Seismic Travel-time Tomography beneath Merapi Volcano and its Surroundings: A Preliminary Result from DOMERAPI Project

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Abstract. Many geophysical methods at various scales have been applied to understand the internal structure beneath Merapi volcano and its magmatic process. As part of the DOMERAPI project, a seismic experiment was conducted from October 2013 to mid April 2015 in order to determine the deep magma source beneath the volcano through seismic travel-time tomography. The earthquake events were identified and picked manually and carefully to determine the hypocenters. They were then relocated to get precise hypocenter locations before running the seismic tomographic imaging. The data from the BMKG network from the same period of time as mentioned above were also incorporated to minimize azimuthal gap, because the majority of events occurred outside the DOMERAPI network. The checkerboard resolution test result depicts that the area around the network can be well resolved. Compared to previous studies, our result shows a higher resolution at shallow depths, i.e., less than 35 km and a low velocity material imaged to ascend diagonally from the deeper area.
Keywords: Merapi, DOMERAPI, BMKG seismic tomography, low velocity.
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1. Introduction

The Merapi volcano is one of the most active volcanos in the world. The eruption period occurred from two to six years [1]. The Merapi eruption type is dominated by pyroclastic flows caused by lava dome collapse [1,2]. A different eruption type, which is more explosive and of higher magnitude, such as the 2010 eruption, occurs less frequently, i.e. every 50 to 100 years [3,4]. Many earth scientists have studied various methods to determine the Merapi internal structure from local to regional scale. Two magmatic systems have been identified beneath Merapi down to 5 km depth beneath the summit by seismological studies [1,2]. A low velocity material ascending from the partial melting zone to volcanic arc was detected by travel-time seismic tomography by using MERAMEX network [5,6]. The result was updated by incorporating data from the BMKG network [7]. The seismic ambient noise tomography using MERAMEX network showed the low group velocities beneath Merapi volcano could be deleniated from 2 to 12 s periods [8]. The same method had been applied using DOMERAPI network [9]. The result showed the higher resolution than the previous study. It showed not only low group velocites beneath Merapi and Merbabu but also high group velocites beneath them [9]. The Merapi eruption system is controlled by a deep magma source [10]. It could not be detected clearly by seismic studies as mentioned above because of the limitation in data resolution. The DOMERAPI seismic experiment, which was conducted from October 2013 to mid April 2015, has a target, i.e. to determine the deep magma source and its magmatic process beneath the volcano through travel-time seismic tomography.

2. Data and Method

The DOMERAPI seismic network covers Merapi and Merbabu volcanoes. The average distance between seismometers is about 4 km. Opak fault is also covered by the network with a fewer density of seismometers compared to the two volcanoes (see figure 1.a). The majority of earthquakes occurred outside of the network. Data from the BMKG network were included in order to minimize the azimuthal gap [11]. The contribution of the earthquakes located outside the DOMERAPI network is essential to delineate the deep structure beneath Merapi volcano given that the volcano-tectonic earthquakes (VT) occur at maximum 5 km below the summit [1,2]. The total number of earthquakes used in this study is 372. These events were recorded by 70 seismic stations (53 from DOMERAPI network and 17 from BMKG network) and were used to compute travel-time seismic tomography. The events and the network are restricted in the area: 108^o-112^oE and 6^o-11^oS. Computation of hypocenters and travel-time seismic tomography for P and S phases or P phase only was performed for events recorded at least by six stations. The minimum of six stations is used to obtain over-determined criteria. The Geiger method was applied to compute hypocenter determination with Hypoellipse software [12,13]. The hypocenters were relocated firstly before running travel-time tomography using a double-difference method [14,15]. The SIMULPS12 was used to compute travel-time seismic tomography [16,17]. The method has been successfully applied widely in various places to delineate the subsurface structure. The subducting slab in the Bungo chanel and Shikoku area had been detected successfully by the method [18]. The method also could detect clearly subduction slab beneath Bali island [19]. The method is also reliable to delineate subsurface structure beneath volcano. The magma source beneath Lokon and Guntur volcanoes could be delineated clearly by the method [20,21].

Figure 1.b shows epicenter distribution and seismic networks in the study area. The initial model used for travel-time seismic tomography computation is a 1-D P velocity model obtained with a previous regional study of central Java [5]. It used a Vp/Vs ratio of 1.73 [22]. The smallest horizontal and vertical grid is 10 km and 5 km, respectively. This grid size is smaller than those used in the previous studies [5,6,7].

