Gravity Modelling And Second Vertical Derivative Calculation To Analysis Subsurface Structure At Wayratai Geothermal Prospect Area, Lampung

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Abstract. Wayratai Geothermal Prospect Area, Lampung is near a cluster of Mount Ratai with geological condition in the form of young volcanic sediment such as lava, breccias, and tuff obtained from the eruption of Mount Ratai. To determine geothermal potential in Wayratai area, we needed some preliminary surveys such as geological, geochemistry, and geophysical survey. Based on geological mapping, we obtained several point of manifestations such as 5 hotspring points (with a temperature 86-90°C), mudpool, steaming ground, and altered rock. After that, performed with a geophysical survey using the gravity method to determine subsurface structure and describe the initial conditions of the geothermal system. Gravity method is used because this method is sensitive to analyze the vertical changes, and can describe the subsurface conditions based on density variation of rock. Based on data acquisition and literature studies performed on Wayratai geothermal prospects area, obtained 2D and 3D subsurface model based on density variations. From the model, obtained area with a density value 2.3-2.6 gr/cm³ and depth from 400 to 2000 m were assumed to be a reservoir zone. Then, the area with a density value 2.8-3.2 gr/cm³ and depth from 2000-2500 m assumed to be a heat source. With these density, we can assume that the rock in reservoir area is calcareous-brecia and in the heat source is an andesitic-basaltic rocks. Based on the analysis of second vertical derivative calculation, obtained value of SVD maximum is greater than SVD minimum which indicated that the area is a basin structure or normal fault, and its strengthening of the assumption that the modelling of the geothermal reservoir is graben form.

1. Introduction

Wayratai geothermal prospect area is located at Pesawaran district, 40 km from the capital city of Lampung Province with coordinates 5°36.7’S and 105°10.38’E. Wayratai geothermal prospect area bordered by two clusters of young volcanic, namely Mt. Ratai and Mt. Pesawaran are located in the north, Mt. Menangis in the west and Ratai Bay in the east. With this conditions, Wayratai area is attracted to do an preliminary study on the geothermal potential. Some preliminary studies were conducted to determine geothermal potential such as geological, geochemistry, and geophysical surveys. Based on the geological mapping performed in Wayratai area, we obtained several point of manifestations such as 5 hotspring points (with an average temperature of 85-98°C), mudpool, steaming ground, and altered rock (silica sinter) spreading at the prospect area. From the results of geological and geochemical surveys, geophysical surveys then performed with using the gravity method to determine the subsurface conditions.

2. Theory

In this research, we collect the data information from:

2.1. Regional Geology

The condition of the surface geology at Wayratai geothermal prospect area (Figure 1) is composed by the composer deposition of swamp deposits (Qs), alluvial (QA), young volcanic deposit (Qhv),
Lampung Formation (QTl), Hulusimpang Formation (Tomh), Sabu Formation (Tpos), Tarahan Formation (Tpot), Menanga Formation (Km), unconsolidated sediment from Mt.Kasih, Way Galih Schist (Pzgs), Piabung Dacite, and Dulan Granodiorite[8].

Figure 1. Geological Map of Wayratai Geothermal Prospect (Modifier from[5]).

Based on structural geology, Sumatera island is located along the southwestern edge of the Sunda Shelf, on the extension of the Eurasian Plate to mainland Southeast Asia is part of the Sunda Arc. Oceanic crust that have lay a portion of the Indian Ocean and the Indian-Australian Plate, have subducted tilted along the Sunda Trench in the west coast of Sumatra. Lane slope meeting is included in the Sunda Arc trench system that stretched more than 5,000 miles from Burma to eastern Indonesia[5].

The location of the arc and trench are contained now that possible since the Miocene. The pressure caused by the oblique subduction periodically mirrored by parallel faults to the edge of the plate and proved in the Sumatra Fault System which runs along the island arc sequence and Merentas sequence. With connected to the arc of magma, from west to east, Sumatra can be divided into four tectonic, namely: Mentawai lane, Bengkulu Fore Arc lane, Magma Arc lane, and Barisan Rear Arc lane or Jambi-Palembang lane[8].

