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Subsurface Modeling Based on Gravity Data of Rendingan-Ulubelu-Waypanas (RUW) Geothermal Field, Lampung, Indonesia

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Abstract. Indonesia is located along the archipelago which has abundance of volcanoes along the arc. Therefore, Indonesia has a very high geothermal energy potential, such as the Rendingan-Ulubelu-Waypanas Geothermal Field in Tanggamus Regency, Lampung Province. Geophysical exploration is required to characterize the subsurface geothermal system. One of the methods that can be used is gravity method. The data used in this study is an analog Rendingan-Ulubelu-Waypanas Geothermal Field Complete Bouguer Anomaly Map of 2005. The analog map was then converted into digital map for further data processing. Separation of regional and residual Bouguer anomalies has been performed using moving average and spectral filter methods, in which the spectral analysis was conducted in 1D and 2D. The value of Bouguer background density used for 2.5D subsurface modeling is 2.67 g/cc. The gravity anomalies obtained in this study can be interpreted as follow. The existence of high anomalies under Mount Waypanas was interpreted as a Tertiary intrusion of granite with a density contrast of 0.22 g/cc. While low anomalies in the northern part was interpreted as a Quaternary intrusion of diorite with a density contrast of -0.22 g/cc, which acts as the heat source of the system. The reservoir of the system is the Quaternary young volcanics exposed on the surface with averaged thickness of 1500 m. We concluded that the fluid flow in this geothermal system is the meteoric water from Mount Rendingan and Mount Tanggamus, which has a higher topography, flows to a lower topography area in the Mount Waypanas, The fluid flow also creates an upflow under Mount Rendingan.

1. Introduction

Rendingan-Ulubelu-Waypanas (RUW) Geothermal Field is situated at the southern end of the Great Sumatra Fault System. This field is surrounded by a volcano ring consisted of Mount Tanggamus, Mount Kabawok, Mount Waypanas, Mount Kukusan, Mount Sulah, Mount Rendingan, Mount Kurupan, and Mount Duduk in the center. The regional geology of the research area is dominated by Quaternary young volcanics (Holocene-Pleistocene) such as breccias, lavas and tuffs. Hulusimpang Formation (Miocene-Oligocene) consists of volcanic and lava breccia. The basement rock is Gunungkasih Complex with low to moderate metamorphic sequence in the northeast of the research



area [1]. An analog complete Bouguer anomaly map of Rendingan-Ulubelu-Waypanas (RUW) geothermal field [2] was used as the initial data which has then been converted into a digital map for further processing. Gravity anomaly data helped to characterize the subsurface geothermal system. The interactions between heat sources, potentially reservoir rocks, and fluid flow will form a geothermal system, where each element has different densities, which has then been interpreted as the cause of gravity anomaly.

2. Data

In this study, the initial data used is the complete Bouguer anomaly map of Rendingan-Ulubelu-Waypanas (RUW) geothermal field (Figure 1), Lampung, Indonesia [2]. Gravity survey was conducted by Pertamina in 1991-1992, using over 500 stations with 250 m spacing around the Rendingan-Ulubelu-Waypanas (RUW) geothermal prospect, a research area of approximately 150 km². Regional-scale gravity survey was conducted by Pertamina outside the Rendingan-Ulubelu-Waypanas (RUW) geothermal prospect area.

