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Identification of Geothermal Ulubelu Reservoir Base on SVD Analysis and Modelling of 3D Gravity Anomaly

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Abstract

The Ulubelu geothermal field is located at about 30 km northern Kotaagung Lampung. The field lies in steep terrain between 300 and 1600 m above sea level but mostly from 700 to 800 m, with around Mt. Ridingan, Mt. Kukusan, Mt. Waypanas and Mt. Kabawok. To understading subsurface structure Pertamina has conducted geophysics exploration surveys in the area since 1991 including gravity, electrical resistivity and self-potential methods.

Data reduction and terrain correction were then applied to the observed gravity data to produce complete Bouguer anomalies. However, the complete Bouguer anomalies reflected a combination of local and regional subsurface effects. In order to get only local subsurface effects the regional effect was calculated and then subtracted from the complete Bouguer anomalies. In this study, the regional gravity values over the study area were assessed using moving average with with windows array 7 km. From SVD analysis, structure in Ulubelu geothermal prospect influenced by Sumatera main structure with NE-SW orientation. Analisys well production in Ulubelu area shown that prospect geothermal field have negative SVD. From Bouger anomaly suggested that the Ulubelu geothermal field could be associated with a graben structure. From 3D inversion modeling shown that geothermal reservoir lays at 500 m deepness from mean sea level. Geothermal prospect area in Ulubelu located at Western and Eastern well production.

Keyword: Bouguer anomaly, geothermal, Ulubelu

Introduction

Gravity method is one of the various methods used in geophysics to determine the subsurface structure based on differences in rock density. This method is sensitive to vertical changes so it is suitable to use for studying: intrusion contacts, bedrock, structural geology, and others.

Ulubelu geothermal area is located in Tanggamus-Lampung, and at this point Pertamina Geothermal Energy is conducting exploration and exploitation of geothermal energy to harness into electricity to power 2x55 MWE. To obtain subsurface structure of Ulubelu geothermal area, it has been done several geophysical surveys, one of which is a gravity survey method.

To know the detailed structure of the subsurface geothermal prospect areas, and to determine the location of the geothermal reservoir at Ulubelu, it is necessary to analyze the gravity anomaly data in detail by applying some analysis techniques and subsurface modeling. This research will be done processing gravity data, in order to obtain the Bouguer anomaly, SVD (second vertical derivative) analysis, the separation of local and regional effects and 3D modeling of the subsurface structure of the area Ulubelu from complete Bouguer anomaly.

Basic Theory

Gravity at the earth's surface, indicating the magnitude of the pull of anomalous object beneath the surface with the direction to the center of the earth, and it is a derivative of the force generated by Newton's law (Telford. dkk, 1990). Theory of gravity was first proposed by Sir Isac Newton (1642-1727) who explains that the force of attraction between two objects is proportional to the mass multiplication of the two objects and inversely proportional to the square of the distance. While the gravity acceleration is gravity mass unity.

$$F = G\frac{m_1.m_2}{r^2} \quad (1)$$

$$g = G\frac{m}{r^2} = G\frac{\rho V}{r^2} \quad (2)$$

where F, G, m, ρ, r and V each is a force of gravity, the universal constant of gravity, mass, density, distance and volume.

Regional Geology Ulubelu

Ulubelu located in the village Muaradua, Pagaralam and within 45 km from the district Talangpadang or about 125 km from the city of Bandar Lampung **(Figure 1).** Ulubelu geothermal area is located near the Sumatra fault which is very active and also located on steep topography with an altitude between 300 to 1600 m, with the prospect area is located at an altitude between 700-800 meters surrounded by mountains Rindingan, Kukusan, Kabawok and Waypanas (Mulyadi dan Guntur, 1998).

Surface thermal manifestations Ulubelu geothermal field, consists of fumaroles, hot springs, lakes and hot water. Fumaroles appeared in the village Muaradua, Pagaralam and M. Duduk. Chloride water are present at a lower place, from 400-700 meters, the southern section (Daud, 200). All these scattered around Ulubelu stream, and spread to the southern part of the mountain southwest Kukusan (**Figure 2**). Ulubelu lake located in the central part of the geothermal prospect location at an altitude of 700 m, and was among Mountain Duduk and Muaradua village.

