The use of gravity anomaly data to estimate the depth of mohorovicic discontinuity in bali area used power spectral analysis

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Abstract. Gravity is a geophysical method that can be used to measure the contrast difference in subsurface density for the interpretation of geological structures. Gravity is a non-destructive geophysical method so it is widely used in subsurface research. Bali is an area with a complex tectonic order because of its location which is part of the east Sunda arc. Bali is formed due to the subduction process of the Indo-Australian Ocean crust transition zone with Australia's continental crust to the west and the Banda arc. This study aims to estimate the depth of sediment and limits of discontinuities of the island of Bali using the method of power spectral density analysis. The data used is gravity anomaly data from TOPEX on the island of Bali. Principle method of power spectral density analysis is to analyse the phenomenon of the harmonic oscillator in nature. The data of gravity obtained will be transformed using Fourier series so as to change the time domain into the frequency domain. From the results of processing obtained if the rocks on the island of Bali is a Miocene rock with an initial body density of 2.6 gr/cm³. The depth of shallow discontinuity ranges from 519.35 m hi to 5.92 km with an average depth of 2.63 km. While the depth of discontinuities in the range of 18.30 km to 69.62 km with an average depth of 43.39 km. It is estimated that the sediments of Bali island are shallow because of the rock age of the island of Bali which is still young adrift in the geological time scale.

1. Introduction

Bali is an area with a complex tectonic order because of its location which is part of the east Sunda arc. Bali is formed due to the subduction process of the Indo-Australian Ocean crust transition zone with Australia's continental crust to the west and the Banda arc [1]. The island of Bali has a back arc thrust characteristic located in the north of Bali island as a result of the meeting of two large plate of the world. The gravity anomaly can be determined by using gravity measurements at measuring point surface of the earth [2]. Gravity anomaly can use for determine contrast density in a region so as to represent subsurface structures [3]. Gravity is a non-destructive geophysical method so it is widely used in subsurface research. The density of a rock can be determined using the gravity method by differentiating the density of an anomaly source with the surrounding environmental density [4]. In the determination of the discontinuity limit gravity method that is often used is the method of power spectral density analysis.

Power spectral density analysis method is a method that analyzes the phenomenon of the harmonic oscillator in nature. The principle of spectral analysis refers to the transformation of the Fourier series, changing the time domain into the frequency domain [5]. In the power spectral data gravity method
will be transformed use Fourier series to change time domain into the frequency domain. Power spectra analysis aims to obtain the spectrum distribution of the oscillator phenomenon. Power spectral density shows the power of energy variation as a frequency function \[6\]. There is a strong frequency variation and a weak frequency in the power spectral density it may be possible to estimate the inner discontinuity limits and shallow discontinuity limits in a region. Density variations can represent patterns of subsurface structures \[7\]. The frequency variation can be known from the graph gradient of the power spectral density curve. The gradient value is proportional to the depth value of the discontinuity field. The gradient on the power spectral density analysis curve is divided into two types: large gradient represents the depth of deep discontinuity of the regional anomaly while the gradient with a sloping slope represents the depth of shallow discontinuity of the anomaly residual.

Based on regional gravity anomalies general geological conditions are indicated by low-frequency anomalies whereas for residual anomaly gravity is indicated by the high-frequency anomaly. In a previous study \[8\] conducted a gravity anomaly data study with a power spectral analysis to estimate the thickness of the sediment and the thickness of the Mohorovicic discontinuity layer in East Java, resulting in deep shallow depth discontinuities for East Java at average depth 2.7 km and 25.6 km. Setiadi \textit{et.al} undertook a sub-surface geology interpretation study using the power spectra method \[9\]. Apriani \textit{et.al} conducted a spectral analytical study of gravity anomaly data, to estimate the thickness of sediment in DKI Jakarta \[10\].

The gravity field anomaly is a superposition of regional gravitational anomalies and residual gravity anomalies \[11\]. So from the method of power spectral density analysis will be obtained regional anomaly gravity, residual gravity anomaly, and noise. This study aims to estimate the depth of the discontinuity limit on the island of Bali using the method of power spectral analysis to determine the thickness of the sediment. Estimated depth of the discontinuity limit can be used to determine the age of rock coating on the island of Bali from the thickness of the obtained sediment.

