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3D *Vertical Electrical Sounding* (VES) At Mount Pandan Hot Springs Area, East Java, Indonesia

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Abstract

1D measurement had been carried out using Schlumberger configuration in geothermal area of mount Pandan, East Java, Indonesia to identify patterns of hot water distribution. Data acquisition was conducted at 16 points of VES (Vertical Electrical Sounding) with a grid research design covering hot water manifestations. The resistivity value obtained from the results of data processing was ranged from 1.06 Ωm to 20064.09 Ωm. The interpretation of data 1D in geoelectrical resistivity was obtained by depth and type of resistivity values. The layer containing hot water was estimated to be in clay sand with a resistivity value <20.00 Ωm, the water-resistant layers were estimated to be in tuff rock with a range of resistivity values from 20.01-50.00 Ωm, the aquifer layers were estimated as sandstone with a range of resistivity values from 50.01–100.00 Ωm and hot springs layers were predicted as volcanic breccia with a resistivity value >100.01 Ωm. 3D modeling interpretation displayed the patterns of hot water distribution that had been evenly clustered and spread. The patterns of the distribution came from the northwest to the northeast area.

Keywords: *Hot Water, Mount Pandan, Geoelectric, Resistivity, VES, Schlumberger.*

1. Introduction

Geothermal is one of the renewable and eco-friendly alternative energies. In addition, its presence in Indonesia is very abundant, considering that Indonesia has many volcanoes. Based on the data, one of the geothermal energies that is estimated to have considerable potential in Java is the area of mount Pandan, precisely located in Bojonegoro Regency, East Java, and is predicted to have manifestation of geothermal energy around 60 MWe with a surface temperature of more than 35ºC [1]. This is evident by the emergence of hot springs in Banyukuning and Jari (Selo Gajah) area. Mount Pandan area is a volcanic area included in Kendeng lane in the southern part. It consists of roughly shaped hills with slightly sloping steep, reaching 150 m to 897 m height. Its constituent rocks consist of sediments rocks such as carbonate clay, clay rock, sand and volcanic rocks associated with geothermal manifestations in the form of warm springs and alteration rocks. Mendala Kendeng has young volcanic rocks of late plistocene containing lava deposits [1], [2].

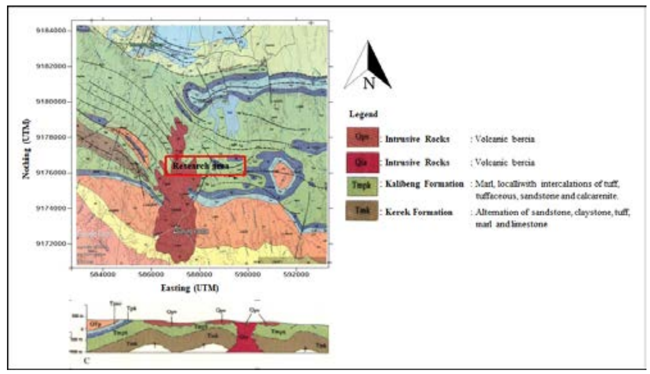

Fig. 1 Geological Map of Bojonegoro Region [2]

The geological structure at mount Pandan geothermal area is in the form of topographical alignment, river alignment, hot spring appearance, and primary data in the field is in the form of lithological offsets and cesarean breccias. Based on these conditions there are two types of geological structures that develop, namely normal faults and horizontal faults. In general, the orientation of the geological structure at mount Pandan area is predominantly northeast and northwest-southeast, although there are several faults with relatively east-west direction [1], [2]. A unit that cannot be separated from geothermal systems is a source of heat energy contained in hot water, water vapor, and rocks along with other related minerals. Geothermal is renewable, relatively eco-friendly energy which has great potential and can reduce national energy dependence on fuel oil [3].

Geothermal investigation related to the patterns of hot water distribution has a significant relationship with the structure and manifestation of geothermal energy that can be done by subsurface investigation using geophysical methods. One suitable geophysical method to determine subsurface conditions is to use the geoelectrical resistivity method [4]. The method is active by injecting the flow

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through an electrode responded by a potential electrode. The difference in the subsurface layer will give varying resistivity values [5].

