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3d Structure Modeling Using Inversion Based on Gravity Data for Geothermal Area Cisolok, West Java

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Abstract

Areas with fault existance and presence hot springs manifestation often suspected have good potency of geothermal. One of them is in the area Cisolok, Province West Java. This is what supports to study about this, with the aim to analyze structure lower the surface based on 3D inversion data modeling and 2D residual anomaly results by measuring gravity data. On this research, in an area of 70 km^2, data used for measurement as much as 116. Then, the data is subjected to reduction for invention complete bouguer anomaly. Gridding and filtering treatments are also carried out to get residual anomaly data, continued by the 3D inversion process using Singular Value Decomposition (SVD) and Occam. Inversion is aimed for getting a 3D density model that decent to be interpreted and analyzed. The results are some maps classified residual anomalies in class high, medium, and low anomaly. High anomaly interpreted as andesitic lava and basalt lava, with the anomaly 5.2 – 36.2 mGal. Anomaly between -9.8 – 5.2 mGal interpreted as rock volcanic weathered. While the lowest is rock which changed because of heat consequence and structure fault, so the anomaly value from -45.2 to -9.8 mGal. The distribution of density value in 2D cross-section is also obtained based on 3D incision on the volcano-stratigraphic map. According to interpretation, rocks in the research area associate with the fault zone controlling manifestation surface. For density in medium level, 1.7 – 2.4 gr/cm^3, interpreted as rock breccia volcanic. It is also estimated that andesite intrusion is seen from the existence pattern form breakthrough to the depth of 0-700 m, where the value of density height, worth to 2.4 – 2.8 gr/cm 3.
Keywords: residual anomaly, density, inversion, geothermal, structure

Introduction

Indonesia is a country that has high potential for renewable energy in the form of geothermal. Based on data from the Directorate General of New Renewable Energy and Energy Conservation (Ditjen EBTKE) 2021, Indonesia has geothermal reserves of 23.9 giga watt (GW). Based on data from geological records until 2019 submitted by the Directorate General of EBTKE in 2020, the existing geothermal potential has only been utilized by 8.9% worth 2130.6 MW. One area that has geothermal potential in West Java Province is Cisolok. Supported by several manifestations in the form of hot springs located in the fault zone, it can strengthen the estimation of potential in the area. It is estimated that the Cisolok area has an estimated reserve of 45 Mwe. Seeing the potential of the data obtained, it is necessary to conduct further surveys to determine the subsurface conditions of the area.

The geophysical method that can be used in the initial survey to map the subsurface conditions of the geothermal area is the gravity method. This method can determine subsurface conditions based on the distribution of the density values of the constituent rocks. This method is used because it is quite effective for identifying subsurface structures. Meanwhile, modeling of the gravity method that applies 3D inversion for the geothermal potential area is widely carried out in various regions, such as in Bradys in 2016 by Witter, et al., in Sipholon by Parapat in 2017, and in Eburu in 2020 by Maithya, et al.

According to Rahma in 2014, three-dimensional (3D) modeling is very accurate compared to two-dimensional (2D) modeling, this is because 3D modeling can provide information related to the depth of the anomaly, the position of the anomaly and the volume of the anomaly being studied. This 3D modeling will use the combination of 2 inversion methods, namely SVD (Singular Value Decomposition) and occam inversion. The SVD method was chosen because it has the best approximation solution even though a System of Linear Equations (SPL) does not have a solution. Merging with occam inversion is done to maximize the match between the measurement data and the calculation and minimize the level of roughness of the resulting model.

Based on the reviews of previous studies, this study aims to provide an analysis of the distribution of subsurface density values in the study area, as well as provide an interpretation of the subsurface structure through a 3D inversion model of gravity data. In the processing, spectrum analysis is needed to be able to estimate the depth and wavelength. Meanwhile, in the modeling process, inversion is carried out to obtain a match between the model parameters that produce the response and the observation data.

