Preliminary Results of Receiver Function Forward Velocity Modelling at Merapi Volcano

M F R Auly1, A K Ilahi1, I Madrinovella1, S Widyanti1, S K Suhardja1, D Y Fatimah1, A D Nugraha2, Z Zulfakriza2, S Widiyantoro2,3, J-P Métaxian4, M Ramdhan5

1 Faculty of Exploration and Production Technology, University of Pertamina, Jl. Teuku Nyak Arief, Simprug, Kebayoran Lama, Jakarta 12220, Indonesia
2 Global Geophysics Research Group, Faculty of Mining and Petroleum Engineering, Institute of Technology Bandung, Jalan Ganesa No. 10, Bandung 40132, Indonesia
3 Faculty of Engineering, Maranatha Christian University Bandung, Jalan Surya Sumantri No 65, Bandung 40164, Indonesia
4 ISTerre, IRD R219, CNRS, Université de Savoie Mont Blanc, Le Bourget-du-Lac, France
5 Agency for Meteorology, Climatology and Geophysics, Jalan Angkasa I, No. 2, Kemayoran, Jakarta, Indonesia

*corresponding author’s e-mail: s4ndy104@gmail.com

Abstract. The tectonic setting of Java island, located at southwestern edge of the Eurasia continent, is dominated by the subduction of Indo-Australia plate. One of the characteristics of active subduction is active seismicity, the generation of arc magmatism and volcanic activity. Mt. Merapi is one example of active volcano related with the subduction process. It is one of the most active volcanoes with location close to high population area. To better understand this area, we employed the Receiver Function technique, a method to image sub surface structure by removing the vertical component from horizontal component. First, we collected high magnitude events and processed RF with water level deconvolution method. Then, we constructed synthetic model with initial velocity input from previous tomography model. Note that we used reflectivity method in generating synthetic model with input parameters matched with parameters from real data processing. Next, we adjusted velocity inputs mainly on tops sediments (1-3 km) to include sediment layers and volcanic rocks, mid-depth low velocity zone that may be related with magma chamber and depth of crust-mantle boundary. Current forward velocity models show a relatively good agreement from 3 stations (ME25, ME32 and ME36). We estimate a thin layer of sediments followed a zone of velocity layer at a depth of 10-15 km and crust-mantle boundary ranging from 26-29 km. In this study, simulated that the signal of sediments layer and low velocity layers interfere main crust mantle boundary that supposed to be highest signal after the P wave in the typical receiver function study.

Keywords: Synthetic Receiver Function, Mount Merapi, Magma Reservoir, Low Velocity Zone
1. Introduction

Java island is located at the southern part of the Eurasian plate, where the Australian plate is subducting the Eurasian plate. [1] explained that the convergence rate between Australia and Indonesia is 67 mm per year and the slab angle of the slab is getting steeply downward (70°-80°) from a depth of 50 km to the north of Java [2]. Based on the distribution of earthquakes in the global catalogue [3], the plate's depth under the southern part of Java Island is around 100-120 km. The magmatism and volcanic activity that characterize Central Java are primarily affected by the subduction process. Altogether there are two main volcanic arcs, the Southern Mountain Arc (SMA) and the Modern Volcanic Arc (MVA) [4],[5]. Mount Merapi is part of the MVA and the focus of this study.

Studies on Mt. Merapi have been done using various geophysical and geological methods. Studies using the gravity method with high resolution show evidence of high-density bodies under the crest of Mt. Merapi, Merbabu, and Telomoyo, which can be interpreted as magma reservoirs [6], [7], using GPS and slope data, concluded that the primary magma reservoir is located between 6-9 km depth below the summit. The result of a tomography study [8] shows there is an anomaly of high Vp/Vs ratio beneath the peak of Mt. Merapi at a depth of ∼5 km and ∼15 km, which is interpreted as shallow and intermediate magma bodies. Local earthquake tomography was deployed using the data from the same network as this study and found three active zones with a high Vp/Vs ratio beneath the summit [9].

The closest related study is the RFs study that estimates the crust thickness from the DOMERAPI network [10]. The receiver function (RF) is one of the methods used to determine the reflectivity that occurs in the Earth structure. This technique uses the principle that if the P wave encounters a boundary that separates rock layers with high-velocity contrast, an S wave will then be created in the boundary. The converted S wave will then be recorded at the recording station after the P wave because the S wave velocity is always slower than the P wave velocity. If the layer below the boundary has a higher velocity than the value above it, then a positive pulse will be created, and vice versa, if the layer above the boundary has a higher velocity value than the layer below it, the negative pulse will be created. The receiver function is then calculated through deconvolution between the radial component and vertical component. [10] showed complex RFs in this area with lower amplitude signal from crust-mantle boundary and a pattern of negative RFs signals beneath Mt. Merapi. In this study, forward RF modeling has been carried out by generating synthetic RFs from a series of velocity model. Synthetic models are then matched with stacked observed RFs. We focused on the three layers, the first is the sediment of top of layers, a low velocity zone representing a possible magma chamber and crust-mantle boundary depth. This study attempts to provide more detailed information about the structure of the earth's crust beneath Mt. Merapi.
2. Data and method
This study uses recorded data from the DOMERAPI seismic network installed in the area around Mt. Merapi. A total of 53 broad-band seismometers were installed during October 2013 to mid-April 2015, with an average distance between stations is ~ 4km. Earthquake data collected are 150 with magnitude > 5.5 and have epicentral distances of 30 - 100 degrees. The location of the recording station is shown in figure 2.

