Gravity data processing of field camp geophysics in Karangsambung (2005-2019)

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Abstract. Gravity data was collected from a previous survey in Karangsambung 2005-2019 (before the restriction of field camp activities due to the Covid-19 pandemic). Luk-Ulo Mélange Complex in the Karangsambung area has been the subject of local and regional studies for geoscience students due to the interesting exposure of outcrops that have been interpreted as product of subduction (the Indo-Australian plate under the Eurasian plate in the Late Cretaceous to Early Paleocene time). The data for this gravimetric study based on 2592 observations over an area of inside (9.1 x 9.1) square kilometers. The gravity data were observed by students in the field camps for several years and then we compile. In this work we present simple data processing and simple calculation for modeling. The Bouguer anomaly map was processed using a density estimate of 2.31 g/cc for slab-Bouguer and terrain correction/reduction. The residual anomaly map was obtained by simple calculation of trend surface analysis (second order polynomial order). The inverse model was calculated using a simple algorithm for 2.5D and the program was built by accommodate topographic variations in the study area. Slice sections (SW-NE) of residual anomalies with a length of more than 8 km were inverted to obtain the contrast density distribution as a subsurface model. The subsurface images can then be analyzed and correlated with geological surface maps in the study area. The work in this paper is mainly presented as an illustration of simple data processing and inverse modeling, so that the outcomes of this work are: (1) Bouguer anomaly map, (2) residual anomaly map, and (3) contrast density distribution as SW-NE section in the Karangsambung area. The value of the Bouguer anomaly map from this study is in the range of 88 to 112 mGal, and the value of the residual anomaly map is in the range of -12 to 10 mGal. The contrast density distribution from the inverse model in this study is in the range of -0.3 to 0.6 g/cc.

1. Introduction
During the covid-19 pandemic, we summarize the activites of gravity data acquisition (2005-2019) of annual field camp course and also provide the link-up to the reference value of gravity from absolute gravimeter that previously observed in ITB campus [1]. The map compilation of gravity observation cover lithostratigraphy unit as part of Luk-Ulo Melange Complex, Karangsambung Complex, and Waturanda Volcanics (referred to tectono-stratigraphy of Lok Ulo Area [2]). The work in this paper is mainly presented as an illustration of simple data processing and inverse modeling. Gravity data processing, filtering, and modeling was calculated using simple formulation. Background density for Bouguer gravity anomaly calculated with density estimation. Extensive computation with larger area for terrain correction was conducted in this study during density estimation stage. The comparison of inverse modeling using Simple Bouguer Anomaly (SBA) and Complete Bouguer Anomaly (CBA) also calculated to provide density distribution in the subsurface. We would like to understand the density contrast distribution using standard or general inverse calculation as initial step for quick correlation with near surface lithology. More complex subsurface model could be needed with strong intervention from interpreter using more flexible modification for model geometry and contrast density value in the subsurface.
2. Bouguer Gravity Anomaly

Bouguer anomaly map is calculated using 2592 gravity observations \( g_{obs} \) in this study area. The mathematical formulation for SBA and CBA in this work was calculated using equation (1) and (2), respectively. More details formulation for each corrections \{theoretical gravity \( g_0 \), free-air correction \( g_{fa} \), Bouger slab correction \( g_{sb} \), terrain correction \( g_t \)\} also can seen in previous study [3] and [4]. Based on textbook [5] we summarize the equations SBA \( \Delta g_{sba} \) and CBA \( \Delta g_{cba} \) as follow:

\[
\Delta g_{sba} = g_{obs} - g_0 - g_{fa} - g_{sb},
\]

\[
\Delta g_{cba} = \Delta g_{sba} - g_t.
\]

For the last two corrections (Bouger slab correction and terrain correction), we use Parasnis density estimation [6]. The density estimation with more than 2500 data illustrated in figure 1. The gradient of linear trend from dot plot in figure 1 shows the density estimation 2.31 gr/cc for the study area.

A Terrain correction was calculated using digital elevation model [7]. We devide topographic/terrain effect for each gravity stations into near zone and intermediate zone. Sloped triangular body and rectangular body, respectively used in the calculation for near and intermediate zone (more detail formulation can seen in previous study [3] and [4]). In this work, very high cost computation conducted for near zone and intermediate zone (to cover terrain radius more than 20 km) involving 443.556 discretization of digital elevation model with 100 meters interval grid. Far zone with 2.7 km average of interval grid to cover terrain radius more than 200 km also conducted with 32.341 discretization of digital elevation model.

The comparison of gravity data processing shown as maps in figure 2. The elevation data (figure 2a) qualitatively shows strong negative correlation with the value in gravity observation (figure 2b). Theoretical/normal gravity (figure 2c) shows increasing value as a function of latitude. Free-air anomaly (FAA), SBA, and CBA shown respectively in figure 2d, figure 2e, and figure 2f. The value of the FAA, SBA, and CBA from this work are respectively shown in the range of 75 to 125 mGal, 80 to 102 mGal, and 88 to 112 mGal.
3. Regional-Residual Gravity Anomaly

Bouguer anomaly maps (SBA or CBA) most of the times are considered as a superposition of sources at various depth. The effects of deeper sources in the subsurface is commonly called as regional gravity anomaly, while the residual gravity anomaly is commonly the term for gravity field (Bouger anomaly) after near surface noise and regional anomaly have been removed. Filtering out the regional gravity anomaly (long-wavelength) or residualizing process is usually is not complete (both regional and residual are distorted by the effects of each other).