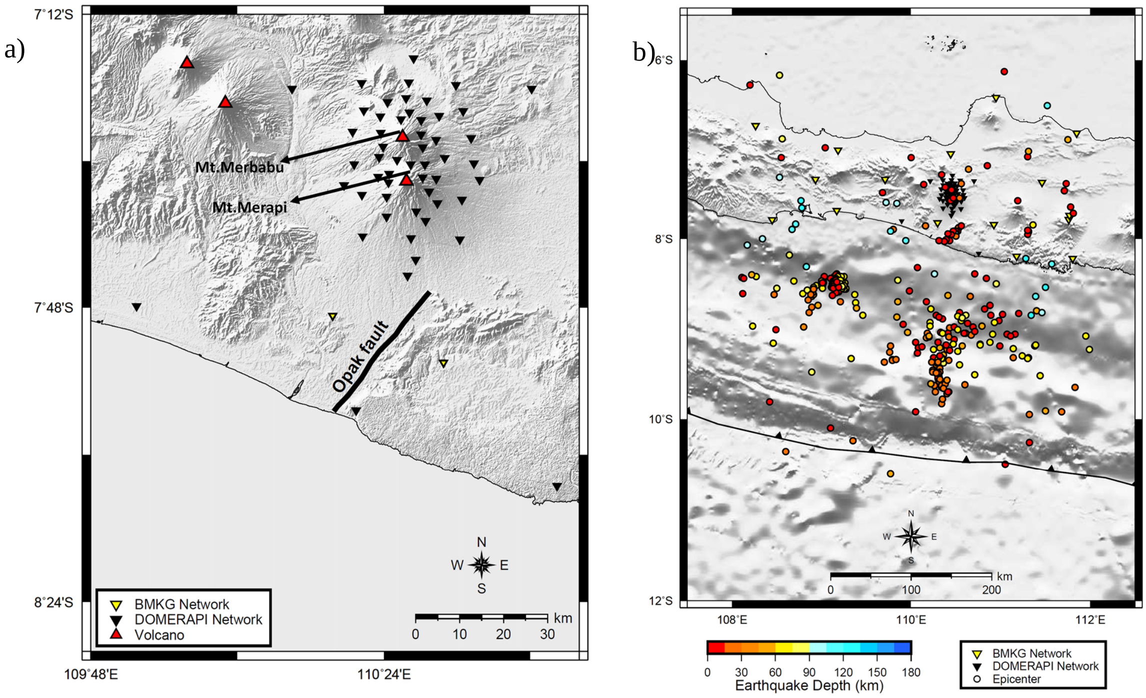

Figure 1. **a.** The stations distribution of DOMERAPI (black inverted triangles) and BMKG (yellow inverted triangles) networks in the study area.
b. The seismometer and epicenter distribution used in the travel-time seismic tomographic imaging.

3. Results and Discussion

The total number of ray paths we used is 16,101 (11,074 for P wave and 5,054 for S wave). The inversion was performed for Vp and Vp/Vs ratio. For the Vp/Vs ratio inversion we used an equal ray path number of P and S. Ideally, the total number of of P and S wave data is equal, but in the real condition the number of S is less than P wave because in general the signal to noise (S/N) ratio is lower for S wave than for P wave. The low S/N ratio produces an un-clear onset. The Checkerboard Resolution Test (CRT) that we conducted shows that the area beneath the study area could be recovered well, especiallly for depths lower than 35 km. The recovery of the CRT for the depth of more than 60 km is still reasonably good although the anomalies are weaker than the upper anomalies. In this paper we only shows P wave tomogram as a premilinary result of DOMERAPI project. Figure 2 shows the CRT result and Vp tomogram beneath Merapi volcano.

