The morphology of large-scale debris avalanche deposit in Cianjur plains, West Java, Indonesia

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Abstract

The large-scale debris avalanche deposit (DAD) process are quite rarely occurring but the impact is catastrophic. Large-scale flank collapse from ancestral Gede volcano resulted in the deposition of debris avalanche deposit that manifested as prominent hummocky hill landform covering 192 km² area in Cianjur plains, West Java, Indonesia. Although the deposit covers large areas and showing unique volcanic landscape morphology, the study on the debris avalanche deposit is limited. Here we show the result of field reconnaissance, satellite photo and digital elevation model analysis to understand the morphology of large-scale debris avalanche deposit including distribution and morphological characteristics. The interpreted thickness of the deposit ranging from 200-500m, although the hummocky hill with well-rounded texture is only 50–100 m height due to intense erosion in the tropical region with the remaining portion of the megaclast blocks buried. The distribution of hummocky hills indicate that the flow constrained by pre-existing basin configuration. The debris avalanche deposit showing fan-like morphology that characterized block facies located near the fan mouth, while the matrix facies with matrix-supported smaller blocks in the distal part. The mouth of debris avalanche deposit located just south of Cianjur township with the highest concentration of megaclast block as block facies that interpreted as the main depositional axis. The block facies apparently stopped by lineament of SW-NE oriented Cimandiri valley to the southeast and NNE-SSW oriented Cisokan river lineament to the east which interpreted as buried normal fault that considered as the barrier to confine flow of block facies deposition.

Introduction

The prominent geomorphological feature in Cianjur plains (West Java, Indonesia) are the hummocky hills that composed of basaltic andesite rocks deposited covering the area of 192 km² located south of Cianjur township (Fig. 1). The hummocky hill morphology identified by van Bemmelen and named 777 (Triple-seven) Hills (Agustin and Bronto, 2019). Sudjatkiko (1972) described the cluster of conical hills consist of large fragment of basaltic blocks and Ilmi et al. (2018) conducted geoelectric survey to identify volcanic rock distribution with resistivity reading more than 100 ohm.m.

The hummocky hills considered important for the environment since most of them are still considered as green zones and covered with hard-wood vegetation (Fig. 2). The climate in the area is characterized by tropical rainforest climate with moderate rainfall from June to September and heavy rainfall from October to May resulting in heavy vegetation cover in the hummocky hill morphology. Some of the hills are already exploited for the stone and sand for construction commodities. The preliminary interpretation of the hummocky hills was resulted from a large-scale debris avalanche process (> 10km³) due to the catastrophic SE-sector flank collapse of the ancestral Gede volcano (Belousov, 2015). Gunung Gede is considered as dormant volcano in the modern times, but previous experiencing pre-historic violent eruption (Angkasa, 2019). The upstream extent, however, is hard to identify due to limited exposure and intensive erosion that remove any indication of volcanic sector collapse. The original topography of

debris avalanche deposit with hummocky hills landform expected to be intensively eroded due to large amount and high intensity of rainfall the humid tropical region.

The research of debris avalanche deposit that induced by flank collapse initiated by St Helens volcanic eruption in 1980 (Malone, 1995 and Glicken, 1996). Prior St Helens eruption, debris avalanche deposit commonly only interpreted as laharic or pyroclastic deposit (Ui et al., 2000). The large-scale debris avalanche deposit (DAD) process with large megaclast block are quite rarely occurring but the impact are catastrophic and potentially disastrous for the nearby communities since it may destroy the nearby low-lying flat area. The debris avalanche process in the ocean setting may induce mega-tsunami, for example Tenerife, Canary Islands (Paris, 2017), Krakatau in 1883 (Hildenbrand, 2018), and Krakatau in 2018 (Perttu, 2020 and Grilli et al., 2019).

The classical debris avalanche deposit that associated with volcanic activity are from Augustine Volcano in Alaska, Bandai-san in Japan and Hawaii. Another large-scale debris avalanche observed in Socompa Volcano in Chili that covering area of 490 km² with vertical height of 3000-meter and transported 35 km from volcanic edifice collapse, the associated volcanic activity identified by fine-grained pumice deposit (Francis, 1985).