Based on the purpose, the geoelectrical methods are divided into two; sounding and mapping methods [4]. Sounding method is used to see the differences in rock resistivity vertically downward, usually using Schlumberger (VES) configuration. It provides detailed information of conductive zones, actual resistivity values and thicknesses. Mapping method is used to see the differences in lateral rock resistivity [6]. Initial surveys performed in the manifestations of mount Pandan showed that there were hot springs that turn on the surface out. The hot springs were clustered and came close together which became an early indication of geothermal potential in the area. Geothermal research related to the estimation of hot water distribution in the geothermal area of mount Pandan had not been yet found out. The direction of the distribution needs to be done as an initial step to estimate the geothermal potential in the area.

2. Materials and Methods

The research was conducted in a village called Jari, Gondang District, Bojonegoro Regency, East Java. The tool was a set of OYYO type McOhm-EL resistivity meter. Geophysical exploration was carried out by the geoelectrical resistivity methods to obtain an overview of the subsurface structure of the earth [7]. The acquisition of Schlumberger (VES) configuration was designed in the form of a grid covering spring manifestations, an shown in Fig 2. The number of acquisition consists of 16 VES points, with the distance among the VES points was 300 m, the line length of the Schlumberger configuration was 210 m with the flow electrode space AB/2.

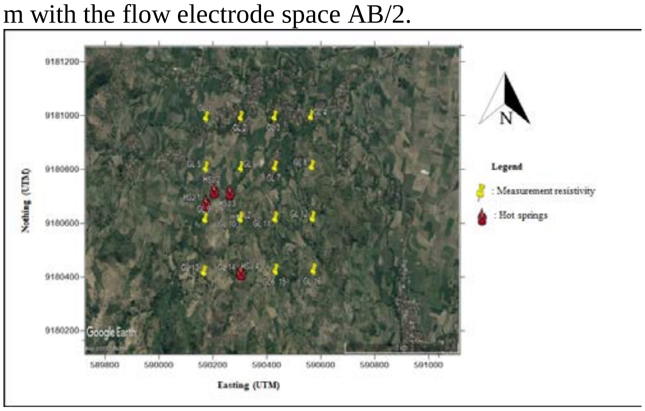

Fig. 2 Survey design map for the acquisition of geoelectrical resistivity data

The data was corrected for field geometrical correction according to the distance or line space [8]. The data processing was divided into 2 (two) stages:

1. 1D data processes. The inversion data was carried out to determine the type of inversion model and data interpretation for subsurface structures from sounding point observation data [9]. After analyzing the resistivity values of the constituent rocks of each layer, the model of the presence of hot water layers at each VES point was then predicted. The 1D model of the presence of hot water layers is shown in Fig 2.
2. 3D data processes. The processing of 1D would be correlated with sounding points to get a cross section of rock lithology resulting in 3D modeling [10]. Fig 4 shows the description of subsurface conditions at mount Pandan area. Each VES point was interpolated to see the similar conditions under the surface. The low resistivity values obtained at each VES point were then grouped and interpreted to identify the patterns of hot water distribution [7]. Fig 3 show the value of material resistivity in the model based on the measurement results was matched with the material resistivity values according to the references to determine if there is suitability [11].

The process of data interpretation was performed by checking the contrast of 3D model-based rock resistivity. Besides, referring to the information can describe the geological model of the research area which is then adjusted to the general rock geology literature [12]. From the results of inversion, the resistivity data was made by the boundary of the soil layers by looking at the tendency of color which indicates the value of resistivity. The results of the interpretation obtained from the contrast of these types of prisoners can provide a physical depiction of the rock [5]. Based on the model, the aquifers distribution and faults as manifestations of hot springs, the direction of its flow and distribution could be estimated [6].

