

**PENENTUAN KAWASAN BENCANA BERDASARKAN PENDEKATAN *MULTIFACTOR*
(DESAUNETTES, KARAKTER DAN KETEKNIKAN BATUAN) PADA RUNTUHAN
TUBUH GUNUNG API MANGLAYANG, WEST JAVA, INDONESIA**

*DETERMINATION OF DISASTER-PRONE AREAS BASED ON A MULTIFACTOR APPROACH
(DESAUNETTES, ROCK CHARACTERISTICS AND ENGINEERING) ON THE MANGLAYANG
CATASTROPHE VOLCANO EDIFICE, WEST JAVA, INDONESIA*

**Putu Ayu Andhira*¹, Faishal Aziz¹, Muhammad Khozi¹, Teuku Yan Waliana Muda
Iskandarsyah¹, Johanes Hutabarat¹, Hendarmawan¹**

*Email: putu22005@mail.unpad.ac.id

¹Fakultas Teknik Geologi, Universitas Padjadjaran, Bandung, Indonesia

Abstrak

Gunung Manglayang merupakan gunung api *extinct* berlokasi di Jawa Barat, memperlihatkan morfologi amphitheater berbentuk tapal kuda dan diduga mengalami fenomena *sector collapse* yang menghasilkan endapan *debris avalanche*. Penelitian ini bertujuan mengidentifikasi jejak *sector collapse*, mengkarakterisasi endapan *debris avalanche*, serta menentukan kawasan aman, rawan, dan bahaya longsor. Metode penelitian meliputi Digital Elevation Model (DEM), klasifikasi bentuklahan Desaunettes, observasi geologi lapangan, analisis litologi, serta evaluasi kestabilan lereng. Hasil penelitian menunjukkan adanya morfologi amphitheater yang membuka ke arah tenggara sebagai indikasi *sector collapse*. Morfologi hummocky tersebar pada jarak 2 – 6 km dari kerucut gunung dan didukung oleh keberadaan breksi *debris avalanche* yang memperlihatkan struktur *jigsaw crack* dan bongkah berukuran besar. Integrasi parameter morfologi, karakteristik batuan, dan analisis kestabilan lereng menunjukkan bahwa kawasan perbukitan curam memiliki tingkat kerawanan longsor tertinggi, sedangkan morfologi hummocky umumnya berada pada kondisi stabil saat ini. Pendekatan multifaktor ini memberikan kerangka yang lebih komprehensif untuk mengidentifikasi jejak *sector collapse* sekaligus mendukung penyusunan zonasi kawasan rawan bencana pada gunung api purba.

Kata kunci: *Debris Avalanche*, Desaunettes, Geomorfologi, Gunung Api Manglayang, Kestabilan Lereng, *Sector Collapse*.

Abstract

Manglayang is an extinct volcano in West Java characterized by a horseshoe-shaped amphitheater morphology, suggesting a past volcanic sector collapse that generated debris-avalanche deposits. This study aims to identify evidence of sector collapse, characterize debris-avalanche deposits, and delineate stable, susceptible, and hazardous landslide zones. The methodology combines Digital Elevation Model (DEM) data, Desaunettes landform classification, geological field observations, lithological analyses, and slope stability assessment. The results reveal a southeast-facing amphitheater interpreted as the main sector-collapse scar. Hummocky landforms are widely distributed between 2 – 6 km from volcanic cone and supported by debris-avalanche deposits characterized by volcanic breccias with jigsaw-crack structures and abundant large boulders. The integration of geomorphological, lithological, and geotechnical parameters indicates that steep hilly terrains represent the highest landslide susceptibility, whereas hummocky terrains are generally stable under present conditions. The proposed multifactor approach provides a comprehensive framework for reconstructing ancient volcanic collapse processes and improving disaster-prone area mapping in extinct volcanic terrains.

Keywords: debris avalanche, Desaunettes classification, geomorphology, Manglayang Volcano, sector collapse, slope stability.

I. INTRODUCTION

Mount Manglayang is a stratovolcano located between the City of Bandung, East Bandung Regency, and Sumedang Regency, West Java, Indonesia. The elevation approximately 1,818 m masl. Mount Manglayang is considered the eastern boundary of the active Lembang Fault, which extends approximately 22 km in a west–east direction. [1], [2]. The volcano summit exhibits a crown-shaped collapse amphitheater with an approximate diameter of 4–5 km [3], and is composed of Undifferentiated Volcanic Deposits (Qyu) [4]. Based on the Indonesian Volcano Database, Mount Manglayang is not categorized as a Type A, Type B, or Type C volcano [5]. The absence of documented volcanic activity since 1600, together with the lack of identified geothermal manifestations, suggests that Mount Manglayang can be interpreted as an extinct volcano..

Mount Manglayang is situated in a strategically important area within the expanding eastern Bandung metropolitan region, encompassing Bandung City, Bandung Regency, and Sumedang Regency (Figure 1). This region has also developed into a major center for education, residential development, economic growth, and nationally strategic infrastructure, including the Trans-Java Toll Road.

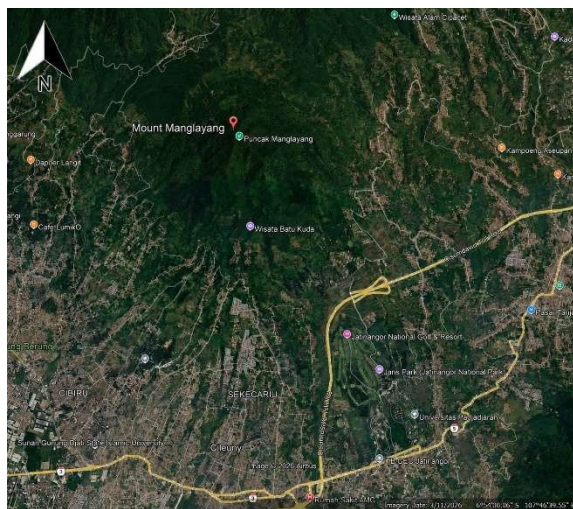


Figure 1. Spatial Land-Use Development in the Foothills of Mount Manglayang (Source: Google Earth, 2026).

Volcanological research has predominantly focused on active volcanoes to support hazard assessment and disaster mitigation (non-profit oriented) as well as the exploration of mineral and non-fossil energy resources (profit oriented). In contrast, studies of dormant or extinct volcanoes, particularly those aimed at assessing potential geological hazards, disaster susceptibility, or

supporting regional development, remain relatively limited. Furthermore, the geological succession of volcanic deposits associated with Mount Manglayang has not yet been comprehensively characterized or described in sufficient detail on existing geological maps.

From a geomorphological perspective, Mount Manglayang is characterized by an amphitheater-shaped horseshoe morphology, a younger volcanic cone, and a series of low hills. These morphological features potentially record the volcano's genetic evolution and provide important evidence for interpreting volcanic depositional processes, stratigraphic relationships, and structural lithological characteristics [6]. Volcanic morphological analysis enables the identification of volcanic material transport pathways, thereby facilitating the estimation and delineation of volcanic hazard zones [7].

Volcanic deposits are characterized by substantial variability in lithology and rock mechanical properties. Lava flows generally exhibit higher rock strength than volcanoclastic deposits, such as pyroclastic, epiclastic, and cataclastic materials [8] [9]. The latter commonly display a broad spectrum of mechanical strengths, ranging from competent to weak, thereby increasing their susceptibility to slope failure and landslides.

