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Hypocenter Distribution Analysis of Sinabung Volcano During January-May 2017

Dewi Putri Rosyilaray[1], Agus Setyawan[2], Mohammad Hasib[3], Ahmad Basuki[4]

[1]Magister of Physics, Physics Department, Faculty of Science and Mathematics, Universitas Diponegoro, Tembalang Campus, Semarang, Indonesia, 50375, Indonesia
[2]Physics Department, Faculty of Science and Mathematics, Universitas Diponegoro, Tembalang Campus, Semarang, Indonesia, 50375, Indonesia
[3]Research Center for Geological Disaster, National Research and Innovation Agency (BRIN), Jl. Sangkuriang, Bandung 40135, Indonesia
[4]Center of Volcanology and Geological Hazard Mitigation (PVMBG), Bandung, West Java, 40122

Corresponding Author: Dewi Putri Rosyilaray

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ABSTRACT

Scientists can use the depth of earthquake starting points (hypocenters) to pinpoint earthquake zones and track earthquake patterns. This method was applied to volcanic earthquakes (Volcano-Tectonic) to find the hypocenter distribution under Sinabung Volcano. By analyzing earthquake depths with a special technique (Geiger's method with Adaptive Damping) found the hypocenter distribution to be 2-5 kilometers down.

Keywords: Hypocenter, GAD method, Sinabung Volcano, seismic.

INTRODUCTION

Indonesia stands out as a global hotspot for volcanoes. When it comes to volcanoes, Indonesia reigns supreme with one of the highest counts on Earth. [1]. Indonesia boasts a staggering 129 volcanoes scattered throughout its many islands. (This paraphrase emphasizes the impressive number and uses "boasts" to highlight the abundance [2]. Indonesia's position at the crossroads of three massive tectonic plates has resulted in its fiery landscape, with a staggering number of volcanoes dotting its islands [3]. Indonesia's unique geology, shaped by the clash of tectonic plates, makes it prone to earthquakes. The severity of these earthquakes is measured using various factors, including the depth of their starting point (hypocenter). One technique employed to pinpoint the source mechanism of these earthquakes is Geiger's Method with Adaptive Damping (GAD) [4]. The Geiger method works by comparing the predicted arrival times of earthquake waves at different stations with the actual recorded times. This helps scientists pinpoint the location of the earthquake's source (hypocenter) [5]. By analyzing seismic waves within volcanoes, scientists can gain valuable insights into the inner workings and changing dynamics of volcanic activity [6] [7] [8] [9].

Sinabung Volcano erupted again from September 2013 to February 2014 and the recent was in January 2015 [10]. Sinabung's fiery reign continued in 2017, spewing towering columns of ash [11]. Sinabung roared back to life on August 2nd, 2017, spewing ash a staggering 4.2 kilometers high. The eruption also unleashed pyroclastic flows, superheated avalanches of gas and rock, that surged up to 4.5 kilometers to the southeast [11]. In December 2017, Sinabung Volcano erupted again, spewing ash column as far as 4.6 kilometers [11].

A rise in earthquake activity demands close attention [12]. Keeping a watchful eye on what's brewing under a volcano is crucial [13], such as the hypocenter of volcanic earthquake (i.e. Volcano-Tectonic earthquake) [14]. This study uses seismic analysis to investigate hypocenter distribution of sinabung volcano during January – May 2017.

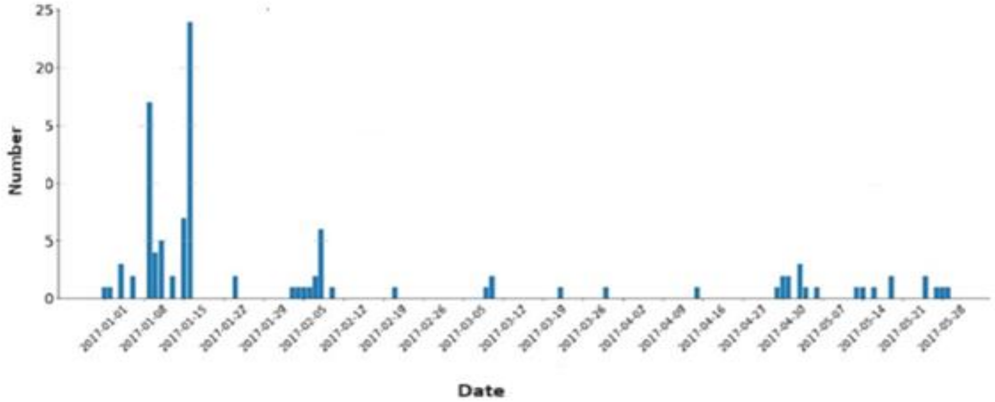

Fig. 1 Data from the PVMBG catalog reveals volcanic tremor activity (VT earthquakes) at Sinabung Volcano between January and May of 2017