Debris avalanche deposit in Indonesia found in Gunung Galunggung, with characteristic hummocky hills near Tasikmalaya, and Gunung Raung, East Java with 48 km distance from volcanic edifice (Bronto, 1989). Nursalim et al. (2016) conducted research of debris avalanche deposit in Gunung Papandayan that deposited in 1772 with 2957 victims and recent avalanche in 2002. The large-scale debris avalanche phenomena has disastrous hazard potential that destroying tens to hundreds km². However, the research for the debris avalanche deposit of Gunung Gede is quite limited although the volcano located close to densely populated area including Jakarta and Bandung metropolitan.

The deposit mostly consists of basaltic-andesite lava of the debris avalanche deposit (Fig. 4) in Cianjur plains will be older than 43500 years BP (Middle to Late Pleistocene), and it was covered with laterite deposit of around 17000 years BP (Belousov et al., 2015). Belousov et al. (2015) also analyzed the sample from lava blocks of debris avalanche deposit that composed of high-silica basalt with moderate concentration of Mg and high proportion of Al that typical of high-alumina basalt of subduction zones with no identified association with pyroclastic deposit. It is inferred that the large-scale debris avalanche was deposited by single episode of cold avalanche with no associated volcanic activity due to large-scale gravitational flank collapse.

The understanding of the morphology of debris avalanche deposit is crucial to identify the size, mechanism and emplacement processes (Hayakawa, 2018). Furthermore, it will help to quantify the potential hazard from such violent future catastrophic events (Harpel et al., 2019). This is the first report presenting the morphology of debris avalanche deposit in Cianjur plains. The study will benefit our understanding of large-scale debris avalanche process is critical to assess the hazard potential in the volcanic province especially in the tropical climate region.

Methods

We described the morphology of debris avalanche deposit in Cianjur plains, West Java, Indonesia using the modern satellite image from Google and Maxar Technology in 2020 that readily available. The size and shape analysis of hummocks morphology related to large-scale debris avalanche deposit can be conducted since the hummocks have clear boundaries and readily identifiable to understand the size and characteristics of debris avalanche process and transport mechanism (Hayakawa et al., 2018). The hummocky hills in Cianjur plains are relatively large enough to be observed from the satellite image, therefore the other method such as aerial photograph is not required for their identification and morphological analysis.

The megaclast fragment block of the deposit can be identified from satellite image due to irregular hummocky topography and still covered by dense vegetation due to hill steepness and infertile soil that unsuitable for cultivation due to their rocky composition. The dense vegetation covers hummocky hill also partly due to humid tropical climate in the area. While the slightly flat topography of surrounding area of matrix already utilized as agriculture area. Therefore, there is contrasting satellite image characteristics can be defined to identify hummocky hills and surrounding region. The latest satellite image data also capable to identify the stone quarry area.

The Digital Elevation Model (DEM) from DEM Nasional (DEMNAS) also utilized to derive topographic contour map and to construct the topographic profile in order to characterize the morphology of debris avalanche deposit. DEMNAS data was constructed from various source including IFSAR, TERRASAR, and ALOS PALSAR. The hummocky hills also further confirmed using inverted Wang-Liu sink-fill algorithm using Digital Elevation Model (DEM) data using QGIS software to identify local convex mound (Wang and Liu, 2006 and Hayakawa et al., 2018). The inverted hummocky hills become depression that enable to obtain potential water flow direction using the lowest elevation in the surrounding eight cells. The flow direction map roughly corresponds to the local mounds and can be used as indication to confirm the hummocky hills geometry (Fig. 3). Reconnaissance field visit conducted to verify the observation from satellite and DEM data.

Discussion

The large-scale debris avalanche deposit in Cianjur plains as basinal area covering 192 km² area that manifested as hummocky hills depositional landform that composed of largely intact megaclast block that transported from volcanic edifice. The observed hummocky hills concentrated within the distance of 18 to 28 km away from the peak of Gede volcano.

The megaclast fragment block diameter size ranging from 50 to 500 m with average of 350 m, that also implies the similar thickness of the individual block, as similarly observed from the experimental research conducted by Paguican et al. (2014) that showing large-size hummocks usually have minimal difference in size distribution. The interpreted maximum thickness of 200 m corresponding to elevation difference

throughout debris avalanche deposit ranging from 300 m to 500 m (Fig. 6), and also considering the observed diameter of hummocky hills from satellite image data. The height of the hummocky hill is around 50–100 m since only less than half of the block to be exposed with the remaining portion of the megaclast blocks buried. The study area is located in the tropical climate region with high humidity and high annual precipitation of more than 2000 mm resulting on intense erosion and heavy vegetation cover. Hence, the original topography of the debris avalanche block is not preserved and significantly eroded due to active erosion during at least 11,700 years ago since Late Pleistocene time of deposition. The areal extent of the hummocky morphology is considered to be intact and indicating the original rounded shape and dimension of the debris avalanche block.