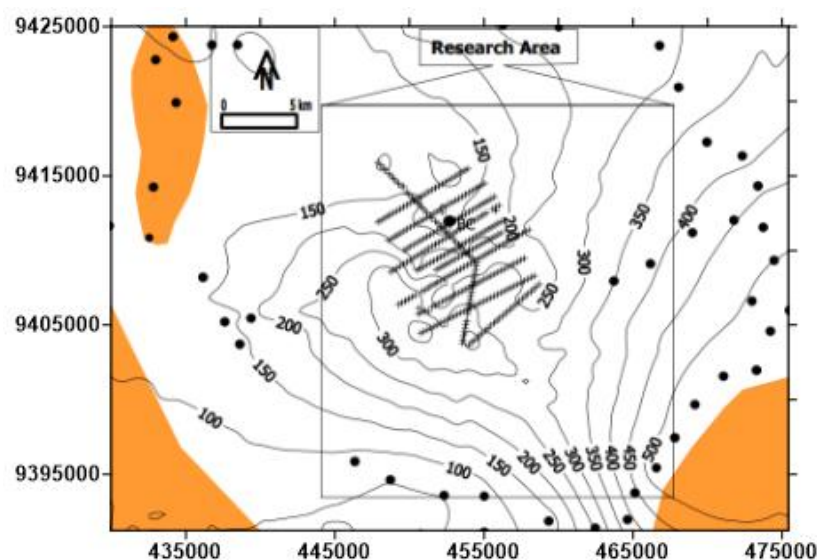


Figure 1. Complete Bouguer anomaly map [2] used as the data in this study.

3. Methodology

3.1. Digitizing of the Complete Bouguer Anomaly Map

The analog complete Bouguer anomaly map was georeferenced to adjust the coordinates of the research area. To input the anomaly value, several contour lines of anomaly values were made, referred to the analog map. The known values were then interpolated and extrapolated by kriging to the entire research area and resulted to a digital map of the complete Bouguer anomaly in Figure 2. These processes were conducted using Surfer software.

3.2. Spectral Analysis

Spectral analysis was performed using 1D and 2D method. 1D Discrete Fourier Transform (DFT) [3] was applied to convert the space-domain signal into frequency interval, also the coefficient of real and imaginary numbers. In 1D spectral analysis, 31 sample lines were used, 18 north-south lines and 13 east-west lines, as shown in Figure 3. Spacing between each line is 2500 meters. The amplitudes and wavenumbers were calculated and plotted into a graph of wave number versus ln amplitude, thus the trend of regional and residual anomaly was obtained and window of moving average filter can be

calculated. Averaged window obtained was 27.81 and rounded up to the nearest odd number, that is 29.

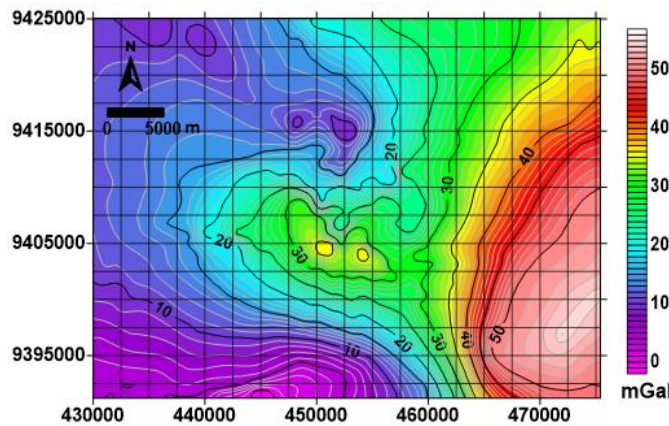


Figure 2. Plot of sample lines used in 1D spectral analysis on the digital complete Bouguer anomaly map.

To perform 2D spectral analysis, 2D Fast Fourier Transform (FFT) [3] was applied using Oasis Montaj software, in order to sample a signal over a period of time (or space) and divided into its frequency component. In this algorithm, 2D DFT equation was used. Radially averaged power spectrum in Figure 3 was calculated from the signal with a frequency less than the Nyquist frequency. This calculation aimed to display and compares the information contained in two-dimensional spectrum in a one-dimensional view.