The North Bandung Area, including the foothills of Mount Manglayang, has been classified by the Bandung City Government as a high landslide hazard zone [10], this classification is largely associated with the dominance of volcanoclastic deposits, particularly tuff, in combination with volcanic and fluvial landforms exhibiting gentle topography that grades into steep slopes toward the southern part of the study area [11]. Furthermore, ecological degradation and land-use conversion [12], [13] have become contributing factors that exacerbate both ecological and geological hazards. Despite the growing vulnerability of the region, studies investigating landslide hazards in the Manglayang Mountain area remain limited and have primarily focused on localized slope stability assessments.

According to historical records, a major landslide disaster occurred in the Mount Manglayang region in 1977. The landslide involved the collapse of hilly terrain, which subsequently blocked the valley between adjacent hills, forming a natural dam that impounded rainwater with a storage volume of several thousand cubic meters. Unable to withstand the increasing water pressure, the landslide dam eventually breached, triggering a catastrophic flood that inundated the Ujungberung area, including

Cigending, Ciporeat, Cipanjalu, and surrounding localities. Large logs transported by the floodwaters were deposited across the Ujungberung main road, causing severe disruption to transportation and extensive damage to the affected areas. [14], [15].

Based on these considerations, research on the potential for landslide hazards at Mount Manglayang is of considerable importance. This study aims to identify and analyze the morphological characteristics and associated depositional products of the mountain, as well as to assess the extent and spatial distribution of landslide hazard potential within the Mount Manglayang area. The findings of this research are expected to provide a scientific basis for delineating stable, susceptible, and high-hazard landslide zones, thereby serving as a valuable reference for local government authorities in formulating evidence-based disaster risk management and land-use planning policies.

II. LITERATURE REVIEW

A. Regional Geological

The study area is located within the Bandung Geological Map Sheet compiled by P.H. Silitonga (1973). According to the regional geological framework, the Mount Manglayang area and its surroundings comprise two principal geological units. The first is the Undifferentiated Older Volcanic Deposits Unit (Qvu) of Quaternary age, which is predominantly composed of volcanic breccia, lahar deposits, and interbedded lava flows. The second is the Undifferentiated Younger Volcanic Products Unit (Qyu), also of Quaternary age, consisting of tuffaceous sand, lapilli, volcanic breccia, lava, and agglomerate. These volcanic materials are interpreted to have been derived partly from Mount Tangkuban Parahu and partly from Mount Tampomas. Between Sumedang and Bandung, this unit forms a series of small plains, relatively flat surfaces, and low hills that are mantled by yellowish-gray to reddish soils.

According to [4] as cited in [16] Mount Manglayang is interpreted to have formed after the evolution of the Ancient Sunda Volcano and prior to the Old Tangkuban Parahu Volcano, approximately between 105 ka and 55 ka. During this period, a sectoral volcanic collapse is inferred to have occurred, producing a horseshoe-shaped amphitheater estimated to have formed between 90 ka and 75 ka. This collapse structure opened toward the southeast and was subsequently followed by the emplacement of the younger Mount Manglayang

volcanic cone within the center of the collapse depression.

The evolution of Mount Manglayang, together with its volcanic textural and structural characteristics, is closely associated with the Lembang Fault located to the north and the broader geological setting of the Bandung Basin. However, the present study focuses primarily on the geomorphological characteristics of the volcano and their relationship to potential geological hazards.

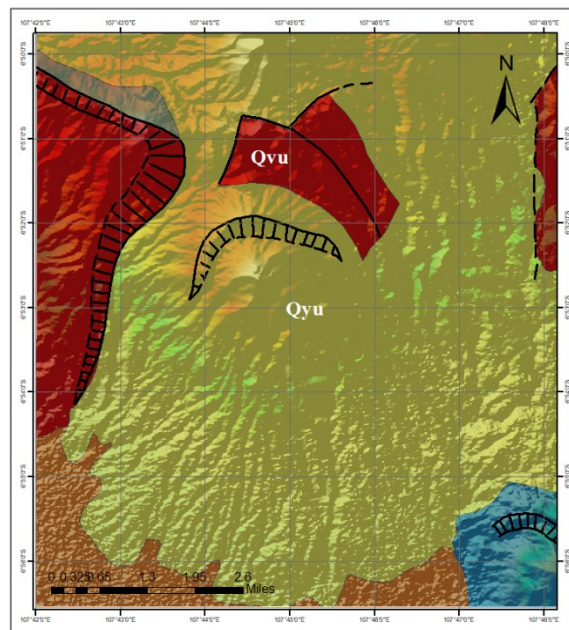


Figure 2. Regional Geological Map of the Study Area [4]

B. Volcanic Deposits

The term "**volcaniclastic**" is a non-genetic term that refers to any aggregate of volcanic-derived fragments, regardless of their origin. In contrast, "**pyroclastic**" refers exclusively to aggregates produced by explosive volcanic activity and deposited by transport processes generated directly by that activity. Other types of volcaniclastic rocks include those that have been fragmented, deposited, or both, through epiclastic processes, which comprise normal surface processes involving weathering and erosion. Accordingly, the term "**epiclastic**" is used here to describe deposits or rocks produced by normal surface fragmentation processes (e.g., weathering, physical abrasion, and gravitational collapse) or ultimately deposited through normal surface transport mechanisms (e.g., traction, suspension, and mass-flow processes), irrespective of the mode of fragmentation. In this context, the use of the term

"epiclastic" extends beyond its more traditional source-based definition [6][17][18].

C. Volcano Phenomenon: Sector Collapse and Volcanic Debris Avalanche

Sector collapse, defined as the partial collapse of a volcanic edifice, is a catastrophic phenomenon in volcanic evolution that can generate volcanic debris avalanches. Several well-documented historical examples of sector collapse include Mayuyama Volcano and Mount Bandai in Japan, as well as Mount St. Helens in the United States [19]. This phenomenon is triggered by volcanic seismic activity, fault movement, and magma intrusion [20], [21], [22] [23]. Two scenarios have been recognized in which specific structural features may develop prior to a sector collapse, thereby providing the potential for predicting such events. The first scenario involves the intrusion or emplacement of a lava dome, as documented at Mount St. Helens [24], [25], the second involves gradual slope displacement, or flank spreading, driven by gravitational forces as a consequence of progressive slope weakening associated with hydrothermal alteration [26], [27].

Sector collapse may occur repeatedly on the same volcano when one or more flanks become unstable [28], [29], the collapse scars commonly exhibit the same opening direction, although the orientation may vary between successive collapse events [30], [31], [32], [33]. Debris avalanches generated by sector collapse produce a distinctive hummocky volcanic topography, consisting of volcanic hummocks composed of boulders or volcanic block facies embedded within a fine-grained matrix [34], [35], [36], [37]. The block facies comprise transported portions of the volcanic edifice and may consist of intact volcanic rock masses, fractured volcanic clasts, or a heterogeneous mixture of volcanic and non-volcanic lithologies [38]. During a sector collapse, part of the volcanic edifice undergoes catastrophic failure. The resulting collapse debris ranges in size from boulders to blocks hundreds of meters across and may include megablocks, lava blocks, brecciated lava (autobreccia), volcanic breccia, angular boulders, and a matrix of crushed volcanic debris. These deposits are typically distributed within the proximal to medial sectors of the volcano [35].

