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Subsurface Analysis Using Gravity Data at Lili Sepporaki Geothermal Area

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Abstract. Gravity survey plays an important role in early stage of subsurface imaging in geothermal system. The aim of this study is to understand the subsurface structure and possibly the heat source based on rock density distribution with three dimensional inversion modeling (3D). In 2010, Center of Mineral Resources, Coal and Geothermal of Indonesia was performed gravity survey at Lili Sepporaki geothermal area with 205 stations within a 10 x 10 km coverage area. The complete Bouguer anomaly was obtained with the density of 2.8 g/cm3 and this density was used to do 3D modelling. Bouguer anomalies ranging from 40 mgal to 62 mgal were observed in the study area with low anomalies values located in the northern part and high anomalies located in the southern part of the study area. Based on the 3D inversion modeling results, there are low density rocks with values between 2.0 - 2.3 g/cm3 around the hot springs of the research area with a depth of <1 km. These rocks are interpreted as rocks that associated with fractures forming a fault zone that controls the surface manifestation of the study area. High density rocks with values between 3.0 - 3.3 gr/cm3 are located south of research area with depth >2 km. This rocks are interpreted as intrusive igneous rocks and are thought as the heat source of geothermal systems in the study area.

1. Introduction

Geothermal potential in Sulawesi is the third largest after Java and Sumatra, which is around 3229 MWe spread in 76 locations. Most of the geothermal potential in Sulawesi Island is associated with non-volcanic environments. Non-volcanic geothermal is a geothermal system that is not related to Quaternary volcanic activity, found in sedimentary, plutonic, and metamorphic environments associated with tectonic processes with manifestations characterized by the presence of hot springs (Gupta and Roy, 2006). This research area is one of the geothermal potential areas, but until now it has not been used indirectly for electricity generation. The existence of geothermal systems in this area is characterized by geothermal manifestations in the form of hot springs with temperatures of 84.20C to 970C. Geothermal Lilli Sepporaki is located in a non-volcanic environment which is dominated by tertiary volcanic brick bounded by the active Palu Koro fault.

One of the geophysical methods used in geothermal exploration is the gravity method. Gravity method is a geophysical method based on differences in gravitational fields due to differences in the density of constituent rock layers beneath the earth's surface (Kearey et al., 2002; Pradana et al., 2017). The

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physical magnitude measured in the gravity method is the acceleration of the earth's gravity to get the physical quantity of density. The acceleration data of gravity obtained during measurement is processed into an anomaly of gravity acceleration of the earth which is called an anomaly bouguer. From the results of data processing, modeling both forward modeling and inversion modeling is carried out to determine differences in rock density, so that the data can be used to determine subsurface geological structures in the study area (Telford et al., 1990).

In geothermal exploration, gravity methods are generally used to describe subsurface structures that control geothermal systems (Porkhial et al., 2015), and also to find out which magma or intrusive rock bodies are related to heat sources from geothermal systems (Represas et al., 2013). Separation of regional and residual anomalies using filtering butterworth. The butterworth filter provides a maximum flat response price on the passband frequency and a zero price at the stopband (Shaker and Oweis, 2016). To delineate rock density contrasts associated with structural zones and heat sources, 3D inversion modeling is done using UBC-GIF Grav3D software using the algorithm from Li and Oldenburg (1998b) (Martakusumah et al., 2015). This inversion modeling is not unique or not single meaning that an anomaly response can be produced by several subsurface models (Grandis, 2009).

2. Geology of Lili Sepporaki Geothermal Area

Lili-Sepporaki geothermal area is located in the region of West Sulawesi, which is dominated by volcanic rocks. Based on stratigraphy (Figure 1), the formation that existence in the Lilli geothermal area consist of Walimbong Volcanic (Tvw), Andesite Feldspatoid (Tf), Andesite Porphy (Tp), Indivisible Volcanic (Tvt), Basaltic Basaltic Lava Bobongbatu (Tlbb), Lava Andesite Buttu Sawergading (Tls), Lava Andesite Buttu Butu (Tlb), Lava Andesite Buttu Talaya (Tlt), Lava Andesite Buttu Dambu (Tld), Lava Andesite Buttu Kamande (Tlk), Lava Andesite Buttu Sawergading (Tls) Alluvium (Qal) (Setiawan et al. 2010).

