Pyroclastic Deposits Identification using Near-Surface Seismic Refraction Tomography in Rawa Dano Volcanic Complex, Banten, Indonesia

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Abstract. Rawa Dano is a caldera lake which resulted from Dano Purba Volcano’s massive eruption, and it produced a huge amount of pyroclastic deposits that typically formed complex volcaniclastic series. Due to the lack of information regarding the subsurface properties of Rawa Dano area, therefore in this study, a low-energy seismic refraction survey was carried out to identify the distribution of pyroclastic deposits resulted from intensive volcanic eruptions. The data were acquired from two lines in two different sites. Variations of longitudinal velocity in the seismic vertical cross-section suggest that there are more than one type of deposits existed in the area. The results show two main refractors which are related to the deposition of different facies. The seismic velocity shown in the upper part of the seismic tomography model indicates that the pyroclastic deposit has a great thickness. This finding suggests that the eruptions happened massively. By combining the results from both sites, it could be inferred that the preceding one is even bigger in magnitude. The result is in agreement with the earlier surface geological study, which explains a similar conclusion. This research demonstrates the capability of seismic refraction tomography to map the distribution and condition of volcanic deposits around Rawa Dano Volcanic Complex.

Keywords: seismic refraction, velocity, Rawa Dano, volcanic, pyroclastic

1. Introduction

Indonesia is a country located in the Ring of Fire Zone. The fact that it is susceptible to volcanic activities that would create disastrous problems such as pyroclastic fall and flow, which are the products of volcanic eruptions. We can encounter those pyroclastic deposits that were often deposited during different volcanic eruption episodes and typically combined to form complex volcaniclastic series. In some locations, the detailed mechanism of those volcanic events remains unknown due to the lack of evidence and research. The same situation has happened in the area of Rawa Dano. This area is a caldera-like morphology in the middle of Dano Volcanic Complex, which is located in Serang District, Banten Province, Indonesia.

Many international papers mention the utilization of many models to map the distribution of pyroclastic cover deposits, such as slope gradient or elevation [1], and a combination of variety of
morphological parameters (for instance [2, 3, 4]). Mainly, these studies have concentrated on analyzing the spatial framework. Research in the Rawa Dano area is still rare, and only focused on surface geological studies. Enhancing our understanding with additional information about the subsurface condition would be beneficial to this study of volcanism. Therefore, this study is aimed to investigate the distribution of the volcanic deposits by identifying their subsurface properties which could differentiate them from soils and basement layer.

Among many geophysical methods in near-surface exploration, seismic refraction tomography is one of the most effective approaches to investigate near-surface geology. This method is generally used to characterize the shallow subsurface layers, which related to the objective of this study is, for example, crustal structure survey [5]; seismic refraction investigations of ignimbrite [6], stratigraphically verified pyroclastic deposits [7], and soil structure [8]. The seismic refraction method in this paper is applied to delineate the distribution of Rawa Dano Volcanic Complex's pyroclastic deposits by using an artificial source of seismic signal, hence making it possible getting the information from depths.

2. Geological Condition
Rawa Dano is a caldera with a lake and swamp with 2,500 hectares coverage [9]. Two significant eruptions caused these features from Dano Purba Volcano during Pleistocene. Upper Banten Tuff deposit (Qvtb) is the vital deposit in this study area, which consists of tuff, pumice tuff, sandy tuff (at the top), crystal tuff, rocky lapilli tuff, glass tuff, and inserts of clay tuff. Dano Muda volcanic rock deposits (Qvd) are in the form of lava flow, composed of andesite or jointed basalt, volcanic breccia, and tuff. Dano Tua volcanic rock deposits (Qpd) consist of lava flow composed of andesite or jointed basalt, volcanic breccia, and tuff. Younger mountain rock deposits (Qhv) consist of volcanic breccia, lava, tuff, lava flows, and other volcanic eruptions (Mount Aseupan, Mount Parakasak) [10].

Figure 1. Map of the study area in Rawa Dano (modified from [11]/[12]).

Dano Purba Volcano’s first eruption episode is identified as a magmatic eruption. This eruption was likely to have immense explosive power, as indicated by the constituent components, which were more than 5 cm in size (more than lapilli size). This episode’s eruption took place with a pyroclastic flow mechanism characterized by lapilli fumarole pipe. After the first phase was completed, there was a hiatus period marked by the presence of a fairly thick paleosoil as indicated by traces fossil of insects [11]. The duration of the eruption is not specific. After the eruption pause is over, another eruption occurs with a magmatic type with two different eruption mechanisms. Based on the geological map of the Serang [12], this eruption happened in the Early Pleistocene. This volcano likely erupted due to the reactivation of subduction in Southern Java during the Plio-Pleistocene period [13, 14]. It is well known that at that time, many volcanoes erupted by producing early quaternary deposits. However, it is not yet significant.
to answer when this eruption occurred. Therefore, it is necessary to analyze age measurements by carbon dating to ensure the hypothesis.