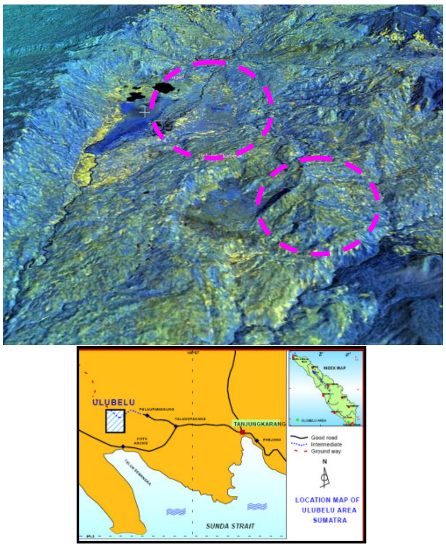

Figure 1. Location of the study area Ulubelu, and surrounding areas

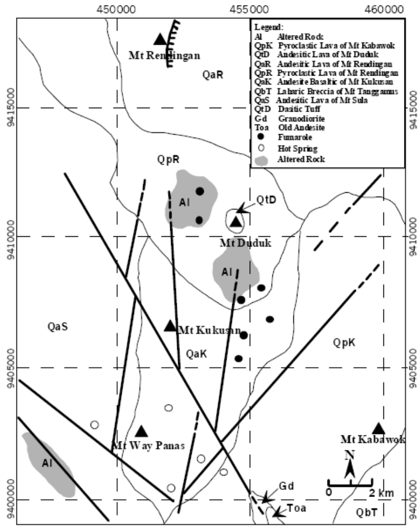

Figure 2. Geological surface of Ulubelu area (Daud, dkk. 2000)

Methods

The study begins by processing data from gravity observations, subsequent correction which includes correction of normal gravity, free air correction, Bouguer correction and terrain correction to obtain the Bouguer anomaly. The next process is the second vertical derivative (SVD) of the complete Bouguer anomaly and filtering to obtain regional and local anomalies research area by using the moving average method. Modeling structures in 3D subsurface inversion is performed by using Grav3D program, while the subsurface analysis and interpretation done by compiling and overlay some data such as geological data, data of geothermal manifestation , topographic data, the data fault , Bouguer anomaly data, the data of regional anomalies, residual anomalies, the data boreholes and other.

Result and Discussion

1. Bouguer anomaly

Bouguer anomaly Ulubelu geothermal prospect area is shown in **Figure 3**. Low anomaly located in the northern part of the study area between Mt. Duduk and Mt. Rindingan. This anomaly occupies the weathering zone and lakes area of Ulubelu. In this area appear several geothermal manifestations such as the hot springs. Low gravity anomaly in the middle a little to the north is suggesting that this low anomaly associated with graben, a large caldera, or as a result of pyroclastic rocks of the mountains Rindingan, who hoard the graben.

Qualitatively, the low Bouguer anomaly characterizes the existence of a structure that is believed to be the 'old crater rim' which also occurs in several places in the southern segment of the Sumatran Fault Zone (SFZ), for example, in the western part of Liwa. Limiting structures on the crater rim is usually a normal fault, which is relatively circular.

Ulubelu geothermal prospect area (Ulubelu geothermal reservoir) may be in this area. The southern part of the study area in a mountain area Kukusan occupies a high gravity anomaly. These anomalies are directly related to the presence of rocks with high density resulting from the freezing of magma beneath the volcano. The presence of rocks with a high density of magma freezing results, which generally have higher temperatures, it is possible as a heat source of the geothermal system in the area.

2. *Second Vertical Derivative (SVD)*

Second vertical derivative of the Bouguer anomaly is equal to the negative of the second order horizontal derivatives. Theoretically, this method is derived from Laplace's equation; it means that the anomalous 'second vertical deivative' can be done by means of horizontal derivatives, which are practically easier to work with (Elkins, 1951). The results of the second vertical derivative describe the sources of anomalies that are shallow, so it is identical to the residual anomaly. Map of second vertical derivative Bouguer anomaly Ulubelu and surrounding area are shown in **Figure4.**

In the second vertical derivative anomaly map, it appears the low anomaly in the northern part of this study area between Mt. Rindingan and Mt. Duduk same as Bouguer anomaly pattern. The second vertical derivative results reinforce the prediction of that geothermal reservoir is located in the area between Mt. Rindingan and Mt. Duduk.

