

3D Geothermal Modelling Using Gravity Survey on Dolok Marawa, Simalungun District, North Sumatera

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Abstract. In North Sumatera, gravity method is applied to identify the geothermal model. This method measured the earth gravitational field. This research has 160 measurement points covering 9 square kilometers. We obtained complete Bouguer anomaly values ranging 85 mGal – 130.68 mGal interpreted as a heat source of andesitic igneous rocks that are affected by the presence of Mount Bahtopu magma chamber. We interpreted the values between 40 mGal - 80 mGal as reservoir and caprock. The 3D gravity inverse modelling conducted using Gravblox, and identifying the following lithologies; Toba Pyroclastic Fall (Qjt) with density 1.92 g/cm^3 , Toba Pyroclastic Flow (Qjt) with density 2.00 g/cm^3 , Mount Bahtopu Andesite (Qlb) with density 2.4 g/cm^3 , and 2.6 g/cm^3 which is interpreted as heat source in form of andesitic rock and Mount Bahtopu magma chamber. This heat source is estimated to be at a depth of 1.45 km to 3.78 km below the surface.

1. Introduction

Geothermal energy was formed by volcanic activity and considered as alternative energy in the replacement of fossil fuels that have limited reserves. The geothermal component consists of a heat source, reservoir rock, caprock, fluid, and structure. Dolok Marawa geothermal field located in Simalungun district, North Sumatra is characterized by the presence of hot springs and travertine deposition. Therefore, to utilize the prospect area, a proper exploration method that can describe the subsurface condition of a thermal system is required.

One of the geophysical methods that are capable of describing subsurface conditions of a geothermal system is gravity method. Gravity method can delineate subsurface conditions based on the variation of rock density by measuring gravity differences. The investigation was conducted to determine geothermal structures that exist in Marawa Dolok region, Simalungun District, North Sumatra.

2. Literature Review

The utilization of geological information for the geophysical survey in the study area is imperative. It helps to correlate the origin forming of an exploration object or target, for instance geothermal. Geologically, Dolok Marawa has the following lithologies unit from old to young in chronological order; Limestone Unit Bahbotala (Tgb), Andesite Mountain Sipapagus (Qls), Andesite Mountain Bahtopu (Qlb), Flow Pyroclastic Toba (Qat), pyroclastic fallout Toba (Qjt), Travertine (Qtr) and Alluvium (Qa). Age of Andesite lava Mount Bahtopu was $1.9 \pm 0.2 \text{ Myr}$ (Pliocene). The bedrock (basement) is crystalline and older than Middle Miocene. Base on geomorphological condition, Dolok



Marawa is divided into four morphology unit, which are in the form of steep hills, gently undulating hills, moderate undulating hills, and flat morphology. Geological structure information in the study area consists of fault Bahtopu and fault Bahbotala. The faults trend are in the direction of N 325° E. These fault is the cause of the presence of some geothermal manifestations in the form of hot springs and deposition of travertine [1].

3. Basic Theory

Gravity method is a geophysical method that measures the variations in the gravitational field of the earth [2]. The difference of the gravitational field occurred by mass variations in the earth's crust. The goal of this method is to associate the variations of the gravitational field to density distribution and type of rocks. The distribution of non-uniform density is caused by existing geological structures beneath the earth's surface. This method is splendid to discover the geological subsurface configuration on a broad scale based on the difference in density of each rock.

The following factors that are influenced the Gravitational value such as latitude position, the position of the sun and moon to the earth (tides), elevation, topographical condition surround area, and subsurface rock mass density variation. Gravity measurements intend to determine the value of gravity at the observation point towards a benchmark. Thus, the value of gravity observation point in the reference frame that is equal to the value of the gravitational reference point can be determined. In order to determine the value of gravity observation point one needs to do the following steps: (1) Measurements calibration; (2) Gravity meter readings conversion; (3) Feedback conversion; (4) Instrument height correction; (5) Latitude correction; (6) Earth tidal correction; (7) Drift correction.