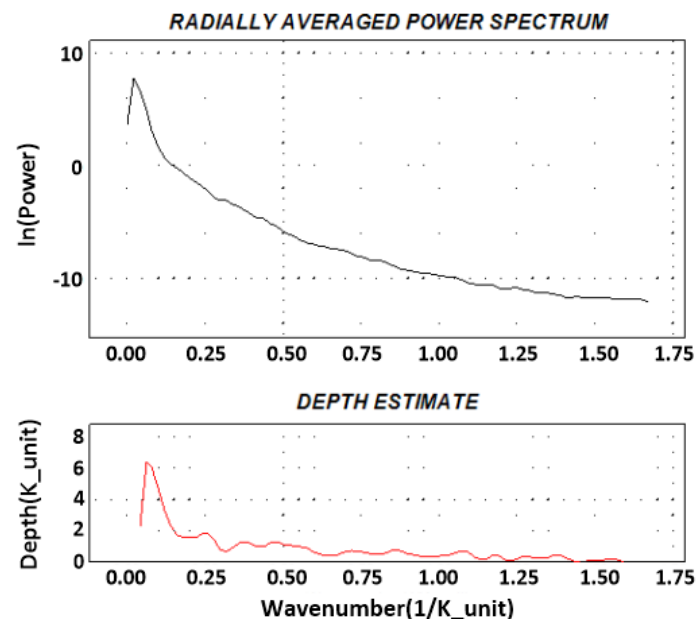


Figure 3. Radially averaged power spectrum display and its depth estimation.

3.3. Moving Average Filter

Moving average method determines the regional value at a grid point based on the anomalous value located around it [4]. The window resulted from one dimensional spectral analysis was used as the grid spacing in moving average. This method applies as a low pass filter, which will pass anomalies with low frequency with a large depth range, resulting in a regional Bouguer anomaly. To obtain the residual Bouguer anomaly, the complete Bouguer anomaly was reduced by the regional Bouguer anomaly. The regional and residual Bouguer anomaly maps resulted from the spectral filter method are shown in Figure 4.

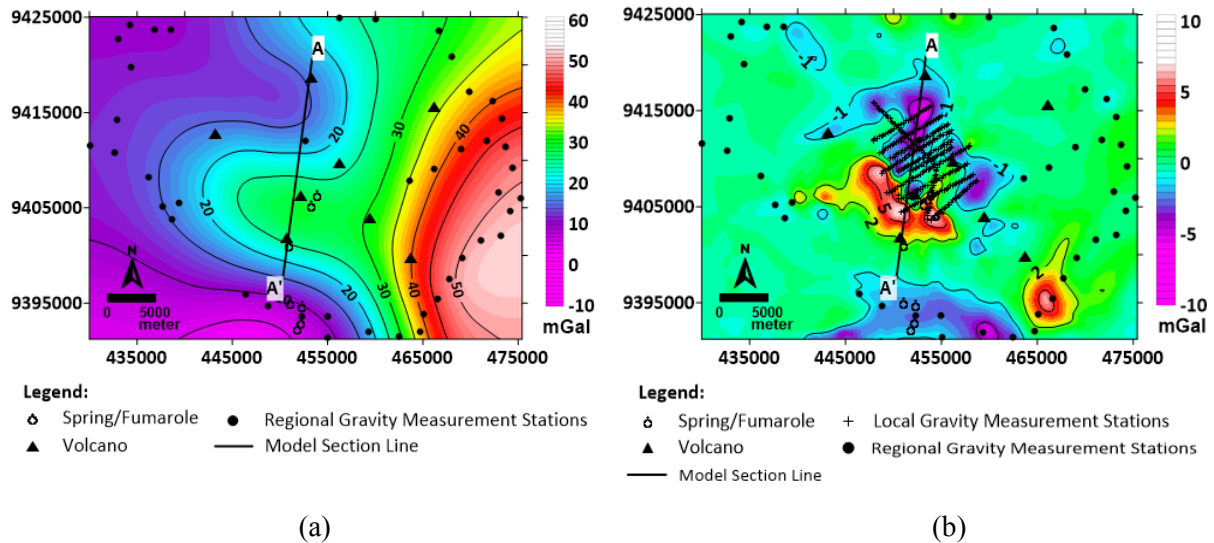


Figure 4. Filtered Bouguer anomaly maps by moving average filtering, (a) Regional Bouguer anomaly map, (b) Residual Bouguer anomaly map.