Results of screening SVD produce local anomalies, which describe the shallow unconformity, which may be a 'reservoir' Ulubelu geothermal field. Meanwhile, the Heat source probably derived from Mt. Kukusan, which is characterized by a high anomaly. The pattern of faulting structures (dashed black line) is strongly influenced by the structure of the main structure of Sumatra which is northwest-southeast trend (NW-SE), which is believed to be the 'seal' for the reservoir to drain the fluid is not laterally.

Areas that were given circle color 'purple', on the top of which is characterized by negative anomalies equal or relatively equal magnitude to the present production, which is thought to be a potential area for new development. Distribution anomalies indicate that the area of the top of the purple circles is in the same system with the present production.

Mt. Duduk position which is at the low anomaly area is alleged that the mountain has become a part of the reservoir. The morphology of the mountain just looks simply because aspects of landscape or topography.

For areas with a potential for a purple circle on the west G. Kukusan, can not be analyzed further to determine whether the area is a geothermal prospect areas. This is because the data is very limited in the area, which is probably due to the influence of the extrapolation.

To answer the curiosity, should again be some gravity trajectory in the western part. At least, we will get closure from the distribution of low anomaly there. When we've got closure, then we can propose the development in the zone or region. As the implications of the closure, it is necessary to answer the question: Is the brown circle zone located in the same system with the present production.

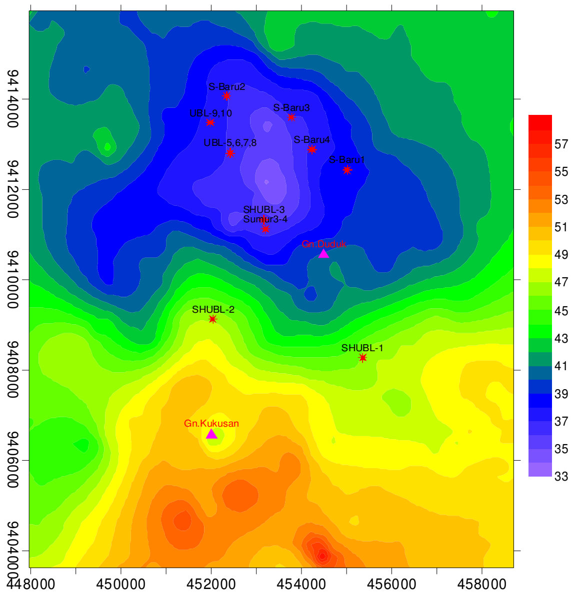

Figure 3 Bouguer Anomaly in the study area

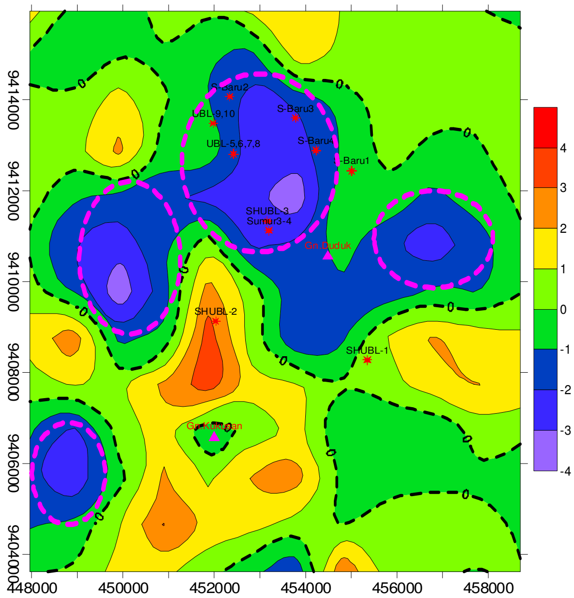

Figure 4 Second vertical derivative Bouguer anomaly

3. Separation of regional and local anomalies

Bouguer anomaly caused by anomalous objects that are close to the surface, and far away from the earth's surface. Because the purpose of geophysical exploration is to study the general structure of the near surface (basin hydrocarbons, geothermal reservoirs, natural resources, geological structure), then various attempts have been made to separate the residual effects of the regional effects. In this study, the separation of the Bouguer local from regional Bouguer anomaly used moving average method.

