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The Subsurface Modelling of Karaha-Telaga Bodas Geothermal System using Gravity Method

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Abstract. The Complete Bouguer Anomaly (CBA) map from 1997 gravity survey at Karaha-Telaga Bodas, West Java, Indonesia is used to make a model of the subsurface geothermal system. A two-dimensional cross-section of the system is produced using a 2.5-D forward modeling. Initially, the print CBA maps of the Karaha-Telaga Bodas geothermal system is digitized. Next, the digital map is separated by using the moving average and spectral filtering methods, so a regional and residual anomaly maps are obtained. The subsurface modelling is made based on geological information of the area to produce a model that can represents the real condition as similar as possible. The line chosen for modelling has a North - South orientation, passing through Karaha and Telaga Bodas to foresee both of the geothermal system in one cross-section. Subsurface model interpretation shows that there are two separate granodiorite intrusion body with density contrast of 0.5 g/cc below Karaha - Telaga Bodas. This conclusion coincides with the intrusion body found during drilling operation. The intrusion body is possibly the heat source of the system. The reservoir of this system is interpreted as volcanic breccia with thickness of two kilometres in Telaga Bodas and keeps thinning towards Karaha. The fluids of the Karaha-Telaga Bodas Geothermal System are estimated to come from acid sulphate water and meteoric water entering from Telaga Bodas, as well as meteoric water entering from Karaha. There is an upflow in the South, Telaga Bodas.

1. Introduction

Geothermal energy is one of several alternative energy form which is being supported to be used widely in Indonesia. Exploitation of geothermal energy can be a solution for the energy crisis problem. Indonesia, which is located between three active tectonic plates, makes the potential of geothermal energy exploitation is very high. For the preliminary step of geothermal exploration, gravity method is used because it allows the user to make a model of geothermal system which is composed by different types of rocks with different types of geometry.

Data used for this research is the print Complete Bouguer Anomaly (CBA) Map of Karaha-Talaga Bodas Geothermal System (Figure 1), acquired from 1997 gravity survey by GENZL. The Karaha-Telaga Bodas Geothermal System is located in West Java, Indonesia, and is a vapor-dominated geothermal system with its highest temperature reaching up to 350°C [1]. Some surface manifestations are found in the Southern and Northern part of the research area. In the most South part of the system

(Telaga Bodas), areas with fumarole (Saat Crater), acidic lake (Telaga Bodas) and hot springs are found 1750m above sea level. Meanwhile, in the North-East-ern part of the research area (Karaha Crater), small areas of solfatara, hot soil, mudpools, and more hot springs are found [1].

First, print CBA map is digitized before anomaly separation is done. Then, using the digital CBA map, anomaly separation is done, creating a map of the regional and residual anomalies. Separation is done using two methods, which are moving average and spectral filtering.
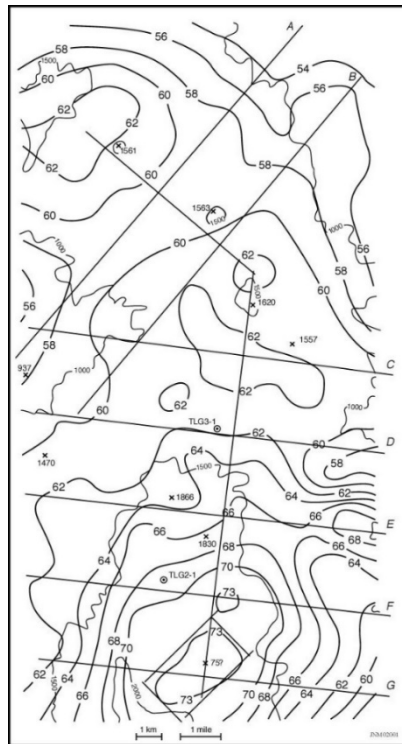

Figure 1. Print Complete Bouguer Anomaly (CBA) Map of Karaha-Talaga Bodas Geothermal System [2]

Result of this research is the geothermal system model which is made based on the subsurface geophysical model from forward modelling. From the model, we can estimate what are the components that makes up the geothermal system as well as the rock types of the system.

