The Crater Configuration of Kelud Volcano, East Java, Indonesia after the 2014 Eruption

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Abstract: ***Kelud volcano in East Java, Indonesia erupted on April 14, 2014. The previous activity in 2007 produced the lava dome that influenced the characteristic of the eruption. The progress on the destruction of the lava dome might give the information on the type of the eruption whether a single eruption as usual or a prolonged activity. While the direct observation to the crater was not possible due to the high degree of the danger, remote sensing method provides the information on the state of lava dome destruction and the configuration of the crater. This information would contribute the important basis for the issuance of go-return sign for the evacuees terminating the crisis. The remote sensing interpretation used satellite imageries taken a few days after the eruption. The interpretation used also the terrestrial photographs taken after the 2007 dome formation. Topographic map prepared by the Volcanological Surveys in 1968 provides the basis for the estimation and calculation. The preliminary information of the configuration of the crater would contribute to the planning for reconstruction and repair of the draining tunnel system of Kelud volcano. The amount of water in the coming crater's lake might exceed in order of 20 million cubic meters. The lava dome extended about 300 meters in E-W and around 200 meters in N-S directions. The volume estimation gives the figure of 2.7 to 3 million cubic meters. Extended to the root the volume might increase to about 5 to 6 million cubic meters. The new hole left by the April 14 eruption occupied 70% of the lava dome with the diameter of 175 meters and the total hollow of about 3.5 to 4.2 million cubic meters.***

Keywords: Kelud volcano, eruption, lava dome, crater configuration

1. Introduction

Kelud volcano is located in East Java, Indonesia at the latitude $7^{0}56'$ South and longitude $112^{0}18.8'$ East (Figure 1). Recently, on February 14, 2014 the volcano erupted, sending ash as far as 700-kilometer distance to the west following the prevailing wind. The eruption seemed to take place without sufficient warning resulting in the spontaneous evacuation. Because the volcano used to erupt frequently at the repose period of about 15 to 25 years, people quite prepare with the situation. Furthermore, the aborted eruption 8 years earlier has strongly increased the awareness of the people. Since then people have been in full alert.

The aborted eruption of 2006 totally changed the volcano's character. Since hundreds years ago, the volcano has been predominantly explosive, leaving a hole in the crater. The impermeable floor of the crater caused the accumulation of rainwater forming the crater's lake. The 2006 eruption produced lava dome and dried up the crater's lake water and thus no information on water monitoring available. The water lake yielded data on temperature, gas composition, gas bubbling, and chemical composition. Those information contributed significantly to the prediction of eruption as was the case in 1990 (Sudradjat, 1991).

The large amount of 40 million cubic meters of lake water volume had caused the severe devastation in the distal area of the volcano. The construction of tunnels in 1920 significantly reduced the amount of water to 2 million cubic meters in an effort to minimize the danger. However, during the course of the activity the crater's bottom proved to be unstable.

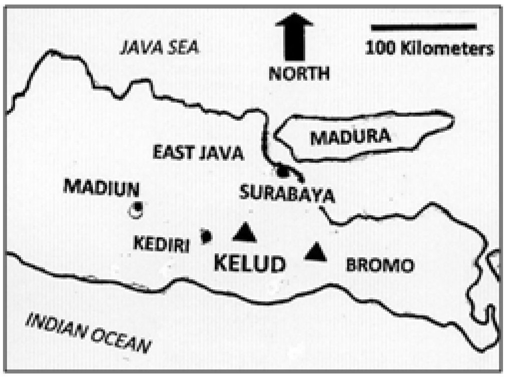

Figure 1: Index map shows the location of Kelud Volcano, East Java, Indonesia

The present study provides the preliminary information on the configuration of the crater's lake bottom, aiming to contribute to possible reconstruction planning of the outlet tunnels. Further, the configuration of the crater might indicate that Kelud volcano has retained its unique rhythmic and explosive characters. The authors wish to express their gratitude to the Faculty of Geology Padjadjaran University for the support to prepare and publish this article.