Before process of regional-residual anomaly separation by this method, first made the irregular grid with a grid spacing of 250 m in the Bouguer anomaly and determine the width of the window which will be used in this method.

In determining the width of the window, first performed on the cross-sectional slice some bougernya anomaly map. From the sectional Fourier transformation to obtain the graph between the wave number and amplitude of the Bouguer anomaly. From this graph which is obtained k limit and residual regional boundaries as the basis for determining the width of the moving average window. In this study the effect of the residual obtained depth is 3.5 km.

Filtering results of a moving average method with a window (7 x 7 km), is obtained by the regional Bouguer anomaly (**Figure 5**) and residual anomalies (**Figure 6**) research area.

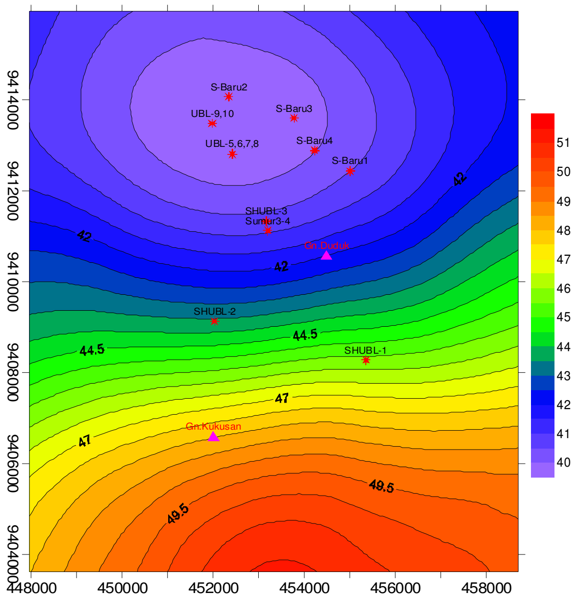

Figure 5 Regional Bouguer Anomaly in the study area

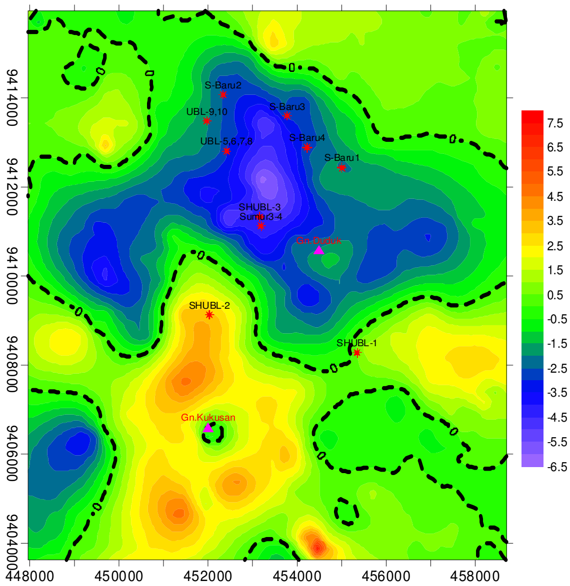

Figure 6 Local Bouguer Anomaly in the area of research and production wells

Regional Bouguer anomaly map of the study area (**Figure 5**), indicating that the South has a high anomaly while the northern regions have low anomaly. This indicates that the basement of the study area has a shallow depth section on the South and the North. Of the anomaly pattern is docked in the middle indicates a fault trending faults in the West - East. While local Bouguer anomaly map (**Figure 6**) showed a low anomaly in the middle northern study area, between Mt. Duduk and Mt. Rindingan. This area is estimated as the area of geothermal prospects in the area. Besides the low anomalies also appear at the Southwest area of research is in the West Mt. Kukusan. Height anomalies located in the South area of research areas precisely around Mt. Duduk and Mt. Kukusan. Looking at the pattern of anomalously high circular structure made possible due to the intrusion which is likely to behave as a heat source of the geothermal system (Kamah, 2000).

4. 3D inversion of Local Bouguer Anomaly.

