Delineation of The Sumatra Fault in The Central Part of West Sumatra based on Gravity Method

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Abstract. The Sumatra Fault System is elongated across the Sumatra Island, Indonesia, Southeast Asia including the central part of West Sumatra, Indonesia, Southeast Asia. The Sumatra Fault and subsurface structure on the Central Part of West Sumatra had been analyzed using gravity method. Bouguer anomaly data were obtained from GRDC (Geological Research and Development Centre) maps, Bandung, Indonesia (i.e. without terrain correction). In this study, terrain correction had been applied to these Bouguer data. Bouguer anomaly in a horizontal plane at 3000 meters high and equivalent depth of mass point 7000 meters were obtained using Dampney Method. Residual and regional anomalies were separated using upward continuation method at 8000 meters high. The result of the SVD on residual anomaly shows two negative anomalies on northwest – southeast. The zero miligal per meter square quantity coincides remarkably well with trace faults which is a part of the Sumatra Fault System. Two negative anomalies are located around the Sianok Segment and Sumani Segment.

1. Introduction

The study area is concentrated in the central part of West Sumatra which is part of West Sumatra, Indonesia, Southeast Asia. This study area lies between latitudes 0°N – 1°S and longitudes 99,76°E – 101,50°E. The Sumatra fault system is elongated across the Sumatra Island, Indonesia, including the central part of West Sumatra, Indonesia. The Sumatra fault is one of the active faulting in Indonesia. The fault zone of the Sumatra Fault runs along the entire 1600-km long Bukit Barisan mountain range on the west side of the Sumatra island [1]. From topographic maps and stereographic aerial photographs shows that the Sumatran Fault is highly segmented [2]. Topographic depressions, volcanoes, and east-west aligned magnetic anomalies are the signs found at the junction of the segments [1]. In addition to this, we can prove segmentation of the Sumatra Fault with subsurface identification. We can use geophysical method for subsurface identification.

Gravity method is one of the several methods in geophysics for subsurface identification of geological structure including faults. Local variations in the densities of rocks cause minute changes in the gravity field [3]. The gravity method is a passive method so does not need source to use and this is one of the advantage of the gravity method. The another advantage of gravity method is the gravity field relatively easy to interpretate because variations of the earth’s gravity is relatively uniform. Gravity field in the central part of West Sumatra has never been specifically discussed. In this study, we had been discussed the gravity field in the central part of West Sumatra and its correlation with the
Sumatra Fault. To enhance gravity anomalies, we have applied terrain corrections, upward continuation method and Second Vertical Derivative (SVD) to gravity data.

The geological information of the study area were obtained from the geological maps of Padang [4] and Solok Quadrangle [5]. The main fault of the study area is a part of the Great Sumatra Fault which trends to the northwest – southeast and represents as dextral fault [4]. The Great Sumatra Fault is associated with the formation of volcanoes and the other fault directions are northeast – southwest and north – south [4]. The simplification of the geological map of the study area is shown in Figure 1.

2. Method

Gravity data were obtained from Geological Research and Development Center (GRDC) Bandung, Indonesia, Southeast Asia in the form of contour maps for Padang [6] and Solok Quadrangle [7]. Gravity data in these contour maps were acquired with LaCoste and Romberg model G land gravity meters [6] and [7]. Latitude corrections were made using Geodetic Reference Systems, 1967. Bouguer corrections were computed using a density of 2,67 \( \text{tm}^{-3} \). Terrain corrections have not been applied because sufficiently reliable topographic maps were unavailable [6] and [7].

Gravity data has obtained from Bouger contour maps with 1,5 km of spacing grid. After the Bouguer contour map is extracted into gravity data, we have applied terrain corrections [8]. For terrain corrections, we have obtained topographic maps which include land via http://earthexplore.usgs.gov/ and marine via http://www.marine-geo.org/portals/gmrt/about.php. For inner and outer zone, we had been used 5 km [9] and 167 km [10], [11], [12], [13] and [14], respectively.

2.1. Reduction Bouguer anomalies onto a horizontal plane

Bouguer anomalies are measurements on an irregular grid with variety of elevations so, we have been projected onto a horizontal reference plane with Dampney Method [15]. Bouguer anomaly measurements on an irregular grid and at a variety of elevations can be synthesized by an equivalent source of discrete point masses on a plane of arbitrary depth below the surface [15]. By keeping the depth of the plane within certain limits relative (shown in Equation 1) to the station spacing, the synthesized field closely approximates the true gravity field above the topography.

\[
2.5\Delta x < (h - z_i) < 6\Delta x
\]  