2. Methodology

This study relies heavily on the interpretation of pictures and images both terrestrial and outer space. The topographic map of the crater area provides the basic information for the remote sensing interpretation. The map with the scale of 1: 2,000 depicted detailed information about the relief of the crater with the accuracy of 2.5 meter height interval. It shows clearly the configuration of the lake boundary and the debris deposit at the coastal area. The map made the estimation on the lava dome's volume and the size of the hole left by April 14 eruption possible. The Volcanological Surveys of Indonesia prepared the map in 1968 (Kusumadinata, 1979).

The satellite images made public by United States National Aerospace Agency through Geological Surveys of America contribute the most important information. In the situation where the volcano was still active and approaching the crater seemed to be impossible, the satellite image depicted the situation of the crater's floor just relatively shortly after the eruption. The information leads to the prediction of the status of the eruption. The satellite image showing that the lava dome has largely destroyed might answer the question of the continuation of the eruption. The piecemeal destruction of the lava dome usually leads to the prolonged eruption, among others demonstrated by Galunggung in 1982 (Katili & Sudradjat, 1984).

The professional photographs shot by Kushendratno and Sutawijaya (2007) provide the information on the shape and size of the lava dome. The thermal infrared image taken in the night clearly shows the temperature and the configuration of the developing lava dome. Similarly, the photograph taken from different angle by Kushendratno and Sutawijaya (2007) made the estimation of size and volume of the dome possible. Some objects with known size such as the pad at the coast of the lake stands clearly, which might provide the scale for the estimation. Thus, the orientation and the location of the object to construct the configuration of the crater's bottom might be possible.

Some other images available at the gallery of the Agency of the Volcanology and Mitigation of Geological Hazards contribute significantly to the interpretation. The Surveys made the images open for public through its website. Alzwar (1985) presented the comprehensive information about the geology and hazard mitigation in the special publication of the Volcanological Surveys. The data constitute the basis for the remote sensing interpretation.

3. Result and Discussion

The remote sensing interpretation of the available data leads to the preparation of the schematic map with the original scale of 1:1,000 (Figure 2). The map shows the following results:

A. Location of the lava dome

The lava dome locates at the middle of the crater's lake. The position caused the lake water to drain through the tunnels and left only a small portion in the SW part. This location is the outlet of the crater's lake, which fortunately remained intact. The dome covers almost the entirely floor of the lake. Based on the topographic map, the size of the dome exceeds the diameter of 300 meters. The configuration of the crater's bottom controlled the shape of the lava dome's base forming somewhat elongated in E-W direction. The shorter diameter was about 200 meter in approximately N-S direction.

The measurement on the height of the lava dome produced the figure of 140 meters at the minimum. At first by November 2014, the dome appeared conical but by December, when the growing process might have ceased, it exhibited the perfect dome shape. The interpretation on satellite image confirmed the configuration of the dome.

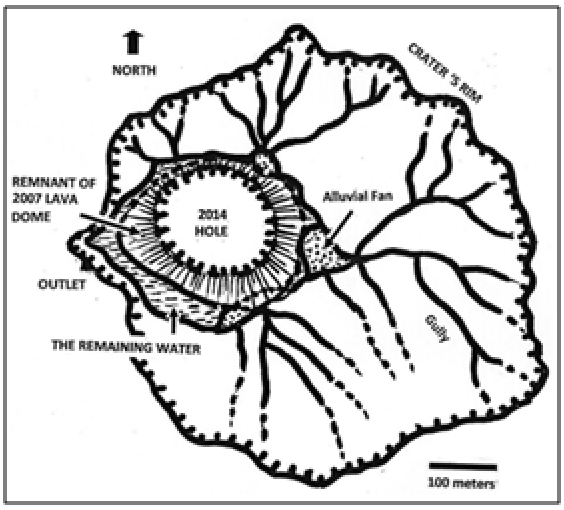

Figure 2: The map shows the morphologic configuration of the crater after the April 14, eruption. The original scale of the map was 1: 1,000 prepared by Volcanological Surveys of Indonesia.

