Sedimentology of the June 2006 block-and-ash flows at Merapi Volcano, Java, Indonesia

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Introduction

My research focuses on pyroclastic-flow hazards at Merapi Volcano in Indonesia. It integrates studies of the transport and emplacement mechanisms of block-and-ash flows from the most recent eruption of Merapi in June 2006, the application of geophysical mass flow models to this eruption and petrological investigations of the volcano's magma system prior to the renewal of the volcanic activity in early 2006.

Merapi, an andesite volcanic complex in heavily populated Central Java (Fig. 1), is also one of Indonesia's most active and dangerous volcanoes. Nearly eighty eruptions have been recorded since the mid-1500s and almost half of these are known to have been accompanied by block-and-ash flows ("Merapi-type" nuées ardentes), often related to episodes of gravitational dome collapse. About 15 of these eruptions have caused fatalities.

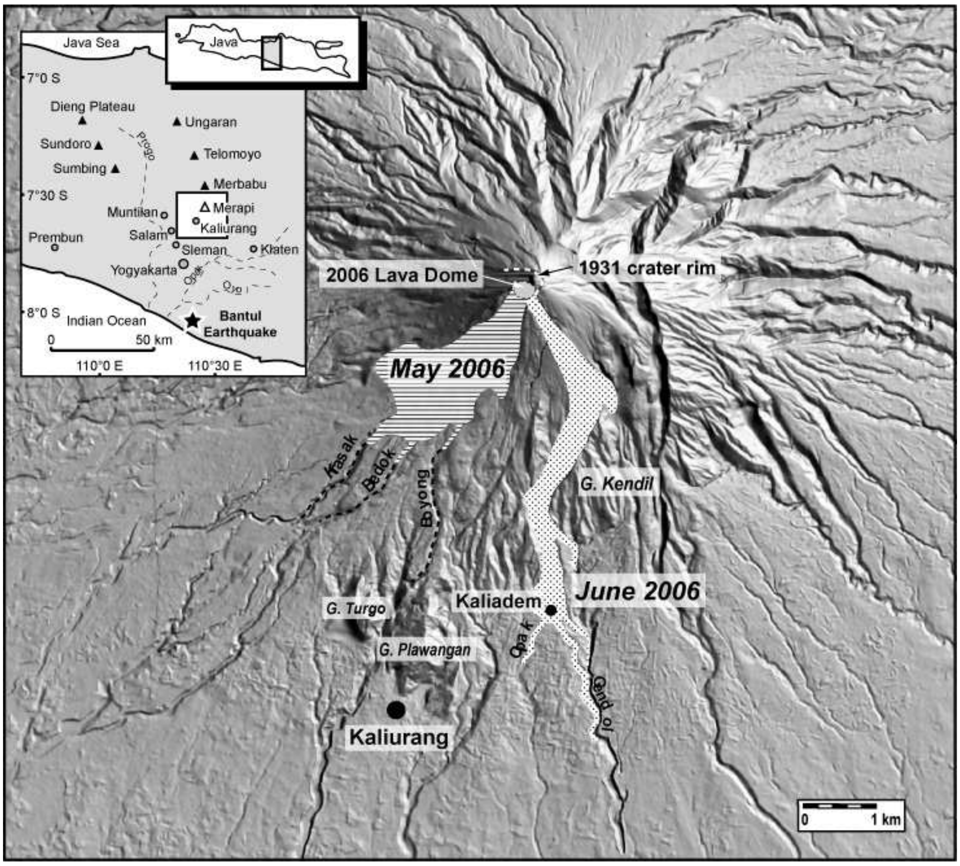

Fig. 1. Distribution of the 2006 eruption deposits on the south-western and southern flanks of Merapi. Inset map shows the location of Merapi volcano in Central Java. Digital elevation model courtesy of C. Gerstenecker, Technische Universität Darmstadt, Germany.

