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Overview of the 2006 eruption of Mt. Merapi

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A R T I C L E I N F O

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A B S T R A C T

In the last part of the 20th century and the beginning of the 21st century, Mt. Merapi in Central-Java Indonesia erupted about every 2–5 years. Most of the eruptions were low in explosivity, with VEI-3 or less. Eruptions usually involve the formation of a lava dome, either in the beginning or in the end of the eruptive episode.
For the 2006 eruption, the precursory signal was first observed in the middle of the year 2005 with a decrease in EDM slope distances to points on the rim, an increase of seismicity and a possible increase of SO_2 emissions. Those early events marked the beginning of a more continuous period of inflation, which led to the eruption. In total, the pre-eruption displacement of the southern rim reached at least 2.4 m toward the measuring station in Kaliurang (KAL). From late April until June 2006, a lava dome grew on the summit with a volume that gradually increased until it reached about 4.1 million m^3 in 38 days. The total of erupted magma was about 5.3 million m^3 dense-rock-equivalent (DRE). The dome subsequently collapsed in three steps from June 4 to June 14, leaving an open scar on its southeast side. In this paper we detail the changes of dome morphology that were monitored by taking successive photographs from similar positions. The eruption in 2006 marked a significant change in summit morphology, from west-southwestward opening during the 20th century to the currently southeast orientation. Also, an Mw 6.4 earthquake occurred on 26 May, midway through the eruption, which adds interesting questions about the relationship of the eruption and the earthquake.
EDM data from 2006 and previous eruptions show that the summit remains inflated after each eruption, i.e., no significant deflation occurs following eruptions. The lack of post-eruption deflation suggests that magma remains in the shallow parts of the edifice after the eruption. As a result, the complex of summit lava domes and their intrusive roots grow with time and Merapi's rim and summit become progressively more unstable and prone to collapse.

1. Introduction

Indonesia has about 130 active volcanoes, of which Mt. Merapi is one of the most active ones (Kusumadinata, 1979; Siebert et al., 2010). Mt. Merapi is surrounded by less active volcanoes such as Mt. Sundoro, Mt. Sumbing, Dieng Plateau, Mt. Ungaran and Mt. Lawu. The volcano is special among the others because it erupts frequently, with an average interval between eruptions, in the last century, of less than 7 years.

The sequence of events within eruptions differs from one eruption to the next. Some begin with lava dome formation which culminates in a collapse and produces pyroclastic flows (PFs). Others begin with an explosion and then end with dome formation. Lava dome extrusion is a characteristic of Mt. Merapi's eruptions and usually lasts for several months.

Most lava domes become unstable and collapse. Other domes or dome relics stay stable and become part of the volcano morphology even though almost all are destroyed during a later eruption. Domes that grow exclusively on the summit are symmetrical and round, e.g., 1940 (Voight et al., 2000) or 1992 (Beauducel et al., 2000). Most, though, grow beyond the flat summit area and become elongated, stubby lava flows ("coulee"), e.g., those of 1986, 1994 and 1997. PFs are usually generated from collapses of an unstable dome, and confined to valleys of the upper and mid slopes. Indeed, "Merapi-type" PFs are usually described as those that originate from collapse of lava domes (Bardintzeff, 1992).

In most eruptions of the 19th and 20th centuries, and perhaps earlier, PFs were directed toward the northwest to southwest flanks. These sectors became a 'traditional' direction for Mt. Merapi eruptions. As settlements moved higher and higher on the volcano, growth was fastest on the other, supposedly safe sides. As a result, there is a high population density on the volcano's flanks, especially on the southern flank where some villages are only 4 km from the summit. Although eruptions are usually less than VEI 3, PFs could reach up to 10 km from the summit

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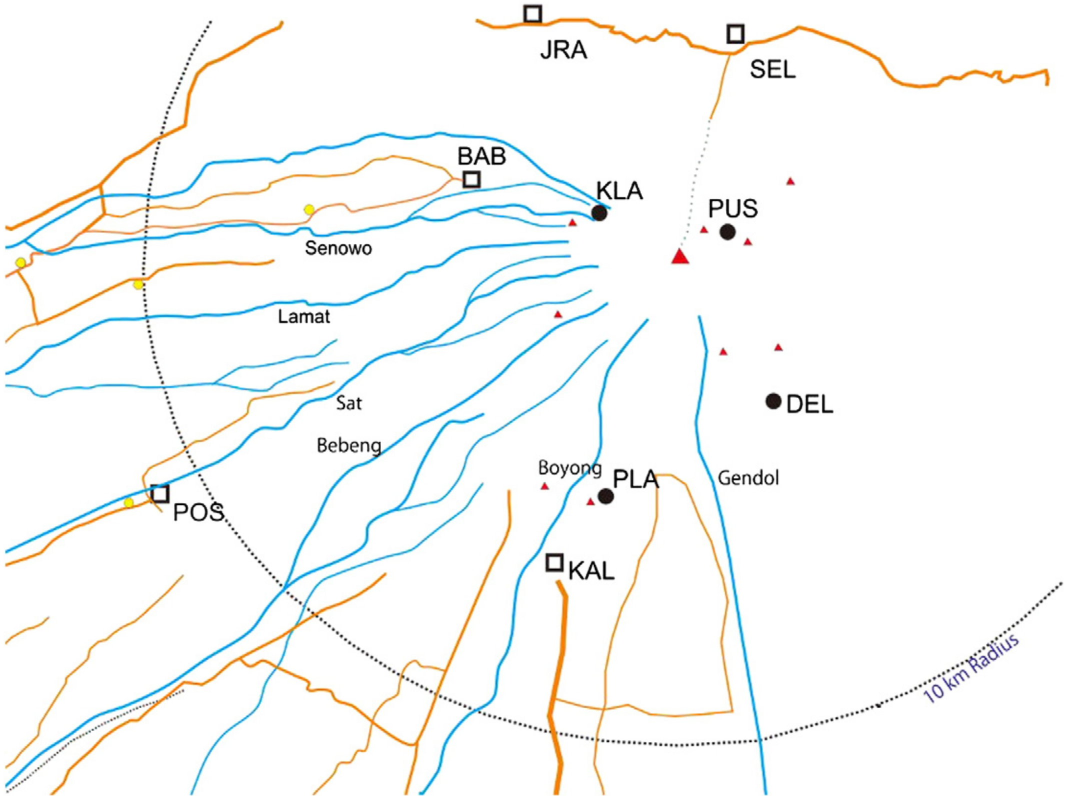

