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SPATIAL DISTRIBUTION OF GEOMORPHOLOGICAL UNITS IN THE GUNUNGSUNGGING AREA, SUKABUMI REGENCY, WEST JAVA

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ABSTRACT

The geomorphological landscape of southern Java has developed through long-term interactions between tectonic activity, lithological diversity, and surface processes related to the convergence of the Eurasian and Indo-Australian plates. One of the regions that records this complex evolution is the Ciletuh–Jampang area, which displays a variety of landforms associated with uplifted terrains and differential erosion. This study focuses on the Gunungsungging area, Sukabumi Regency, West Java, with the objective of identifying geomorphological characteristics and defining geomorphological units based on landform attributes and lithological control. Geomorphological analysis was conducted using an integrated approach combining morphographic, morphometric, and morphogenetic methods. Digital elevation data derived from SRTM were processed using ArcGIS and Global Mapper, and the results were validated through systematic field observations. Morphographic analysis indicates that the study area is dominated by low hill landforms with elevations generally ranging between 50 and 175 m above sea level. The drainage system exhibits two primary patterns: parallel drainage, developed on moderate slopes and elongated ridges, and dendritic drainage, commonly associated with more homogeneous lithology and gentler slopes. Morphometric analysis reveals that flat to gently sloping terrain (0°–4°) predominates across the study area, with steeper slopes occurring locally. Morphogenetic interpretation suggests that exogenous processes, particularly weathering and dissolution, play a dominant role in shaping the landscape, while the influence of tectonic activity is relatively limited, as evidenced by minimal structural deformation. Karstification features, including caves and dissolution forms, are well developed within limestone unit. Based on the integration of geomorphological parameters, the study area is divided into three geomorphological units: gently sloping structural low hills, gently sloping denudational low hills, and gently sloping karst low hills. These results contribute to a better understanding of landscape development in the Ciletuh region and provide a geomorphological framework for further geological and environmental studies.

Keywords: DEM, Geomorphology, Gunungsungging, Spatial, West Java

INTRODUCTION

Indonesia is an extensive archipelagic nation located at the convergence of major lithospheric plates, with its physiography fundamentally controlled by the Sunda and Sahul continental shelves. This tectonic configuration has generated a highly diverse landscape shaped by the combined effects of tectonism, volcanism, sedimentation, and prolonged surface processes (Darman, 2000).

The geological evolution of the archipelago involved the accretion of Gondwana-derived crustal fragments along the Eurasian margin, followed by intense Cenozoic subduction and collision that reshaped the surface morphology (Hall, 2009). These processes are clearly expressed in the geomorphological landscape, where variations in relief, slope, and drainage patterns reflect differences in lithology, structural framework, and dominant surface processes. Continuous interaction between endogenous forces, such as uplift and faulting, and exogenous processes, including weathering, erosion, and fluvial reworking, has produced spatially diverse geomorphological units across the Indonesian region. Consequently, the study of geomorphological units and their spatial distribution provides critical insight into the evolution of Indonesia's dynamic landscapes, particularly in tectonically active regions such as southern West Java.

A prominent example of this complex evolution is the Ciletuh–Jampang area in Southern Java, which features a distinctive horseshoe-shaped amphitheater morphology and the Jampang Plateau, the latter formed by Pliocene tectonic uplift reaching 700 meters above sea level (Hardiyono et al., 2015; Haryanto et al., 2018). Analyzing this region through a geomorphological lens—which focuses on the physical and chemical processes that modify Earth's surface—reveals that its rugged topography is a product of both historical tectonic activity and varying rock resistance (Thornbury, 1970; Verstappen, 1985; Firmansyah et al., 2023).

Physiographically, the study area is part of the Southern Mountains physiographic zone (van Bemmelen, 1949). This zone represents an anticlinorium formed as a result of subduction between the Eurasian Plate and the Indo-Australian Plate south of Java Island during the Late Oligocene (Katili, 1975). Regionally, the tectonic position of the Ciletuh-Jampang area lies on the southern flank of this E-W anticlinorium (Haryanto et al., 2018).

Based on the regional geological map of the Jampang and Balekambang sheets (Sukamto, 1973), the research area is composed, from oldest to youngest, of the Cikarang Formation (Tmjc), Cibodas Formation (Tmci), Bentang Formation (Tmbu), and the Citanglar Coastal Deposits (Qpcb) (Figure 2). The geological structures that developed in the Southern Mountains Zone have undergone three tectonic phases (Baumann, 1973) starting from the Oligocene epoch up to the Quaternary period; these tectonic phases were frequently accompanied by volcanism. Integrated petrographic, petrological, and biostratigraphic studies have enhanced the understanding of carbonate sedimentation, volcanic influence, and stratigraphic evolution in southern West Java, particularly within the Cibodas Formation and the Jampang Formation (Prinaldi et al., 2023; Pratiwi et al., 2023; Maulana & Pratiwi, 2024; Pratiwi et al., 2024; Ramdhani et al., 2024). Recent geomorphological research highlights that the spatial distribution of landform units is governed by the combined effects of lithology, tectonic framework, and surface processes. In tectonically active regions, such as southern Java, geomorphological patterns commonly reflect denudational and structural controls acting upon heterogeneous rock units (Sulaksana et al., 2015; Haryanto et al., 2018). Advances in geomorphological mapping techniques, particularly the use of digital elevation models and integrated morphometric analysis, have enhanced the interpretation of landform variability and landscape evolution at local to regional scales (Goudie, 2018; Bishop et al., 2019). This study is conducted in the Gunungsungging area, Sukabumi Regency, West Java, which is geographically situated between 106°32′32.11″–106°35′17.74″ E and 7°21′56.04″–7°19′11.76″ S (Figure 1.). The research applies an integrated geomorphological approach, incorporating morphographic, morphometric, and morphogenetic analyses, to investigate the spatial distribution of geomorphological units. By examining landform characteristics, geomorphological processes, and lithological controls, this study seeks to identify and classify geomorphological units and to generate a detailed geomorphological map illustrating their spatial relationships. The final objective is to produce a geomorphological map that integrates landform characteristics with the distribution of their constituent lithology. The findings provide insight into landscape evolution in southern West Java and offer a scientific basis for further geological, environmental, and land-use studies.

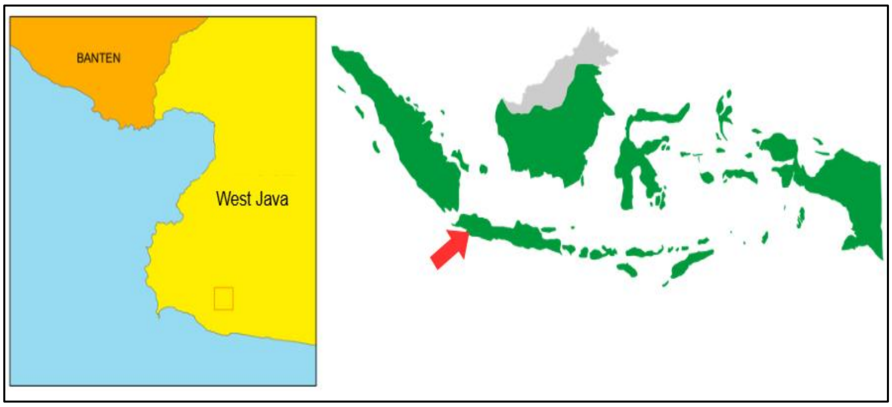


Figure 1. Study area located in Surade Subdistrict

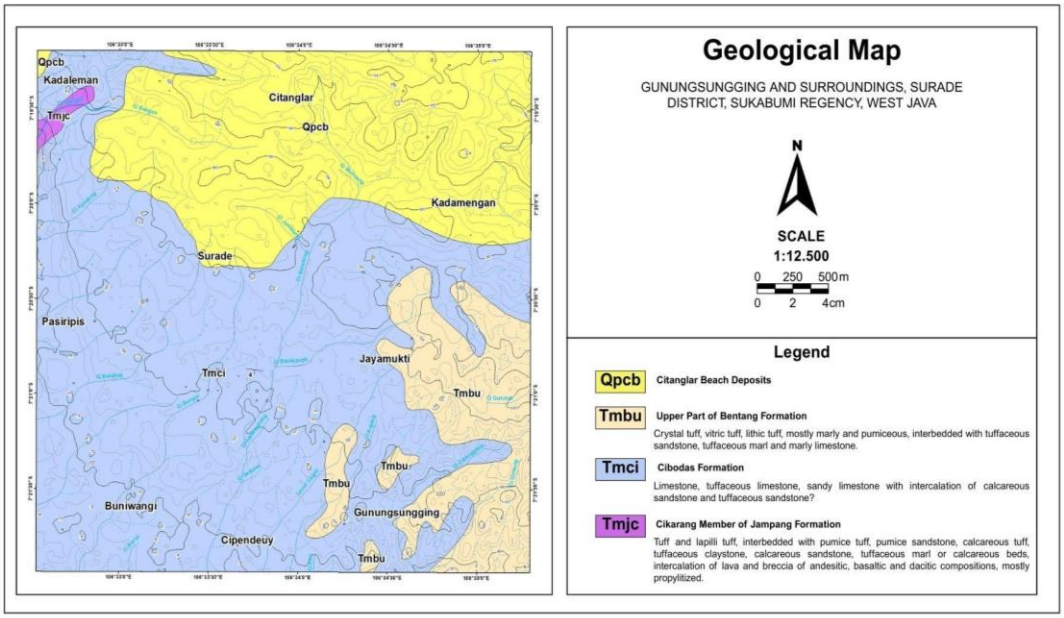


Figure 2. Geological map of the study area. Modified from the Regional Geological Map of the Jampang and Balekembang Sheets (Sukamto, 1975)

RESEARCH METHOD

The identification of the research area's geomorphological characteristics was based on remote sensing analysis of SRTM DEM data, which was processed using ArcGIS and Global Mapper software. Subsequently, this was based on field observations to correlate or validate the results of the remote sensing analysis. The research stages conducted can be observed in the following research flowchart (Figure 3).

The determination of geomorphological units is based on the following geomorphological aspects:

Morphography

Morphographic analysis includes landforms, valley shapes, and drainage patterns. The analysis of drainage patterns is conducted based on topographic maps, examining the incisions of intermittent and main river channels within the research area. These are then compared with the modified drainage patterns (Howard, 1967) as cited in Van Zuidam (1985). After this analysis is completed, a morphographic map is produced that interprets the elevation intervals in the research area.

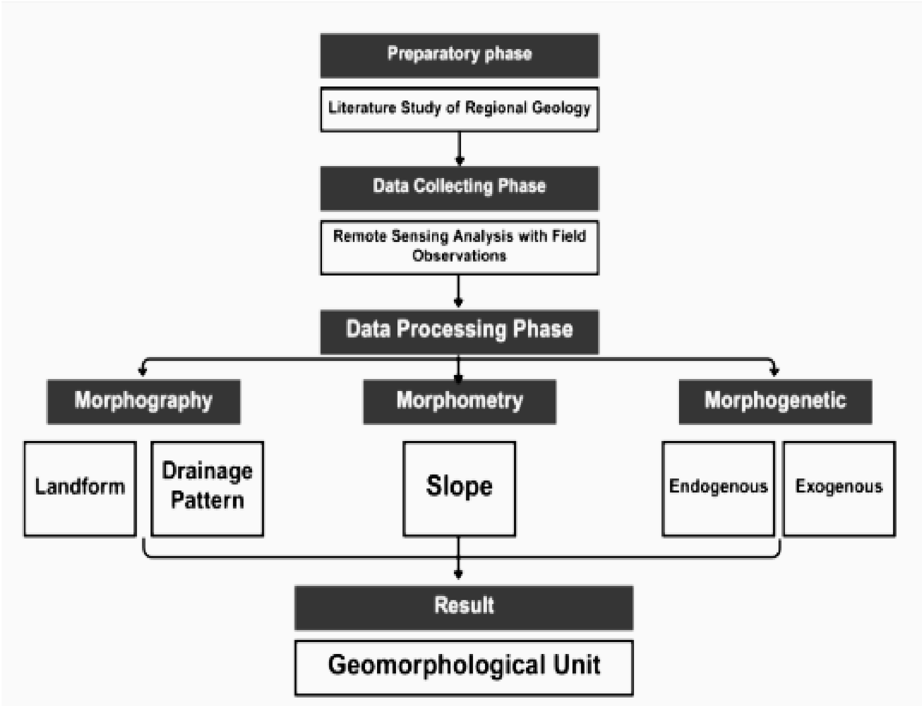


Figure 3. Research Flowchart

Morphometry

Morphometric analysis is conducted by calculating the slope gradient, which is then classified based on the percentage and angle of the slope. To determine these values, calculations are made based on the difference in elevation versus the horizontal distance. Once the slope gradient is determined using the established methods, the calculation results are obtained and subsequently displayed as a morphometric map.

Morphogenetics

Morphogenetics refers to the influential factors in the formation of a landform or morphology. The morphogenetic analysis in the research area involves a comparison between the data on the developing drainage patterns and the constituent lithology data of the area.

RESULT AND DISCUSSION

Based on integrated morphographic, morphometric, and morphogenetic analyses, the research area is subdivided into several geomorphological zones. According to the landform classification of Van Zuidam (1985), as modified by Bermana (2002), the study area is characterized by a single dominant morphographic unit, namely low hills with elevations ranging from 50 to 100 m above sea leve (Figure 4).

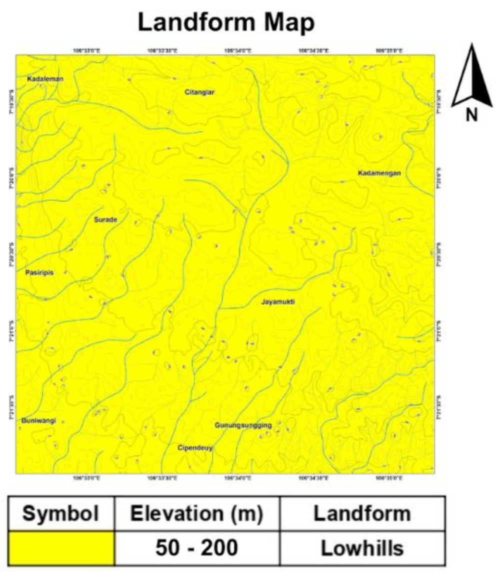
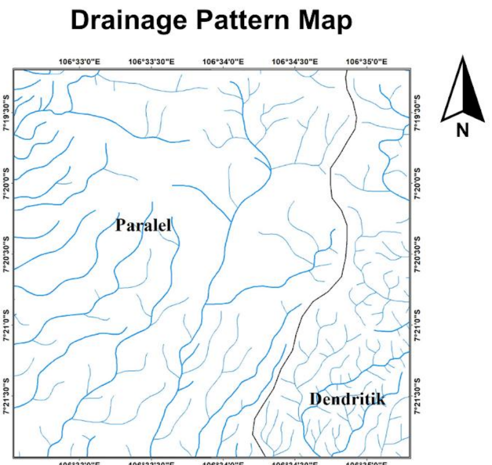


Figure 4. Landform map of study area

Two main drainage patterns are identified, consisting of parallel and dendritic patterns (Figure 5). The parallel drainage pattern occupies approximately 65% of the total study area and is predominantly developed in the western part of the area, including the Ci Pari, Ci Kujang, Leuwicagak, Ci Jambegirang, Ci Selaawi, Ci Badakputih, Ci Barehong, Ci

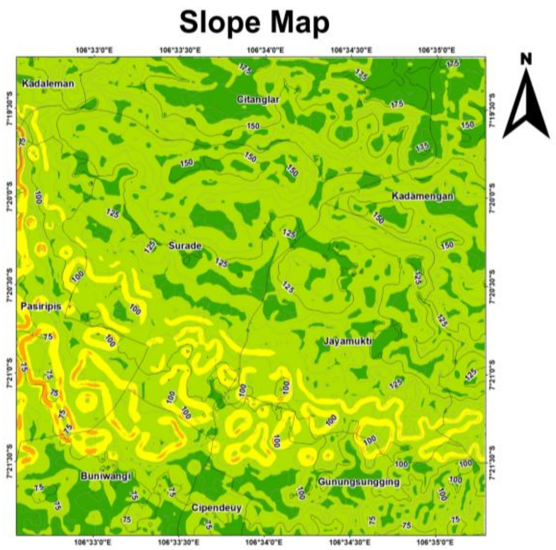
Muncang, Ci Jamblang, Ci Burial, Ci Bungur, Ci Beledug, Ci Kondang, and Ci Gangsa rivers. This pattern reflects moderate to steep regional slopes and is typically associated with elongated, parallel ridge-and-valley landforms. In contrast, the dendritic drainage pattern covers about 35% of the study area and is mainly observed in the eastern sector, including the Ci Gintung, Ci Calenggang, and Ci Gurutuk rivers (Figure 5).



Drainage Pattern (Howard, 1967)	Streamflow Direction
Paralel	NE - SW
Dendritic	N - S - SW

Figure 5. Drainage pattern map of study area

This pattern, characterized by a branching network resembling of tree limbs, commonly develops on limestone lithology and fluvial deposits, where relatively homogeneous and less resistant rocks promote drainage dispersion. Morphometrically, dendritic drainage occurs on flat to gently sloping terrain, indicating a strong lithological control on valley development. Morphometric analysis reveals that the study area is characterized by relatively gentle topography, as illustrated by the distribution of slope gradients shown in Figure 6. Flat areas with slope angles ranging from 0° to 2° constitute approximately 20% of the research area and are commonly developed on valley floors and low-relief surfaces. Gently sloping terrain, with gradients of 2°–4°, represents the dominant morphological condition and is widely distributed throughout the study area. Areas with moderate slopes, ranging from 4° to 8°, account for about 20% of the total area and are generally confined to hill flanks and transitional geomorphic zones. The overall geomorphological character of the area is influenced by the interaction of endogenous and exogenous morphogenetic processes. Endogenous processes, mainly tectonic activity, have contributed to the regional geological framework; however, their geomorphic expression within the study area is relatively weak. This is evidenced by the limited structural deformation, the presence of nearly horizontal stratification, and the scarcity of major fractures. Exogenous processes, on the other hand, exert a stronger control on landscape evolution. Physical and chemical weathering are widely developed, as indicated by changes in rock colour and mechanical strength in both limestone and sandstone, particularly in the southern sector of the study area. Furthermore, dissolution processes play a significant role in carbonate terrains, as demonstrated by the development of karst features such as stalactites and stalagmites, which reflect active karstification within the Gunungsungging karst cave.



Symbol	Slope	Slope Class
	0° - 2°	Flat
	2° - 4°	Gently Sloping
	4° - 8°	Sloping
	8° - 16°	Slightly Steep

Figure 6. Slope map of study area

GEOMORPHOLOGY

Based on the analysis conducted on topographic maps, supported by morphographic, morphometric, and morphogenetic aspects, the geomorphology of the research area is divided into 3

Geomorphological units (Figure 7 and Table 1), as follows

Gently Sloping Structural Low Hills

This unit occupies approximately 25% of the total research area, distributed in the western to northwestern parts of the research area (Cigangsa river, Kadaleman).