2. Methodology

2.1. Digitization
Digitization is done using Surfer Software. The process begins with determining the WGS84 zone (World Geodetic System 1984) of the research area and georeferencing so that the resulting map will correspond to the coordinate position on the surface of the earth. The WGS84 zone of the research area is 49S. However, due to the absence of coordinate information of the research area, the georeferencing is done by overlaying the topographic contours that are on the print CBA map with the topographic maps obtained. The overlaying process is done using QGIS 3.0 Software with reference points used are the topographic contours that is considered representative. After the coordinates on the print CBA map in accordance with the coordinates on the surface of the earth, digitization process is done by plotting contour lines of anomalous values on the map.

2.2. Moving Average

Moving average [9] is done using Surfer Software. First, data collecting is done by using 21 grid-forming lines (8 North-South orientation lines, and 13 West-East orientation lines) on the digital CBA map. The distance between each line is 1000 meters. Next, data interpolation is done so the empty space between the lines can have value as well. The following step is doing one-dimensional Discrete Fourier Transform (1-D DFT) [5], which is done to change the space domain of the data to wavenumber domain. Then, spectral analysis is done so the window value for the moving average process can be obtained, and for this research, the window value used is 15. The final product is the regional anomaly map. The residual anomaly map is obtained by substracting the CBA map with the regional anomaly map.

2.3. Spectral Filtering

Spectral filtering method [7] is done using Oasis Montaj software. First, we must prepare the grid, which is the digital CBA map, in order to make the signal to be periodic. After the grid is ready, spectral analysis is performed using two-dimensional Forward Fast Fourier Transform (FFT) [6]. Then, the 2-D Forward FFT result is used as an input to produce a radially averaged power spectrum of data. Separation is done by using a Gaussian Regional/Residual Filter with a standard deviation of 0.1243.

2.4. Forward Modeling

Forward modelling [8] used is 2.5-D Forward Modelling. It is done using ModelVision Software. The data used for the input is the topographical map and residual anomaly that obtained using moving average method.

Modelling is done by first choosing the line. Then a model is made using density model based on subsurface geology condition that may occur in research area, and also literature to cover up the scarce information of drill data of research area. In addition, the width of the grid on the topographic map is changed from 100 meters to 200 meters because when using the smaller grid, a mismatch occurs between the grid width and the residual anomaly map, which can result in an anomaly miscalculation. Background density value used is 2.3 g/cc, which is the same with the one used on the CBA map.

3. Result and Discussion

Figure 2 shows the digital CBA map from the digitization process. From the digital CBA map, we can see there is a distribution of high-level anomaly in the South part of the map (Telaga Bodas), and makes a radially symmetric shape.
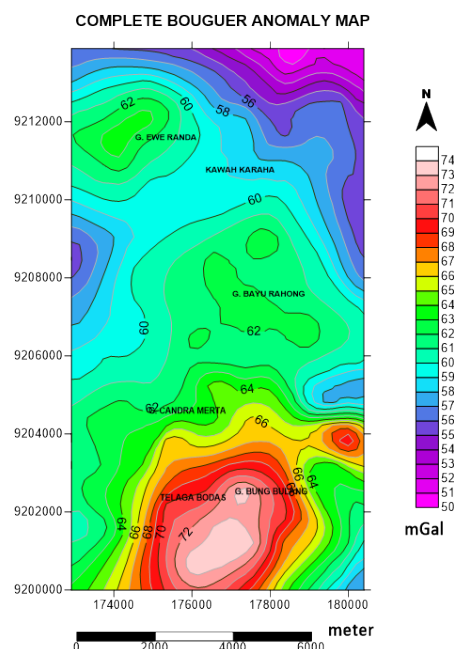

Figure 2. Digital Complete Bouguer Anomaly (CBA) Map of Karaha-Talaga Bodas Geothermal System. Modified from Tripp et. al [2]