2.2. Geothermal System

Geothermal energy is the heat stored in the rock beneath the earth's surface and the fluid contained therein. Geothermal system consist of elements that made up the system. Essential elements of constituent geothermal system is separated in three aspects, contained a heat source, a permeable reservoir rock, and fluid that bring the heat flow[2].
White\textsuperscript{(9)} was assumed that the geothermal fluids contained in hydrothermal reservoir come from surface water, such as rainwater (meteoric water) which penetrated the subsurface and heated by a heat source (Figure 2). After that, water will enter the cracks into permeable rocks. The heat will be propagated through the rock (by conduction) and through the fluid (by convection). Heat flow then transferred by convection occurs because buoyancy. Gravity makes the water always has a tendency to move down. But, if the water is in contact with a heat source, the heat transfer will occur so that the water temperature becomes higher and the water becomes lighter. This causes more hot water moves upward and cooler water moves downward to the bottom reservoir, make the water in circulation or convection system.

The temperature of reservoir depend on the intensity of the heat that goes from the heat source rock, characteristic of rock thermal, such as the ability to spread out the hot rock and store heat (conductivity and heat capacity of rock), the ability of the fluid in the rock (permeability). Because of the diversity of rock properties, of course, the temperature from one place to another isn’t same, unique, within the reservoir temperature is not homogeneous, and different from one reservoir to another reservoir. Based on the magnitude of temperature, Hochstein\textsuperscript{(3)} classifies geothermal system into three, namely:

- The high-temperature reservoir, is a system with containing fluid in reservoir with temperature above 225°C.
- The medium-temperature reservoir, is a system with containing fluid in reservoir with temperature between 125°C and 225°C.
- The low-temperature reservoir, is a system with containing fluid in reservoir with a smaller temperature below 125°C.

2.3. Gravity Method

The theory of gravity is applied at Newton’s Law which state that the force of attraction between two particle depends on the distance of the mass of each particle, which formula :

\[
\vec{F}(r) = -G \frac{m_1 \ m_2}{r^2}
\]  

(1)

Where :
- \( F(r) \) : Force of attraction (N)
\( M_1, m_2 \) : Mass of object 1 and 2 (kg)
\( r \) : Distance between two objects (m)
\( G \) : Universal Gravitation constant (6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2})

Gravity anomaly read on the surface or called Complete Bouguer Anomaly (CBA) is the value of gravity observations that have been reduced with elevation and terrain correction. The equation is:

\[
\Delta g(x, y, z) = g_{obs} - (g_\varphi - FAC + BC - TC)
\]  

Where :
\( \Delta g(x, y, z) \): Complete Bouguer Anomaly (mGall)
\( g_{obs} \): Observed Gravity
\( g_\varphi \): Latitude Correction
\( FAC \): Free Air Correction
\( BC \): Bouguer Correction
\( TC \): Terrain Correction

2.4. Spectrum Analysis & Moving Average Filter

Spectrum Analysis is used to determine windows length in filtering process, can be used to separate regional and residual anomaly. Spectrum analysis using fourier transformation to change anomaly to be sinusoidal signal in various of frequency. The result of fourier transformation are formed amplitudo spectrum and phase spectrum. With this transformation, we can obtain the information about depth with the gradient, can estimate the value of wave number \( (k) \) and amplitude \( (A) \) to calculate windows length, this value is used to filtering process to separate about regional and residual anomaly. Blackely\(^{[1]}\) makes the derivative of spectrum from gravity potential that observed from horizontal area, afterthat, he do the logaritmic from result of fourier transformation, and get relationship between amplitudo \( (A) \) with wave number \( (k) \) and depth \( (z_0 - z') \):

\[
\ln A = (z_0 - z')|k|
\]  

Anomaly then separate with using moving average filter which have a character to pass anomaly with high frequency (High-Pass Filtering), there are not replace phase and rectangular filter, so can conform to process gravity data. Moving Average Filter equation in 1D and 1 windows is\(^{[6]}\):

\[
\Delta g_n(x_i) = \Delta g(x_i) - \frac{1}{N} \sum_{k=-n/2}^{k=n/2} \Delta g(x_i - k)
\]  

Whereas moving average filter in 2D for windows width NxN is:

\[
\Delta g_{reg}\left(\frac{N + 1}{2}, \frac{N + 1}{2}\right) = \sum_{i=1}^{N} \sum_{j=1}^{N} \frac{\Delta g(i, j)}{N^2}
\]  