(1)
2.2. Upward continuation

Bouguer anomalies in a horizontal plane, resulted from reduction onto a horizontal plane, is mixing of regional and residual anomaly. Residual and regional anomalies were separated with upward continuation method [16]. Upward continuation transforms the potential field measured on one surface to the field that would be measured on another surface farther from all sources [17]. The potential field is completely known if over another surface and no masses are located between the two surfaces. The fact that gravity fields obey Laplace’s equation permits us to determine the field over an arbitrary surface. By Fourier transforming the measured data, multiplying by the exponential term of equation, and inverse Fourier transforming the product, a level to level continuation can be achieved. Fourier transform of upward continuation is given by Equation 2 [17].

\[ F[f] = e^{-\Delta z k} \delta \]

(2)

2.3. Second Vertical Derivative (SVD)

Delineation of the Sumatra Fault were made using Second Vertical Derivative method. The second vertical derivative can be obtained from the horizontal derivatives because the gravity field satisfies Laplace’s equation [3]. If \( \phi \) is measured on a horizontal surface, then Laplace’s equation can be transformed to the Fourier domain [17] as shown in Equation 3.

\[ \mathcal{F}\left[ \frac{\partial^2 \phi}{\partial z^2} \right] = |k|^2 \mathcal{F}[\phi] \]

(3)

Hence, the second vertical derivative of a potential field measured on a horizontal surface is framed as a three-step filtering operation: Fourier transform the potential field, multiply by \( |k|^2 \), and inverse Fourier transform the product [17].

3. Result and Discussion

Terrain correction had been applied to Bouguer data and results values – 50.71 to 44.04 mgal. Gravity field in the central part of West Sumatra which is applied terrain correction is shown in Figure 2.

![Figure 2. Bouguer anomaly have been applied terrain correction in the central part of West Sumatra based on data from GRDC maps. Low to high anomaly is marked by colour scale (mgal).](image)
We do not make detailed interpretation in these anomalies to avoid ambiguity of interpretation. As we have explained in method that Bouguer anomalies are measurements on an irregular grid with variety of elevations. Because of that, we have continued our data processing. Bouguer anomaly has been projected onto a horizontal reference plane with Dampney method. The result of these method is Bouguer anomaly in a horizontal plane at 3000 meters high and equivalent depth of mass point 7000 meters. Bouguer anomalies in a horizontal plane is mixing of regional and residual anomaly. Because of they are mixing, we need to separated them. Regional and residual anomaly have been separated with upward continuation method with 8000 meters high. The result of Upward Continuation is regional and residual anomaly. To delineation of the Sumatra Fault in the study area, we have been used Second Vertical Derivative (SVD) Method to residual anomaly. The SVD Map on residual anomaly in the study area is shown in Figure 3.

![Figure 3](image)

**Figure 3.** The SVD Map of residual anomaly in the central part of West Sumatra. Low anomalies are concentrated in the surrounding area of Maninjau and Singkarak. SVD Map forms elongated zero contours which correspond to the faults.

Low anomaly in the surrounding area of Maninjau Caldera in Figure 3 is assumed as a deficit massa of the large eruption. Maninjau is a large collapsed caldera that was resulted from a large eruption of silicic pyroclastic material (220 – 250 km$^3$) [18]. Low anomaly in the surrounding area of Singkarak Lake is assumed by subsidence of the lake. At present, all of the faults in the Singkarak Lake are active, therefore subsidence of the lake still continues [19]. The lowest anomaly in the southwestern part of the lake is correlated with a structural graben. Sumani Segment runs northwestward from the volcanic terrane of Lake Diatas to the southwestern flank of Lake Singkarak which occupies a structural graben [2].

The resultant Second Vertical Derivative (SVD) gravity map forms elongated zero contours which correspond to the edges of local geologically anomalous density distributions features [20]. The zero miligal per meter square quantity coincides remarkably well with most lithological boundaries when compared with the major geologic contacts [20]. In this study area, the zero miligal per meter square quantity has no correlated with litology boundaries [21]. The SVD map forms elongated zero countours which correspond to the faults which is a part of the Sumatra Fault. The zero miligal per meter square quantity coincides remarkably well with fault segmentation. When compared with Map of geometrically defined segments of the Sumatra Fault System [2], two negative anomalies are located around the Sianok and Sumani Segment.
4. Conclusion

We had been specifically discussed the gravity field in the central part of West Sumatra and its correlation with the Sumatra Fault. To enhance gravity anomaly, we have been used terrain correction, upward continuation and SVD method. From gravity method, we can prove segmentation of the Sumatra Fault in the central part of West Sumatra. Deliniation of the Sumatra Fault in the central part of West Sumatra with gravity method shows that two negative anomalies are located around the Sianok and Sumani Segment.

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