There is not much significant difference found when the two regional anomaly maps are compared (Figure 3). The same goes with the two residual anomalies (Figure 4). On the residual anomaly map, a high-level anomaly is also found in the South part of the map (Telaga Bodas). This result correlates perfectly with the hypothesis that says there is a heat source located at a relatively shallow depth underneath Telaga Bodas [2].
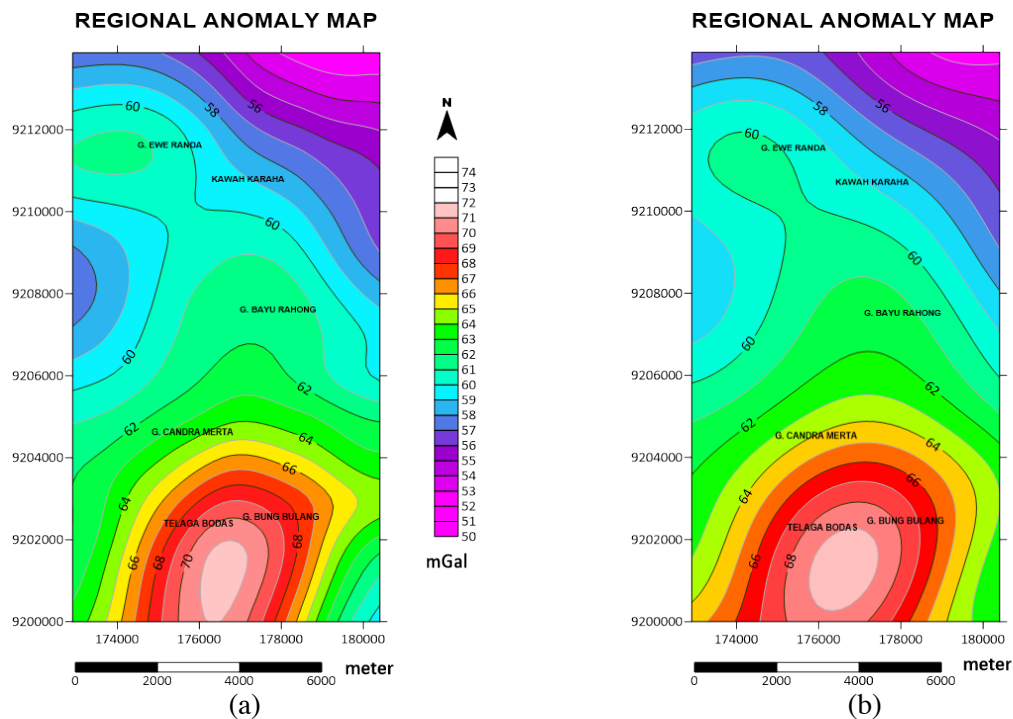

Figure 3. Regional anomaly map obtained using (a) moving average method and (b) spectral filtering.
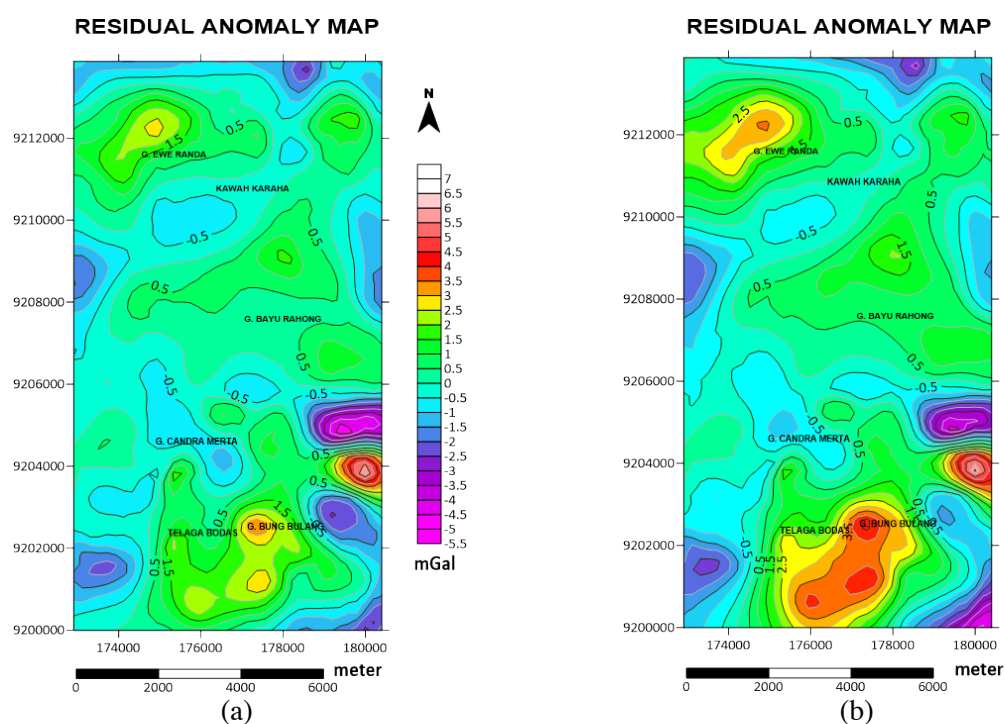