Morphographically, this area has a low hill landform with elevations ranging from 50-100 masl. Based on morphometric analysis, this area has a slope gradient ranging from 2-4%, which indicates a gently sloping slope (Van Zuidam, 1985). This unit has blunt U-shaped to V-shaped valleys. The drainage pattern developing in this unit is parallel. In this unit, the exogenous process contributing to the landform's formation is weathering. The lithology composing this unit is carbonate sandstone and limestone.

Gently Sloping Denudational Low Hills

This geomorphological unit occupies approximately 40% of the total research area and is dominantly distributed in the research area (Pasiripis, Kademangan, Citanglar, Surade, Kadaleman, Jagamukti, and Pasiripis). Morphographically, this unit has a low hill landform with elevations ranging from 75-175 masl (meters above sea level). Based on morphometric analysis, this area has a slope gradient ranging from 2-4%, which indicates a flat slope (Van Zuidam, 1985). The drainage patterns developing in this unit are dendritic and parallel. In this unit, the exogenous process contributing to the landform's formation is weathering. The lithology composing this unit is limestone and carbonate sandstone.

Gently Sloping Karst Low Hills

This unit occupies approximately 35% of the total research area, distributed from the southeast to the southwest of the research area (Gunungsungging, Cipeundeuy, and Buniwangi). Morphographically, this area has a lowland landform with elevations ranging from 50-125 masl. Based on morphometric analysis, this area has a slope gradient ranging from 2-4%, which indicates a gentle slope (Van Zuidam, 1985). This unit has blunt U-shaped to blunt V-shaped valleys. The drainage patterns developing in this unit are dendritic and parallel. In this unit, the exogenous processes contributing to the landform's formation are weathering and dissolution. The lithology composing this unit is dominated by limestone and some carbonate sandstone.

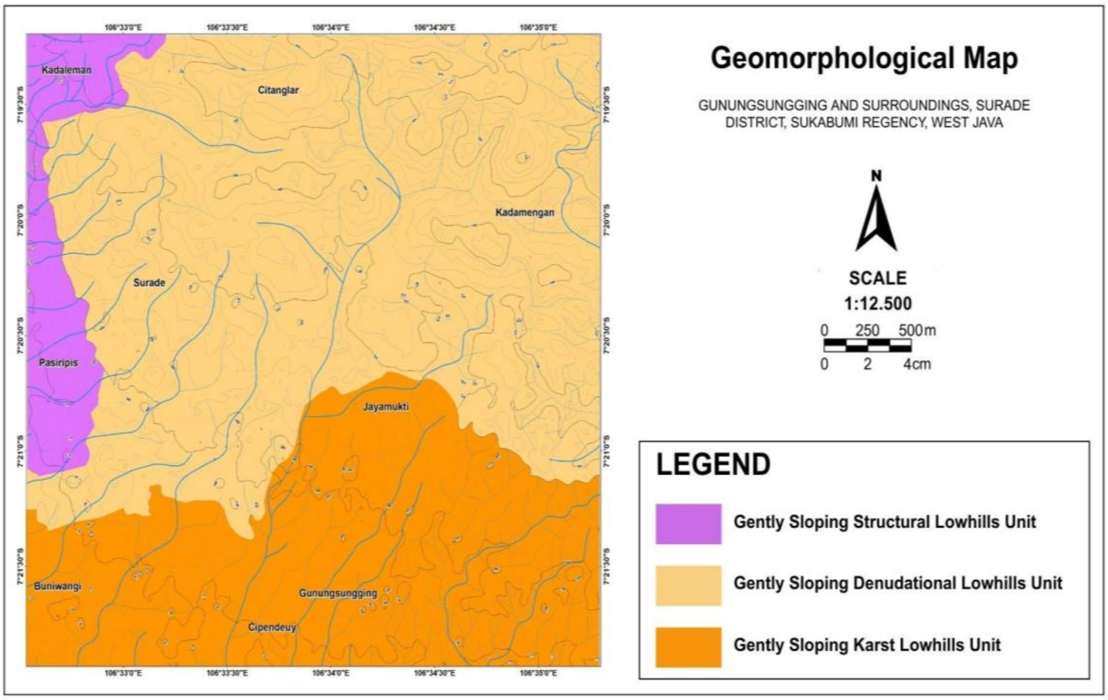


Figure 7. Geomorphological map of the study area

No	Geomorphological Unit	Symbols	Geomorphological Aspect						Lithology
			Morphography			Morphometry	Morphogenetic		
			Drainage Pattern	Landform	Valley	Slope	Endogenous	Exogenous	
1	Gently Sloping Structural Lowhills		Paralel	Lowhills (50 - 100 m)	U-V	Gently Sloping (2 - 4°)	Tectonism	Weathering & Erosion	Limestone, Fine Sandstone, Medium Sandstone, Coarse Sandstone
2	Gently Sloping Denudasional Lowhills		Paralel - Dendritic	Lowhills (75 - 175 m)	U	Gently Sloping (2 - 4°)			Limestone, Fine Sandstone, Coarse Sandstone, Alluvium
3	Gently Sloping Karst Lowhills		Paralel - Dendritic	Lowhills (50 - 125 m)	U	Gently Sloping (2 - 4°)		Karst Dissolution	Limestone, Fine Sandstone

Table 1. Geomorphological units of the study area and the explanations

CONCLUSION

The geomorphological configuration of the Gunungsungging area reflects a spatially variable landscape shaped by lithological diversity and surface processes operating within the Southern Mountains of West Java. The area is dominated by low hill morphology, with drainage systems exhibiting parallel and dendritic patterns that vary spatially in response to slope gradients and rock characteristics. Slope analysis indicates that flat to gently sloping terrains are widespread and form the principal geomorphic setting of the area. These conditions strongly influence drainage development and landform expression.

In terms of morphogenesis, surface processes such as weathering and dissolution play a major role in controlling present-day morphology, particularly in areas underlain by limestone. Tectonic activity, while significant in establishing the regional structural framework, shows limited direct expression in surface landforms within the study area. By integrating morphographic, morphometric, and morphogenetic data, three geomorphological units were identified and mapped: gently sloping structural low hills, gently sloping denudational low hills, and gently sloping karst low hills. The spatial distribution of these units corresponds closely with lithological variations and dominant geomorphic processes. This research funding contributes to a better understanding of landscape development in the Gunungsungging area and may serve as a reference for future geological, environmental, and land-use studies in southern West Java.

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MIDDLE MIOCENE TO HOLOCENE GEOLOGICAL HISTORY AND POTENTIAL OF BABAKAN JAWA AREAS, MAJALENGKA DISTRICT OF WEST JAVA-INDONESIA

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ABSTRACT

This research activities were conducted in the Sidamukti, Babakan Jawa, Cibodas areas and surroundings, Majalengka District, West Java Province. The main objective of this research is to determine the geomorphological characteristics, lithology, geological structures, and geological potential in the research area. The methods used include field observations, laboratory analysis, interpretation of topographic maps and satellite imagery, as well as structural analysis using stereonet. The research results show that the geomorphology of the study area was formed by the interaction of endogenic forces (tectonic and volcanic) and exogenic forces (weathering and erosion), resulting in five main geomorphological units, namely Very Gentle Denudational Hills Unit, Steep Intrusive Hills Unit, Volcanic-Structural Steep Longitudinal Hills Unit, Structural-Denudational Volcanic Steep Hills Unit, and Structural Sedimentary Hills Unit. The stratigraphy of the area consists of four rock units composed of claystone units, sandstone units, tufan sandstone units, and andesite units ; and alluvium deposit. The developed geological structures indicate the influence of extensional stress with a strike-slip component that forms normal faults and reverse faults trending northwest–southeast. The geological potential of the area includes geological resources such as andesite, sand, and gravel, as well as the geotourism potential of Taman Gunung Batu Karang. On the other hand, steep hilly areas with weathered lithology show vulnerability to mass movements, making them landslide-prone areas. The results of this research are expected to serve as a basis for sustainable natural resource management and geological disaster mitigation.

Keywords: Geomorphology, Rock Units, Stratigraphy, Geological Structure.

INTRODUCTION

The Sidamukti, Babakan Jawa, Cibodas, and surrounding areas in Majalengka District, Majalengka Regency, West Java are located at coordinates 108°11'54.2112‟ E – 108°14'39.21” E and 6°52'54.8652" S – 6°50'9.8664" S. This area is located in a transition zone between volcanic hills and alluvial plains, resulting in diverse morphology and lithology. This area also exhibits complex structures such as folds and faults. This complexity makes the region significant for research in order to understand the distribution of lithology, geological structure characteristics, and geological history that influence the formation and changes of rocks in the area.

This study aims to identify geomorphology, map lithological distribution and stratigraphic relationships, determine the orientation and type of geological structures, compile interpretations of geological history, and evaluate the geological and disaster potential of the study area.

REGIONAL GEOLOGY

Regional Physiography

Van Bemmelen (1949) divided West Java into five main physiographic zones, namely the Jakarta Coastal Plain Zone, the Bogor Zone, the Bandung Zone, the Bayah Mountain Zone, and the Southern Mountain Zone (Figure 1).

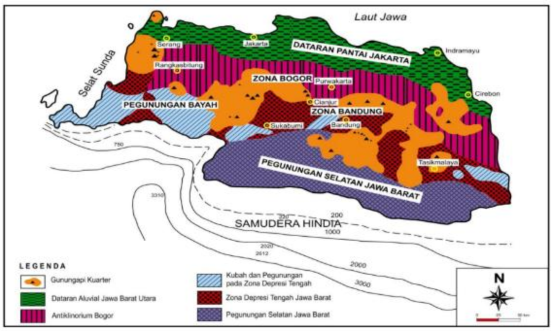


Figure 1. Physiographic map of West Java (modified from Van Bemmelen, 1949)

The study area is located in the eastern part of the Bogor Zone, which is known for its folded hills composed of deep marine sedimentary rocks from the Tertiary period. The anticlinorium structure that dominates this area has undergone additional deformation in several places in the form of faults that are thought to have formed during the Pliocene to Pleistocene periods, in line with regional tectonic activity such as the Lembang Fault and the uplift of the Southern Mountains (Wardhana et al. 2016). The research area also included in the Majalengka Sub-Basin, which is part of the Bogor Basin.

Regional Stratigraphy

The area studied is included in the Majalengka Geological Map Sheet (Isnaniawardhani et al., 2020), which depicts the composition of rock types from the youngest to the oldest:

1) Alluvium (Qa) consists of various materials such as clay, silt, sand, and gravel formed as Holocene river deposits.
2) Horenblenda Andesite (ha) is an intrusive rock type that appears as a dike with a width of between 20 and 30 meters.
3) The Citalang Formation (Tpc) is dominated by tuffaceous sandstone, tuffaceous clay, and conglomerate originating from the Pleistocene period.
4) The Kaliwangu Formation (Tpk) includes claystone components and intercalations of tuffaceous sandstone, conglomerate, and limestone, which were formed in a transitional environment during the Pliocene period (Rachman & Winantris, 2023)
5) The Lower Member of the Halang Formation (Tmhl) dominated by breccia with andesite fragments, several tuff, clay, and conglomerate intercalations originating from the Middle to Upper Miocene.
6) The Cinambo Formation Shale Member (Tomcu) consists of shale interspersed with sandstone and limestone that appeared in the Lower Miocene.
7) The sandstone member of the Cinambo Formation (Tomcl) consists of thick greywacke with intercalations of shale and clay, showing a regular layering pattern and turbidite traces that describe deposits from a deep marine environment in the Lower Miocene.

RESEARCH METHOD

This research was conducted in four stages, namely preliminary study, field activity, data processing, and data integration and interpretation. The preliminary study included a literature review, analysis of the Arjawinangun Sheet geological map, and interpretation of satellite imagery to identify alignment patterns, landforms, and flow patterns, which would later be used to plan the activity route.

The field activity process produced primary data that included lithology identification, structural orientation measurements, sediment structure observations, outcrop documentation, and sample collection from a total of 58 observation stations.

Geomorphological observations were conducted to verify the image interpretation results and confirm the relationship between lithology, structure, and topography.

The collected data were processed using microscopy and laboratory analytical parameters, with petrographic analysis applied to determine mineralogy and texture, and micropaleontological analysis performed when fossils were present in the samples. A total of 13 samples were used in this study, consisting of 6 samples formicropaleontological analysis and 7 samples for petrographic investigation. All collected from various locations in the study area to ensure comprehensive spatial representation (Figure 2).

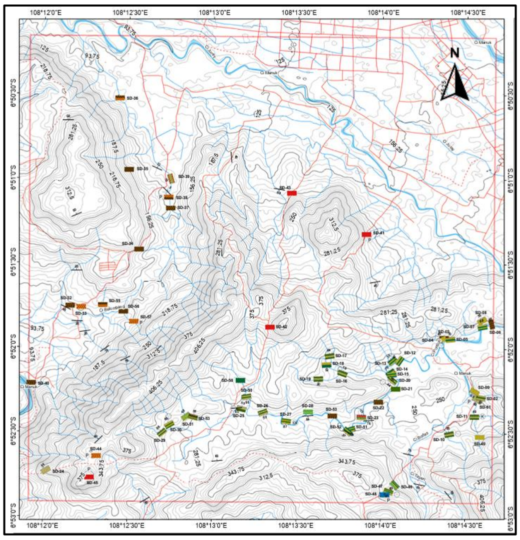


Figure 2. Map of sample analysis collection locations (Scale 1 : 12.500)

Micropaleontological analysis was conducted at the Micropaleontology Laboratory, using a binocular stereo microscope for microfossil picking and a biological microscope + camera for microfossil documentation. Thin section preparation and petrographic examination were carried out at the Petrographic Laboratory, using polarizing microscope . Both laboratories are located at the Faculty of Geological Engineering, Padjadjaran University. All information generated was integrated to create geological maps, correlate rock formations, interpret geological history, and evaluate geological potential and disaster risk in the study area.

RESULT

Geomorphology of the Study Area

Geomorphology is the study of the Earth's surface and the processes that shape it. Geomorphological analysis in this study includes morphography, morphometry, and morphogenetics (Figure 4), which are used to identify landform units in the study area.

Morphography

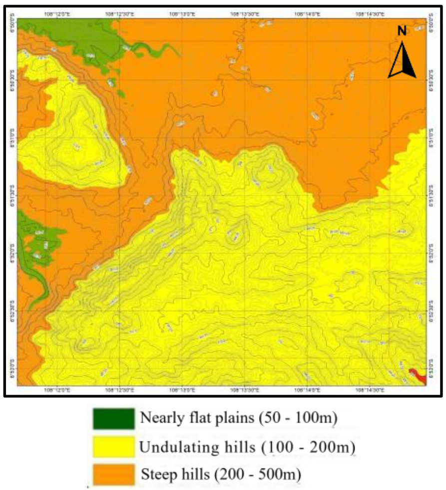
Based on Fossen's classification (2016), the landforms of the study area consist of nearly flat plains, undulating hills, and steep hills (Figure 3a). The nearly flat plains have an elevation of about 50–125 meters with a very low slope and are located in the northwest and southwest of the study area. Undulating hills occupy the northern to central parts with an elevation of 125–200 meters, while steep hills are located in the south-east and part of the northwest with an elevation of 200–375 meters. The river flow patterns that developed included trellis, parallel, and subparallel patterns, indicating the influence of geological structures on the direction of the valleys and the development of landforms (Figure 3b).

Morphometry

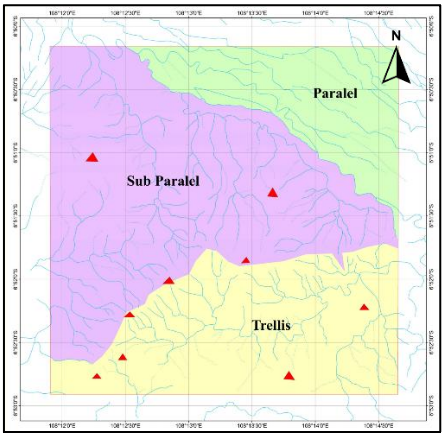
Morphometric analysis shows six classes, namely flat, very gentle, gentle, moderately steep, steep, and very steep (Figure 3c). The flat to very gentle classes are mainly found in the northern part, while the gentle to moderately steep classes dominate the central area. The steep and very steep classes are found on the elongated hills in the Sidamukti and Cibodas areas, reflecting a more rugged topography and potential for slope instability. The distribution of these slope classes indicates elevation changes influenced by structural controls and the lithological characteristics of the hills.

Morphogenetic

The landforms at the study site are the result of interactions between endogenous and exogenous forces. Tectonic activity created northwest-southeast and northeast-southwest oriented lineations, which influenced the formation of elongatd hills and parallel valleys (Figure 3d). Volcanic impacts are evident through the presence of andesite intrusions and tuff deposits, which have caused hard rock outcrops to appear on the surface. On the other hand, exogenous processes such as weathering, erosion, and sedimentation formed valleys and alluvial plains in lower areas. The interaction between these two forces resulted in complex geomorphological variations, ranging from structural hills to young alluvial plains, which are now used for settlement and agriculture.



(a)



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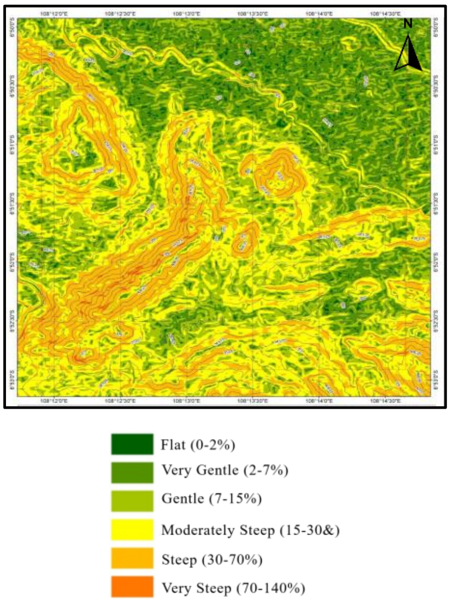
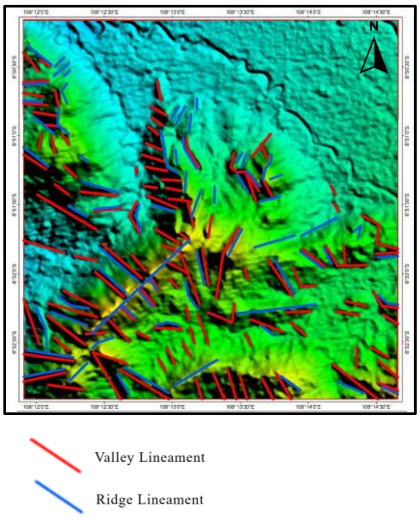


(c)



(d)

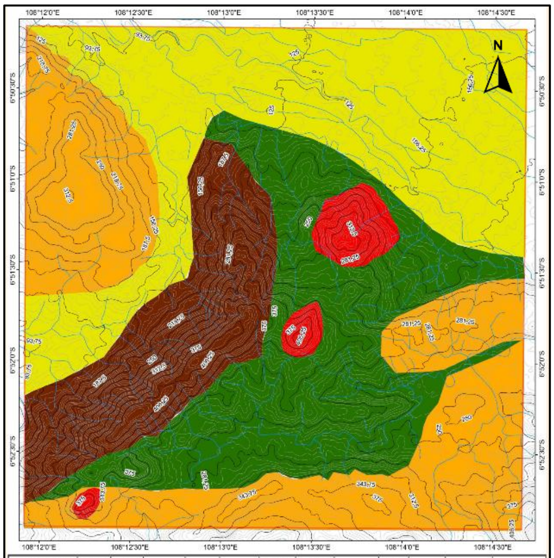
Figure 3. (a) Landform Map of the Study Area (Scale 1 : 12.500); (b) Map of the Flow Patterns in the Study Area (Scale 1 : 12.500); (c) Slope Map of the Study Area (Scale 1 : 12.500); (d) Alignment Map of the Study Area (Scale 1 : 12.500).