3.4. Spectral Filtering

Spectral filtering method filters a signal using a wavelength filter to sort out which signal are the regional or residual signal. To characterize the regional and residual Bouguer anomalies, gaussian filter was designed according to the average power spectrum profile of two-dimensional spectral analysis result. The regional and residual Bouguer anomaly maps resulted from the spectral filter method are shown in Figure 5.

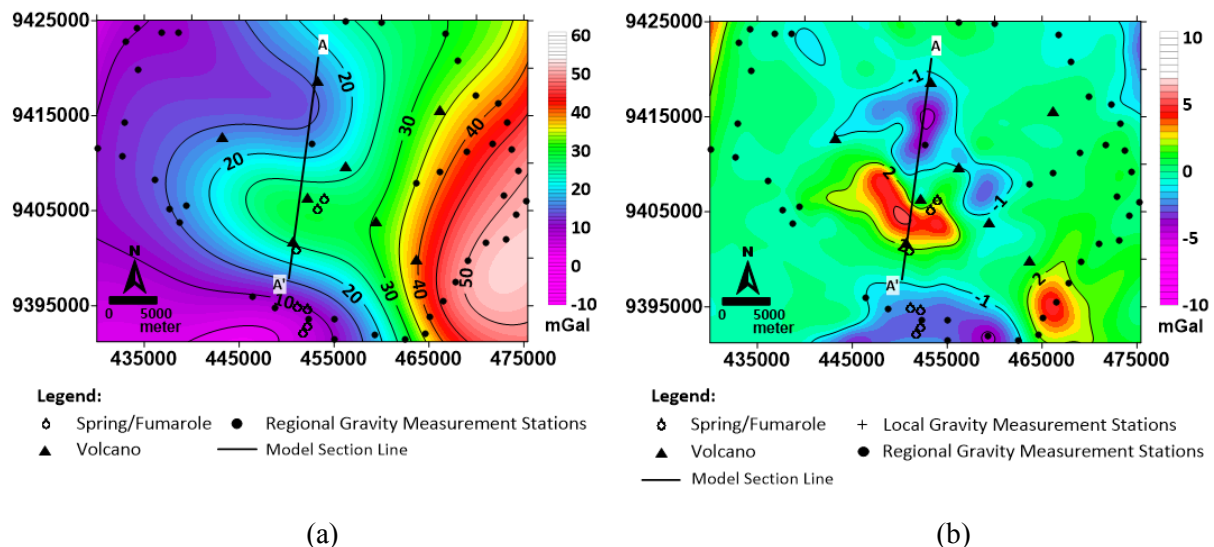


Figure 5. Filtered Bouguer anomaly maps by spectral filtering, (a) Regional Bouguer anomaly map, (b) Residual Bouguer anomaly map.

3.5. Forward Modeling

Residual bouguer anomaly data resulted from spectral filtering was used for 2.5D forward modeling. Software used for 2.5D forward modeling is Encom ModelVision. In 2.5D forward modeling, the north-south oriented A-A' line is used. Bouguer background density value applied in forward modeling is 2.67 g/cc [5]. Subsurface geology model was characterized by considering the geology map of research area [6]. Density value applied to subsurface model referred to the research conducted by Suharno [2] and rock density table [7]. Subsurface geophysical model of line A-A' obtained from

forward modeling is shown in Figure 6. Based on the geophysical model, subsurface geothermal system model was then interpreted, as shown in Figure 7.

