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Research Article

SUBSURFACE MODELING OF YOGYAKARTA BASIN USING INVERSION METHOD OF GRAVITY DATA

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ABSTRACT
Measurement of the relative gravitational field in the central part of the south area of Yogyakarta has been successfully completed. This survey successfully measured the relative gravity field in 470 points which are evenly distributed. These cover area of 31 km *x* 31 km and are mostly located in Bantul Graben Yogyakarta. This study aims to determine the depth or thickness of the top basement sedimentary basins and modeling conditions of Yogyakarta Basin based on the constituent rock density contrast value.
We used of a La-coste & Romberg gravity meter type G-1118 MVR and GPS Trimble Navigations 4600 LS to measure the height measurement point, The distribution of the point measurements was performed by a semi grid pattern with the measurement path passing through the existing road or footpath to the distance about 1-2 km and the distance between the point of measurement varies around 0.5 km - 2 km. The relative gravity data is measured then doing the process, among others calibration readings into the unit of mgal, drift correction, high correction tools, tidal correction, normal gravity correction, free air correction, Bouguer correction and terrain correction. The gravitational field of data processing had been done with completed, called The Complete Bouguer Anomaly (CBA) in topography (at the point of measurement). The CBA data residing in topography then projected on a horizontal plane at a height of 500 m with the equivalent point source approach to mass at a depth of 5000 m using Damney method. The CBA data which had been on a flat surface and then separated used upward continuation method. Therefore the local component removed and lived regional component then do further modeling and interpretation. In this study used the inversion method using Grav3D software in order to determine the condition of layering of sedimentary rocks in the subsurface in this study area. Based on the inversion modeling results it can be concluded that the rocks making up the Yogyakarta Basin has a value of density contrast varies between -0.16 g / cc to 0.9 g / cc with bedding pattern in the form of syncline structure. The syncline structure has a depth of sedimentary rock in the middle between 6 km to7 km and on the edges have a depth of 2 km to 3 km.

***Keywords**: Inverse Method, Gravity Method, Density Contrast, Subsurface, Yogyakarta Basin*

INTRODUCTION
The Research area is located in the central part of southern region of Yogyakarta, Indonesia. It lies between Oya River as the east border and Progo River as the west border, between an active Merapi volcano in the north, and the Indian Ocean in the south. The Research area as a physiography area known as a Bantul Graben illustration is presented in Figure 1, and the detailed topography in UTM coordinate is presented in Figure 2.
Yogyakarta Basin is tectonically controlled by the subduction events the Indian-Australian oceanic plate subducting beneath the Eurasian continent plate since the middle Eocene to the present-day (Smyth *et al.*, 2005). Indian-Australian oceanic plate relative moves to the speed of about 6-7.1 cm /year is approaching the Eurasian continental plates are relatively stable. The Global plate tectonics of Indonesia is presented in Figure 3 (BMKG, 2013).
Because the subduction events Yogyakarta Basin is in the fore arch basin, as tectonically very active, forming ancient volcanism, which is active today is Mount of Merapi, which is the most active volcano in the world. Since Yogyakarta Basin position near the subduction zone earthquakes tends to occur naturally.

