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Geological Structure Identification using Derivative Analysis of Gravity Method

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Abstract
The gravity method is a geophysical method that can be used for exploration activities to identify subsurface geological structures through variations in the gravitational field due to differences in rock mass density below the surface based on measurements of variations in the earth's gravitational field. In this study, the gravity method was used to detect subsurface structures. The modeling is used to identify based on the gravity anomaly data that has been obtained and also see the structure of the regional geology of the area. The values depicted at the study site for the complete Bouguer anomaly range from 69.3 mGal to 95.5 mGal. The first horizontal derivative map of the research area shows the maximum value as the contact area or changes in the value of the anomaly caused by geological structures. Then the second vertical derivative map shows the 0-boundary plane identified by faults. In the analysis of the FHD curve, it shows that there is a maximum value that indicates the boundary of the contact area of the layer, and SVD shows a value that passes the zero limit so that it delivers the existence of a fault structure in the Suoh area of West Lampung.

Keywords: gravity, Bouguer anomaly, structure geology, FHD, SVD

1. Introduction

The gravity method is a geophysical method that can be used for exploration activities to identify subsurface geological structures through variations in the gravitational field due to differences in rock mass density below the surface based on measurements of variations in the earth's gravitational field [1].

This subsurface structure is derived from the Bouguer anomaly seen on the surface, so that in practice what is investigated is a difference in the gravity of each observation point [2]. The research area is located in the Suoh-Sekincau geothermal potential in the Regency, West Lampung. The geophysical method used in this study is the gravity method to explain the subsurface structure and the exit zone of geothermal fluid to the surface [3].

In this study, the gravity method was used to detect subsurface structures. The model is used to identify based on the gravity anomaly data that has been obtained and also see the structure of the regional geology of the area. The objectives of this research are: to be able to determine the regional and residual depth of the research area by spectrum analysis and to identify the geological structure using the First Horizontal Derivative (FHD) and Second Vertical Derivative (SVD) methods.

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2. Regional Geology

West Lampung Regency is composed of surface deposits, sedimentary rocks, and volcanoes (Figure 1). The rock composition from the youngest to the oldest in West Lampung Regency is Alluvium, Limestone unit, Quaternary Volcanic Rock, Ranau Formation, Simpangaur Formation, Seblat Formation, and Hulusimpang Formation.

The alluvium is clay, fine sand, sand, gravel, or other rock grains that are deposited by flowing water. Limestone in the study area has a compound value of CaO = 51.04%, MgO = 1.56%. Young Quaternary rocks in the study area include young Quaternary rocks consisting of volcanic deposits and falls that have not been well consolidated, mainly composed of rhyolite tuff (sand tuff) and pumice breccia. Old Quaternary Rocks in rock formations consisting of andesite lava, lava breccia, and tuff with clay inserts containing charcoal, this unit is well consolidated. The Ranau Formation (Qtr) is a formation composed of pumice-tuff breccia which is a rock or mineral silicate compound from the sedimentation of volcanic material.

It contains alkaline oxide smelting components and quite high iron oxide dyes. The Simpangaur Formation (Tmps) is a formation composed of tuffaceous sandstones. The Seblat Formation (Toms) is a formation composed of alternating sandstone – claystone – siltstone – limestone. The Hulusimpang (Tomh) Formation is a formation composed of volcanic-lava-tuff breccias [4].

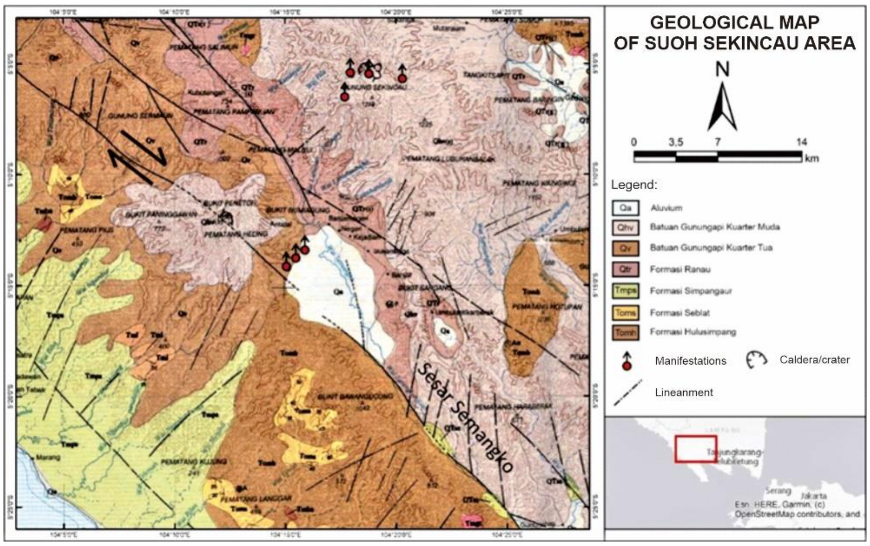

Figure 1. Geological map study area [4].