Geomorphological Units

The geomorphology of the study area was formed by the interaction of endogenous forces, namely tectonic and volcanic forces, with exogenous forces in the form of weathering, erosion, and sedimentation. This interaction resulted in diverse landforms, ranging from alluvial plains to steep hills controlled by volcanic structures and intrusions. Based on a combination of morphography, morphometry, and morphogenetics (Figure 4).

Description of the geomorphological map.

1) Steep Intrusive Hills Unit (Figure 5a) with red color, characterized by the presence of andesite rock as a result of plutonic intrusion. This unit has an elevation of 200–500 meters with a slope of 30–70%, forming a V-shaped slope as a result of strong vertical erosion. The subparallel flow pattern reflects the homogeneity of lithology and slope. The combination of igneous rock resistance and exogenous processes forms a steep relief dominated by erosion.



Geomorphological Unit	Color Symbol	Drainage	Formation	Tectonic	Landform	Valley Shape	Elevation (m asl)	Class	Slope (%)	Endogen	Exogen	Lithology
Steep Intrusive Hills		Sub-parallel	Andesite (Intrusion)	-	Hilly	V-shaped	200–500	Steep	30–70	Volcanic	Weathering, erosion	Igneous rock (Andesite)
Very Gentle Denudational Hills		Parallel	Citalang, Cinambo, Alluvium	Folding, Fault	Lowland – Hilly	U-shaped	50–200	Very Gentle – Gentle	2–15	Tectonic	Weathering, erosion	Sandstone, tuff, conglomerate, claystone, alluvium
Structural-Denudational Volcanic Steep Hills Unit		Sub-parallel	Citalang, Cinambo, Halang	Fold	Hilly	V-shaped	200–500	Moderately Steep – Steep	15–70	Tectonic, Volcanic	Weathering, erosion	Tuff, breccia, sandstone
Volcanic-Structural Steep Longitudinal Hills Unit		Trellis, Sub-parallel	Citalang	Fault	Hilly	V-shaped	200–500	Moderately Steep – Very Steep	15–140	Tectonic	Weathering, erosion	Tuff, sandstone, breccia, conglomerate
Structural Sedimentary Hills		Sub-parallel, Trellis, Parallel	Cinambo, Halang	Fault, Fold, Joint	Hilly	U–V-shaped	200–500	Flat – Steep	0–70	Tectonic	Weathering, erosion	Breccia, sandstone, claystone

Figure 4. Geomorphological map of the study area (Scale 1 : 12.500); (b)

2) Very Gentle Denudational Hills Unit (Figure 5b), colored yellow, characterized by a landscape that has undergone intensive leveling, composed of the Citalang Formation, Cinambo Formation, and relatively soft alluvial deposits. The elevation of this unit ranges from 50 to 200 meters with a slope of 2 to 15%. Parallel drainage patterns and U-shaped slopes indicate the dominance of lateral erosion and deposition. The morphogenesis of this unit is controlled by tectonic structures that have been modified by long-term weathering and erosion processes.

3) Structural-Denudational Volcanic Steep Hills Unit (Figure 5c) in orange, formed from a combination of structural, volcanic, and denudation processes. This unit consists of the Citalang, Cinambo, and Halang Formations, which have undergone folding and faulting. The elevation reaches 200–500 meters with a slope of 15–70% and a V-shaped slope profile. The developed flow pattern is subparallel, indicating a strong structural influence despite modification by weathering and erosion processes.

4) Volcanic-Structural Steep Longitudinal Hills Unit (Figure 5d) with brown color, showing the most obvious tectonic influence, marked by ridges northwest-southeast oriented. Elevation ranges from 200 to 500 meters with a slope of 15 to 140%. Trellis and subparallel flow patterns develop following the straightness and fractures of the rock, so that structural control over the morphology is very strong. The constituent lithology is andesite and tuff with varying resistance, resulting in steep slopes with the potential for landslides.

5) Structural Sedimentary Hills Unit with green colour, controlled mainly by tectonic deformation that produces folds, faults, and fractures in the sedimentary rocks of the Cinambo and Halang Formations. This unit has an elevation range of 200–500 meters and a slope of 0–70%, reflecting lithological and structural heterogeneity. Subparallel, trellis, and parallel flow patterns develop following the orientation of the structure. Variations in U- and V-shaped slope profiles indicate a combination of lateral and vertical erosion in breccia, sandstone, and claystone.

(a) (b)

(c) (d)

Figure 5. Geomorphological photos of the research area (a) Steep Intrusive Hills Unit; (b) Very Gentle Denudational Hills Unit; (c) Structural-Denudational Volcanic Steep Hills Unit; (d) Volcanic-Structural Steep Longitudinal Hills Unit.

Stratigraphy of the Study Area

Rock units were classified based on dominant lithology, uniformity of characteristics, stratigraphic sequence, and other lithological features. Data obtained from the stratigraphic analysis in the research area consists of correlations between lithology and fossil content from several rock units to determine age (Pangaribuan et al., 2023). Field observations and analysis resulted in a geological map showing four rock units and alluvium deposit, arranged from youngest to oldest (Figure 6).

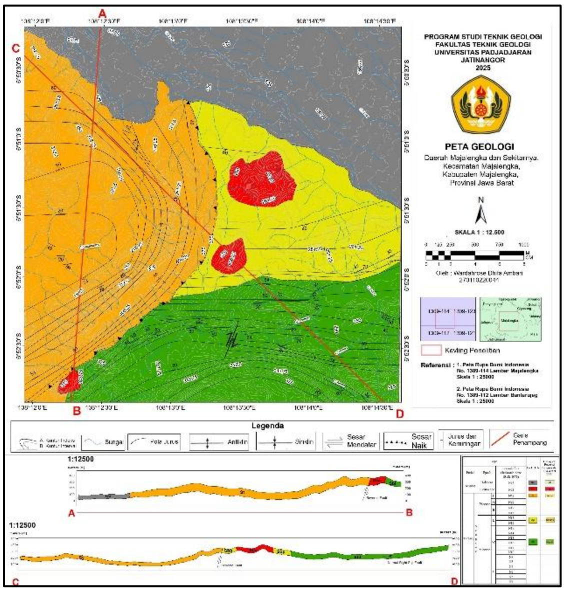


Figure 6. Geological Map of the Study Area (Scale 1 : 12.500).

1) Claystone Unit (Sbl), represented by the color green, has a wide distribution in the east-west direction. Its lithology is dominated by claystone, with intercalations of sandstone, siltstone, carbonate rock (packstone), and breccia insertions. The claystone is grayish brown to blackish brown in color, with a fine texture, soft to moderately compact, and shows parallel layering (Figure 7a).

   The components included clay minerals, fine quartz, and calcite, breccia intercalations are thought to originate from submarine landslides. The carbonate rocks show packstone rich in bioclastic fragments, indicating deposition in a moderately energetic shallow sea. Analysis of foraminifera fossils at several stations shows that Sbl is relatively Middle Miocene in age (N9–N15) with a bathyal (200–2000 m) depositional environment. Regional comparability shows that Sbl has similar lithology, age, and depositional environment to the Cinambo Formation Shale (Nmcsh) (Isnaniawardhani et al. 2020).

2) Sandstone units (Sbp), represented by the yellow color, are widely distributed in the west-central part of the study area. The lithology is dominated by sandstone, with minor intercalations of claystone and breccia. Weathered colors range from grayish brown to blackish brown, while fresh colors range from light gray to black. Grain size varies from very fine to coarse sand, generally medium to coarse, subangular to subrounded in shape, with good sorting, tight packing, and moderate to good porosity and permeability (Figure 7b). Sedimentary structures include parallel lamination, graded bedding, and load casts, indicating deposition in a fluctuating energy environment.

   Petrographic analysis shows dominant mineral composition of quartz, with feldspar, rock fragments, and carbonate cement. Foraminiferal fossil analysis indicates a relative age of Late Miocene–Early Pliocene (N16–N18) with a Neritic–Bathyal (200–2000 m) depositional environment, indicating deposition in shallow seas transitioning to land. Regional comparability shows that Sbp is similar to the Halang Formation Breccia (Nmhbx) in lithology and distribution patterns (Isnaniawardhani et al. 2020).

3) The Tufan Sandstone Unit (Sbpt), represented by the color orange, dominates the western part of the study area. Its lithology consists of coarse tuff as the dominant component, tufan sandstone, breccia, and volcanic conglomerate. The weathered color ranges from reddish brown to brownish gray, while the fresh color ranges from yellowish black to blackish gray. The grain size is generally coarse, angular–subangular in shape, poorly sorted, loosely packed, and brittle to hard in texture. The massive structure and tuff texture indicate the deposition of reworked volcanic material through water, with environmental energy phases varying from high to moderate, possibly in

a fluvial to proximal deltaic environment (Figure 7c).

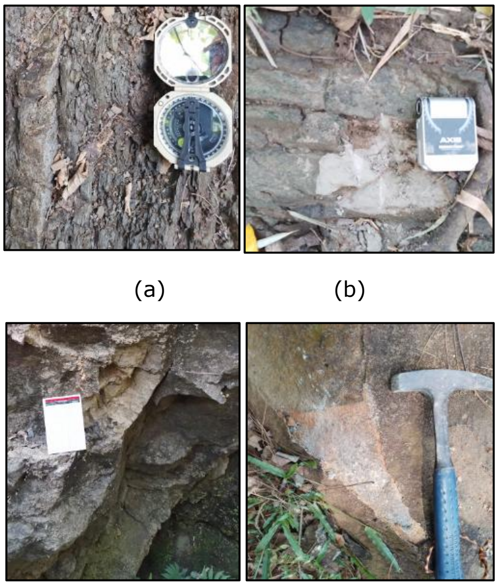
Petrographic analysis shows a dominance of volcanic rock fragments, vitric, quartz, pyroxene, feldspar, and oxide minerals. Regional comparison shows that Sbpt is similar to the Citalang Formation Limestone (Npcs), which dates back to the Late Pliocene and was formed in a terrestrial environment (Isnaniawardhani et al., 2020). This finding is consistent with the interpretation of the Citalang Formation lithofacies as a fluviatile depositional environment in the form of braided rivers (Al hakim and Rizal, 2022).

4) The Andesite Unit (Sba), represented by the color red, is distributed across three areas in the north-south part of the study area and cuts through all previous units. Its lithology consists of porphyritic to aphantic andesite with an inequigranular-hypidiomorphic granular texture and hypocrystalline crystallinity (Figure 7d).

   The main minerals consist of plagioclase, quartz, biotite, pyroxene, hornblende, and accessory minerals in the form of iron oxides. The massive structure and absence of layering indicate an intrusive origin, consistent with the mineralogical composition observed. Regional comparability shows that Sba has similar lithological characteristics, age (Late Pliocene–Early Pleistocene), and terrestrial deposition environment to the andesite in the surrounding area (Isnaniawardhani et al. 2020).

5) Alluvium deposits (Qa), dominate the northern part of the study area, are gray in color, and occupy flat to gently sloping areas in urban and residential areas. Its lithology consists of loose material in the form of gravel, pebbles, sand, and silt with poor sorting, mostly originating from surrounding rocks such as andesite, tuff, and sandstone. This unit is not yet consolidated and was formed by erosion, transportation, and deposition processes that are still active, reflecting a modern fluvial to alluvial environment.

   Regional comparisons show that this unit has similar lithological characteristics, age (Holocene), and terrestrial deposition environment to alluvial deposits in the surrounding area (Isnaniawardhani, et al. 2020).



(a) (b) (c) (d)

Figure 7. Close-up photos of each rock unit (a) Claystone Unit; (b) Sandstone Unit; (c) Tufan Sandstone Unit; (d) Andesite Unit.

Geological Structure of the Study Area

Analysis of the geological structure in the study area was conducted through observation of strike, dip, and determination of the presence of faults and folds. The pattern that emerged showed a main northwest-southeast direction, reflecting the impact of tectonic pressure that formed elongated hills and parallel valleys.

1) Joints

   Joints were observed at one main location (ST-11). Joints analysis shows a pattern of fractures that reflects an extensional stress regime with a tendency toward strike-slip faulting mechanisms according to Fossen (2016) classification.

2) Faults

   The results of the fault analysis show a combination of normal-flat faults with a right-lateral slip component. This mechanism describes an extensional state accompanied by a rightward block shift, consistent with the alignment pattern. In addition, an uplift fault was found in the western part of the plot, which is thought to be a normal fault that has undergone inversion due to regional compression.

3) Folds

   The folds that grow in the research area mainly consist of anticlines and synclines with a northwest to southeast direction. The types of anticline and syncline folds found include variations from open to closed folds, with varying slopes, ranging from steep to sharply sloping, and weak to fairly strong thrusting.

DISCUSSION

Geological History of the Study Area

Reconstruction of geological history describes the depositional history of formations in the study area from the Miocene to the Holocene. This interpretation is obtained through stratigraphic analysis, which includes correlation between lithologic units, fossil content identification for age determination, and petrographic analysis to determine rock composition (Adam & Rochmana, 2022). The geological history of the study area shows a gradual development from a deep marine to a terrestrial environment.

The oldest unit observed in outcrops at Babakan Jawa is the Middle Miocene Claystone Unit, formed in a deep marine turbidite environment and characterized by flute cast structures and parallel lamination, indicating deposition by high-energy currents. The observed turbidite sequences also display well-developed Bouma sequences, providing further evidence for a deep-marine depositional setting (Firdaus et al., 2023). Above it is the Late Miocene Sandstone Unit, which depicts the process of basin shallowing to a shallow marine environment and transition to land. The presence of cross bedding and graded bedding structures which formed during and after the deposition of the sandstone, indicates an increase in the amount of sediment from the land. The relationship between the claystone and sandstone units in stratigraphy shows a difference in age based on microfossil data, indicating an unconformable relationship .

At the end of the Pleistocene, volcanic activity produced the Tufan Sandstone Unit, which covered older sediments, followed by the formation of the Andesite Intrusive Rock Unit, which cut through the previous unit and marked the magmatic phase after the deposition process. The intrusion becomes a younger unit that penetrates rock units that are older in age based on the law of cross-cutting relationships. Deposition of the unit occurred from the Early Miocene to the Late Pleistocene with depositional environments ranging from deep marine, shallow marine, to terrestrial volcanic deposits. This is similar to deposition in the Majalengka Sub-Basin which occurred from the Early Miocene to the Late Pleistocene (Philetas et al., 2019).

The youngest unit is the Holocene to Recent Alluvium Deposits, consisting of clay, silt, sand, and gravel formed from modern weathering and sedimentation processes. These deposits are found in lowlands, river valleys, and foothills and are still being formed today.

The age of the rock units was determined using an integrated approach. For units containing microfossils, foraminiferal analysis provided bio-stratigraphic age control. For fossil-free units, relative age was established through interpretation of stratigraphic contacts and structural relationships such as intrusive cutting, and all were correlated with regional stratigraphic data (Isnaniawardhani et al., 2020).

Geological and Disaster Potential of the Research Area

The research area has considerable geological resources, especially in terms of geotourism and land use. One of its main attractions is the Soliter Intrusion Hill in Gunung Batu Karang Park, which consists of andesite rocks. The isolated hill with steep slopes is unique and has high scientific value, making it a potential educational tourist site for learning about rock intrusion processes and how igneous rocks are resistant to erosion. In addition, the potential for nature tourism is further enhanced by the presence of the Gunung Panten Paragliding area (Figure 8a) and Gili Rafting Majalengka (Figure 8b). Both places utilize the shape of the hills and river flows for sports-based recreational activities and education about the shapes of the earth's surface. In addition, the alluvial plains in the study area also have high economic potential as agricultural land. The fertile soil and adequate irrigation system support farming and corn cultivation activities carried out by the local community.

(a)

(b)

(c)

Figure 8. Geological and Disaster Potential of the Study Area (a) Gunung Panten Paragliding Tourism; (b) Gili Rafting Majalengka Tourism; (c) Landslide in Sidamukti Village, Majalengka.

The research area also shows the possibility of geological disasters, especially landslides (Figure 8c), The research area also shows the possibility of geological disasters, especially landslides, which are closely related to steep terrain, geological structure, and rainfall patterns (Selaby et al., 2021; Fathaya et al., 2023). Slopes with a gradient of 30-70 percent and the presence of geological structures such as tectonic plates and weathering zones increase the likelihood of landslides. Several landslide events in the surrounding area indicate that weak areas on slopes often become the starting point for soil and rock release.

Weathering factors such as high rainfall in Majalengka Regency also increase the risk of landslides because they increase water saturation and reduce the resistance of slope materials. Human activities such as clearing land for agriculture on steep slopes without implementing soil conservation measures further destabilize the slopes. The combination of factors such as rock type, geological structure, slope inclination, rainfall, and land use makes landslides a major geological hazard. Therefore, mitigation efforts such as land use regulation, improvement of drainage systems, and public education are needed to reduce the risk of disasters.

CONCLUSION

Based on the results of field activity and data analysis, it can be concluded that there are five geomorphological units, namely Very Gentle Denudational Hills Unit, Steep Intrusive Hills Unit, Volcanic-Structural Steep Longitudinal Hills Unit, Structural-Denudational Volcanic Steep Hills Unit, and Structural Sedimentary Hills Unit.

The stratigraphic aspect shows four rock units from old to young, namely the Claystone Unit (Sbl), Sandstone Unit (Sbp), Tuff Sandstone Unit (Sbpt), and Andesite Unit (Sba); and Alluvium Deposit (Qa). This sequence illustrates the shallowing of the basin from a deep marine (turbidite) environment to the present-day land.

Geological structure analysis indicates the influence of an extensional regime with a horizontal shear component, reflected in the NW–SE alignment pattern and the presence of dextral normal–horizontal faults. In the western part, there are also thrust faults resulting from the inversion of normal faults due to regional compression. In addition, anticline–syncline folds with a general NW–SE orientation are also widespread.

The geological history of the study area shows a change from deep sea to land. Initially, there were Middle Miocene claystone layers in a turbidite environment. Later, Late Miocene sandstone layers appeared, indicating a process of shallowing and an increase in sediment supply from the land. At the end of the Miocene to Pliocene, forces formed a normal fault in the western part of the study area (shown on the map as a thrust fault due to its current position) (Figure 6). The formation of this normal fault caused the northern part of the area to subside, forming a basin that would later be filled with younger sedimentary layers (alluvial deposits). This structure was initially seen as a normal fault, as evidenced by the age difference, where the layers on the hanging wall block are younger (tufan sandstone unit) than those on the foot wall block (claystone and sandstone units.