Sector collapse is recognized by its distinctive horseshoe-shaped amphitheater morphology. The resulting debris avalanche deposits commonly attain thicknesses of up to 300 m and comprise a poorly sorted mixture of clasts ranging from volcanic ash to

large boulders. Intact lava blocks and megaclasts can be transported over distances exceeding 100 m from the volcanic edifice. Unlike lahars, which are water-saturated mass flows, debris avalanches are predominantly dry gravitational mass movements with little or no liquid water involved during transport [39]. Although debris avalanches are most frequently associated with volcanic flank collapse, they may also be generated by the failure of lava domes and cinder cones [40].

D. Desaunettes Classification

The physiographic classification proposed by [41] is based on measurable topographic characteristics, particularly slope gradient and local relief. This classification does not infer the genetic origin of landforms; rather, it categorizes landscapes according to their morphological expression.

Within the Desaunettes classification, hummocky morphology is characterized by small, rounded mounds separated by shallow depressions. These landforms generally exhibit relatively steep slopes while maintaining low local relief.

The interpretation of debris-avalanche deposits requires the integration of geomorphological mapping with detailed geological observations, including the characteristics, structures, textures, and spatial relationships of volcanic lithologies; the distribution of boulders and megablocks; the identification of fractured clasts displaying jigsaw-crack patterns; and the recognition of collapse scars exhibiting amphitheater- or horseshoe-shaped morphologies [20], [34], [42].

In this study, the Desaunettes classification was employed as an initial approach to classify volcanic landforms using slope gradient and local relief derived from a Digital Elevation Model (DEM) [43]. Areas classified as exhibiting a hummocky morphology were not automatically interpreted as debris-avalanche deposits. Instead, these areas were regarded as potential geomorphic indicators of sector-collapse deposits that require further verification through lithological observations, petrographic analyses, and field evidence. This methodological approach enables an objective classification of volcanic landforms while maintaining a clear distinction between morphological description and genetic interpretation, thereby reducing uncertainty in the identification of debris-avalanche deposits within the landscapes of extinct volcanoes.

E. Rock Strength and Slope Stability

The stability of volcanic slopes is controlled by geological conditions, topographic morphology, hydrological processes, and the geotechnical properties of volcanic materials. The geotechnical behavior of volcanic deposits is governed by lithological characteristics, the degree of weathering, hydrothermal alteration, grain-size distribution, permeability, and the pattern of discontinuities. Lava lithologies generally exhibit relatively high shear strength owing to their coherent rock mass and high internal friction angle, whereas clastic deposits (pyroclastic, epiclastic, and cataclastic deposits), unconsolidated materials, and hydrothermally altered volcanic rocks possess lower cohesion and reduced shear strength. These variations directly influence cohesion (c'), effective internal friction angle (ϕ'), and unit weight (γ), which are the principal parameters controlling slope stability according to the Mohr–Coulomb failure criterion [44].

From a geomorphological perspective, slope angle is the most influential factor because it governs the magnitude of gravitational driving forces acting on a hillslope. As slope gradient increases, gravitational forces also increase, resulting in greater shear stress along potential failure surfaces [45], [46].

In geotechnical engineering, slope stability is commonly evaluated using the **Factor of Safety (FoS)**, defined as the ratio of resisting forces to driving forces acting along a potential failure surface. A slope is generally considered stable when the FoS exceeds 1.5, marginally stable when the FoS ranges from 1.2 to 1.5, critically stable when the FoS approaches 1.0, and unstable when the FoS is less than 1.0. The Factor of Safety integrates morphometric conditions and material properties into a single quantitative indicator of slope stability [45], [46].

This integrated approach enables the identification of sector-collapse scars, debris-avalanche deposits, and structurally weakened volcanic sectors while simultaneously assessing their present mechanical stability. Consequently, the integration of volcanic deposit characteristics, DEM-derived morphometric parameters, and Factor of Safety analysis provides a comprehensive framework for reconstructing volcanic evolution, evaluating sector-collapse processes, and assessing the stability of volcanic slopes.

III. METHODOLOGY

The research employed both quantitative and qualitative geomorphological analyses, including morphometry, morphology, relief, and morphogenetic assessments, which were integrated with field data on lithological distribution to characterize the rock units and identify geological processes occurring within the volcanic edifice. Rock strength and slope stability were evaluated using the Safety factor (Fs) as the principal parameter for delineating landslide hazard zones. Petrographic thin-section analysis was conducted to verify the lithological characteristics of the rock units identified within the study area.

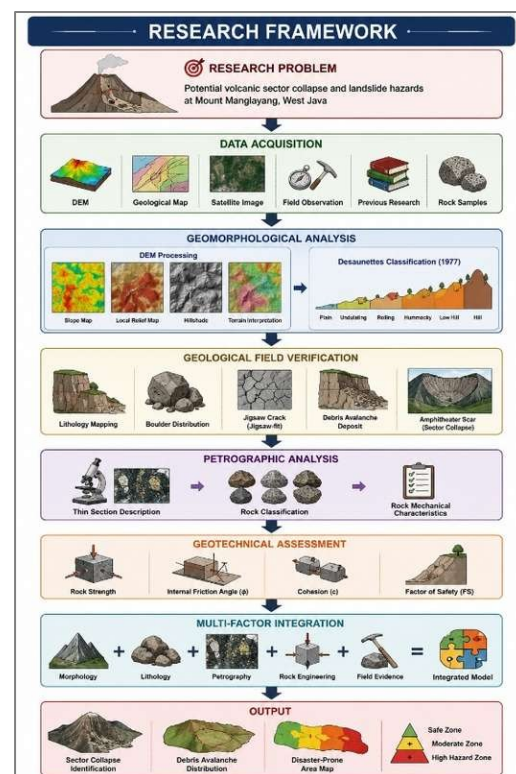


Figure 3. Research Framework.

A. Digital Terrain Analysis

Terrain analysis is closely related to morphological analysis; therefore, various derivative datasets generated from a Digital Elevation Model (DEM) can be utilized to analyze the Earth's surface morphology. Visual interpretation of morphology requires data that provide a near three-dimensional representation of the terrain. Such a quasi-three-dimensional visualization enables the identification and interpretation of fundamental landform features, including elevated areas (highlands), plains, and valleys [47].

B. Relief Model

The relief classification employed in this study is based on the system proposed by Desautettes (1977) in *Catalogue of Landforms for Indonesia*. Relief classes were used to interpret surface landforms and morphology prior to conducting further analyses aimed at determining the genesis of each landform. This classification is established based on slope gradient and local relief (elevation difference), as presented in (Table 1.) [47]. The processing of the Digital Elevation Model (DEM) data and the generation of the relief model were carried out using ArcMap 10.3 software.

Table 1. Morphological Classification based on [41].