Regional Characteristics

In this study, the study area is in the Cisolok-Cisukarame area which is included in the Bandung Zone and Bogor Zone. The Bandung zone is a depression between mountains (intermontagne depression) which is composed of the dominance of quaternary volcanic products. This zone curves from Pelabuhan Ratu following the Cimandiri Valley to the east through Bandung City and ends at Segaran Anakan at the mouth of the Citanduy river. This zone is partially filled by young volcanic products and alluvial deposits. Meanwhile, the Bogor Zone stretches from Rangkasbitung through Bogor, Purwakarta, Subang, Sumedang, Kuningan and Majalengka. The Bogor Zone is a folded hilly area formed from deep-sea tertiary sedimentary rocks forming an anticlonorium. In this zone, the Lembang fault and the uplift of the southern mountains are formed. The rocks that make up the Bogor zone are strongly folded sedimentary rocks of Neogene age and breakthrough rocks. (Van Bemmelen, 1949).

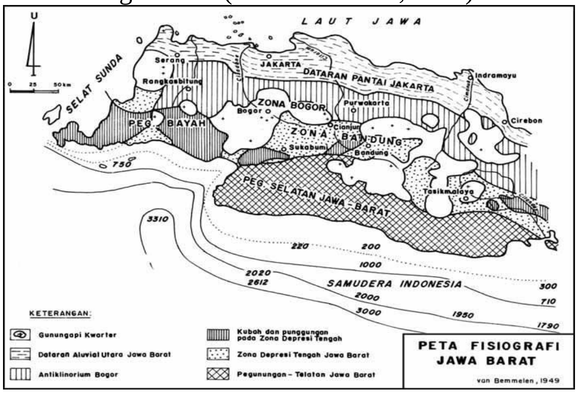

Figure 1. West Java physiographic map, the orange box is a modified research area (Van Bemmelen, 1949)

In terms of volcano-stratigraphy, the lithology that composes the Cisolok area consists of groups of sedimentary rocks, intrusive rocks and acidic volcanic rocks (dacite-granodiorite) which are the oldest rocks, then there are groups of volcanic rocks with intermediate composition (andesite-basalt) and the youngest deposits in the form of alluvium scattered around the south of Pelabuhan Ratu (Directorate of Geothermal, Directorate General of EBTKE, Center for Mineral, Coal and Geothermal Resources, 2017).

Geothermal System

The Cisolok geothermal source is estimated to be related to the volcanic activity of Mount Halimun and Mount Talaga. A productive geothermal reservoir must have high porosity and permeability, large enough size, high temperature, and sufficient fluid content. It is estimated that the rocks that make up the Cisolok geothermal reservoir are derived from sedimentary and dacite rocks from the early to mid-Miocene. Cover rock that is impermeable or has low permeability is needed to prevent the escape of hot fluid accumulation in the reservoir. In the volcanic environment associated with tectonic movements causing the formation of gaps in the rock cover. The existence of geochemical processes causes hydrothermal changes and mineral deposition that can close the gaps formed (Kasbani, 2009). Geologically, the Cisolok geothermal system model belongs to the type of hot water dominated system (Directorate of Geothermal et al., 2017) fluids with up-flow zones in the Cisukarame area and out-flow in the Cisolok area. The reservoir temperature is around 185-212 C with intrusion as a heat source (Sumartha et al., 2020).