3. Materials and Methods

The data used in the research in the research area is secondary data which is data from satellite measurements accessed through the website: http://topex.ucsd.edu/cgibin/get_data.cgi provided by the Script Institute of Oceanography, University of California San Diego USA. The amount of data used in this study was 304 data. The satellite gravity data obtained in the form of FAA (Free Air Anomaly) and topographical data for the FAA data do not require FAC (Free Air Correction) because the measurements are at the same elevation datum. Processing needs to be corrected to get the Complete Bouguer Anomaly value which is calculated using Geosoft 8.3.4 Software. The corrections used are Bouguer and terrain corrections. In the spectral analysis stage [5], Fourier transforms analysis was performed using Complete Bouguer Anomaly data to change the data domain from spatial distance to spatial frequency with Numeri software [6]. All anomalies were observed, both from shallow and deep areas, therefore it is necessary to separate regional and residual anomalies from Bouguer anomalies. In this study, the author uses a separation with the moving average method. The moving average is the average of the gravity anomaly data, the result of this method is a regional anomaly, and the residual anomaly is obtained from the difference between the Bouguer anomaly and the residual anomaly [7]. The software used for this process is Oasis Montaj

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software. After obtaining the residual and regional anomaly from the filtering moving average, then the residual anomaly is calculated derivative to get the FHD anomaly map and then calculated using the Elkins matrix to get the SVD map [8].

4. Result and Discussion

4.1 Complete Bouguer Anomaly

A complete Bouguer Anomaly is a gravitational anomaly that describes the shape of the density distribution of rocks below the surface and the superposition results from deep (regional) anomaly sources and shallow (residual) anomaly sources that occur due to the influence of mass contained in the area around the subsurface of the measurement area. The processing steps to get the Complete Bouguer Anomaly value from the FAA data are then corrected to get the Complete Bouguer Anomaly value. In this process, Bouguer correction and terrain correction are carried out. The density obtained in this research area is 1.32 g/cc which is used to obtain the Complete Bouguer Anomaly value.

From the Complete Bouguer Anomaly map contained in Figure 2, the value of the anomaly distribution is obtained with a range of values from 61.4 mGal to 101.7 mGal. These results are a response to variations in rock mass density in the study area. Based on these results, the anomaly values are grouped into 3, namely low anomaly, medium anomaly, and high anomaly.

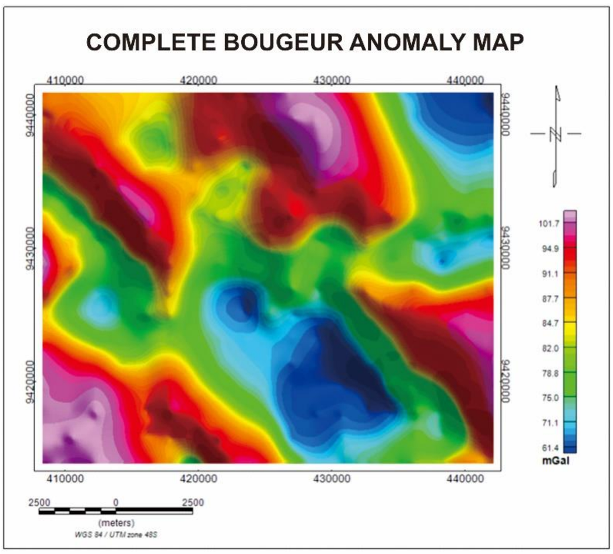

Figure 2. Complete Bouguer anomaly map of the study area.

Fig. 2 also presented the low anomalies are shown in areas that have a color from blue to light blue with a value of 61.4 mGal to 75 mGal. The moderate anomaly is in the green to a yellow area with a value of 78 mGal to 87 mGal. This anomaly is a transition anomaly between high and low anomaly. The high anomaly is in the red to the pink area. This anomaly dominates the Southwest area which shows the presence of rocks that have high contrast density values.