2. Method

2.1. Data retrieval

Data used in this research is free anomaly air gravity (Free Air-Anomaly) from TOPEX which can be accessed at (http://topex.ucsd.edu/cgi-bin/get_data.cgi). The data obtained have received tidal correction, latitude correction, and free air correction. The focus of the research area is the island of Bali with the limits of the research area of the study at 7.93 LS- 8.92 LS and 114.39 BT- 115.83 BT. Preliminary data in the form of FAA still needs correction with Bouguer correction so as to obtain the value of SBA (Simple Bouguer Anomaly).

2.2. A subsection

The data obtained from TOPEX cannot be directly used as input in power spectral because Bouguer correction must be done to obtain SBA value as input in power spectra. Figure 1 shows the research flow diagrams used to estimate the limits of discontinuities of the island of Bali. FAA data obtained from TOPEX is predicted from \(\rho\) (mass density) using Parasnis and Nettleton method. The estimated value of \(\rho\) is used to get Bouguer Correction (BC) value \[12\]. After the value of BC is obtained the initial FAA value is subtracted by the value of BC so as to obtain a simple Bouguer anomaly (SBA). BC is an anomaly gravity correction due to the excess mass between the measurement site and the reference plane \[13\]. Bouguer correction serves to calculate the effect of mass attraction between the measurement site and the reference plane \[15\].
Power spectral density analysis method is used because the method can separate anomaly gravity from residual anomaly and regional anomaly. From the separation of residual anomalies and regional anomalies, an estimate the depth discontinuity limit on Bali island will be obtained. In the method of power spectral density anomaly gravity data is transformed from time domain into frequency domain of wave number in Fourier series [15]. After the SBA data was obtained, 11 cross-sections were made on the SBA data on the island of Bali to obtain an anomaly profile. Fourier series transformation in anomaly gravity data is performed using the following equation [16]:

$$
\Delta \tilde{g}(x_i) = \sum_{n=0}^{N} \lambda_n \left( A_n \cos \frac{n \pi x_i}{L} + B_n \sin \frac{n \pi x_i}{L} \right)
$$

(1)

The power spectral density equation for dimension 1 can be written to be:

$$
E_n = (A_n^2 + B_n^2)
$$

(2)

The uniform density distribution below the surface of the earth can be caused by the geological structure inside [17]. If the density distribution is random, so no correlation occurs in the gravity value, the frequency of response can be 1, so the power spectral density equation becomes:

$$
E_n = Ce^{-2\omega |d|}
$$

(3)

$$
\log E = \log C - 2\omega |d|
$$

(4)

where:

- $C$ = constant
- $\omega$ = angular frequency
- $d$ = depth of boundary field
To obtain two logarithmic prices which is the difference of two power spectrums in equation (6), it is obtained:

\[ |d| = \frac{1}{4\pi} \log \frac{E1}{E2} = \frac{1}{4\pi} \tan \phi \]  

where:
- \(E1, E2 = \) power spectrum
- \(k1, k2 = \) Wave number
- \(\phi = \) slope angle of the power spectrum curve

The data used is the result of slicing data from 12 trajectories that have been made. The value of power spectra and wave number is obtained from the processing using the MATLAB program. The processing using MATLAB will be obtained the relationship between wave number and power spectra in graphic form. There are 2 gradients on the graph relation of wave number and power spectra. The gradient represents the ultimate in the two discontinuity limits. Low frequency gradients represent deep discontinuities while high frequency gradients represent superficial discontinuities [8].

3. Results and Discussion

Simple Bouguer anomaly is an anomaly gravity data that has been corrected using Bouguer correction without using field measurement data. The Bouguer anomaly expresses the difference in the actual gravity of the earth by the gravity of a theoretical homogeneous earth model in a particular reference datum [18]. FAA data and topography obtained from TOPEX is processed first to obtain simple bouguer anomaly value. From the processing area of the island of Bali has an anomaly bouguer average of 68 mgal with the largest anomaly concentrated on the area of Mount Agung with bouguer anomaly of 334 mgal. Figure 2 shows an anomaly bouguer map on Bali island.

