Shallow Depth Study Using Gravity & Magnetics Data in Central Java - Yogyakarta

Muhammad Fawzy Ismullah M, Muhammad Altin Massinai, Maria

Geophysics Dept., Hasanuddin University
E-mail: altin@science.unhas.ac.id

Abstract. Gravity and magnetics measurements carried out in Karangsambung – Bayat – Wonosari track, Central Java – Yogyakarta region as much as 34 points for subsurface identification. Modeling and interpretation using both data at 3 sections. Section A lies on Karangsambung area and reach to 1900 m. Section A showed formation of 0.000001 – 0.0014 nT and 2.00 – 2.80 g/cm³ like alluvium, basalt and tuff. Section B lies on Wates - Yogyakarta area and reach to 1700 m. Section B showed formation of (-0.01) – 0.02 nT and 2.40 – 3.00 g/cm³ like andesite intrusive and Merapi volcano sediments. Section C lies on Bayat - Wonosari area and reach to 2000 m. Section C showed formation of 0.00016 – 0.0005 nT and 2.30 – 3.14 g/cm³ like limestone, tuff and diorite intrusive. Based on modeling results from 2D structure inversion method can identify the formation of sediments from volcano activity on Karangsambung – Bayat – Wonosari track, Central Java – Yogyakarta region. The method of this study shows potential application for identify the formation of volcano activity from 2D structure.

1. Introduction
Gravity and magnetics measurements carried out along Karangsambung – Bayat – Wonosari. Gravity or/ and magnetics are two methods which usually used together to identify natural resource (like identify geothermal [1]), geo-engineering and environment (like detection of underground cavities [2]) or study general geology condition (like identify Makassar subsurface condition [3]). The gravity and magnetics methods are geophysical method which used potential field on subsurface to identify physical properties. Gravity surveying measures variations in the Earth’s gravitational field caused by differences in the density of subsurface rocks [4]. Magnetics is generally more complex and variations in the magnetic field are more erratic and localized [5]. The advantages used gravity and magnetic together is to get precisely about subsurface object with depth and dimension.

Karangsambung – Bayat – Wonosari included Southern Mountain Zone in Eastern Java. The geology condition on this area is chaotic caused by volcano activity in the past. The aim at this study is to identify general geology subsurface condition on research area. The method of this study shows potential application to identify the formation of volcano activity from 2D structure.

2. Regional Geology
Karangsambung – Bayat – Wonosari lies on Central Java and Yogyakarta region, from geology condition included Eastern Java. The Eastern Java based on structure and stratigraphy [6] divided into four tectonostratigraphic zone (figure 1). There are, from south to north: (1) Southern Mountain Zone,
(2) Present-day volcanic arc, (3) Kendeng Zone and (4) Rembang Zone. The research area lies on Southern Mountain Zone.

This zone is volc ano Eocene – Miocene arc which his sediments composed siliclastic, volcanoclastic, volcano and carbonates with dip to southern. Southern Mountain Zone based by Cretaceous bed rock like outcrop in Karangsambung and Bayat. Outcrop in Karangsambung covered accretion complex rock called Luk Ulo Melange Complex, form phyllite, blue schist, eclogite, ultramafic, ophiolite, basalt, calcilutite, chert planted at shale matrix. In Bayat, bed rocks outcrop covered phyllite, schist and marble. The oldest sediment rocks which sediment above angular unconformity covered conglomerate with bed rock and sandstone fragment like at Middle Eocene Nanggulan Formation and Wungkal-Gamping Formation. Above conglomerate and quartz sandstone, there are transgression sediments covered coal, sandstone and siltstone. Volcano material Southern Mountain Zone has to increase northern whereas bed rocks material proportion decreased. The sediment thickness until 100 m with limited outcrops in western, are in Karangsambung (Karangsambung Formation), Nanggulan (Nanggulan Formation) and Bayat (Wungkal-Gamping Formation).

