Delineating geothermal system through 3D geomagnetic and gravity data inversion on Blawan Ijen geothermal area, East Java

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Abstract. Blawan-Ijen is a caldera hosted geothermal system that located in Bondowoso, East Java. To delineate the existence of the geothermal system of Blawan-Ijen, gravity and geomagnetic studies were conducted. Since no impressive manifestation in this area, to delineate the prospect area is very challenging. Both methods are used to detect the presence of basements and potential heat sources. Gravity data processing was processed to obtain CBA and residual gravity anomalies, while geomagnetic data was processed until reduce to pole. The results of data processing are used for 3D inversion of gravity and geomagnetic data to find out anomaly distribution horizontally and vertically. To understanding potential heat source, 3D inversion results are displayed at an elevation of 500 m to 1,000 m. The existence of resources using the geomagnetic method is represented by a low magnetic anomaly value as an indication of demagnetized rocks, but high gravity anomalies are seen in the demagnetization area. The potential heat source from gravity and geomagnetic interpretation located in the center of the Blawan-Ijen geothermal prospect, that is the northern part of the south mountainous area, those areas are located around Mt. Gendingwuluh and the northern part of Mt. Genteng and Mt. Glaman.

Keywords: Geomagnetic, gravity, 3D Inversion, Blawan-Ijen

1. Introduction

The Blawan-Ijen geothermal field is located on the easternmost of Java island, Bondowoso Regency, East Java Province. This geothermal area is well known due to the existence of the Ijen Crater which became an attraction for tourists. Ijen Crater is the result of magmatic activities from Mount Ijen which still continue until today. In the crater, there are still many solfatara and sublimation of sulfur which become mining commodities for the surrounding community.

There are no impressive manifestations indicating an upflow system on Blawan-Ijen geothermal area. Therefore, the Blawan-Ijen area is classified as "Hidden Geothermal". The manifestations found in Blawan area is typical of bicarbonate hot springs with temperature no more than 50 °C. This manifestation is characterized as a geothermal outflow system. This manifestation is influenced by Ijen water crater lake from the dilution process [1]. The tectonic structure perhaps takes an important
role in controlling the geothermal system in Blawan-Ijen area such as Blawan normal faults which has an N-S direction [2].

From Blawan-Ijen geological regional conditions, the Ijen volcano complex is located in the front of the Sunda Arc Quaternary volcano. The Arc formed the western part of Indonesia’s subduction zone system, which extends 3,000 km from the Andaman Islands in northern Sumatra to Flores in the Banda Sea. This subduction is formed as a result of the north of the Indo-Australian Plate subduction under the Eurasian Plate with a speed of about 6–7 cm/year [3].

In the physiographic division, the Ijen area is located in the Solo zone, the Sensu-stricto Solo subzone. This subzone is a row of young volcanoes stretching from east to west, respectively, the mountains of Ijen, the Iyang complex, the Lamongan complex, and the Tengger - Semeru complex. Furthermore, it was mentioned that the Ijen area originated as a volcanic cone formation that formed during the Upper Pleistocene [4].

Gravity and geomagnetic data conducted in two periods, those are 2017 and 2018 [5]. There are 178 measurement station data distributed in almost all of the research areas with spaces of 600–1,000 meters.

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2. Methodology

2.1. Gravity method

The gravity method is a method that utilizes the density contrast of rocks. This method is used for the identification of structures. In geothermal exploration, the gravity method can be used to detect the presence of heat source. The heat source in geothermal system associated with volcanic (Blawan-Ijen) comes from cooling pluton with high density.

Gravity data processing is a process to obtain CBA from gravimeter observation data. There are several corrections such as tide correction, drift correction, latitude correction, free air correction, Bouguer correction, and terrain correction. The next process is the separation of regional and residual anomalies. This separation used TSA (Trend Surface Analysis) with the first order of the polynomial equation. The results of the residual anomaly were then used for the 3D inversion process using the Oasis Montaj software. The gravity data processing can be seen in figure 1.

2.2. Magnetic method

The geomagnetic method is a method that utilizes the susceptibility of rocks. Due to hydrothermal activity, there is a demagnetization process becoming a low magnetic value happened in the geothermal system especially in the reservoir.

The processing of geomagnetic data starts from magnetometer acquisition data which is then corrected from diurnal correction and IGRF correction. After the correction process, the total magnetic anomalies in Blawan-Ijen were obtained. The anomalies obtained is still in dipole magnetic anomalies. The reduction to pole (RTP) process is carried out to show that the anomaly originates from the causative body [6]. The results from RTP will be followed by the 3D Inversion process. Similar to gravity data processing, geomagnetic data processing can be seen in figure 1.