4. Methodology

The study was carried out in the area Dolok Marawa, Simalungun District, North Sumatra Province on 6 to 30 September 2006 with coordinate 473883.442 - 483081 Easting and 342949 – 351889 Northing. We used the gravimeter Lacoste & Romberg inc. g-802 models with 160 measurement points as shown in Figure 1. The data is processed using Ms. Excel, Pasut Software, Rockwork 99, Microdem, Gravi900, Surfer10, Oasis Montaj, and Gravblox for 3D modeling.

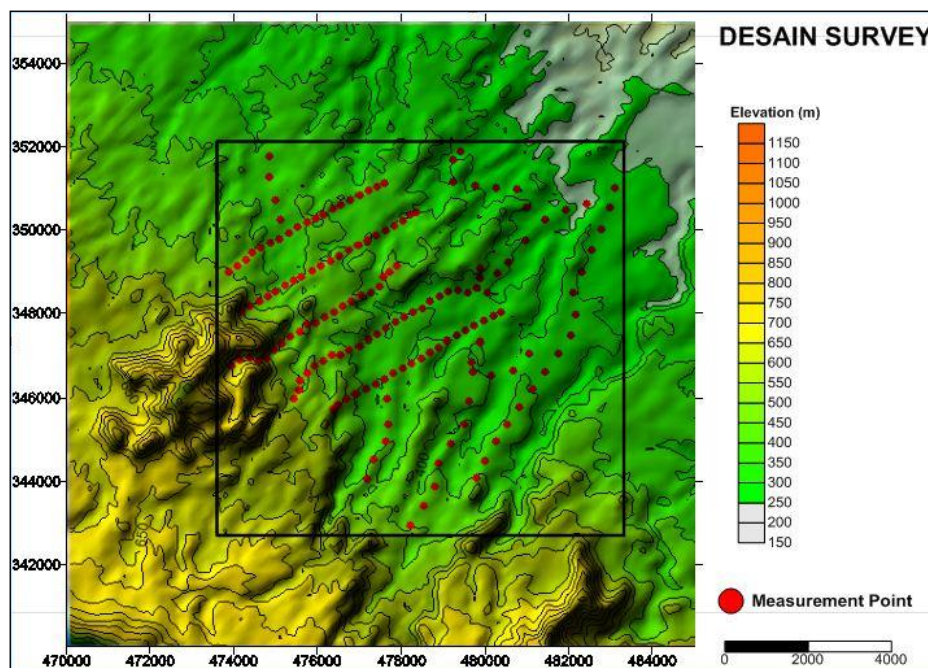


Figure 1. Design Survey

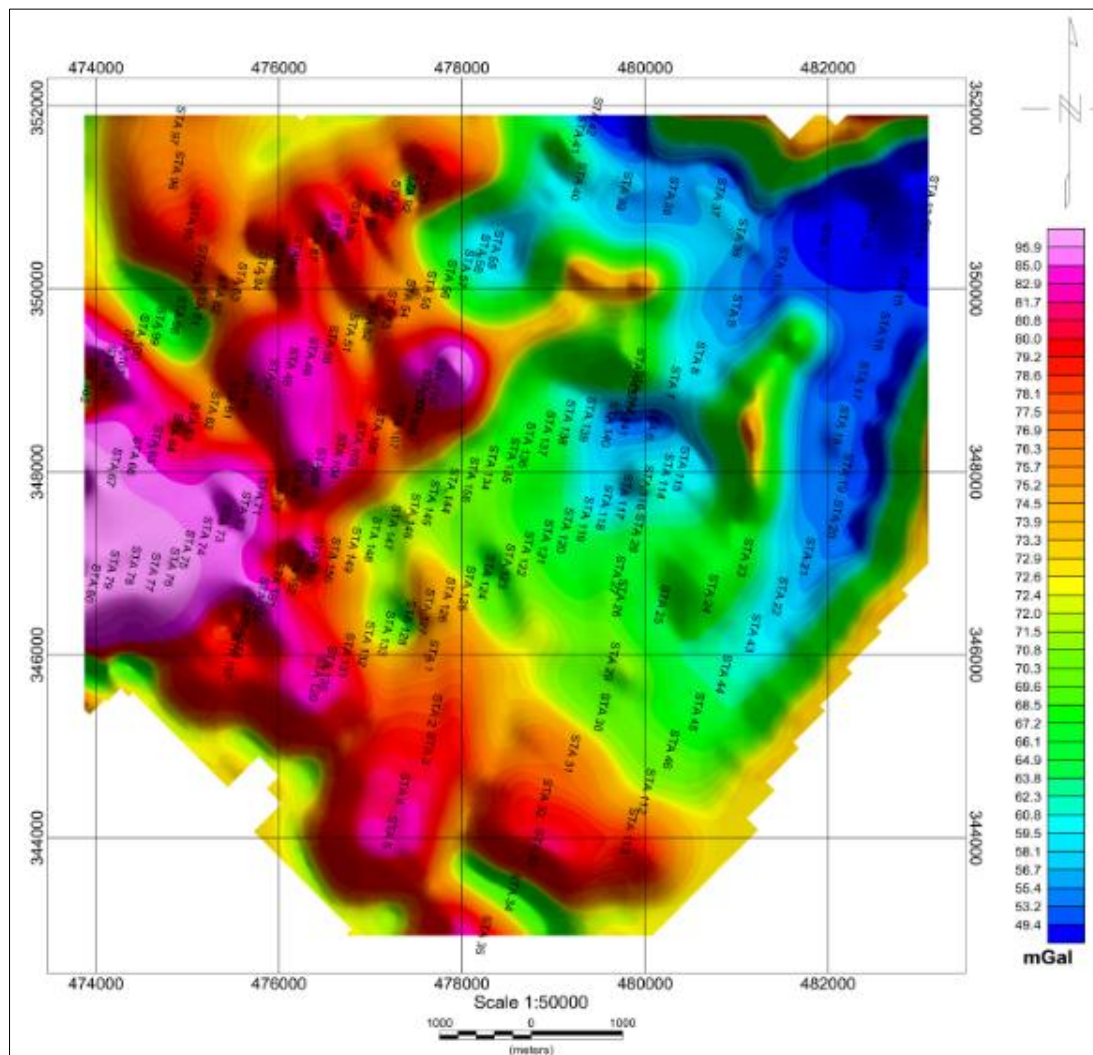


Figure 2. Complete Bouguer anomaly map

5. Results and Discussion

The gravitational variation in study area represented in the form of complete Bouguer anomaly values. These values correspond to the distribution of density in the subsurface. We interpret the geothermal component in map view (Figure 2) according to Bouguer anomaly values as the following classification.

The Heat source has high Bouguer value of 85 – 130.86 mGal as andesitic igneous rock and is influenced by Mt. Bahtopu magma chamber in western part of research area, while reservoir and caprock have low Bouguer value of 40 – 80 mGal. This variation occurs due to the density distribution of the heat source that composed of andesitic igneous rock and has higher Bouguer value than caprock and reservoir. Meanwhile, the low anomaly value is associated with the presence of fluids that filled the fracture causing a density reduction of rocks. It is hard to discriminate caprock and reservoir since it has a close range of density value. It corresponds to a gravitational theory where density is directly proportional to gravitational acceleration.