Figure 1: Illustration of the research area

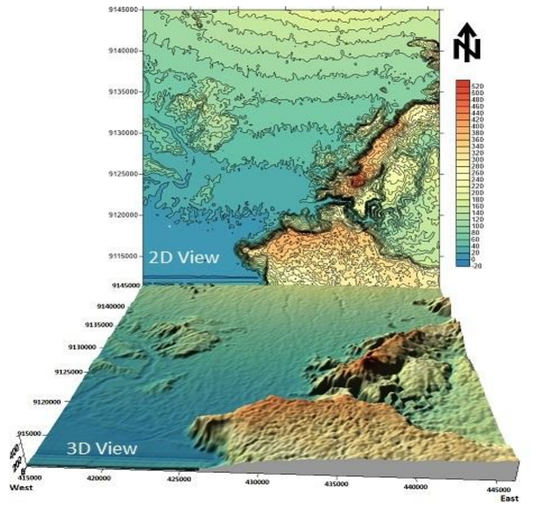

Figure 2: Detail topography in 2D and 3D view of the research area

The earthquake on May 26-th, 2006 occurred due to the activation of a fault in the Yogyakarta Basin (Elnashai *et al.,* 2008). As most experts in earth sciences (Sulaiman *et al.*, 2008; Sarah *et al.*, 2008; Mulyaningsih *et al.*, 2009) assumes that the earthquake causes activation of the Opak Fault. Because of the position of Yogyakarta Basin at the fore arch basin which is estimated age is still young and relatively shallow depth so that predicted less prospects for the hydro carbon (Koesumadinata, 1983). The research on Yogyakarta Basin is slightly let alone the use of the geophysical methods approach. This research is aimed to determine the depth of sedimentary rocks in Yogyakarta Basins and to draw model of subsurface conditions based on the rock density contrast using 3D inverse method of gravity data. The results of this study are expected to provide an overview of the condition and structure of the subsurface rock in Yogyakarta Basin. It is also expected to be a reference for further studies of Yogyakarta Basin.

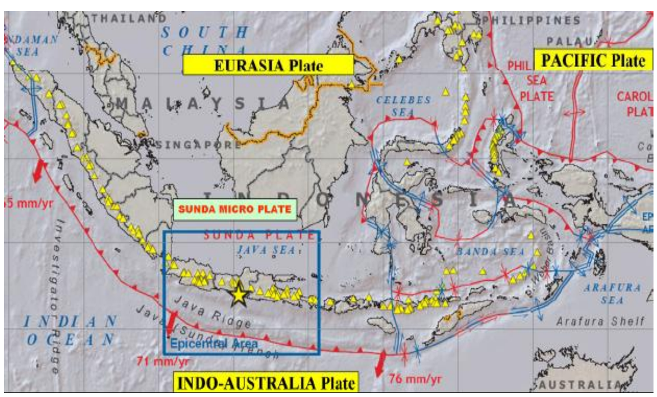

Figure 3: Global tectonics of Indonesia (Elnashai *et al.*, 2008)

MATERIAL AND METHODS

2.1. Geology of Research Area

Based on the distribution of physiographic zones of Central Java compiled by Van Bemmelen (1949), the study area is part of the Southern Mountains Zone. The morphology of the study area can be grouped into three units. The first is the plains unit, it is located on the west side of Opak River which is part of the low-lying Yogyakarta. This area is composed by alluvial sediments volcanic Mount of Merapi. The second is strong undulation unit hills that is stretched along the east side of the Opak River. This area is composed of sedimentary rocks. The last is the plateau which is part of the Highlands Wonosari. This area is composed of limestone and reefs. The Stratigraphy of the study area generally composed of gravity sedimentation results in the Miocene epoch (Toha *et al.*, 1994). The regional stratigraphic column of the results of previous research studies is summarized in Figure-4 (Wahyuningsih *et al.*, 2009) and the Geologycal map (Rahardjo *et al.*, 1995; Sarah *et al.*, 2007) of research area is presented in Figure 5.

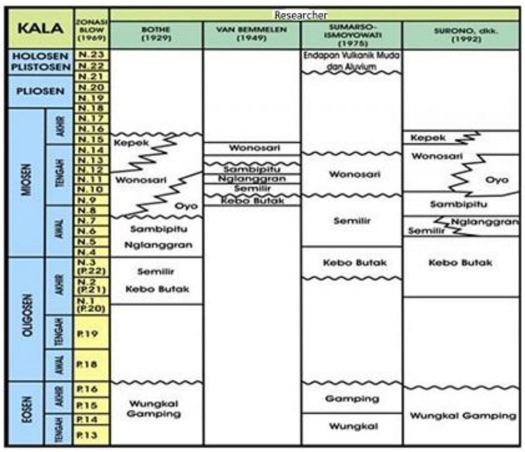

Figure 4: Stratigraphic column of the research areas of previous researchers in Wahyuningsih *et al.*, (2009)