In May 2006, after five years of quiescence, volcanic activity at Merapi resumed with lava dome growth and the generation of block-and-ash flows directed mainly toward the south-western sector of the volcano (Fig. 1). After the devastating Bantul earthquake on 27 May, the activity peaked in June 2006, when a shift in dome growth direction and breach of the eastern crater rim, allowed flows to travel down the volcano's southern and south-eastern flanks which weren't affected by pyroclastic flows for more than a century. On 14 June, the largest block-and-ash flows reached distances of ~7 km from the summit in the Gendol river valley, causing two fatalities and the total destruction of the village of Kaliadem (Fig. 1).

The 2007 fieldwork was partially funded by the IAS grant and focused on the generation and emplacement mechanisms of block-and-ash flows from the June 2006 eruption by combining a detailed study on the sedimentological, stratigraphical, granulometric and componentry characteristics of the deposits. Compilation of these data will allow generation of a conceptual model of transport and deposition of such pyroclastic flows at Merapi, which can be directly integrated into an improved hazard assessment at this high-risk volcano.

Preliminary results

The survey of the entire extent of the deposits in the Gendol River valley (Fig. 1), from proximal to distal reaches, has enabled the construction of a detailed map and the recognition of three types of deposits related to the generation and emplacement of block-and-ash flows during the 2006 eruption (Fig. 2).

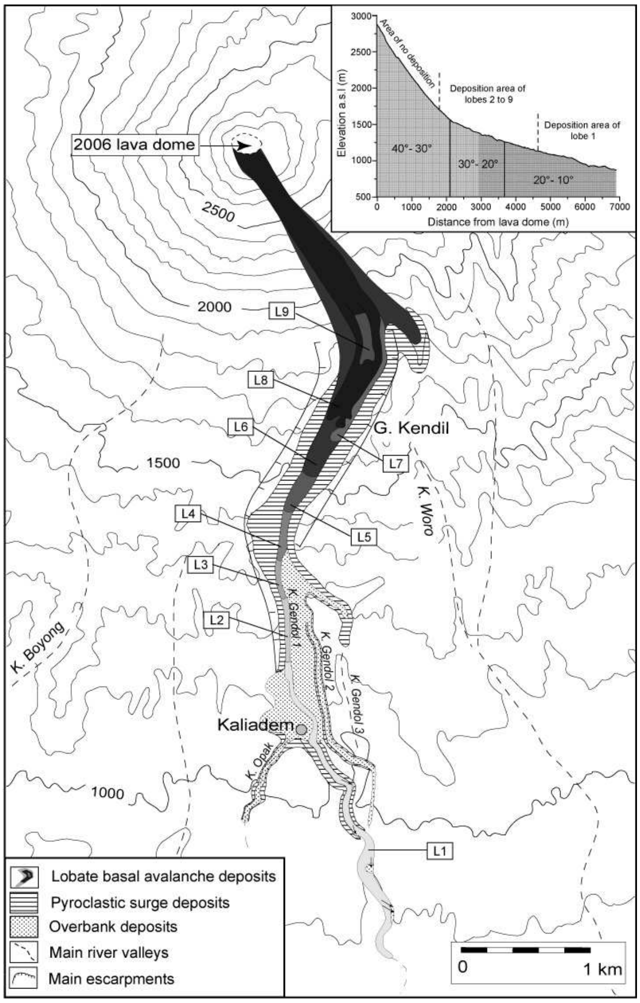

Fig. 2. Detailed map of the June 2006 block-and-ash flow deposits on the southern flank of Merapi. Typical longitudinal profile along the pre-2006 topographic surface with the distribution of individual lobe deposits is shown in the inset.

Individual lobe numbers (L1-9) are also shown. Contour heights are in meters.