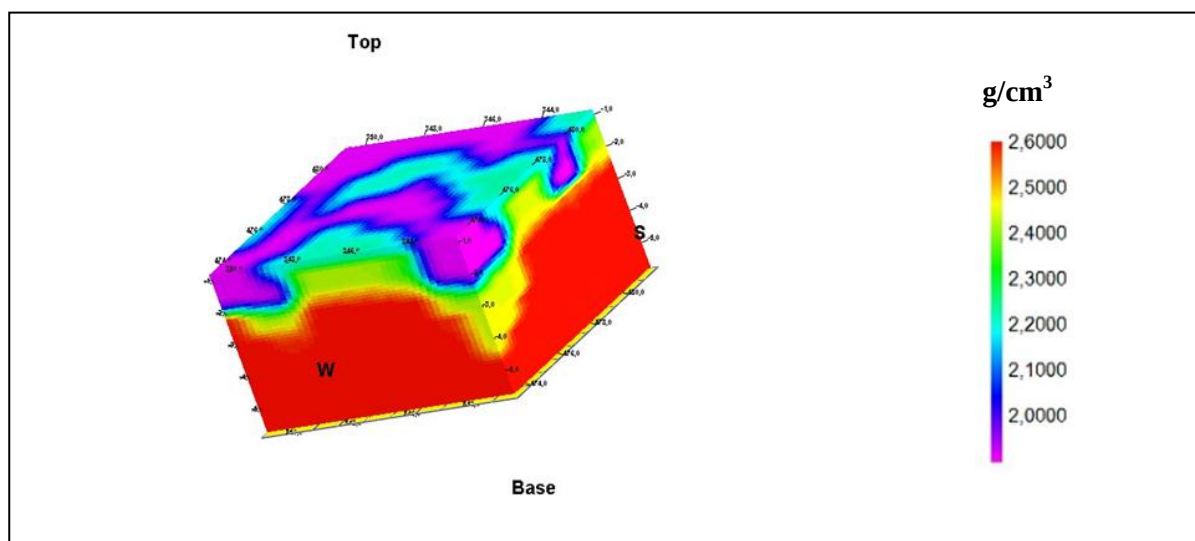


Figure 3. 3D Geothermal Model of Dolok Marawa

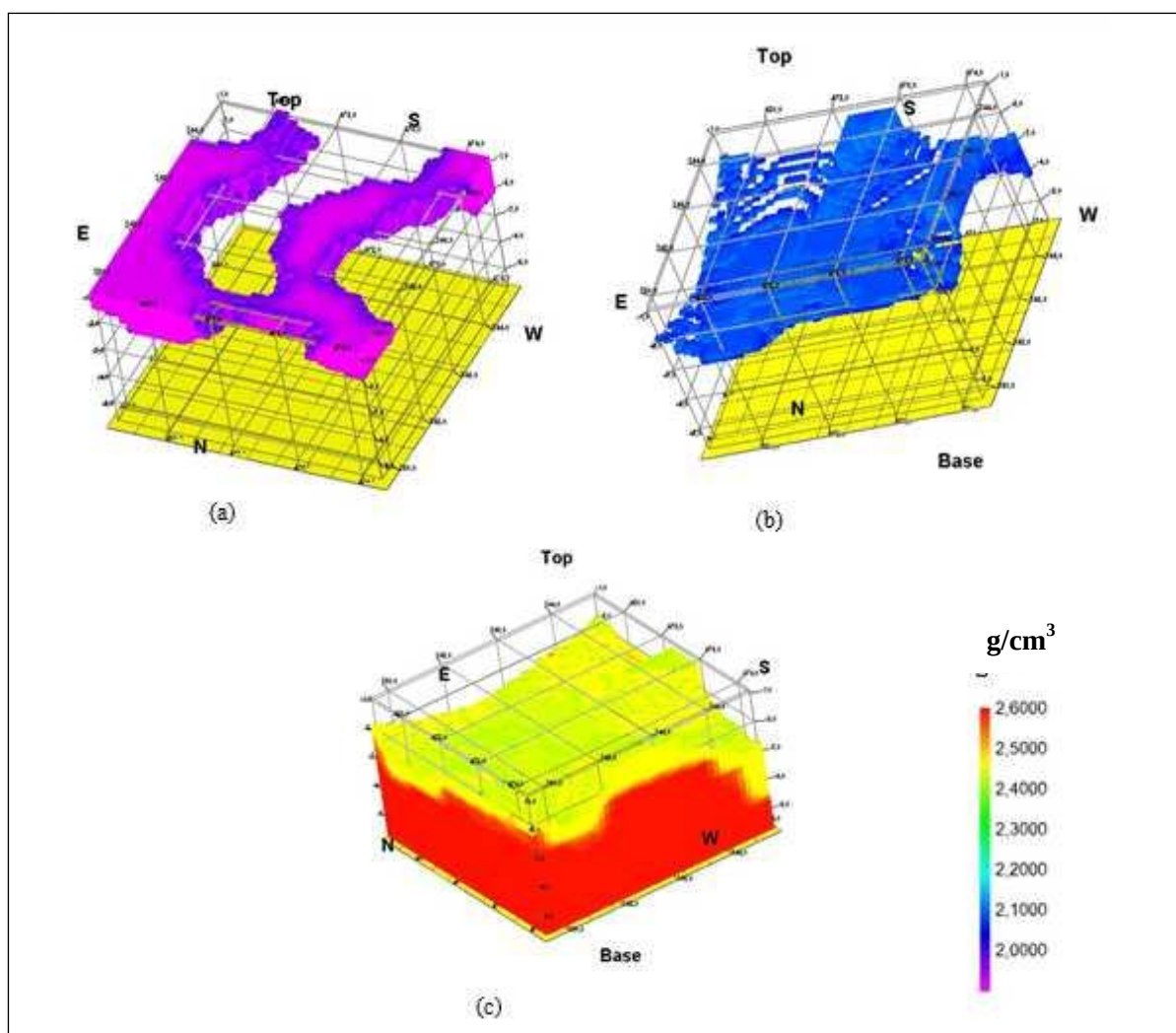


Figure 4. 3D view of geothermal components (a)caprock, (b) reservoir, and (c) heat source

Afterward, we need to analyze the position of the geothermal components and its density. It is more accurate to analyze the geothermal components in 3D model instead of 2D map view. Therefore, the inversion applied to generate the 3D model (Figure 3) and convert the Bouguer values into density.

According to 3D model, the determined components are caprock, reservoir, and heat source. In Figure 4 we focused on the certain component to have a clearer view of its propagation. According to 3D model, the heat source is located at 1.45 – 3.78 km depth represented by yellow color in 3D model with a density of 2.42 g/cm³. Reservoir rock located at a depth of 1 – 1.99 km with a density of 2.21 g/cm³ represented by blue color. Caprock located at a depth of 1 km with a density of 1.92 g/cm³ and represented by magenta color. This interpretation corresponded with a density of coring data in the study area as shown in Table 1. The coring data are taken randomly to represent some of the formations in the study area.

Table 1. Density of Rock Samples

No.	Sample code	Rock	Density g/cm ³
1	7	Dacite	2.15
2	C-750	Dacite	2.15
3	19	Andesitic	2.28
4	45	Andesitic	2.44
5	R-48	Andesitic	2.28

6. Conclusion

Employing a 3D gravity model, we have successfully obtained a reasonably estimated depth of heat source, reservoir, and caprock of geothermal system instead of 2D map views in Dolok Marawa Region. The results are confirmed by coring and correspond to the modeling result. Generally, the geothermal component in Dolok Marawa are composed mainly of three types of density parameters that are supported by core data and can be explained as follows; (1) The heat source has density of 2.42 g/cm³ and Bouguer values of 85 – 130.68 mGal at 1.45 – 3.78 km depth. (2) The reservoir and caprock cannot be discriminated in the complete Bouguer anomaly map with values of 40 – 80 mGal but are obviously separated in a 3D model. (3) Caprock has a density of 1.92 g/cm³ at up to 1 km depth, and reservoir rock has a density of 2.21 g/cm³ at 1 – 1.99 km depth.

References

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