The spatial distribution of hummocky hills is densely concentrated in certain distance from the source and not following conventional distance-size relationship as also observed in debris avalanche deposit of Mt. Erciyes, Central Turkey by Hayakawa et al. (2018). The debris avalanche deposit of Gede Volcano concentrated in Cianjur plains which located 18 to 28 km to the southeast of Gede Volcanic Complex and similar deposit is not found elsewhere. The absence of hummocky hill morphology in the upstream zone and also surrounding Gunung Gede implies the unidirectional flow of debris avalanche from the source of volcanic sector collapse. The longitudinal section shown in Fig. 6(C) indicate relatively similar gradient along main depositional axis, while the traverse section showing mounded feature of the topography of debris avalanche deposit and the nearby alluvial fan deposit.

Distribution Constraint

The distribution of hummocky hills landform as manifestation of debris avalanche deposit also indicates the constraint of existing topography, where the lowland area become the depositional area and flanked by highlands which might divert the distribution of debris avalanche deposit. The volcanic debris avalanche deposit covering most of Cianjur plains that bounded by two old volcanic mounds of Pasir Pongkor to the north and Gunung Campaka to the southwest as indicated with traverse topographic section in the Fig. 6 (C). The morphology of debris avalanche deposit bounded by previously existing highland of Pliocene and Older Quaternary volcanic rocks and the block facies that composed of heavily fractured and brecciated lava rocks ended at Cimandiri valley to the south and Cisokan river fault lineament to the east (Fig. 1).

The distribution of debris avalanche deposit in Cianjur plain following fan-shape geometry originated from the flank collapse of ancestral Gede volcano following narrow gorge (~ 5km) that become mouth fan morphology. The inverted Wang-Liu fill-sink processing result also confirm the distribution of hummocky hills with fan-shape morphology (Fig. 3). The mouth of fan shape located in the northwestern area and dominantly dispersed toward southeast until bounded by NE-SW oriented lineament of Cimandiri valley that separating from nearby highland region, and some deposited toward NE. The mouth of debris avalanche deposit located 18 km from modern Gede volcano with runout up to 30–40 km. The configuration of hummocky hills that located near mouth of debris avalanche deposit showing apparent block imbrication with fan-shaped orientation indicating the block are dispersed from relatively narrow

mouth. The narrow fan mouth morphology indicate that debris avalanche deposit forced to flow into narrow and steepened valley path from the source then dispersed in the low-lying flat area of Cianjur plains. The southern limit defined by NE-SW oriented highland region that comprise of Pliocene volcanic rocks, while the southeastern limit of block facies defined by Cisokan River lineament with NNE-SSW orientation. It is noted that the Cisokan river lineament may represent buried normal fault.

The megaclast fragment of block facies shows similar size with rounded to sub-rounded texture with megaclast-supported configuration. The rounded texture of the megaclast fragment block may indicate the long runout of block transportation from the volcanic edifice with indication traction process during gravity-driven transportation. The circular-based or rounded shape of megaclast block usually formed in rapidly emplaced long runout model, while elongated shape indicate cohesive avalanche material with moderate runout (Paguican et al., 2014).

Facies Classification

The flank collapse phenomena of volcanic edifice are ranging from landslides, rock fall and avalanches with various scale from small to large-scale. This study will focus on the large-scale debris avalanche with fragment block size of 100 to 500 m (Fig. 5). The resulted debris avalanche deposit commonly left scar in the volcanic edifice with amphitheater morphology. However the remnant of amphitheater morphology in Gede Volcano is currently unable to be identified. The debris avalanche deposit in Cianjur plains may be differentiate into block facies and matrix facies (Fig. 7 and Fig. 8), while the block facies of debris avalanche deposit commonly manifested as hummocky hill morphology with various geometry and arrangement (Ui et al., 2000).

The mouth of debris avalanche deposit located just south of Cianjur township with the highest concentration of megaclast block considered as block facies with megaclast-supported framework that interpreted as the depositional axis (Fig. 7), resulted on the majority of well-rounded megaclast fragments (100-500m) constitute most of the hummocky hills. The remaining Cianjur plains covered with the matrix facies of such deposits with sparse megaclast block occurrence (Fig. 8).