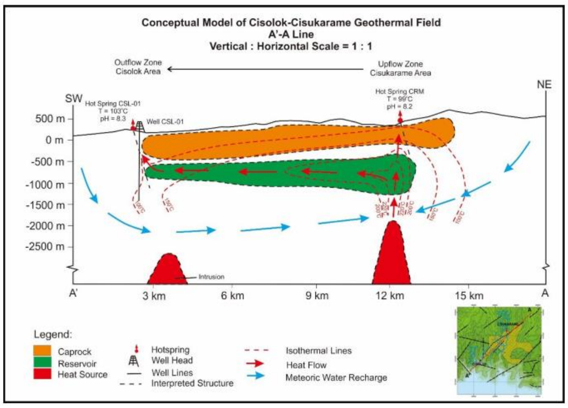

Figure 2. Illustration of the conceptual model of the Cisolok-Cisukarame geothermal system (Sumartha et al., 2020)

Basic Principles of Gravity

Newton's law is a law that explains the force of attraction between objects with a certain mass. In accordance with Neyton's 1st law, that the two objects will attract each other due to the gravitational force field whose magnitude can be expressed in the equation (Hinze, 2013):

$$F_g = G\frac{m_1 m_2}{r^2}$$

Where F_g is the force of attraction (N) between m_1 and m_2, G is the gravitational constant with a value of $6{,}67 \times 10^{-11}$ Nm^2 kg^{-2}, m_1 and m_2 is the mass of the object (kg) and r is the distance between the centers of the two objects (m).

Gravity readings are generally influenced by five factors, including latitude, altitude, topography, tides, and variations in rock density below the surface (W.M. Telford, 1991). Therefore, the measurement results from this method need to be corrected first to reduce the factors that influence it. The results of the measurements will produce the magnitude of the gravitational field and gravitational field anomaly.

The corrections made to reduce the influencing factors are tide correction, drift correction, latitude correction, free air correction, terrain correction, bouguer correction, and complete bouguer anomaly.

Spectrum Analysis

Spectrum analysis is a fourier transformation process (transformation from time domain to frequency) which results in an amplitude spectrum and a phase spectrum so that it can estimate the depth with an estimated wave number (k) and amplitude (A) which will be inputted in the filtering process for the separation of regional and residual anomalies.

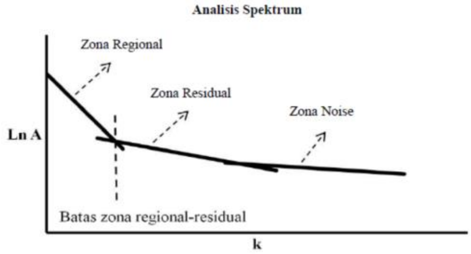

Figure 3. Graph of the relationship between amplitude and wavenumber in spectrum analysis (Blakely, 1995)

Gaussian Filter

Gaussian filter is a linear filter that utilizes the distribution of data in the gauss kernel matrix obtained from convolution operations on a data matrix that is already in frequency. The following is shown in the equation:

$$G(i,j) = c.e - \frac{(i-u)^2 + (j-v)^2}{2\sigma^2}$$

Where c is constanta, $G(i,j)$ gauss kernel matrix in position (i,j), σ is constanta which is adjusted to the size of the gauss kernel matrix and i, u, j, v is members in the matrix (Yuwono, 2015).

Singular Value Decomposition (SVD)

Singular Value Decomposition (SVD) is a powerful method for inverting single or numeric matrices (unconditional systems). Standard matrix equation solving can fail under these conditions. The advantage of the SVD method is that you don't need to know a priori the problem. SVD is very commonly used in size-independent matrices (Carlson, 2011).

Occam

The occam inversion method is an inversion to maximize the match between the measurement results and the calculated data. The occam inversion in the Grablox software, namely occam d (occam density) is useful for optimizing the block density value so that the resulting model is smoother. Occam inversion is an inversion method that utilizes the roughness of a model (Constable et al., 1987).

Data and Method

The research location is in the Cisolok geothermal area, West Java. The data used is secondary data in the form of gravity data from measurements made in the Cisolok geothermal area, West Java as many as 75 measurement points with 116 data. The base station is located at coordinates X (easting) = 662959.85 and Y (northing) = 9230634.83 with a height of 48.05 meters and a G-absolute value of 978218.8508 mGal.