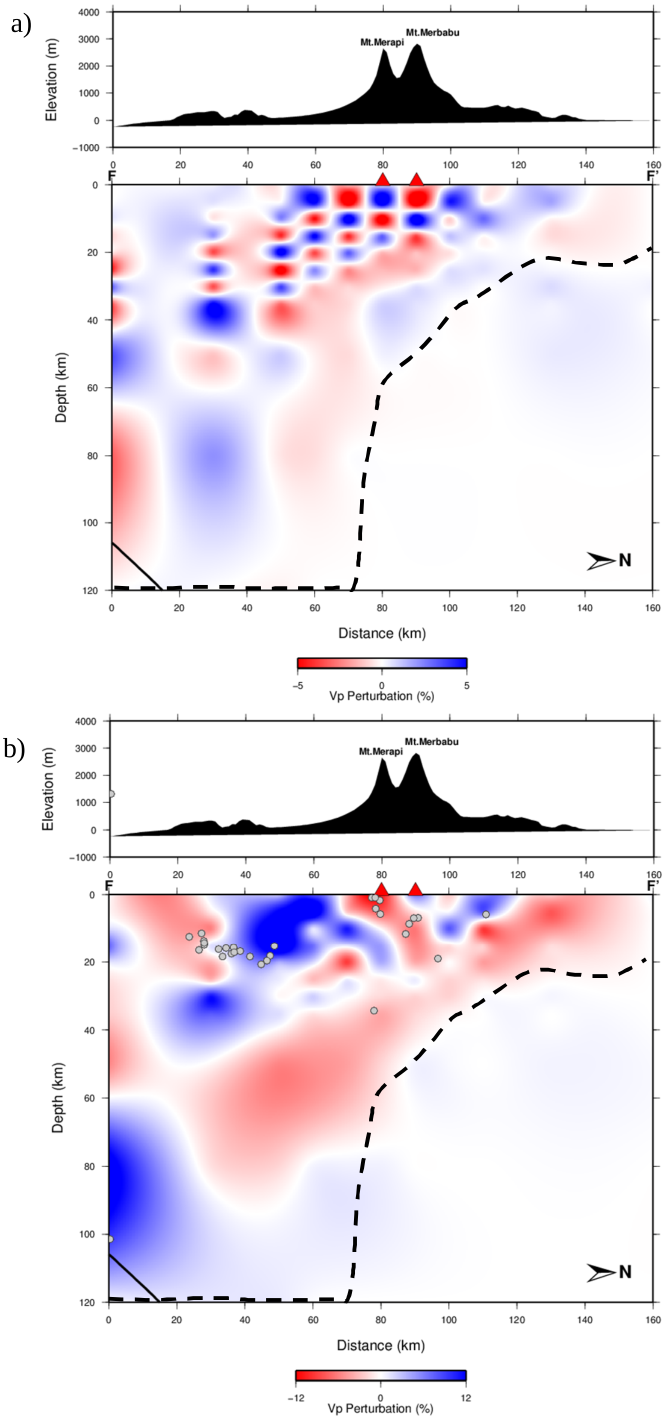

Figure 2. **a.** The CRT result beneath Merapi volcano and its surroundings. Black line depicts the slab 1.0 model [23]. The Dashed line indicates the area with good resolution.
b. Tomogram Vp beneath Merapi volcano and its surroundings. Black and dashed lines are the same with those in (a).

The previous results had not showed a low velocity material ascends diagonally from depth of about 100 km [5,6,7]. The denser station distribution of this study is likely to enhance the resolution beneath study area. The Vp tomogram shows that the low velocity beneath Merapi volcano is dipping southward. It is consistent with the result from a previous study [5]. The other study with D-InSAR method stated that the conduit is dipping to the north-west direction [24]. An impermeabel zone with high velocity was detected beneath Merapi volcano from the depths between 12 and 27 km. The zone could not be detected clearly in the previous studies due to limitation of data. The low and high velocity zones at 100 km and 12-27 km depths, respectively are consistent with the two main magmatic systems characterized by petrological studies beneath Merapi volcano, known as deep and intermediate magma reservoirs [10]. Shallow magma reservoir could not be detected by this study because of the limited data coverage [1,2,10]. The high velocity materials beneath Merbabu volcano is interpreted as a large solidified magma body/intrusion/conduit. The large body serves as a barrier of melting rock from the deep reservoir to the surface. It may infer that Merbabu volcano is less active than Merapi volcano. The fact shows that the last eruption of the Merbabu volcano was in 1797 [25]. We also interpreted that the boundary between low and high velocities at the southern part of the study area represents the Opak fault. The boundary of these low and high velocities originated from the difference of rock physical properties [5]. The existence of low velocity around the seismogenic zone may change the long-term stress concentration [26, 27].

4. Concluding Remarks

The data taken from both DOMERAPI and BMKG networks are effective to improve the resolution beneath the Merapi volcano, especially for depths less than 35 km. The existence of deep and intermediate reservoirs could be detected clearly at depths of around 27 km and 12 km, respectively. The dipping low velocity material ascends from the depth about 100 km. The results also imply that Merbabu volcano is less active than Merapi volcano. To the south of Merapi volcano there is the contact zone between high and low velocity anomalies interpreted as the Opak fault zone.

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