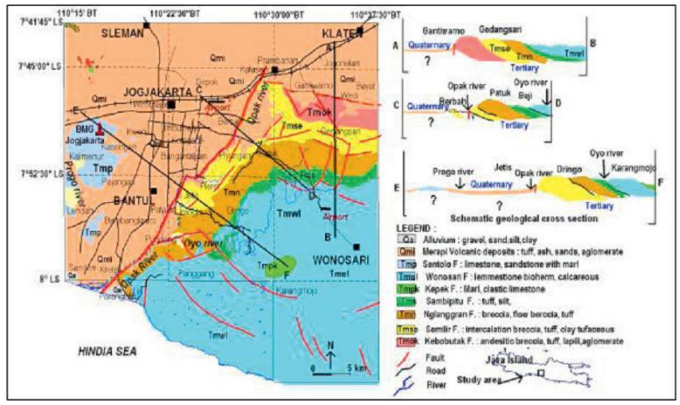

Figure 5: Geological map of the study area modification from the map compile by Rahardjo *et al.*, (1995) in Sarah *et al.*, (2007)

The oldest lithology of Yogyakarta Basin is Pre-Tertiary metamorphic rocks as bedrock and successively there on from old to young is (Wahyuningsih *et al.*, 2009): The first and the oldest of sedimentary rocks is the Wungkal Gamping Formation. This is characterized by calcarenite with inserts sandstone and mudstone. This formation deposits at the Upper Middle Eocene. Wungkal Gamping formation is an integral and inseparable formation (Surono, 1989; in Wahyuningsih *et al.*, 2009). The second is called the Kebo Formation. This formation consists of successively of conglomerate, sandstone, tuffaceous shale and silt. Pillow lavas are found in some places and diorite intrusion. The thickness of this formation reaches 800 m and deposits on the marine environment. The thirth is the Butak Formation. This formation is composed of breccias, tuffaceous sandstone, conglomerate, pumice, mudstone, and shale. It deposits in the marine environment over the Oligocene epoch. In some places, it is difficult to separate between Kebo Formation and the Butak Formation. Therefore, it is called Kebo-Butak Formation. The fourth is the Semilir Formation (Tmse). It is composed of interbedded of tuff, pumice breccia, tuff dacite and andecite tuff, tuffaceous mudstone and shale.

This formation deposits at the end of the Lower Miocene and the oldest rocks which exposed in the study area. The fifth is the Nglanggran Formation (Tmn). This formation is composed of volcanic breccia with fragments of andecite, flow breccias, agglomerates, lava and tuff. The Middle Miocene formations bottom and inter-fingering with Semilir Formation. The sixth is the Sambipitu Formation (Tms). It deposits at the Middle Miocene. This formation is composed of sandstones and successively of shale, siltstone, tuff and conglomerate. This formations is deposits over the Nglanggran Formation. The seventh is the Oyo Formation. This formation is composed by succesively of bioclastic limestone, marl with inserts calcarenit and fragmental limestone conglomerate. It deposits in shallow exposure conditions with agitation calm waves in the Middle Miocene epoch. The eight is the Wonosari Formation (Tmpw). It is composed of limestone reefs, calcarenite and tuffaceous calcarenite. This formation is deposited at Middle Miocene to Upper Miocene and is aligned above the Sambipitu Formation. The last and the youngest formation is the Kepek Formation. It is composed successively of layered limestone and marl. This formation deposits at Upper Miocene with a thickness of 200 m and is stratigraphically related inter-fingering with the Wonosari Formation. The top layer is the alluvial deposits of the Mount Merapi product.

2.2. Methods

The study was conducted by measuring the relative gravitational field in the area that served as the research object, namely Bantul regency area which is the largest research area, all of the city of Yogyakarta area, a small part area in Sleman regency, Gunung Kidul regency and Kulon Progo regency as presented in Figure 2. Those measurements were taken at each point and at each measuring point predetermined path to completion. Distribution locations measuring point is semi-grid and random, located on the roads side are there in the area of research. In making measurements, use looping and binding system to drift correction.