Residualizing can also be thought as predicting the values expected from deep features and then subtracting them from gravity field (Bouger anomaly) values, so as to leave the shallower effects [8]. In this work, we illustrate the regional-residual gravity anomaly with simple calculation of trend-surface analysis (TSA). For regional anomaly, we use the representation of second order polynomial surface and the parameters of the analytic surface are determined by a least-square fit.

The illustrations of simple filtering/residualizing process for this work are shown in figure 3. As comparison we work with SBA and CBA as gravity field. In figure 3a (SBA) map are use to find the parameters of analytic surface (regional anomaly from SBA). The TSA with second order polynomial surface from SBA is shown in figure 3b and residual anomaly from SBA is shown in figure 3c. In figure 3d (CBA) map are use to find the parameters of analytic surface (regional anomaly from CBA). The TSA with second order polynomial surface from CBA is shown in figure 3e and residual anomaly from CBA is shown in figure 3f. The value of the residual anomaly maps are shown in the range of -12 to 10 mGal.
Figure 3 The illustration of residualizing process: a) SBA, b) regional anomaly from SBA, c) residual anomaly from SBA, d) CBA, e) regional anomaly from CBA, and f) residual anomaly from CBA.

4. Inverse Modeling

After data processing, we attempt to present the simple illustration of quick modeling calculation. The inverse calculation from residual anomaly were conducted to obtain the contrast density distribution as a subsurface model. The subsurface images can then be analyzed and correlated with geological surface maps in the study area.

The physical parameter distribution will be calculated in the scheme of 2.5D subsurface modeling. The location of line section (SW-NE) in the study area for 2.5D subsurface modeling is shown in figure 4. The SW-NE section overlayed over elevation map (figure 4a), residual from SBA map (figure 4b), and residual from CBA map (figure 4c). The slice section (SW-NE) from figure 4 is illustrated in figure 5.

Figure 4 The SW-NE section overlayed over: a) elevation map, b) residual map from Simple Bouguer Anomaly, and c) residual map from Complete Bouguer Anomaly.
The forward calculation using a set of rectangular prism can be calculated using Pluoff equation [9] that extensively used in several study (such as: [10], [11], [12], and [13]). The more general of matrix notation of forward calculation for synthetic data (d) with model parameter (m) can also be expressed as follow:

\[ d = Gm, \]  

where \( G = G_{ij} \) is the Kernel matrix. Generally, the linear inverse problem for equation (3) is solved to get the estimated value of a model parameter (\( \hat{m} \)). Residual gravity anomaly as observational data input (\( d_{obs} \)) used in the computation for the solution of inversion problem (a minimum-norm solution). The inverse problem is under-determined and the computational scheme in this work also involves the initial model (set-up as default form of an uniform model parameter \( \hat{m}_{k=0} = 0 \)). The miss-fit data for \( k \)-iteration calculated using root-mean-square-error (RMSE). The minimum-norm solution is updated iteratively in the \( k \)-iteration using the following equations:

\[ \hat{m}^{k+1} = \hat{m}^k + \Delta m^k, \]  

\[ \Delta m^k = G^T D (D G G^T D + \varepsilon I)^{-1} D (d_{obs} - G \hat{m}^k). \]  

In equation (5), the superscripts \( T \) describe matrix transpose, the symbol \( \varepsilon \) is a damping factor, and \( I \) is the identity matrix. Mendonca and Silva [14] used a normalized matrix \( D \) with diagonal matrix elements.

Inverse modeling using residual gravity anomaly from SBA and CBA can be seen in figure 6 and figure 7. Density distribution for SW-NE section shown in colour scale of density contrast (-0.3 to 0.6 g/cc). The background density for inverse modeling can be recall the value from Parasnis density estimation (2.31 gr/cc). Using simple calculation of inverse modeling, in this work we can see famous feature of high value of contrast density distribution around Parang Mountain and Paras Mountain. For quick correlation of density distribution in the near surface, we present the marker from geological map [2] in figure 6 and figure 7. Some lithostratigraphy unit along SW-NE section as surface marker are coded as follow: Sc (Scaly Clays), Cb (Clay Breccia), Vb (Volcanic Breccia) and Bd (Basalts and Diabas). The lithostratigraphy unit along SW-NE section is part of Luk-Ulo Melange Complex, Karangsambung Complex, and Waturanda Volcanics. More interesting results could be shown with 3D model for the next work. More integrated results form the latest publication in this area (such as: [15],[16], [17], and [18]) can be integrated in the next interpretation report.
5. Conclusion

The work in this paper is mainly presented as an illustration of simple data processing and inverse modeling, so that the outcomes of this work are: (1) Bouguer anomaly map, (2) residual anomaly map, and (3) contrast density distribution as SW-NE section in the Karangsambung area. The density estimation from this work is 2.31 gr/cc and we get CBA map from this study is in the range of 88 to 112 mGal, while the value of the residual anomaly map from CBA is in the range of -12 to 10 mGal. The contrast density distribution from the inverse model in this study is in the range of -0.3 to 0.6 g/cc.

Simple calculation for processing and modeling in this work successfully recover subsurface density with good correlation with litostratigraphy unit in study area. More detail correlation between contrast density and near surface lithology should be considered in the next step for final model and interpretation.

6. References

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