Valley-confined basal avalanche deposits (Fig. 2) are exposed in the main Gendol River valley, herein referred to as Kali (Indon. = river) Gendol 1, and form about nine < 100 m wide, overlapping lobes that are in part exposed for tens to hundreds of meters along their flow axis. Runout distances of individual flow lobes range from 2 to 7 km from the summit. These lobes represent a record of successive flows generated during and after the major pyroclastic-flow-forming events on June 14. The basal avalanche deposits cover an area of 3.6 km^2.

While the basal avalanche deposits are strictly confined to Kali Gendol 1, some deposits fill the interfluves and the surrounding valleys (Fig. 2). These deposits are herein referred to as overbank deposits because of their potential to overspill ridges and valley walls and to be subsequently channeled into the surrounding river valleys of Kali Gendol 2, Kali Gendol 3 and Kali Opak (Fig. 2). While the direction taken by the channeled overbank flows emplaced towards the east into Kali Gendol 2 and Kali Gendol 3 mostly follows that of the main river valley, Kali Gendol 1, the south-western direction of the overbank flow into Kali Opak differs by a high angle (around 45°) from the main flow direction (Fig. 2). The overbank deposits outcrop mainly within an area of 0.5 km^2 between 3.5 and 5 km from the summit (Fig. 2).

The June 2006 block-and-ash flow deposits have associated thin deposits from a dilute ash cloud surge that overlies the basal avalanche. These deposits are mostly restricted to valley margins and outer banks, < 1 km to the west and east at their maximum extent (Fig. 2). They are composed of fine ash of 10-50 cm thickness in some areas on ridges and interfluves. The area covered by these ash-cloud surge deposits is 0.6 km^2. The total area covered by the June 2006 block-and-ash flow deposits is 4.7 km^2.