After that the residual anomaly is:

\[
\Delta g_{res}(i, j) = \Delta g(i, j) - \Delta g_{reg}(i, j)
\]  

2.5. Second Vertical Derivative

Second Vertical Derivative method is used to show local or regional anomaly. This method is good to know discontinuity from subsurface structure, especially fault structure in a survey area. Based on
theory, this method obtained from derivative of Laplace Equation for gravity anomaly in surface with equation\(^{(7)}\):

\[ \nabla^2 \Delta g = 0 \]  

(7)

or:

\[
\frac{\partial^2 \Delta g}{\partial x^2} + \frac{\partial^2 \Delta g}{\partial y^2} + \frac{\partial^2 \Delta g}{\partial z^2} = 0
\]

(8)

so second vertical derivative can be:

\[
\frac{\partial^2 \Delta g}{\partial z^2} = -\left(\frac{\partial^2 \Delta g}{\partial y^2} + \frac{\partial^2 \Delta g}{\partial x^2}\right)
\]

(9)

For 1-D data (graphical data) the equation is:

\[
\frac{\partial^2 \Delta g}{\partial z^2} = -\frac{\partial^2 \Delta g}{\partial x^2}
\]

(10)

Second vertical derivative equation and 1-D data show the second vertical derivative from the surface gravity anomaly is equal from negative value of second horizontal derivative. It means that second vertical derivative anomaly can through horizontal derivative which practically more easy to do it. From calculation, we can obtain the characteristic:

- For basin/normal fault applied:

\[
\left(\frac{\partial^2 \Delta g}{\partial z^2}\right)_{\text{max}} \geq \left(\frac{\partial^2 \Delta g}{\partial z^2}\right)_{\text{min}}
\]

(11)

- For intrusion/reverse fault applied:

\[
\left(\frac{\partial^2 \Delta g}{\partial z^2}\right)_{\text{max}} \leq \left(\frac{\partial^2 \Delta g}{\partial z^2}\right)_{\text{min}}
\]

(12)

3. Result and Discussion

![Figure 3. Wayratai Geothermal Prospect Area view in Google Earth](image)
Wayratai geothermal prospect area is located at the coordinates 5° 36.7’ S and 105° 10.38’ E, 40 km from Bandar Lampung which can be reached in 2 hours drive (see Figure 3). Gravity measurements performed by gravity base points at the Wayratai Brigid 3 base that calibrated by gravity base points at Physics Building University of Lampung. Gravity measurements were made from 10 until 12 June 2015 as many as 30 point measurement points with grid spacing 200 meters.

Based on measurement results show the Wayratai geothermal prospect area has an altitude from 142 m to 548 m (see Figure 4 left). From gravity Observation data (see Figure 4 right), show the area with high anomaly in the Southeast direction with a value 977985-978015 mGall and the area with low anomaly in the Northwest direction with a value 977910-977945 mGall. By using topographic data and g.Obs data, we can conclude that both of data have a reverse value (correlation data is -1), its indicated that the data acquired is good.

![Figure 4. Topographic Map (left) and Gravity Observation (right) Map](image)

![Figure 5. Surface Density Estimation Chart with Parasnis Method](image)

$$y = 1.7449x - 41.747$$

$$R^2 = 0.7788$$
In this research, we used Parasnis and Nettleton method to analyze estimation of surface density that use in Bouguer and Terrain correction. With Parasnis method, obtained the surface density estimation in research area is 1.75 gr/cm$^3$ (see Figure 5). With Nettleton method, obtained the surface density estimation is 1.75 g/cc (see Figure 6). Based on both results, we conclude to use that value (1.75 gr/cm$^3$) as a surface density in correction. G.Obs data have corrected for latitude, free air, Bouguer and terrain called Complete Bouguer Anomaly (CBA).

**Figure 6.** Surface Density Estimation Chart with Nettleton Method

Based on the CBA map (see Figure 7), showed the area with low anomaly from -45 to -49 mGall in the middle of research area, and the area with high anomaly from -32 to -38 mGall is located in the northern and southern of research area.

