京都大学防災研究所年報　第 54 号 B　平成 23 年 6 月
Annuals of Disas. Prev. Res. Inst., Kyoto Univ., No. 54 B, 2011

Learn from 2010 Eruptions at Merapi and Sinabung Volcanoes in Indonesia

Masato IGUCHI, Kazuhiro ISHIHARA, SURONO*
and Muhamad HENDRASTO*

* Center for Volcanology and Geological Hazard Mitigation, Indonesia

Synopsis

In 2010, noteworthy eruptions occurred at Sinabung, North Sumatra and Merapi in Central Java, Indonesia. Sinabung volcano erupted on August 27 after dormancy more than 400 years and repeated 7 eruptions till September 7. At Merapi volcano, explosive eruption occurred at the summit on October 26 accompanying resultant blast and pyroclastic flow. The eruptive activity reached at the peak on November 3-5, generating continuous pyroclastic flow which ran southward 17 km in distance. We obtain important lessons from these eruptions for evaluation of volcanic activity and prediction of volcanic eruption. Evaluation of volcanic activity is still difficult at volcanoes after long-term dormant period. Quick response to obtain data is important to compensate the gap from the last eruption. It is difficult to predict activity of volcanoes under the condition of open-conduit system, too. Associated with extension of flow length of pyroclastic flow, restricted zone was extended up to 20 km and 380,000 people evacuated from Merapi volcano. Japan has not been experienced by risk management for such a large number of evacuees from volcanoes. Countermeasure planning against volcanic eruptions with disaster in wider area should be established.

Keywords: Merapi volcano, Sinabung volcano, pyroclastic flow, phreatic eruption, volcanic disaster prevention

1. Introduction

Center for Volcanology and Geological Hazard Mitigation (CVGHM), Geological Agency (GA), Ministry of Energy and Mineral Resources is responsible to issue alert level for 127 active volcanoes in Indonesia and to provide recommendation of hazard mitigation from the volcanoes. CVGHM is one the centers belonging to GA (previous Directorate General of Geology and Mineral Resources), which has collaborated with Disaster Prevention Research Institute (DPRI) of Kyoto University since 1993 for the studies on volcanic eruption mechanism, volcanic activity and geological hazards in Indonesia.

The 127 active volcanoes are categorized into Type-A (magmatic eruptions after 17th century), Type-B (eruptive activity before 17th century) and Type-C (only fumarolic activity). Volcanoes Type-A have been monitored by CVGHM continuously using at least one seismometer, however monitoring system has not covered most of Type-B volcanoes.

In 2010, characteristic eruptions occurred at two volcanoes in Indonesia. One was Sinabung volcano in North Sumatra and the other was Merapi volcano in Central Java (Fig. 1). At the Sinabung volcano, no historic eruptions were recorded and the volcano was designated as Type-B. Therefore no monitoring system was installed at the volcano. On August 27,