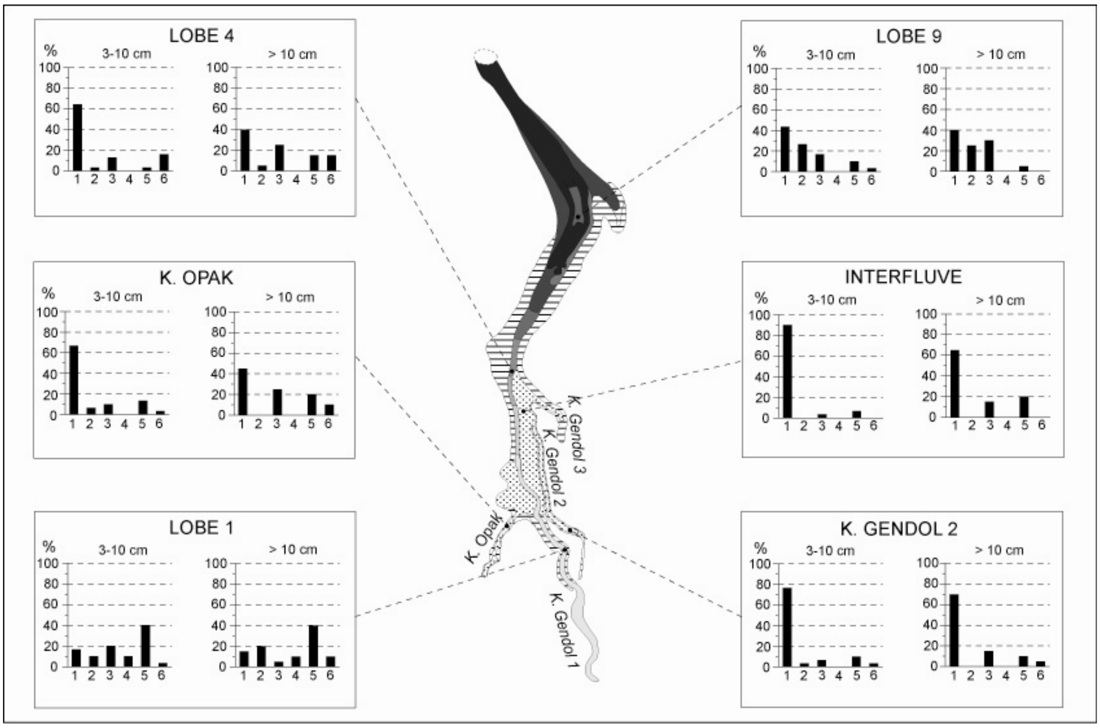

Fig. 3. Main lithological component contents (vol.%) at selected sites within the June 2006 block-and-ash flow deposits on the southern flank of Merapi (symbols as in Fig. 2). Group1 = light grey scoria; Group 2 = dark grey scoria; Group 3 = light grey dense clasts; Group 4 = prismatically jointed clasts; Group 5 = hydrothermally altered clasts; Group 6 = oxidised clasts.

Surface particle assemblage analyses were performed as follow: the composition of coarse clasts (3-10 cm and > 10 cm fractions) was determined at several sites (2×2 m) on the flow surface, particularly on each basal avalanche lobe in the main river valley, on interfluves and in valleys covered by channelled overbank deposits. Each surface particle analysis was undertaken at ~100 m from individual lobe fronts to avoid coarse-enriched clast deposits at the termination facies. In general, 30 clasts were counted for the 3-10 cm fraction and 20 for the > 10 cm fraction. Particles were classified lithologically into six main components, which are representative of the rock types found within the different flows generated during this period (Fig. 3).

The juvenile component of the June 2006 block-and-ash flow deposits range in density from 1.7 to 2.6 g/cm^3 (mean 2.2 g/cm^3, n= 25). The two other components identified – hydrothermally altered and oxidised clasts (Groups 5 and 6, respectively) – are lithologically and geochemically distinct from the juvenile material and represent accidental lithics, which were incorporated into the flows during transport. They range in density from 1.8 to 2.4 g/cm^3 (mean 2.1 g/cm^3, n= 20). The percentages of each component at the different sites, together with their respective locations along the flow surface, are presented in Fig. 3.

Componentry analysis revealed significant variations in the abundances of the main lithological components of the lobate basal avalanche deposits with distance from source and between the basal avalanche and overbank deposits (Fig. 3). These data allow correlation between the generation of successive flows and associated deposits: the generation of the June 2006 block-and-ash flows involved both single and multiple-collapse events including fresh material from the 2006 lava dome as well as from the altered and fumarolised portion of eastern crater rim.