Slope (°)	Relief range (m)	Morphology
0 – 2	<1	Plain
2 – 8	1 – 10	Undulating Plain
8 – 16	1 – 10	Rolling Plain
>16	1 – 10	Hummocky
>16	10 – 50	Low Hill
>16	50 – 300	Hilly
>16	> 300	Mountainous

C. Field Observation

Field observations were conducted to collect fundamental geological data, including lithological distribution, rock structures, rock sampling, stratigraphy, geological structures, and volcanic geomorphology. Field data were acquired using the Avenza Maps application installed on an Android device. The use of Android-based mobile devices plays a significant role in geological mapping because they enable digital data acquisition and are equipped with integrated sensors that facilitate and enhance field mapping activities [48].

D. Lithological Analysis

Lithological characterization was undertaken to determine the distribution of rock units within the study area and to classify them based on similarities in lithological characteristics and the associated geomorphological features [6], [17], [18]. The classification of volcanic deposits was based on a genetic rock nomenclature.

Petrographic analysis, involving thin-section preparation and microscopic examination, was performed to identify and classify the rocks based on their mineralogical composition. All minerals present

in the thin sections were systematically identified, their optical properties were described, and their modal proportions were estimated. The optical characteristics evaluated included crystal habit, cleavage, inclusions, color, pleochroism, refractive index, relief, twinning, texture, zoning, crystallographic orientation, extinction angle, interference colors, optic axis characteristics, and optical sign.

E. Determination of Rock Strength for Delineating Stable, Susceptible, and Hazard Zones

Based on the previously classified morphological groups, slope stability was evaluated to determine whether each slope falls within the stable, susceptible, or hazardous category. The assessment considered several parameters, including the lithology composing each morphological unit, slope gradient, and the factor of Safety (Fs), which was calculated using Equation (1) [46].

$F\phi = \frac{\tan \phi'}{\tan \phi d'}$	(1)
---	-----

where **Fs** = factor of safety; **$\tan \phi'$** = internal friction angle; and **$\tan \phi d'$** = field-measured slope angle.

The values of cohesion (c) and internal friction angle (ϕ) were adopted from values reported in the literature [49], [50], [51], [52], as this study did not include laboratory rock strength testing. Subsequently, the factor of safety (Fs) was calculated for each morphological group. The classification of slopes into stable and unstable zones was based on the criteria presented in (Table 2).

Table 2. Relationship between factor of Safety (Fs) values and landslide occurrence [52], as cited in [53].

FS Value	Potential Landslide Hazard
< 1,07	Potential for Landslides
1,07 < SF < 1,25	Previous Landslide Occurrence
> 1,25	Rare Landslide Occurrence

IV. RESULTS AND DISCUSSION

A. Desaunettes Morphological Analysis

Morphometric relief map analysis reveals the presence of three amphitheater- or horseshoe-shaped landforms that are interpreted as the remnants of partial volcanic edifice collapse, representing a sector collapse (SC) event with openings toward the southeast. In addition, two smaller horseshoe-shaped morphologies were identified, opening toward the southwest and northeast, respectively (**Figure 4**).

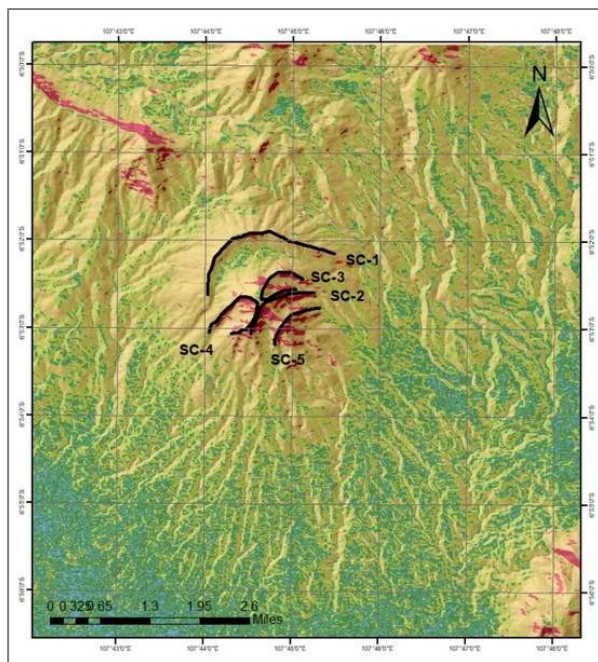


Figure 4. Relief – Morphometry Map

To further support the interpretation of a sector collapse event, a morphometric landform classification was conducted based on the classification system proposed by [41]. In this classification, slope gradient and local relief were used as the primary variables for distinguishing morphological units. As shown in (**Figure 5**), six landform categories were identified:

1. Plain
2. Undulating Plain
3. Rolling Plain
4. Hummocky Terrain
5. Low Hills
6. Hills

* **Note:** In the map legend of (**Figure 5**), the Hills category is not displayed because its spatial extent is

extremely limited, making it indistinguishable at the scale of the map.

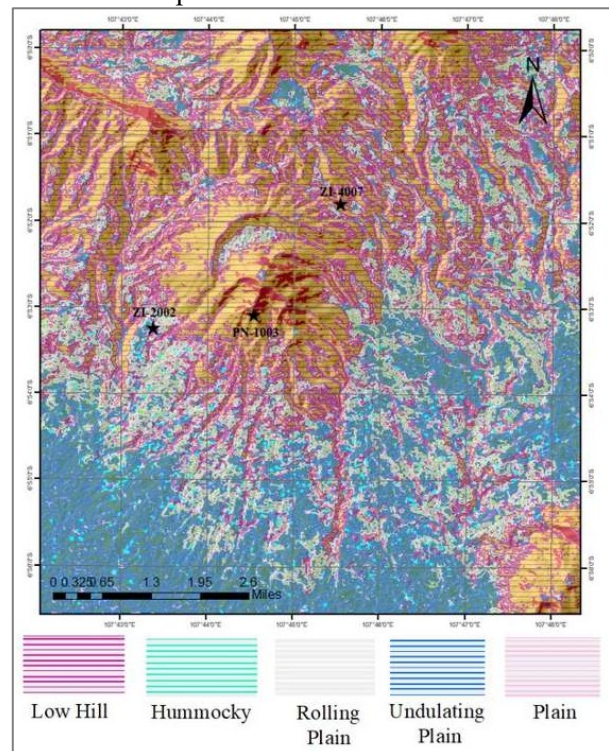


Figure 5. Desaunettes Morphology Map

The presence of hummocky morphology in the Mount Manglayang area may indicate the occurrence of debris avalanche deposits, which are recognized as characteristic products of volcanic sector collapse events. Evidence of past sector collapse or flank collapse suggests that such mass-wasting processes may have directly or indirectly threatened the surrounding communities, underscoring the importance of reconstructing the volcano's collapse history for hazard assessment.

B. Lithological Characteristics of the Morphological Groups

Several outcrops exhibit structural and textural characteristics that are consistent with a volcanic sector collapse and are interpreted as debris avalanche deposits (**Figure 5**). The debris avalanche deposits observed within the study area are characterized by volcanic breccia containing fragmented lithic clasts exhibiting jigsaw-crack (**Figure 6 & 7**). These clasts are supported by a matrix ranging from very fine-grained volcanic ash to lapilli-sized material. In terms of sorting, the deposits are very poorly sorted, with randomly distributed grain sizes, and exhibit a massive, structureless, and chaotic fabric.



Figure 6. Observation Station ZI-4007 showing a debris avalanche deposit characterized by a jigsaw-crack structure.



