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The Characteristics of Lahar in Merapi Volcano, Central Java as the Indicator of the Explosivity during Holocene

Karakteristik Lahar di Gunung Merapi, Jawa Tengah sebagai Indikator Explosivitas pada Holosen

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Abstract

Merapi Volcano in Central Java has been the most active volcano during Holocene time. As a strato volcano, Merapi exhibits alternating volcanic activities of effusive and explosive characters and self destruction. The explosivity index has evolved during the last ten thousand years. The effusive activities were characterized by the occurrence of lava flows, the development of lava dome, and the production of the "nuee ardente d'avalanche" called Merapi type. The explosive stage is frequently accompanied by the occurence of pyroclastic flows. The present investigation is attempted to reveal the relationship between the characteristics of lahar and the evolution of the activity of Merapi Volcano. The quantitative analysis was focused on the size and shape of the lahar components particularly that of pumice as the main indicators in 73 measured stratigraphic columns of lahar deposits. In addition, the main chemical element rim structures of hornblende identified in lahar components indicate the different lahar units. There are five lahar units and five groups of Merapi activities which can be distinguished. It can be concluded that the characteristics of lahar reflect the evolution of the activities in the past. The risk analyses of Merapi Volcano therefore can be enlarged to cover the possible hazard based on the lahar characteristics.

Keywords: Merapi, volcano explosivity index, lahar component, lahar characteristics, Holocene

Sari

Gunung Merapi di Jawa Tengah adalah sebuah gunung api yang termasuk paling aktif selama Holosen. Sebagai sebuah gunung api strato, kegiatan Gunung Merapi dicirikan oleh perulangan antara kegiatan eksplosif dan efusif serta penghancuran diri. Tingkat eksplosivitas berevolusi sepanjang Holosen. Kegiatan efusif ditandai dengan leleran lava dan pembentukan kubah lava yang menghasilkan "nuee ardente d'avalanche" jenis Merapi. Kegiatan eksplosif disertai dengan pembentukan aliran piroklastika. Penelitian dilakukan untuk mengetahui hubungan antara karakteristik lahar dengan evolusi letusan. Penelitian ini difokuskan pada ukuran serta bentuk komponen pembentuk lahar, terutama pumis sebagai indikator utama. Dengan pendekatan probabilistik melalui uji statistik parametrik pada 73 kolom stratigrafi lahar, diperoleh gambaran hubungan antara pembentukan lahar dengan evolusi letusan. Unsur kimia utama serta struktur rim horenblenda pada komponen lahar telah berhasil dipergunakan sebagai pembeda tiap jenis letusan. Dari penelitian ini dapat dibedakan lima satuan lahar dan lima pengelompokan kegiatan Gunung Merapi. Dari penelitian ini dapat disimpulkan bahwa karakteristik lahar merupakan fungsi evolusi letusan Gunung Merapi pada masa lampau. Dengan demikian, maka analisis bahaya dan risiko untuk masa yang akan datang dapat dilakukan dengan lebih baik.

Kata kunci: *Merapi, indeks letusan gunung api, komponen lahar, karakteristik lahar, Holosen*

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Introduction

Merapi Volcano is located in Central Java, Indonesia (Figure 1). The volcano has been continuously active during the Holocene time (Newhall, 2000). The volcano exhibits the alternating activities between explosive and effusive. In the last 10,000 years, the explosivity index has been evolving. A self destruction took place resulted from the volcano tectonic sliding (Bemmelen, 1933). Undulated and gently folded sediments in the southwest of the volcano were supposed to be the impact of the sliding.

The effusive activity was characterized by a continuous lava dome development. The conduit is almost filled with the moving lava flow with intermediate viscosity containing relatively poor of gas. The lava dome development, thus, characterized the activity of the volcano. Because the dome is accumulated in a breached crater, it produces lava tongues extending down to the southwest direction where the breach is located. The steep angle of the uppermost part of Merapi Volcano finally was not able to hold the tongues.

The front and the margin of the tongue broke down producing the lava avalanche. During the sliding, the gas content in the lava fragment dissolved together with the broken fragment producing the glowing cloud of Merapi type (Escher, 1931). Fall deposits in this case is regarded as co-ignimbrite in the form of ash fall, so it included in one unit with the ladu as the motor of lahars. Two types of lahars are eruption lahars and rain lahars. Rain lahars occur when the rain falls on the summit area for a period of time and carries them along the pyroclastic flow-deposit in the upper course of rivers originating from the summit area. Explosion lahars occur when the eruption takes place in the volcanoes with crater lake, *e.g.*: Kelud Volcano (Wirakusumah *et al.*, 1989).

The present investigation aims to reveal the relationship between lahar and the origin of the materials. The characteristic of lahars using a quantitative method has been studied. The characteristics of individual lahar might lead to a distinguishing factor of the explosivity index.