DATA AND SEISMIC STATION

This research relies on seismic data collected by the Center for Volcanology and Geological Hazard Mitigation (PVMBG) during their monitoring of Sinabung Volcano's activity. This study focuses on volcanic tremor (VT) earthquake information collected from Sinabung Volcano between January and May of 2017.

This study utilized five seismic stations for data collection. These stations are listed in Figure 1 and include Sukanalu (SKN), Lau Kawar (KWR), Sigarang-garang (SGG), Mardingding (MDD), and Gamber (GBR). The study also employed a summit reference point located at 98.39278° and 3.17°, which is marked by a yellow triangle in **Fig. 2**.

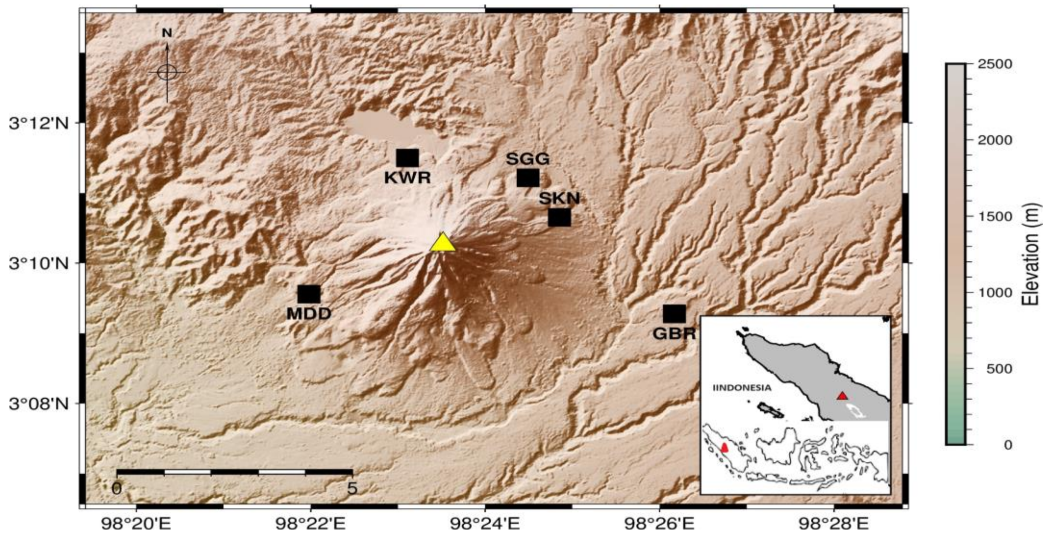

Fig. 2 illustrates the locations of the seismic stations used in this study to monitor Sinabung Volcano. Black rectangles represent the five seismic stations, while the yellow rectangle depicts the volcano's active crater

The identified arrival times (picking) of the P and S waves within the volcanic tremor (VT) earthquake waveforms in **Fig 3** [15]. There's a time gap of 1 to 4 seconds between the faster P-waves and the slower S-waves. VT earthquakes have a certain frequency range. VT-A earthquakes rumble with higher frequencies, typically between 5 and 15 Hz. In contrast, VT-B earthquakes vibrate at lower frequencies, ranging from 3 to 5 Hz [16]. The epicenters of VT-A earthquakes cluster closely to the currently erupting crater of Sinabung Volcano [17].