Figure 7. Observation Station ZI-2002 showing a debris avalanche deposit characterized by a jigsaw-crack structure.

Numerous boulders ranging from approximately 1 to 10 m in diameter were observed at several field stations within the proximal and medial sectors of Mount Manglayang (**Figure 8**).

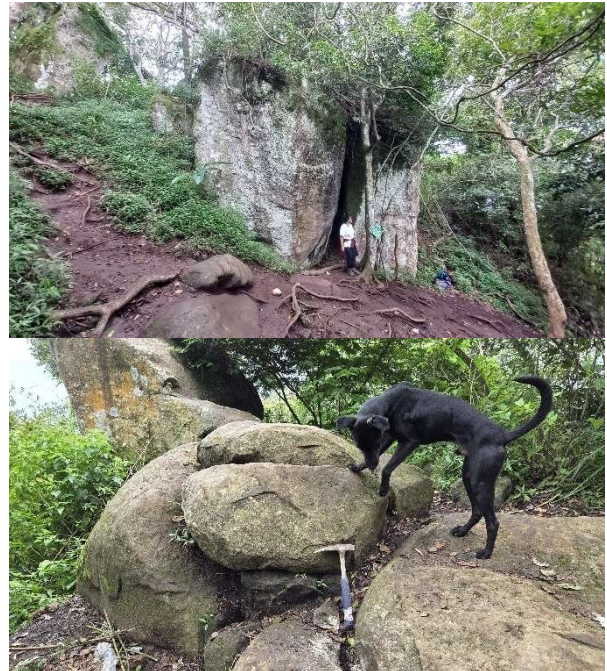
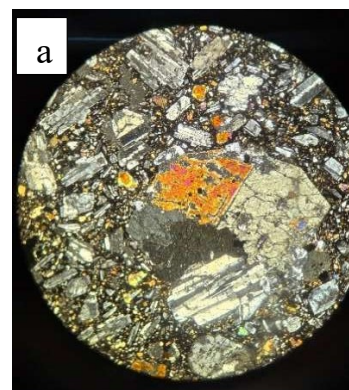


Figure 8. Observation Station PN-1003 Batu Lawang Boulder.

Thin-section verification does not always support the results of field-based lithological observations because debris avalanche deposits are secondary (reworked) deposits. Representative rock thin sections collected from the study area are presented in (**Figures 9 and 10**). The thin section from observation station PT. Checking-1001 was identified as basaltic-andesite, whereas the thin section from observation station PN-1001 was identified as vitric tuff.



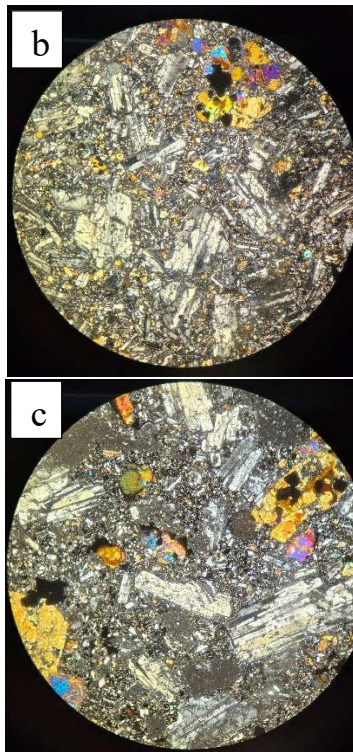


Figure 9. Thin sections from PT. Checking-1001 Station showing (a) lava (bottom), (b) autobreccia (middle), and (c) lava (top).

These thin sections provide lithological information that is essential for determining the

cohesion and internal friction angle parameters required for slope stability analysis within the hazard zonation framework of this study. Likewise, thin sections of clastic volcanic rocks, such as tuff and the matrix of volcanic breccia, provide valuable insights into the engineering characteristics of both competent and weak rock materials.

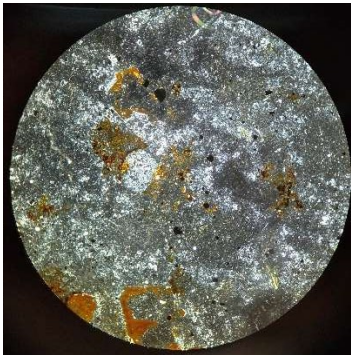


Figure 10. Thin section from PN-1001 Station showing pyroclastic fall deposits.

C. Delineation of Stable, Susceptible, and Hazard Zones

The identification and delineation of stable, susceptible, and hazard zones for each morphological group were conducted as follows (**Figure 11**).

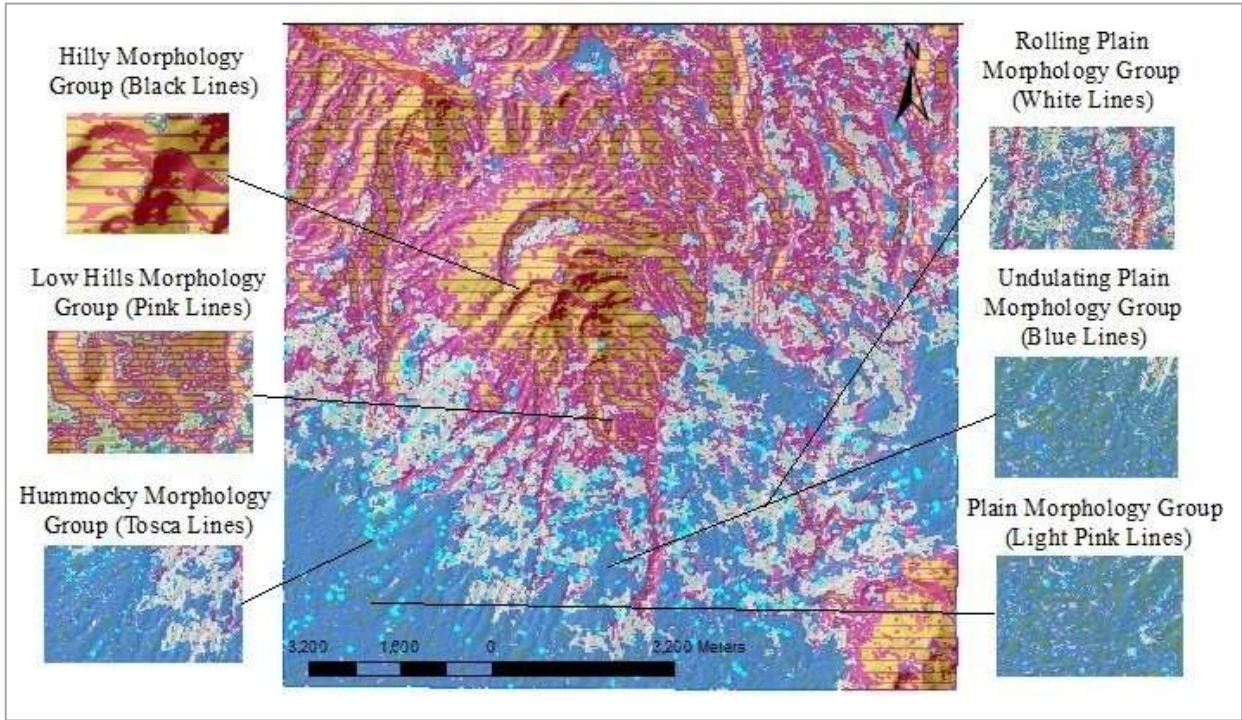


Figure 11. Distribution map of Stable, Susceptible, and Hazard Zones based on the Desautettes morphological classification.

