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First horizontal derivative and Euler Deconvolution in application for reconstructing structural signature over the Blawan-Ijen Geothermal area

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Abstract. A ground gravity survey was conducted over the Blawan-Ijen geothermal area covering about 176 km² area. A total of 72 stations were measured with 1.0 – 1.5 km spacing. The data obtained were then processed using several corrections for gravity data to get Complete Bouguer Anomaly (CBA). The gravity method was chosen because of the ability to detect geological structures corresponding to the rocks density of the field study. Two types of gravity technique, First Horizontal Derivative (FHD) and Euler Deconvolution (ED), have become widely used to interpret the structure condition. FHD technique delineates a geological boundary of different density body while ED technique estimates a source location and depth of structures. Furthermore, 3-D inversion of magnetotelluric data result was also used as a reference to support 2-D gravity forward modeling. The main structure which probably controlled the emergence of Blawan-Ijen hot spring is indicated by maximum FHD value at the northern part area. Moreover, the ED result shows the depth of structures in Blawan-Ijen geothermal area is mostly about 250 – 1000 meters.

1. Introduction

The Blawan-Ijen geothermal area is located in East Java, Indonesia, at a distance of about 266 km from Surabaya city, Indonesia as shown in Figure 1. The area is identified as an active geothermal system, characterized by the presence of several volcanic center as the intrusion which appears on the inside of Kendeng Caldera. Blawan hot spring and Ijen crater are emerged as the surface manifestations in this area. Thus the understanding of structures that controlled the geothermal system is very needed to support the determination of permeable zone.





Figure 1. Location of Blawan-Ijen geothermal area.

Geological observation and gravity survey have been conducted to delineate the structure of Blawan-Ijen geothermal area. Geological investigation was carried out using remote sensing analysis to determine the existence of regional structures. Meanwhile, the gravity method was used to provide information regarding the density distribution in the subsurface. Gravity data analysis using First Horizontal Derivative (FHD) and Euler Deconvolution (ED) techniques was performed to find out the anomalous geological features in order to detect structural or lithological contrasts with the estimation of depth in the subsurface.

The result from remote sensing, FHD and ED were then integrated and involved in the 2-D forward model of gravity data to describe the subsurface condition of Blawan-Ijen geothermal system. Furthermore, the forward modeling is assisted using 3-D inversion of MT data as a reference model. By combining the studies above, it is expected that the permeability zones could be recognized more convincingly.

2. Geological Structure

Blawan-Ijen is a geothermal area controlled by the existence of a wide Kendeng Caldera. Several volcano-tectonic structures are found inside and even throughout the caldera. The deformation might be caused by tectonic activity, new magmatic intrusion, or combination of those two which reactivate the caldera floor structures. From the remote sensing analysis, the tectonic structures such as Kendeng-Merapi, Cemara-Kukusan probably controlled the emergence of volcanic product inside the caldera. The tectonic structure perhaps takes an important role in controlling geothermal system in Blawan-Ijen area such as Blawan normal faults which has N-S direction as shown in Figure 2. The presence of manifestations are hot springs which are located in the northern part of the Blawan area, no more

manifestations are found in other areas. The presence of hydrothermal product in Blawan-Ijen area is characterized by the alterations which obtained from remote sensing analysis and found during geological mapping.