Lilli's geological structure pattern is clarified into seven structure patterns. Based on the seven structure patterns, the most important that controlled the existence of geothermal surface manifestation is the structure pattern N10-200^{0}E / N190-200^{0}E and N110-120^{0}E / N290-300^{0}E. The intersection of both of this faults form the media that flowing hydrothermal fluid to the surface. There is a depression structure that located in the Lilli geothermal area. It is characterized by the rest of the escarp depression that formed a curve up to half radial. Based on morphology and regional structure patterns, the forming depression is thought to be the result of collapse of the previously formed axes. Geothermal systems in the research area is thought to be limited by this depression and characterized by the surface manifestations that formed hot springs (Setiawan et al. 2010).

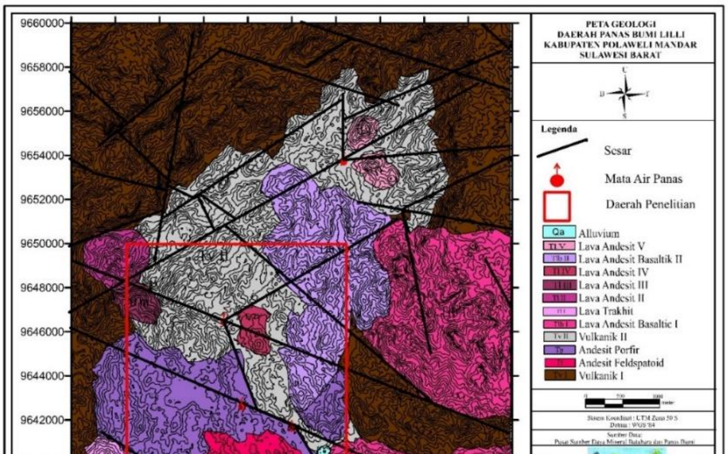

Figure 1. Geology of Lili geothermal area (Center of Geological Resources, 2011)

3. Gravity

3.1. Complete Bouguer Anomaly

In 2010, Center of Mineral Resources, Coal and Geothermal of Indonesia (PSDMBP) was performed gravity survey at Lili Sepporaki geothermal area with 205 stations within a 10 x 10 km coverage area. The measurements were made with the LaCoste & Romberg type G-802 gravitimeter at 205 stations on an area of approximately 100 km2. Figure 2 shows distribution of the gravity stations in the region. The spacing between the stations varies from 250 m to 450 m. In this study, estimation of rock density was carried out using the parasnis method. The parasnis method is based on the Bouguer anomaly equation assuming the Bouguer anomaly is zero. In this method, the variable x (tide correction to latitude correction) and y (bouguer and terrain correction) are plotted on the cartesian coordinate, then a linear line equation can be searched by the least square method. Figure 2 shows the distribution of data from curve (0.04185h-terrain) vs (g_Obs-g_theoritis + 0.3085h) with the density used to make terrain correction is 1 g / cm3. Linear regression (least square) on the distribution of data shows rock density of 2.80 g / cm3. In complete bouger anomaly calculation, for bouguer correction and terrain correction using a density of 2.80 g / cm3.

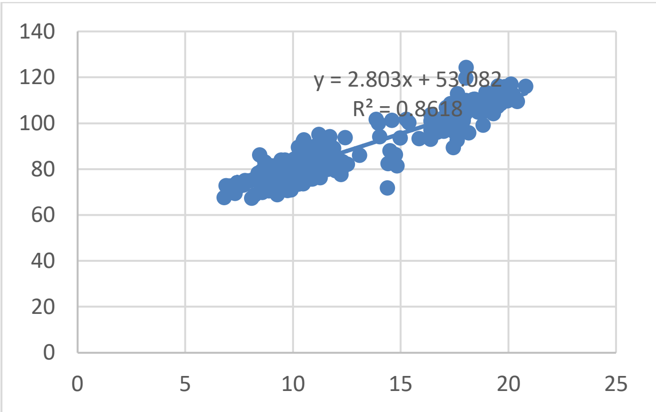

Figure 2. Parasnis method to estimate the average density at Lili Sepporaki geothermal area.