1. Hilly Morphology Group

Characterized by slope gradients of 45°, 51°, and 58° (randomly selected samples) and is located in the central part of the study area. This morphological group is composed predominantly of andesitic lava, which has an internal friction angle (ϕ) of 55° [46], [49]. The calculated **Factor of Safety (FS)** values are **1.20** for a 45° slope, **1.07** for a 51° slope, and **0.90** for a 58° slope. Based on these FS values, the slopes within this morphological group can be classified as **stable, potentially unstable, and unstable**, respectively. An FS value of **0.90** indicates that slope failure has already occurred. However, because this slope is contiguous with adjacent slopes exhibiting relatively stable and marginally stable conditions, the overall morphological unit is classified as a **high-hazard zone**.

2. Low Hill Morphology Group

Characterized by slope gradients of 11°, 27°, and 46°, located in the central part of the study area. This morphological group consists of **andesitic lava** with an **internal friction angle of 55°**, **crystal tuff** with an **internal friction angle of 42°**, and **pyroclastic breccia** with an **internal friction angle of 38°**. The calculated FS values are **4.02** for an 11° slope, **1.77** for a 27° slope, and **1.37** for a 46° slope. Based on these FS values, this morphological group is classified as **stable**.

3. Hummocky Morphology Group

Characterized by slope gradients of 4°, 8°, 15°, and 17°, distributed across the central, southern, and southeastern parts of the study area. This morphological group is composed of **crystal tuff**, with an **internal friction angle of 42°**, and **pyroclastic breccia**, with an **internal friction angle of 38°**. The calculated FS values are **11.17** for a 4° slope, **5.55** for an 8° slope, **3.36** for a 15° slope, and **2.55** for a 17° slope. Based on these FS values, this morphological group is classified as **stable**.

4. Rolling Plain Morphology Group

Characterized by slope gradients of 12°, 14°, and 12°, occurring in the southern and southeastern parts of the study area. This morphological group is composed of **lithic tuff** with an **internal friction angle of 40°**, **pyroclastic breccia** with an **internal friction angle of 38°**, and **lapilli tuff** with an **internal friction angle of 35°**. The calculated FS values are **3.94** for a 12° slope, **3.13** for a 14° slope, and **3.29** for

the second 12° slope. Based on these FS values, this morphological group is classified as **stable**.

5. Undulating Plain Morphology Group

Characterized by slope gradients of 3°, 5°, and 8°, distributed across the southwestern, southern, and southeastern parts of the study area. This morphological group is composed of **pyroclastic breccia**, which has an **internal friction angle of 38°**. The calculated FS values are **14.90** for a 3° slope, **8.93** for a 5° slope, and **5.55** for an 8° slope. Based on these FS values, this morphological group is classified as **stable**.

6. Plain Morphology Group

Characterized by very gentle slope gradients of 0.2° and 1.5°, occurring in the southwestern, southern, and southeastern parts of the study area. This morphological group is composed of **pyroclastic breccia**, which has an **internal friction angle of 38°**. The calculated FS values are **223.82** for a 0.2° slope and **29.83** for a 1.5° slope. Based on these FS values, this morphological group is classified as **stable**.

The application of the morphological classification proposed by [41] as generally been limited to morphological subdivision alone [54], [55], [56], [57], [58]. In the present study area, the Desautettes approach has not previously been integrated with volcanic hazard zonation through the assessment of rock strength and field-observed geological characteristics. Hummocky morphology associated with volcanic sector collapse is no longer preserved in its original form, as the intervening depressions between hummocks have been infilled by eruptive deposits from the younger Manglayang Volcano. Furthermore, no regional-scale investigation has been conducted in the Mount Manglayang area to delineate the spatial distribution of landslide hazard zones.

The spatial distribution of the morphological classification groups (Figure 5) exhibits a close correspondence with the drainage pattern within the study area. The drainage network is interpreted to be associated with surface water that interacts with the groundwater system. Simultaneously, groundwater content strongly influences the geotechnical properties of both soils and rocks, whereby increasing groundwater saturation reduces both cohesion and the internal friction angle. Consequently, the spatial distribution of safe, susceptible, and hazardous zones is dynamic and may change over time in response to groundwater

infiltration and variations in subsurface water conditions.

Based on the analyses conducted, hazard zonation is controlled by multiple interrelated factors, including slope gradient, lithological distribution and characteristics, rock strength, and groundwater content. The combined influence of these factors determines whether a particular area can be classified as safe, susceptible, or hazardous with respect to landslide occurrence.

V. CONCLUSION

Mount Manglayang experienced a large-scale collapse of a substantial portion of its volcanic edifice, commonly referred to as a *sector collapse*, which produced an amphitheater-shaped (horseshoe-landform) collapse scar opening toward the southeast. In addition, smaller-scale volcanic flank collapses occurred on the southwestern and northeastern flanks of the volcano. The sector collapse of Mount Manglayang generated extensive volcanic debris-avalanche deposits and a characteristic hummocky topography composed of isolated volcanic mounds.

The debris-avalanche deposits identified within the study area are characterized by volcanic breccias containing fragmented lithic clasts exhibiting *jigsaw-crack* and *jigsaw-fit* textures. These deposits are supported by a matrix ranging from very fine-grained volcanic ash to lapilli-sized material. The deposits are poorly sorted, displaying a highly heterogeneous grain-size distribution and a massive, structureless fabric. Numerous volcanic boulders measuring approximately 1–10 m in diameter were observed at several proximal and medial observation sites on Mount Manglayang.

Based on the Desautettes landform classification, hummocky topography is distributed across the medial to distal sectors of Mount Manglayang, with a total of 668 hummocky landform occurrences identified, although most are only partially preserved. Nevertheless, this classification provides an important preliminary framework for delineating the remnant debris-avalanche deposits of Mount Manglayang, which are presently buried beneath younger volcanic deposits. The mapped hummocky landforms are predominantly aligned along valley corridors extending through the medial and distal sectors of the volcano. This spatial distribution suggests that hummocky topography represents a reliable geomorphological indicator of the transport pathway of the sector collapse and its associated debris-avalanche deposits. Consequently, the

distribution of hummocky landforms may serve as a valuable proxy for identifying former debris-avalanche pathways and delineating areas that may be susceptible to future volcanic mass-movement hazards affecting settlements located on the lower slopes and surrounding foothills of the volcano.

ACKNOWLEDGEMENT

The author acknowledge the use of AI technologies (ChatGPT, Copilot, or Gemini) for generating method illustrations. No AI tools were used for data analysis or content writing. the authors take full responsibility for all content and the final version of this work.

