Investigation of Rawa Dano Volcanic Deposits and Its Paleotopography Using Ground-Penetrating Radar

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Abstract. The detailed mechanisms of volcanic eruptions happened around Rawa Dano, Banten, Indonesia, remain undiscovered. One of the key features to this geological event is the presence of a 13.7 km × 6.5 km caldera-like morphology in the middle of Banten tuff deposits. Surface geological investigation in the area indicates that the eruptions are massive and occurred in several periods. Low-frequency ground-penetrating radar (GPR) signals are used as an aid to identify the unexposed part of the deposits in this volcanological study. Common-offset GPR surveys were carried out along three measurement lines traversing over the deposit outcrops. An outcrop which is exposed after sand mining activities at one of the survey locations shows dipping interfaces between the upper pyroclastic flow deposits, pumice-rich deposits, paleosol, and the lower pyroclastic fall deposits. These stratigraphic contacts are detected as well under the surface which are clearly recognizable in radar images. The GPR cross-section also shows some other reflections due to different deposit types. The overall results of the GPR profiles give the idea about the thickness of each type of volcanic deposits and the paleotopography in the surrounding area.

Keywords: ground-penetrating radar, Rawa Dano, pyroclastic, deposit, paleotopography

1. Introduction

Rawa Dano is located in the western part of java, Serang City, Banten Province. Geological map [1] shows that the majority of this area is covered by a pyroclastic deposit namely Banten Tuff formation, the map also shows that there is a caldera structure in Rawa Dano indicating volcanic activities in the past. A recent geological study of the Banten Tuff formation by [2] reveals that in early Pleistosen there has been multiple eruption in Rawa Dano. Eruptions happened in two types of mechanism which are pyroclastic fall and flow mechanism with two gaps of volcanic activities in between those eruptions. [2]

In order to find more information regarding these volcanic events especialy information about the geological features in the subsurface, a geophysical approach is needed.

Based on the difference of the physical properties and geometries of subsurface objects, ground-penetrating radar (GPR) is able to differentiate interface between layering of rocks or even objects such as pipes, cables, etc., which enables the application of this method in geology and geotechnical sector.
Several previous research regarding the use of GPR method on volcanic materials can be found. In volcanic setting, research by [4] demonstrates the possibilities of GPR method in characterization of air fall deposits, dykes, structures, and different types of lava flows based on difference in radar signatures and mean EM velocities exhibited by each volcanic material. A similar attempt was done by [5] to characterize pyroclastic fall and flow deposits of Tambora Volcano, the correlation between radar data and volcanic stratigraphy is able to indicates that the reflection might be caused by interface between soil-pyroclastic deposit and of pyroclastic flow and fall deposit. Another research also by [6] aims to identify longitudinal structure of pyroclastic flow deposits at Merapi Volcano in Java Indonesia. Those research shows the reliability of GPR method to be used in identifying volcanic materials in the subsurface.

GPR method with low frequency was used to identify the unexposed part of volcanic deposit and paleosol layering caused by the gap of volcanic activities in this area. Common offset GPR survey was carried out in three lines survey traversing over the deposit outcrop which exposed after sand mining activities in one of the survey location. The outcrop shows a dipping interfaces between the upper pyroclastic flow, pumice rich, paleosol, and the lower pyroclastic fall deposits. The depth and thickness of each layers identified from GPR data interpretation can then be used to estimate paleotopography along with the behavior of past volcanic activities in the area such as duration and magnitude of the eruption.

2. Study Area
The Rawa Dano lies in an ancient caldera of Danau volcanic complex on the north-western tip of West Java, Indonesia at an elevation of around 100 m above sea level (asl) in a caldera of a Plio-Pleistocene volcanic complex on the western tip of Java Island, Indonesia. (Fig. 1) The adjacent high volcanic terrain is mostly between 400−700 m asl. The deepest part in Rawa Dano is a crater which was largely occupied by swamp. The sediment of the swamp consists of fine grained lake deposits (organic silty clay and silty gyttja with shells), with minor intercalations of peat and fluvial sands [7]. Peat deposits prevail in the central swamp area with sequences of up to 4-5m thickness just below the surface. The Danau volcanic complex is of Plio-Pleistocene age and formed in several of eruptive phases, culminating in the eruption of the voluminous Banten pumice tuffs (also known as ‘Bantam’ tuffs) and formation of the large [8][1]. Banten Tuff (Qvpb) is a pyroclastic deposit that is quite important in the western tip of Java. Banten Tuff (Qvpb) is crucial because it has an extensive distribution which almost covered the entire area of Banten. In the middle of Banten Tuff’s (Qvpb) distribution, there is a caldera with a rectangular shape which has an area of about 13.7 km x 6.5 km. [2]

