Structural Geology Identification based on Derivative Analysis Gravity Data in Tangkuban Perahu Mountain

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Abstract

The earth comprises structures with different rock types, properties, and characteristics. It can be known by applying the laws of physics in the form of geophysical methods such as the gravity method. Gravity is a passive geophysical method widely used for geodynamic and exploration studies in estimating fault structures. This research aims to model the subsurface geological structure based on the results of derivative analysis of gravity data related to geothermal prospects. The data used are GGMplus gravity acceleration data and topography (elevation) from each measurement point, totaling 6889. The data was then subjected to several corrections to produce a complete Bouguer anomaly. Then, the next stage is derivative analysis, which is used to obtain a subsurface geological structure model and geothermal prospects for the Tangkuban Perahu area. Based on the correlation between derivative analysis and two-dimensional modeling results, it can be seen that the Tangkuban Perahu geothermal system is controlled by structures in the form of horsts and grabens formed due to Tangkuban Perahu volcanic activity. The Tangkuban Perahu geothermal reservoir prospect is estimated to be at a depth of around 0.6 km – 2.8 km with a density ranging from 2.15 g/cc to 2.45 g/cc, which is estimated to be basalt breccia.

Keywords: *Gravity, structure geology, modeling, tangkuban perahu, geothermal.*

I. INTRODUCTION

Geothermal energy is stored in rocks below the earth's surface and the fluids therein. The use of geothermal energy as an energy source began in the early 20th century when electricity was first produced from geothermal steam in Larderello, Italy, in 1904 [1]. Exploration and development of geothermal resources play an important role in Indonesia's energy diversification and sustainability. Geothermal energy is a promising renewable energy source with great potential to meet the world's sustainable energy needs.

One area in Indonesia with large geothermal potential is the Tangkuban Perahu area in West Java. However, to maximize this potential, a deep understanding of the characteristics of the geothermal reservoirs in this area is needed [2].

The earth comprises structures with different rocks, properties, and characteristics. Properties and characteristics can be known by applying the laws of physics appropriate to the properties and characteristics you want to investigate. To find out these physical properties, you can use geophysical methods. One of them is the gravity method. Gravity is a passive geophysical method widely used for geodynamic and exploration studies in estimating fault structures. Gravity measurements are carried out to obtain a picture of the subsurface, which can be used to interpret structures, basements, and faults. Gravity is also a method that is very sensitive to changes in the lateral and vertical direction. Therefore, this method is often used to study geological structures, bedrock, rock intrusions, sedimentary basins, and ancient river deposits [3].

This method utilizes differences in gravity that occur due to differences in rock density below the earth's surface. By measuring variations in gravity, we can map the distribution, depth, and geological structure of geothermal reservoirs in the Tangkuban Perahu area. The gravity method can also be used to create models of subsurface structures that will be used as a reference for interpretation. By carrying out this interpretation, it is hoped to provide better information and description of the conditions of geothermal prospect areas [4].

The author used 2013 GGMplus (Global Gravity Model Plus) satellite gravity data. GGMplus data has the advantage of the densest spatial resolution compared to other satellite gravity data such as TOPEX and BGI [5]. GGMplus has a spatial resolution of 200 m and can be used for the initial mapping of an area as a general description of an area before collecting more local primary data [6]. In this final project, the geothermal potential of the Tangkuban Perahu area will be studied using the gravity method, and gravity mapping will be important in exploring geothermal resources in this area.

This research aims to identify the subsurface geological structure of the research area based on the results of derivative analysis and obtain a distribution model of subsurface density values and geothermal prospects for the research area.

A. Regional Geology

West Java, as part of the island of Java, is the outermost island of the southern arc of Asia; besides that, due to subduction, Java has unique and complicated geological conditions. West Java was part of a complex mixing zone between oceanic and continental crust rocks in the pre-Tertiary era. The existing rocks consist of metamorphic, volcanic, and igneous rocks, known only from drilling data in the northern part of the West Java Sea [7].

Geologically, the West Java area comprises igneous, sedimentary, and volcanic rocks (Figure 1). In the early Tertiary (Paleocene), a mélange complex was formed in southwest West Java (Cileteuh Bay), considered part of the subduction zone towards Central Java. In the north of West Java, products from volcanic eruptions began to be deposited, which were deposited in the Jati Barang Formation. During the Eocene, West Java was in an elevated condition characterized by an unconformity. At the same time, the Rajamandala - Sukabumi area was a fluvial terrestrial area where the Gunung Walat Formation was present, which filled the basin in the arc (interarc basin).