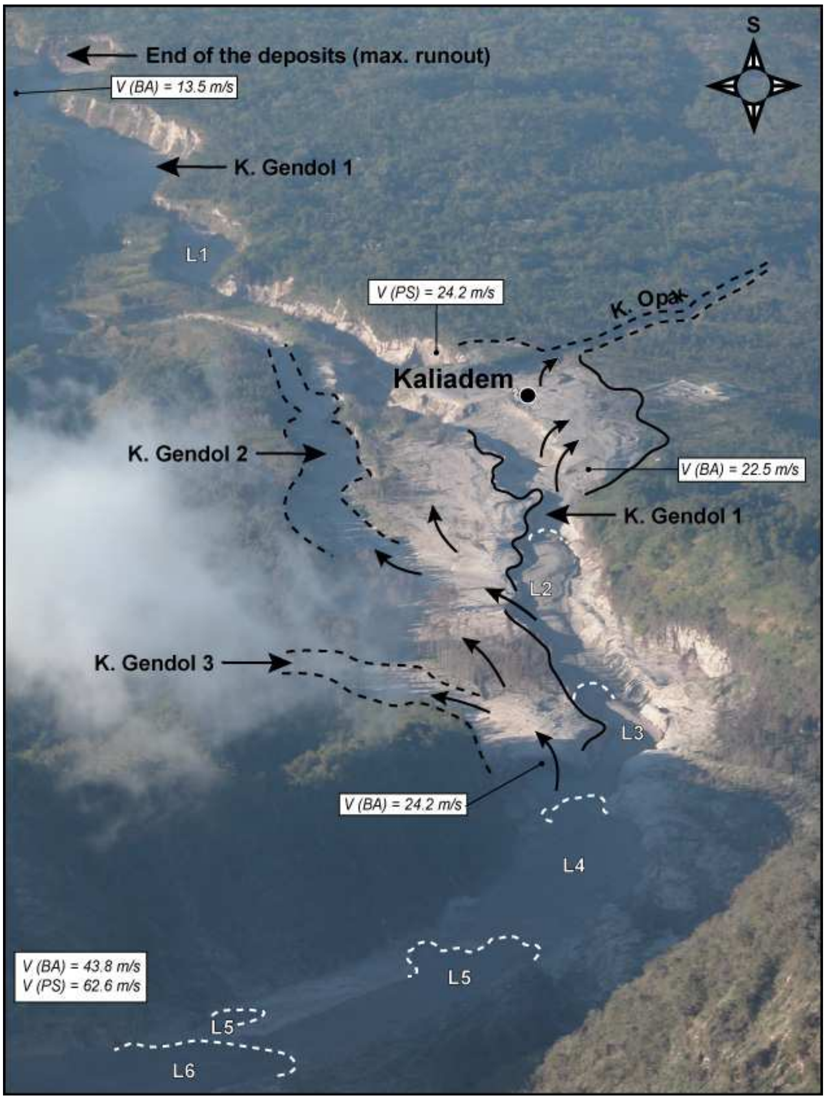

Fig. 4. Photograph taken from the summit of Merapi showing the distribution of the June 2006 block-and-ash flow deposits on the volcano's southern flank.

Numbers and white dotted lines correspond to individual lobe deposits. The lobe front of the largest block-and-ash flow on June 14 (end of the deposits) is located at ~7 km from the summit. Black arrows indicate areas where the basal avalanche overspilled valley margins.

Minimum velocities at flow bends for the basal avalanche (V (BA)) and the pyroclastic surge (V (PS)) are also shown.

Moreover, the variations in distribution, surface morphology and lithology of the deposits are strongly related to varying modes of transport and deposition of the different flows. The block-and-ash flows generated during the peak of activity on June 14 are interpreted to be unsteady, rapidly agitated inertial granular flows and correspond to a flow generated by a sustained, multiple-pulse dome-collapse event over a period of tens of minutes. In contrast, the block-and-ash flows generated after June 14 are interpreted to have formed from quasi-steady granular pyroclastic density currents and correspond to flows generated by a short, single-collapse of parts of the 2006 lava dome, that may involve variable amounts of accidental lithics from the old and unstable part of the eastern crater wall.

The minimum temperatures of the block-and-ash flows generated on June 14 range between 165°C for the ash-cloud surge and around 400°C for the basal avalanche and deposits associated with overbank flows. The minimum velocities for the basal avalanche show a decrease from 43.8 to 13.5 m/s along the full flow length and from 62.6 to 24.2 m/s for the ash-cloud surge (Fig. 4).

The overbank flows here refer to areas where the marginal basal avalanche flow could escape from weakly channel confines and spread laterally into ridges and interfluves (Figs. 2 and 4). Due to their potential to be re-channeled into the adjacent river valley and sometimes to flow at high angles from the main basal avalanche flow direction (Fig. 4), they are considered as the most hazardous part of block-and-ash flows. The conditions that lead to their development during flow emplacement must be taken into account for guiding future pyroclastic flow hazard assessment at Merapi.

Acknowledgements

I wish to acknowledge the support provided by IAS. The grant was used to cover fieldwork costs and was of primary importance to complement this study and obtain new data on the internal architecture of the deposits. This will allow acquisition of a unique combination of data on deposit morphology and internal structure from proximal to distal reaches of the June 2006 deposits, which will help to better understand particle transport and deposition of such pyroclastic flows.