Figure 3 shows the complete Bouguer anomaly map of the study area. Bouguer anomalies ranging from 40 mgal to 62 mgal were observed in the study area. There is low value (40 mgal to 54 mgal) anomaly spreads to the north dominantly, northwest and northeast from the study area. These negative anomaly areas are considered related with the fault that controlled the geothermal system in the region. There is a high value anomaly (55mgal t0 62 mgal) that spread in the southern part of the dominant, southwest and southeast of the study area. coinciding with the high-density igneous rocks.

3.2. Residual Anomaly

The complete Bouguer anomaly that has been obtained contains all possible anomalous sources that are below the surface, namely regional anomalies and residual anomalies (Hinze et al., 2013). The regional Bouguer gravity anomaly is resulting from the presence of deeper and broader structures. The residual Bouguer gravity anomaly is resulting from the presence of smaller and more superficial ones. To get the target that has been determined, the anomalies need to be separated (Setianingsih et al., 2013). In this study, the separation of the complete Bouguer anomaly was carried out using the Butterworth filter. The butterworth filter provides a maximum flat response price on the passband frequency and a zero price at the stopband. This filter can be carried out a high pass filter and filter passes through low (low pass filter) (Shaker and Oweis, 2016).

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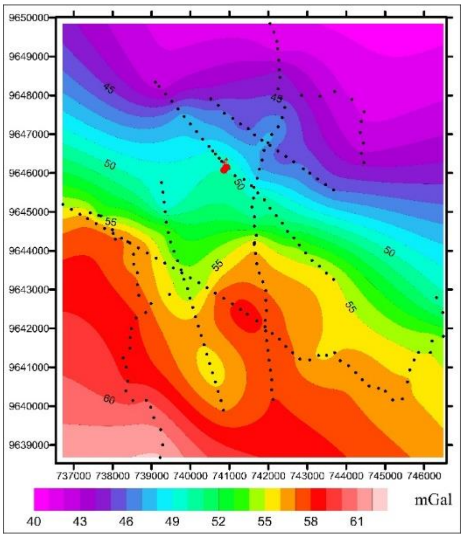

Figure 3. Complete Bouguer anomaly of Lili-Sepporaki geothermal area

Figure 4 shows the residual Bouguer anomaly map of the study area. Residual Bouguer anomalies ranging from -2.4 mgal to 2.4 mgal were observed in the study area. There is low value (-2.4 mgal to 0 mgal) anomaly spreads to the north dominantly and in middle of southern from the study area with the direction northwest to southwest. The low value anomaly probably related to the fault zone in the subsurface and and the fault that controlled and formed surface manifestations. There is a high value anomaly (0 mgal to 2.4 mgal) that spread in the southern part of the dominant, southwest and southeast of the study area. coinciding with the high-density igneous rocks.