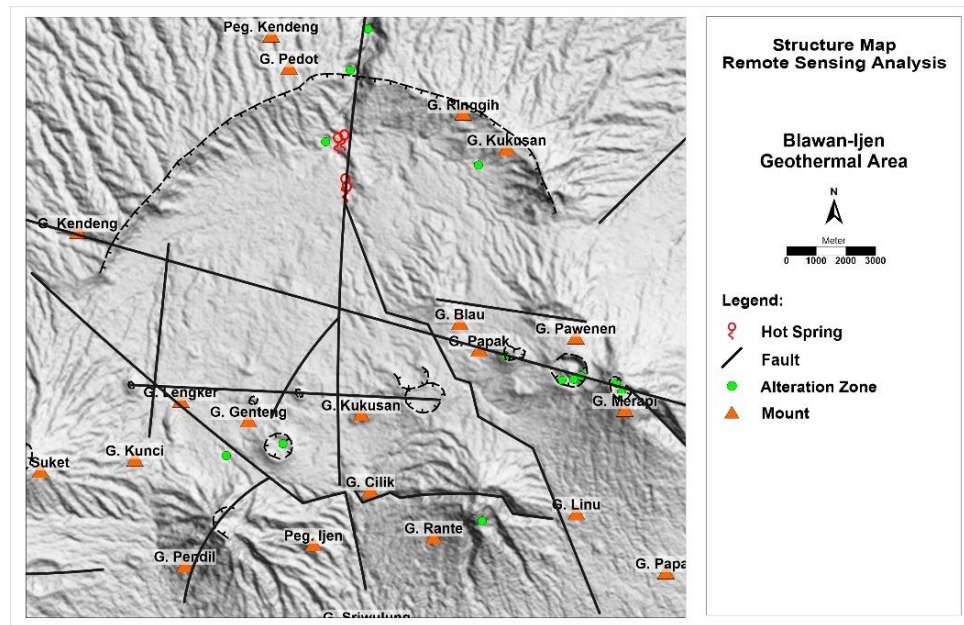


Figure 2. Geological structure based on remote sensing analysis.

3. Gravity Method

Blawan-Ijen geothermal area is located in high terrain and mostly covered by andesitic lava. Gravity measurements are acquired for 72 stations with the spacing of 1 - 1.5 km covering about 176 km² area. The acquisition was conducted by using CG-5 Gravimeter. Several corrections are necessary for data reduction to obtain Complete Bouguer Anomaly (CBA). The CBA was calculated using density value of 2.8 g/cc. The high density value represents andesitic lava that dominated this area.

Furthermore, the CBA result shows the presence of high anomalies in the southern part of the study area shown in Figure 3. The high anomalies could be associated with the mountainous areas such as Mt. Lengker, Mt. Genteng and Mt. Kukusan. As seen on the topographical map of the Blawan-Ijen area, the southern part is characterized with mountainous features that more complex compared to the northern area. It shows the possibility of the southern part area as a path of lava eruption. The high anomaly is also observed in the central of the study area which probably correlated with the basement of the Blawan-Ijen Caldera. The high anomaly in the central of caldera becomes a very interesting point in Blawan-Ijen geothermal system which is expected to be related with the existence of heat source. It will be displayed with forward modelling in the next discussion.

Separation of regional and residual anomalies was done using trend surface analysis method with the first order polynomial equation. Residual anomaly represents the result of shallow penetration. The result of residual anomaly has a similar pattern to CBA result. As shown on CBA map, high anomaly found in the southern part of the study area has good correlation with the indicated intrusion area. It is supported by the appearance of mountains in the southern area.

In the residual map shown in Figure 4, the high anomaly is also observed in the Mt. Blau and Mt. Papak. It is probably a reflection of rock intrusion supported by high topography on the surface. An indication of high anomaly is also seen in the northern part of the study area, which is situated close to the rim of Blawan caldera. However, additional gravity data is needed to be acquired in the area to

confirm the high anomaly indication. Furthermore, as indicated in the CBA map, a high anomaly in the central of the study area is also seen in the residual anomaly. It indicates the existence of basement or hot rock which has the possibility to be the heat source in the Blawan-Ijen geothermal system.