The main equipment used to measure the gravitational field at the points of measurement is a unit of La-coste & Romberg gravity meter type G-1118 MVR which has a precision in the order of micro gal (1 gal = 1 g / cm^2). The next equipment are two units (one set) of GPS Trimble Navigations 4600 LS type to measure the coordinates of the point of measurement (position and height), and a Garmin III plus GPS for field orientation.

The supporting equipment used in this study include a geological compass to measure the direction of strike and dip of outcrops, a topographic map study area to determine the points of measurement, a geological map to see rocks distribution and a Note book which includes Golden Surfer Software, Microsoft Exel, Grav3D, and Matlab for data processing and modeling.

Data measurement such as time, coordinates and altitude measurement point and the data are obtained from gravity meter. The data readings obtained from the gravity meter then they are calibrated in units of mgal, then the correction of tidal and drift correction of the obtained value of gravity observations (g_{obs}). The value of g_{obs} then corrected to normal gravity (gravity latitude), free air correction, Bouguer correction and terrain correction (Telford *et al.,* 1990; Reynold, 1997).

The gravitational fields data which are completely corrected or reduced, is called the Completed Bouguer Anomaly (CBA) in the topography. Rock density values used in the Bouguer correction is 2.2 g/cc which selected with Netleton analytical method (Netleton *et al.,* 1976).

Methods equivalent mass point from Damney (Blakely, 1995) is used for projection on a flat surface on the value of the BAC in topography. The CBA obtained at an altitude of 500 m above sea level with a depth equivalent mass point source at a depth of 5000 m below sea level.

The CBA data that was projected on a flat surface still contained local and regional components. In order to separate the regional anomalies and the local anomalies upward continuation method is used (Grant *et al.,* 1965). To model the subsurface conditions of the Yogyakarta Basin and perform a 3D inverse modeling of the CBA regional components data are used Grav3D software from UBC (made by UBC Geophysical Inversion Facility, Department of Earth and Ocean Sciences, University of British Columbia).

Gravity inversion method is to determine the density distribution of rocks in the earth's gravitational field using measurement data carried on the surface of the earth.

RESULTS AND DISCUSSION

From the measurements results of the gravity field survey, using appropriate processing method described in the previous chapter, obtained the regional component of CBA as presented in Figure 6.

It can be seen in Figure 6, the value of CBA in the central part of the study area, in the southwest toward the northeast were indicated by the dark blue color.

This qualitatively reflected the condition of the subsurface rocks which had small density contrast value or the relative thickness of the sediment rocks. South, east, north and northwest area have a relatively greater value CBA indicated with a yellow brown to red; it reflected the conditions in the subsurface rocks. These conditions had a high density contrast value or the thickness of the sediment rocks that is relatively shallow.

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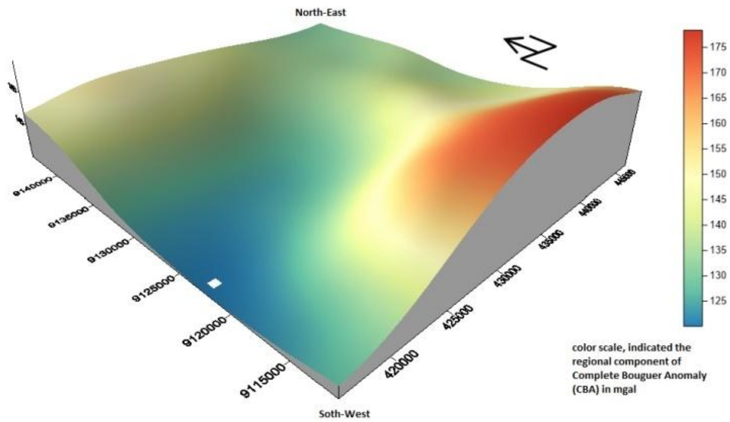

Figure 6: The regional component of Complete Bouguer Anomaly in the research area

From the regional component of CBA data, in the subsurface modeling based on the rock density contrast value with software grav3D from UBC. The modeling results illustrate the cross-sectional distribution of the rock density contrast. The Cross-section in the southern part is presented in Figure 7. The Cross-section in the middle part is presented in Figure 8. The Cross-section in the northern part is presented in Figure 9. The subsurface diagonal cross-section in the southwest to the northeast direction is presented in Figure 10.