Data obtained from the Center for Coal and Geothermal Mineral Resources (PSDMBP) of the Geological Agency of the Ministry of Resources and Energy (KESDM) and the SRTM 90m Digital Elevation Model Map (DEM) in the Cisolok area were first corrected, so that the complete bouguer anomaly was obtained. Then, a calculation analysis is carried out which includes gridding, spectrum analysis, filtering, and 3D inversion modeling until the expected 3D density model is realized.

Result and Discussion

Gravity data obtained from field measurements need to be corrected first to reduce several factors that affect the measurement data with a reference value of the average density of the earth's crust of 2.67 gr/cm3. The final result of the correction is the complete bouguer anomaly value which has the distribution of values as shown in Figure 4. To obtain the complete bouguer anomaly value, interpolation/gridding is required. Gridding itself is a process of data that is scattered irregularly and there is empty data to produce a complete regular grid of bouguer anomaly data (Lama et al., 2019). The determination of the gridding method can be adjusted to the distribution of the data so that the most optimal results are obtained.

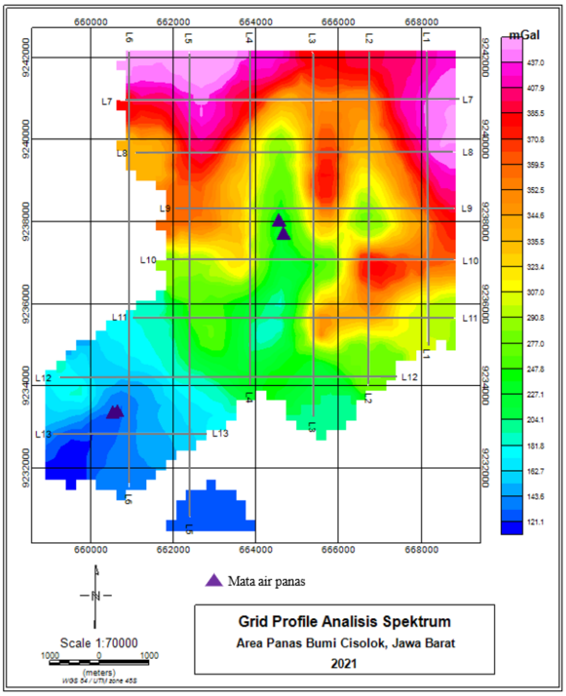

Figure 4. Complete Bouguer Anomaly Map with Grid Profile, 13 lines

On the complete Bouguer anomaly map, various contour patterns can be seen which can be classified into 3 patterns, namely high, medium and low anomalies. The high anomaly pattern has a value between 344.6 mGal to 437 mGal. This anomaly pattern dominantly appears in the west to the east which is in the halimun lava formation with the constituent rocks in the form of andesite lava and basalt lava. This pattern is influenced by the presence of Halimun Mount.

This anomalous pattern appears in the tapos breccia formation composed of volcanic breccia and agglomerates which have a younger age than the halimun lava formation and the citorek tuff formation. The value of the low complete bouguer anomaly has a value range of 121.1 mGal to 247.8 mGal which is dominantly in the southwest direction. This anomalous pattern appears in the Citorek, Dacite, Citarete tuff and Citarete limestone formations. The complete bouguer anomaly map shown in Figure 4 shows that the high bouguer anomaly pattern is more dominant in the study area. This shows that the rocks that make up the study area are dominated by volcanic rocks.

The input data from the spectrum analysis is the distance between the measurement points and the value of the gravity anomaly that has been sliced. The sample interval for the grid profile is 350 meters. From the graph ln A to wavenumber (k) it can be seen that the estimated depth of the regional anomaly and the residual anomaly will be used to determine the depth limit of the 3D model to be made. The result of the coefficient on the variable x by considering the value of R2 is used to determine the fit of the model. In line 1 spectrum analysis (figure 5), the results show that the regional depth is at -5284.6 meters and the residual depth is at -757.02 meters. The constant value for the regional anomaly is 11.542 and the residual anomaly is 6.0628. After that determine the cut off value and wavelength on line 1.