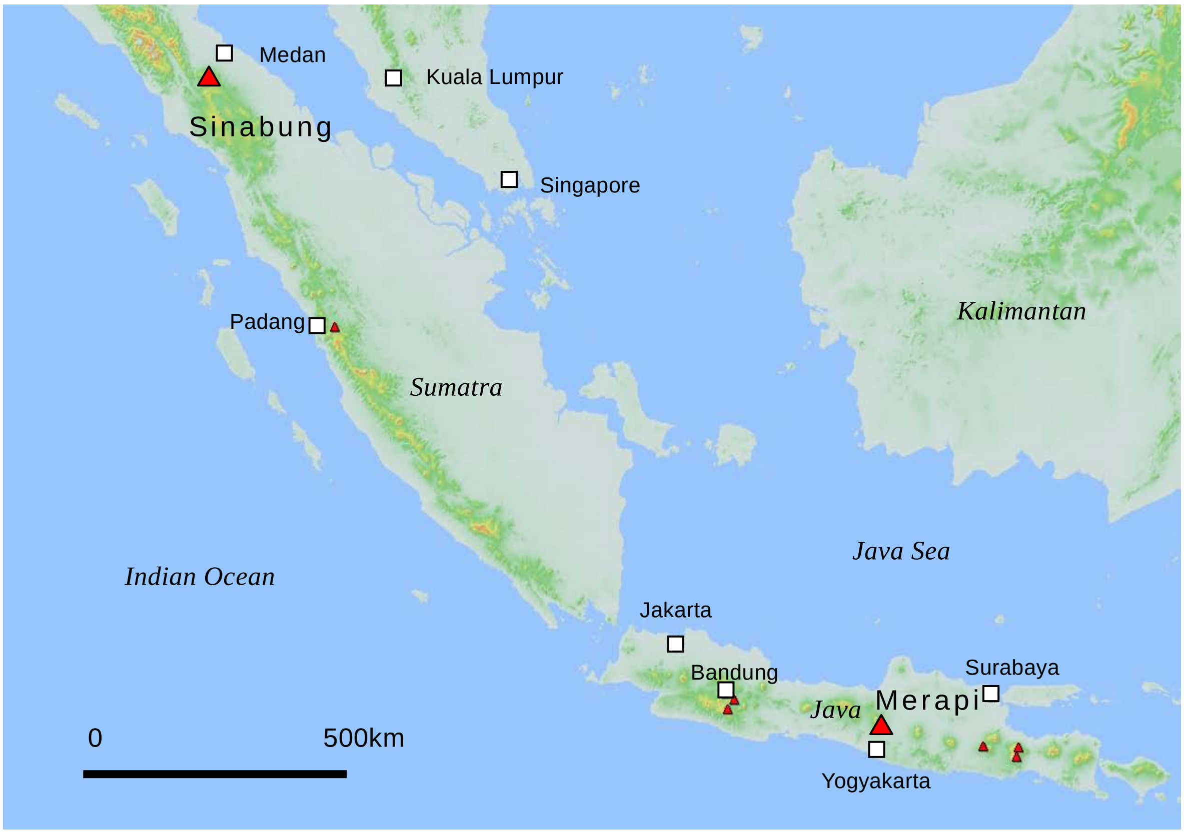

Fig. 1 Location of Sinabung and Merapi volcanoes

a phreatic eruption occurred at the summit of the volcano after dormant period at least 400 years.

Eruptive activity in October and November at Merapi volcano was different from recent eruptive activities of the volcano, which showed effusion of lava, growth of lava dome and collapse of the lava dome generating pyroclastic flows within several kilometers. Eruptions on October 26, 2010 was explosive one destroying old lava dome formed in 2006, and eruptive activity during the period from November 3 to 5 was tremendously bigger than the recent eruptions. The eruption style was characterized by continuous generation of pyroclastic flow and ash emission from the crater opened by the explosion on October 26.

CVGHM is a counterpart of DPRI as the leading institute of volcano group under the project "Multi-disciplinary Hazard Reduction from Earthquakes and Volcanoes in Indonesia" of project "Science and Technology Research Partnership for Sustainable Development (SATREPS)" promoted by Japan Science and Technology Development (JST) and Japan International Corporation Agency (JICA). After these eruptions in 2010, Japanese volcanologists were sent to Sinabung and Merapi volcanoes to evaluate volcanic activity and enhance volcano observation and surveys as a quick response team. In addition, vice-president of Indonesia requested Japan and US governments to dispatch volcanological experts during the crisis of Merapi volcano in November and Japan Disaster Relief Team was sent.

In this paper, volcanic activities of Sinabung and Merapi volcanoes in 2010 are summarized and discuss what we Japan side should learn from the eruptive activities and countermeasure against these volcanoes to mitigate from volcanic hazards.

2. Sinabung volcano

Sinabung volcano (Fig. 1) is located north of Lake Toba formed by gigantic caldera eruption. In 2010, eruptive activity awoke after >400 years dormancy. After the first eruption on August 27, CVGHM sent quick response team to the volcano. The second eruption occurred at 00:10 on August 29. Instantly CVGHM issued warning level 4 (highest level) for evacuation of local residence

Photo 1 Eruption at Sinabung volcano at 6:23 on August 30, 2011. Photograph taken by CVGHM.

even though no monitoring system was installed at the volcano. The most scaring matter is possibility of occurrence of large magmatic eruption after long-term dormant period and large eruptions, such as Pinatubo eruption in 1991 after 500 years dormancy (Newhall et al., 1996).

2.1 Eruptive activity in 2010

White plume with 20 m height was observed on August 28, showing increase in volcanic activity. The second eruption occurred with sound at 00:10 (local time = UTC+7h) on August 29. Sinabung volcano was designated as Type A volcano. Local residence in 6 km radius from the summit evacuated from the volcano. Volcanic ash cloud reached 1500 m high from the summit. The third eruption occurred in the next morning (06:23 local time) on August 30. The volcanic ash column rose 2000 m high (Photo 1). On September 3, two eruptions occurred at 4:38 and 17:59, ejecting volcanic ash cloud 2000 m and 1000 m high, respectively. The eruption at 0:23 on September 7 was quite explosive. Sound by the explosion was heard in a range of 20 km from the volcano. The volcanic ash column reached at the height of 5000 m. In the night (19:03), a minor eruption occurred. During the eruptive activity period, 7 eruptions were recorded. All the eruptions were phreatic type and no new magmatic material was found in volcanic ash.