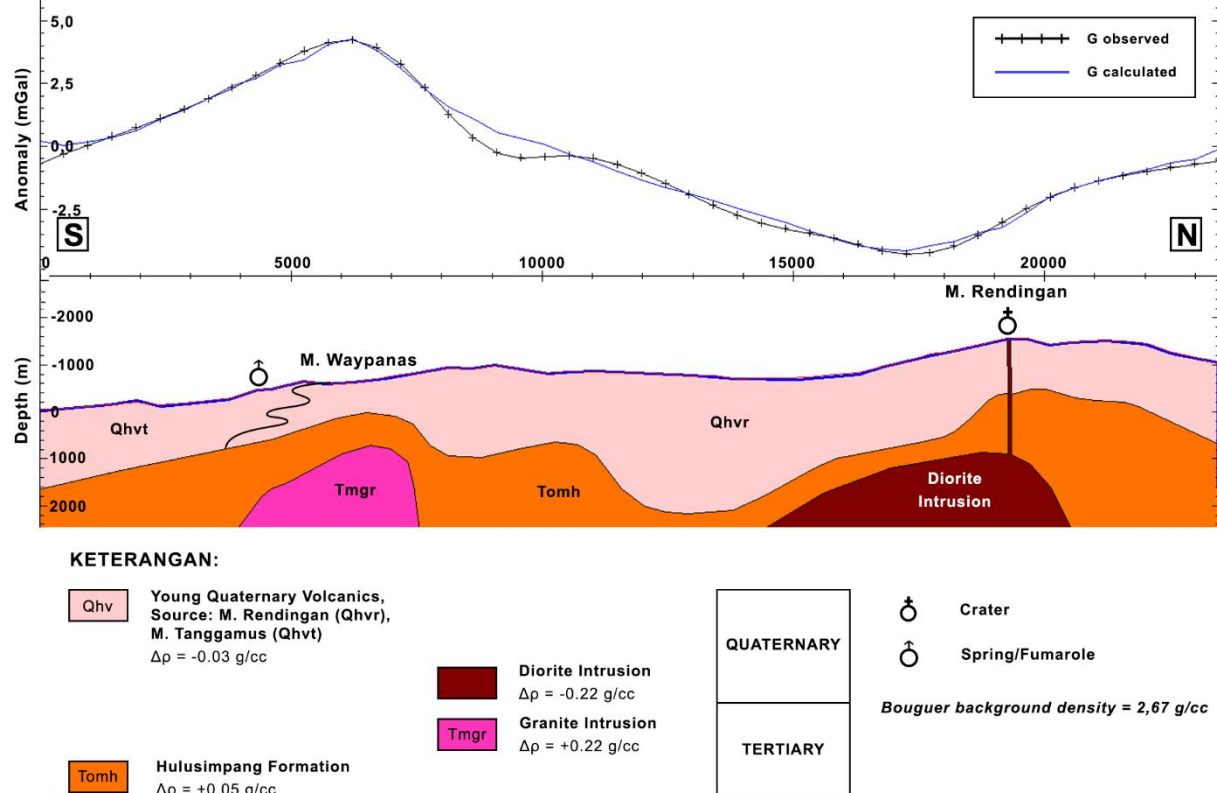


Figure 6. Subsurface geophysical model of line A-A' resulted from 2,5D forward modeling.

