Determination of Hypocenter Using Geiger Method in Sinabung Volcano, April-July 2016 Period

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Abstract. Sinabung is a volcano located in the Karo Highlands, Karo District, North Sumatra, Indonesia, with the highest peak of 2460 meters mean sea level. Volcanic earthquake is an earthquake that occurs due to volcanic activity. This is caused by the movement of magma upwards in the volcano. This study aims to determine the type of earthquake, hypocenter position and epicenter of volcanic earthquakes in Sinabung volcano in April-July 2016. The principle of this study was carried out by analyzing volcanic earthquake data in Sinabung volcano in April-July 2016. The data is recorded data (seismogram) or in other words is secondary data from Sinabung volcano on 7 seismometer stations namely Sukanalu, Lau Kawar, Sigarang-Garang, Mardinding, Gamber, Sibayak, and Kebayaken stations. Earthquake data in April-July 2016 revealed that there were 24 earthquake events in a period of 3 months which were the results of picking up the P and S waves, where volcanic earthquakes were obtained only in the form of volcanic earthquake type A and type B volcanic earthquake. Sinabung volcano has an earthquake activity that high enough so that the status of Sinabung volcano is still at level III (standby) status. Based on the hypocenter of several VA and VB earthquakes that occurred in April-July 2016, it can be concluded that the distribution of the hypocenter of the volcanic earthquake shows that the maximum depth of the volcanic earthquake is 10,000 meters and the position of the earthquake is spread at the point between Sinabung volcano and Mount Sibayak.

1. Introduction

Volcanic earthquake (volcano) is an earthquake that happen because of volcanic activity, either it is magma movement reaching earth surface or eruption/gas wind erupted from inside the volcano [1]. Indonesia is one of country located at intersection of tectonic plates, those are Eurasia Plate, Indo-Australia Plate and Pacific Plate [2]. These plates boundaries are subduction zone thus forming mountain ranges and compression structures [3]. Because of these, Indonesia is known to have the most active volcanoes in the world, 127 (30%) of them are located in Indonesia [4]. One of the active volcanoes located in North Sumatera is Sinabung volcano. Sinabung volcano is at Karo Regency, 80 kilometers away from Medan, the capital city of North Sumatera [4]. This mountain which 2460 meters mean sea level was formed at northwest edges of fractured basin Toba Tua [5]. Seismic activities note that since 1600-2000s, the volcano never erupted, but then suddenly became active in 2010 [2]. Sinabung volcano erupts volcanic materials reaching 7 to 8 kilometers height [6].
Besides, Sinabung volcano has four main craters including stratovolcano or layered volcano, alternating between lava melting and pyroclastic in every single eruption period [7] [8]. This study analyze Sinabung volcano to reveal earthquake capacity happening either it is shallow volcanic earthquake or deep volcanic earthquake by using GAD method (Geiger’s method with Adaptive Damping) [9] [10]. Geiger Method is iteration steps by optimizing least square in order to determine hypocenter location [11] [12]. The basic of this method are minimizing travel time residuals between observation data and calculated travel times by calculating using distant seismic networks by employing spherical earth travel time [13]. Geiger Method needs input such as arrival time parameter, velocity model and station location on Cartesian coordinate [14] [15]. This method uses arrival time of P wave and/or S wave as input. The equation is solved by using damped least square with adaptive damping. The damping constant is adapted with previous iteration results, thus stable solution may be obtained [16]. Because GAD method uses arrival time of P and S wave, researcher do pick of arrival time from waveform which resulted from Sinabung volcano. From this research, by knowing hypocenter and magma movement prediction, recommended disaster mitigation information can be constructed for society living nearby Sinabung volcano.