Methodology

The quantitative method is applied to analyze the distribution of the lahar components. The measured sections were recorded in the field. The steep river walls at the upper middle slope of the volcano were generally chosen as the locations of the measured sections. As many as 73 sections were studied. The important elements in the measurement of lahar section were the grain size and shape of the components, particularly the pumice fragments and the components originated from the pyroclastic fall. In describing the physical characteristics of the components, the size measurement was based on Wenthworth's classification, the shape on Sneed and Folk, whilst the sorting was based on Folks (Boggs, 1995). The lahar deposit was assumed to be deposited under a non-Newtonian flow mechanism.

In the laboratory, the petrographic and chemical composition was analyzed. The variation of TiO, Fe_2O_3, MgO, CaO, and K_2O_3 might indicate different styles of the activity. The basic magma commonly produces the effusive rocks. The degree of explosivity index might also be reflected by the chemical composition of the products. Therefore, the chemical composition of lahar components might also reveal the explosivity index. The development of hornblende crystal was studied to observe the rim structure. The difference of the rim size indicates the type of crystallization. Lava flows and eruptive materials contain hornblende crystals with different size of the rim structure.

Finally, the collected data were analyzed by a simple statistical method applying ANOVA and MANOVA.

Results of investigation

The geomorphological study identifies four classes of the slope based on the steepness of the angle, namely upper, middle, lower, and foot plain with the slope steepness of >60%, 20-60 %, 5-20% and <5% respectively. The class reflects the volcanic facies proposed by Vessel & Davies (1981) namely central, proximal, medial, and distal. The "break in slope" dividing each classis located in elevation of 2300, 1100, and 650 respectively. The classification apparently reflects the lithologic assemblages of the rock.

The evolved eruption is was detected from the variations of lahar deposit. The effusive products and the explosive one can be distinguished from lahar