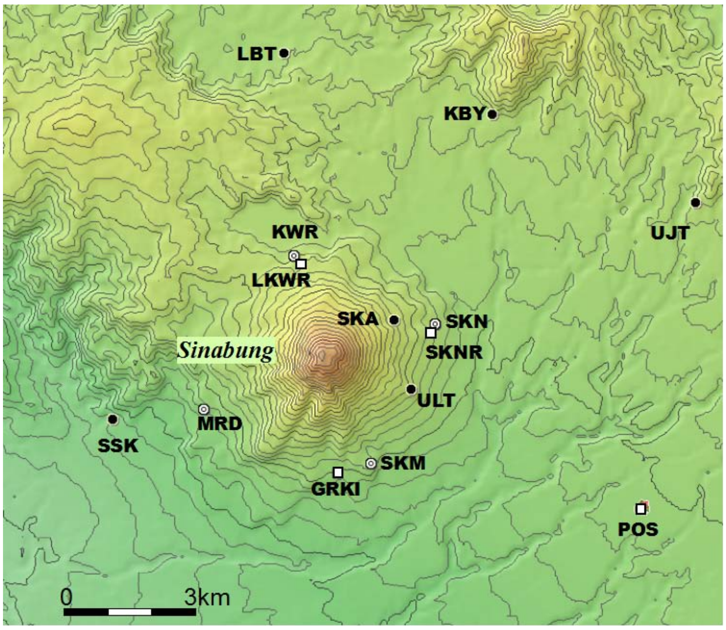

Fig. 2 Volcano observation stations at Sinabung volcano. Double circles indicate permanent seismic stations. Dots are temporary seismic stations. Squares show GPS stations.

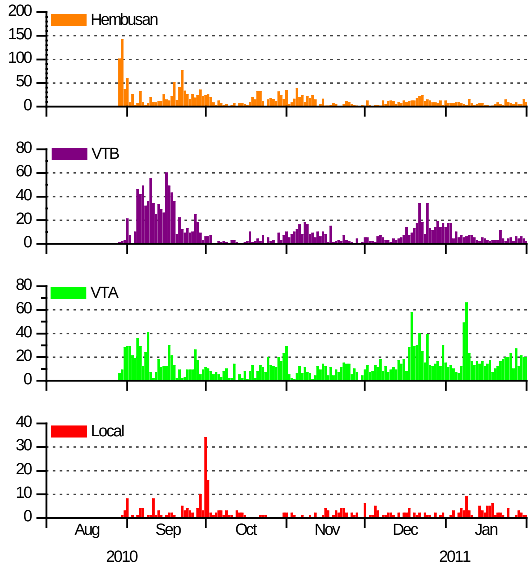

Fig. 3 Daily number of types of volcanic earthquake during the period from August 29, 2010 to January 31, 2011.

2.2 Quick response

Firstly, CVGHM sent quick response team and declared the warning level 4 (highest level “Awas”) 10 minutes after the first eruption on August 29 for evacuation of local residence.

Next, CVGHM quickly installed a short-period seismometer at east flank (station SKN) and transmitted the signal to an observatory installed temporarily 8.0 km southeast from the summit crater because no monitoring system was installed at the volcano before eruptions in August, 2010. Successively CVGHM installed 3 seismic stations to surround the summit crater. The seismic signals transmitted by FM radio to the observatory have been recorded on drum recorders and digitally stored continuously. The seismic data have been transmitted to the main office of CVGHM in Bandung, West Java by VSAT system. Ground deformation observations have been done by a tiltmeter installed at south flank and EDM surveys have been repeated at eastern flank.

2.3 Seismicity of volcanic earthquakes

Volcanic earthquakes at Sinabung volcano are classified into VTA, VTB and hembusan (Indonesia language) type. VTA and VTB types are volcano-tectonic earthquakes. VTA earthquake has clear P and S-waves. VTB is similarly dominated