REFERENCES

- [1] E. Hidayat, B. Brahmantyo, and E. Yulianto, "Analisis Endapan Sagpond pada Sesar Lembang," *Jurnal Geoaplika*, vol. 3, no. 3, pp. 151–161, 2008.
- [2] Marjiyono, Soehamini, and Kamawan, "Identifikasi Sesar Aktif Daerah Cekungan Bandung dengan Data Citra Landsat dan Kegempaan," *Jurnal Sumber Daya Geologi*, pp. 81–88, 2008.
- [3] B. Brahmantyo, "Benteng Hijau Terakhir Bandung," *Forum Articles Kompas*, 2009.
- [4] P. H. Silitonga, "Peta Geologi Lembar Bandung, Jawa Barat. Skala 1 : 100.000," 1973, *Pusat Penelitian dan Pengembangan Geologi, Badan Geologi, Kementerian Energi & Sumber Daya Mineral Republik Indonesia. , Bandung*.
- [5] PVMBG (Pusat Vulkanologi & Mitigasi Bencana Geologi), *Data Dasar Gunung Api Indonesia*. Badan Geologi, Kementerian Energi & Sumber Daya Mineral Republik Indonesia. , 2011.
- [6] R. A. F. Cas and J. V. Wright, *Volcanic Successions Modern And Ancient*, 2nd ed., vol. 1. London: Chapman & Hall, 1987. doi: 10.1007/978-0-412-44640-5.
- [7] E. Aydar *et al.*, "Morphological analysis of active Mount Nemrut stratovolcano, eastern Turkey: evidences and possible impact areas of future eruption," *Journal of Volcanology and Geothermal Research*, vol. 123, no. 3–4, pp. 301–312, May 2003, doi: 10.1016/S0377-0273(03)00002-7.

- [8] Y. V. Frolova, "Specific Features in The Composition, Structure, and Properties of Volcaniclastic Rocks," *Moscow University Geology Bulletin*, vol. 63, pp. 28–37, Mar. 2008.
- [9] M. J. Heap and M. E. S. Violay, "The Mechanical Behaviour and Failure Modes of Volcanic Rocks: A Review," *Bull. Volcanol.*, vol. 83, no. 5, p. 33, May 2021, doi: 10.1007/s00445-021-01447-2.
- [10] H. S. Husodo, "Cegah Ancaman Gunung Manglayang, Pemkot Bandung Fokus Perbanyak RTH di Cibiru dan Mandalajati," *Pikiran Rakyat*, Bandung, Jan. 29, 2026.
- [11] A. Patonah, "Investigasi Serta Edukasi Potensi Kerentanan Longsor Kecamatan Jatinangor dan Sekitarnya," *Indonesian Journal of Community Engagement*, Jun. 2017.
- [12] I. Herdiana, "Menyesalkan Kerusakan Ekologis Gunung Manglayang, Padahal Kearifan Lokal Mengingatkan Kita Agar Hidup Harmonis Dengan Alam," <https://bandungbergerak.id/>.
- [13] D. Sinaga, "Jatinangor (Bukan) Kota Pendidikan," <https://www.cnnindonesia.com/>.
- [14] BisnisBandung.com, "Gunung Manglayang, Sisa Letusan Gunung Sunda Purba Menyimpan Misteri Jatuhnya Kuda Semprani," [BisnisBandung.com](https://bisnisbandung.com).
- [15] S. Fatimah, "Situs Batu Kuda di Bandung yang Penuh Misteri," *Detik Travel*, Bandung, Dec. 10, 2020.
- [16] A. P. Agung, "Hubungan Evolusi Dapur Magma Kompleks Gunung Api Sunda Terhadap Gunung Manglayang, Jawa Barat," Skripsi, Institut Teknologi Bandung, Bandung, 2019.
- [17] R. V. Fisher and H.-U. Schmincke, *Pyroclastic Rocks*. 1984.
- [18] S. Bronto, *Publikasi Khusus: Geologi Gunung Api Purba.*, 1st ed., vol. 1. Bandung : Badan Geologi, Kementerian Energi & Sumber Daya Mineral Republik Indonesia, 2010.
- [19] B. V. W. D. Vries, N. Kerle, and D. Petley, "Sector Collapse Forming at Casita Volcano, Nicaragua," *Geology*, vol. 28, no. 2, pp. 167–170, 2000.
- [20] L. Siebert, H. Glicken, and T. Ui, "Volcanic Hazards From Bezymianny- and Bandai-Type Eruptions," *Bull. Volcanol.*, vol. 49, no. 1, pp. 435–459, Feb. 1987, doi: 10.1007/BF01046635.
- [21] K. Nakamura, "Volcanoes as Possible Indicators of Tectonic Stress Orientation — Principle and Proposal," *Journal of Volcanology and Geothermal Research*, vol. 2, no. 1, pp. 1–16, Apr. 1977, doi: 10.1016/0377-0273(77)90012-9.
- [22] W. J. McGuire, A. D. Pullen, and S. J. Saunders, "Recent Dyke-Induced Large-Scale Block Movement at Mount Etna and Potential Slope Failure," *Nature*, vol. 343, no. 6256, pp. 357–359, Jan. 1990, doi: 10.1038/343357a0.
- [23] N. Vidal, "Les Avalanches de Débris Volcaniques: Etude des Dépôts et Nouveau Schéma de Déstabilisation de Flanc à Partir de l'Exemple du Stratovolcan du Cantal (Massif Central, France) (Modélisation Analogue et Numérique)," Ph.D. Thesis, Université Blaise Pascal, Clermont-Ferrand, 1998.
- [24] F. Donnadieu and O. Merle, "Experiments on The Indentation Process During Cryptodome Intrusions: New Insights Into Mount St. Helens Deformation," *Geology*, vol. 26, no. 1, p. 79, 1998, doi: 10.1130/0091-7613(1998)026<0079:EOTIPD>2.3.CO;2.
- [25] L. Siebert and M. E. Reid, "Lateral Edifice Collapse and Volcanic Debris Avalanches: a Post-1980 Mount St. Helens Perspective," *Bull. Volcanol.*, vol. 85, no. 11, p. 61, Oct. 2023, doi: 10.1007/s00445-023-01662-z.
- [26] B. V. W. D. Vries and P. W. Francis, "Catastrophic Collapse at Stratovolcanoes Induced by Gradual Volcano Spreading," *Nature*, vol. 387, no. 6631, pp. 387–390, May 1997, doi: 10.1038/387387a0.
- [27] B. Voight and D. Elsworth, "Failure of Volcano Slopes," *Géotechnique*, vol. 47, no. 1, pp. 1–31, Feb. 1997, doi: 10.1680/geot.1997.47.1.1.
- [28] A. Tibaldi and L. Vezzoli, "A New Type of Volcano Flank Failure: The Resurgent Caldera Sector Collapse, Ischia, Italy," *Geophys. Res. Lett.*, vol. 31, no. 14, Jul. 2004, doi: 10.1029/2004GL020419.