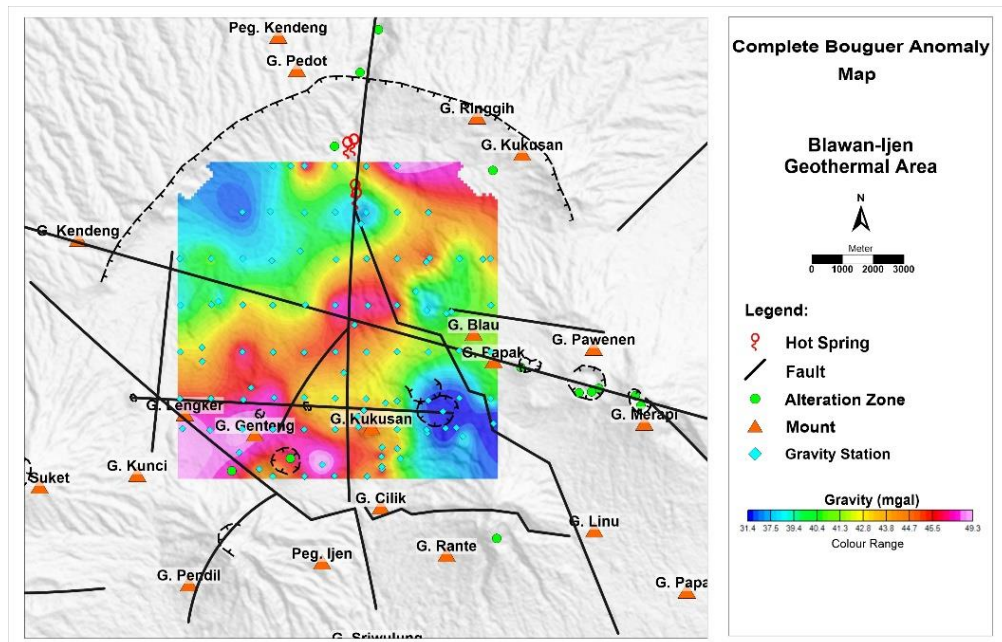


Figure 3. Complete Bouguer Anomaly map of Blawan-Ijen.

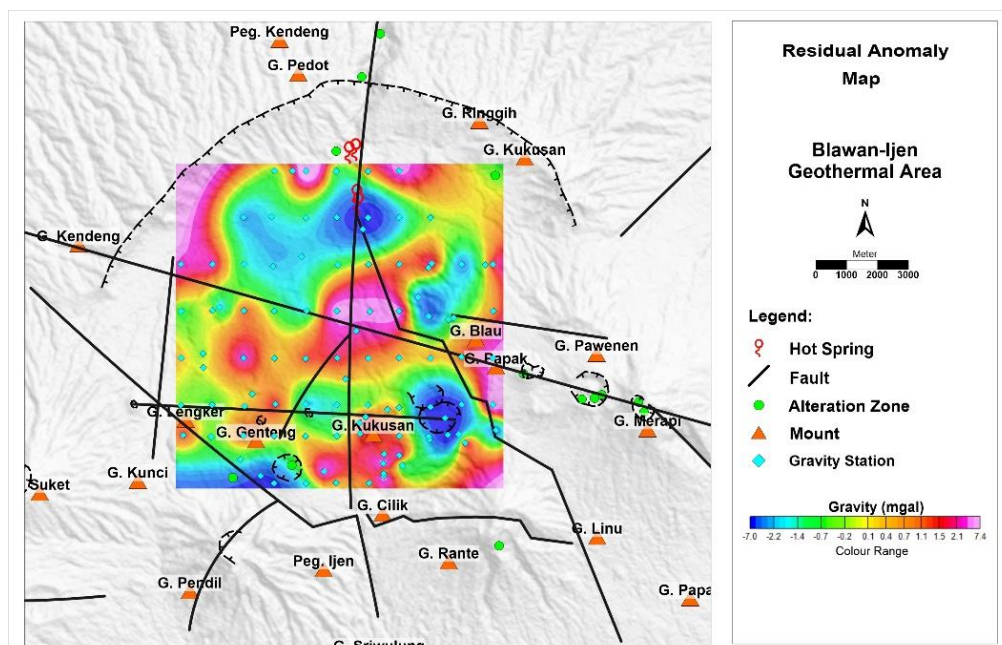


Figure 4. Residual anomaly map of Blawan-Ijen.

3.1. First Horizontal Derivative

The First Horizontal Derivative method is used extensively to locate the boundaries of density contrast from gravity data. This is a method for detecting the edges caused by fault structures or geological boundaries [1]. Most of these methods are high-pass filters based on the horizontal and vertical derivatives of the gravity anomaly [2]. The First Horizontal Derivative (FHD) maximizes any change of density. The formula is given below:

$$FHD = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2} \quad \text{HD} \quad = \quad \frac{\partial g}{\partial x^2} + \frac{\partial g}{\partial y^2} \quad = \quad \frac{\partial g}{\partial x^2} + \frac{\partial g}{\partial y^2} \quad = \quad \frac{\partial g}{\partial x^2} + \frac{\partial g}{\partial y^2} \quad (1)$$

where $(\partial g/\partial x)$ and $(\partial g/\partial y)$ are the horizontal derivatives of the gravity field in the x and y directions respectively. The method contends that the horizontal gradient of the gravity anomaly caused by a tabular body tends to overlie the edges of the body if the edges are vertical and well separated from each other [3]. The greatest advantage of the FHD method is that it is least susceptible to noise in the data because it requires only the calculation of the two first-order horizontal derivatives of the field [4]. The location of maximum FHD may be used as an indicator of the locations of edges of the source.