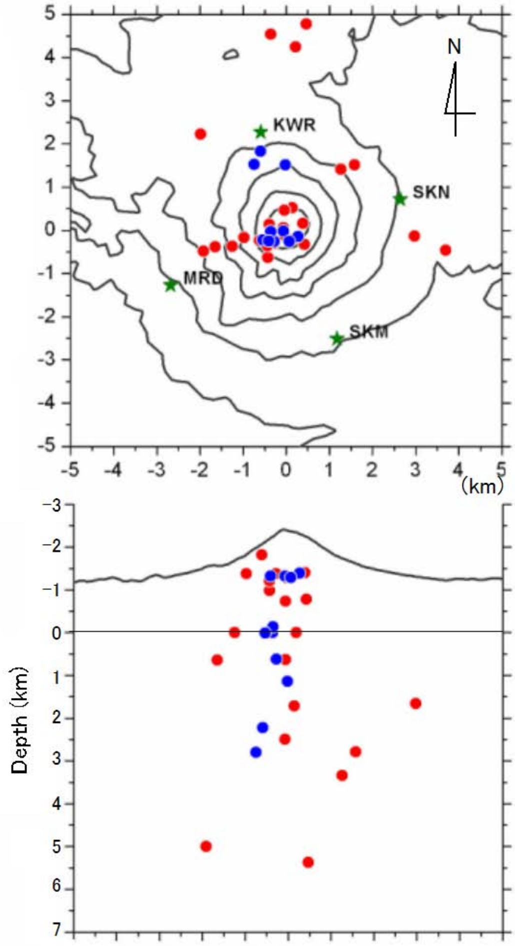

Fig. 4 Hypocentral distribution of volcano-tectonic earthquakes at Sinabung during the period from September 6 to 7. Red and blue dots indicate hypocenters before and after the explosive eruption at 00:23 on September 7.

by high-frequency component; however S-phase is not clearly distinguished from P-wave onset. It is interpreted that VTA and VTB are deep and shallow volcano-tectonic earthquakes, respectively. Hembusan type occurs associated with emission of volcanic gas.

Observation of volcanic earthquake started on August 29. As shown in Fig. 3, more VTA type earthquakes occurred than VTB earthquakes until September 4. After September 5, number of VTB type increased and more VTB type were recorded than VTA type. This suggests that hypocentral area migrated from deep part to shallow part. Fig. 4 shows hypocenter distribution of volcano-tectonic earthquakes. Before the eruption at 00:23 on

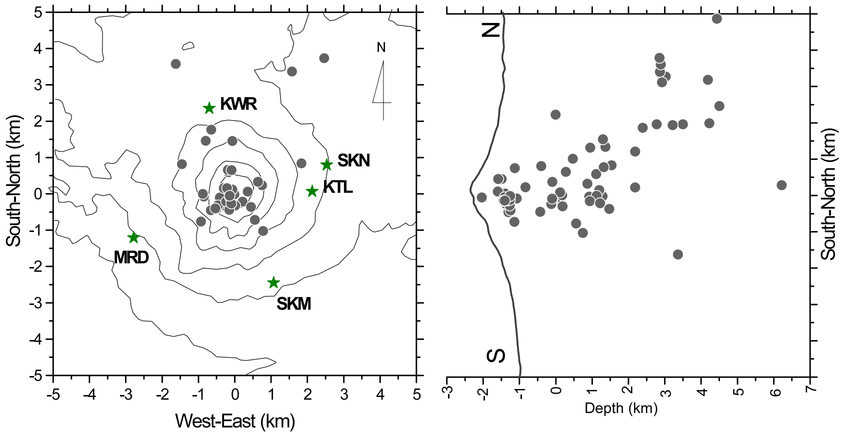

Fig. 5 Hypocentral distribution of volcano-tectonic earthquakes at Sinabung during the period from September 8 to 22. Stars indicate seismic stations.

September 7, the hypocenters of volcano-tectonic earthquake were dispersed widely around the volcano and the focal depth ranged from -1 to 8 km below sea level. After the explosion on September 7, the hypocenters were concentrated immediately beneath the crater at depths from -1 to 3 km except 3 earthquakes at north flank. Fig. 5 shows hypocenter distribution during the period from September 8 to 22. Most of the hypocenters were located beneath the summit area and north flank. Some hypocenters were located northeast off the seismic network.

Number of VTB type earthquake kept at the daily number level of 30-60 events/day from September 5 to 19; however the number decreased on September 20. Then, CVGHM decreased the alert level to 3 “Siaga” on September 23 and level 2 “Waspada” on October 3.

2.4 Activity after October, 2010

Seismicity of volcano-tectonic earthquake decreased in October; however the seismicity still stays at high level. The daily number of VTA type earthquake increased in the middle of December and January 8 and 9, 2011. This indicates possibility of resume of eruptive activity or more violent eruptions after minor precursory eruptions on August and September 2010.

In order to examine the possibility of transition from phreatic eruption to magmatic, Kyoto University and CVGHM extended the seismic network. The permanent stations are installed in an area 3 km from the summit, however significant seismicity was found northeast of the permanent seismic network (Figs. 4 and 5). Therefore, 3 stations were installed north and northeast off the Sinabung volcano and additionally 2 on the flank and 1 west off the volcano (Fig. 2).

Ground deformation of the volcano has been monitored by Electro Distant Measurement (EDM) at eastern flank. Although significant change has not been detected yet, possible transition of eruption type from phreatic to magmatic may cause detectable ground deformation. In February 2011, 3 GNSS stations were installed on the flanks of the volcano and a reference station at POS observatory (Fig. 2). GNSS data are continuously transmitted to POS observatory by wireless LAN and baseline analysis are made automatically by Spider software (Leica) to detect appearance of ground deformation in quasi-real time.