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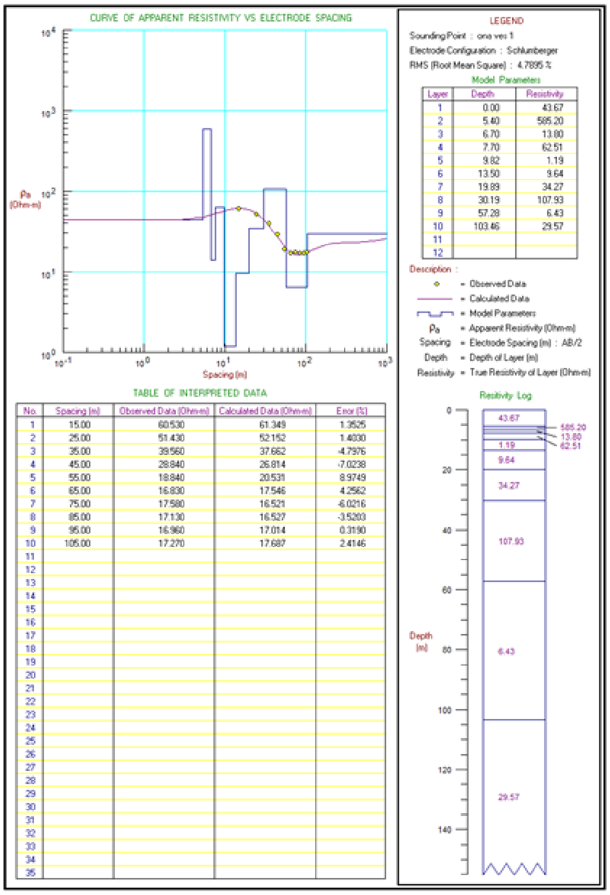

Fig. 3 Results of ID inversion at VES points

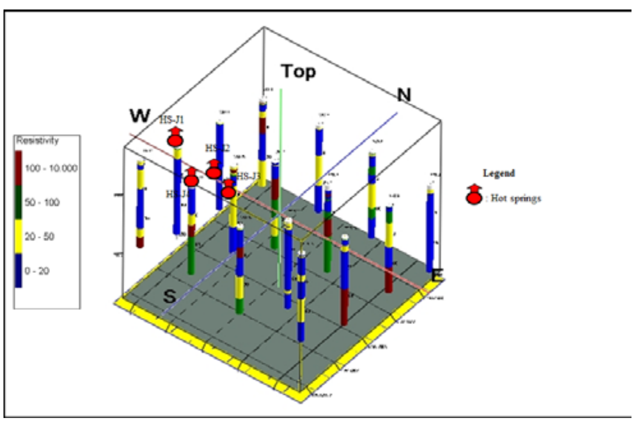

Fig. 4 Results of the interpolation of VES point

3. Results and Discusion

Geothermal manifestations, in the form of hot springs at mount Pandan, there are four hot springs that is hot springs Jari 1 (HS-J1), hot springs Jari 2 (HS-J2), hot springs Jari 3 (HS-J3) and hot springs Jari 4 (HS-J4) with a temperature 50^0C, 40^0 C, 48^0C and 58^0 C. Hot springs Jari 1 (HS-J1) and hot springs Jari 4 (HS-J4) are right at point VES 9 and point VES 14. Hot springs Jari 2 (HS-J2) and hot springs Jari 3 (HS-J3) are located ± 100 m from point VES 9. The hot springs come out through rock fractures that are clustered and come close together.

