Delineation of sedimentary sub-basin and basement configuration based on the upward continuation filter and 2d and 3d modeling of gravity data (a case study: Rembang Area and its surroundings)

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Abstract. East Java Basin is classified as a classical back-arc basin so that it is indicated that the basin has a complex structure and stratigraphy where there is an area called Rembang High. Rembang High is a gravity anomaly term that appears in Northern of East Java Basin area which has a higher value than other physiographic zone and is assumed to be associated with Rembang anticline. It is interesting to study the basement configuration and sedimentary sub-basin presumption. The gravity anomaly is superposition of all anomaly sources in the subsurface, namely regional and residual anomaly. The separation of regional and residual anomaly is done by using upward continuation filter. Optimum continuity height can be obtained from the cross correlation of two continuity heights. The residual anomaly was obtained from the difference between Bouguer and regional anomaly. In addition to use the optimum continuity height, anomalous source depth estimation is obtained by using spectral analysis. The results obtained using both upward continuation and spectral analysis shows the same optimal depth value of 3500 meters or 3.5 kilometers. 2D and 3D modeling is done to facilitate the interpretation of the condition of geological structures below the surface. The modeling result shows the existence of rocks that are raised (basement high) at a depth of 3.5 kilometers and basin depocenter at a depth of 5 kilometers with a basement which is assumed as a metasediment rock has > 2.7 g/cm³ density.

1. Introduction
Rembang High is an area in the North East Java basin which shows high Bouguer anomaly values compared to other physiographic zones in the area. Rembang High is suspected to occur due to the raised basement, but it is also suspected to be associated with Rembang anticline. The Rembang Zone comprises of the Eocene-Pliocene sequence which includes the edge sediments such as shallow seawater clastic sediments and carbonate sediments. In this zone, formed a large fault-bounded in the south-southwest known as Rembang high. The basements in the High Rembang zone include ophiolite, metamorphic rocks such as slate and igneous diorite [1]. Both anomalies interact and create an overlapping anomaly. Therefore, the anomalies have to be separated. There are various filters that can be used to separate the

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two anomalies, one of them is the upward continuation filter. Upward continuation is a step of changing the potential field data measured at a surface level into data as if measured at a higher surface level [2]. However, there are two main problems in this filter that is 1). The conventional Upward Continuation produces overattenuates on the region and 2). The height of continuity must be known in order to produce a regional anomaly [3]. The determination of height continuity can be done by comparing continuous gravity anomaly to different heights or subjective approach. However, this approach is not very effective to provide the correct optimum height because it creates ambiguity in the resulting data. This study aims to obtain an upward continuation elevation value objectively in order to produce an optimal regional anomaly and delineate the sedimentary sub-basin based on Residual Anomaly Map. The benefits of this study are to provide an alternative approach to obtain the optimum continuation elevation value in obtaining regional anomalies as well as provide an initial description of the subsurface geological conditions of the study area, including: sedimentary sub-basin delineation, basement configuration, geological structure patterns and the depth of basement in the area of Rembang and its surrounding areas.

2. Review of literature

Bouguer anomaly is a superposition of overlapping regional and residual anomalies, so the separation of the two anomalies is necessary. This separation is done by using upward continuation filter. This filter is used because it can transform the measured potential field measured on a surface so that the potential field elsewhere on the surface of the measurement tends to accentuates anomalies caused by deep sources (regional effects). The potential gravity field data that is as if measured at a higher level of the earth's surface reflects the potential field that lies beneath the earth's surface at equal distances between the earth's surface and its upper surface level. In that position, the upward continuation filter eliminates the effects of shallow anomalies and generates regional anomalies. However, it also provides information about the depth of residual anomalies associated with the boundary between the sedimentary layers and the basement. The determination of the height continuity can be done with an objective approach as described in Zeng, et. al (2007) which is by using cross correlation. The cross correlation \( r \) between regional anomaly \( g_1 \) and upward continuity anomaly \( g_2 \) can be measured by using the following equation:

\[
r_{g_1g_2} = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} g_1(x_i,y_j)g_2(x_i,y_j)}{\sqrt{\sum_{i=1}^{M} \sum_{j=1}^{N} g_1^2(x_i,y_j) \sum_{i=1}^{M} \sum_{j=1}^{N} g_2^2(x_i,y_j)}}
\]

The correlation between the two heights is represented by the value \( r \), with \( g_1 \) as a Bouguer anomaly value on the first height continuity and \( g_2 \) as Bouguer anomaly value on the second height continuity. When the upward height continuity is less than the optimal value, the upward continuity anomaly clearly consists of two (2) components: regional anomalies and residual anomalies. Whereas if the height of upward height continuity is greater than the optimal value, the residual anomaly will decrease and almost disappear. Such conditions will result in a regional component.