2. Data and Methodology
Seismic records of earthquakes at Sinabung volcano is processed using Software Swarm 2.7.2 and GAD. Software Swarm is used for determining earthquake type and arrival time picking of P and S wave, while GAD program is used for determining hypocenter and epicenter from the earthquakes. The data used include seismic records from April to July 2016 measured by 7 seismometers at Sinabung volcano stations. But the proceeded data was chosen only in April, May and July. This is because error of data records in June thus cannot be proceeded. Earthquake or seismic activity observations was done by using data records (seismograph) transmitted from observation stations to Volcanology Observation Center. Nearby Sinabung volcano, there are 7 stations used: Sukanalu, Lau Kawar, Sigarang-Garang, Mardinding, Gamber, Sibayak and Kebayaken. Coordinate data of the stations are provided in Table 1. below:

| No. | Station Name          | Easting  | Northing |
|-----|-----------------------|----------|----------|
| 1.  | SKN (Sukanalu)        | 434756.00| 351016.00|
| 2.  | LKW (Lau Kawar)       | 431671.00| 352796.00|
| 3.  | SGR (Sigarang-Garang) | 434243.00| 352275.00|
| 4.  | MMD (Mardinding)      | 429590.69| 349224.74|
| 5.  | GBR (Gamber)          | 437352.89| 348700.42|
| 6.  | SBY (Sibayak)         | 444684.00| 358076.42|
| 7.  | KBY (Kebayaken)       | 436267.00| 356063.00|
The following is flowchart of Sinabung volcano earthquakes data processing:

![Data Processing Flowchart of Sinabung Volcano Earthquakes](image)

Figure 1. Data Processing Flowchart of Sinabung Volcano Earthquakes

3. Result and Discussion

3.1. Result

The results provide 24 earthquakes in period of 3 months, where volcanic earthquakes obtained are volcanic earthquake type A and type B. Besides, there are another kind of earthquake recorded: far tectonic earthquake, low frequency earthquake and wind earthquake. From all of these obtained earthquakes, only VT_A and VT_B were proceeded. Station locations and Sinabung volcano peak using Google Earth are visualized in Figure 2, while earthquake plotting against epicenter is visualized in Figure 3. Hypocenter seen from North-South and East-West is visualized in Figure 4 and 5.
Figure 2. Locations of Stations Using Google Earth. Yellow Spots Indicate Locations of Sinabung Volcano Observation Stations, Orange Triangle is Sinabung Volcano Peak.

Figure 3. Earthquake Type A and B Positions in Sinabung Volcano in Period of April-July 2016
Figure 4. Earthquake Type A and B Hypocenter Positions in Sinabung Volcano From April to July 2016 (South-North Based).

Figure 5. Earthquake Type A and B Hypocenter Positions in Sinabung Volcano From April to July 2016 (East-West Based).
3.2. Discussion
Data processing was done to obtain volcanic earthquake hypocenter and epicenter positions in period of April-July 2016. Processing was done by using GAD method which use arrival time of P and S wave. After identification of earthquakes in Sinabung volcano, 27 wind earthquakes, 6 low frequency earthquakes (LF), 10 far tectonic earthquakes, 14 VTA earthquakes and 10 VTB earthquakes were obtained, resulting 24 volcanic earthquakes in total from April-July 2016. These indicate earthquake activity of Sinabung volcano is high enough thus Sinabung volcano status is at level III (standby). From Origin 7 Program, it can be seen the volcanic earthquakes type A and B epicenter and hypocenter locations, where maximum value of volcanic earthquake depth in the hypocenter distributions is 10.000 meters and earthquakes spots spread between Sinabung volcano and Mount Sibayak. Volcanic earthquake hypocenter seen indicate that during period of April-July 2016, earthquake locations dominate at around lower parts of Sinabung volcano. These are because of magma activity and volcanic eruption in 2016.

4. Conclusions
From data processing of volcanic earthquakes type A (VA) and B (VB) in Sinabung volcano, it can be concluded that types of recorded earthquake in Sinabung volcano are Shallow Volcanic-Tectonic Earthquake (VTB), Deep Volcanic-Tectonic Earthquake (VTA), Far Tectonic Earthquake, Low Frequency Earthquake and Wind Earthquake. The amount of identified volcanic earthquake in Sinabung volcano are 24. Sinabung volcano hypocenter distributions are clustered under the volcano reaching 0,5-10 kilometers depth. Based on the hypocenter distributions shown in the previous visualization, the distributions are seen from about North to Southeast of Sinabung volcano reaching 10 kilometers depth.

5. Acknowledgments
Researcher give great thanks to Allah SWT, who has given health and strength so that researcher can finish this research. Researcher also would like to thank parents, supervisors and all friends in Geophysics Department. We also would like to thank Center for Volcanology and Geological Hazard Mitigation (PVMBG) for granting us to publish final data, and also to Hasanuddin University for giving financial support for this research.

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