The presence of fault structure is indicated by maximum FHD value. The interpreted structures from FHD is represented by the light cyan dashed lines (Figure 5). The structure from FHD result in the northern part area corresponds to the structure which has N-S orientation delineated from remote sensing analysis (black colour). The structure is probably controlled the existence of Blawan hot spring in the northern area. Moreover, maximum FHD value is also seen in the western and eastern part of study area which may be associated with W-E structure from remote sensing. The intersection of the structures allows the surrounding area of the structures had a good permeability.

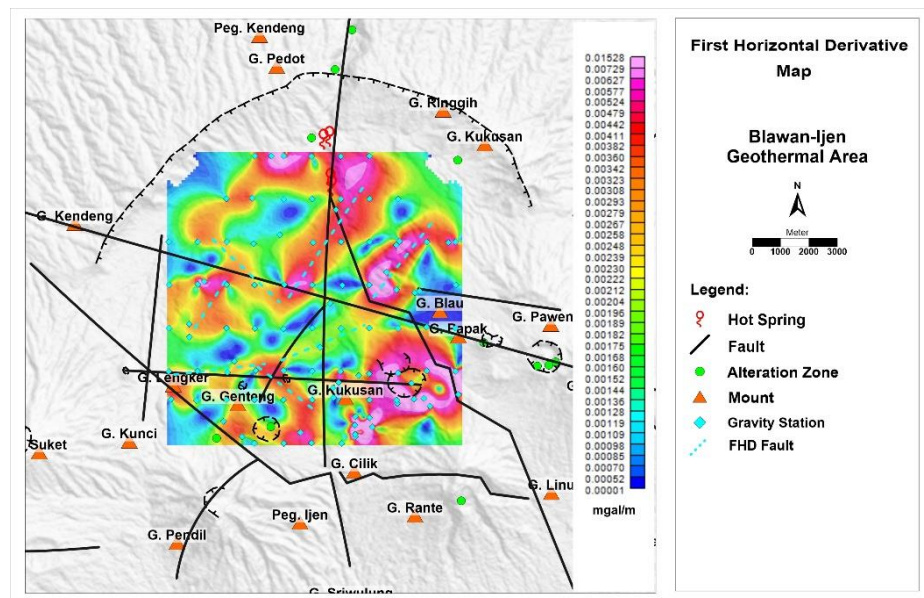


Figure 5. First Horizontal Derivative map of Blawan-Ijen.

3.2. Euler Deconvolution

Euler deconvolution technique is used to estimate the source depth locations of the gravity anomaly or magnetic anomaly in a region. The Euler depth solution is not only estimate the depth (z_0) but also delineate the horizontal boundaries [5]. Therefore, Euler deconvolution aids the interpretation of fault analysis as well as FHD. It involves the determination of the position of the causative body based on an

analysis of the gravity field and the gradients of that field and some constraint on the geometry of the body [6]. The 3D equation for Euler deconvolution is given below [7]:

$$(x - x_0) \frac{\partial g}{\partial x} + (y - y_0) \frac{\partial g}{\partial y} + (z - z_0) \frac{\partial g}{\partial z} = \eta(\beta - g) \quad (2)$$

Equation (2) can be rewritten as:

$$x \frac{\partial g}{\partial x} + y \frac{\partial g}{\partial y} + z \frac{\partial g}{\partial z} + \eta g = x_0 \frac{\partial g}{\partial x} + y_0 \frac{\partial g}{\partial y} + z_0 \frac{\partial g}{\partial z} + \eta \beta \quad (3)$$

where (x_0, y_0, z_0) is the position of a source whose total gravity is detected at (x, y, z) , β is the regional value of the gravity, and η is the structural index (SI), which can be defined as the rate of attenuation of the anomaly with distance. Structural index (SI) needs to be carefully selected as the expected geological bodies [8]. We used $SI = 0$ in identification of fault.