Figure 1. Map of investigation site in Rawa Danau, Banten, Indonesia (modified from [1][2])
This research takes precisely in the area that produces the tephra-stratigraphic correlation. This correlation is identified into four eruptive facies units that exist in one outcrop which called the type locality, each of these facies are then characterized. The four facies have eruption types with different mechanisms. The eruption mechanism of three upper facies sediment is pyroclastic flow. Meanwhile, the mechanism of facies in their subsequent layer is pyroclastic fall [5].

![Diagram of GPR Working Scheme and Common-Offset Technique](image)

**Figure 2.** a) GPR Working Scheme, b) Common-Offset Technique (modified from [11])

To identify an unexposed part of the deposits in this volcanological study, we used ground-penetrating radar (GPR) with low-frequency signals. The research sites are located at 6°11′56.1″S 106°05′29.1″E and 6°10′27.5″S 106°08′49.9″E. This survey location was used for sand mining activities, resulting in an exposed outcrop which shows dipping interfaces between the upper pyroclastic flow deposits, pumice-rich deposits, paleosol, and the lower pyroclastic fall deposits.

3. **Methodology**

Ground Penetrating Radar (GPR) is one of the active geophysical method that used radio wave propagation in range 10 – 2000 MHz for detecting reflected wave from subsurface objects as its responses [9][10]. For the instrument, GPR consists of two antennas which are transmitter and receiver antenna. The wave signals are emitted to the ground through the transmitter antenna, when the signals hit some reflectors, some energy would be reflected to the receiver and the remains are continued to the next layer (Fig. 2).

The magnitude of reflected wave ($r$) depends on relative dielectric permittivity (RDP) difference from a layer to another layer [10], that can be described with:

$$r = \frac{\sqrt{RDP_2} - \sqrt{RDP_1}}{\sqrt{RDP_2} + \sqrt{RDP_1}}$$  \hspace{1cm} (1)

Because radio wave is considered as an electromagnetic wave, its propagation is controlled by some physical properties such as dielectric constant (RDP), conductivity ($\sigma$), and permeability ($\mu$), but permeability is less concerned. The quality of GPR data, either the resolution or depth of penetration are determined from antenna frequency and subsurface properties [11]. Soils with high conductivity would produce high levels of attenuation, it caused penetration depth to decreased. Electric conductivity from the soils itself could increase as the amount of water, salt saturation, and clay content increases. Hence, this research should consider whether the sites of investigation can produce an accurate result or not.

This research used 50 & 100 MHz frequency antennas with maximum penetration approximately about 40 m. The frequency was chosen with consideration that the object is estimated to be located at a depth of 50 m. The other reason is the common assumption that this frequency is suitable for soil layer and geological studies. Before running the measurement, it is necessary to set up several parameters on GPR instrument to get maximum result. The parameters used are 9 for medium permittivity, 1200 ns for time range, and 32 for stacking.
There are two sites in this investigation. The first site which located near the main source of eruption consists of 2 lines with profile length about 140 m (named Line 1-1 and Line 1-2). Due to massive attenuation occurred in depth below 25 m, recording duration for one GPR trace was shortened to 400 ns. The first site is an active mining site where the outcrop is exposed after soil extraction. Another site is located in the eastern side of the first site (away from Rawa Dano caldera) and it is lower in elevation. The surface of this area made of more solid layer which was assumed to be the basement. In the location of abandoned sand mining area, 2 lines of GPR survey were carried out with distance of 80 and 50 m for Line 2-1 and Line 2-2 respectively. Location of these GPR profiles are shown in Fig. 3.