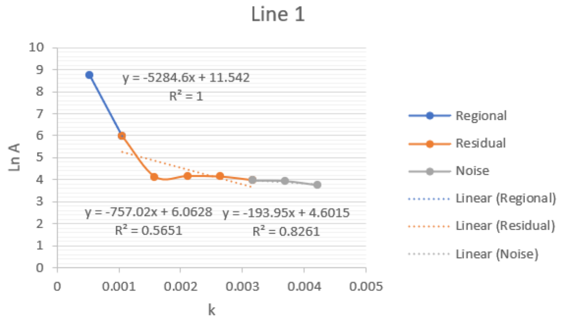

Figure 5. Graphic of ln A vs wavenumber (k) profile line 1

The same process is also carried out on line 2 to line 13. The results obtained from the spectrum analysis process are that the regional anomaly depth estimation is 4733.32 meters, the residual anomaly depth estimation is 707.066 meters and the gravity anomaly wavelength is 5148.19 meters which will be used in the filtering process. Table 1 shows that the spectrum analysis process produces estimates of regional and residual depths, cut off values, and wavelength (λ).

Regional Anomaly

The regional bouguer anomaly map shows a high anomaly with a value of 352.2 mGal – 437.3 mGal in the northwest - north - northeast direction which is interpreted as having a high density value of the constituent rocks. This high anomaly value is thought to be in the form of andesitic lava and basalt lava from the halimun lava formation. The moderate anomaly in the southeast to west direction has a value of 247.8 mGal – 352.2 mGal, it is interpreted that the constituent rocks have a density between high- and low-density rocks. This anomaly value is thought to be in the form of volcanic breccia and agglomerates originating from the tapos breccia formation. The dominant low anomaly is located in the southwest direction with a value of 121.2 mGal – 247.8 mGal. It is interpreted that the constituent rocks in the form of dacite are derived from the dacite formation, the tuff members of the citarete formation consisting of limestone, tuff and limestone, and sandstone from the limestone members of the Citarete formation.

Residual Anomaly

Residual anomaly maps can be divided into 3 types, namely high, medium and low anomaly patterns. The high anomaly has a value between 5.2 mGal to 36.2 mGal. The high anomaly has a dominating distribution in various directions which is thought to be andesitic lava and basalt lava. The moderate anomaly has a value of -9.8 mGal to 5.2 mGal with an even distribution which is thought to be composed of weathered volcanic rocks. The low anomaly has a value of -45.2 mGal to -9.8 mGal which dominantly has a north trend and slightly spreads in the southeast, southwest, northwest and northeast directions.