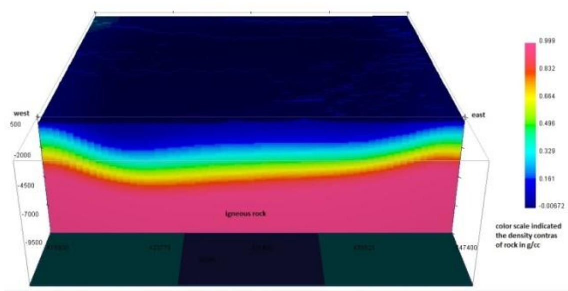

Figure 7: Subsurface cross section west (left) to east (right) at 9118300 northing (southern area of research)

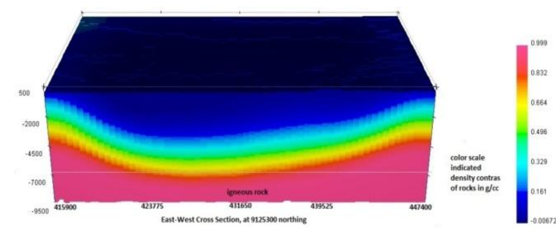

Figure 8: Subsurface cross section west (left) to east (right) at 913000 northing (the middle area of research)

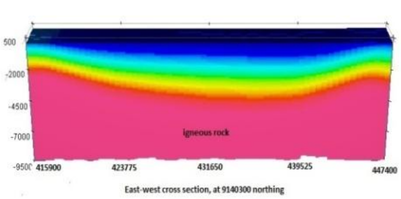

Figure 9: Subsurface cross section west (left) to east (right) at9140300 northing (northern area of research)

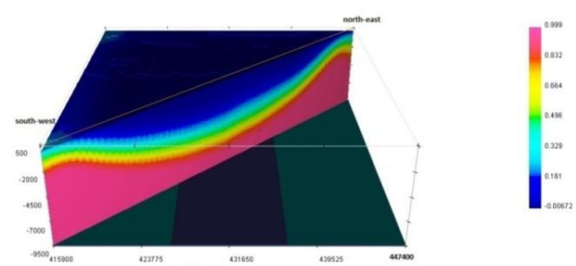

Figure 10: Subsurface cross section diagonally in the southwest to the northeast direction

While the distribution of density contrast from the upper view in 1000 m depth below sea level is presented in Figure-11, in 2000 m depth below sea level presented in figure 12 and in 4000 m in depth below sea level is presented in Figure 13, as well as the depth of the basin appeared on the Figure 14.

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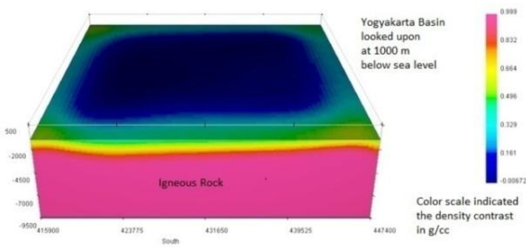

Figure 11: Subsurface cross section density contrast from the upper view at a depth of 1000 m below sea level

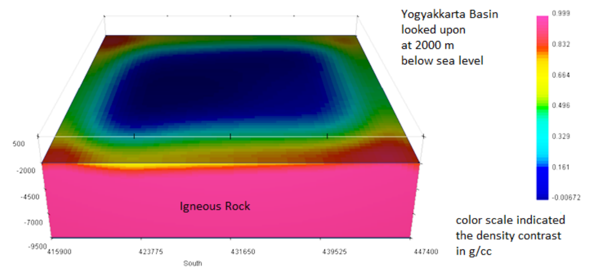

Figure 12: Subsurface cross section density contrast from the upper view at a depth of 2000 m below sea level

