Implementation of ESA-MWT method satellite gravitation data to estimate the depth of moho layer and subduction zone in Indo-Australia plate of Central Java

M. Syamsu Rosid and Windy Aulia Ramadhanti
Department of Physics, FMIPA Universitas Indonesia, Depok 16424 Indonesia

E-mail: syamsu.rosid@ui.ac.id

Abstract. A study has been conducted to measure the depth of the Mohorovicic (Moho) discontinuity and the Indo-Australian Plate subduction zone in Central Java. Both of these structures have high density contrast and thus are very sensitive to gravity methods. This study uses satellite image gravity data derived from satellite Geodetic Satellite (GEOSAT) and European Remote-Sensing 1 (ERS-1). Satellite data obtained in the form of free air anomaly which then corrected Bouguer using the average density of the Parasnis method of 2.64 g/cm$^3$ so obtained Complete Bouguer Anomaly (CBA). The identification of Moho layers and subduction zones was done using the Energy Spectrum Analysis - the Multi Window Test (ESA-MWT) method with 19 lines of South-North. ESA-MWT results get 9 layers with depths that can reach more than 100 km. The Moho layer is identified as the 4$^{th}$ layer at varying depths from 28 to 63 km. The subduction zone is also identified by ESA-MWT with a depth of about 60 km and deeper to the North. The dip of slab looks sloped down at 40$^\circ$ at the South of Central Java. The dip of slab in the middle of mainland Central Java seen sharply sloped down into the North with a dip of about 75$^\circ$. All these results are well confirmed by the seismic data of the earthquake in Central Java.

1. Introduction
Indonesia is a country that located in the ring of fire. The zone has many natural hazards, such as earthquake, volcanic eruption, and tsunami because of high tectonic activity. Indonesia is located between three tectonic plates, which are Eurasian Plate, Indo-Australian Plate, and Pacific plate [1]. The boundaries where two tectonic plates meet and collide each other called subduction zone. One plate will bend and slide underneath the other, curving down into the mantle. This study is located in Central Java as the area has the subduction zone of Indo-Australian Plate and Eurasian Plate as well as surface tectonic activity [2]. Indo-Australian Plate in South will be gone smoothly under Eurasian Plate in North [3].

Mohorovicic discontinuity or Moho is the lower boundary of crust and upper boundary of mantle. It is boundary between crust and mantle layer of Earth. Moho has different values according on movement of two plates that produce Mountains. It is also according to isostatic theory [4], will be thicker in mountain area and be thin in flat land.

It well known that density of continental and ocean crust are respectively 2.7 g/cm$^3$ and 2.9 g/cm$^3$ [5]. Meanwhile, the density of mantle is 3.3 g/cm$^3$. Gravity method is suitable to apply as there is contrast density of crust and mantle. From Energy Spectral Analysis-the Multi Window Test (ESA-MWT) method, the depth of contrast density will be identified [6].
1.1. Regional Geology
Compared to West and East Java, the central part of Java is narrower, the length is only 100-120 km across [7]. This is because the Java Sea extends inland with a broad bright between Cirebon and Semarang, so that the northern lowland is more restricted or even absent. The greater part of Southern Mountains also goes down beneath the sea level between Nusa Kambangan and the Southern Mountains of East Java.

1.2. Mohorovicic Discontinuity
A subsurface discontinuity was firstly described by Andrija Mohorovicic based on his interpretation of earthquake seismic data recorded in Europe [8]. Mohorovicic identified a velocity changing that could be interpreted as the response to abrupt change in both seismic compressional and seismic shear waves. Therefore, the discontinuity layer that generate the high velocity contrast namely as Moho layer. For the last 20 years, depth of Moho successfully found from gravity data through spectrum analysis [8]. In gravity data, Moho is described as the density contrast between crust and mantle layer of Earth. Previous studies show that the Moho layer in the mainland of Central Java area is varied at depth of 27-39 km [9] and 36-39 km [10]. They were able to detect an average crustal thickness and so the depth of Moho based on receiver function P-wave earthquake seismic data.

1.3. Subduction Zone of Indo-Australian Plate and Eurasian Plate
Both Indo-Australian Plate and Eurasian Plate are treated respectively as ocean and continental crust. There is an arc that was generated by subduction of Indo-Australian oceanic plate underneath Eurasian continental crust as shown in Figure 1. The crust looks thin and apparently young compared to the mantle as it consists largely of volcano-plutonic rocks formed in Tertiary age [11]. In Java, only few of ignimbrite was deposited [3]. Most of the magmatic rocks are intermediate. The Indo-Australian oceanic crust south of trench is covered by around 200 meter of pelagic sediments in Tertiary age [12]. The Christmas Island which situated next to south of the trench, could be predicted in the future it will be subducted in the Java trench.