During the Early Oligocene, it was marked by an unconformity at the peak of Mount Walat in the form of a quartz sandstone conglomerate, a tectonic uplift throughout the area. During the Late Oligocene, it started with marine transgression, which formed from southeast to northeast. The position of Bogor, West Java, separates the edge of the shelf (off-shelf platform) in the south from the Sunda shelf in the north. On the northern edge of this shelf, the Rajamandala Formation reef was formed, preceded by the deposition of the Batuasih Formation carbonate shale. The Gantar Formation was also deposited in the northern part in the form of carbonate reefs and occurred during repeated erosion and trend regression cycles. At the same time, uplift occurred until the Early Miocene along with volcanic activity, which produced fold and fault structures in a southwest-northeast direction.

During the Miocene, after the Rajamandala formation, the Bogor Basin was filled with turbidite deposits and volcanic debris. Meanwhile, the Jampang and Cimandiri Formations were deposited in the southern part. To the north, the Parigi and Subang Formations were deposited. Middle Miocene uplift was followed by west-east trending folding and faulting. In the Late Pliocene, there was uplift followed by weak folding. The Cimandiri zone experienced strike-slip faulting. Meanwhile, the deposition of the Bentang Formation took place.

In the Quaternary Period, many geological events were characterized by volcanic activity so that the entire surface was covered by volcanic product units. The Bandung area experienced blockage of the Citarum River by lava eruption from Tangkuban Perahu, so it was flooded with water, and Lake Bandung was formed. Bandung and surrounding areas such as Padalarang and Cimahi formed many lake deposits during flooding. Finally, Lake Bandung leaked in the Sang Hyang Tikoro limestone area, and during that time, volcanic products from Tangkuban Perahu were deposited again. Late Pliocene uplift was followed by weak folding, which resulted in the Bentang Formation, where the rocks have relatively gentle slopes. This was followed by tectonic activity so that the Cimandiri Zone experienced horizontal faulting with a direction of around N 45°E cutting through the previous structure.