Transportation and Emplacement Processes

From the field observations, most outcrops show highly fractured and brecciated basaltic lava with irregular fractures (Fig. 4). As other analogs, these fractured features indicate fracturing during the transportation process. The megaclast block in Cianjur plains has a distinct rounded shape and almost uniform in size with average diameter of 350 m. This might imply that the megaclast was transported as a traction process with long runout from the source (ancestral Gede edifice), that created the roundness texture and sorting along the way. The debris avalanche deposit of ancestral Gede volcano is quite different from other analogs that usually show as chaotic jigsaw and irregular in shape.

The catastrophic debris avalanche transported around 50 to 125 km³ volcanic rock from the ancestral Gede volcano's edifice that located 17–35 km to the Cianjur plains in a single episode. Gede volcano considered as dormant volcano in the modern time (Angkasa, 2019), but the debris avalanche deposit

may indicate violent catastrophic avalanche in the pre-historic era. The large volume of debris avalanche deposit infers the possible giant ancestral Gede volcano as a source of volcanic flank collapse.

Conclusions

The large-scale debris avalanche deposit in Cianjur plains as basinal area covering 192 km² area with fan-shape geometry originated from the flank collapse of ancestral Gede volcano following narrow gorge (~ 5km) that become mouth fan morphology. The debris avalanche deposit in Cianjur plains showing unique morphology of hummocky hill of basaltic andesite lava blocks that characterized block facies, while the matrix facies with matrix-supported smaller blocks in the distal part showing slightly mounded feature indicating the flow constrained by pre-existing basin configuration. The morphology of debris avalanche deposit bounded by previously existing highland of Pliocene and Older Quaternary volcanic rocks and the block facies that composed of heavily fractured and brecciated lava rocks ended at Cimandiri valley and Cisokan river fault lineament. The megaclast fragment of block facies shows similar size with rounded to sub-rounded texture with megaclast-supported configuration. The rounded texture of the megaclast fragment block may indicate the long runout of block transportation from the volcanic edifice with indication traction process during gravity-driven transportation. The megaclast fragment block diameter size ranging from 50 to 500 m with average of 350 m, that also implies the similar thickness of the individual block.

Declarations

Competing interests The authors declare no competing interests.

Disclaimer The views presented in this work are those of authors and do not necessarily represent the views of the Universitas Padjadjaran or any other institution mentioned herein.

References

- Agustin, F. & Bronto, S. 2019. Remote sensing volcanostratigraphy Gede Volcanic Complex and surrounding area, West Java, Indonesia. *Journal of Geology and Mineral Resources* 20(1), 9-16
- Angkasa, S.S. 2019. Geology, mineralogy and sulfur isotopic studies of proximal volcanic products at the Tangkuban Parahu Volcano, Indonesia, dissertation for doctoral degree, Department of Earth Resource Science, Akita University, Japan
- Belousov, A. et al. 2015. Volcaniclastic stratigraphy of Gede Volcano, West Java, Indonesia: How it erupted and when, *Journal of Volcanology and Geothermal Research*, 301, 238-252