With the continuation of tectonic activity, this fault underwent a change in direction due to compressive forces from the surrounding area and transformed into a thrust fault. Furthermore, this process created a fold structure, which was the result of deformation due to compression in the western and southern parts of the study area. At the end of the Pliocene, volcanic activity produced tuffaceous sandstone layers, followed by andesite intrusions as part of the magmatic phase after the deposition process was complete. This sequence of layers ends with alluvial deposits from the Holocene to the Recent period, which were formed by modern weathering and sedimentation processes (Hutomo & Firmansyah,2020).

Geologically, the study area has positive potential in the form of shallow aquifers (the presence of porous volcanic and sedimentary rocks), minerals (andesite, sand, gravel), and geotourism potential. Agricultural potential is also developing on the alluvial plains. However, this area is prone to landslides due to steep slopes, weathered lithology, and high rainfall, and is influenced by active tectonic structures. Therefore, land use and geohazard mitigation need to be carefully planned.

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GEOLOGICAL EVOLUTION OF OLIGOCENE TO PLEISTOCENE LEBAKSIUH, WEST JAVA, INDONESIA

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ABSTRACT

This study intends to map and analyze the geological conditions in Lebaksiuh, Sidamukti, and the surrounding area of Sumedang and Majalengka Regencies, West Java, Indonesia. The methods used include field observation, laboratory analysis, and literature review. The geomorphological units comprises steep high volcanic uplands, steep high structural uplands, steep low structural hills, and gently sloping denudational lowland, with sub-dendritic, radial, and modified trellis drainage patterns occupying most of the area. Field observation data shows that the area consists of five lithostratigraphic units which are the andesite Unit (Ha), claystone Unit (Nmcsh), sandstone Unit (Npcs), tuff Unit (Npct), and alluvium unit (Qa). The geological evolution that starts with the formation of the Oligocene andesite unit (Ha). Then deposition of the Cinambo shale unit (Nmcsh) in early Miocene with a deep marine depositional environment, then an Intra-Miocene tectonic activity compresses the region, followed by a compressional release in the Miocene-Pliocene age and sea regression phase that shaped the local basin. In the Pliocene, Citalang sand (Npcs) and tuff unit (Npct) are deposited in a fluvial depositional environment. Reactivation of the older faults happened after the deposition. lastly accumulation of the alluvium unit (Qa) in the Quaternary Holocene age. Structural geology plays a huge role in the area with a regional thrust fault that divides the Citalang and Cinambo formation in the south which showed an arcing pattern that opens to the north, and a more local fold structure that arced mostly in north-south direction, and fault structures present in the Citalang formation. Potential geological resources in the area are Sand and andesite, and can be used for building material. Contrastingly, the geological hazards include landslides and earthquakes.

Keywords : Citalang, Geological Mapping, Lebaksiuh, Majalengka, Structural Geology

INTRODUCTION

West Java is located along the active convergent margin between the Indo-Australian Plate and the Eurasian Plate, making it one of the most tectonically complex regions in Southeast Asia. Since the Paleogene, continuous subduction has driven crustal deformation, arc magmatism, and sedimentary basin development, resulting in a highly heterogeneous geological framework (Hall, 2017; Hall & Spakman, 2015). These long-lived geodynamic processes have produced overlapping lithostratigraphic units with contrasting ages and origins, particularly in southern West Java. The research area is situated in Lebaksiuh, Sidamukti, and the surrounding area of Sumedang and Majalengka Regencies, West Java, Indonesia. Specifically at 108° 9 '10'' and 108°11'54" East longitude, and 6°49'36'' to 6°52'20'' South latitude (25km in area). Based on the Arjawinangun regional geological map, the area consists of four different formations, which are the Citalang Formation, Shale Member of the Cinambo Formation, Hornblende Andesite, and Alluvium. This sequence of far different aged formations overlapping with each other, creates a lot of questions. Earlier studies indicates that the area is formed because of a mega slump (Tija, 1965), tectonism and sedimentation (Martodjodjo, 1984), meteor strike, and ancient volcanic caldera (Sunardi, 2023). From all the different interpretations, this study tends to integrate geomorphology, stratigraphy, and structural geology coupled with petrography and paleontology to understand the geological evolution, rock distribution, and depositional dynamic. This research prioritizes collected field data and laboratory analysis to better interpret these aspects of the area. The main output is to produce a geological map of the area in 1:12.500 scale.

RESEARCH METHOD

The methods used in this study consists of preparation, field data acquisition, laboratory analysis, data analysis, and final compilation. The workflow follows standard geological mapping procedures that's usually applied in detailed surface geological investigations. The study utilized primary and secondary geological data. Primary data consisted of direct field observations of geomorphology, lithology, stratigraphy, and geological structures. These data included outcrop descriptions, structural measurements, geomorphological observations, and rock samples from each outcrop. Secondary data comprised regional geological maps, Indonesian Topographic Maps (RBI), and published geological literature that's relevant to the objectives. A base map at a scale of 1:12,500 was generated through digitization of RBI topographic data that's used as the primary spatial framework for all field plotting and interpretations.

Preparation Stage

The preparation stage was conducted before going to the field to help make the data acquisition efficient and systematic. This stage includes administrative permitting, inventory of available regional geological and topographic maps, and compilation of supporting literature. Topographic data were digitized and rescaled to the scale of 1:12,500 to make the intended base map. Preliminary topographic interpretation was carried out to identify major morphological features which will be used to design observation routes and prioritize target areas for field observation.

Field Data Acquisition

Field data acquisition used GPS positioning combined with direct field orientation. Observation points were recorded using a GPS device and plotted on a base map. Field orientation relied on matching natural and artificial features observed on site with features shown on the base map. Each observation point included megascopic examination of the outcrops. Lithological description covered rock type, color, grain size, texture, sedimentary or igneous structures, and weathering degree. Bedding orientation measurements, including strike and dip, uses a geological compass. Stratigraphic layer thickness was measured with measuring tapes where exposure allowed. Structural elements such as joints, folds, and faults were identified and documented. Indicators of lithological or structural change were recorded to support unit boundary interpretation. Other data acquisitions includes field documentation, outcrop sketches oriented to geographic north, and collection of rock samples for laboratory work.

Laboratory Analysis

Laboratory analysis supports lithological and stratigraphic interpretation. Petrographic analysis used thin sections observed under a microscope to identify mineral composition, texture, and fabric. The petrographic descriptions also followed standard rock classification schemes.

Paleontological analysis focused on small foraminifera and palynological content to determine relative age and depositional environment of sedimentary units. Sample preparation involved mechanical disaggregation, chemical treatment using NaOH and hydrogen peroxide, sieving, drying, and microscopic identification following established laboratory procedures.

Data Processing and Analysis

Data processing and analysis integrates field observations with map-based interpretation. Geomorphological analysis comprises morphographic, morphometric, and morphogenetic characteristics, supported by drainage pattern evaluation. These aspects help identifying the original and modified geomorphological patterns and their relationship with geological controls.

Stratigraphic analysis applied informal lithostratigraphic units defined by physical characteristics, stratigraphic position, and lateral continuity. Unit boundaries were placed at clear lithological changes or inferred transitions using references from the regional geological map, where exposure was limited and lateral unit distribution followed geological continuity

Structural geological analysis involved plotting structural measurements on the base map and interpreting lineaments, fault slickenside and it’s aspects, fold geometry, ridge and valley alignment, and abrupt river deflection.

Geological history reconstruction combined all the interpretations into a relative chronological sequence describing sedimentary deposition, tectonic deformation, and erosion events.

RESULT

Geomorphology

Early analysis starts with the morphography analysis with the landform aspects using the classification by Van Zuidam (1983). The research area consists of High hills, Low hills, Inland lowland, and Lowland. Shown by Figure 1.

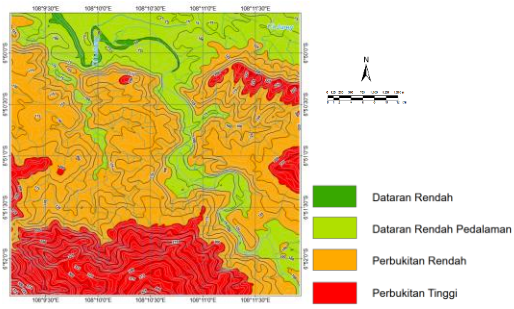

Figure 1. Morphography map

The morphometry analysis shows that the research area consists of flat to very steep areas. Most of the flat areas are located in the north and west, while the steeper areas are in the south and east side of the area (Figure 2).

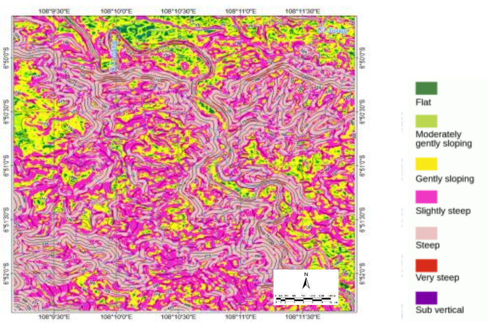

Figure 2. Morphometry map

Following the morphogenetic classification of van Zuidam (1985), landform development is primarily controlled by volcanic and tectonic activities. Tectonic influence is indicated by consistently oriented lineaments with a northwest–southeast trend, suggesting compressional forces responsible for the simultaneous formation of ridges and valleys. Volcanic activity is identified by the presence of igneous rock units, initially recognized from regional geological maps (Djuri, 1995) and then confirmed by field observations.

Drainage Pattern is classified based on Howard, 1967. The research area has 3 distinct drainage patterns, which is: Radial (at the southern areas), Modified trellis (at the western areas), and Sub-dendritic (at the eastern areas) (Figure 3).

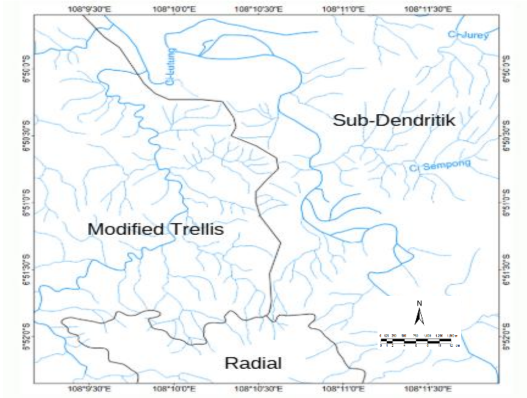

Figure 3. Drainage pattern map

From these four aspects, the geomorphological aspects of the area is divided into 4 classes: Gently sloping denudational lowlands, Steep low structural hills, Steep high structural uplands, and Steep high volcanic uplands (Figure 4 and Table 1).

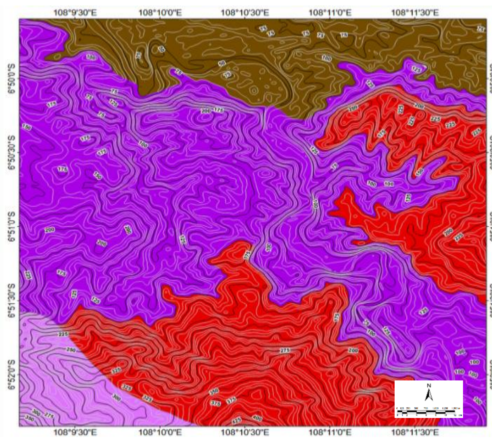

Figure 4. Geomorphology map

Geomorphological Unit	Symbology	Geomorphological Characteristics							
		Morphography			Morphometry		Morphogenetic		
		Landform	Valley	Drainage Pattern	Slope	Class	Endogenous	Exogenous	Composing Lithology
Gently Sloping Denudational Lowlands		Lowlands	U shaped	Subdendritic	2-7%	Gently Sloping	Geological Structure	Weathering & Erosion	Alluvium
Steep Low Structural Hills		Low Hills	U-V shaped	Modified Trellis	8-16	Steep	Geological Structure		Sandstone, Tuff, Conglomerates, Breccia, Andesite (intrusion)
Steep High Structural Uplands		High Uplands	U-V shaped	Modified Trellis	8-17	Steep	Geological Structure		Sandstone & Shale
Steep High Volcanic Uplands		High Uplands	U shaped	Radial	8-18	Steep	Volcanism		Hornblende Andesite & Tuff

Table 1. Geomorphological characteristics of study area

Stratigraphy

The stratigraphic framework uses informal lithostratigraphic units. One unit can record deposition from more than one geological event. Unit boundaries follow the spatial distribution and continuity of lithological characteristics observed in the field. Four lithostratigraphic units are identified, ordered from oldest to youngest as the Andesite Unit (HA), Claystone Unit NMCSH, Sandstone Unit NPCS, and Tuff Unit NPCT.

The Andesite Unit HA consists of intrusive andesitic rocks and forms the oldest unit in the succession. The rocks range from massive to vesicular andesite with porphyritic to aphanitic textures. interpreted data and maps shows that the unit associates with the fold axis near the unit, it in turn indicates emplacement prior to major sedimentary deformation and before deposition of overlying sedimentary units.

The Claystone Unit NMCSH is dominated by claystone with interbeds of sandstone and siltstone. Turbidite related sedimentary structures, including graded bedding and parallel lamination, are common. Petrographic results classify the samples as mudstone. Regional stratigraphic correlation assigns an Early Miocene age and links the unit with the Cinambo Formation shale member. Depositional conditions correspond to deep marine slope environments related to turbidite systems. Local facies reflect unstable slope processes, including deposits interpreted as mudflow products.

The Sandstone Unit NPCS forms the most extensive unit in the area and shows strong lithological variation. Sandstone dominates, accompanied by conglomerate, siltstone, and claystone interbeds. Cross bedding, parallel lamination, graded bedding, and slump structures indicate high energy depositional processes. Petrographic analysis classifies the sandstone as arkosic wacke. Age and environment interpretation relies on regional correlation due to the absence of diagnostic fossils. The unit correlates with the Pliocene Citalang Formation and reflects deposition in terrestrial to fluvial systems. Stratigraphically, the Sandstone Unit unconformably overlies the Claystone Unit and is conformably overlain by the Tuff Unit.

The Tuff Unit NPCT consists mainly of crystal tuff with minor volcanic breccia. The unit is massive, well sorted, and rich in volcanic glass, lithic fragments, and mineral crystals. Fossils are absent due to volcanic origin. Regional correlation assigns the unit to the Pliocene Citalang Formation and places deposition contemporaneous with the Sandstone Unit. The Tuff Unit conformably overlies the Sandstone Unit and records ongoing volcanic activity during terrestrial sedimentation.

Structural Geology

Regionally, the study area lies within the Bogor Zone, which experienced multiple deformation phases. Two main tectonic episodes are recognized, a Middle Miocene phase and a stronger Pliocene to Pleistocene phase. Middle Miocene deformation involved regional uplift and folding with dominant east west fold axes and north south trending faults. These structures controlled deformation of Lower Miocene sedimentary units. During the Pliocene to Pleistocene, tectonic intensity increased and produced strike slip faults with dominant northeast southwest movement. Younger structures locally overprinted earlier folds and faults, creating complex structural relationships. Structurally, the Lebaksiuh area is affected by regional compressional tectonics associated with Java subduction, expressed by folds, thrusts, and strike-slip faults that locally reactivate older structures. Fault-controlled basins and uplifted blocks have played a significant role in controlling sedimentation patterns and volcanic emplacement (Haryanto & Setiadi, 2018; Bronto, 2019).

Additional structural influence comes from the Citanduy Fault system and trends associated with the Sumatra Pattern marked by northwest southeast oriented strike slip faults and folds. These structures acted as zones of weakness and promoted repeated deformation and local uplift. Interaction between Bogor Zone tectonics, the Citanduy

Fault system, and Sumatra Pattern structures controls the structural configuration of the study area.

Structural interpretation relies on topographic lineament analysis derived from DEM data, supported by field measurements of bedding orientation, fault planes, and joint systems. The dominant lineament trend within the study area trends southwest northeast, contrasting with the regional northwest southeast pattern. This relationship indicates a younger deformation phase that is imposed on the regional fold thrust belt of Java. Bedding orientation data and structural cross sections show folding as the dominant structural style, particularly in the central part of the study area (Figure 5).

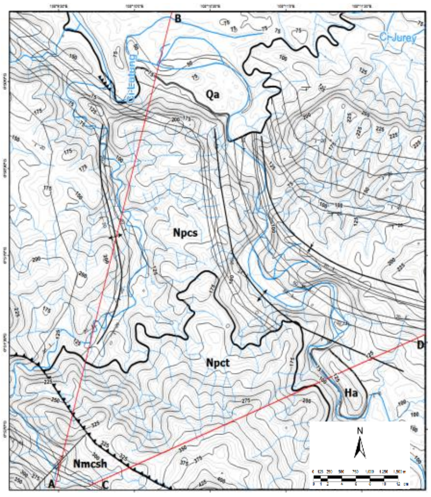

Figure 5. Structural/strike trend map

Folds

Based on the strike trend map and cross section, there are three major folds that make up the area, consisting of two anticlines and one syncline, with varying axial orientations. The western anticline trends mostly in a north–south direction, while the eastern anticline–syncline pair shows a change in orientation from north–south to northwest–southeast toward the south. This variation reflects local modification of fold geometry by younger tectonic forces. The fold analysis and interpretation are strengthened with a field documentation of folding beds along the interpreted fold line.

From the stereographic analysis using Dips, it can be confirmed based on fold classification criteria, the anticlines are interpreted as moderately inclined horizontal folds, while the syncline is classified as an upright horizontal fold. These folds are interpreted to have formed under a compressional stress regime consistent with regional tectonic evolution.

Faults

From the field data collected, there are four different stations that show indications of faults in the form of fault mirrors. From these four stations, six different fault mirrors were identified,with variations in fault orientations, the faults are difficult to analyze using the stress principles of Moody and Hill, 1959, because the compression regime, which can also be observed from stress indicators and fold interpretations, shows different stress directions. Therefore, fault analysis was carried out for each structural lineament. From the six fault mirror data, four were analyzed using stereonet analysis, namely CS 1 located in the southwestern part of the study area, CS 2 located in the northern part of the study area, and CS 5 and CS 6 located at the boundary between the Miocene clay unit and the Pliocene tuff unit. CS 3 was not analyzed because it has the same continuation direction and fault type as CS 2. CS 4 was also not analyzed because it is similar to CS 5. The following figures present the results of fault analysis using stereonets.

The results of the fault analysis indicate that CS 1 is a thrust fault, although field data show that the fault can be classified as a strike-slip fault (dextral). Therefore, it can be interpreted that the fault in the southern area can still be concluded as a thrust-slip fault, where there is strike-slip displacement as well as the influence of reverse faulting (oblique fault), because when viewed from the aspects of drainage pattern and geomorphology of the fault zone, there are indications of horizontal displacement. CS 2 is interpreted as a thrust fault, and the field data also indicate a thrust fault. However, the continuity of this fault is not indicated by any other aspect except for this fault mirror.

The analysis of CS 5 and CS 6 was combined because they are located within the same lithology (station). The results show that CS 5 is a thrust fault, while CS 6 is a normal slip fault. The difference between these two results indicates that the two faults occurred at different times under different tectonic regimes. With that the relationship between fault types suggests an early phase of extension followed by a dominant compressional regime. This evolution reflects regional tectonic processes affecting the Bogor Zone, where older extensional structures were repeatedly reactivated during later contractional events. This interpretation is strengthened by the fact that the CS 5 and CS 6 area lies along a thrust fault line on the regional geological map of Arjawinangun by Djuri.