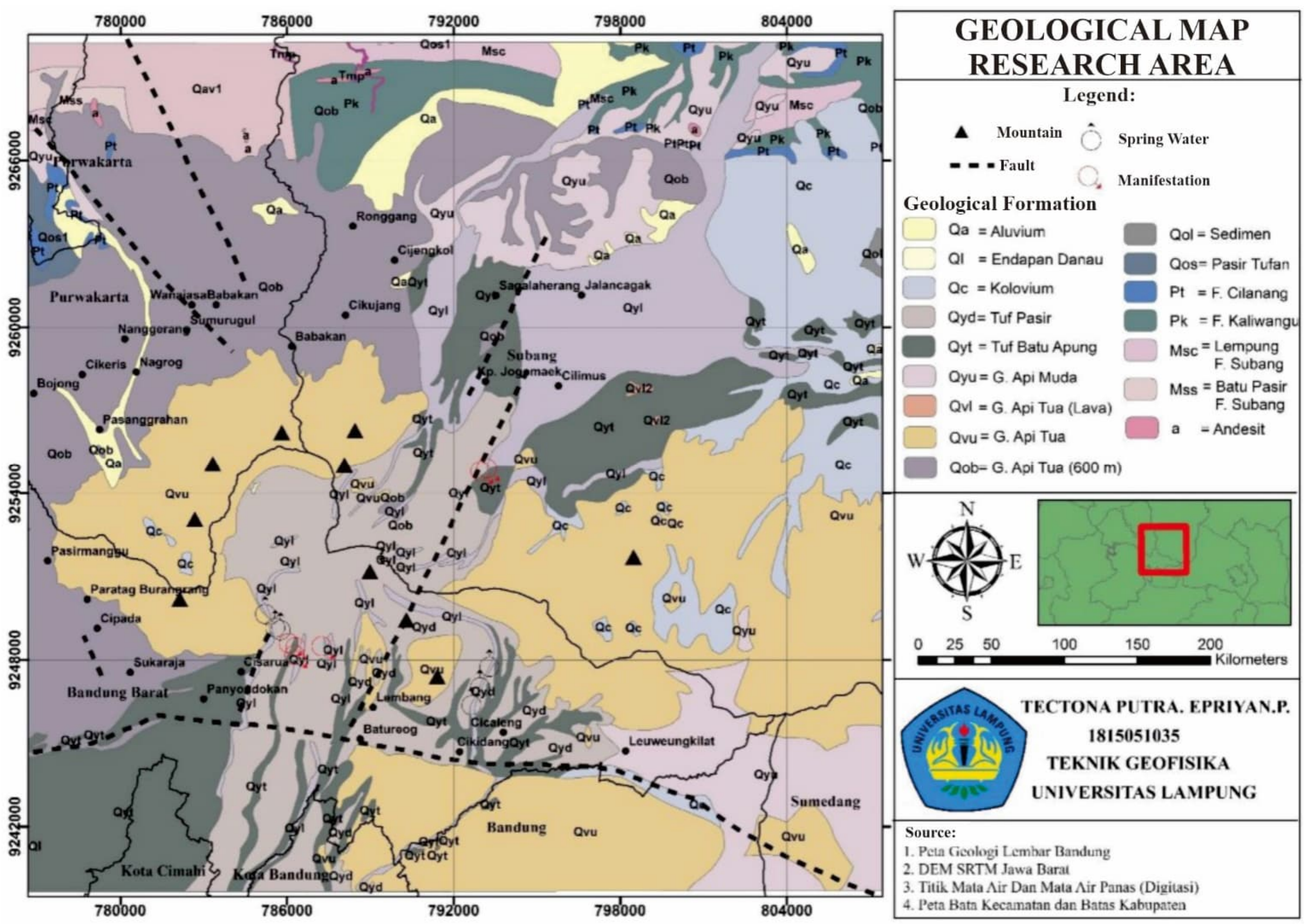

Figure 1. Regional geological map of the research area [8].

II. Materials and Methods

The gravity data used is 6889 GGMPlus satellite gravity data points downloaded from the Bureau Gravimetrique International website at https://bgi.obs-mip.fr/data-products/grids-andmodels/modele-global-ggmplus2013/ [9].

The next stage uses a spectrum analysis method using the Fourier transformation to change the distance domain to the frequency domain. With spectrum analysis, the frequency content of the data can be determined so that the depth of an anomalous gravity object below the surface can be estimated. Low frequencies associated with long wavelengths indicate regional areas representing deep and extensive structures. While high frequencies associated with short wavelengths indicate residual areas representing shallow structures, very high frequencies indicate noise caused by various factors. In this research, spectrum analysis was carried out on three sections representing our desired areas. Fourier transformation was then carried out from these three trajectories using Numeri software. All data obtained from the trajectory is then processed using Ms. Excel to find the lnA value and the wave number k value, which will later be used to estimate the depth.

The Bouguer anomaly in the gravity method is caused by differences in rock density, both those close to the earth's surface and those far from the earth's surface. Effects originating from rocks in shallow areas are called residual anomalies, while effects originating from deeper rocks are called residual anomalies. In this study, the separation of regional and residual anomalies was carried out using the moving average method. Moving average is the average of gravity anomaly data, where the result of this method is a regional anomaly, and residual anomalies are obtained from the difference between the Bouguer Anomaly and the residual anomaly. Surfer software is used for this process; the anomaly separation process begins by entering Bouguer anomaly data into Surfer software, and then the optimal window width value obtained in the spectrum analysis process is entered as the separation input value.

Derivative analysis, namely First Horizontal Derivative (FHD) and SVD, is used in data processing. This SVD filter is used on the residual anomaly map to determine the boundaries of existing structures in the research area. The results of this derivative analysis processing will be used as supporting data for subsurface structural analysis to determine the distribution of structures in the research area.

Subsurface modeling in this research uses 2D forward modeling and 3D inverse modeling using Geosoft Oasis Montaj software and Grablox 1.6b software. The forward modeling stage is carried out by inputting distance data and residual anomaly data based on the slices or trajectories that have been created. The path determination stage is carried out by drawing a track that passes through high and low anomalies, which are indicated as fault areas. The 3D inverse modeling stage is carried out by inputting mesh and residual anomaly data to create a 3D model of the research area close to the actual model. Next, an analysis was conducted to determine the research area's geothermal reservoir and heat source.

III. Results and Discussions

A. *Complete Bouguer Anomaly*

The complete Bouguer anomaly map results show an anomaly range of 14 mGal to 39 mGal, a response to variations in rock density in the study area. The anomaly value is divided into three parts: low, medium, and high. Low anomalies are shown in purple to blue with a value range of 14 mGal to 20 mGal in the northeast and some in the northwest of the study area. Medium anomalies are shown in light green to dark green with a value range of 20 mGal to 28 mGal in the northern part of the study area from the northwest to the northeast and partly in the southwest tip area. High anomalies are shown in yellow to red with a value range of 28 mGal to 39 mGal in the middle of the anomaly map, starting from East-Southeast-South-West to the North of the study area.