![Diagram](image_url)

**Figure 1.** The tectonostratigraphy of Eastern Java [6].

Above that unconformity settled sediment series composed volcanoclastic sediment from Kaligesing Formation in Kulonprogo, Kebobutak in Bayat and Besole and Mandalika Formation in Pacitan, Oligo-Miocene age and covered all of Southern Mountain Zone. This volcanoclastic sediments sequent record development Southern Mountain Oligo-Miocene volcanic arc. The volcano activity covered wide area, explosive and assumed Plinian-type. This sediment composed andesite until rhyolite and this lithology composed thick volcano ash, tuff, pumice breccia, andesite breccia, lava dome and lava flow with thickness 250 until more than 2000 m. The upper boundary from this volcanoclastic signed by short volcano activity assumed super eruption produced Semilir Formation.

[6]. When Oligo-Miocene volcanism activity decreased, even death, than erosion and the material re-sedimented as next sediment sequent. Besides that the next sediment sequent signed by wide carbonate shelf like in Wonosari (Wonosari Formation) and Pacitan (Punung and Campurdarat Formation). The thickness around 500 m and reefs developed in highlands limited by fault or in volcano former area. In top there are volcanic ash layer contains zircon, based on U-Pb time indicated 10 − 12 million year ago [6]. This age assumed related to re-appeared volcano activity on Late Miocene, in Sunda Arc position in recent [7].
3. Data and Methods
Gravity surveying measures variations in the Earth’s gravitational field caused by differences in the density of subsurface rocks. Although known colloquially as the “gravity” method, it is in fact the variation on the acceleration due to gravity that is measured [4]. One hopes to locate local mass of greater or lesser density than the surrounding formations and learn something about them from the irregularities in the earth’s field. It is not possible, however, to determine a unique source for an observed anomaly. Observations normally are made at the earth’s surface, but underground surveys also are carried out occasionally [5].

Magnetic and gravity methods have much in common, but magnetics is generally more complex and variations in the magnetic field are more erratic and localized. That is partly due to the difference between the dipolar magnetic field and the monopolar gravity field, partly due to the variable direction of the magnetic field, whereas the gravity field is always in the vertical direction, and partly due to the time-dependence of the magnetic field, whereas the gravity field is time-invariant (ignoring small tidal variations). Whereas a gravity map usually is dominated by regional effects, a magnetic map generally shows a multitude of local anomalies. Magnetic measurements are made more easily and cheaply than most geophysical measurements and corrections are practically unnecessary. Susceptibility is the fundamental rock parameter in magnetic prospecting. The degree to which a body is magnetized is determined by its magnetic susceptibility. The magnetic response from rock and minerals is determined by the amounts and susceptibilities of magnetic materials in them [5].

Figure 2. Location map. Coordinate system in UTM (meter). Section A,B,C will interpret in next part.

Gravity and magnetics measurements carried out in Karangsambung – Bayat – Wonosari track, Central Java – Yogyakarta region as much as 34 points on Tuesday, May 12th 2015. We began from LIPI campus (Karsam at figure 2) at Karangsambung to Gunungkidul area (S41 at figure 2). We used Gravimeter Scintrex CG-5 to get gravity respond and Magnetometer GSM 19-T to get magnetic respond. We took data on the road along Karangsambung to Gunungkidul. The data covered gravity respond, magnetic respond, time and elevation. The data processing covered several steps, showed at figure 3.