Euler deconvolution result shown in Figure 6 provides an estimation of the depth from 10 meters to above 2000 meters. The Euler solution in this area is mostly dominated with depth of 250-1000 meters. The structural interpretation from FHD does not always give a similar result with ED. One of the possible indications is because of the dipping of interpreted fault. It will be shown in the gravity data modelling. ED with a straight line pattern can indicate the existence of a fault in the study area. ED does not only provide an estimation of the depth of the fault but also density contrast, as shown by a circular feature in Figure 6. This phenomenon can be found in the southeastern part of the study area.

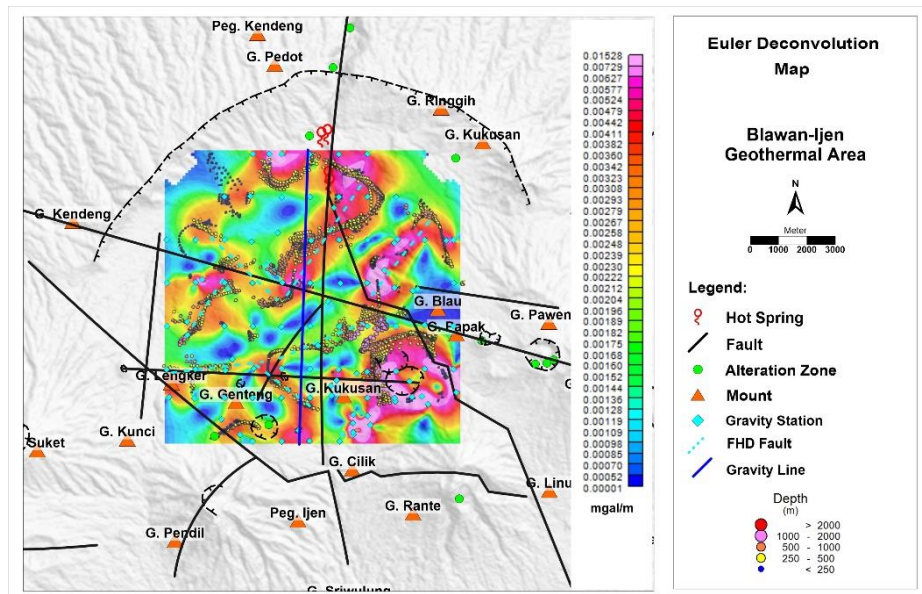


Figure 6. Euler Deconvolution map of Blawan Ijen.

4. Forward Modeling

The forward modelling of gravity data is performed under control of MT 3-D inversion result. This 2-D forward modelling was done using Zond2DGM software. The forward modelling result provides density distribution from the uppermost part (overburden) to the bottom (basement) as shown in Figure 7. The modelling result gives an indication of basement density of about 3.3 gr/cc while the reservoir of about 2.8 gr/cc. For the clay cap, the density value is ranging from 2.2 - 2.3 gr/cc while for the uppermost part ranging from 3.0 - 3.3 gr/cc. The uppermost part has a high-density value which probably represents

andesite lava. The Euler solution produces the depth in the range from near surface (about 100 m depth or associated with 1400 m elevation) to 0 m elevation. However, the Euler solution produces a value of the depth that relatively close to the surface. It is also situated close to the density contact.