4.2 Spectral Analysis

The spectral analysis method is used by performing Fourier transform which is used to convert a function in time or distance into a function in frequency or wave. Using this method, it is possible to determine the width of the filter window that will be used to separate regional and residual anomalies from the complete Bouguer Anomaly. On the complete Bouguer Anomaly map of the research area, 4 lines are drawn. The trajectory is used to represent the anomaly values found in the research area where the Fourier Transform will be carried out. In spectral analysis, low-frequency values come from shallow sources and high frequencies come from deep sources. The results of the FFT process are the real and imaginary values obtained from each path which will then be processed to obtain the amplitude (A), ln A, frequency, and wavenumber values of k. The amplitude value (A) is generated by calculating the square root of the real and imaginary values. The value of ln A is generated by logarithmizing the value of the amplitude (A). The calculation of the frequency value depends on a predetermined spatial domain. Where by knowing the value of k. After the calculated value, the plotting is carried out on the value of k and the value of Ln A. so that the cut-off value in the area will be obtained which will be used in determining the size of window width.

In Table 1, the average regional anomaly depth value is 4638.1 meters, these results are interpreted as the average depth of the upper and lower crust boundaries, while the average residual anomaly depth is 532.9 meters which is interpreted as a boundary between the basement with sedimentary rocks in the study area. In the stage of determining the window width of the 4 lines in Table 2, the average value is 31.64 by rounding the nearest odd number to 31. Then the Moving Average filter uses a window width (N) of 31.

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Table 1. Depth of regional anomalies and residual anomalies only

Line	Depth of regional anomalies (m)	Depth of residual anomalies (m)
1	3821.9	480.1
2	4650.3	415.9
3	5409.4	783.5
4	4670.9	452.3

Table 2. Wave number (k) and width window (N).

Line	k	N
1	0.00101	31.01
2	0.00107	29.27
3	0.00115	27.24
4	0.00106	29.60

4.3 FHD and SVD Analysis

In this study, an analysis of the FHD was carried out which was used to determine the geological contact boundary which was then correlated with the SVD. The results obtained by performing the FHD analysis are shown in Figure 3a. The maximum value is marked in pink which has a value of 0.005 mGal/m and the minimum value is marked in blue which has a value of 0.0004 mGal/m. The maximum and minimum values on the FHD map are an indication of the presence of a fault as shown in Figure 3a which is an indication of the presence of a fault based on Horizontal Gradient analysis. SVD analysis needs to be done for gravity data processing because it can help in making further 2D modeling. This SVD method uses the Elkins series equation. This method can be used to generate shallow or local sources of anomalies that appear in the residual anomaly map. This method is quite effective to determine the discontinuity of the subsurface structure, especially the presence of faults in a research area. Figure 3b is the result of the SVD map of the research area, there are geological structures, in this case, it will be proven by doing FHD and SVD correlations with the aim of seeing density contrasts below the surface. In the processing of this analysis using Oasis Montaj Software by making a trajectory on the residual anomaly, FHD, and SVD maps which will then be compared in Microsoft Excel.

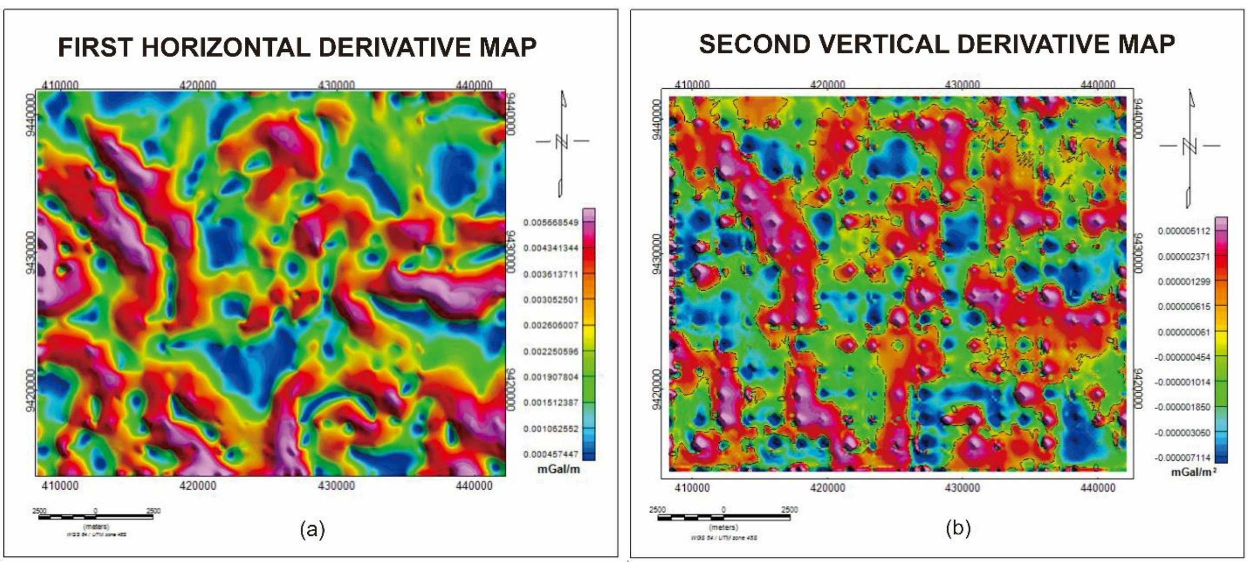

Figure 3. FHD and SVD map of the study area.