3. Merapi volcano

3.1 Recent eruptive activity

In contrast to the Sinabung volcano, Merapi volcano has frequently repeated eruptions in historical time and has been well-monitored by Volcano Technology Research Center under CVGHM. Time intervals of eruptions ranged one to several years, especially since 15th century. Eruption of the volcano was characterized by pyroclastic flow caused by collapse of lava dome, called “Merapi-type”. Fig. 6 shows distribution of pyroclastic flow after 1900. Most of pyroclastic flows reached at distance 4-5 km. Length of the

Fig. 6 Distribution of pyroclastic flow at Merapi volcano after 1900

pyroclastic flows in 1930, 1961 and 1969 exceeded 10 km. The pyroclastic flow in 2006 entered into Gendol River till 7 km. Typically, a sequence of volcanic activity was commenced by occurrence of volcano-tectonic earthquake at depth of 2-4 km beneath the summit and then followed by emergence and growth of lava dome at the summit accompanying MP-type earthquakes and rock-falls. Immediately before occurrence of pyroclastic flow, volcano-tectonic earthquake occurred at shallow depth beneath the summit (Ratdomopurbo and Poupinet, 2000; Hidayati et al., 2008).

3.2 Eruptive activity on October 26, 2010

The eruptive activity in 2010 was different from the previous ones. Fig. 7 shows temporary change of RSAM based on seismogram at station Plawangan 5km SSW from the summit of Merapi. Based on the RSAM data, the 2010 activity can be divided into 5 periods; (1) precursory period from September to the first explosion on October 26, (2) the first explosion, (3) tentative declination of activity from October 27 to November 2, (4) continuous occurrence of pyroclastic flow in 3-5 November (climax of 2010 eruptive activity), (5) gradual declination of eruptive activity after November 6.

Fig. 8 shows daily number of types of volcanic earthquake at Merapi volcano. “Guguran” type earthquake occurs associated with rock-fall from lava domes at the summit. MP-type is low-frequency earthquake with dominant frequency of 4-5 Hz. Hypocenters are located at quite shallow depth beneath the summit (Ratdomopurbo and Poupinet, 2000). Types of VTA and VTB are volcano-tectonic earthquakes at deep and shallow part of the volcano. Hypocenters of VTA are located at depths of 2.5-5 km beneath the summit and VTB type earthquakes occur at shallower than 1.5 km. A seismicity gap was indentified at a depth range of 1.5-2.5 km (Ratdomopurbo and Poupinet, 2000; Hidayati et al., 2008).

VTA and VTB began to increase from September 12 and the numbers gradually increased. CVGHM raised the alert level 2 (Waspada) on September 20. The daily numbers of MP earthquakes continued to increase. The numbers of guguran, MP and VT earthquakes accelerated in the middle of October as shown in Fig. 8. CVGHM raised the alert level 3 (Siaga) on October 21. The seismicity of these types of earthquakes continued to increase. The numbers of VTB earthquakes attained 80 on October 23, and 24 and the numbers exceeded 200 on October 25.

The increase pattern of cumulative seismic energy of 2010 activity is compared with 3 recent eruptive activities in 1-year period prior to each climax (Fig. 9). Although the patterns were different, amounts of seismic energy in 1997, 2001

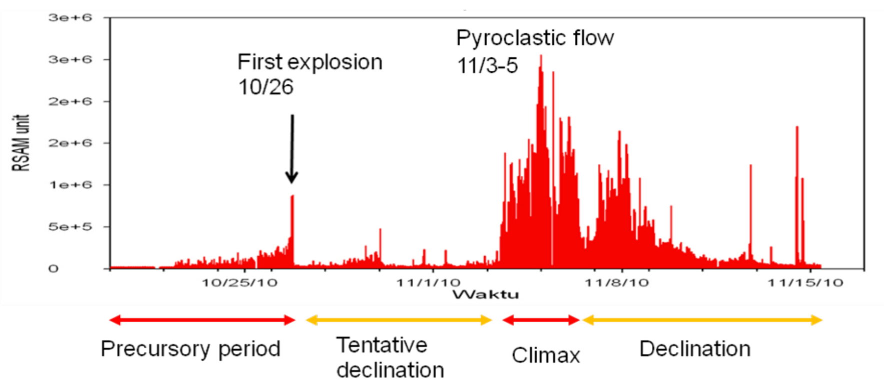

Fig. 7 Temporal change of RSAM during the period from October 20 to November 15, 2011