![Figure 2. Map of bouguer anomalies on Bali island](image)

Figure 3 shows a slicing of 11 trajectories on the island of Bali. This slicing aims to obtain the anomaly gravity profile used in the power spectra input. Slicing making does not use a spacing of a fixed distance but slicing is done on areas with interest anomaly gravity. The trajectory aims to obtain
the spectral distribution of anomaly gravity so as to represent the depth of the anomalous source by transforming in the Fourier series from the time domain to the frequency domain.

![Figure 3. Map of Bouguer anomalies on Bali island with 12 line](image)

The anomaly profile of line 9 and line 10 is made close together because in that region it has an anomaly gravity so that it is necessary to have slicing with adjacent spaces to represent the limit of discontinuity well. Regional anomalies are identified as deeper anomalies while anomaly residuals are identified as more shallow anomalies. Here are the results of power spectral density processing on the island of Bali from line 1 to line 12.

![Figure 4. Line 1 power spectral analysis of Bali Island](image)

![Figure 5. Line 2 power spectral analysis of Bali Island](image)
Figure 6. Line 3 power spectral analysis of Bali Island

Figure 7. Line 4 power spectral analysis of Bali Island

Figure 8. Line 5 power spectral analysis of Bali Island

Figure 9. Line 6 power spectral analysis of Bali Island

Figure 10. Line 7 power spectral analysis of Bali Island

Figure 11. Line 8 power spectral analysis of Bali Island
In figure 4 to figure 15 shows the results of power spectral graphs depicting 2 different gradients. Figure 11 and Figure 12 are seen if there is noise depicted from the wave spectral and power spectral relationship curves. The noise data is near the anomaly residual gradient. Each density contrast in each segment represents a shallow and deep anomaly source [19]. Each trajectory of slicing has a different gradient pattern because of different anomaly profiles in each slicing path [20]. Line 1 to line 4 delivers a considerable inner discontinuity limit ranging from 56 km to 69 km. The more heading east until line 12 the estimated depth limit of discontinuities within the island of Bali is shallower with depths ranging from 18 km to 40 km.
Table 1. Average depth of shallow and deep discontinuity in Bali area

| Line  | Deep discontinuity | Superficial discontinuity |
|-------|--------------------|---------------------------|
| line 1| 69.6204            | 5.9267                    |
| line 2| 68.6036            | 5.9267                    |
| line 3| 56.3363            | 3.8146                    |
| line 4| 68.0653            | 3.9007                    |
| line 5| 18.3037            | 1.3119                    |
| line 6| 30.8751            | 2.3497                    |
| line 7| 29.4714            | 2.2411                    |
| line 8| 33.7828            | 0.51935                   |
| line 9| 40.1816            | 1.4662                    |
| line 10| 33.6673           | 1.3558                    |
| line 11| 34.7158           | 1.9443                    |
| line 12| 37.1457           | 0.9176                    |
| Average| 43.39741667       | 2.639554167               |

From the result of data processing shown by Table 1 is obtained if the average depth of shallow discontinuity is 2,639 km and the discontinuity is 43,397 km. Among the 12 tracks that have been made of path 1 is the deepest inner depth discontinuity with a depth of 69.62 km. While track 8 is a path with the shallowest superficial discontinuity limit with a depth of 519.35 m. Allegedly if the layer of rocks located on the island of Bali is a Miocene rock that is still a layer of young rocks in geology timescale.

4. Conclusion

Although Bali is a region with high tectonic activity the island of Bali is a region with a young age in the geological timescale. This is based on the results of power spectral analysis of Bali island obtained if the average depth of shallow discontinuity of 2.639 km and discontinuities in the amount of 43.3974 km. the rocks on the island of Bali is a Miocene rock with an initial body density of 2.6 gr/cm$^3$. The depth of shallow discontinuity ranges from 519.35 m hi to 5.92 km with an average depth of 2.63 km. While the depth of discontinuities in the range of 18.30 km to 69.62 km with an average depth of 43.39 km. It is estimated that the sediments of Bali island are shallow because of the rock age of the island of Bali which is still young adrift in the geological time scale.

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