3. Research Method

The research was conducted in the border area of Central Java-East Java covering four (4) districts, namely Kudus, Rembang, Salatiga and Ngawi. Geographically, the study area lies in coordinates: 110.5° - 111.5° E and 6.5° -7.5° S.

The gravity research data used are secondary Bouguer anomaly data of Kudus, Rembang, Ngawi and Salatiga areas. Secondary data Bouguer Anomaly obtained as much as 4482 data along with coordinates (Latitude, Longitude). The initial stage of the research is to make Bouguer Anomaly contour map. Furthermore, the process of spectral analysis is done on the contour map of Bouguer Anomaly with 10 tracks, namely the track 1 to track 10. The trajectory is directed from North to South so it can represent
the high anomalies in the North and the lower anomalies in the South. Then the separation of regional and residual anomalies using the Upward Continuation filter was done. At this stage, an upward continuation of the Bouguer Anomaly with some height continuity is accomplished. The sample interval used is 500 m, with continuity heights ranging from 1000 to 9500.

After an anomaly map at some of the height continuity was generated, then cross correlation between two consecutive heights was done. The correlation results were presented in the form of correlation graph to the height resulting in maximum deflection. This deflection can be known by drawing a line between two end points, the starting point and the end point. Then a difference between the correlation curve with two point-connecting line was done. The height associated with the maximum deflection is the estimated optimal height. The final stage of the data processing is to do the 2D forward modeling and 3D inversion. 2D modeling is done by using oasis montaj 6.4.2 software. The residual anomaly map is done by slicing using gm-sys application, then the response of the calculation data and the field data that have not fit appeared. Then to generate a matching data response, a subsurface parameter was made which refers to the geological conditions in the study area. 3D inversion modeling aims to determine the distribution of mass density values below the surface of the earth and to find out the configuration of basement in the research area by using Grablox software. The inversion method on Grablox software used is Occam inversion where the purpose of the inversion of this software is to optimize the density and block size. In this research, two occam inversions was done, namely occam which aims to maximize the density value of blocks so that the resulting model is smoother and occam h which aims to maximize block height (layer depth). The density distribution obtained from the inversion shows the configuration of basement determined based on the reference of rock density value.

4. Result and Discussion

4.1 Bouguer Anomaly Map

The Map of Bouguer Anomaly Research Area shows anomaly values in the study area ranged between -50.8 mgal to 47.6 mgal.

4.2 Filter Upward Continuation

On the Bouguer Anomaly Map that has been obtained is then performed an Upward Continuation filter at several continuation height that aims to find out the optimal regional anomaly. The height continuation used ranging from 1000 m to 9500 m with a range of values between heights as much as 500 m.

Figure 1. Bouguer Anomaly Map of the research area which includes Kudus, Rembang, Ngawi and Salatiga area
Figure 2. The graph $h$ to the cross-correlation value and the line connecting the starting and ending points. The line is used to find out the optimum $h$ by making a value interpolation which then obtained a difference between the cross-correlation value and the result of the interpolation of the line on the same $h$.

4.3 Sub-basin Delineation

Figure 3. The graph $h$ to the result of the difference of cross-correlation and value interpolation which generated maximum deflection. The maximum deflection is related with the optimum $h$.

Figure 4. Residual Anomaly Map resulted from the Bouguer anomaly difference and Regional anomaly difference. There are high and low patterns. The high pattern shows the high Bouguer anomaly value represented by the color pink. The low pattern shows Bouguer anomaly value represented by the color light blue.