Figure 4. Residual anomaly map obtained using (a) moving average method and (b) spectral filtering.

The cross-section line has a North – South orientation, passing through Karaha and Telaga Bodas, so the geothermal system of Karaha – Telaga Bodas can be observed. Figure 5b shows the Karaha-Telaga Bodas Geothermal System model based on the geophysical model (Figure 5a). Generally, the rocks forming up the system is Quaternary-age [4]. There are two intrusion bodies with density contrast of 0.5 g/cc and separated underneath Karaha and Telaga Bodas. Both intrusion bodies are interpreted as granodiorite and are estimated as the heat source of the Karaha–Telaga Bodas geothermal system. This conclusion is further proven to be credible by the founding of granodiorite intrusion when drilling on the location [3].
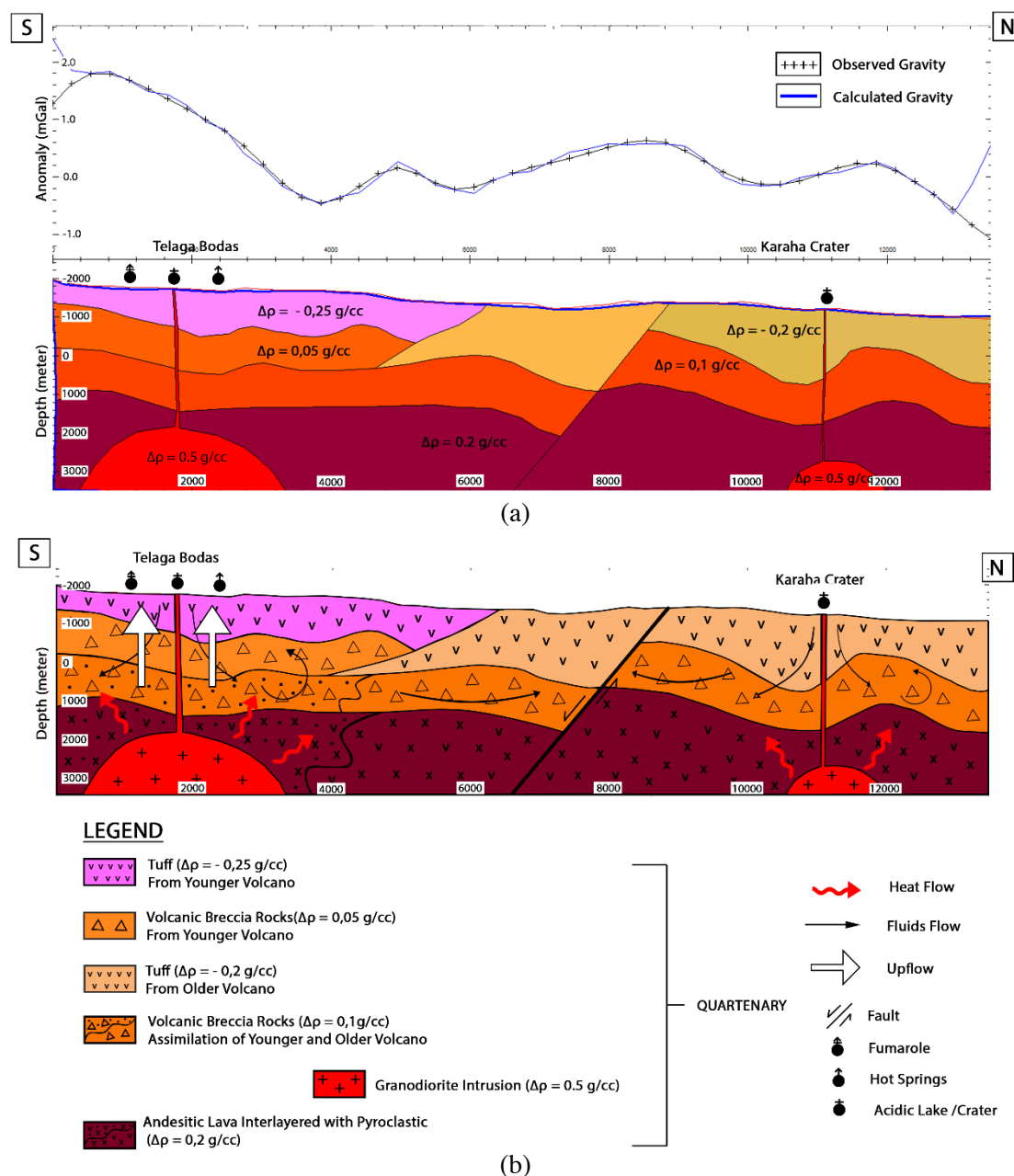