We used several corrections on gravity and magnetic data. Just as the water in the oceans responds to the gravitational pull of the moon, and to a lesser extent of the sun, so too does the solid earth. Earth tides give the rise to a change in gravity. This can correct by Tidal Correction. Drift correction used because gravimeter reading change (drift) with time as a result of elastic creep in the springs, producing an apparent change in gravity at a given station. The drift can be determined simply by repeating measurements at same stations at different times of the day. Elevation correction is normally adequate to cope with slight topographic effect on the acceleration due to gravity. Latitude correction
is negative with distance northwards in the northern hemisphere or with distance southwards in the southern hemisphere. This is to compensate for the increase in the gravity field from the equators the poles. The basis of free-air correction is that it makes allowance for the reduction in magnitude of gravity with height above the geoid, irrespective of the nature of the rock below. Whereas the free-air correction compensates for the reduction in that part of gravity due only to increased distance from the centre of mass, the Bouguer correction is used to account for the rock mass between the measuring station and sea level. Bouguer correction calculates the extra gravitational pull exerted by a rock slab of thickness h metres and mean density which results in measurements of gravity called Simple Bouguer Anomaly [4]. In magnetic processing, we used IGRF correction. This correction produced by International Geomagnetic Reference Field (IGRF), who recalculated a theoretical value for the field strength of the Earth’s magnetic field for any location on earth. Survey data at any given location can be corrected by subtracting the theoretical field value, obtained from the IGRF from measured value [4].

Modeling used 2D structure inversion method. The first step is section determination. The chose section that have SBA and magnetics respond near measurement point to reduce interpolated value. Based on geology and geophysics observation track, chose three sections on Karangsambung, Wates – Yogyakarta and Bayat – Gunungkidul. The input data area SBA value, magnetics respond and true elevation. The output model is cross-section based susceptibility and density rock information.

![Figure 3. Workflow diagram.](image)

### 4. Results and Discussion

Section A lies on Karangsambung area and reach to 1900 m. Section A showed formation of 0.000001 – 0.0014 nT and 2.00 – 2.80 g/cm³ (figure 4). There are 10 models divided into eight units. Qa – Alluvium sediments composed of clay, silt, sand, pebble and gravel. Teok – Karangsambung Formation composed of claystone with limestone block, conglomerate, sandstone, limestone and basalt. Karangsambung Formation is the oldest formation which assumed as Java basement [7]. This formation had anticline structure. Tomt – Totogan Formation composed of breccia with claystone component, sandstone, limestone and basalt. There is thrust fault that is force interaction on anticline structure of Karangsambung Formation. Tmw – Waturanda Formation had coarse sandstone on lower, and upper become breccia with andesite component; basalt and sandstone base mass, tuff. Tmp – Penosogan Formation signed by interludes between lime-sandstone, claystone, tuff, marl and
calcarenite, influenced by turbid flow. There was reverse fault influenced by tectonic effect on past. Tmpb – breccia Halang Formation had breccia with andesite, basalt and limestone, coarse tuff sandstone mass base, sandstone layer and basalt lava. Tmph – Halang Formation had interludes between sandstone, limestone, marl and tuff with breccia layered, influenced by turbid flow and sea water slide down [8]. Overall, section A composed alluvium, basalt and tuff.

Figure 4. (Top left) Magnetics anomaly, (Top right) Simple bouguer anomaly. The colour refer to value of parameter, blue is low and red is high. (Bottom) Cross-section model from Section A. Blue line is simple bouguer anomaly (mGal) and red line is magnetic anomaly (nT).

Table 1. Susceptibility and density from cross-section A.

| Label                                      | Colour | Susceptibility (nT) | Density (g/cm$^3$) |
|--------------------------------------------|--------|---------------------|--------------------|
| Qa – Alluvium sediments                    |        | 0.0013              | 2.00               |
| Teok – Karangsambung Formation             |        | 0.00019             | 2.80               |
| Tomt – Totonogan Formation                 |        | 0.00001             | 2.10               |
| Tmw – Waturanda Formation                  |        | 0.000015            | 2.71               |
| Tmp – Penosogan Formation                  |        | 0.000011            | 2.57               |
| Tmpb – Breccia Halang Formation            |        | 0.00012             | 2.37               |
| Tmph – Halang Formation                    |        | 0.000001            | 2.80               |