The residual anomaly map shows a maximum contour value of 11.6 mGal and the lowest value of -9.9 mGal. The residual anomaly shows the existence of high pattern and low pattern indicated by the pink color for the high pattern and dark blue for the low pattern. This high anomaly shows the presence of rocks with large density contrast. The high anomaly value in the northern part is a response from the volcanic area on Mount Muria. Meanwhile, the pattern of the height that spreads in the middle of the West-East direction is a response of the high structure (Basement high) known as Rembang High. Based on the geology of the study area, this high pattern is also influenced by the presence of metasediment rocks that produce high density values. The lower anomaly in the southern part indicates rocks with low density contrast. This type of rock with low density is shown by the sedimentary rocks that possibly are
the sub-basins located in the study area. On the residual anomaly map shows 5 patterns suspected as sediment sub-basins, consisting of sub-1, sub-2, sub-3, sub-4 and sub-5. Sub-2 shows a wider sub-basin area compared to other sub-basins. Sub-1 to sub-4 are located in Southern area that spread in Salatiga and Ngawi areas. Meanwhile, the sub-5 is between Mount Muria and Rembang High around Kudus area.

4.4 Basement Configurations

On the A-A’ trajectory based on the svd graph, six faults are modelled which consists of five horsts and one graben. The horsts rise due to the presence of compression or strong pressure in this case caused by the push and pressure from the formation of Basement High. When the magma pushes the basement, there are fragile zones that are unable to withstand the pressure causing the fracture to occur. Graben occurs in the sediment sub-basin, this is certainly possible because the sedimentary rocks are more fragile than the basement and subsidence occurs due to the overburden of sediments above it.

![Figure 5. Cross-section resulting from the A-A’ trajectory inversion](image1)

![Figure 6. Cross-section resulting from the B-B’ inversion trajectory](image2)

The rock density of 2.5 g/cm³ is interpreted as a limestone with a thickness of ± 2000 m which is found at a depth of 2000 - 4000 m. 2.4 g / cm³ rock density is interpreted as claystone with the thickness of 1000m and found at 1000-2000 m depth. The 2.3 g / cm³ rock density is formed by Pliocene sediments interpreted as feldspathic sandstones with a thickness of ± 1000 m. The cross section of B-B’ modelled in Figure 4.16 has a trajectory length of 110 km in the northeast-southwest direction. This trajectory is selected because it passes through the High Rembang zone and the zone of the sediment sub-basin. Based on the geological map, the trajectory B-B’ is passed through seven formations, namely Aluvium (Qa), Fm. Bulu (Tmb), Fm. Ngayong (Tmn), Kapung Member Fm. Kalibeng (Tmkk), Fm. Kalibeng (Tmvp), Fm. Kerek (Tmk) and inseparable volcanic rocks (Qvu).

Based on the 2.5 D modelling of the B-B’ trajectory in Figure 4.26, the basement configuration is modeled at various depths caused by the presence of high and low areas, besides a high basement is formed at a distance of 20 km to about 45 km. On the B-B’ trajectory, four faults, which consists of two horsts and two grabens are modeled. The horsts occur around the Basement High due to pressure and push at the time of its formation. Based on the SVD graph, on the B-B’ trajectory, there are grabens, which are in the vicinity of Basement high and sediment sub-basin. Meanwhile on trajectory A-A’, there is one graben that exists around the sediment sub-basin due to the sedimentary rocks are more fragile than the basement and subsidence occurred due to the overburden of the sediment above it.

5. Conclusion

The optimum continuity height resulting from the correlation between two continuous heights is obtained at 3500 m. This value indicates a shallow anomaly discontinuity limit, which is also obtained from the spectral analysis. Spectral analysis showed a shallow discontinuity limit of 3551.5 m and a discontinuity limit of 25397.5m. Based on the residual anomaly map, the anomaly pattern consists of
the high and low pattern. The high pattern is a pattern that shows a high anomaly value (4.5 to 9.6 mGal) which is suspected as basement high or Rembang high. Meanwhile, the low pattern shows a low anomaly value (-4.6 to -9.8 mGal) which is suspected as the sediment sub-basin region. It is suspected that there are five sub-basins consisting of sub-1, sub-2, sub-3 and sub-4 located in the Southern area and sub-5 region located between Mount Muria and Rembang high. Based on the modeling result, there is a basement high that has a density of 2.7 g/cm³ to 3.0 g/cm³ suspected as igneous rock and metasedimentary rock. This basement is formed due to the high's circular fault in the southeast-southwest direction. In addition, the sedimentary rocks formed in the area of study showed a density value of 2.55 g/cm³ which is interpreted as a limestone, rock with a density of 2.4 g/cm³ is a claystone and rock with a density of 2.35 g/cm³ is a sandstone. The deepest depocenter of the sediment sub-basin reaches a depth of 6 km.

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