B. Volume of the dome

The interpretation on the terrestrial photographs yielded the size of the lava dome as outlined above. Calculation of the volume produced the amount of 2.7 to 3 million cubic meters of the dome. Assuming the root is almost similar in size with the upper part, the volume might increase to about 5 to 6 million cubic meters. The estimation of the ejected materials might be comparable to the eruption of 1951, where volcanic ash fell down in Jakarta. The 2014 eruption sent volcanic ash as far as Bandung and beyond to the west. The 1951 eruption produced ejected materials about 200 million cubic meters (Kusumadinata, 1979). This figure agrees with the annual rate of replenishment of magma from the lower chamber located some 20 kilometers to the upper chamber of 5 kilometers put forward by Sukhyar and Pardyanto (1992). The annual rate of replenishment amounted to the average of 6.25 million cubic meters. Calculating the rate of replenishment and the repose period from 1990 to 2014, one might come to the figure of 150 million cubic meters of the ejected materials at the 2014 eruption. This amount indicates the Volcanic Explosivity Index (VEI) 3 close to 4.

Based on those assumptions the recent eruption might eject materials slightly less than 200 million cubic meters. The April 14 eruption has blown up about 70% of the total volume of the lava dome or about 3.5 to 4.2 million cubic meters. This means the contribution of the lava dome to the amount of ejected materials was very small, namely less than 3%. However, it contributed significantly to the grainsize of the ejected materials. The coarse lapilli and pebble size fell down as far as 10-kilometer distance, which had never experienced in the previous eruptions. The destruction of the dome resulted in the bigger size ejected materials.

C. Size of the hole

The hole left by April 14 eruption had a perfect circular shape. Surrounding the rim accumulated the ejected materials supposedly the fragments of the destructed lava dome. The hole occupied about 70 % of the dome's surface, with the diameter of about 175 meters. Assuming that the root of the lava dome might extend as the same size with the height of the dome, the volume of the hole might be at the range of 3.5 to 4.2 million cubic meters. This means that the volume of the hole augmented an insignificant volume to the crater's lake. In the 1966 and 1990 eruptions, the water volume reached 20 million cubic meters. This amount caused the eruption lahar to travel about 30 kilometers.

D. Configuration of crater's bottom

The configuration of the crater's bottom changed due to the eruption. The 1951 eruption had lowered the bottom about 79 meters, resulting in additional 20.1 million cubic meters in the crater's volume (Alzwar, 1985). This situation strongly influenced the draining tunnel constructed after the 1919 eruption to reduce the lake water volume until 2 million cubic meters, which subsequently needed the reconstruction and repair. However, the technical problem hampered the construction of the tunnel to the lower level. Therefore, the lake water volume remained about 20 million cubic meters in the eruption of 1966 and 1990. Figure 3 shows the development of the crater's floor configuration before and after the 1919 eruption, the aborted eruption of 2007 and finally the 2014 one-shot eruption.

E. Volume of the future crater's lake

The recent activity of 2007-aborted eruption and the 2014 eruption left the crater bottom an undulated surface, with the center located at the deepest point of the original crater's lake bottom. Taking into account that the tunnels remain intact, while the amount of the remnant of the lava dome and the 2014 hole is about the same amount it seems safe to estimate that the water volume might be around 20 million cubic meters, similar with the situation in 1966 and 1990 eruption.

The potential lava plug formation at the upper part of the diatrema needs to investigate. The remnant of the lava dome might disperse under the water when inundated. To keep the lake water optimal for volcanic monitoring, while maintaining the mitigation of the eruption lahar, the tunnels system needs to repair and perhaps reconstruct.