(a)

(b)

Figure 5. (a) Geophysical model and (b) geothermal system model of Karaha-Telaga Bodas Geothermal System.

Orange colored layers are interpreted as volcanic breccia rocks with density contrast of 0.1 gr/cc for the older rocks and 0.05 gr/cc for the younger rocks. It is estimated to be the reservoir of the system with thickness of two kilometres in Telaga Bodas and keeps thinning towards Karaha. Outcrop rocks found on the surface is interpreted to be tuff which comes from the younger volcano (light yellow) and older volcano (light purple) with density contrast of -0.25 g/cc and -0.2 g/cc, respectively. The oldest layer in the model is interpreted to be andesitic lava interlayered with pyroclastic which is the assimilation of the products from the younger and older volcano, with density contrast of 0.2 g/cc.

The fluids of the Karaha-Telaga Bodas Geothermal System are estimated to come from acid sulphate water and meteoric water entering from Telaga Bodas, as well as meteoric water entering from Karaha. Furthermore, upflow is observed to be present in Telaga Bodas as a result of the seeping of sulfate acid water from the surface and then heated in shallow depth [3].

4. Conclusion

Digital CBA map of Karaha – Telaga Bodas Geothermal System is obtained. From the map, distribution of high-level anomaly is located in the Southern part of the map, Telaga Bodas, and makes a radially symmetric shape.

Two regional anomaly maps and two residual anomaly maps are obtained, which are the result of separation using the moving average and spectral filtering methods. When compared, no significant difference is present. Furthermore, on both of the residual maps, the mid-level anomaly distribution is located on the Souther part, Telaga Bodas.

Karaha-Telaga Bodas geothermal system model is obtained based on geophysical model. The heat source of the system is estimated as granodiorite intrusion with density contrast of 0.5 g/cc, and reservoir is estimated as volcanic breccia rocks with density contrast of 0.1 g/cc and 0.05 g/cc. It has thickness of two kilometres in Telaga Bodas and keeps thinning towards Karaha. The fluids of the system are estimated to come from acid sulphate water and meteoric water entering from Telaga Bodas, as well as meteoric water entering from Karaha. There is an upflow in the South, Telaga Bodas.

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