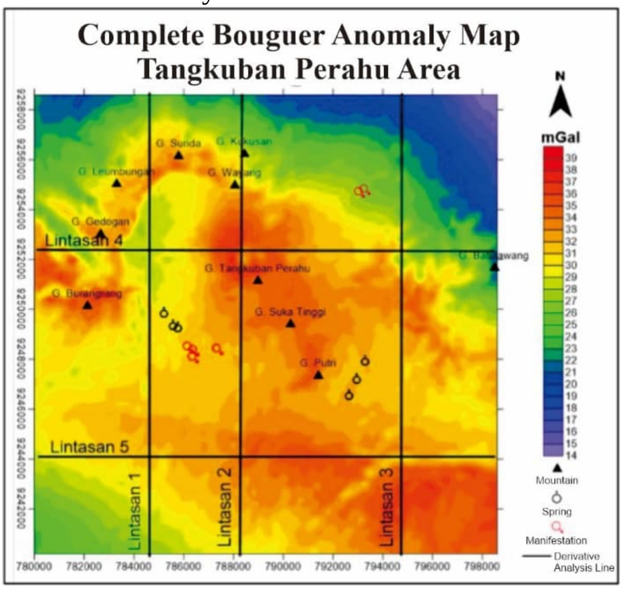

Figure 2. Complete Bouguer Anomaly contour map of the study area with spectrum analysis lines.

B. *Spectrum Analysis*

Based on the spectrum analysis graph on line 1, the regional boundary zone and residual are at kc = 0.001438. The spectrum analysis results on the cross-section of line 1 show that the depth of the regional anomaly is 2210 meters. Meanwhile, the residual anomaly is at a depth of 487.94 meters. On line 2, the graph illustrates that the regional boundary zone and residual are at kc = 0.001737. The spectrum analysis results on the cross-section of line 2 show that the depth of the regional anomaly is 2113.3 meters. Meanwhile, the residual anomaly is at a depth of 193.17 meters. On line 3, the graph illustrates that the regional boundary zone and residual are at kc = 0.001364. The spectrum analysis results on the cross-section of line 3 show that the depth of the regional anomaly is 2539.6 meters. Meanwhile, the residual anomaly is at a depth of 224.23 meters. On track 4, the graph illustrates that the regional boundary zone and residual are at kc = 0.001284. The spectrum analysis results on the cross-section of line 4 show that the depth of the regional anomaly is 2590.5 meters. Meanwhile, the residual anomaly is at a depth of 167.48 meters. On track 5, the graph illustrates that the regional boundary zone and residual are at kc = 0.001341. The spectrum analysis results on the cross-section of line 5 show that the depth of the regional anomaly is 2477.6 meters. Meanwhile, the residual anomaly is at a depth of 308.37 meters.

After analyzing the spectrum of each track on the complete Bouguer Anomaly map, the depth value of the deep anomaly (regional) and shallow anomaly (residual) is then averaged, and the wave value (k) and window width (N) are averaged.

The average depth of the deep (regional) anomaly field is 2400 meters, interpreted as the average depth of the basement, while the average depth of the shallow (residual) anomaly field is 282 meters, interpreted as the boundary zone between the basement and sedimentary rocks. Meanwhile, the average value of the wave number (k) is 0.001421, and the average determination of the window width from 5 tracks has been obtained with a value of 22.17294, with the nearest odd rounding being 23. So, the Moving Average filter uses a window width of 23.