Figure 1. Modelling of tectonic plates in Central Java [2].

2. Experimental Methods
The methodology of this study is generating a model of subsurface layers. The model is based on satellite gravity data to estimate the presence of Moho layers and subduction zones in Central Java. The gravity data could be accessed through http://topex.ucsd.edu/cgi-bin/get_data.cgi. The gravity anomaly data has already been corrected until free air correction [13]. The next step correction is Bouguer correction to get a value of simple anomaly Bouguer (SBA). The SBA then divided into regional and residual anomaly. We use SBA rather than CBA (complete Bouguer anomaly) as there is no terrain correction.
Performing Energy Spectrum Analysis-the Multi Window Test (ESA-MWT) method to anomaly Bouguer for finding depth estimation of Moho and slab based on density contrast. The method works based on the energy spectrum analysis obtained from the 2D Fourier transform. In order to obtain graph of estimation depth and window size, the data should be put in a windowed sub-region to make ESA well works [14]. An estimated depth map will be yielded after operating ESA procedure at multiple points along lines or one region [6].

3. Results and Discussion

In Bouguer correction, the average density value of study area is applied by using Parasnis approach of 2.64 g/cm³. Figure 2 shows the gravity variation in the study area. The gravity value (also its expected density value) decline to the North. It may indicate that the density of ocean crust is bigger than the continental crust. Both of ocean and continental crust in Figure 2 may represented by gravity value of 260-440 mgal and 100-240 mgal. In North, the gravity anomaly is negative as the Java Island is more likely covered and dominated by sediment.

Applying the ESA-MWT technique to simple Bouguer anomaly data produces a radially average spectrum (RAPS) graph. Plotting the number of test point versus depth resulting subsurface density contrast layers as shown in figure 3. The layers are along line AB from South to North ward, from Indonesia’s Ocean across land of Central Java. Both figure 2 of Bouguer anomaly and figure 3 of topography maps show an interesting subduction zone. The subduction line is extended along the South Java Island at a distance of about 230 km from the southern coastline of Java Island and is at a depth of more than 5000 m bsl (below sea level). The presence of the subduction is strongly evident in both figures since it has both contrast of gravity (rock density) and topography as well as a good alignment line trend. The density contrast is happened between the ocean crust of Indo-Australian plate and the continent crust of Eurasia plate. Topographic contrast is also there as the lighter continent crust level is higher than the heavier oceanic crust ones. The trend of subduction line is also clearly seen extending along almost West to East topographic contour line of -5000 m level.
Figure 3 shows the Moho as 5th subsurface layer of South-North line (line AB) with varying depth of 28 up to 63 km. The layer to the South looks increasingly degrading. On the contrary, it becomes more and more thickened while on the island of Java. Even in some locations where there is a volcano above it, the Moho layer tends to be deeper. The phenomena are confirmed by isostacy concept. The presence of this Moho layer is strongly associated with the thickness of the crust layer. In the ocean area, the Moho layer looks more shallow and thinner. Otherwise, on the continent land the layer tends to be deeper and thicker.

The slab is estimated as the 9th layer of line AB at depth of 60 km and more. The existence of slab also can be detected from Multi Scale-Second Vertical Derivative (MS-SVD) method, which able to detect the location and type of fault. MS-SVD method successfully detected the two faults of P and Q shown in figure 4. Both faults of P and Q are identified at about 60 km and 170 km respectively from southern of the AB line. The faults are reverse faults which represents the Indo-Australian plate movement that plunged under the Eurasian plate. The faults perfectly match with ESA-MWT method at figure 3.
reverse fault of P found in 66 km depth, while the fault of Q is identified at depth of around 110 km. The dip of faults (of slab) also can be identified from the MS-SVD analysis. The slab's slope is quite gentle 20° in the trough of subduction zone at the bottom of the Indian Ocean and has increased to 40° in South Central Java of fault P. The slab's slope in the middle of the Central Java plain (of fault Q) looks very sharply down to the North with a slope of about 75 degrees.

![Figure 4. MS-SVD curves show both the location and type of the detected 2 faults of P and Q](image)

4. Conclusion
ESA-MWT method is successfully identified the presence of both the Moho layer and the subduction zone in the Central Java. The Moho layer extends from South to North at varying depths from 28 to 63 km. While the subduction layer was detected at a depth of 66 km in the Indian Ocean and down to 110 km deep in the middle of mainland Central Java. The slab slope is quite gentle 20° in the zone of the two plates encounter and grew up to 40° at a distance of about 60 km from the southern end of the AB line and further sharpening the slab slope up to 70° in an area about 70 km from the south coast of Central Java. MS-SVD method able to identify the location and type of fault, which is a proof of Indo-Australian Plate existence.

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5. References
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