Approach to the calculation of the gravity response by using a prism object upright sides, with spaces Δx and Δy is one alternative that can be done, the suitability of the model objects in the field depends on the number and dimensions of the prism are arranged. Plouf (1976), calculate the gravity response caused by a prism-shaped object models:

$$g = G\Delta\rho \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2}\mu_{ijk}\left[z_k \arctan\frac{x_i y_i}{z_k R_{ijk}} - x_i \log\left(R_{ijk}+y_i\right) - y_i \log\left(R_{ijk}+x_i\right)\right] \quad (3)$$

Where: $R_{ijk} = \sqrt{x_i^2 + y_j^2 + z_k^2}$ $\qquad \mu_{ijk} = (-1)^i (-1)^j (-1)^k$

In this study Bouguer anomaly, 3D inversion is using the program 3D Grav. Results of 3D inversion shown in **Figure 7** and **Figure 8**. Results of 3D modeling indicate a model of low-density (<2 g / cc) between Mt. Duduk and Mt. Rindingan likely as a geothermal reservoir in that area. Reservoir is a graben structure filled by pyroclastic rocks of the Mt. Rindingan and it is at a depth of 500 - 2500 m below MSL.

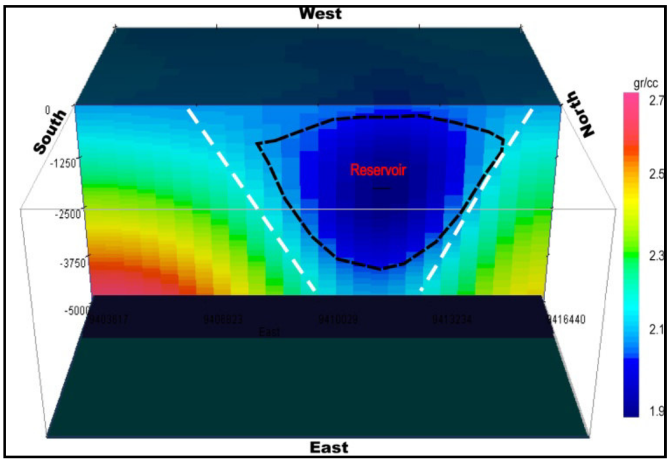

Figure 7 3D inversion model residual Bouguer anomaly

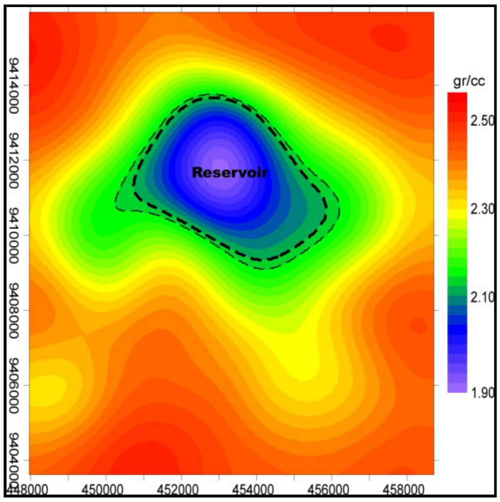

Figure 8 3D inversion results of model density distribution at a depth of 1000 (msl)

Conslusion

Low gravity anomaly in the area of geothermal prospects Ullubelu associated with the graben in the area, which is filled by pyroclastic rocks mountain Rindingan products which have undergone alteration. The pattern of fault structures in Ulubelu geothermal prospect area is strongly influenced by the Sumatra main structure trending northwest-southeast (NW-SE), which is believed to be the seal for the reservoir to drain the fluid is not laterally. Besides, there is also the structure of the southwest-northeast trending fault (NE-SW) which is perpendicular to the main fault.

Looking at present production wells located in the central region with low value anomalies SVD, it is possible that the area west and east of the well production is now an area with huge potential as the production wells. Besides, there are also other prospect areas to the west of the Mt. Kukusan, this area has a low value relative anomaly SVD together with the prospect now. However, the prospect of this should be done further research since at least the data in the area. 3D inversion results show that the geothermal reservoir is at a depth of 500-2500 m below MSL. Geothermal prospect areas in addition to wells drilled in the area now (in the middle) is also found in western and eastern regions. Heat source probably derived from G. Kukusan characterized by anomalously high in the area.

Acknowledgements

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