Section B lies on Wates - Yogyakarta area and reach to 1700 m. Section B showed formation of (-0.01) – 0.02 nT and 2.40 – 3.00 g/cm$^3$ (figure 5). There are eight models divided into seven units. a – andesite located in here is outcrop from intrusion. Tmok – Kebobutak Formation had negative susceptibility value, influenced by mineral on rock composer this formation. Several minerals known had negative susceptibility value like quartz and anhydrite (-0.01) nT and calcite (-0.001 – (-0.01)) nT [5]. This formation composed of andesite breccia, tuff, lapilli tuff, agglomerate and andesite lava flow inset. Tmps – Sentolo Formation composed of limestone and clay-sandstone. Qml – young Merapi
volcano sediment is tuff, ash, breccia, agglomerate, lava indivisible. Tms – Semilir Formation composed of interludes between breccia and tuff, pumice breccia, dacite tuff, andesite tuff and tuff marl [9]. KTm – metamorphic rock signed by schist, marble, metamorphic volcanic rock, metamorphic sediment rock and slate [10]. Tpdi – Pendul diorite is igneous rock signed by red color. Overall, section B covered volcano product like andesite intrusive and Merapi volcano sediments.

![Figure 5](image-url)  
*Figure 5.* (Top left) Magnetics anomaly, (Top right) Simple bouguer anomaly. The colour refer to value of parameter, blue is low and red is high. (Bottom) Cross-section model from Section B. Blue line is simple bouguer anomaly (mGal) and red line is magnetic anomaly (nT).

| Label                                      | Colour | Susceptibility (nT) | Density (g/cm³) |
|--------------------------------------------|--------|---------------------|-----------------|
| a – Andesite intrusion                      |        | 0.0013              | 3.00            |
| Tmok – Kebobutak Formation                 |        | -0.01               | 2.60            |
| Tmps – Sentolo Formation                   |        | 0.0012              | 2.50            |
| Qml – Young Merapi Volcano sediments       |        | 0.02                | 2.70            |
| Tms – Semilir Formation                    |        | 0.008               | 2.40            |
| KTm – Metamorphic Rock                     |        | 0.0023              | 2.43            |
| Tpdi – Pentul Diorite                      |        | 0.0013              | 3.00            |

Section C lies on Bayat - Wonosari area and reach to 2000 m. Section C showed formation of 0.00016 – 0.0005 nT and 2.30 – 3.14 g/cm³ (figure 6). There are nine models divided into eight units. Tpdi – Pentul Diorite signed by red color. The outcrop of this formation is micro-diorite intrusion (figure 7a). KTm – metamorphic rock composed hill geomorphology on Gunungajah Village result from schist and phyllite weathering (figure 7b). Tomk – Kebobutak Formation, upper part: sandstone interlude, claystone and acid tuff thin layer, lower part: sandstone, siltstone, claystone, shale, tuff and agglomerate. Tms – Semilir Formation signed by tuff, dacite – pumice breccia, tuff sandstone and shale [10]. Geomorphology in Tancep Village, Gunungkidul regency showed tuff outcrop which part
of Semilir Formation (figure 7c). Tmng–Nglanggran Formation covered volcano breccia, agglomerate, andesite – basalt lava and tuff. Tmss – Sambipitu Formation had sandstone and claystone. Tmwi – Wonosari Punung Formation had limestone, marble – tuff limestone, conglomerate limestone, tuff sandstone and siltstone. Tmo – Oyo Formation of tuff – marble, andesite – tuff and conglomerate – limestone [10]. Clastic limestone outcrop in Oyo River is the part of Oyo Formation (figure 7d). Overall, section C covered diorite intrusive, limestone and tuff.

Figure 6. (Top left) Magnetics anomaly, (Top right) Simple bouguer anomaly. The colour refer to value of parameter, blue is low and red is high. (Bottom) Cross-section model from Section C. Blue line is simple bouguer anomaly (mGal) and red line is magnetic anomaly (nT).