Joints

The results of stereonet analysis of joints from two measurement points in the study area show variations in the orientation of the principal stress, with indications that are local in nature. In the joint measurement area, the minimum stress (σ_3) is dominant, which indicates a stress condition that could generate a thrust fault. However, this point is considered insufficient to validate the presence of such a fault because of its distance from the location where fault mirrors were identified relative to the joint measurement location.

Geological History

The geological history of the study area shows the interaction from all the earlier aspects from oligocene up until the quaternary period (Figure 6).

During the Oligocene period, the Andesite Unit (Ha) was formed. Its interpreted as an intrusive volcanic rocks based on Arjawinangun regional geological map . This unit represents the oldest unit in the area and forms the basement that the younger sediments will form over.

Then, during the Miocene, the Nmcsh claystone unit was deposited in a deep marine depositional environment, specifically on the slope, resulting in turbidite deposits. Other units located outside the study block were also deposited during this time. Subsequently, during the intra-Miocene, a compressional regime occurred that formed elongated fold mountains with a Java fold thrust belt pattern in the southern area outside the study block.

Later, from the Miocene to the Pliocene, a compressional release occurred, producing normal faults at the boundary between the Nmcsh claystone unit and other units, with the northern block as the downthrown block and the southern block as the footwall. As a result of this normal faulting, the northern part of the normal fault was eroded, causing an unconformity with the overlying units. This was followed by regression until the Pliocene, which caused the depositional environment to change from deep marine to fluvial or continental settings. During this phase, the Sandstone Unit (Npcs) was deposited, followed shortly by the emplacement of the Tuff Unit (Npct), reflecting increased volcanic activity contemporaneous with sedimentation.

A renewed and more intense compressional tectonic phase during the Pliocene–Pleistocene reactivated pre-existing faults. Earlier normal faults were inverted into thrust faults, and new folds developed with stress orientations distinct from those of the intra-Miocene compression. This deformation phase was responsible for the formation of the fold structures observed in the study area and led to the re-exposure of the Andesite Unit along fold axes, particularly in the eastern part of the area.

Finally, during the Quaternary, prolonged weathering and erosion of uplifted rocks supplied unconsolidated sediments to lowland areas. These materials were transported downstream and deposited as alluvial deposits, representing the youngest geological units in the study area and recording ongoing surface processes under the current geomorphic regime.

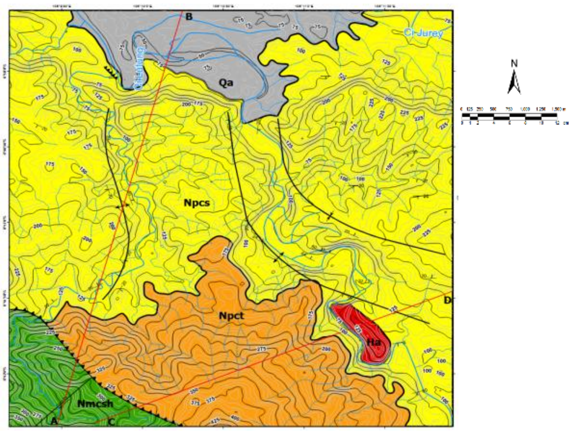

Figure 6. Geological map of research area

DISCUSSION

The output of this research has been reached, which is to show the geological condition in the area. The field observation data and laboratory analysis are enough to draw a conclusion about the geomorphology, stratigraphy, and geological structures. Similarities have been concluded from the previous studies. such as, differences in folds and lineament orientation between the area and outside the area, the similarities of the lithology and sedimentary structures in each unit. But there are also differences, the southern fault has no prominent mark that proves the arch that opens to the north pattern, the tuff unit (Npct) and sandstone unit (Npcs) has no clear distinction of age (caused by limited laboratory data), and the formation of the tuff unit (Npct) still has many questions surrounding its deposition mechanism and if it really conformed with the sand unit.

CONCLUSION

The study area records a complex geological evolution represented by a succession of rock units from oldest to youngest in the Lebaksiuh, Sidamukti, Kadu, and surrounding areas. Geological development began in the Oligocene with the formation of the Andesite Unit (Ha). This was followed in the Early Miocene by deposition of the Claystone Unit (Nmcsh) in a deep-marine slope environment, characterized by turbidite sedimentation. Then, during the intra Miocene, a regional compressional regime occurred that formed the Java fold thrust belt. Subsequently, from the Miocene to the Pliocene, a phase of compressional release took place, which generated normal faulting and produced an unconformity between the claystone unit and the younger units. At the same time, regression occurred and led to the deposition of the Sandstone Unit (Npcs) and the Tuff Unit (Npct) during the Pliocene within a fluvial depositional environment, where the tuff reflects contemporaneous volcanic activity. Later, during the Pliocene to Pleistocene, renewed and more localized compression occurred, causing fault inversion, folding, and uplift of the andesite unit. Finally, during the Quaternary, erosion and downstream transport of weathered material resulted in the deposition of alluvial sediments (Qa) in lowland areas.

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GEOMORPHOLOGY OF CISEWU AREA AND ITS SURROUNDINGS, GARUT REGENCY, WEST JAVA, INDONESIA

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ABSTRACT

This study analyzes the geomorphological phenomena of the Cisewu area and its surroundings, Garut Regency, West Java, through an integrated approach encompassing morphographic, morphometric, morphogenetic, and morphotectonic was used to analyze landforms as a basis for establishing geomorphological units. The methods used included mapping the earth's surface, Digital Elevation Model (DEM) analysis, slope gradient measurement, drainage pattern interpretation, and lineament analysis. The results indicate the presence of five distinct geomorphological units, namely an Andesitic Intrusive Dome, very steep structural valley, moderately steep volcanic valley, steep volcanic ridge, and very steep structural ridge. Morphometric analysis shows the dominance of steep (16°–35°) to very steep (>35°) slopes, reflecting strong control by geological structures and resistant lithology. Rectangular and trellis drainage patterns indicate control by fault and joint structures. Morphotectonic analysis using geomorphic indices (Bs, Vf, Af, Smf) indicates ongoing Quaternary tectonic activity, particularly in the Cilayu Sub-Watershed. The formation of these geomorphological units is the result of the interaction between volcanism during the Late Miocene–Pliocene and tectonic deformation by northeast–southwest-trending strike-slip faults. The results of this study provide a scientific basis for land-use planning and landslide hazard mitigation in the study area.

Keywords: Cisewu–Garut, geomorphology, morphotectonics, remote sensing, slope gradient, landforms.

INTRODUCTION

From a geological perspective, Java Island was formed as a volcanic arc resulting from the subduction of the Indo-Australian Plate beneath the Eurasian Plate from the Late Cretaceous to Recent (Smyth et al., 2008). This complex and ongoing tectonic interaction has not only produced high volcanic activity and seismicity, but also formed diverse physiographic regions with distinctive morphology, one of which is the Southern Mountains Zone of Java (Van Bemmelen, 1949). Geomorphology is a scientific discipline that studies landforms and landscapes along with the processes that shape them, providing an analytical framework to understand the evolution of the Earth’s surface (Tarolli & Sofia, 2021). This study includes analysis of the influence of endogenic forces (tectonic and volcanic), exogenic forces (fluvial processes, weathering, and erosion), as well as the role of anthropogenic activities in modifying landscapes (Viles, 2022). Modern geomorphological approaches integrate field observations, remote sensing data, and numerical modeling to holistically reconstruct landscape evolution histories and to identify potential resources and geological hazards (Bishop et al., 2020).

The Cisewu area in Garut Regency physiographically belongs to the Southern Mountains Zone of West Java. This region is characterized by hilly to mountainous morphology with steep slopes, deep and narrow river valleys, and structurally controlled drainage patterns. This complex landscape is the result of prolonged interaction between Tertiary volcanism and Quaternary tectonic deformation associated with regional fault systems, such as the Cimandiri Fault to the north (Martodjojo, 2003). The lithology is dominated by Miocene–Pliocene volcanic and volcaniclastic rocks that have undergone uplift and intensive weathering. Although several regional geological studies have been conducted, detailed geomorphological information integrating morphotectonic aspects for the Cisewu area remains very limited. Therefore, a comprehensive understanding of the geomorphological characteristics and genesis of this region is crucial as a scientific basis for land-use planning, resource management, and mitigation of geological hazards such as landslides that frequently occur on steep slopes.

Based on this background, this study aims to: (1) identify and classify geomorphological units based on morphographic, morphometric, , morphotectonic aspects, and morphogenetic through lithology and geological structure; (2) evaluate indications of relative Quaternary tectonic activity through geomorphic indices analysis (morphotectonic analysis); and (3) interpret the main geomorphological processes that shaped the current Cisewu landscape. Geographically, the study area is located in the Cikarang area and its surroundings, Cisewu Subdistrict, Garut Regency, West Java Province (Figure 1).

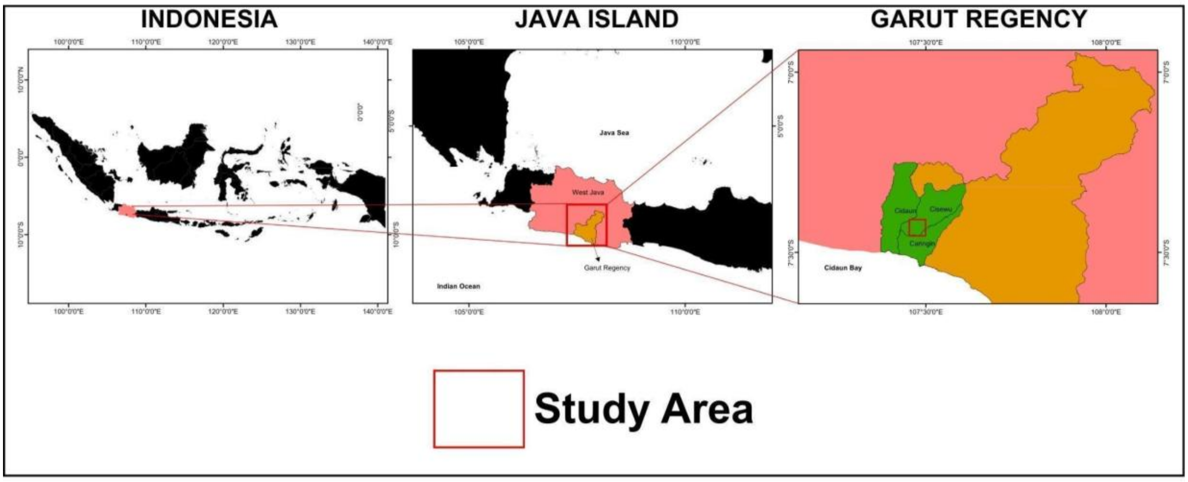

Figure 1. Study area located in Cisewu Subdistrict.

REGIONAL GEOLOGY

Physiography of the Study Area

Physiographically, the study area belongs to the Southern Mountains Zone of West Java (Van Bemmelen, 1949) (Figure 2). This zone extends along the southern coast of Java Island with a width of approximately 50 km and is characterized by highland to steep hilly morphology that has undergone intensive folding and uplift processes since the Miocene. The Cisewu area, as part of this zone, exhibits hilly to mountainous morphology with rugged relief, steep slopes, and deeply incised narrow valleys. These physiographic conditions result from complex interactions between Sunda Arc tectonic activity, volcanism, and denudational processes that have operated intensively since the Miocene to the Quaternary. The development of regional morphology is strongly controlled by Miocene–Quaternary volcanic and sedimentary rocks that have undergone structural deformation, producing landform units in the form of steep structural ridges and steep structural valleys aligned with regional structural lineaments.

Stratigraphy of the Study Area

The stratigraphy of the study area consists of rock units ranging in age from the Late Miocene to the Quaternary, recording the geological evolution of the Southern Mountains Zone from deep-marine to terrestrial environments with dominant volcanic influence. Based on the Regional Geological Map of the Sindangbarang and Bandarwaru Quadrangles (Koesmono, 1996), the regional stratigraphy indicates that the rocks in this area range in age from the Late Miocene to the Quaternary. Previously identified lithostratigraphic units include the

Bentang Formation (Tmb), the Koleberes Formation (Tmk), the Undifferentiated Older Volcanic Unit (QTv), and Pyroxene Andesite (pa). The Bentang Formation represents the oldest unit, deposited in a deep-marine environment, whereas the volcanic units reflect intensive magmatic activity during the Late Miocene to Pliocene (Figure 3).

Geological Structure of the Study Area

The study area, particularly in the Cilayu River area located in the southeastern part, belongs to the Margahayu Fault segment. This fault is part of the active fault system in Garut Regency. Based on systematic mapping conducted by the Geological Agency, the Margahayu Fault is classified as a left-lateral strike-slip fault that still shows Quaternary activity (Moechtar et al., 2024).

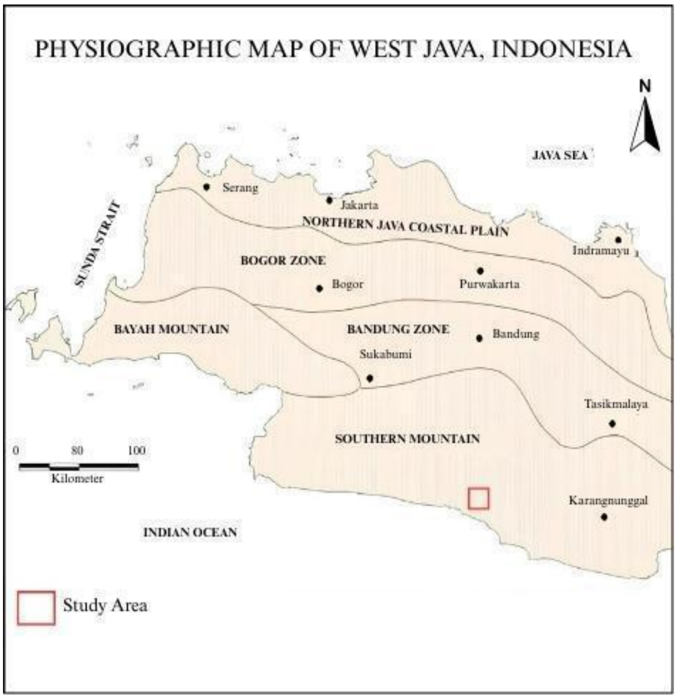

Figure 2.Modified illustration of the Physiography of Western Java, Indonesia.

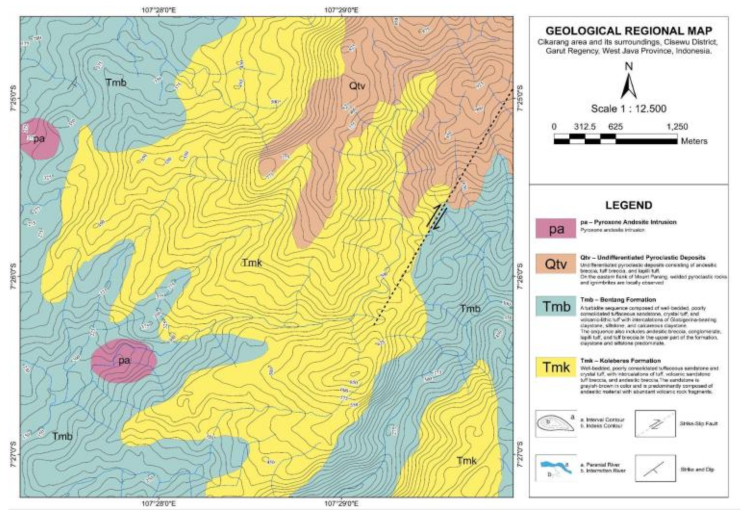

Figure 3. Geological map of the study area. Modified from the Geological Map of the Sindangbarang and Bandarwaru Quadrangles (Koesmono, 1996).

RESEARCH METHOD

This study integrates field methods and spatial data processing. Field data collection includes surface geological mapping at a scale of 1:12,500, outcrop observations, geological structure measurements, and rock sampling. Morphographic analysis was conducted by classifying landforms based on absolute elevation and valley morphology (Van Zuidam, 1985). The morphographic map was prepared using DEMNAS data processed with GIS software.

Drainage pattern analysis was carried out based on river pattern forms following the classification of Howard (1967). The river data used were obtained from RBI data of Garut Regency.

Morphometric analysis focused on slope gradient, which was classified into six classes: flat (0°–2°), gentle (2°–8°), moderately steep (8°–16°), steep (16°–35°), very steep (35°–55°), and extremely steep (>55°). Slope gradient values were obtained through GIS processing using the Slope function. This classification refers to a modification of Van Zuidam (1985) with adjustments for volcanic–structural terrains.

Morphogenetic analysis was conducted by identifying endogenic processes (volcanism and tectonics) and exogenic processes (weathering, erosion, and mass movement) based on lithology and geological structures.

Morphotectonic analysis was conducted by calculating four quantitative geomorphic indices (El Hamdouni et al., 2008 in Nugraha, R.P.D., 2023). The indices calculated include the Basin Shape Index (Bs), Valley Floor Width-to-Height Ratio (Vf), Asymmetry Factor (Af), and Mountain Front Sinuosity (Smf). The Valley Floor Width-to-Height Ratio (Vf) and Mountain Front Sinusicity (Smf) indices were calculated for the study area at a scale of 1:12,500, while the Basin Shape Index (Bs) and Asymmetry Factor (Af) were measured following the sub-watersheds included in the study area, which are Cilayu, Ciawi, and Cilaki, at a scale of 1:100,000.

RESULT AND DISCUSSION

Based on the integration of morphographic, morphometric, and morphogenetic analyses conducted on field data and remote sensing data, the geomorphological characteristics of the Cisewu area can be systematically described and interpreted. The following discussion presents the results of each analytical aspect and their synthesis into coherent geomorphological units. Morphographic analysis reveals variations in landforms and drainage patterns that reflect lithological and structural control.

Landforms

Based on elevation classification, the study area is dominated by two main landforms: high hills (500–925 m a.s.l.) and hills (200–500 m a.s.l.). High hills occupy the northeastern part (Gunung Tumpeng complex) and the southeastern part (along the Cilayu River), formed by resistant volcanic and intrusive rocks. This morphology is the result of tectonic uplift and magmatic intrusion followed by intensive denudation. Meanwhile, hills with moderate elevation dominate the central part of the study area, composed of more erodible volcaniclastic rocks, forming gentler morphology. Low hills (100–200 m a.s.l.) are only locally present in the southern and northeastern parts, generally associated with alluvial plains or rock bodies that have undergone very intensive weathering. The distribution of these landforms shows a strong correlation with lithological distribution and the presence of major fault structures (Figure 4).