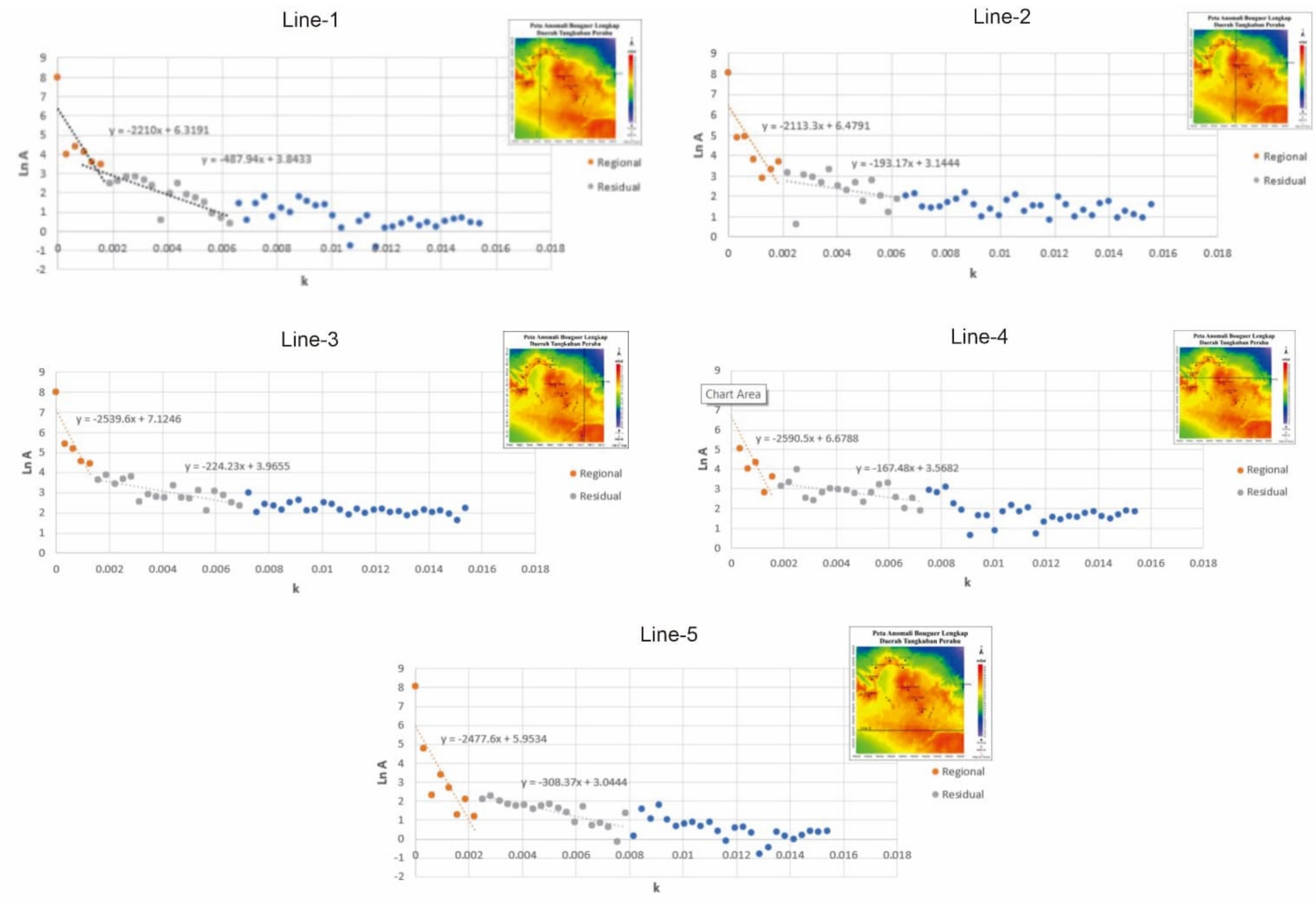

Figure 3. Graph of ln A vs k on lines 1 to 5.

C. Gradient Analysis

This study used the First Horizontal Derivative (FHD) and Second Vertical Derivative (SVD) methods from residual Bouguer anomaly values. Identification of fault structures, intrusions, lithological boundaries, and anomaly model boundaries is indicated by the horizontal gradient value of the minimum or maximum first-order residual Bouguer anomaly, and the horizontal gradient value of the second-order residual Bouguer anomaly is equal to 0 (zero). The FHD map has a range of anomaly values ranging from -0.03 mGal/m to 0.024 mGal/m. From the FHD anomaly, it can be seen that there is a dominant maximum anomaly value in the northwest-southeast direction. The SVD values range from -7 mGal/m2 to 10 mGal/m2. It can be seen that several areas around Mount Remas are limited by an SVD value of 0, which is indicated as a fault; this may be influenced by the presence of local fault faults in the research area.

Based on the results of overlaying the geological map of the research area with the SVD structure, it can be seen that there is a correlation between the SVD structure and the faults on the geological map. However, some correlations are not parallel to the faults on the geological map. The map above shows a similarity in the dominant direction between the delineated structure and the geological structure, namely the west-east direction (Figure 4).