- [29] A. V. Zernack, J. N. Procter, and S. J. Cronin, "Sedimentary Signatures of Cyclic Growth and Destruction of Stratovolcanoes: A Case Study From Mt. Taranaki, New Zealand," *Sediment. Geol.*, vol. 220, no. 3–4, pp. 288–305, Oct. 2009, doi: 10.1016/j.sedgeo.2009.04.024.
- [30] A. M. F. Lagmay, B. V. W. D. Vries, N. Kerle, and D. M. Pyle, "Volcano Instability Induced by Strike-Slip Faulting," *Bull. Volcanol.*, vol. 62, no. 4–5, pp. 331–346, Nov. 2000, doi: 10.1007/s004450000103.
- [31] H. Yoshida and T. Sugai, "Magnitude of The Sediment Transport Event Due To The Late Pleistocene Sector Collapse of Asama Volcano, Central Japan," *Geomorphology*, vol. 86, no. 1–2, pp. 61–72, Apr. 2007, doi: 10.1016/j.geomorph.2006.08.006.
- [32] E. M. R. Paguican, B. V. W. D. Vries, and A. M. F. Lagmay, "Volcano-Tectonic Controls and Emplacement Kinematics of The Iriga Debris Avalanches (Philippines)," *Bull. Volcanol.*, vol. 74, no. 9, pp. 2067–2081, Nov. 2012, doi: 10.1007/s00445-012-0652-7.
- [33] E. M. R. Paguican, B. V. W. D. Vries, and A. M. F. Lagmay, "Hummocks: How They Form and How They Evolve in Rockslide-Debris Avalanches," *Landslides*, vol. 11, no. 1, pp. 67–80, Feb. 2014, doi: 10.1007/s10346-012-0368-y.
- [34] L. Siebert, "Large volcanic Debris Avalanches: Characteristics of Source Areas, Deposits, and Associated Eruptions," *Journal of Volcanology and Geothermal Research*, vol. 22, no. 3–4, pp. 163–197, Oct. 1984, doi: 10.1016/0377-0273(84)90002-7.
- [35] T. Ui and H. Glicken, "Internal Structural Variations in a Debris-Avalanche Deposit From Ancestral Mount Shasta, California, USA," *Bull. Volcanol.*, vol. 48, no. 4, pp. 189–194, Aug. 1986, doi: 10.1007/BF01087673.
- [36] T. Ui and H. Glicken, "Debris Avalanches," in *Encyclopedia of Volcanoes*, H. Sigurdsson, B. Houghton, H. Rymer, J. Stix, and S. , Eds. , McNutt, Eds., Academic Press , 2000, pp. 617–626.
- [37] G. J. Orton, "Volcanic Environments," in *Sedimentary Environments—Processes, Facies and Stratigraphy*, H. G. Reading, Ed., Blackwell Science Ltd., 1996, pp. 485–567.
- [38] S. G. Evans and J. V DeGraff, *Catastrophic Landslides: Effects, Occurrence, and Mechanisms*. Boulder: Geological Society of America, 2002.
- [39] T. Ui, "Volcanic Dry Avalanche Deposits — Identification and Comparison With Nonvolcanic Debris Stream Deposits," *Journal of Volcanology and Geothermal Research*, vol. 18, no. 1–4, pp. 135–150, Oct. 1983, doi: 10.1016/0377-0273(83)90006-9.
- [40] A. Nursalim, N. Sulaksana, and E. Sukiyah, "Peran Aspek Geomorfologi Dalam Menentukan Karakteristik Endapan Debris Avalanche Gunung Papandayan, Garut, Jawa Barat ," *Bulletin of Scientific Contribution: GEOLOGY*, vol. 14, pp. 33–44, 2016.
- [41] J. R. Desaunettes, "Catalogue of Landforms for Indonesia: Examples of a Physiographic Approach to Land Evaluation for Agricultural Development," *Soil Research Institute*, 1977.
- [42] H. Glicken, "Rockslide-Debris Avalanche of May 18, 1980, Mount St. Helens Volcano, Washington," 1996.
- [43] J. G. Speight, "Landform Pattern Description From Aerial Photographs," *Photogrammetria*, vol. 32, no. 5, pp. 161–182, Jan. 1977, doi: 10.1016/0031-8663(77)90012-6.
- [44] O. Hungr, S. Leroueil, and L. Picarelli, "The Varnes Classification of Landslide Types, An Update," *Landslides* , vol. 11, pp. 167–194, 2014.
- [45] J. M. Duncan, S. G. Wright, and T. L. Brandon, *Soil Strength and Slope Stability*. John Wiley & Sons, 2014.
- [46] B. M. Das, *Principles of Geotechnical Engineering*, 7th ed. Stamford: Cengage Learning, 2010.
- [47] F. Maritimo, W. Budianta, and A. Setianto, "Detail Morphological Analysis to Mapping Surface Litological Characteristic Unit," *KURVATEK*, vol. 10, no. 1, pp. 99–110, Apr. 2025, doi: 10.33579/krvtk.v10i1.5740.
- [48] Y. K. Yeon, "Kmapper: A Field Geological Survey System," *ISPRS International Journal of Geo-information*, vol. 10, pp. 405–415, 2021.
- [49] E. Hoek and E. T. Brown, "Practical Estimates of Rock Mass Strength," *International Journal*

- of Rock Mechanics and Mining Sciences*, vol. 34, no. 8, pp. 1165–1186, Dec. 1997, doi: 10.1016/S1365-1609(97)80069-X.
- [50] G. Shi and R. E. Goodman, “Generalization of Two-Dimensional Discontinuous Deformation Analysis For Forward Modelling,” *Int. J. Numer. Anal. Methods Geomech.*, vol. 13, no. 4, pp. 359–380, Jul. 1989, doi: 10.1002/nag.1610130403.
- [51] D. C. Wyllie and C. Mah, *Rock Slope Engineering*, Fourth. CRC Press, 2004.
- [52] J. E. Bowles, *Sifat - Sifat Fisik Dan Geoteknis Tanah: Mekanika Tanah*. Erlangga, 1986.
- [53] R. B. Hermawan, N. S. Surjandari, and R. H. Dananjaya, “Analisis Stabilitas Lereng Dengan Perkuatan Soil Nailing Menggunakan Program Komputer (Studi Kasus: Desa Tambakmerang, Kecamatan Girimarto, Kabupaten Wonogiri),” *e-JurnalMatriks Teknik Sipil*, Jun. 2017.
- [54] R. Abdissalam, S. Bronto, A. Harijoko, and A. Hendratno, “Identifikasi Gunung Api Purba Karangtengah di Pegunungan Selatan, Wonogiri, Jawa Tengah,” *Jurnal Geologi Indonesia*, vol. 4, Dec. 2009.
- [55] S. Bachri, O. Murao, M. N. Fathoni, and R. R. Hakiki, “The Role of Geospatial Technology and Landform Mapping for Volcanic Secondary Hazard Anticipation in Semeru Volcano, Indonesia,” *Forum Geografi*, pp. 163–187, Jul. 2025.
- [56] S. Bachri *et al.*, “Geomorphological Mapping and Landform Characterization of Semeru Volcano After The Eruption in 2021,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1180, no. 1, p. 012004, May 2023, doi: 10.1088/1755-1315/1180/1/012004.
- [57] F. Maritimo, W. Budianta, and A. Setianto, “Analisis Morfologi Detil Untuk Memetakan Karakteristik Satuan Batuan Permukaan,” *KURVATEK*, vol. 10, no. 1, pp. 99–110, Apr. 2025, doi: 10.33579/krvtk.v10i1.5740.
- [58] M. Jalaludin, H. Giovano, and M. Baihaqy, “Analisis Bentuklahan Di Sepanjang Bukit Barisan, Kabupaten Pesisir Barat, Provinsi Lampung,” *Jurnal Kajian Ilmu dan Pendidikan Geografi*, vol. 4, no. 1, pp. 10–15, Jan. 2021.