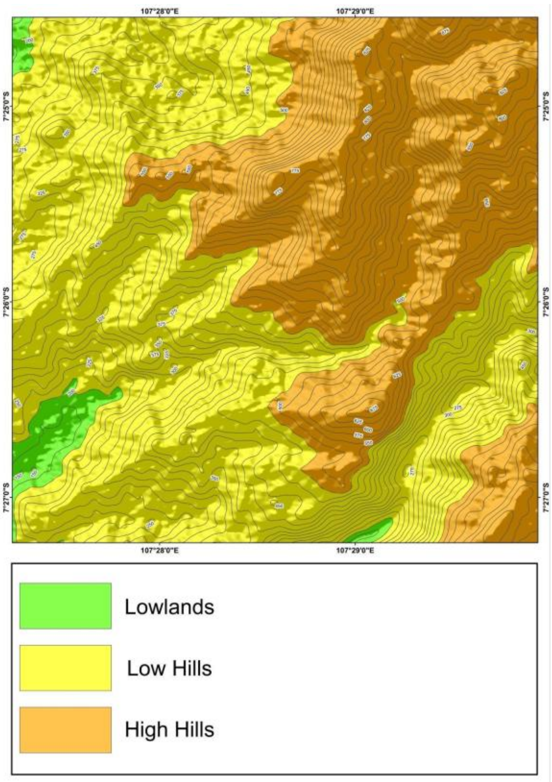

Figure 4. Landform map of study area showing low and high hills dominated (Scale 1:12.500)

Drainage Pattern

The drainage patterns developed in the study area are strongly influenced by geological structures and rock resistance (Howard, 1967; Van Zuidam, 1985). Rectangular and trellis drainage patterns dominate the study area, particularly in the southern and southeastern parts. These patterns are characterized by tributaries joining the main streams at near right angles, indicating strong control by joint and fault systems (Figure 4). Such patterns commonly develop in relatively homogeneous rocks that are dissected by discontinuous structures. In contrast, sub-dendritic drainage patterns are found around the andesite intrusive body (e.g., Gunung Tumpeng). This pattern indicates stronger lithological control than structural control, where massive and homogeneous intrusive rocks cause tributaries to join at more acute angles. The diversity of drainage patterns records the history of tectonic deformation and lithological variation within the study area (Figure 5).

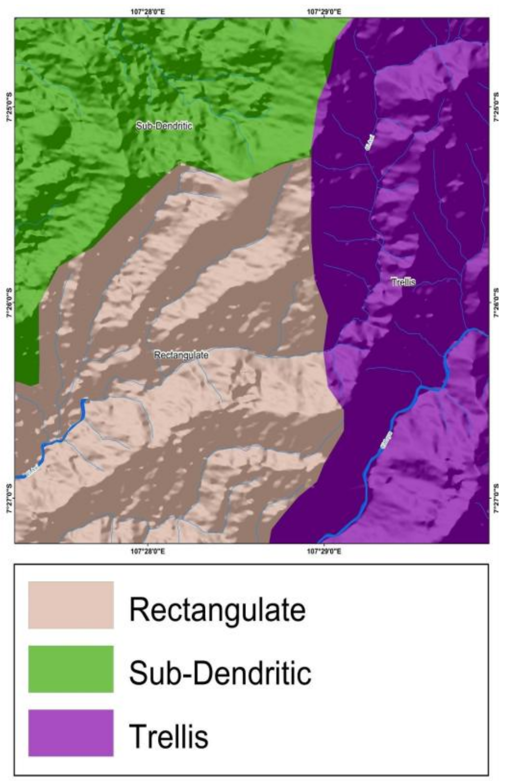

Figure 5. Drainage pattern map of study area (Scale 1:12.500)

MORPHOMETRY

Quantitative slope gradient analysis provides an overview of topographic steepness and its relationship with exogenic processes.

Slope Class Distribution

The DEM processing results show that more than 60% of the study area has steep (16°–35°) to very steep (>35°) slopes. These steep to very steep slopes are concentrated in the northern and southeastern parts. This distribution directly reflects the influence of resistant rocks such as andesite and volcanic breccia, as well as the influence of tectonic deformation that created uplift zones. Slopes with slightly steep (8°–16°) generally dominate areas undergoing moderate vertical erosion (depression) by river systems. Meanwhile, slopes that are flat to slightly sloped (0°–8°) only occupy very limited areas, mainly in the western part, which is dominated by tuff that is more easily eroded. The dominance of steep slopes has significant implications for landslide susceptibility if the constituent lithology is weathered rock and rainfall patterns are significant (Figure 6). weathered rock and rainfall patterns are significant (Figure 6).

MORPHOGENESIS

The development of the Cisewu landscape is the result of dynamic interactions between endogenic and exogenic processes.

Endogenic Processes

The most influential endogenic processes are volcanism and tectonics. Volcanic activity during the Late Miocene–Pliocene formed the main rock bodies, including andesite lava, volcanic breccia, and tuff. These volcaniclastic materials constitute the primary components in landform development. Subsequently, compressional tectonic activity associated with subduction generated northeast–southwest-trending strike-slip faults. Uplift along these fault zones formed elongated structural ridges and steep fault-controlled valleys, particularly along the Cilayu River. These tectonic processes are still relatively active during the Quaternary, as indicated by sharp geomorphological features and morphotectonic analysis results.

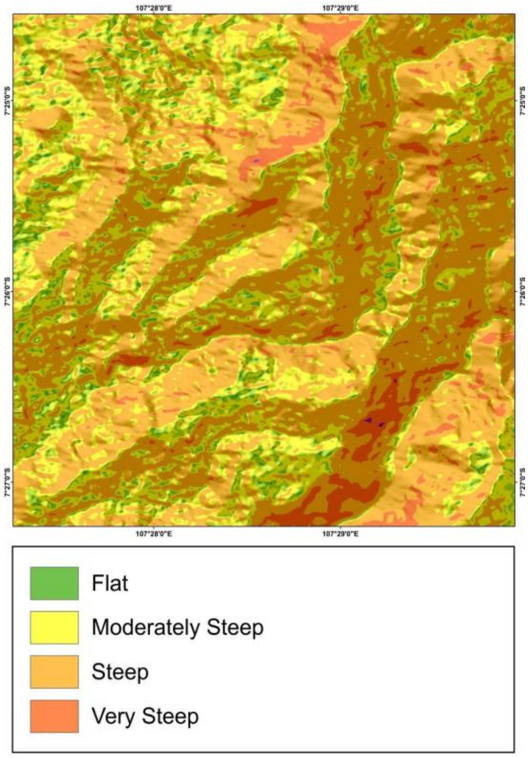

Figure 6. Slope Gradient Map of study area showing the dominance of steep to very steep slopes (Scale 1:12.500)

Exogenic Processes

Exogenic processes act as the main sculpting agents of the uplifted landscape. Chemical and physical weathering occur intensively in volcaniclastic rocks, producing thick soil mantles and loose materials that are easily eroded. Fluvial erosion is the most dominant exogenic process, forming deep V- and U-shaped valleys. Major rivers such as the Cilayu River undergo rapid downcutting in response to tectonic uplift. In addition, mass movement processes such as creep and landslides are very common on steep slopes composed of unconsolidated materials, widening valleys and narrowing ridges.

MORPHOTECTONICS

Quantitative morphotectonic analysis is an approach to determine the relative level of tectonic activity in a region that can be observed through the topography of an area (Nugraha, R.P.D., 2023). In this study, the analysis was carried out by calculating four main geomorphological indices following the methodology of El Hamdouni et al. (2008), which was applied to three sub-river basins for the Valley Shape (Bs) and Asymmetry Factor (Af) indices, namely the Cilayu River Basin in the east, the Ciawi River Basin in the centre, and the Cilaki River Basin in the west. The Valley Floor Width-Height Ratio Index (Vf) and Mountain Front Sinusicity Index (Smf) were also calculated for the study area. These four indices complement each other in providing an overview of relative tectonic dynamics and identifying active deformation zones. The values of these indices can also be influenced by lithological factors and valley filling processes, in addition to tectonic factors.

Basin Shape Index (Bs)

The Basin Shape Index (Bs) was calculated for the three sub-watersheds (Figure 7a.). The results show that the Cilayu and Ciawi sub-watersheds have a moderate tectonic class, while the Cilaki sub-watershed has a low tectonic class.

Asymmetry Factor (Af)

The results of the Asymmetry Factor (Af) calculation for the three sub-watersheds (Figure 7b.) show varying values but are classified as low tectonic class (Class 3) according to the criteria of El Hamdouni et al. (2008), with values ranging from 46 to 56.2.

Valley Floor Width-to-Height Ratio (Vf)

Based on the calculation of the valley floor width-to-height ratio, values ranging from 0.44–0.50 fall into the active tectonic class, values of 0.85–0.95 into the moderate tectonic class, and values of 1.06–1.61 into the low tectonic class. Areas with active–moderate tectonic classes are distributed in the eastern part, while moderate–low tectonic classes occur in the western part of the study area (Figure 7c.).

Mountain Front Sinuosity (Smf)

The results of mountain front sinuosity calculations show active tectonic class values ranging from 1.07–1.14, moderate tectonic from 1.10–1.40, and low tectonic from 1.60–1.75. Areas with active–moderate tectonic classes are distributed in the eastern part,

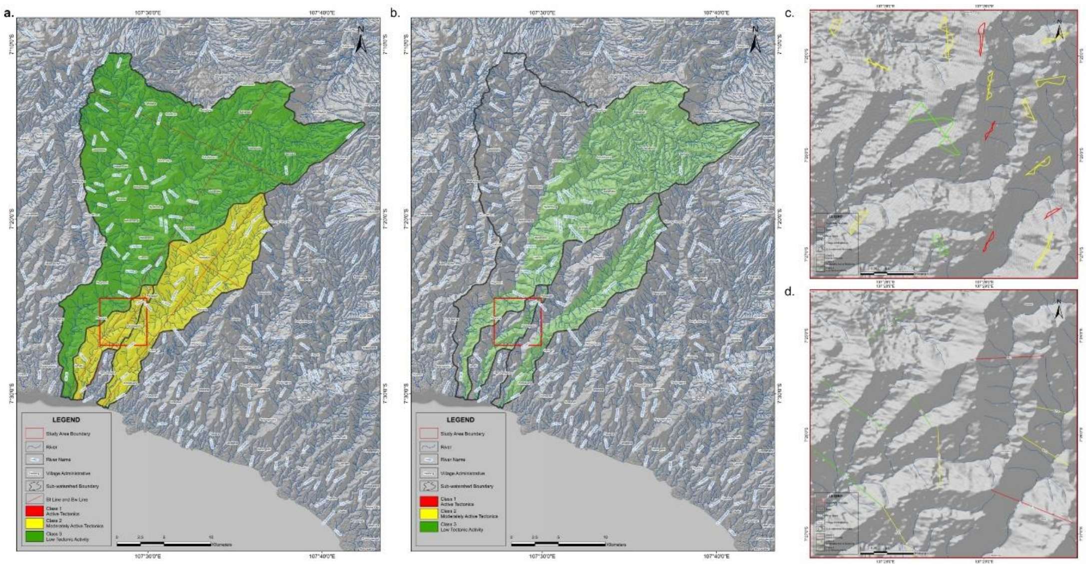

Figure 7. Maps of Geomorphological Indices of the Study Area Showing Bs index (a), Af Index (b), Smf Index (c), and Vf index (d).

whereas moderate–low tectonic classes are found in the western part of the study area (Figure 7d.).

Geomorphological Units

Based on the synthesis of all aspects discussed above, the study area can be divided into five geomorphological units, each of which has distinctive genesis, morphology, and dominant processes (Table 1).

Steep Volcanic Ridge Unit

This unit occupies the northern to northeastern part of the study area (Figure 8a.). It is composed of volcanic rocks (tuff, breccia, and andesite lava) resulting from Miocene–Pliocene volcanic activity. The main forming processes are volcanic accumulation and uplift, followed by denudation that shapes ridge morphology. Steep slopes (16°–35°) are controlled by rock resistance and jointing. Trellis to rectangular drainage patterns indicate the influence of secondary structures. This unit is relatively stable; however, it is susceptible to surface erosion and landslides in areas with weathered or brittle rocks.

Very Steep Structural Ridge Unit

The constituents of resistant rocks such as andesite, allowing the development of very steep slopes (35°–55°). Very deep and narrow V-shaped valleys are characteristic of this unit, indicating intensive fluvial downcutting that keeps pace with tectonic uplift. Trellis drainage patterns are well developed and reflect strong structural control. This unit represents the most tectonically dynamic unit and is located in the southeastern part along the Cilayu River (Figure 8b.). Its formation is primarily controlled by uplift along northeast–southwest-trending strike-slip faults. This unit has very high susceptibility to mass movement hazards and riverbank erosion.

Moderately Steep Volcanic Valley Unit

Occupying the southwestern and northwestern parts of the study area, this unit is composed of less resistant pyroclastic materials such as tuff and lapilli breccia(Figure 8c.). Gently sloping valley morphology with slope gradients of 8°–16° is formed through dominant lateral fluvial erosion acting on relatively soft and weathered rocks, resulting in wider U-shaped valleys. Structural control in this unit is not as strong as in the structural ridge unit. Exogenic processes such as weathering and sheet erosion are more dominant.

Very Steep Structural Valley Unit

Located within the Cilayu River, this unit is part of an active fault zone (Figure 8d.). Very steep slope gradients (35°–55°) result from concentrated vertical river erosion within weak zones (fault zones). Rocks along valley walls are composed of andesite. rellis drainage patterns indicate almost absolute structural control. This unit is highly susceptible to mass wasting processes and riverbank erosion.

Intrusive Dome Unit

This unit is represented by a pyroxene andesite intrusive body that intrudes surrounding rocks, forming a positive dome morphology such as Gunung Tumpeng (Figure 8e.). The main forming processes are magmatic intrusion and exhumation through denudation. Steep slopes (16°–35°) develop due to the high resistance of intrusive rocks. Sub-dendritic drainage patterns radiating from the dome summit reflect the massive and homogeneous nature of the intrusive rocks. This unit is geomorphologically stable; however, weathering processes along its margins may generate debris.

Figure 8. Appearance of geomorphological units in the study area, such as Steep Volcanic Ridge Unit (a), Very Steep Structural Ridge Unit (b), Moderately Steep Volcanic Valley Unit (c), Very Steep Structural Valley Unit (d), and Intrusive Dome Unit (d).

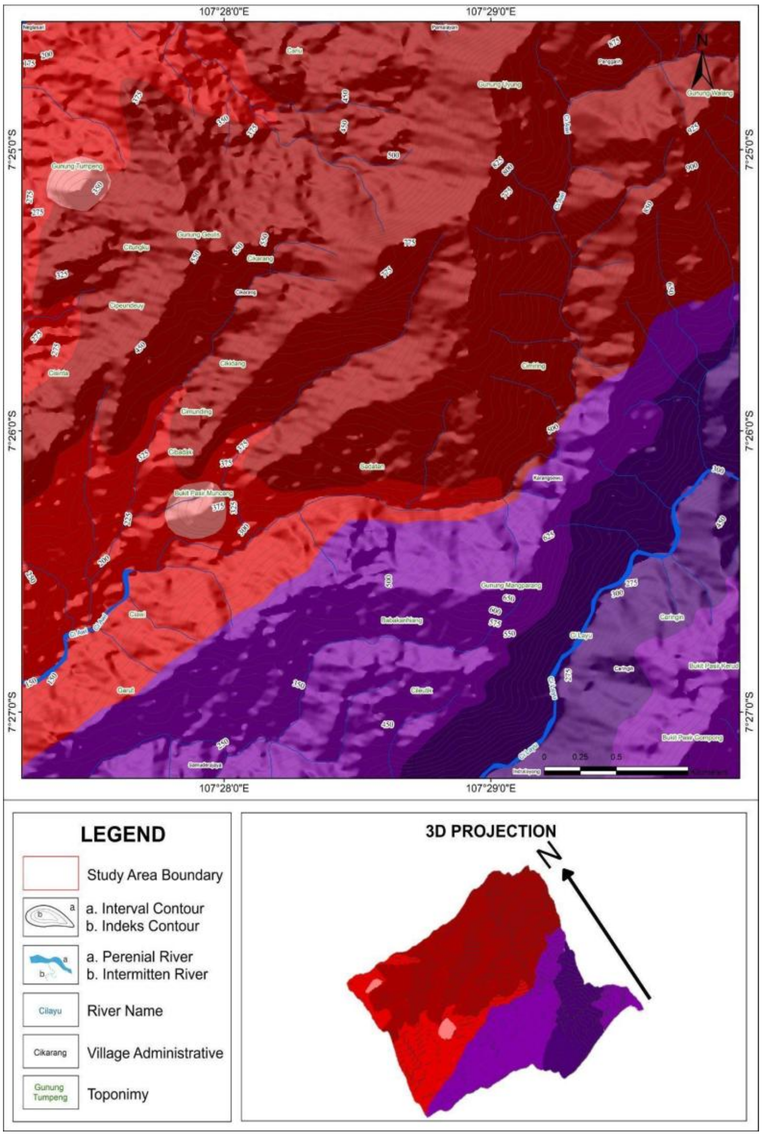

Figure 9.Geomorphological map and 3D projection of the study area

Table 1. Geomorphological units explanations

No	Geomorphological Unit	Symbol	Geomorphological Aspects						
			Morphography			Morphometry	Morphogenetic		
			Landform (masl)	Valley Shape	Drainage Pattern	Slope Class(°)	Endogenous	Exogenous	Constituent Lithology
1	Steep Volcanic Ridge		High Hills (500-925)	V	Trellis-Rectangular	Steep (16-35)	Volcanism		Tuff, Lapilli, Breccia, and Andesite Lava
2	Very Steep Structural Ridge		High Hills (500-675)	V	Trellis-Rectangular	Very Steep (35-55)	Tectonics & Volcanism		Andesite Lava and Tuff
3	Moderately Steep Volcanic Valley		Hills (150-500)	U	Rectangular	Moderately Steep (8-16)	Volcanism	Erosion & Weathering	Tuff, Lapilli, and Breccia
4	Very Steep Structural Valley		Hills (275-500)	V	Trellis	Very Steep (35-55)	Tectonics & Volcanism		Andesite Lava
5	Intrusive Dome		Hills (300-375)	V	Sub-Dendritic	Steep (16-35)	Volcanism		Pyroxene Andesite

CONCLUSION

Based on the integrated analysis of morphography, morphometry, morphogenesis, and morphotectonics, this study concludes that the geomorphology of the Cisewu area consists of five main units formed by the interaction between Late Miocene–Pliocene volcanism and northeast–southwest-trending strike-slip fault tectonic deformation. The drainage pattern is rectangular and trellis-shaped, with steep slopes forming a sharp V-shape on relatively hard andesite rock. This is interpreted as having resulted from geological structural control and is supported by geomorphic indices (Bs, Vf, Af, Smf) indicating relative Quaternary tectonic activity in the Cilayu River, located in the eastern part of the study area. The dominance of steep to very steep slopes and active tectonic conditions increases the susceptibility of the area to landslides. The results of this study can serve as a scientific basis for spatial planning and disaster mitigation in southern West Java.