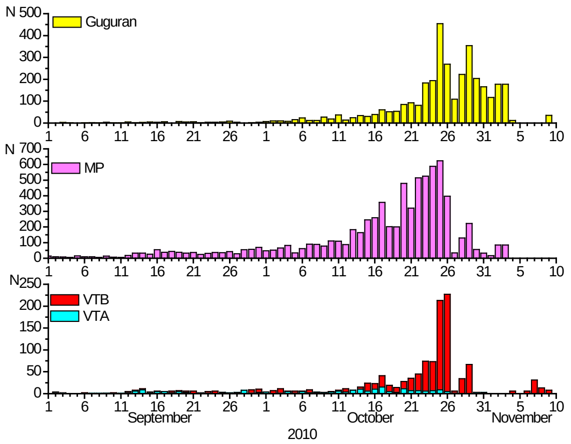

Fig.8 Daily numbers of volcanic earthquakes during the period from September 1 to November 9. “Guguran” occurs associated with rock-fall. MP is a multi-phase event dominated by low-frequency. Types of VTA and VTB are volcano-tectonic earthquakes at deep and shallow part of the volcano, respectively.

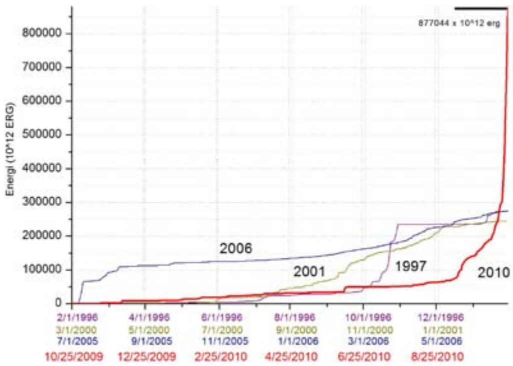

Fig. 9 Comparison of patterns and amounts of increase in seismic energy among 1997, 2001, 2006 and 2010 crisis

and 2006 activities stayed at a level of $\approx 3\times10^{17}$ erg. The seismic energy release prior to eruptions on October 26 was 3 times larger. The seismic energy had exceeded at the level of 3×10^{17} erg on October 22. It accelerated after that and attained 8.8×10^{17} erg on October 25, one day before the first explosion.

The ground deformation patterns corresponded to increase in the seismicity. Fig. 10 shows temporal change in slope distance from Kaliurang Observatory to a benchmark (Rk4) on the south flank near the summit. It was measured by EDM at least once a day, if possible. The slope distance was shortened by 3 m from early September to October

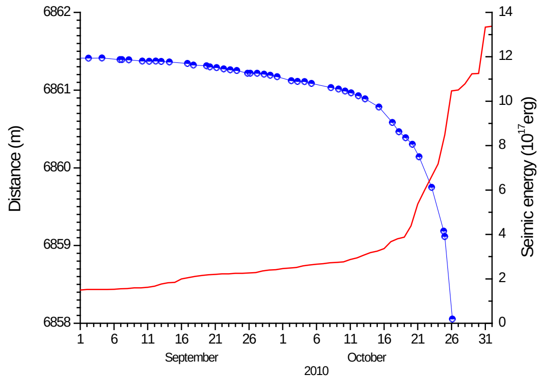

Fig.10 Acceleration pattern of shortening of slope distance (blue) and increase in seismic energy (red)

26, corresponding inflation of the volcanic body. The slope distance decreased at a rate 0.0016m/day till September 12 and the decrease rate increased to 0.0043mm/day during the period from September 13 to October 5. The rate accelerated after October 13, and the slope distance was shortened by 1.06 m only for 27 hours immediately before the explosion.

Based on accelerations of increase in seismicity of volcano-tectonic earthquake and inflation of volcanic body, CVGHM judged that Merapi had high possibility of explosive eruption and raised alert level to the highest (4, Awas), one day before the first explosion. Restricted zone was set up within 10 km from the summit and 69,000 local residents evacuated.

By the explosive eruption, the old lava dome effused in 2006 activity was destroyed and crater of 200 m diameter was formed at the summit. Fragments from destroyed old lava dome were thrown away in the range of 3 km from the summit. Blast was directed to SSE direction and pyroclastic flow reached 8 km away from the summit along Gendol River. Due to the blast, many houses were broke down and more than 30 people, who stayed in the restricted zone, were killed.

3.3 Eruptive activity on November 3-5, 2010

After the explosive eruption on October 26, a few pyroclastic flow were repeated every day, especially 33 pyroclastic flows were recorded on October 30. The pyroclastic flow did not continue for long time (less than one hour). Although the number of volcano-tectonic earthquake decreased after the explosive eruption, comparing high seismicity immediately before occurrence of explosion, the seismicity of volcano-tectonic earthquake still stayed at high level originating 30 and 40 events on October 28 and 29, respectively. Therefore, alert level was kept at 4 (Awas) from restricted zone of 10 km.