3. Methodology
The study area is located in 2 sites, Site 1 in Pancanegara (6°11'56.1"S 106°05'29.1"E) and Site 2 in Kadu Jaya (6°10'27.5"S 106°08'49.9"E) as shown in Fig. 1. This research uses seismic refraction to identify rock layers based on velocity [15]. Seismic refraction is calculated based on the time it takes for a wave to travel through the rock from the seismic source to the receiver at different distances [16]. We can define the depth of the first (1) and second (2) layer as:

$$Z_1 = \frac{T_1V_1}{2 \cos \alpha}$$  \hspace{1cm} (1)

$$Z_2 = \left[ T_{12} - \frac{zz_1}{v_1v_3} \sqrt{(V_2)^2 - (V_1)^2} \right] \frac{V_2V_3}{2\sqrt{(V_3)^2 - (V_2)^2}}$$  \hspace{1cm} (2)

Like other geophysical methods, seismic refraction survey has three main steps: acquisition, processing, and interpretation. Data acquisition is conducted using seismic refraction instruments to get refraction data. The seismic refraction instrument has three main components: geophones (connected to the main unit), source, and main unit. We use Summit X One as the main unit with a hammer as an artificial low-energy source. Data acquisition took place on Site 1 and Site 2 (Fig. 2). For Site 1, 24 geophones were arranged along 120 m seismic profile in S-N direction. For Site 2, 20 geophones were positioned in S-N direction with the length of 76 m. Each geophone’s spacing is 4 m, and shot points are every 8 m, started from 4 m behind the first geophone and ended 4 m in front of the last geophone (Fig. 3). To process the data, we use Easy Refract software to do quality control, pick the first break wave, velocity analysis, and obtain a velocity model of the subsurface layer. Then, interpretation can be done by analyzing the final velocity model to define the subsurface condition.

![Figure 2](image)

**Figure 2.** Seismic refraction survey location in (a) Site 1 and (b) Site 2.
4. Results and Discussions

4.1 Site 1

Seismic refraction survey in Site 1 is aimed to observe the existence of volcanic deposits from different eruption stages, their thickness, as well as the depth of basement layer from their velocity contrast. Based on the data processing results at Site 1, as shown in Fig. 4, there are only two layers of different velocity values were obtained. The first layer, shown in brown, has a primary velocity (Vp) value of 1177.75 m/s and a secondary velocity (Vs) of 565.77 m/s with the shallowest depth of 31 m and the deepest 91 m below the surface. The second layer, shown in green, has a Vp of 1537.14 m/s and a Vs of 738.42 m/s. Both layers have a significant difference in velocity, which apparently describes that it is related to two different types of rock.

Fig. 4 shows that, however, there are no shallow refractors detected. It indicates that neither there are shallow variations of volcanic deposits nor significant velocity differences between layers. The latter could be a more reasonable conclusion by considering the prior geological studies, as stated in chapter 2. From the result of the velocity map and morphological cross-section in Site 1, it can be seen that the first refractor is encountered at a depth greater than 25 m. This layer is getting more in-depth on the right side of the cross-section, showing that this layer is dipping to the north direction. This condition is most probably associated with the deeper pyroclastic deposit, which predates the one on the surface. This layer is having a greater Vp as it got more consolidated after gravitational pressure. This result also suggests that the surface volcanic deposits is having a great thickness. Taking into account the distance from the survey location to the center of the volcanic complex (12 km), this finding also provides further support for the hypothesis that the Rawa Dano eruptions were massive. Unfortunately, this outcome has been unable to give supporting information to explain the eruption stages.

![Figure 3. Acquisition geometry](image)

![Figure 4. Velocity map (left) and morphology (right) of refractors in Site 1.](image)
Figure 5. Velocity map (left) and morphology (right) of refractors in Site 2.

4.2 Site 2
The second investigation in Site 2 was carried out to measure the extent of pyroclastic depositions in a farther location which is 7 km to the east from Site 1 or 19 km from the center of Rawa Dano caldera. This investigation is resulting in subsurface velocity map and morphology as seen in Fig. 5. Compared to Site 1, the result of data processing at Site 2 also shows velocity variations with depth. The first layer has a Vp of 473.14 m/s and a Vs of 227.29 m/s from the surface until the deepest of 11 m below the surface. The second layer has a Vp of 603.91 m/s and a Vs of 290.11 m/s. In this cross-section, the second layer is also dipping to the north direction.

Site 2 was the sand mining location which was abandoned for a relatively long time. Measurement was conducted on a dry surface pumiceous volcanic rock which was severely weathered and having bad grain sortation [11]. One interesting result is that the velocity range of the subsurface layers observed in Site 2 differs significantly to the one measured in Site 1. A possible explanation for this is that the layers are made of different facies, although all of them are volcanic products. Different facies here could also suggest that they were formed in different stages. It is interesting to note that the upper layer of Site 2 has a great thickness which indicates another massive eruption happened earlier. The second layer could be related to basement rocks. However, there is not enough information about its geological properties to be correlated to the observed seismic velocity. One unanticipated finding is that the dipping direction of the subsurface layer of Site 1 and Site 2 confirm each other, which could give an additional idea about the paleotopographic condition around Rawa Dano Volcanic Complex.

5. Conclusions
This study aims to use the seismic refraction method to identify the subsurface geological condition based on seismic velocity. This study has shown that velocity variation with depth and affected by the thickness of layer, compaction, and facies. The results show the deeper position of refractors to the right from the two layers of both sites. The result indicates possible paleotopographic condition around Rawa Dano Volcanic Complex and effect of gravitational pressure caused the greater value of Vp. Facies differences may cause the different value of Vp from both sites. Another interesting result is massive eruption as the product of Dano Volcano’s eruption, shown with great thickness in the velocity map. Further studies need to be carried out to explain the eruption stages of Rawa Dano. Additional geophysical method and core data may suit to confirm this study.
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