![Figure 2. Location of the seismometer installed for this study. The red and blue triangles are Mt. Merapi and Mt. Merbabu [10]](image)

To better understand geological structure beneath the mountains, we performed forward modelling to create synthetic RFs from the determined velocity model. Then, the synthetic seismogram is matched with the observed RFs until they showed good agreement. We used the reflectivity code [11]. Note that the forward modelling carried out in this study used the assumption that the subsurface conditions are isotropy. Figure 3 is an example of synthetic RF result from synthetic velocity model based on ak135 velocity model.

![Figure 3. Synthetic RF results (left) from a synthetic crust and upper mantle velocity model (right) based on the ak135 velocity model. In the synthetic RF results, the red and blue curves are the results using a filter frequency of 1.5 Hz (low frequency) and 4 Hz (high frequency).](image)

In the example of synthetic RF, we used 2 different frequency which are low frequency and high frequency, although in reality, the frequency filter used is low frequency because it is more representative of the frequency of the earth. The purpose of using a high-frequency filter in this study is to simplify the RF synthetic modelling that causes a high-frequency response in RF readings such as thin layers and multiples. In a simple model that has a change in Vp and Vs at a depth of 35 km, we can observed 4 signals: The first positive signal at 0 second showed the incoming P wave arrival, the second positive signal at 4.6 second showed the converted Ps phase from the boundary, and the third positive and negative signal are the multiples. We modified the velocity model input by adding two layers: the first is sediment layer and the second is low velocity layer representing possible magma chambers beneath the Mt. Merapi.
Figure 4. Synthetic RF for velocity models with a 3 km thick sedimentary layer near the surface and Moho at depth of 35 km.

Figure 5. Synthetic RF for velocity model with a 3 km thick of low velocity layer at a depth of 15 km and Moho at depth of 35 km.

Figure 6. Synthetic RF results (blue line) from the tomography velocity model [8] and the results of RF observations (red line) from Suhardja et al. (2019) for stations ME25, ME32 and ME36 (top to bottom)

3. Result and discussion

As a preliminary understanding for constructing a synthetic velocity model, we used a 1-D velocity model from a tomography study by Ramdhan et al. (2019) to estimate the depth of the low velocity zone and Moho at ME25, ME32, and ME36 station.

Figure 6 is a comparison of the synthetic RF results based on the tomography velocity model from tomography study [8] and the results of the observed RF results from previous study [10]. Visually, the similarity of the resulting signals do not show good agreement. The RF results from tomography are also unable to respond to signals that have negative amplitudes at the time of arrival of 1-2 seconds as in the results of observed RF, which may be the result sediments at shallow depths below Mt. Merapi.
Figure 7 show the best velocity model that we can match with stack RFs by finding the best combination of shallow sediment thickness and depth of low velocity layer as magma chamber, dan Moho depth. Station ME25 and ME32 station have shown a good visual matching at the arrival time of 1-10 s, but the RF result at ME36 station seems to lack good visual matching. We observed for arrival time after 10 s, the signals have a poor correlation with real data. This might be related with more complex structures and its multiples. The velocity models that has sediment layer, LVZ, and Moho for each station which can then be made a simple subsurface section (figure 8).

In the summary, negative amplitude that appears in the RFs at 0-4 seconds can be caused by two objects, a thin layer of sediment near the surface and the presence of a low velocity zone at a certain depth. Based on the results of synthetic RF at the ME25, ME32, and ME36 stations, the depth of the magma chamber varies. The depth of the magma chamber seems to be getting shallower towards the Mt. Merapi area, as shown by the simple cross-sectional model in figure 8. The crust thickness also getting thin near Mt. Merapi.

4. Conclusion
Based on the results of RF forward modeling, the main signals that appear in the results of RF observations consist of 3 main sources, the sedimentary rock layer with a thin thickness, the low velocity zone which is identified as the magma chamber and the boundary of the earth's crust and the upper mantle, Moho discontinuity. However, identifying the source of the multiples from the observed RF results is quite difficult to do because the multiples response to the RF signal is very complex so that the compatibility of the synthetic RF signal with the observed RF after 10 s does not have a good
correlation. The results of this study indicate that the depth of the LVZ which is interpreted as a magma reservoir obtained from the synthetic velocity model ranges from 5-15 km with a depth that is getting shallower towards the south, the area around Mt. Merapi. These results support the results of previous studies which explain that the result from tomography study [8] showed there is an anomaly of high Vp/Vs ratio beneath the peak of Mt. Merapi at a depth of ~5 km and ~15 km and study using GPS and slope data which suggests that the main magma reservoir is located between a depth of 6-9 km below the summit [7].

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