- Bronto, S. 1989. Volcanic Geology of Galunggung, West Java, Indonesia. Dissertation, University of Canterbury.
- Francis, P.W., et al. 1985. Catastrophic debris avalanche deposit of Socompa volcano, northern Chile, *Geology*, v.13, p. 600-603
- Grilli, S. et al 2019. Modelling of the tsunami from the December 22 2018 lateral collapse of Anak Krakatau volcano in the Sunda Straits, Indonesia, *Scientific Reports*, vol. 9, article no. 11946, DOI: 10.1038/s41598-019-48327-6
- Glicken, H. 1996. Rockslide-debris avalanche of May 18, 1980, Mount St. Helens volcano, Washington, U.S. Geological Survey, Open-file report 96-677
- Harpel, C.J. et al. 2019. The Orange Tuff: a late Pleistocene tephra-fall deposit emplaced by a VEI 5 silicic Plinian eruption in West Java, Indonesia, *Bulletin of Volcanology*, 81:33
- Hayakawa, Y.S., et al. 2018. Characteristics of debris avalanche deposits inferred from source volumen estimate and hummock morphology around Mt. Erciyes, central Turkey, *Natural Hazards and Earth System Sciences*, 18, 429-444
- Hildenbrand, A., Marques, F.O., dan Catalao, J. 2018) Large-scale mass wasting on small volcanic islands revealed by the study of Flores Island Azores), *Nature Scientific Reports*, 8:13898
- Ilmi, I., Taufan, Y.A., Denis, M., Nur, A.A., dan Syafri, I. 2018. Andesite prospect identification using geolistric method in Cilaku District, Cianjur Regency, West Java. *Bulletin of Scientific Contribution* 16(3): 229–236 (in Indonesian with English abstract).
- Malone, D.H. 1995. Very large debris-avalanche deposit within the Eocene volcanic succession of the northeastern Absaroka Range, Wyoming, *Geology*, v.23, no. 7, p. 661-664
- Nursalim, A., Sulaksana, N., dan Sukiyah, E. 2016. The role of geomorphological aspect to define the characteristic of debris avalanche deposit Gunung Papandayan, Garut, Jawa Barat, *Bulletin of Scientific Contribution*, Fakultas Teknik Geologi Universitas Padjadjaran, Volume 14, Nomor 1, 45-54 (in Indonesian with English abstract)
- Paguican, E. M. R., van Wyk de Vries, B., & Lagmay, A. M. F. 2014. Hummocks: How they form and how they evolve in rockslide-debris avalanches. *Landslides*, 11(1), 67–80. <https://doi.org/10.1007/s10346-012-0368-y>
- Paris, R. et al. 2017. Explosive eruption, flank collapse and megatsunami at Tenerife ca. 170 ka, *Nature Communications*, DOI: 10.1038/ncomms15246
- Perttu, A. et al. 2020. Reconstruction of the 2018 tsunamigenic flank collapse and eruptive activity at Anak Krakatau base don eyewitness reports, seismo-acoustic and satellite observations, *Earth and*

Sujatmiko, 2003. Geological Map of Cianjur Quadrangle, , scala 1 : 100.000, Puslitbang Geologi, Bandung.

Ui, T., Takarada, S., dan Yoshimoto, M. 2000. Debris avalanches, dalam Sigurdsson, H eds. Encyclopedia of volcanoes, Academic Press, Tokyo

Wang, L. & H. Liu 2006. An efficient method for identifying and filling surface depressions in digital elevation models for hydrologic analysis and modelling. International Journal of Geographical Information Science, Vol. 20, No. 2: 193-213.

Figures

Figure 1

Location map of the study showing fan-like distribution of debris avalanche deposit (dotted green outline), characterized with hummocky hill morphology in Cianjur plains, West Java, Indonesia. Note that the block facies of debris avalanche deposit diminished to the east along Cisokan River lineament and to the south along Cimandiri Valley lineament.

Figure 2

The hummocky hills identified with irregular topography resulted as erosion of original well-rounded basaltic andesite lava block, covered by dense hard-wood vegetation cover. The remaining flat surrounding utilized for paddy field agriculture farming.

Figure 3

Inverted Wang-Liu fill-sink processing from Digital Elevation Model (DEM) data to identify hummocky hills geometry.

Figure 4

The outcrop photo of fractured and brecciated basaltic-andesite lava blocks that constitute hummocky hills in Cianjur plains.

Figure 5

Distribution map of debris avalanche deposit in Cianjur plain, consisting of block facies and matrix facies. A) longitudinal section, B) traverse section =C) oblique section. Satellite image from Google and Maxar Technology (2020).

Figure 6

Topographic cross section showing the distribution of block facies and matrix facies of Cianjur debris avalanche deposit. A) longitudinal section, B) traverse section =C) oblique section. Note the hummocky topographic irregularity of block facies, and slightly mounded feature of matrix facies toward the distal part of debris avalanche deposit as an indication that the emplacement of debris avalanche deposit was constrained by pre-existing configuration bounded by older Quarternary and Tertiary rocks.

Figure 7

Characteristics of block facies of debris avalanche deposit located in the proximal end of Cianjur plains, with the megaclast fragment block showing dark green hue indicating dense vegetation. Note that the block showing similar size, rounded to sub-rounded texture and megaclast-supported with strong WNW-ESE imbrication trend. Satellite image from Google and Maxar Technology (2020)

Figure 8

Characteristics of matrix facies of debris avalanche deposit located on the distal end of Cianjur plain, with the fragment block showing dark green hue indicating dense vegetation. Note that the block showing smaller size compared to block facies' fragment, rounded to sub-rounded texture and matrix-supported no indication of imbrication trend. Satellite image from Google and Maxar Technology (2020).