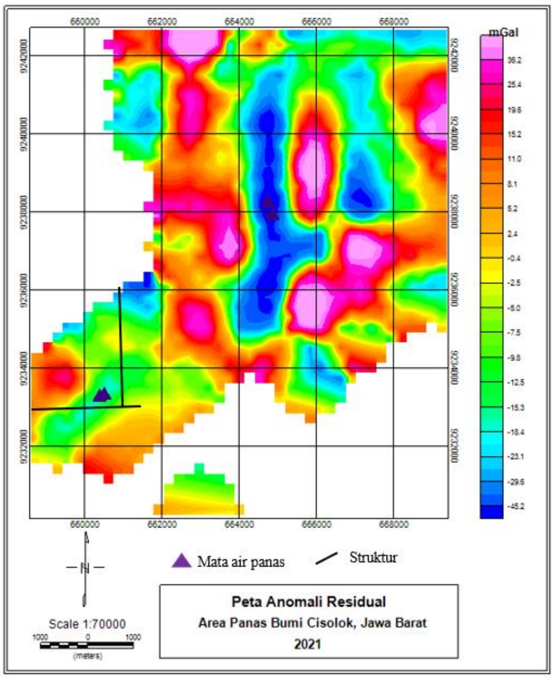

Figure 6. Residual Anomaly Map

3D Inversion Model

In making the initials of the model, it is necessary to first determine the length of the X, Y and Z axes to determine the minor blocks defined as dX, dY, and dZ. The major blocks used on the X axis will be filled by 20 minor blocks (nX), 30 blocks Y axis (nY), Z axis 20 blocks (nZ) so that 12000 minor blocks make up the major blocks into the initial model. Density parameter input is the most important thing in model making, density values from 1.3 gr/cm^3 to 3 gr/cm^3 are used. From the density parameter, an initial model

Tabel 1. Results of spectrum analysis for depth estimation and calculation of the wavelength of gravity survey

Profile	**Regional (m)**	**Residual (m)**	**X (*cut off*)**	**λ (m)**
Line1	-5284,6	-757,02	0,00121	5191,93
Line2	-5394	-745,39	0,001147	5478,912
Line3	-5302,4	-946,03	0,001025	6131,281
Line4	-5307,2	-477,62	0,001089	5770,465
Line5	-4840,6	-550,96	0,001054	5960,592
Line6	-2671,6	-728,67	0,002098	2995,556
Line7	-5299	-843,24	0,001178	5333,149
Line8	-5309,8	-676,58	0,001103	5696,386
Line9	-5959,2	-1050,2	0,000979	6418,912
Line10	-3342,5	-291,95	0,001842	3411,439
Line11	-4062,1	-1130,7	0,001192	5269,513
Line 12	-5823,1	-488,99	0,001021	6152,626
Line13	-2937	-504,51	0,002017	3115,706
Rata-Rata	**-4733,32**	**-707,066**	**0,001304**	**5148,19**

with blocks is generated according to the average density value of the earth's crust of 2.67 gr/cm^3. The resulting density model will have 20 incisions perpendicular to the Z axis, 30 incisions perpendicular to the Y axis and 20 incisions perpendicular to the X axis.

The model that has been created will be processed in 3D inversion. Obtained 1304 data points after the gridding process IDW (Inverse Distance Weighted) as data to be inputted in the modeling process. In this modeling there are 2 stages, namely computation and optimization. The computational process is carried out to determine the suitability of the model by showing the difference in the value of the measurement and calculation results. The optimization steps carried out are optimization of base, density, and occam density sequentially. At each optimization stage, it will affect the error value, where the smaller it will have a good data suitability.
The results of the 3D inversion modeling obtained a density distribution model. The 3D model will then be analyzed with supporting data to assist in the interpretation process. The distribution of low density values is found at depths ranging from 100 to 700 meters with a density value of 1.4 gr/cm^{3}to 1.7 gr/cm^3. It is thought that the low density is associated with the fault structure, this is because there is a pathway for the migration of the hot fluid to the surface. From the results of modeling and vulcanostratigraphic maps, this weak zone research area is located at the same location, namely through the manifestation of hot springs.

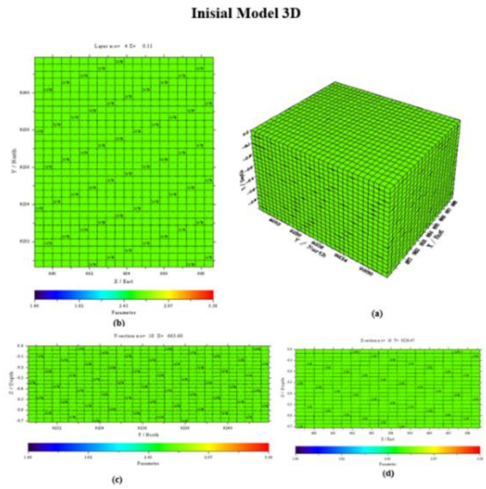

Figure 7. Initial 3D model (a) initial 3d model display (b) h section slicing section (c) y section slicing section (d) slicing x section section