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4.4 Discussion

The FHD results shown in Figure 4 show a maximum value as a contact area or a change in anomaly value caused by geological structures. The maximum value on the FHD curve in slice 1 is depicted by a red line which is a characteristic of FHD in the estimation of the location of the geological structure. The SVD results show that there are minimum and maximum values on the SVD curve which is the contact area limited to a zero value or close to zero as the boundary of the geological characteristics which is the location of the geological structure shown by the red line in Figure 4. Slice 1 passes through the Simpangaur Formation (Tmps), Hulu Simpang Formation (Tomh), and Alluvium (Qa).

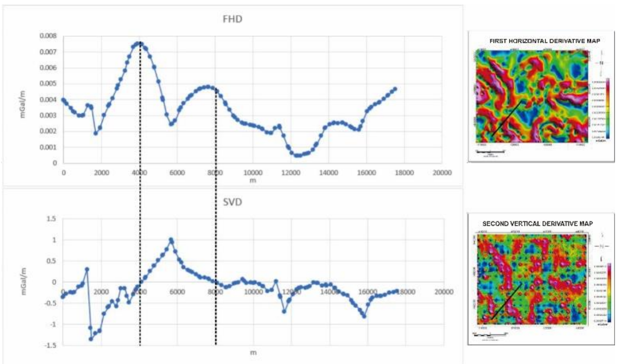

Figure 4. Graph of derivative analysis results on slice 1

Based on the derivative analysis in Figure 4 slice 1 path, it is found that there are fault structures at a distance of 4000 m and 8000 m. This is because of the response to the resulting observation graph. In the analysis of the FHD curve, it shows a maximum value that indicates the boundary of the contact area of the layer and SVD shows a value that passes the zero limit so that it shows the presence of a fault structure [9]. At a distance of 4000 m, the maximum SVD curve has a value of 1 and a minimum value of -0.5 which is suspected to have a downward fault, where the maximum anomaly value is greater than the minimum anomaly. Then at a distance of 8000 m, the maximum SVD curve is 1 and the minimum value is -0.017 which is suspected to have a down fault, where the maximum anomaly value is greater than the minimum anomaly.

The FHD results shown in Figure 5 show that there is a maximum value as a contact area or a change in anomaly value caused by geological structures. The maximum value on the FHD curve in slice 2 is depicted by a red line which is a characteristic of FHD in the estimation of the location of the geological structure plane. The SVD results show that there are minimum and maximum values on the SVD curve which is the contact area limited to a zero value or close to zero as the boundary of the geological characteristics which is the location of the geological structure shown by the red line in Figure 5. Trajectory 2 is located in the old quarter volcanic rock formation (Qv) which is an arrangement of volcanic tuff and breccia, Ranau Formation (Qtr), and young quarter volcanic rock (Qhv).

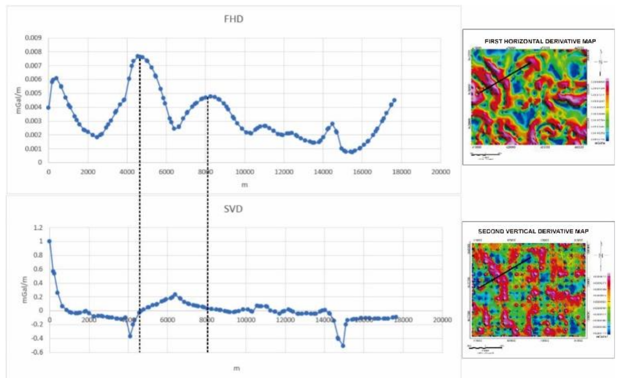

Figure 5. Graph of derivative analysis results on slice 2

Based on the derivative analysis on the slice 2 path, it was found that there were fault structures at a distance of 4500 m and 8000 m. This is because of the response to the resulting observation graph. In the analysis of the FHD curve, it shows a maximum value that indicates the boundary of the contact area of the layer and SVD shows a value that passes the zero limit so that it shows the presence of a fault structure. At a distance of 4500 m, the maximum SVD curve has a value of 0.2 and a minimum value of -0.4 which is suspected to have an upward fault, where the minimum anomaly value is greater than the maximum anomaly. Then at a distance of 8000 m, the maximum SVD curve is 0.2 and the minimum value is -0.002 which is suspected to have a down fault, where the maximum anomaly value is greater than the minimum anomaly. Figure 6 is the result of the correlation between the faults resulting from the SVD method and geological faults. It can be seen that the fault area shows the same correlation.