| Label                                      | Colour | Susceptibility (nT) | Density (g/cm³) |
|--------------------------------------------|--------|---------------------|-----------------|
| Tpdi – Pentul Diorite                      |        | 0.0005              | 3.00            |
| KTm – Metamorphic Rock                     |        | 0.00027             | 3.14            |
| Tomk – Kebobutak Formation                 |        | 0.0003              | 2.51            |
| Tms – Semilir Formation                    |        | 0.000019            | 2.42            |
| Tmng – Nglanggran Formation                |        | 0.0004              | 2.47            |
| Tmss – Sambipitu Formation                 |        | 0.0003              | 2.77            |
| Tmwi – Wonosari Punung Formation           |        | 0.00016             | 2.80            |
| Tmo – Oyo Formation                        |        | 0.00018             | 2.30            |

Section A – B – C represented research area, which showed several formations. The depth until 2,000 m, is shallow depth. The formation composed the volcano product and sediment on research area. The existence of basalt, andesite, dacite and pyroclastic, is tuff, sign the volcano product. The sedimentation processed on this area product sediment rock like alluvium, limestone, sandstone, siltstone, claystone and shale. Breccia and conglomerate on this area composed by volcano fragment,
formed pumice breccia and agglomerate. High pressure and temperature from subsurface made metamorphic on this area, like schist and phyllite. This distribution signed high volcano activity in past, may Oligo-Miocene [7], and covered wide area, assumed Plinian-type [6].

Figure 7. (a) The outcrop of micro-diorite intrusion on Pentul (near D15 at figure 2). (b) The schist and phyllite weathering on Gununggajah Village (near D16 at figure 2). (c) The tuff outcrop on Tancep Village, Gunungkidul (near D17 at figure 2). (d) Clastic limestone in Oyo River (near M4 at figure 2).

5. Conclusion
Formation distribution of Karangsambung – Bayat – Wonosari showed similar type. This showed on the formation of sediments from volcano activity on Karangsambung – Bayat – Wonosari track, Central Java – Yogyakarta region. The volcano product is igneous rock, are basalt, andesite, dacite and pyroclastic, is tuff. This distribution signed high volcano activity in past and covered wide area. The gravity and magnetics method in this study shows potential application to identify the formation of volcano activity from 2D structure in Karangsambug – Bayat – Wonosari, Central Java – Yogyakarta region.

Acknowledgement
We gratefully acknowledge the Kemenristek-DIKTI for funding this research. We thank to Geophysical Engineering Dept., Bandung Institute of Technology (ITB) and Geophysics Dept., Faculty of Mathematics and Natural Science Hasanuddin University (UNHAS) for supporting this research.

References
[1] Arif N, Lantu, Aswad S, Maria 2014 Proc. Seminar Nasional Geofisika Universitas Hasanuddin p 94 – 99
[2] Mochales T, Casas A M, Pueyo E L, Pueyo O, Roman M T, Pocovi A, Soriano M A, Anson D 2008 Environ Geol 53 p 1067-1077
[3] Syahruddin M H 2015 Proc. 2nd Makassar International Conference on Civil Engineering
[4] Reynolds J M 1997 An Introduction to Applied and Environmental Geophysics John Wiley & Sons Ltd.
[5] Telford W M, Geldart L P, Sheriff R R 1990 Applied Geophysics (Cambridge: Cambridge University Press)
[6] Smyth H, Hall R, Hamilton J and Kinny P 2005 Proc. 30th Indonesian Petroleum Association Annual Convention and Exhibition p 251
[7] Prasetyadi C 2007 Dissertasi: Evolusi Tektonik Paleogen Jawa Bagian Timur (Bandung)
[8] Askin S, Handoyo A, Busono H and Gafoes S 1992 Peta Geologi Lembar Kebumen Jawa (Bandung: Pusat Penelitian dan Pengembangan Geologi Bandung)
[9] Rahardjo W, Sukandarrumidi and Rosidi H M D 1995 *Peta Geologi Lembar Yogyakarta Jawa* (Bandung: Pusat Penelitian dan Pengembangan Geologi Bandung)

[10] Surono, Toha B and Sudarno I 1992 *Peta Geologi Lembar Surakarta – Giritontro Jawa* (Bandung: Pusat Penelitian dan Pengembangan Geologi Bandung)