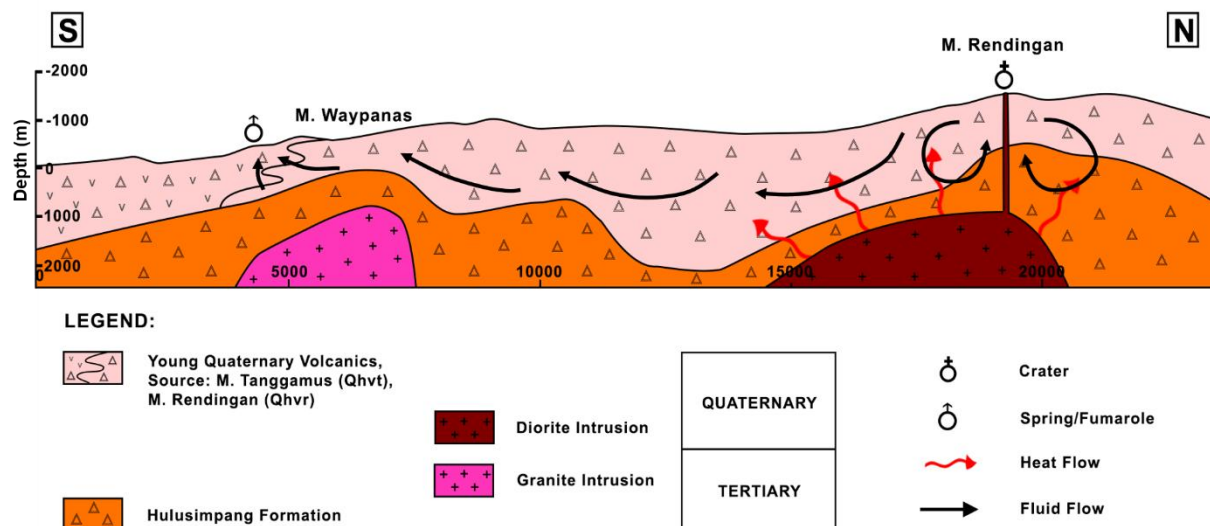


Figure 7. Subsurface geothermal system models of line A-A'.

4. Results and Discussion

The complete Bouguer anomaly map in Figure 3 shows a circle of anomalous region in the center of the research area. This anomaly might be related to the volcano ring of Mount Tanggamus, Mount Kabawok, Mount Waypanas, Mount Kukusan, Mount Sulah, Mount Rendingan, Mount Kurupan, and Mount Duduk in the center.

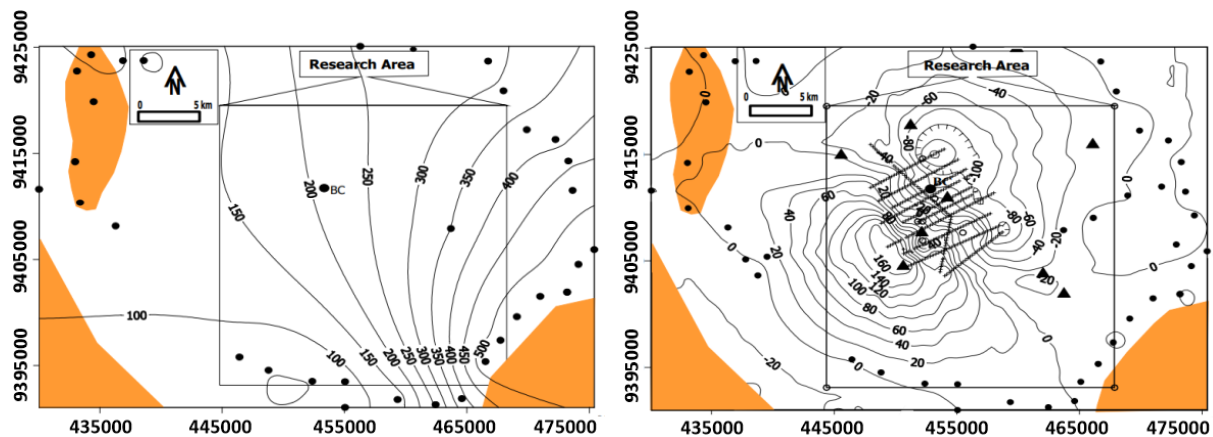


Figure 8. Regional (left) and residual (right) Bouguer anomaly map constructed by Suharno et al. [2].

The regional Bouguer anomaly map resulted by the moving average and spectral filter method was different from the map resulted by Suharno et al. [2], as shown in Figure 8. This is due to the difference of the processed data to construct those maps. Regional Bouguer anomaly map by Suharno et al. [2] was constructed by interpolating the results of gravity measurements in the regional survey, where the measurement stations are only at the outside of the prospect area and have different space. While maps resulted by moving average and spectral filter methods used all available complete Bouguer anomaly data, thus representative at all points. The residual Bouguer anomaly map resulted by the moving average and spectral filter methods have a similar trend to the map constructed by Suharno et al. [2] (Figure 8), where a high and low anomaly contrast present in the center of the study area.