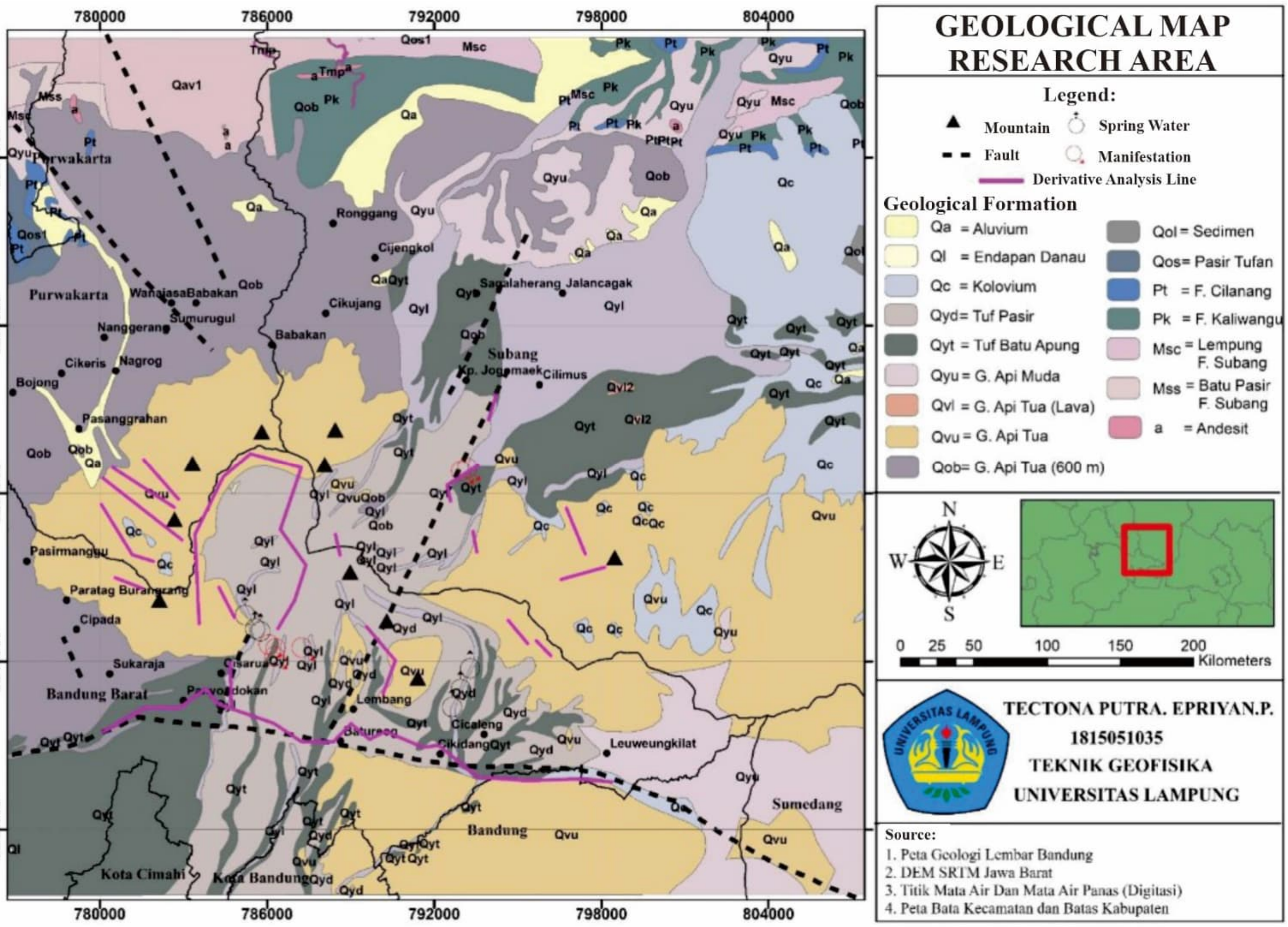

Figure 4. Results of geological map overlay with SVD structure.

D. Discussion

Based on the cross-section of the A-B track in the 3D inversion results shown in Figure 5, it is assumed that the fault structure is in the blue weak zone. This fault is the influence of the formation of a horst in this area, which is thought to have been formed due to rock intrusion in the red area, which caused the area to experience elevation from the surrounding area. The correlation results show that the fault structure on the derivative analysis curve on the A-B path shows relatively similar results to subsurface modeling.

In Figure 5, the depth of around 0.6 km—2.8 km is marked in blue with a density of 2.191 g/cc to 2.45 g/cc, which is thought to be the Tangkuban Perahu geothermal reservoir. This reservoir plays a role in the emergence of springs and hot springs. The reservoir rock is thought to consist of basalt breccia. The fluid in geothermal reservoirs has high porosity, so the existing rocks have low density.

Based on the cross-section of the C-D trajectory in the 3D inversion results shown in Figure 6, it is assumed that the fault structure is in the blue weak zone. This fault is the influence of the formation of a horst in this area, which is thought to have been formed due to rock intrusion in the area-colored red, which caused the area to experience elevation from the surrounding area. The correlation results show that the fault structure on the derivative analysis curve on the C-D path shows relatively similar results to subsurface modeling.

Figure 6 shows a blue depth of around 1 km—2.8 km, with a density of 2.151 g/cc to 2.432 g/cc. This is thought to be the Tangkuban Perahu geothermal reservoir, which plays a role in the emergence of hot springs. The reservoir rock is thought to consist of basalt breccia. The fluid in geothermal reservoirs has high porosity, so the existing rocks have low density.