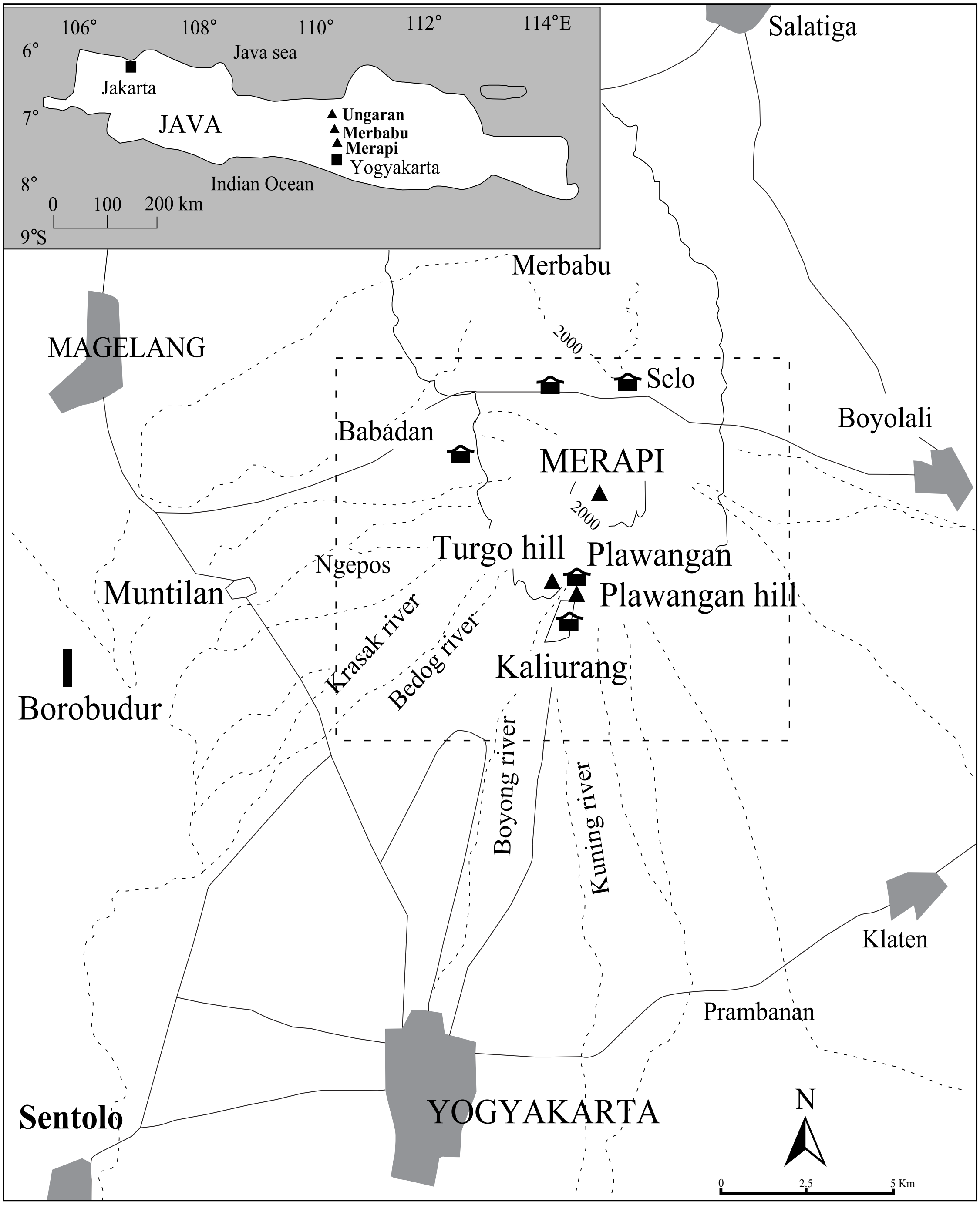

Figure 1. Index map showing the location of Merapi Volcano, Central Java, about 20 km north of Yogyakarta. The volcano is surrounded by cities and population centres. Borubudur and Prambanan Temples are located at the SW and SSE lower slope of the volcano respectively. Five volcano observatories are operated in the Merapi Volcano, namely Plawangan, Ngepos, Babadan, Jarakah, and Selo.

deposit. The elements identifying the eruption style are as follows:

a. Chemical composition of the components. The important chemical elements consist of TiO_2, Fe_2O_3, MgO, CaO, and K_2O_3;
b. The difference rim reaction in hornblende;
c. The number of gravel, pebble, and boulder sizes;
d. The shape of the gravel, pebble, and boulder;
e. The shape and size of pumice.

The chemical composition significantly reflects the variation of the eruption style. The more basic rock tends to produce effusives with less gas content. In general, Merapi produces the relatively poor gases developing lava dome. However, the viscosity was intermediate and thus, the conduit was always filled with the molten rock, moving up slowly feeding the lava dome. The chemical composition, however, can not identify and distinguish the fall or flow of materials.

The hornblende rims demonstrate the significant differences between the eruption product and effusive product. The horenblende rim from the efusive rocks shows the larger rim.

The individual pyroclastic unit shows different sizes, particularly gravels, pebbles, and boulders. However, the bigger size does not show any differences. The same case occurs in the shape of each individual pyroclastic unit.

The pumice fragments show a high explosivity. The size and shape of the fragments can be significantly distinguished between each individual pyroclastic unit.

From those identifications, the component of lahar clearly identify the type of eruption. Furthermore, the population of the components was related to the distance from the source. The bigger sizes of lahar component, in contrast, were unlikely do not follow the rule.

The components of the pyroclastic flows, on the other hand, do not show a significant relationship as outlined above. The size and shape of pyroclastic flow components do not relate to the distance. Although lahar does not follow the Newtonian flow mechanism, a significant relationship of the size and shape of the fragments to the distance is identified.

Based on the above analysis outlined, five lahar units are identified. The units demonstrate the evolution of the eruption style. The repetition of the effusive and eruptive products is depicted in the characteristic of lahars (Figure 2).

The general geologic map of Merapi Volcano shows five groups of activities, namely Pre-Merapi, Old Merapi, Mature Merapi, and Young Merapi. The lahar characteristics reflecting the eruption style might be more applicable to the Young Merapi activity.

Discussion

The chemical composition of lahar components reflects the differences between the effusive and explosive rocks. In the Merapi Volcano the eruption is largely controlled by the gas content. Hartman (1933) identified four types of eruption based on the gas content.

The A-type is the most common condition where the activity is predominated by the lava dome development. The rock contains more mafic minerals and less amount of silica. The viscosity, however, remains intermediate and therefore a dome is formed. The B-type is more eruptive with more gas content. This type is indicated by the mild eruption destructing the lava dome. The lava avalanche might increase because it is triggered off by a mild eruptions. The C-type is almost similar with that of B-type. However, the intensity is much higher. It is interpreted that the magma with higher gas content moves upward within the diatrema.

Finally, the D-type is the eruption caused by magma with relatively high gas content. Every episode consists of four phases, namely the lava dome destruction pushes by the upward movement of the lava, the outpouring of viscous lava and then followed by the paroxysmal eruption. Finally, a new lava dome development took place.

The identification of the physical properties of lahar components opens the opportunity to distinguish the source of the rocks. Hence, the type of eruption might be distinguished. The conclusion drawn might further support the identification of the eruption style in the past. This, in turn, might help to predict the future eruption style and to estimate the risk caused by.