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GEOMORPHOLOGICAL CHARACTERISTICS OF THE PASIRPANJANG AREA AND ITS SURROUNDINGS, CIRACAP, CILETUH, SUKABUMI DISTRICT, WEST JAVA PROVINCE

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ABSTRACT

The study site is considered in the Pasirpanjang and its environs area of Ciracap District, Sukabumi Regency, West Java which has a geomorphologic diversity that could be affected by endogenic and exogenic processes. Therefore, the objectives of this study are to determine the geomorphological features of the area by using morphographics, morphometrics and morphogenetic aspects. We analysis DEM, obtain field data and a review of literature is made. Morphographic analysis consists of landforms and river flow patterns, morphometric analysis includes slope gradients and morphogenetic anlayisis arranges lithology, geological structure and river flow patterns. Study result indicates truly cartographic aspects of the terrain are two types: low hills and high hills; subdendritic and rectangular patterns with changes in slopes ranging from gentle to steep. The geology in the region of the outer rim is caused by tectonic and volcanic activity, as well as exterior weathering and erosion still occurring. The study area is divided into three major geomorphological units depending on combination of these 3 geomorphologic attributes. The findings contribute to a significant geomorphological interpretation that can serve as an important reference for land use planning and mitigation of potential geomorphologic disasters, as well as the advancement of applied geological researches in the Ciracap area and its adjacent locations.

Keywords: DEM, Drainage Patterns, Geomorphology, Pasirpanjang, Sukabumi

INTRODUCTION

The study of the surface of the Earth's shape and the endogenous and exogenous processes that shape it is known as geomorphology (Rafli, D., et al., 2024). This is consistent with Verstappen's (1983) claim that geomorphology is concerned with the origins and development of landforms that arise above and below sea level. In modern geomorphological research, morphographic, morphometric, and morphogenetic methods are used for both descriptive and quantitative analysis. Although the morphological method is used for analyzing topographic parameters such as elevation and slope gradient calculated using DEM (Digital Elevation Model) data, an morphographic approach is used for recognizing and describing landforms. The process of landform formation based on the result of lithology, geological structure, and other geological processes can be clarified by morphogenetic analysis. Because it offers a more thorough and organized picture of geomorphology, this combination of three methods was selected.

As Digital Elevation Models (DEMs) offer detailed topographic information that can be used to derive terrain attributes like slope, aspect, and elevation— which are essential to landform analysis and the interpretation of geomorphic processes—the use of DEM data in geomorphological mapping has advanced in its significance (Wilson & Gallant, 2000). However, the application of DEM-based geomorphological approaches in the Pasirpanjang Village area and its surroundings, Ciracap District, Sukabumi Regency, is still limited. Astronomically, it is located at coordinates 106°30′0.52′′ – 106°32′47.35′′ East Longitude and

7°16′56.37′′ – 7°19′40.12′′ South Latitude. Therefore, this study offers novelty through the integration of morphographic analysis, DEM-based morphometry, and morphogenetic interpretation in geomorphological mapping. This study aims to identify and classify geomorphological units in the study area, with the final result being a geomorphological map equipped with lithological information on each unit.

Regional Geology

In a physiographic study, Van Bemmelen (1949) classified the West Java region into five main zones: the Jakarta Coastal Plain Zone, the Bogor Zone, the Bandung Zone, the Bayah Mountains Zone, and the Southern Mountains Zone. The study area is included in the Southern Mountains Zone, which was formed by subduction activity between the Indo-Australian Plate and the Asian Plate in the Late Oligocene. This zone stretches from west to east following the path of Java Island (Van Bemmelen, 1949).

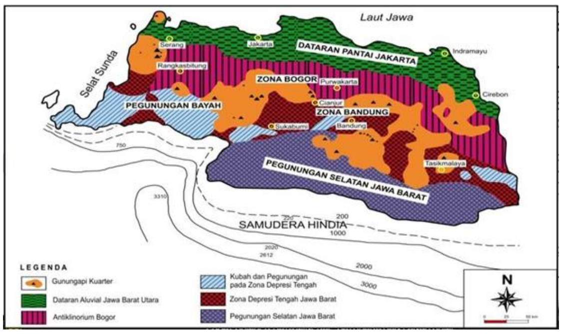

Figure 1. Physiography of the West Java Region (Van Bemmelen, 1949).

Based on Sukamto (1975), on the regional geological map of the Jampang and Balekambang sheets, the research area consists of four formations from the oldest to the youngest, namely the Jampang Formation, Cikarang member (Tmjc), which has the same age as the Cilegok porphyry (Tmcs), the Cibodas formation (Tmcs), and the Citanglar coastal deposits (Qpcb), where the research area is dominated by the Jampang Formation, Cikarang member (Tmjc) (Figure 2). The Southern Mountains Zone experienced three distinct tectonic stages between the Oligocene and Quaternary periods, as described by Van Bemmelen (1949), with tectonic activity frequently associated with volcanism. Combined petrographic, petrological, and biostratigraphic analyses have contributed substantially to elucidating carbonate depositional systems, volcanic controls, and stratigraphic framework in southern West Java, particularly within the Cibodas and Jampang Formations (Prinaldi et al., 2023; Pratiwi et al., 2023; Maulana & Pratiwi, 2024; Pratiwi et al., 2024; Ramdhani et al., 2024).

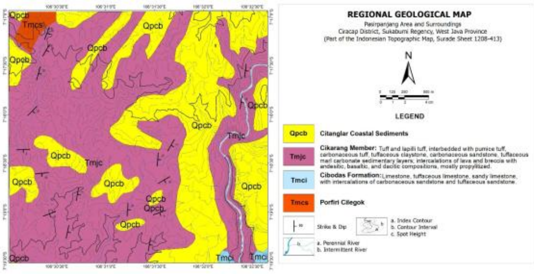

Figure 2. Regional Geological Map of the Research Area

The Jampang region in Sukabumi Regency is part of the Southern Mountains Physiography Zone of West Java, which exhibits diverse landforms and geological settings. Based on geological research in several parts of Jampang (including Central Jampang and West Jampang), the morphology of this area was developed by a combination of tectonic and exogenous processes that interacted over a long period. Local geomorphology is often seen as folded and faulted hills and alluvial plains that reflect the tectonic and sedimentary history of this region, showing the dominance of folded rock settings, faults, and various geomorphological units of varying stages of formation.

RESEARCH METHODS

Digital Elevation Model (DEM) data, geospatial data processing software, field observation data, and a review of necessary earlier studies were used to support the qualitative and quantitative methods used in this study's geomorphological analysis. In order to identify geomorphological features in the study area, geomorphological units were categorized according to morphographic, morphometric, and morphogenetic aspects to make the analysis process easier.

The first stage, morphographic analysis, was carried out by recognizing drainage patterns, valley shapes, and landforms. To improve the results, the drainage network was manually digitized after being automatically extracted from the DEM. The drainage results were validated by comparing them to the Indonesian Topographic Map (RBI) and adjusting them to field conditions. Drainage patterns were classified according to Howard (1967) in Van Zuidam (1985).

Second aspect Morphometric analysis was performed by calculating slope gradients from the DEM using GIS software. Slope values were expressed in degrees and classified according to Van Zuidam (1985), with slope classes ranging from 0° to >55°. The analysis results were then adjusted to field conditions and manually digitized using ArcGIS, and presented as a slope map.

$S = \left(\frac{(n-1).lc}{dx.sp}\right) \times 100\%$ (*Van Zuidam (1985)*)

Where,

S : Slope gradient in percent (%)

n : Number of contours cut by the line

lc : Interval contour

dx : Jarak lateral

sp : Map scale

Third aspect Morphogenetic analysis was conducted by linking the results of morphographic and morphometric analyses with lithological conditions and geological structures. Field data were obtained from 122 observation stations, including observations of lithology, valley shape, and geological structures, and were used to validate the results of the geomorphological analysis.

RESULTS AND DISCUSSION

Morphography or landscape is a primary parameter in geomorphological analysis, distinguished by variations in the relative elevation of the earth's surface. Referring to the Van Zuidam (1985) morphographic classification modified by Ike Bermana (2006), the study area has an elevation of ±50–263 masl and is divided into two landscape units: low hills (50–200 masl) and hills (200–263 masl). Spatially, low hills dominate the southern part of the study area, while hill units develop in the northern part (Figure3).

The lithology and weather resistance of the rock are closely linked to these variations in landforms. While hill units are made up of non-carbonate sandstones and igneous rocks that typically form steeper relief, low hill units are typically made up of relatively resistant carbonate sandstones and tuffs.

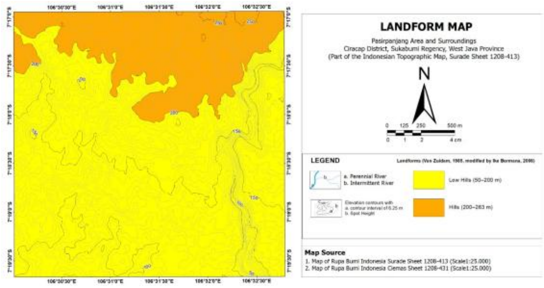

Figure 3. Landform Map of the Research Area

The relationships between landforms, slope gradients, lithology, and geological structures are reflected in river flow patterns. According to the analysis, there are two primary drainage patterns in the study area: rectangular and sub-dendritic (Figure 4)

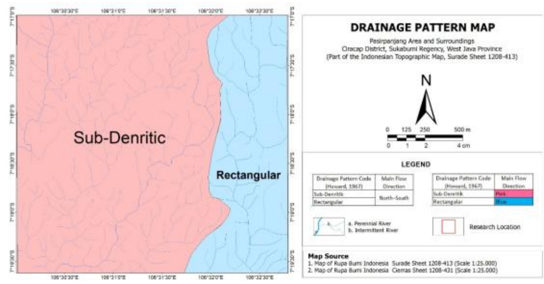

Figure 4. Map of Flow Patterns in the Research Area

The research area's central-western region, particularly the Cibalengbeno and Cidadap Rivers, is where the sub-dendritic pattern primarily forms. This pattern appears in U-shaped valleys, gentle to undulating slopes, and relatively homogeneous lithology. The lithology distribution map, which demonstrates the dominance of uniform rock units in the zone, supports this lithological homogeneity. As a result, the river flow develops freely without strong structural control and forms branches that resemble sub-dendritic.

In contrast, the eastern portion of the study area—especially the Cikarang River—develops a rectangular drainage pattern. The alignment of river flow direction with the orientation of the cracks and faults in the field (Figure 6) indicates that this pattern is governed by geological structures in the form of dominant cracks and faults. Because of structural control and the predominance of vertical erosion, rivers in this zone typically form right-angled bends with V-shaped valleys. A parallel tendency can be seen when comparing the azimuth of river flow and the orientation of cracks and faults. The main cracks in the rose diagram, which are oriented NW–SE and NE–SW, are parallel to the structurally controlled river segments, which are primarily oriented north–south to NE–SW. This indicates that geological structures have an impact on drainage development in this zone.

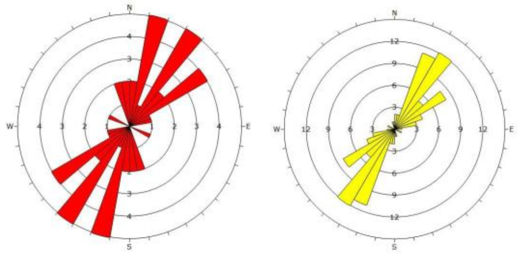

Figure 6. Valley and ridge Rosette diagram of the Research Area

Slope gradients were computed using DEM data for morphometric analysis, and the results were then categorized using the Van Zuidam (1985). The analysis's findings are displayed as a slope map (Figure 6). The study area is divided into three slope classes. The study area's central to southern regions have gentle slopes (4°–8°), which are connected to low to undulating hill units.

Particularly in the central to northeastern and northwestern regions of the study area, zones impacted by lithological and structural controls give rise. Hard rocks and active geological structural zones are linked to extremely steep slopes (16°–35°) that develop longitudinally in a north–south direction. Narrow valleys, steep cliffs, and intense erosion are typical characteristics of this zone.

This slope distribution indicates a strong relationship between morphometry, lithology, and structural processes in the formation of the landscape of the study area.

By contrasting information on the evolution of river flow patterns with the features of its component lithologies, morphogenetic analysis was carried out in the study area. This area is impacted by both exogenous processes like weathering and erosion, which are still going strong today, and endogenous processes associated with tectonic activity, as shown by field structural data such as cracks, fault mirrors, and other fault indications.

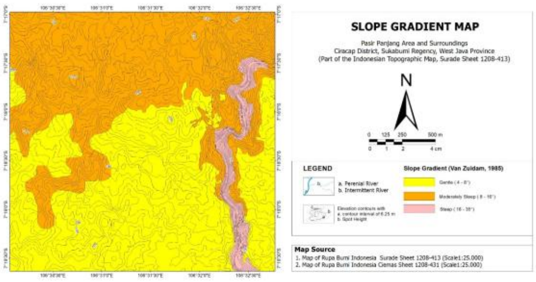

Figure 6. Slope Map of the Research Area

Endogenous processes play a role in shaping the morphology of the study area, primarily through tectonic and volcanic activity. The influence of tectonism is quite dominant, as indicated by the presence of cracks, fault mirrors, and waterfalls in several study locations. However, this tectonic control is not intensively developed, as reflected in the relatively uniform layering pattern with a nearly horizontal dip, indicating a low level of structural deformation. Volcanic processes also contribute, albeit on a limited scale, as indicated by the presence of basaltic lava in the northwest part of the study area, as well as the dominance of pyroclastic material such as lapilli tuff in the constituent rocks.

Exogenous processes are the dominant factors in the morphology of the study area, including weathering, erosion, and sedimentation. Weathering is characterized by changes in rock color and hardness, occurs primarily laterally, and forms U-shaped valleys, with mechanical, chemical, and biological types, including spheroidal weathering. Subsequent erosion and sedimentation processes form a low, undulating hilly landscape.

The geomorphology of the study area is influenced by three main aspects: morphography, morphometry, and morphogenetics, and is supported by analysis of river flow patterns, ridge and valley shapes, and lithology distribution. Based on this analysis, the study area consists of three geomorphological units: low and rather steep structural hills, gentle denudation hills, and low, gentle, and undulating hills (Figure 7 and Table 1).

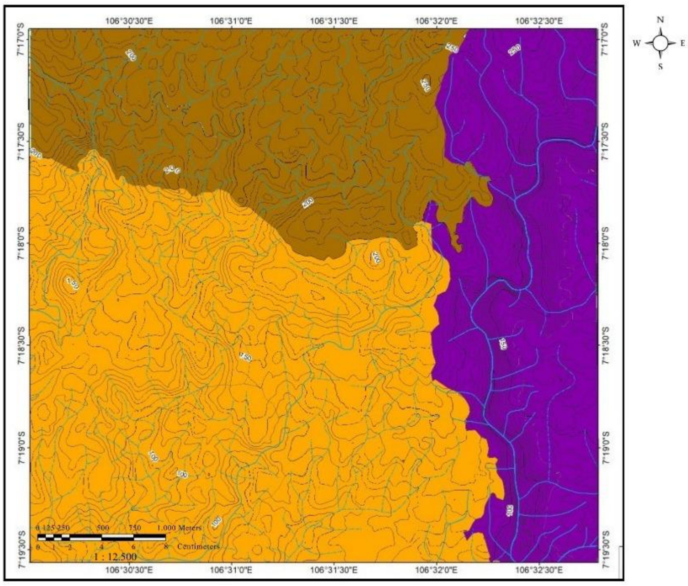

Figure 7. Geomorphological Map of the Research Area

Table 1. Geomorphological Units of the Research Area

Geomorphology								
Geomorphological Unit	Color Symbol	Morphography			Morphometry	Morphogenetic		
		Landform	Valley Shape	Drainage Pattern	Slope Gradient	Endogenic	Eksogenic	Lithology
Steep Structural Low Hills	(purple)	Low Hills	v	Trellis	Steep (16-35°)	Tectonic		Carbonaceous Sandstone and Tuff
Moderately Steep Denudational Hills	(brown)	Hills	u	Sub-Denritik	Moderately Steep (8-16°)		Weathering and Erosion	Non-carbonaceous Sandstone, Tuff, and Intrusive Igneous Rocks
Undulating Gentle Low Hills	(yellow)	Low Hills	u	Sub-Denritik	Gentle (4-8°)	Tectonic		Sandstone and Tuff

Low Hills Structural Steep

This low hills, somewhat steep structural hill geomorphological unit covers approximately 19% of the total study area and stretches from north to south, following the Cikarang River as the main river. Based on field observations, this unit is characterized by low to hilly forms with altitudes ranging from 150–260 meters above sea level and relatively steep slopes, namely around 16°–36°. The geomorphological formation process in this unit is mainly controlled by geological structural activity, especially the presence of faults or cracks that play a role in controlling river flow patterns, thus forming rectangular flow patterns. The valleys that develop in this area generally have a sharp V-shaped cross section, as a result of the dominance of vertical erosion processes. The lithology that forms this unit is sandstone, which has the potential as a source of mining materials, especially for construction purposes. The villages included in this unit are Kadaleman, Caringinnunggal, and Surade.

Denudational Slightly Steep Hills

This slightly eroded hilly geomorphological unit occupies approximately 21% of the study area and is spread from north to northwest. This unit is characterized by hills with an altitude of 200–263 meters above sea level and a relatively steep slope gradient (8°–16°). Its formation is dominated by exogenous processes such as physical, chemical, and biological weathering, as well as erosion. The valleys formed are generally blunt U-shaped due to the dominance of lateral erosion and relatively stable morphological conditions. The drainage pattern is sub-dendritic and relatively regular, so it is utilized by the community as an irrigation system. The constituent lithology consists of sandstone and extrusive igneous rocks that have undergone mechanical weathering and oxidation. The village included in this unit is Cibenda Village.

Low, gently undulating hills

The gently undulating low hills geomorphological unit occupies approximately 60% of the study area and is distributed in the southwest to the central part. This unit is characterized by low hills with an altitude of 50–200 meters above sea level and a gentle slope (4°–8°). Its formation is influenced by endogenous and exogenous processes, but the latter is more dominant due to relatively weak tectonic activity. The formed valleys are generally blunt U-shaped due to the dominance of lateral erosion and stable morphological conditions. The drainage pattern is sub-dendritic and relatively regular, making it suitable for agricultural irrigation. The lithology consists of sandstone and tuff that have undergone mineral alteration. The villages included in this unit are Pasirpanjang, Mekarsari, and Purwasedar.

CONCLUSION

The Pasirpanjang region and its environs display geomorphological features created by the interplay of endogenous and exogenous processes that are still in effect today.

The integration of morphographic, DEM-based morphometric, and morphogenetic analyses shows that dominant denudation processes, lithology variations, and the intensity of geological structures govern landform development.

The study area can be divided into three primary geomorphological units based on these integrated results: low, gently undulating hills, moderately steep denudational hills, and low, steep structural hills. Through the use of an integrated geomorphological approach based on DEM evaluated by field data, this study contributes to scientific research by producing a more detailed and representative classification of geomorphological units. The findings are anticipated to provide a framework for future geological research, resource management, regional planning, and disaster mitigation in the Ciracap region and surrounding area.