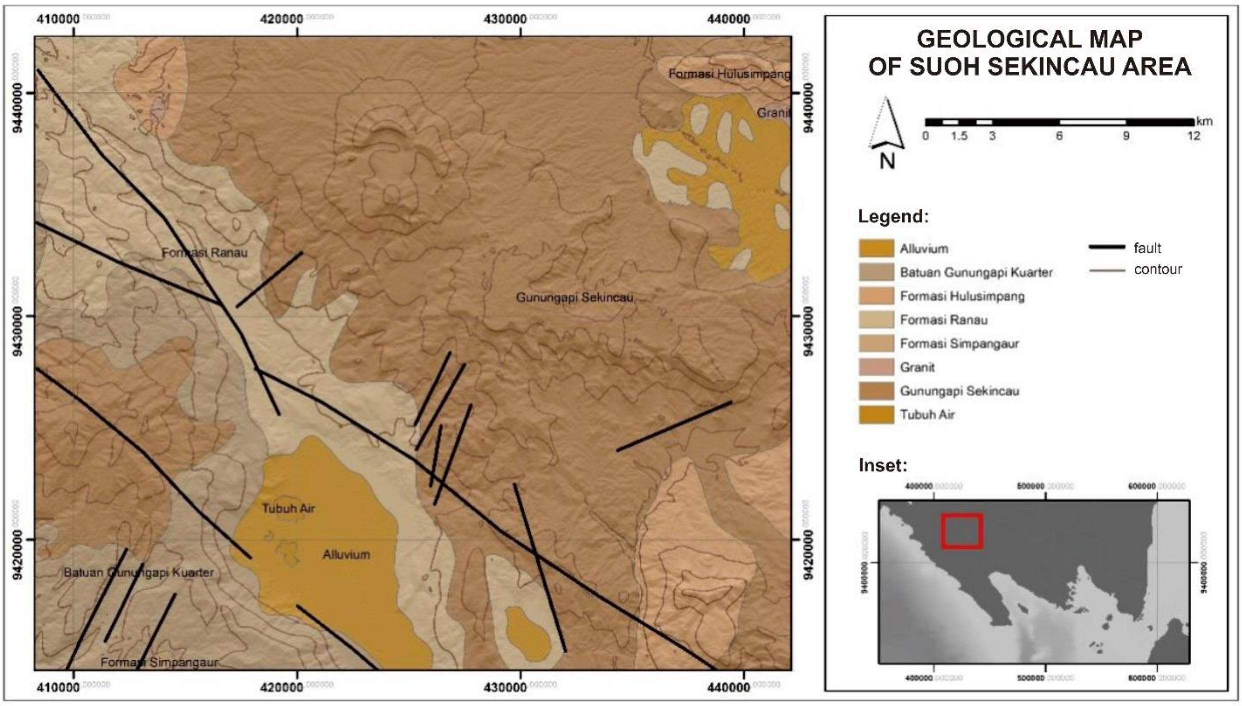

Figure 6. Fault interpretation results based on FHD and SVD compared with geological map

5. Conclusion

Based on the data processing and analysis that has been carried out, it can be concluded that the average regional anomaly depth value is 5604.26 meters, these results are interpreted as the average depth of the upper and lower crust boundary fields, while the average residual anomaly depth is 917,662 meters which are interpreted as a boundary between the basement and sedimentary rocks in the study area. On track 1, there is a maximum density contrast on the FHD map at a distance of 4000m and 8000m. The maximum SVD curve is 1 and the minimum value is -0.5, which is suspected to have a down fault, where the maximum anomaly value is greater than the minimum anomaly. Then at a distance of 8000 m, the maximum SVD curve is 1 and the minimum value is -0.017 which is suspected to have a down fault, where the maximum anomaly value is greater than the minimum anomaly. Then on track 2, there is a maximum density contrast on the FHD map. At a distance of 4500 m, the maximum SVD curve is 0.2 and the minimum value is -0.4, which is thought to have an upward fault, where the minimum anomaly value is greater than the maximum anomaly. Then at a distance of 8000 m, the maximum SVD curve is 0.2 and the minimum value is -0.002 which is suspected to have a down fault, where the maximum anomaly value is greater than the minimum anomaly.

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