A detailed description of the lahar component provides a possibility to distinguish the lahar unit based on the different eruption style. The analysis of chemical composition supports the identifica-

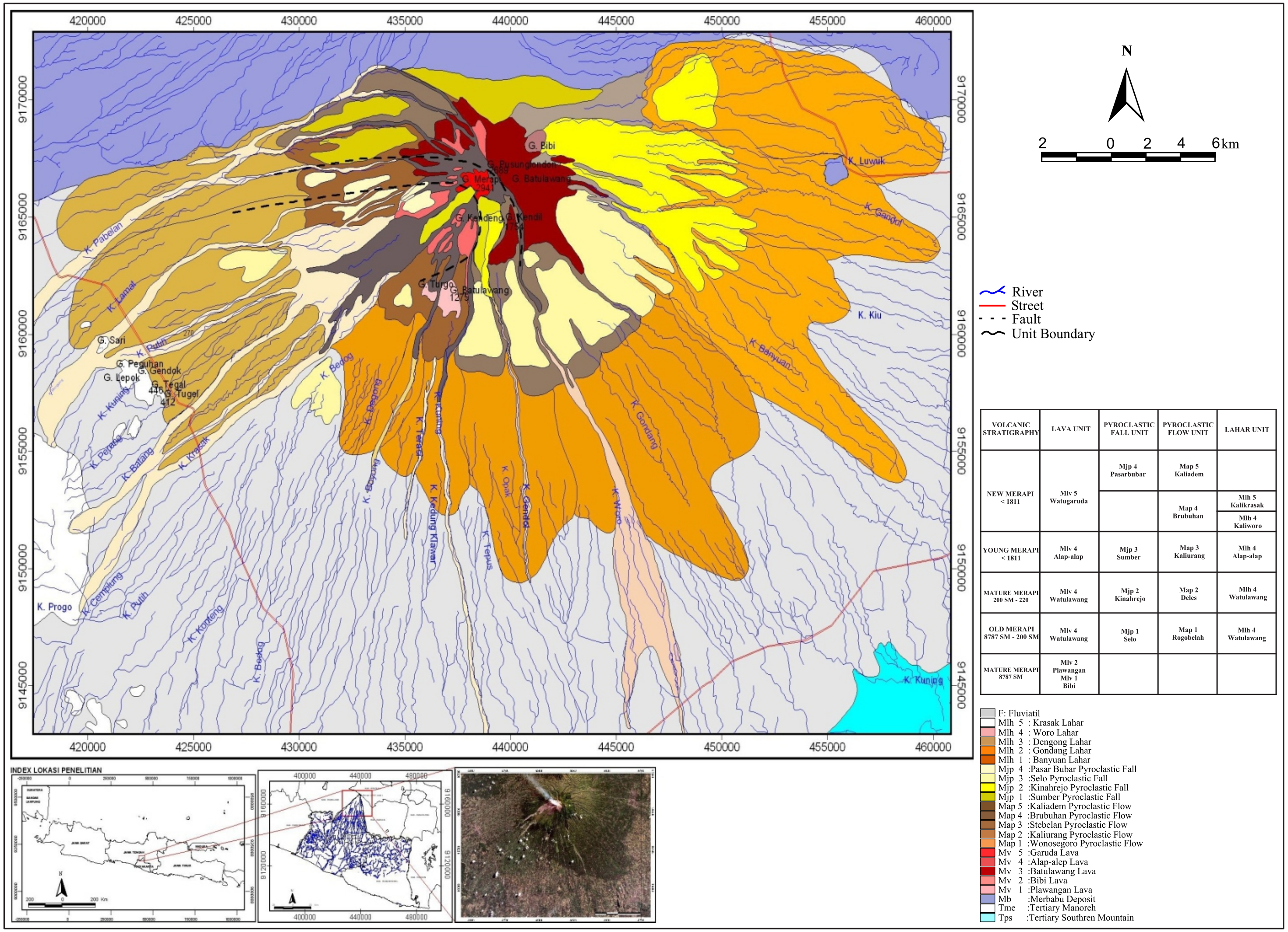

Figure 2. Geologic map of Merapi Volcano showing their volcanic product units and the associated lahar deposits. Thirteen lahar units were identified based on the physical characteristics of the deposits, the presence of pumice with various shapes and sizes, and the chemical composition of the components. In addition, the variation of the crystal rims of horenblende are also important indicators in distinguishing the lahar units. It might be concluded that the characteristics of lahar deposits depicted the nature of Merapi eruption during the Holocene time. (Note: K = River).

tion. The lahar mapping, therefore, could reflect the style of the eruption. In this case, a revision of units is suggested particularly in the southwest sector. The revised lahar map was also prepared during this study.

Conclusions and Recommendation

A detailed study on the physical properties of lahar components might reveal the eruption style in the past. The pumice components are quite significant in this particular case. The individual pyroclastic flow deposit is also able to be distinguished based on the characteristics of its components.

The detailed lahar study might contribute to the estimation of the volcanic risk in the future. It is, therefore, recommended to carry out a detailed description of lahar in the framework of the preparation of volcano geologic mapping.

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