**Figure 7.** Complete Bouguer Anomaly Map
In this research, we performed the 2D Forward Modelling and 3D Inverse Modelling to describe subsurface structure. The first is Forward Modeling, in this method we require the spectrum analysis (with Fourier transformation) to determine the window length in filter to know boundary between regional zones, residual zones, and noise. Based on spectrum analysis, obtained the crossplot graph between In A and K (see Figure 8) that shows linear regression between the zones which gained the window width is 25x25, with depth classification: the surface zone is 33 m, the residual zone is 307 m and the regional zone is 1809 m. From this data, can be a reference to make a 2D Forward model of the subsurface structure.

![Figure 8. Spectrum Analysis (windows width 25x25)](image)

After that, filtering process is requiring to separate CBA data into difference frequence. In this research, we use Moving Average Filter with window width 25x25 to get regional map (see Figure 9 left) and residual map (see Figure 9 right). If we see at residual map, we can get a different anomaly between low and high anomaly in center of the map. By slicing from point A to point B on residuals map, we can obtain a data to make the 2D Forward Modelling.

![Figure 10. Regional Anomaly Map with filter 25x25 (left) and Residual Map (right)](image)
To identify the structure boundary in research area, we analyze the gradient in the form of horizontal gradient (used to know the structure boundary in horizontal) and vertical gradient (used to identify the structure boundary in vertical). In this research, SVD analysis is conducted with Elkins filter to get the structure of research area, and with calculation of gradient analysis from 1-D SVD graph obtained the structure boundary and type of structure to reference the 2D modelling.

![Figure 11. Second Vertical Derivative (Elkins) Mapping](image1)

From SVD mapping (see Figure 11), obtained the area with SVD value equal than 0, this indicated the fault zone or the structure boundary in the center of the map and around of negative anomaly. After analysis, slicing area in the north to south (N-S) in the prospect area, obtained gradient linear of SVD is showed the value of SVD maximum is greater than |SVD minimum| (see Figure 12), so we can conclude in the area have a basin structure (graben reservoir).

![Figure 12. Second Vertical Derivative Calculation](image2)
Based on results of 2D Forward Modeling, obtained subsurface cross-section as shown in Figure 14, where the surface layer with the density 2.4 gr/cc is andesite, the second layer consisted of 3 types of rocks with a density value 2.8 gr/cc is andesite-basaltic, the density is 2.3 gr/cc is a calcareous-breccia rock that is assumed to be a reservoir zone (graben), and the density 2.5 gr/cc is breccia-limestone. Whereas the bottom layer with a density value of 3.2 gr/cc identified andesite-basaltic. This identification is based on the (Telford, 1990) and Mangga (5).

Figure 13. 2D Forward Modelling Wayratai Geothermal Prospect Area Line A-B in direction N-S

Figure 14. 3D Inverse Modelling Wayratai Geothermal Prospect area (Northeast View)
Based on results of the 3D Inverse Modelling, obtained subsurface cross section (see Figure 14) which is focused on reservoir conditions similar to the conditions in 2D Forward Modeling (shape of syncline/graben). In the 3D modeling is known that the reservoir has a density value between 2.35 to 2.57 g/cc are identified as andesite-calcareous with depth 400 to 2000 meter.

5. Conclusion

The conclusions derived from this paper are:
1. Based on Geology and Geochemistry mapping, obtained 5 hotspring points (with average temperature is 85-98°C), mudpool, steaming ground, and altered rock (silica sinter).
2. From SVD mapping and gradient analysis, obtained SVD maximum > |SVD minimum|, this indicated the normal fault structure or basin structure in this area (graben reservoir).
3. Based on 2D Forward modelling and 3D Inverse modelling, obtained subsurface cross-section with top layer with density 2.4 to 2.8 gr/cc is andesite rock, reservoir layer with density 2.35 to 2.57 gr/cc is calcareous-breccia (graben reservoir structure), and basement layer with density 2.8 to 3.2 gr/cc is andesite-basaltic rock.
4. From the gravity modelling, with additional second vertical derivative calculation, we can conclude that the Wayratai Geothermal Prospect Area will be one of the future geothermal power plant in Lampung Province.

Aknowledgement

We would like to thanks Geophysical Engineering UNILA to join data acquisition in this area.

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