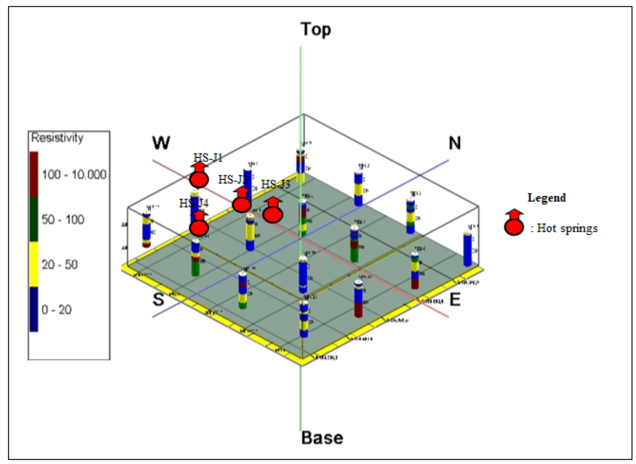

Fig. 5 3D modeling of VES data

Point VES 1 shows the resistivity values ranged from 1.19 Ωm to 585.20 Ωm with 103.46 m depth. The layers containing hot water was also found in 9.62 m, 13.50 m and 57.19 m depth with the resistivity value <20.00 Ωm. While the layers of the hot hot spring was located under the water proof layer and the layer containing hot water. Rock outcrops (*bolder*) which are thought to be volcanic rocks resulting from erosion and river flow sedimentation was also found at point VES 1. At point VES 6, it shows the resistivity values ranged from 1.11 Ωm to 3556.87 Ωm with 123.86 m depth. It is suspected that there was a layer containing hot water at 6.34 m depth with the resistivity value <20.00 Ωm. This is proven by the presence of the hot hot springs layer beneath the layer containing the hot water. This is also evident by the presence of hot springs Jari 3 (HS-J3) within ± 25 m from the point VES 10 with a temperature 48^0C.

At point VES 7, it shows resistivity values ranged from 5.36 Ωm to 108.45 Ωm at 111.26 m depth. It was predicted that there is a layer containing hot water with a resistivity value < 20.00 Ωm in 9.06 m, 18.52m and 25.98 m depth, and also there are crossings of aquifer layers and hot spring layers. This is evident by the presence of hot springs coming out through rock fractures around the point VES 7 at ± 50 m apart. Besides, there was a hot spring layer evident by the presence of volcanic rock outcrops thought to be volcanic rocks in 4.29 m and 57.06 m depth [13]. VES 8 point shows the resistivity values ranged from 1.21 Ωm to 111.98 Ωm with 103.91 m depth. It is suspected that there are crossing layers containing hot water, impermeable layers, aquifer layers and hot spring layers. The layer containing hot water was found 10.98-16.65 m and 68.92 m depth with the resistivity value <20.00 Ωm. It is also evident that there is a hot spring layer in 103.91 m depth, so the hot water comes out through rock fractures.

Point VES 9 showed a low resistivity value ranged from 1.14 14 Ωm to 54.42 Ωm in 126.71 m depth. Allegedly, there were aquifer layers, water-resistant layers and layers containing hot water. At a depth of 18.62-126.71 m, there was a layer containing hot water, this is evident by the presence of hot springs Jari 1 (HSJ1) in the surface with a temperature 50ºC right at the point of data acquisition resistivity. The hot layer appears through rock fractures. Although there were no hot hot spring layers at point VES 9, it is likely that the hot hot spring layers were below 126 m depth. Point VES 9 was right in the west side of point VES 10, where there was a hot spring layer at point VES 10. The hot water flow is thought to originate from the point VES 10 to point VES 9 which has a lower topography. VES 10 point showed the resistivity values ranged from 3.39 Ωm to 106.84 Ω m in 102.55 m depth. It is suspected that there were water-resistant layers, layers containing hot water, aquifer layers and hot spring layers. There was a layer containing hot water with a resistivity value of <20.00 Ωm in 16.89 m depth. This is also evident by the presence of hot springs Jari 2 (HS-J2) within ± 100 m from the point VES 9 with a temperature 40^0C. The resistivity values ranged from 2.90 Ωm to 470 Ωm at a depth of 132.60 m at point VES 12. There were aquifer layers, impermeable layers, layers containing hot water and hot spring layers. There are also layers containing hot water with resistivity value <20.00 Ωm in 2.98 m, 8.66 m and 23.10 m.