Fig. 1. Sketch map showing position of observatory posts (open squares): KAL, POS, BAB, SEL and JRA; and seismic stations (solid circles): PUS, DEL, PLA, and KLA. Solid triangle is Mt. Merapi summit.

(Voight et al., 2000). The proximity of villages to the summit makes them prone to PFs, even small ones.

Our paper describes the chronology of the 2006 eruption of Mt. Merapi based on instrumental monitoring and on monitoring of the lava dome by photography camera.

2. Monitoring of Mt. Merapi

From seismic monitoring (Fig. 1), the Center of Volcanology and Geological Hazard Mitigation of Indonesia (CVGHM) distinguishes six different types of seismic events: type-A (VTA, deep volcano tectonic quake, >2 km depth), type-B (VTB, shallow volcano tectonic quake, <2 km depth), multi-phase (MP, very shallow seismic event many distinct phases along its duration), low-frequency (LF), tremor, and “Guguran” (=long duration seismic event related to rockfalls or lava avalanches). For Mt. Merapi, MP events always occur during lava dome extrusion (Shimozuru et al., 1969). This event differs from type-A and type-B events in that for a given amplitude, it has a longer duration than that of type-A and type-B.

Seismic events of Mt. Merapi are generally shallow, less than 6 km depth, and most are concentrated on or just below the summit (Ratdomopurbo and Poupinet, 2000). The number of type-A and type-B events is very low, commonly less than 50 during the entire period of an eruption. In general, VTA and VTB events precede eruptions and then are followed by MP and “Guguran”, which occur during or after eruptions (e.g.: 1984 and 1992 eruptions). One of the seismic stations, PUS, the closest one to the summit, is used as the reference for counting statistics of seismic events.

For deformation monitoring, seven EDM prism reflectors were installed on and near the summit, and the EDM shooting was done from three fixed positions on the flank. Tiltmeters were also installed on the northwest part of the summit on the lava dome remain of 1956, L′56 (solid circle near “A” in Fig. 2). Mt. Merapi always shows strong inflation at summit prior to eruptions (Beauducel et al., 2006). In addition, morphologic changes of the dome and summit are monitored by photo cameras operated from observatory posts located at south, southwest, and west flanks of the volcano.

3. Methods for monitoring the 2006 eruption

Daily seismicity was monitored using the seismic station PUS, at 2625 m elevation, just 0.9 km north of the summit. The station PUS has three analogue Mark Product L4-C-1Hz seismometers, one is vertical and two are horizontal. The seismometer output is digitized at frequency of 100 Hz and telemetered to CVGHM office at Jogjakarta, about 30 km away to the south of the volcano. Counting the number of seismic events is done by observing directly on the seismogram papers. As defined previously, based on their appearance on seismogram record, seismic events are distinguished manually as VTA, VTB, MP, LF, Tremor or “Guguran”. Seismic energy is calculated for every type of event based on the observed amplitude. Cumulative seismic energy release from 1990 to 2006, not including “Guguran”, is shown in Fig. 3. During lava dome formation accompanied by intense PFs and rockfalls, the amplitude of “Guguran” becomes dominant and obscures the observation of the other seismic event types. The seismicity of the volcano from 2004 to 2006, represented by the daily count of seismic events, is presented in Fig. 4. During the crisis, Real-time Seismic Amplitude Measurement (RSAM, from Endo and Murray, 1991) was calculated. A 10 minute-window RSAM was used to show the varying intensity of the volcano activity (upper graph, Fig. 10).

EDM measurement was made from three shooting locations: Kaliurang (KAL), located at about 7 km south of the summit; Babadan (BAB), located 4.4 km west of the summit; and Deles (DEL), about 4 km southeast of the volcano. Prism reflectors R1B and R2B were