Based on the results of the analysis with a vulcanostratigraphic cross-section of the A-A' trajectory through the NE-SW trending fault, the manifestation of the Cisukarame hot spring. There is a rock mass that has a high density marked with a red to pink color with a density value of 2.4 – 2.8 gr/cm^{3}which is spread below the surface to form an upward pattern of penetration. The cross section also shows a low density with a value of 1.4 - 1.7 gr/cm^{3}which is suspected as a fault zone that acts as a controller for the emergence of Cisukarame hot springs. In the gray circle further north, a low-density value was also found, presumably a response to the presence of a weak zone in this area. Densities with a value of 1.8 – 2.4 gr/cm^{3}marked in green are estimated to be volcanic breccia rocks originating from tapos breccia formations.

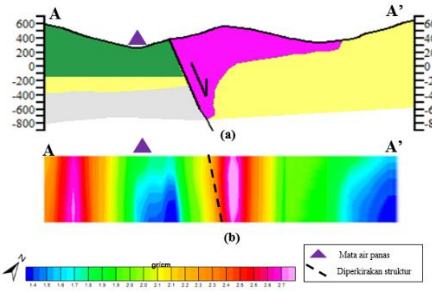

Figure 8. Comparison of the results of the 2D cross-section of the A-A' trajectory. The gray circle is a low-value density corresponding to the weak zone

Making a trajectory on B-B' which has the same NE-SW direction as a vulcanostratigraphic cross-section that can display several structures and pass through 2 manifestations of hot springs. There is a rock mass that has a high density marked with a red to pink color with a density value of 2.4 – 2.8 1.7 gr/cm^{3}which is spread below the surface forming an upward intrusion pattern which is interpreted as andesite intrusion. Meanwhile, the cross section also shows low density with a value of 1.4-1. 1.7 gr/cm^{3}in two places marked with a gray circle, presumably as a weak zone caused by the N-S trending fault which acts as a controller for the emergence of the Cisolok hot springs. Densities with a value of 1.8 – 2.4 1.7 gr/cm^{3}marked in green are estimated to be volcanic breccias originating from tapos breccia formations.

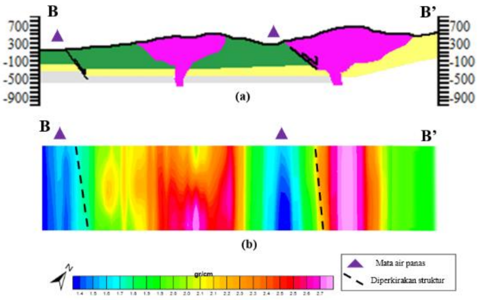

Figure 9. Comparison of the results of the 2D cross-section of the B-B' trajectory. The gray circle is a low-value density corresponding to the weak zone

Conclusions

The subsurface geological conditions of the study area based on residual anomalies are divided into 3, namely: (a) The high anomaly has a value between 5.2 mGal to 36.2 mGal with a dominating distribution in various directions which is thought to be andesitic lava and basalt lava; (b) The moderate anomaly has a value of -9.8 mGal to 5.2 mGal with an even distribution which is thought to be composed of weathered volcanic rocks; and (c) The low anomaly having a value of -45.2 mGal to -9.8 is thought to be related to heat-modified rocks and the presence of fault structures.

The 2D cross-sectional density distribution value from the 3D incision based on the volcano-stratigraphy map shows a low density with a value of 1.4-1.7 1.7 gr/cm^{3}with a depth of 100-700 meters and 0-700 meters on the A-A' trajectory and a depth of 50 -700 meters and 0-700 meters on the B-B' trajectory are estimated to be associated with fault zones that control surface manifestations. High densities are marked with red to pink colors with a density value of 2.4-2.8 1.7 gr/cm^3 which are scattered below the surface forming an upward breakout pattern at a depth of 0-700 meters, estimated as andesite intrusion.

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