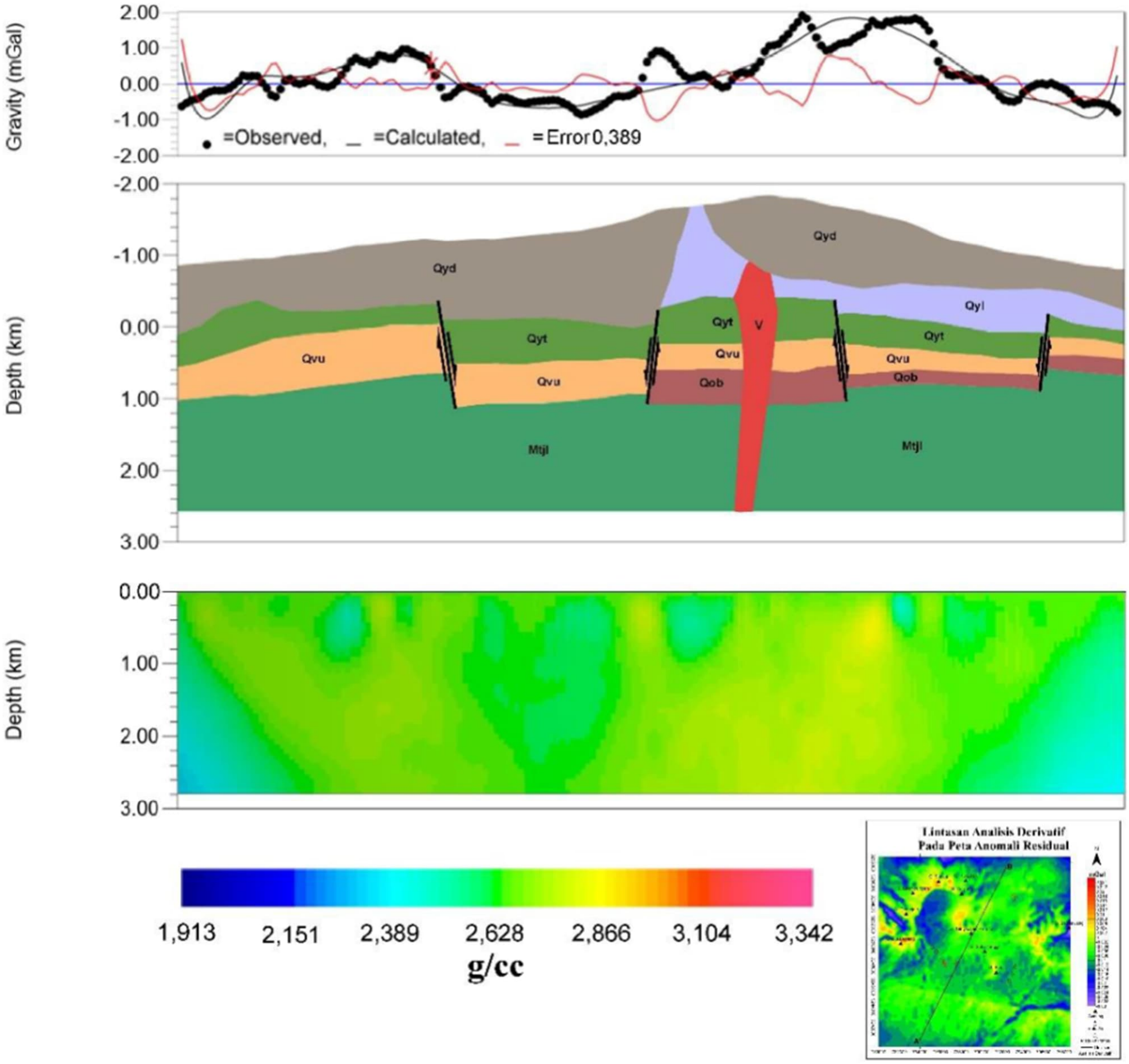

Figure 5. Cross section of the A-B track (a) Residual Bouguer anomaly profile; (b) 2D forward model; and (c) Density distribution model resulting from 3D inversion.