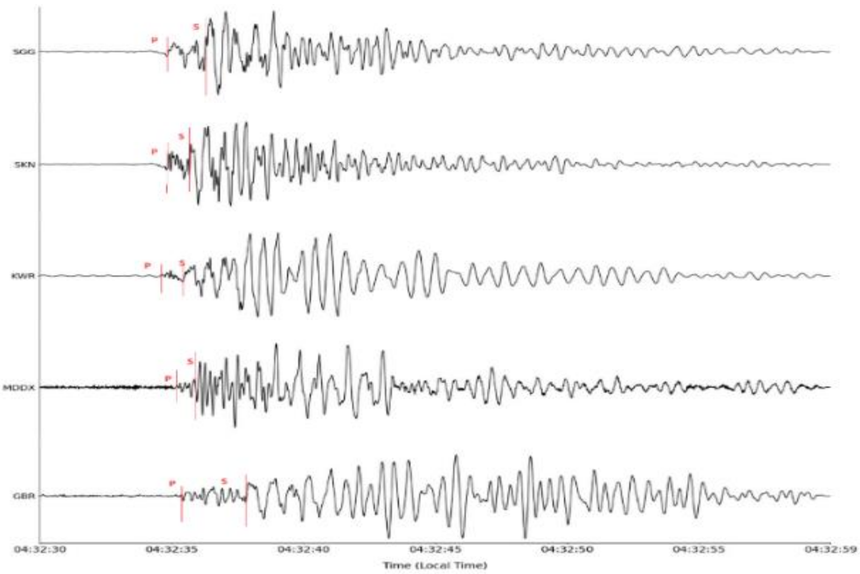

Fig. 3 The P and S waves pick of VT earthquake that occur on January, 31, 2017 18:30:00 local time

MATERIALS & METHODS

By analyzing the arrival times (picks) of P and S waves, scientists can pinpoint the exact moment (origin time) an earthquake starts [18]. To calculate the gradient for each of the 123 volcanic tremor (VT) events, researchers plotted the difference in arrival times between the P-wave and the origin time, as well as the difference between the S-wave and P-wave arrival times. (see Figure 4) [19].

Scientists employed a technique called Geiger's method with adaptive damping (GAD) to pinpoint the hypocenter (source location) of the VT earthquake. This method works by comparing the predicted arrival times of earthquake waves at different stations with the actual recorded times [20]. By using GAD, researchers can achieve a high level of accuracy when pinpointing the hypocenter of VT earthquakes [21]. Adaptive damping is a smart technique that automatically adjusts the influence of certain factors during calculations. In this case, it considers the actual seismic data observed to refine the hypocenter location [22].

Start by feeding seismic data from the monitoring stations into the analysis. Then, experts meticulously examine the wave patterns (waveforms) to identify the exact arrival times of the P and S waves [23]. For accurate calculations, all station locations (longitude and latitude) are converted into a UTM format. Third, running GAD with the output is x, y, z-values in km. To visualize the distribution of earthquake sources (hypocenters), scientists use Origin software to create a 3D-like plot of x (horizontal position) vs. -z (depth) values. The negative sign for z indicates that deeper hypocenters have more negative values.

RESULT AND DISCUSSION

An analysis of 123 volcanic tremor (VT) events revealed a linear relationship between two times differences. This relationship can be expressed by the equation y = 0.667x, where the gradient is 1.76. The x-axis represents the difference between the arrival time of the P-wave and the origin time (tp-to value), and the y-axis represents the difference between the arrival times of the S-wave and the P-wave (ts-tp value). The previous study demonstrated that the line gradient (Vp/Vs-1) of the Wadati diagram is in the range of 0.6 s -0.9 s, which indicates the picking results of the P and S wave arrival time are good to analyse [24]. The Wadati diagram equation values are shown in **Fig. 4**. As expected, the seismic data confirms a well-established principle: the farther a seismic station is from the earthquake source, the longer it takes for the waves to reach that station. The wadati diagram is a parameter of the quality of picking data [25].

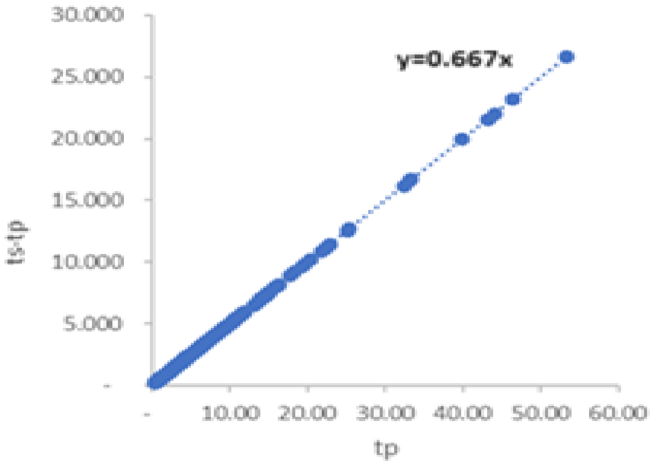

Fig. 4 Wadati diagram of the Sinabung VT earthquake event during January-May 2017