The subsurface model obtained from this study, shown in Figure 6 and Figure 7, suggests that the Oligocene-Early Miocene Hulusimpang Formation, with a contrast density of $+0.05$ g/cc, is the oldest rock unit in the A-A' cross section. The formation consists of volcanic breccia, andesitic-basaltic lavas and tuffs, hydrothermally altered with sulfide-mineral bearing quartz veins. It was then penetrated by Tertiary intrusion of granite. This rock unit was concluded as the cause of positive anomaly under Mount Waypanas, which has positive density contrast ($+0.22$ g/cc) with respect to the Bouguer background density of 2.67 g/cc.

The presence of negative anomaly under Mount Rendingan was inferred as Quaternary diorite intrusion with a negative contrast density of -0.22 g/cc, which penetrated the Hulusimpang Formation right below Mount Rendingan. This intrusion is interpreted as a diorite rock because it was suspected to be associated with Rendingan andesitic lava [2] exposed on the surface, which possibly resulted from the eruption of Mount Rendingan. Another possibility is that an intensive fracture zone caused by faults in the surrounding of Mount Rendingan also contributes to the existence of negative anomaly in that area [2].

Rendingan andesitic lava is a part of young Quaternary volcanics unit with a contrast density of -0.03 g/cc. This Pleistocene-Holocene rock unit was outcropped on the surface, composed of breccia, lava and tuff andesite-basalt, which originated from the eruption of Mount Rendingan and Tanggamus. The subsurface model interpreted from this study is consistent with the geological map of study area [6] and the residual anomaly obtained from complete Bouguer anomaly filtering, as shown in Figure 6.

Tertiary granite intrusion at the A-A' cross section was concluded not to be the heat source of this geothermal system because it would have already cooled down since then, thus cannot generate enough heat for the system. The heat source in this geothermal system is the intrusion of Quaternary diorite below Mount Rendingan, since the last rock unit produced by this magma chamber was at Pleistocene (young Quaternary volcanics), it was then assumed that the rock unit would have enough heat for the geothermal system.

The rock unit that acts as the reservoir of the system is the young Quaternary volcanics exposed on the surface and has thickness of approximately 1500 meters. The fluid involved in the Rendingan-Ulubelu-Waypanas geothermal system is estimated to originate from meteoric water from Mount Rendingan and Mount Tanggamus, which has a higher topography, flows to a lower topography area in the southern part of the study area, around Mount Waypanas. Thermal manifestations in the form of springs and fumaroles were then emerged due to the interaction of fluid activities, heat, and structures in this area. In addition, the fluid flow in Mount Rendingan creates an upflow mechanism below Mount Rendingan, which creates a thermal manifestation in the form of a crater.

5. Conclusion

The complete Bouguer anomaly map of Rendingan-Ulubelu-Waypanas (RUW) geothermal field shows Bouguer anomaly range value of -2 to 56 mGal. The regional Bouguer anomaly map resulted has anomaly range value of 2 to 54 mGal. The residual Bouguer anomaly map resulted by moving average filter and spectral filter have a similar trend, a high (2 to 5 mGal) and low (-5 to -1 mGal) anomaly contrast present in the center of research area.

The gravity anomalies obtained in this study can be concluded as follow. The existence of high anomalies under Mount Waypanas was interpreted as a Tertiary intrusion of granite with a density contrast of +0.22 g/cc. While low anomalies in the northern part was inferred as a Quaternary intrusion of diorite with a density contrast of -0.22 g/cc, which acts as the heat source of the system. The reservoir of the system is the Quaternary young volcanics exposed on the surface with averaged thickness of 1500 m. Fluid flow involved in this geothermal system is the meteoric water originated from Mount Rendingan and Mount Tanggamus, which has a higher topography, flows to a lower topography area in the Mount Waypanas. The fluid flow also creates an upflow under Mount Rendingan. Thermal manifestations in the form of springs, fumaroles, and crater were then emerged due to the interaction of fluid activities, heat, and structures in these areas.

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