In the bottom of this section show discontinuity high resistivity that correlated with normal fault.

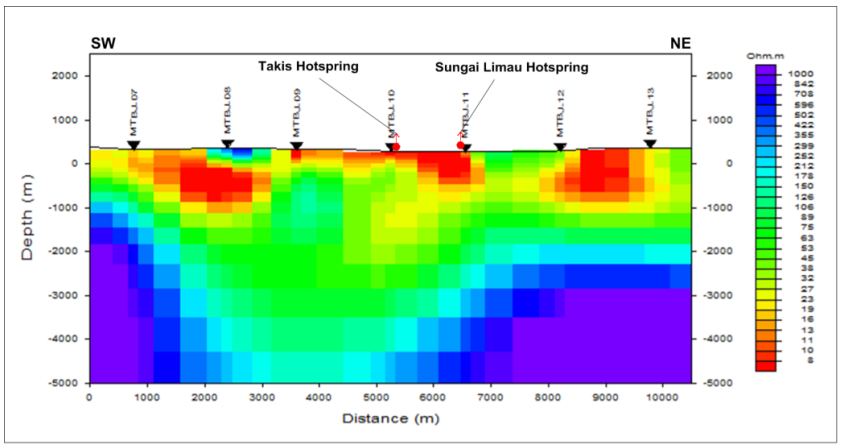

Figure 6. 2D MT model of section 2

Figure 7 show 2D resistivity model of section 3. Low resistivity structure distribute along this section from near surface until 1500 m depth. Shallow low resistivity is situated in the central of this section and become deeper and thicker in southwest and northeast. Contrast low and high resistivity can be seen in the southwest and northeast and predicted as a normal fault indication. Resistivity pattern in the section is similarly with the resistivity structure in geothermal prospect theoretically (Johnston, 1992). That show low resistivity distribution in the upper and become higher resistivity below. In the geothermal prospect, low resistivity is interpreted as a clay cap, and the higher resistivity below is interpreted as a reservoir.

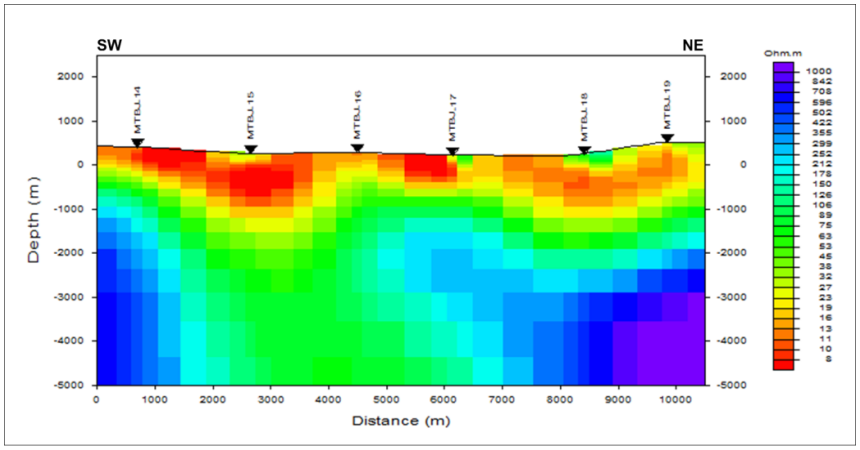

Figure 7. 2D MT model of section 3

Resistivity structure in section 4 is similar with the resistivity structure in section 3 relatively (figure 8). Low resistivity distribute from near surface until 2000 m depth with variety thickness. Shallow low resistivity is situated in the center of this section around Padang Baru hot spring and become deeper and thicker in southwest and northeast. Higher resistivity are distributed the below with pattern like a dome.

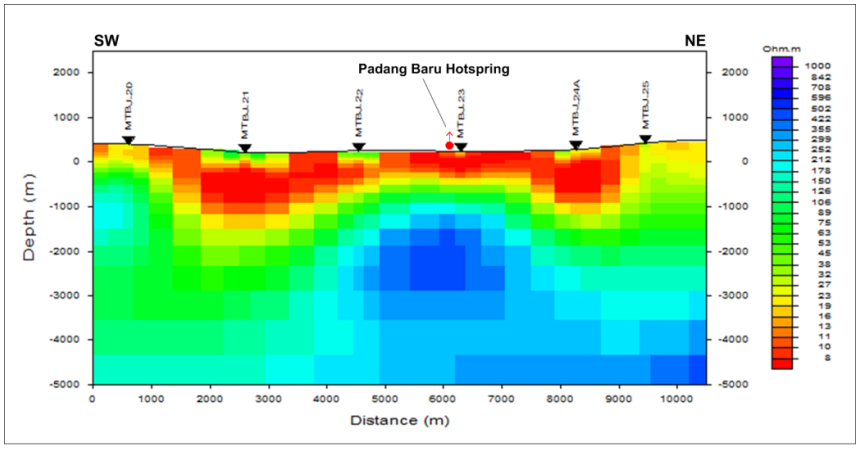

Figure 8. 2D MT model of section 4

To understand a correlation of resistivity distribution and geological condition laterally, we slice the 2D model of resistivity every 250 m depth and display on 3D view (figure 9). The pattern of resistivity distribution form alignment with trending NW-SE correlated with Sumatra fault. In 250 m depth, low resistivity covered most of the area and become smaller distribution in the deeper. High resistivity distribute on northwestern part in shallow depth with opened pattern to the northwest. From 750 m depth, medium resistivity is distributed in central of the area and become higher resistivity in the deeper.