At point VES 13, the resistivity value ranged from 3.94 Ωm to 116.63 Ω in 128.78 m depth. It is suspected that there were water-resistant layers, layers containing hot water and hot spring layers. In 6.62-12.17 m depth, precisely in 46.41 m depth there were also layers containing hot water with a resistivity value of <20.00 Ωm. At point VES 14, the resistivity value ranged from 1.38 Ωm to 450.98 Ωm with 142.79 m depth. It is suspected that there were water-resistant layers, layers containing hot water, aquifer layers and hot spring layers. There was a layer containing hot water in 1.47-29.71 m depth with a resistivity value <20.00 Ωm. This is evident by the presence of hot springs on the surface through rock fractures with a temperature 58ºC. At point VES 14, there were also outcrops of diffuse volcanic rocks [13]. At point VES 15, the resistivity values ranged from 1.93 Ωm to 200064.09 Ωm in 120.37 m depth. It is suspected that there were water-resistant layers, aquifer layers, layers containing hot water and springs layers. Also, there was a layer containing hot water in 4.92-21.76 m and 51.08 m depth with a resistivity value <20.00 Ωm.

Based on the results of 3D interpretation and modeling, it can be seen that the resistivity value <20.00 Ωm as the dominant layer containing hot water was at 10 points VES namely VES 15, VES 14, VES 13, VES 12, VES 10, VES 9, VES 8, VES 7. VES 6, and VES 1. The hot springs came out through rock fractures. There are 6 VES points, namely point VES 16, VES 11, VES 5, VES 4, VES 3 and VES 2, there was a small possibility that there is a layer containing hot water since no hot spring layers found. Based on 3D modeling in figure 6, it is clear that the layers containing hot water appeared to cluster and spread. The conditions in the field also show that there were hot springs appearing through rock fractures that were clustered and closed together. There were also several VES points along the river with a low topography. In accordance with the fluid nature of water flowing from the high place to the low one, the patterns of hot water formed in the field was originating from the northwest to the northeast area.

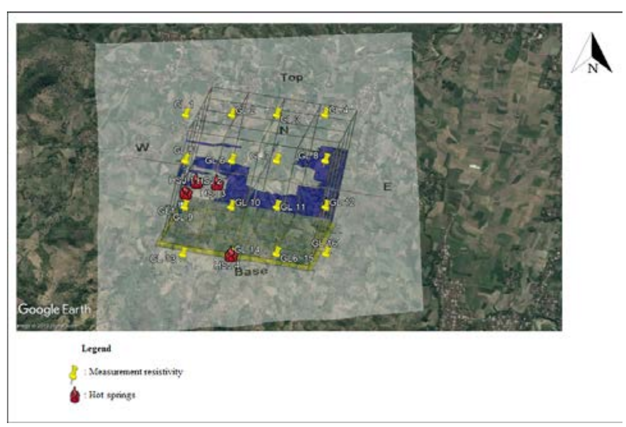

Fig. 6 The results of 3D modeling of the patterns of hot water distribution overlaid in the research area

In general, based on the results of 3D modeling in Fig 5 and Fig 6, it reveals that resistivity values ranges from 1.06 6 Ωm to 20064.09 Ωm. The resistivity value <20.00 Ωm indicated by blue color, that was thought to be the type of layers containing hot water, resistivity value ranged from 20.01-50.00 Ωm with yellow and suspected as a type of water-resistant layer with resistivity value ranged from 50.01–100.00 Ωm with green color, It was thought as aquifer layers and resistivity value > 100.01 Ωm with red color that was suspected to be the hot spring (*volcano*). The layers were thought to be clay sand, sandstone, tuff and breccia. Given the geology of mount Pandan area, there are volcanic rocks in the form of volcanic breccia, crustal formation, namely crossing sandstone, clay, tuff, marl and limestone as well as Kalibeng formation in the form of marl, local tuff inserts, and sandstone [2], [13].

4. Conclusion

The results of 3D geoelectrical resistivity interpretation at mount Pandan area showed the presence of hot springs distribution. The layers containing hot water was thought to be in clay sand with the resistivity value <20.00 Ωm. The water-resistant layers were thought to be in tuff rocks with resistivity values ranged from 20.01-50.00 Ωm, the aquifer layers were thought to be sandstone with resistivity values ranged from 50.01-100.00 Ωm and the hot spring layers were also suspected as volcanic breccia with resistivity values >100.01 Ωm. The patterns of hot water distribution at mount Pandan area had been evenly clustered and spread. The distribution patterns originated from the northwest to the northeast area.

Acknowledgments

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