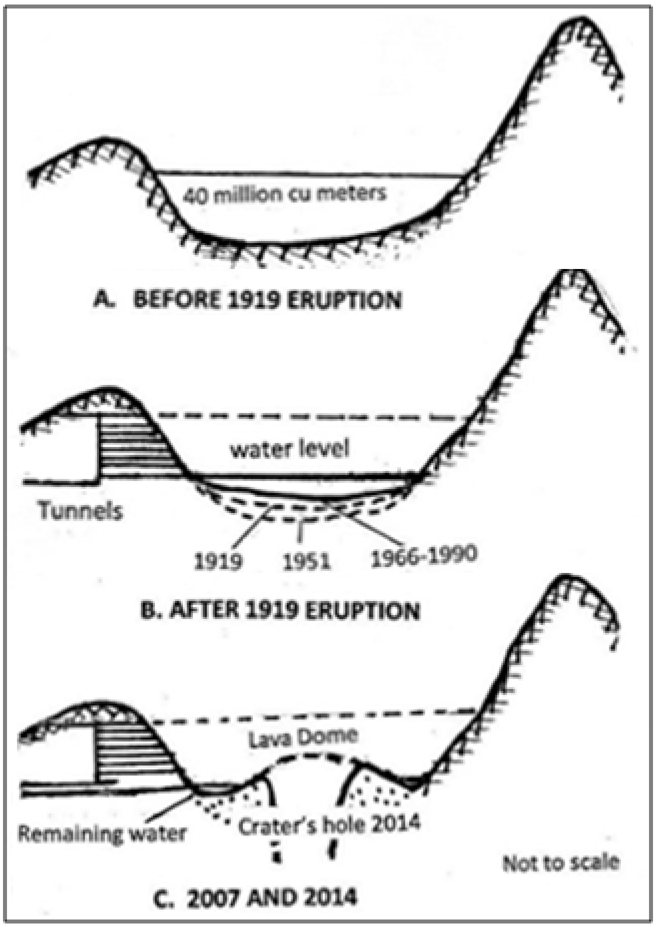

Figure 3: The sketch shows the development of the crater configuration before and after the 1919 eruption and the recent situation showing lava dome and the hole

F. The significance of remote sensing in volcanic prediction

The formation of lava dome in the 2007-aborted eruption of Kelud volcano resulted in the question whether the eruption will take place longer because the destruction of the dome needs sufficient energy. Such a situation might result in the prolonged eruption. The clue laid in the progress of the lava dome destruction. On the other hand, the investigation by land to the summit was impossible due to the high degree of danger, while the go sign for the evacuees to return needs a sound base to issue.

The satellite image has significantly contributed toward the solution of the problem. The image acquired a few days after the eruption shows the evidence that the destruction of no less than 70% of lava dome had taken place; a formation of a hole had given way for the energy to release. Therefore, Kelud volcano retains its eruption character back to the single explosion. This means that that the crisis might only take less than 2 weeks.

The configuration the bottom of crater's lake would determine the volume of accumulated water. In turns, it might influence the coverage of lahar deposits. The lahar dam construction needs to adapt with the new situation. The position of the lake's bottom would contribute to the repair and construction of the draining tunnels.

Further study on evolution of magma composition might reveal the future type of eruption. This would provide the basis for the crisis management policy of Kelud volcano. The study would also give the anticipation of the monitoring method to apply in Kelud volcano in the near future.

4. Conclusions

The progress of the destruction of lava dome indicates the character of the explosion whether single explosive or prolonged eruption. While the direct observation was not possible, remote sensing method by means of satellite imagery, provided information that the large part of the lava dome has gone. New hole occupied most of the location of lava dome. This information is the important basis to declare the crisis over and to issue the go sign to return for the evacuees.

The remote sensing methods provide the information for the volume calculation of the lava dome resulting with the figure of 5 to 6 million cubic meters. Comparing the volume with the total ejected materials which was of the order between 150 to 200 million cubic meters, the contributions of the dome was insignificant; Remote sensing method provides the preliminary information on the configuration of the crater immediately after the eruption. The data would significantly contribute to the estimation of the water volume of the crater's lake water that soon would exist. In turn, this would become the basis for reconstruction and repair of the outlet tunnel system of Kelud volcano. The rough estimation of the incoming water volume of the crater's lake shows the amount in order of 20 million cubic meters.

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