Situation had changed around 11 o'clock on November 3. Pyroclastic flow continuously generated from the crater opened by the explosion. Ash column ejected from the crater reached at altitude 10 km and the volcanic ash was carried westward until West Java, 500 km apart from the Merapi volcano. Length of pyroclastic flow gradually increased due to successive occurrence. The pyroclastic flow reached distance of 11 km on November 3. On November 4, the flow distance increased further till 17 km along the Gendol River (Fig. 11). Restricted zone was extended up to 20 km associated with extension of flow length of pyroclastic flow and 380,000 people evacuated.

After the climax of eruptive activity, occurrence of pyroclastic flow gradually decreased as shown by RSAM in Fig. 7. However volcanic ash continuous emitted from the crater and larger numbers of VT earthquakes were recorded than those at the beginning of precursory period in September. Therefore, it took longer time for CVGHM to downgrade the alert level. CVGHM downgraded the alert level to 3 (Siaga) on December 2 and to 2 (Waspada) on December 13.

4. Lesson from the volcanoes in Indonesia

The eruptions which occurred at Sinabung and Merapi volcanoes in 2010 provide important information to us.

1) Importance of quick response to any volcanic crisis, particularly after long-term dormancy: Sinabung volcano erupted after more than 400 years dormancy on August 27. CVGHM had not installed monitoring instruments at the volcano. Characteristics of eruptions and seismicity associated with eruption had not made clear yet. CVGHM started instrumental monitoring at Sinabung volcano at 10 o'clock on August 29, only 2 days after occurrence of the first eruption and extended the observation network successively. In Japan, 110 volcanoes are designated as "active volcanoes" and 47 are continuously monitored by

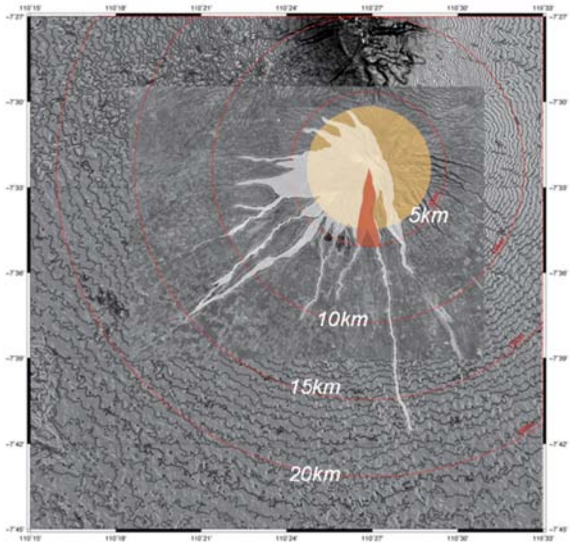

Fig.11 Distribution of pyroclastic flows mainly generated during the period from November 3 to 5. Gray: pyroclastic flow, brown: area reached by ballistics ejected by the explosion on October 26, red: direct surge by the explosion.

Japan Meteorological Agency. Residual 63 volcanoes are not monitored. However, all the volcanoes still have possibility to erupt in the future.

2) Difficulty of predict the climax of eruptive activity: In post-explosive activity during the period from October 27 to November 2, that is, before the climax of eruptivity with continuous pyroclastic flow on November 3-5 at Merapi volcano, no drastic change of activity was recorded. This fact implies that it is still difficult to evaluate and predict transient of volcanic activity after the commencement of eruptive activity. At Merapi volcano, the old lava dome formed in 2006 activity was destroyed by the first explosion on October 26 and a crater was formed at the summit area. As the result, the conduit system became open. As larger eruption was scared, CVGHM kept the alert level at the highest. However, it was difficult to forecast continuous generation of pyroclastic flow from opened conduit. Restricted zone was extended to 15 km on November 3 and then 20 km on November 4, countermeasuring against increase in distance of pyroclastic flow.

We encounter such a difficult at Sakurajima volcano, Kyushu, Japan. The volcano resumed eruptive activity at Showa crater at eastern flank in

June 2006 after 58 years dormancy. The eruption style was phreatic in 2006 and 2007 and changed to magmatic and explosive in February 2008. The explosive activity gradually increased and 1055 explosive eruptions occurred in 2010. However, no drastic changes of seismicity of ground deformation were detected associated with increase in explosive activity. The situation of the Sakurajima stays at open-conduit system, similarly to the Merapi after explosive eruption on October 26. Conventional seismic and ground deformation observations faced limitation at Merapi volcano. Highly integrated observations should include high sensitive ground deformation observation and quick geochemical analysis of pyroclastic material and volcanic gas.