Once all the GPR data has been collected, the data are then filtered using background removal and frequency-based filter. The reflection amplitude was fixed through gain control, so that the results are expected to clearly delineate the soil layer boundaries between tuff or pyroclastic deposits with other soils. All the process (data collection and processing) was carried out using Prism 2.7 GPR software.

4. Result and Discussion
Data processing result from the two measurement lines in Site 1 were shown in Fig. 4. A high-level of unfiltered background noise, indicated by constant straight lines from 0 to maximum distance, makes the reflection data become difficult to interpret. However, the cross-sectional view of Line 1-1 (upper part of Fig. 4) shows some reflectors with various shapes which are visible starting from the depth of 7.5 m. At this depth, there are reflectors in the shape of dunes, which are having a slightly different electrical properties from the overlying soil. One interesting finding is that these morphologies have crisscrossed one another, making it more challenging to analyze. However, by considering such small reflection amplitudes, it can be inferred that this layer consists of the same pyroclastic deposits, but maybe differ in some manners. It could represent the earlier volcanic material deposition than the one exposed on the surface, and it could give the idea of small portion of paleotopography in this area.

The adjacent GPR profile (Line 1-2) shows almost no differences in terms of stratigraphy, except the depth and the position of the reflectors are not the same. It can be seen in the lower part of Fig. 4 that the reflectors are deeper in depth, and farther in distance relative to the first GPR trace. This result indicates that the elevation of this paleotopography is getting low to the East direction. Several high amplitude reflections were detected in the depth about 12 m in Line 1-1 and 15 m in Line 1-2. These reflectors are steeply dipping in the North direction. A possible explanation for this finding might be that the reflection is due to the basement layer which have a clear contrast with the upper volcanic layers. However, due to the limited energy and penetration ability of GPR signal, there could be a potential bias in data interpretation.
In the second part of the GPR survey in Site 2, measurement along the Line 2-1 (Fig. 5) shows a strong reflection with a wavy shape starting from the depth of 6 m below the ground surface. The anomaly is detected along the measurement profile, with some deeper reflector visible at some part where GPR signal is not severely attenuated. There are noticeable signal attenuations below the depth of 20 m which is most probably due to groundwater aquifer. Meanwhile, the GPR cross-section of Line 2-2 shows two main reflectors: the first one is located on its left hand side in a shallow depth; the second reflector is a dipping reflector located on its right hand side after 20 m depth.

![Figure 4. GPR Cross Sectional data in site 1, black lines show the proposed stratigraphic layers.](image)

Comparing the results from Site 1 and Site 2, it can be seen that the strong reflection, which is most likely indicating the basement depth, could be found in shallower depth in Site 2. The thickness of volcanic deposits in this location, is much more reduced compared to Site 1. This finding inferred that the volcanic deposits from volcanic eruptions in Rawa Dano are getting thinner to the east direction. One unanticipated finding is that the second reflector at the end of Line 2-2 is dipping to the west direction, which differs from the rest. This result is probably related to the existence of ancient river, which could also explain the existence of a massive groundwater aquifer at the center. However, with a small survey dimension, this interpretation is uncertain, and need to be proven with more reliable data and methodology.
Figure 5. GPR cross-sectional results from Site 2 (Line 2-1 and Line 2-2). Black lines show the layer of proposed stratigraphy and the squares show the electromagnetic signal attenuation.

5. Conclusions
In this investigation, the GPR method was used to gain more information about volcanic deposits and paleotopographic condition around Rawa Dano volcanic complex. This research confirmed that GPR survey was able to differentiate between underground stratigraphic layers by using their contrast in electrical properties. The results from Site 1 shows that the elevation of the general paleotopography around the location is getting low to the East direction. This study has also found that the volcanic deposits such as upper pyroclastic flow deposits, paleosol, and the lower pyroclastic fall deposits determined from the reflection of the GPR signal on several lines. Furthermore, the volcanic eruptions in Rawa Dano are getting thinner to the east direction, which also indicates that the origin of the volcanic deposits is located to the west from both measurement sites. Taken together, these findings strengthen the idea that volcanic eruptions in Rawa Dano was happened in several periods, which was resulting a number of layers of volcanic deposits.

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