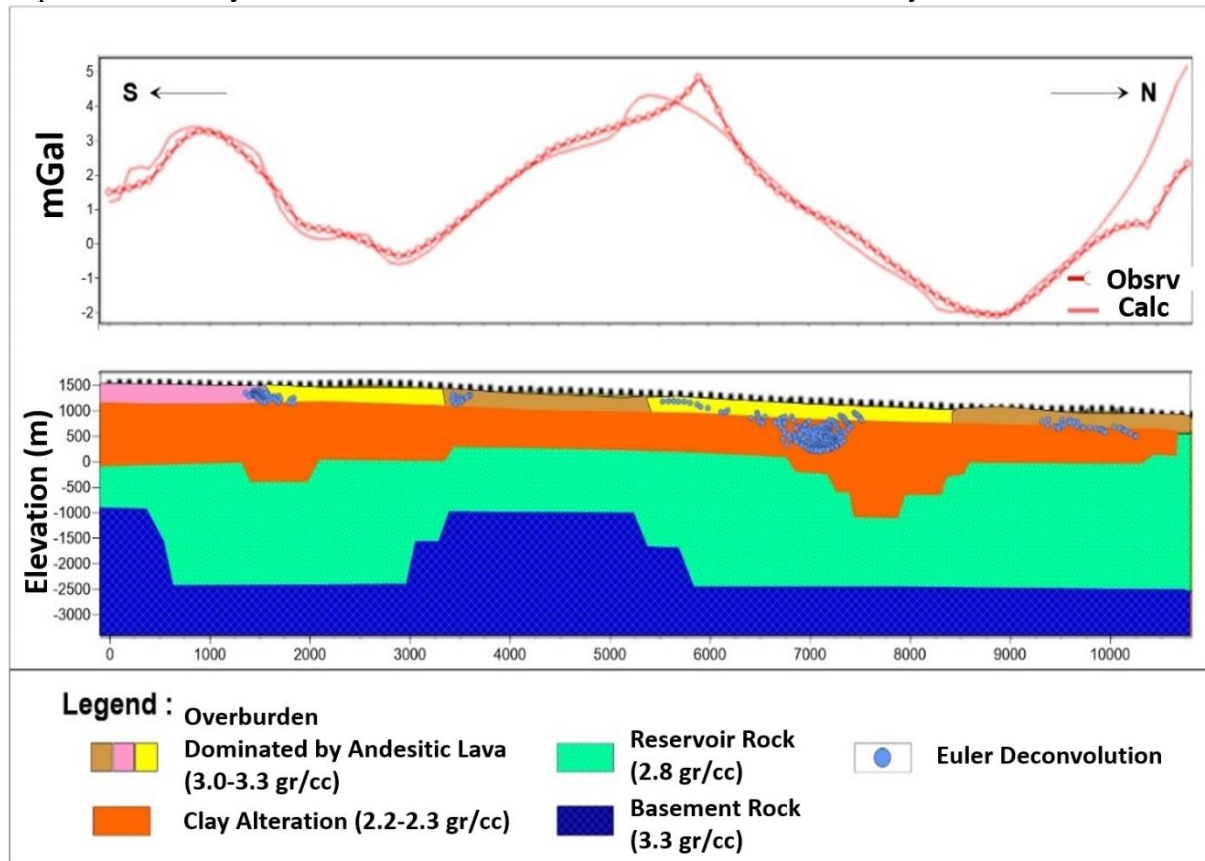


Figure 7. 2-D Forward modeling of Blawan-Ijen gravity data.

5. Discussions

The maximum value of FHD represents a lateral density contrast which is probably associated with fault. The existence of the structure indicates the possibility of permeability. Therefore, the maximum FHD value is likely indicated a good permeability. The result of the Euler deconvolution raises a value that tends to be relatively close to the surface, as shown in forward modelling result. Consequently, the indicated source of fault does not have much contribution to the permeability of the geothermal system. However, fault correlation result based on remote sensing and FHD analysis has a similar pattern. Probably the existence of fault resulted from FHD analysis is a shallow fault. The differences between fault position which derived from FHD and Euler deconvolution show two possibilities, that is a dipping of the fault which is indicated from the remote sensing analysis or it is probably a different fault.

6. Conclusions and Recommendations

From Blawan-Ijen gravity data processing result, the high anomaly has suitability with either the possibility of intrusion or the existence of basement and heat source. Two-dimensional forward modelling provides subsurface density distribution that represents the geothermal system in Blawan-Ijen. However, this modelling needs to be assisted with the MT data, for directing forward modelling result to the convergent model. The structural interpretation of FHD and remote sensing have a similar pattern. Therefore, FHD analysis can be helpful for mapping the geological structure. The main structure that controls the Blawan-Ijen geothermal system can be detected especially in the northern part of the

study area. From the results of the Euler deconvolution, the depth of the fault is obtained generally at 250-1000 meters depth. The Euler deconvolution results tend to occur at the density contrast, as seen in forward modelling result.

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