3. Results and discussion

3.1. Gravity 3-D inversion

The density distribution map per elevation can be seen in figure 2. Elevation 500 m map is an elevation that is relatively close to the surface. The anomalies appear more like local anomalies. High anomalies are seen in several parts especially around the Mountain, which is Mount Anyar, Mount Genteng, Mount Pendlan, Mount Glaman, Mount Gendingwuluh, and Mount Kukusan.
Figure 1. Gravity and geomagnetic processing result (Left side is for gravity processing, right side is for magnetic processing).
Figure 2. Density distribution per elevation resulted from gravity 3D inversion.
Low anomaly is observed in several mountain peaks such as Mount Blau, Mount Mlaten, and Mount Lingker. The manifestation area in the northern part of the study around the Blawan hot spring has a low anomaly value. There are many alterations found and this area is an area close to the fault that might be the cause of the anomaly value in the area.

Towards deeper elevation, the existence of high and low anomalies resulting from gravity inversion data tends not to change many more. Blawan Ijen's gravity anomaly has a positive anomaly that is greater than the negative. It can be concluded that the existence of negative anomalies tends to be a local anomaly. Density distribution maps at deeper elevations, those are 0 m, -250 m, -500 m, -750 m, and -1,000 m, show positive widening anomalies in the central of the research area. Thus, the existence of a positive anomaly is a regional anomaly.

High/positive anomalies in the gravity method reflected the high density values. In geothermal exploration, the positive anomalies are one of the important parameters that correlate with the presence of heat sources in geothermal systems. The heat source comes from magma or plutonic rocks which have high density values. The existence of positive anomalies as previously explained is an anomaly that dominates in the research area. However, that does not mean the anomaly has the potential to be the heat source. There is a high anomaly which is a reflection of the mountains in the southern area. High anomalies from gravity inversion data that might be the center of the heat sources are located in the middle of the research area, which is in the northern area around Mount Genteng, Mount Pendlan, and Mount Gendingwuluh. Based on the results of gravity data inversion, the anomaly at the center of the research area has an increasingly larger dimension at deeper elevations.

3.2. Geomagnetic 3-D inversion

Based on the susceptibility distribution seen in figure 3, susceptibility anomalies in the research area generally show positive anomalies on the outside. But there is a negative anomaly seen at the north of Mount Blau, and also at the eastern of Mount Mlaten. The southern part of the research area such as Mount Kawah Wurung, Mount Glaman, and Mount Kukusan also show negative anomalies.

An interesting part is in the middle of the study area which shows negative anomalies heading to the north. There are two negative anomalies, in the middle part of the study area, which is north of Mount Gendingwuluh and other negative anomalies in the northern part close to the hot spring manifestation in the Blawan area, Mount Anyar, Mount Genteng, and Mount Pendlan.

The 3D inversion of geomagnetic results show at deeper elevation the negative anomalies diminish in the area around Mount Blau and Mount Mlaten. It is different from the negative anomalies in the southern and middle area which tend to larger at deeper layers.

The 3D geomagnetic inversion results show the distribution of susceptibility values of rocks. There are rocks with relatively lower or higher susceptibility values. In geothermal exploration, the focus of the research is susceptibility values related to the demagnetization process due to the hydrothermal process resulted in negative/low rock susceptibility values.

4. Discussion

In the gravity section, there is high anomaly undulation that is described as an anomaly close to the surface. Regional density anomaly is seen in the deeper elevation as seen in figure 4. Refer to the geomagnetic section, low susceptibility was also seen in the deeper elevation. There is an interesting area at distance 2,000–6,000 m. In this part, Low susceptibility anomaly, high density anomaly was found. This area may become the center of geothermal activity in Blawan-Ijen geothermal system. The low anomaly of geomagnetic result is an indication of hydrothermal demagnetization related to reservoir conditions. The high anomaly of gravity result is an indication of potential heat source. The heat source might not be laid on the elevation near below 0 m. It is a representation of plutonic body in deeper elevation. The low-intermediate density anomaly is interpreted as mostly the presence of clay-cap.
Figure 3. Susceptibility distribution per elevation resulted from geomagnetic 3D Inversion.
Figure 4. 3D inversion response based on surface data (geomagnetic and gravity data).

Figure 5. Delineation of prospect area based on 3D inversion result.

The geomagnetic and gravity delineation area have quite large areas (figure 5). From the gravity 3D inversion result, the potential of heat source emerges at deep elevation from the surface. Based on
geomagnetic 3D Inversion, the reservoir zone can be delineated. This delineation is referring to the low susceptibility anomaly. Geomagnetic 3D inversion illustrates that low anomaly is starting from the deep elevation includes the heat source inside. High anomalies in gravity data has explained previously. The greatest influence is caused by regional anomalies, that probably associated with heat source in the form of magma or plutonic rocks in deep elevation.

5. Conclusion
Geomagnetic and gravity data can be used to identify the center of geothermal activity in Blawan-Ijen which located in the middle of the research area. The reservoir is located beneath the low magnetic anomaly as a representation of the demagnetization process due to hydrothermal activity. The indication of heat source come from cooling pluton is reflected as high density anomaly. It is located at deeper elevation as an indication of regional high gravity anomaly. Based on 3D Inversion result, the potential heat source and reservoir can be delineated laterally and vertically.

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