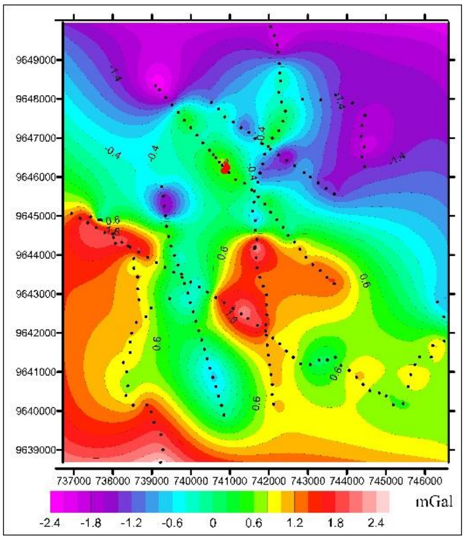

Figure 4. Residual Bouguer anomay of Lili-Sepporaki geothermal area

3.3. 3D Inversion Modelling

The 3-D inversion model is processed use Li and Odenburg algorithm. The result of 3d inversion modelling has varies values from 2.0 gr/cm3 to 3.2 gr/cm3. 3-D inversion model shows that the low density value 2,0 - 2,3 gr/cm3 is located around the hot springs of the research area. The high density value 2,8 – 3,0 gr/cm3 is located the southern part of area which has more than 2000 m depth. To analyze

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and interpretation the three dimensional inversion model, the cross section to show the two dimensional that imaging the subsurface condition to interpretated is created from 3-D model (Parapat et al. 2017). The cross section with the direction from southwest to northeast (Figure 4).

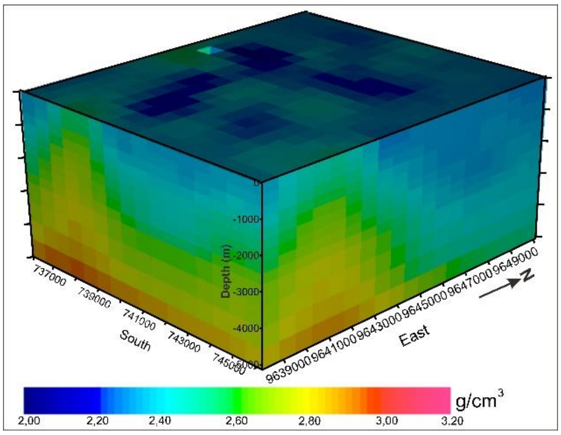

Figure 5. 3-D inversion model of Lili-Sepporaki geothermal area.

This 2-D cross section is located in the dominant the high Bouguer anomaly that area leads to the southeast, where as the medium Bouguer anomaly is in the middle to the northwest and the low Bouguer anomaly is to the northwest. This 2-D cross section model shows that there are the low density rocks with a range of values 2.0-2.3 gr/cm3 at 5000 to 6000 and 9000 to 12000 toward the northeast at depths of <2000 m. This rocks are thought to be associated with a weak that zone associated with fault. There is surface manifestion in this rocks, that matter support the indication that this rocks is associated with fault that controlled the manifestation. While the high density rocks with a range of values from 2.8 to 3.0 gr/cm3 at 0 to 5000 toward the northeast with a depth of >2000 m. This rocks are thought to be associated to intrusive igneous rocks that associated with the heat source of Lili Sepporaki geothermal system. That matter is supported by the location of high Bouguer anomaly values that located in southern part of the research area (Martakusumah et al. 2015; Parapat et al. 2017).

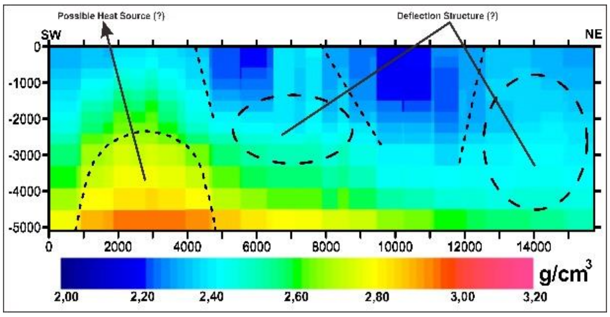

Figure 6. 2-D model cross section of 3-D inversion model of Lili-Sepporaki geothermal area

4. Conclusions

Based on 3-D distribution model of Lili-Sepporaki geothermal area, we can conclude.:

There is a low density value with value 2.0-2.3 g/cm3 which has a thickness of 500-1000 meters, related with the fault zone and high density value with value 2.8-3.0 g/cm3 which has a thickness more than 2000 meters, asummed as igneous rock intrusion.

5. Acknowledgement
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