An underground view (vertical cross-section) of where earthquakes originated (hypocenter distribution) beneath Sinabung Volcano is shown in **Fig. 5a**. The X-axis shows the direction in West - East. The Y axis shows the depth value of the VT. The red circle depicts where most of the VT earthquake starting points (hypocenters) are concentrated. Our analysis reveals a cluster of earthquake starting points (hypocenters) likely between 2 and 5 kilometers beneath the summit. A separate study indicated that VT earthquakes at Sinabung might originate from depths as far as 10 kilometers below the surface. The study also revealed that the epicenters (surface locations directly above the hypocenters) of these earthquakes were scattered between Sinabung Volcano and Mount Sibayak [26]. Nugraha et al. in [27] shows that shallower volcanic tremor (VT) earthquakes, typically occurring at depths between sea level and 2.5 kilometers, are concentrated in the northeastern region of Sinabung Volcano.

A view from the side (vertical cross-section) showing where the Sinabung Volcano earthquakes reached the surface (epicenter distribution). is shown in **Fig. 5b**. The epicenters, which are the points on the surface directly above the earthquake sources, are scattered around Sinabung Volcano's crater. Interestingly, there's a trend of them being located farther northeast as you move away from the summit.

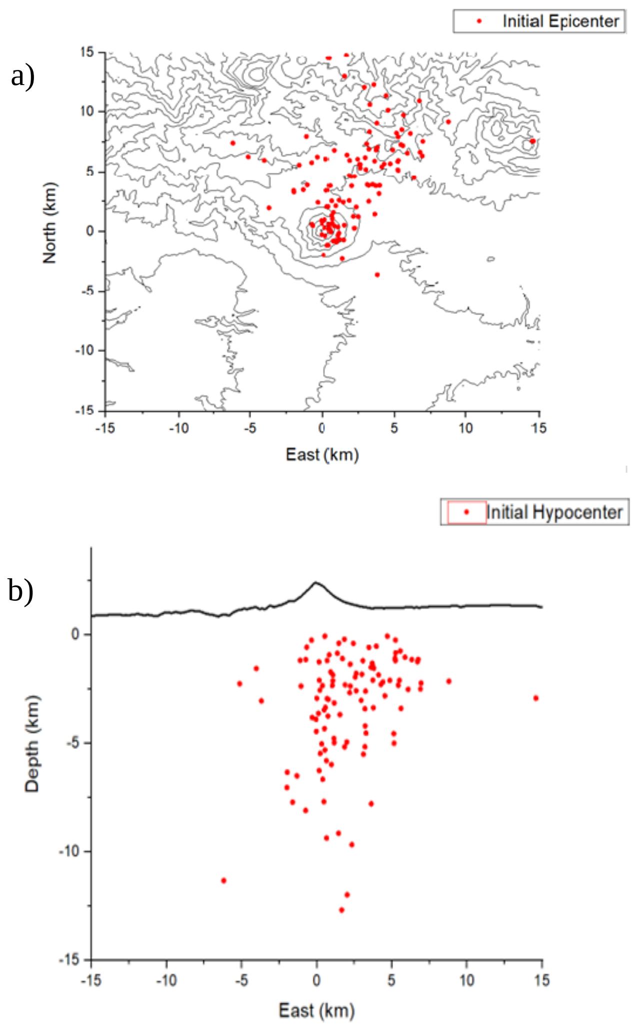

Fig. 5 a) These are the underground locations where earthquakes originate beneath Sinabung Volcano during the period of January to May 2017, b) These are the points on the Earth's surface directly above the earthquake sources (hypocenters) Sinabung Volcano during the period of January to May 2017.

CONCLUSION

This study, focusing on Sinabung Volcano during the period of January-May 2017. Hypocenter distribution is between 2-5 km. 123 event VT earthquake shows that Sinabung Volcano is active. People are expected to be aware if at any time eruption.

Declaration by Authors

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