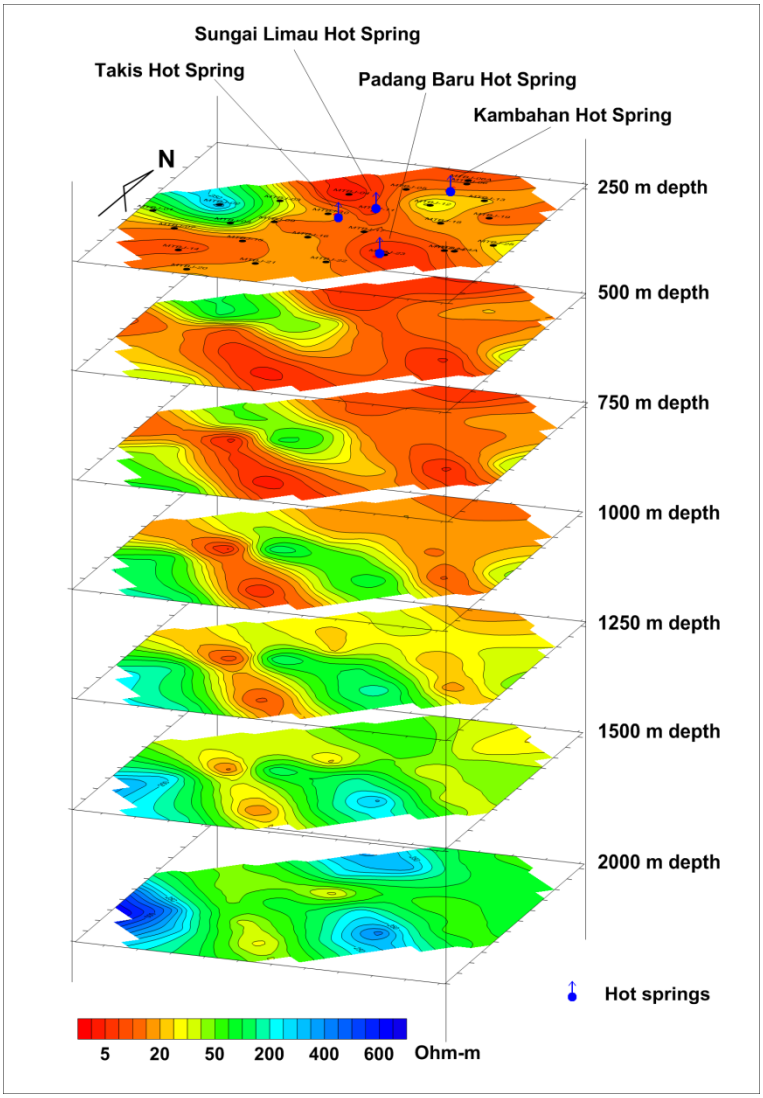

Figure 9. Depth-sliced of resistivity distribution in Bonjol area

5. DISCUSSION

Resistivity structure of this area mainly show three layer of resistivity derived from MT data. First layer is low resistivity (0-20 Ohm-m) that distributed from near surface until 1500 m depth. This conductive layer interpret as altered zone correlated with result of shallow gradient thermal drilling that from 41.26 m until 250.8 m depth is find altered rocks with argillic type which is dominated by montmorillonite and smectite (Munandar, 2009). Second layer is more resistive than the upper layer (30-100 Ohm-m) and indicated high temperature at depth base on gradient temperature is about 18.97 ^{o}C/100 m. The bottom layer is high resistive (>500 Ohm-m).

The conductive layer beneath Padang Baru, Sungai Limau, and Takis hot spring is shallow and thin is about 800 m depth, and correlated with a strong hydrothermal alteration zone. We suggest that this zone corresponds to promising zone correlated with a potential geothermal reservoir.

6. CONCLUSION

Resistivity is one of physical properties that can be use for geothermal promising zone delineation. MT sounding applied in Bonjol Area is a powerful tool for describe resistivity structure and delineate low resistivity zone indicating a potential geothermal reservoir beneath the volcanic area. The interpretation results show that the resistivity structure in this area is commonly divided into three layers. First layer is a low resistivity zone correlated with the strong hydrothermal alteration zone. Second layer is a higher resistivity correlated with the high temperature reservoir, and the bottom layer is a high resistive layer. The promising zone is situated beneath Padang Baru, Sungai Limau, and Takis hot spring which is shown by shallow and thin low resistivity zone.

ACKNOWNLEGMENT

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