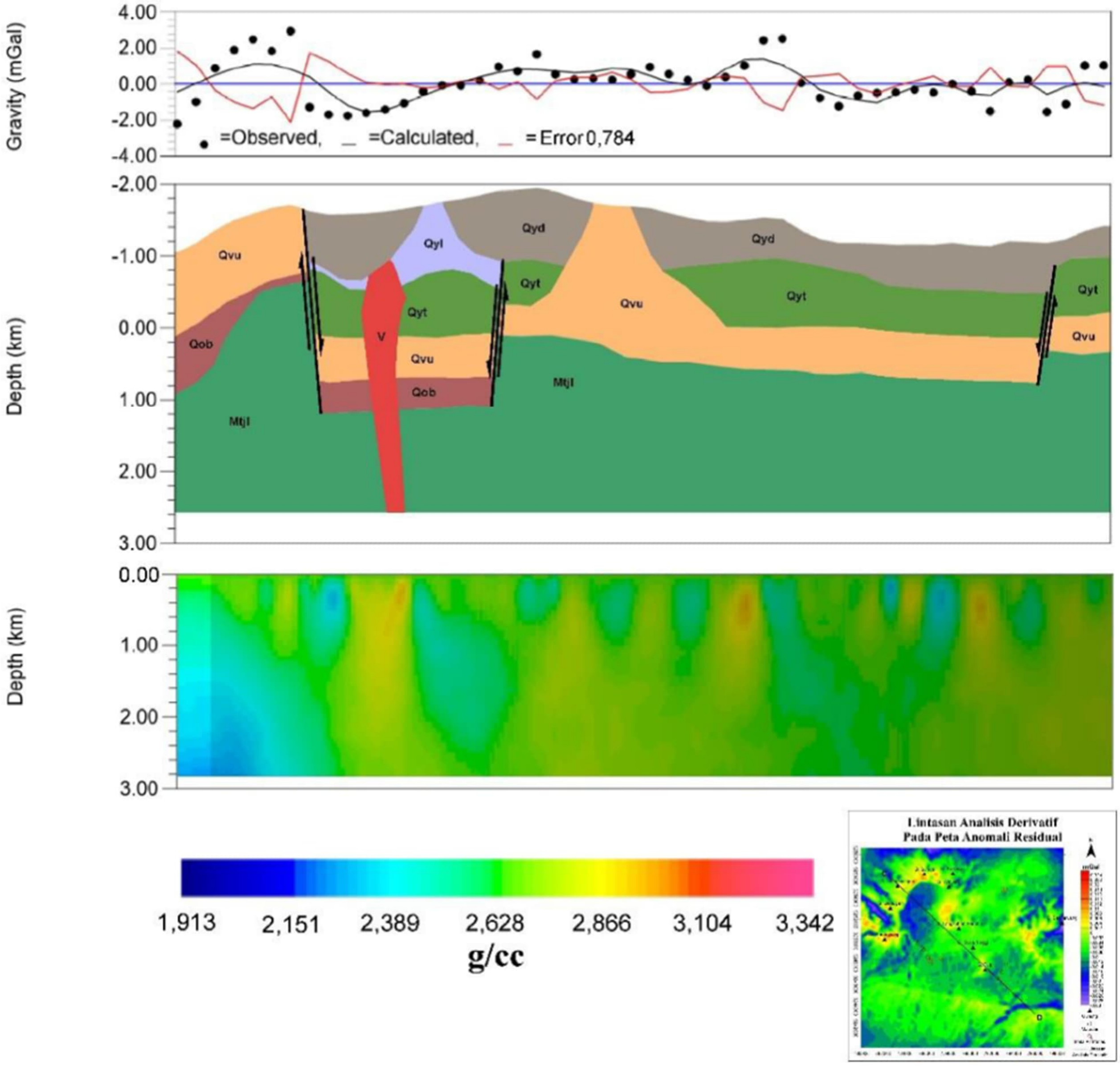

Figure 6. Cross section of the C-D trajectory (a) Residual Bouguer anomaly profile; (b) 2D forward model; and (c) Density distribution model resulting from 3D inversion.

IV. CONCLUSIONS

Based on the gravity data processing and data interpretation that has been carried out, it can be concluded that the boundary of the regional and residual Bouguer anomaly is at a depth of 2400 meters. Derivative analysis shows a fault structure that caused the emergence of hot water manifestations in this area. There are thrust faults in the areas of Mount Leumbungan, Mount Suka Tinggi, Mount Putri, and Mount Tangkuban Perahu. Subsurface density distribution based on 2D forward modeling and 3D inversion in the study area ranges from 1,913 g/cc to 3,342 g/cc, with the weak zone identified as Quaternary sedimentary rock in the form of sand and clay and basalt breccia rock. In contrast, the high zone is related to elevation due to the intrusion of basalt lava rock.

A detailed analysis of the faults in the study area is needed to confirm the structure further. In a derivative analysis of the 3D inversion model, it seems necessary to set the mesh more carefully and perhaps use other data, such as topic or other measurement data in the same area. The correlation between the 2D and 3D models must be seen to get a better 3D model.

V. ACKNOWLEDGMENT

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