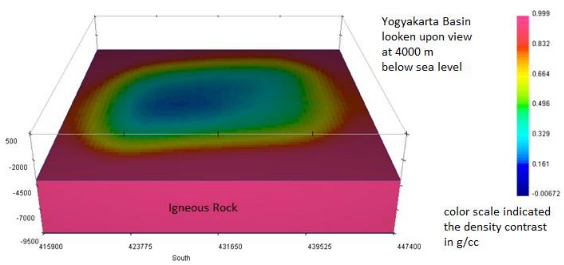

Figure 13: Subsurface cross section density contrast from the upper view at a depth of 4000 m below sea level

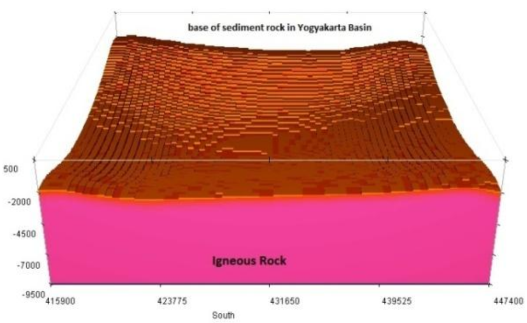

Figure 14: The depth of the bedrock (red color) from the upper view of the Yogyakarta Basin

From modeling result as shown in the figure above it can be concluded that the basin of Yogyakarta form Syncline Structure with a depth of sedimentary rock in the middle between 6 km -7 km and on the edges at a depth of 2-3 km. Based on the rocks density contrast value of the Yogyakarta Basin varied between minimum at - 0.16 g / cc to maximum at 0.9 g / cc which form the layering of the Syncline Structure. The rock with a density contrast – 0.016 g / cc to 0.0 g / cc was presented in the dark blue color which was interpreted as alluvial.

The rock with a density contrast between 0.0 g / cc to 0.1 g / cc was presented in blue color which was interpreted as the Oya Formation, the Kepek Formation and the Wonosari Formation. The rocks with density contrast of 0.1 g / cc to 0.2 g / cc was presented in light blue color which was interpreted as the Nglanggran Formation and the Sambipitu Formation. The rock with a density contrast 0.2 to 0.33 g / cc was presented in light blue color interpreted as the Semilir Formation. The rock with a density contrast 0.33 - 0.496 g /cc was presented in green color which was interpreted as the Kebo-Butak Formation. The rock with a density contrast 0.496 - 0.664 g / cc was presented in yellow color which was interpreted as the Wungkal-Gamping Formations. The rock with a density contrast of 0.664 – 0.882 g /cc was presented in red color which was interpreted as the metamorphic rocks that are the bedrock of the Yogyakarta Basin. While the density contrast between the value of 0.822 g / cc - 0.99 g/cc was presented with pink color which was interpreted as the igneous rocks.

Conclusion

As a conclusion, the syncline structure of Yogyakarta Basin has east-west and north-south direction. The depth of sedimentary rocks in the middle reaches 6 km to 7 km and at the edge varies between 2-3 km. The rocks in the Yogyakarta Basin form-bedding row from bottom to top are the igneous rocks, the metamorphic rocks and the sedimentary rocks. The sedimentary rocks are composed by the Wungkal-Gamping Formation, the Kebo-Butak Formation, the Semilir Formation, the Nglanggran Formation, the

Sambipitu Formation, the Oya Formation, the Wonosari Formation, the Kepek Formation and the top is the alluvial deposits.

Suggestions

Based on the research results, it is suggest to expand the area of research for uncover the structure of the folds in the Yogyakarta Basin syncline pair anticline. It has not been conducted yet because of the limited funds and time. Moreover, it is suggested to review the Geochemistry method to know the possibility of Hydro-Carbon prospect.

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