However, prediction of the first explosion and decision making of evacuation of local habitants around the Merapi volcano should be praised. Based on recent precursory style prior to generation of pyroclastic flows such as 1990's activity, it is expected that a new lava dome appear before occurrence of pyroclastic flow. Associated with growth of the new lava dome, red glow was frequently observed at the summit of Merapi. Whereas red glow was not observed before occurrence of explosion on October 26. Independent of the empirical law of Merapi, CVGHM evaluated that explosive eruption would occur soon and raised the alert level 4 "Awas", 1 days before the explosion on October 26, based on rapid increase pattern and larger amounts of change of seismic energy and inflation of volcanic body. Although scientific knowledge supports prediction that the precursory phenomena in October lead explosive eruption, decision-making to increase alert level to the highest, which indicates recommendation of evacuation, cannot be done only by the scientific knowledge.

3) Restricted zone was extended up to 20 km associated with extension of flow length of pyroclastic flow and 380,000 people evacuated from Merapi volcano. Japan has not been experienced by risk management for such a large number of evacuees. In Izu-Oshima eruption in November 1986, 10,000 people evacuated from the volcano island (Metropolitan Tokyo, 1990). Phreato-magmatic eruption occurred at northwest flank of Usu volcano in March 2000 and 16,000 people evacuated from the volcano (Okada et al., 2002). Before 1914 eruption at Sakurajima volcano, 21,000 people lived in the island and most of them evacuated from the island before and during the eruption. Fortunately, direct disaster such as pyroclastic flow and lava flows stayed within the island. However, large amount of volcanic ash fell in the Osumi Peninsula and thickness of volcanic ash deposit reached >1 m (Omori, 1916) causing mud flows. Kagoshima city was destroyed by earthquake (M7.1) 8 hours after the beginning of the eruption. Countermeasure for volcanic eruptions with disaster in wider area (for example 20 km) should be established.

Acknowledgements

This study is a part of project "Multi-disciplinary Hazard Reduction from Earthquakes and Volcanoes in Indonesia" supported by Science and Technology Research Partnership for Sustainable Development from JST, JICA, RISTEK and LIPI. We would like to extend our gratitude to staff members of Volcano Technology Research Center in Yogyakarta and Sinabung Volcano Observatory attached by CVGHM, who support this study.

References

Hidayati, S., Ishihara, K., Iguchi, M. and Ratdomopurbo, A. (2008): Focal mechanism of volcano-tectonic earthquakes at Merapi volcano, Indonesia, Indonesian Journal of Physics, Vol. 19, No.3. pp.75-82.

Metropolitan Tokyo (1990): Research report on characteristics of volcanic eruption in Izu Islands (Izu-Oshima).

Newhall, C., Daag, A., Delfin, A., Jr., Hoblitt, R., McGeehin, J., Pallister, J., Regalado, M., Rubin, M., Tubianosa, B., Tamayo, R., Jr., Umbal, J., (1996): Eruptive history of Mount Pinatubo. In: Newhall, C., Punongbayan, R. Eds., Fire and Mud: Eruptions and Lahars of Mount Pinatubo, Philippines. PHIVOLCS and Univ. Washington Press, pp.165–196.

Okada, Hm., et al. (2002): Outline of integrated observation and research on 2000 Usu eruption

and volcanic disaster prevention, Report of Grant in-Aid for Scientific Researches (No. 1280001), pp.10-33.
Omori, F. (1916): The Sakura-Jima eruptions and earthquakes, II, Bull. Imp. Earthq. Inv. Comm., 8(2).
Ratdomopurbo, A. and Poupinet, G. (2000): An overview of the seismicity of Merapi volcano (Java, Indonesia), 1983–1994, Jour. Volcanol. Geotherm. Res., Vol. 100, pp.193-214.

2010年メラピ火山およびシナブン火山噴火から学ぶ

井口正人・石原和弘・SURONO*・Muhamad HENDRASTO*

*インドネシア火山地質災害軽減センター

要　旨

2010年には特筆すべき噴火がインドネシアのシナブン火山とメラピ火山において発生した。これらの噴火活動とその対応から我々は，次のことを教訓として得た。1)長期の休止後の噴火活動の評価は依然として難しく，長期の休止期の空白を埋めるための緊急観測が必要である。2)火道最上部が開放した火山での噴火活動の予測はやはり困難を伴う。このような状況では地盤変動観測の高精度化と物質化学的分析が重要となる。3)我が国の火山では火口から20㎞におよぶ警戒区域の設定と38万人にも達する避難者への対応の経験がない。被害区域が拡大した場合の対応を早急に策定する必要があろう。

キーワード：メラピ火山，シナブン火山，火砕流，水蒸気爆発，火山防災