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THE INFLUENCE OF SEDIMENTATION ON SALINITY VARIATION IN THE EAST KUTAI BASIN, EAST KALIMANTAN, INDONESIA

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ABSTRACT

The East Kutai Basin represents a major deltaic system formed under strong river-dominated sedimentary processes, characterized by long-term progradation from marine to terrestrial environments. In such deltaic settings, salinity distributions are generally expected to exhibit systematic lateral and vertical trends, with freshwater dominating proximal facies and saline water occurring in distal marine facies. Vertically, salinity typically increases with depth as a result of progressive progradation through time. This study investigates lateral and vertical salinity variations within the East Kutai Basin and evaluates their relationship with sedimentary facies distribution. Salinity data were obtained from formation water analyses and apparent water resistivity (Rwa) calculations derived from resistivity logs using Archie's equation. These datasets were integrated with net sand maps and electrofacies interpretations to examine salinity patterns across multiple stratigraphic intervals. The results show that while the general lateral trend of low salinity in channel facies transitioning to higher salinity in mouth-bar facies is preserved, significant anomalies are observed. Laterally, mouth-bar deposits locally exhibit unexpectedly low salinity values, approaching those of channel facies. Vertically, salinity decreases with increasing depth in several stratigraphic groups, contrary to the expected progradational model. These anomalies are interpreted to reflect lateral shifting of depositional environments during delta progradation and the expulsion of low-salinity compaction water from overpressured prodelta shales into adjacent sand bodies.

Keywords: East Kutai Basin; deltaic system; salinity anomaly; sedimentation; water resistivity

INTRODUCTION

Salinity distribution in sedimentary basins is closely linked to depositional environments, sedimentary processes, and post-depositional fluid migration. In deltaic systems, lateral salinity variation commonly reflects facies distribution, with freshwater typically associated with proximal fluvial or channel deposits and saline water associated with distal marine deposits such as mouth bars. Vertically, salinity is generally expected to increase with depth in progradational deltaic settings as older, more marine-influenced sediments are buried beneath younger terrestrial deposits. These concepts have been widely applied in deltaic basin analysis and reservoir characterization.

The East Kutai Basin is a major Tertiary sedimentary province located in Kalimantan, Indonesia, which initiated during the Middle to Early Eocene (Moss & Chambers, 1999; Permana, 2018). Structurally, the basin is bounded by the Mangkalihat High to the north, the Paternoster Ridge to the south, the Kuching High to the west, and the Makasar Straits to the east. Characterized as the deepest Tertiary basin in Indonesia, the East Kutai Basin accumulated significant sediment thickness of approximately 13,700 meters (Adli et al., 2021).

The basin represents a large river-dominated deltaic system that developed through repeated progradation cycles. Previous studies have described its depositional architecture, reservoir characteristics, and stratigraphic framework, yet detailed evaluation of salinity distribution and its deviation from conventional models remains limited. Observations from well logs and formation water analyses indicate that salinity patterns in the East Kutai Basin do not always conform to expected lateral and vertical trends.

Several anomalies have been identified, including low-salinity water occurring within mouth bar facies and decreasing salinity with increasing depth in certain stratigraphic intervals. Understanding the origin of these salinity anomalies is important for reconstructing basin evolution and for improving reservoir characterization in deltaic systems.

The objective of this study is to analyze lateral and vertical salinity variations in the East Kutai Basin and to interpret their relationship with sedimentary facies and depositional processes. By integrating salinity data derived from logs and fluid analyses with facies interpretation and net sand mapping, this study aims to identify the geological mechanisms responsible for salinity anomalies in the basin.

A. Research Area Setting

East Kutai Basin is a giant field that contains gas and condensate located on the Eastern boundary of the Mahakam Delta. This field is located in North-South direction, with a length of 75 km and 15 km wide, covers a surface of approximately 1000 km^2 along the median axis in the Mahakam Delta. East Kutai Basin located between the anticline axis trending NNE - SSW, and included in the median axis (Nugrahanto et al., 2023). This basin is also located broadly in the Eastern part of the Mahakam Delta and the direction of the axis syncline within 15 km towards the Western part of the basin. East Kutai basin geological structure consists of two main parts, as follows:

a. Northern part of East Kutai Basin is an anticline structure which extends along 30 km, separated from southern part of East Kutai Basin and adjacent to the fault structure on the northern part of the Mahakam Delta.
b. Southern part of East Kutai Basin is more flat anticlinal structure with a length of 40 km and 7km width.

East Kutai Basin stratigraphy is divided into several zones:

a. Shallow zone: the zone from the surface to the base of Pliocene rocks.
b. Freshwater zones: the zone which lies between the upper Miocene sediment and unconformity surface at 7 Mya.
c. Main zone:
   Upper: between the flooding surface in 7.3 Mya until 9.5 Mya.
   Lower: between the flooding surface in 9.5 Mya until the unconformity surface at 10.5 Mya.

The main zone of East Kutai Basin can be found at a depth between 2,200 m to 5,000 m. The main zone is vertically divided into six stratigraphic units, with each thickness ranged from 300 m until 400 m. Each unit is divided into several sequences within 30-50 m of thickness which limited by flooding surfaces.

B. Depositional Environment and Reservoir Type in East Kutai Basin

Vertically, the whole of East Kutai Basin has progradation model, but on a smaller scale, the cycle pattern of sand retrogradation-progradation cycle are changing as the response of equilibrium between the eustatic variations (changes in sea level relative), the comparison of subsidence (decrease), and also sediment supplies (Permana, 2022). Laterally, most areas of western part in East Kutai Basin are represented by upper delta plain reservoir to delta front proximal part (the part near the delta plain) in the form of channel and mouth bar accumulations. On the east side, delta front sediment in distal part is more dominating. Mouth bar sediment in distal part is dwindling and isolated. Types of reservoirs at East Kutai Basin consist of:

a. Channel

Reservoir in the form channel is sand stone with grain size ranged from coarse sand to fine sand, medium rounded grain shape, well sorted, compact, good porosity (Walker, 1992; Serra, 1990). Coal is found in some areas and in little calcium carbonate is present in the upper part. Channel sediment has an average thickness of 7-20 meters. Cross-section channel sediment can have a thickness ranging up to 30 meters, and have been found at this East Kutai Basin. Channel sediment characterized by fining upward on gamma ray log. Average porosity of the channel sediment which has the thickest and the lowest shale is approximately 15%-27% with average permeability of 100 mD–maximum 1D (Sangree at all., 1993). The geometry model of channel reservoir currently resembles to lateral bar, which in the modern East Kutai Basin has length1-3 Km and width of 300-700 m.

b. Mouth Bar

Mouth bar is large sand stone composed of fine-very fine grain size with medium rounded grain shape, well-sorted, compact, and medium porosity (Walker, 1992). A reservoir in the form of mouth bar has thickness ranged between1 m to5m and average thickness of 3 meters. The maximum sediment accumulation in the mouth sediment can reach until 15meters of the thickness. This sediment facies usually has coarsening upward characteristics in gamma ray log. The thickest and the lowest shale-contain in mouth bar sediment is approximately 13%-18% with an average permeability of 10 mD to 200 mD maximum (Harsono, 1997).

C. Salinity and Facies in East Kutai Basin

In general, the content of salinity in East Kutai Basin varies from west (toward land) to east (toward sea) with the change in lateral facies types. Based on data from the current salinity, lateral variations show that salinity has a basic pattern change that associated to the type of facies. The area containing fresh water in proximal and the area containing saline water in distal. Channel facies generally has low salinity content and gradually increased to the marine environment which is characterized by mouth bar facies.

Based on geological overview, salinity content in East Kutai Basin should increase with depth as the progradation process that happens along the time. In reality, these conditions are not found as the discussion above. Based on the data that has been calculated (salinity from both log and fluid analysis) found the anomalies of salinity data. Lateral variations indicate anomalies such as mouth bar facies which have low salinity content approaching salinity content contained in the channel facies, as well as vertical variations indicate anomalies that show a decrease in the salinity content with increasing depth. These variations arise as a result of several possible factors from facies position and geological phenomenon that have occurred to date.

RESEARCH METHOD

The object of this study is the salinity anomalies in the existed facies types, primarily in mouth bar facies and channel facies. Three data used in this study: salinity data, net sand maps, and completion of log data.

Salinity data found from log fluid analysis. This data serves as quantitative data and basic data which must then be connected in geology, especially towards the interpretation of depositional environments. Calculation salinity of log known as Rwa Method or apparent Rw. Salinity content can be searched by calculating Rwa (water resistivity) from Log Resistivity by using Archie formula (Maurice, 1982). Calculations based on resistivity logs can be done if it meets the following requirements:

a. Reservoir thickness > 2 meters.

b. Layer with a low clay content of volume (low Vsh)

c. Water bearing sand, Sw = 1 (it is believed that the reservoir is fully of water)

Net sand maps are used from selected layers in accordance with the adequacy of salinity data on each layer. Net sand maps are utilized as illustrations of facies, thickness, and overview of research areas for the spread of salinity content in each layer. Completion log data is a standard final display combined log that has been analyzed and used for geological purposes. In the study, the data used to determine the completion log facies types according to their characteristics and is also used as a log correlation of adjacent wells to determine the circumstances surrounding the well. 19 maps were chosen from East Kutai Basin. More than 700 salinity data from the calculation of resistivity logs used in this study.

RESULT

Based on the calculation of salinity data from log and fluid analysis, the range of salinity at each layer is presented in Figure 1. In this study, layer means there presenting delta cycle vertically based on the character electro facies. The layers are divided into three groups:

Group I consist of layers 1A, 1B, and 1C, Group II consists of layers1G and 3A, and Group III composed of layers of 4A up to 5C. The groups are divided based on the difference obtained from the analysis and geological interpretation.

No.	Layer	Salinity (kppm)
1	**1A**	2.48 – 20.91
2	**1B**	2.9 – 21.76
3	**1C**	2.82 – 19.98
4	**1G**	3.72 – 24.46
5	**3A**	5.34 – 18.87
6	**4A**	3.81 – 18.3
7	**4B**	2.74 – 18.25
8	**4C**	4.44 – 16.52
9	**4D**	4.79 – 17.15
10	**4E**	5.77 – 15.64
11	**4F**	4.47 – 16.66
12	**4G-1**	5.02 – 13.57
13	**4H**	5.93 – 13.88
14	**4H-1**	6.62 – 14.45
15	**4I**	3.76 – 13.58
16	**4J**	4.21 – 13.57
17	**5A**	4.91 – 11.04
18	**5A-1**	4.36 – 12.15
19	**5C**	3.62 – 10.36

Figure 1. Distribution of salinity values across stratigraphic layers in the East Kutai Basin based on log- and fluid-derived data.

A. Relation Between Facies and Salinity in Group I

This group is an ideal example of the variation in salinity and associated with the depositional setting from land to sea, also of geological events that affect the variation of the salinity content.

The spread of salinity content in the northern part of East Kutai Basin in this group generally has low salinity content compared to the south. The northern part is dominated by fresh water while the southern part has noticeable variations, even seen the high content of salinity in particular points.

The result of analysis through geological approach identifies that the sediment influx from fluvial is more dominant in influencing the northern area than in the southern area.

This is supported by nets and map layer 1A that represents this group (Figure 2), which shows the volume of accumulated sediment greater in the northern area than in the southern area. This group was likely a result of Nillam Lineament formation showing increased accommodation space for sediment deposition. Thus, it can be seen that the influence of fluvial sediment looks very dominant in the northern area even though the area is in the most distal position.

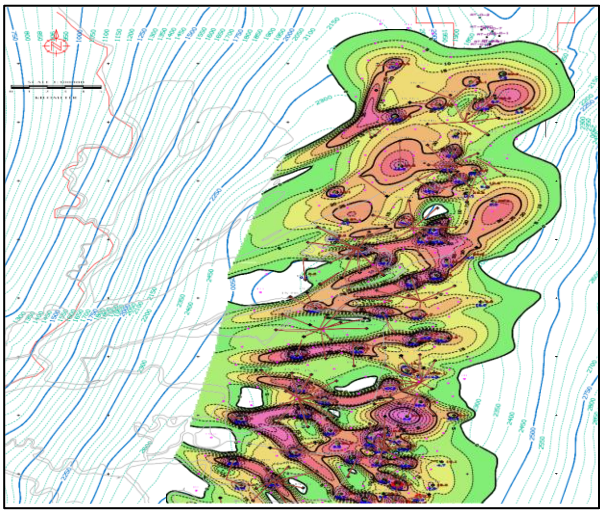

Figure 2. Net sand thickness map of Layer 1A showing sediment distribution and dominant depositional areas in the northern part of the East Kutai Basin.

In this group, anomalies appear as channel sediment that has high salinity content. This is opposite with the mouth bar sediment that has low salinity content. The channel sediment appears with the salinity content that varies depending on the position. The emergence of the channel sediment that has high salinity content is influenced by its own position in distal area, which effected by the sea (Figure 3.b and Figure 4.a).

The mouth bar sediment with low salinity content appears as the result of channel present influence on landward which then lowers the salinity content of the mouth bar sediment (Figure 3.a) and Figure 4.b). The influence of the river along with progradation causes the mouth bar sediment which previously formed in distal turns in median or proximal (landward).

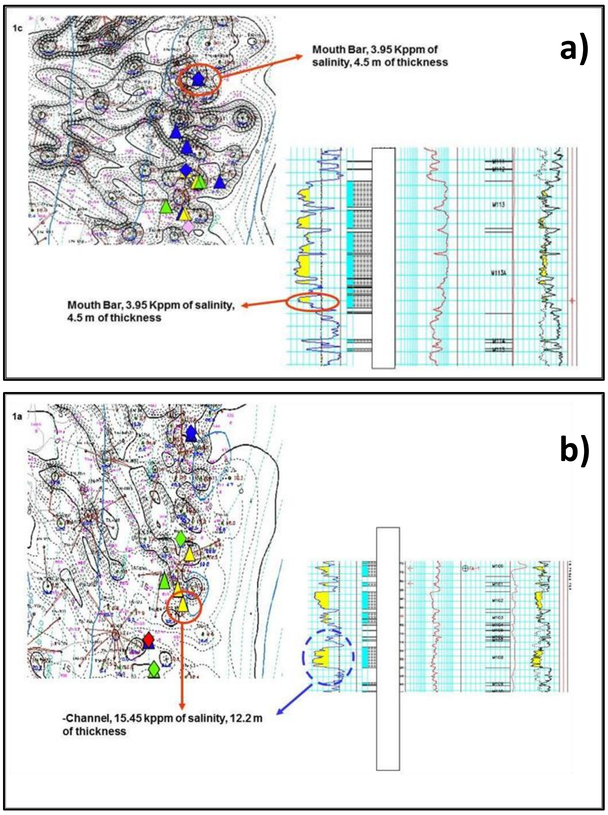

Figure 3. Example of mouth bar facies exhibiting a) low salinity and b) high salinity values in Group I stratigraphic interval.

B. Relation Between Facies and Salinity in Group II

In Group II, the spread of salinity content is varied. The 1G layer starts to change its salinity content spread pattern, whereas in layer 3A the salinity content looks more varied throughout the area. At this layer 1G, variations of salinity content in the northern part began to appear, but still more "fresh" compared to the south. Area with fresh water that looks a little more dominant still appears in the middle region with the distribution of low salinity content in distal position of this layer. This means that the influence of sediment from land or river is still dominant in this middle section. The thickness for the northern region is still thicker than the southern region in this 1G layer.

Channel sediment and mouth bar sediment relatively appear with high salinity content by way of average ranging between 11-16 kppm seen on layer 3A.

The spread of salinity relatively has uniform content in a linear line. Channel sediment and mouth bar sediment have adjacent range of salinity content, this happens because the deposition position is contiguous but both still have visible pattern of increase in salinity towards the sea (eastern part). In layer 3A is not found any striking anomaly. The spread of salinity content and their relation to the facies type are still included as normal, which refers to the depositional environments.

The channel sediment with high salinity content appears as an anomaly. This is because the sediment is located on the distal position that is supported by depositional environment (Figure 5 and Figure 6).

Previous channel depositional environment dominated by the influence of fluvial then turned into environment dominated by the sea with the invisibility of shale sediment domination. The depositional environment change causes the increase of salinity value content on the channel sediment.

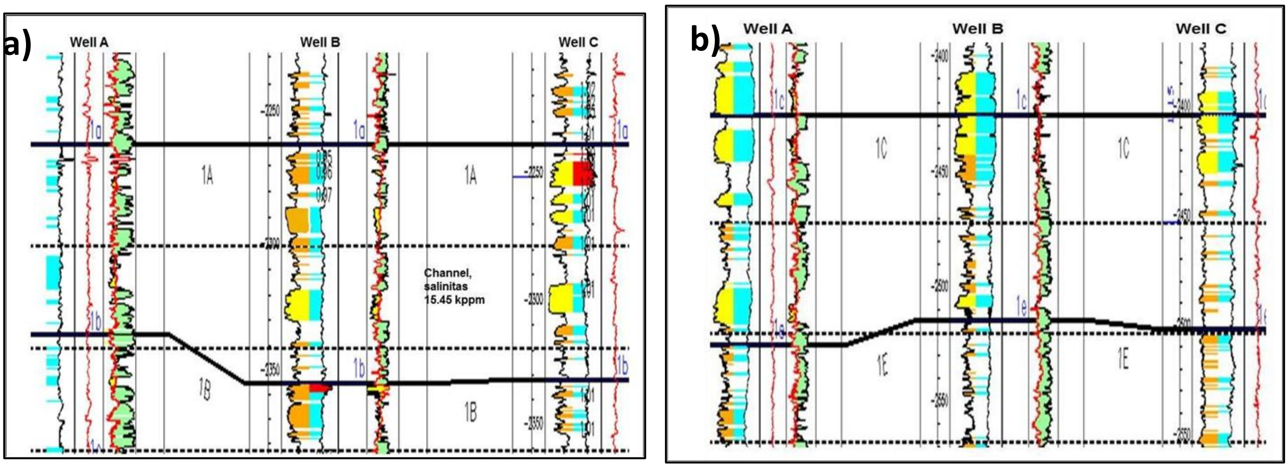

Figure 4. Well correlation illustrating a)channel facies distribution and salinity and b) mouthbar facies and salinity variation in Group I

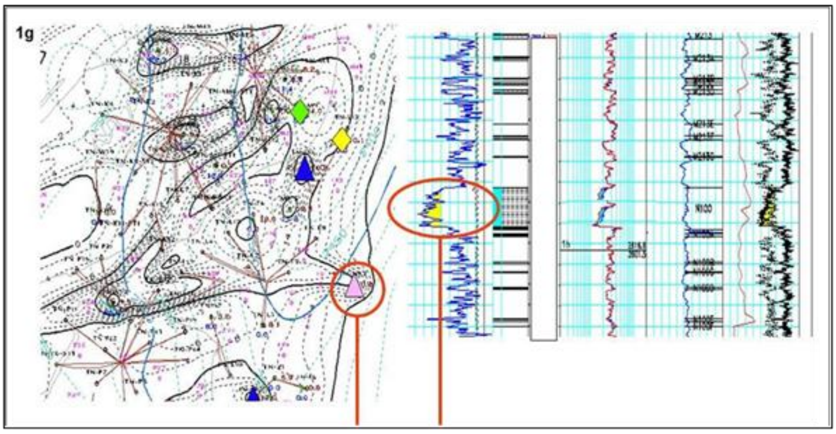

Figure 5. Example of mouth bar facies exhibiting high salinity values in Group II stratigraphic interval.

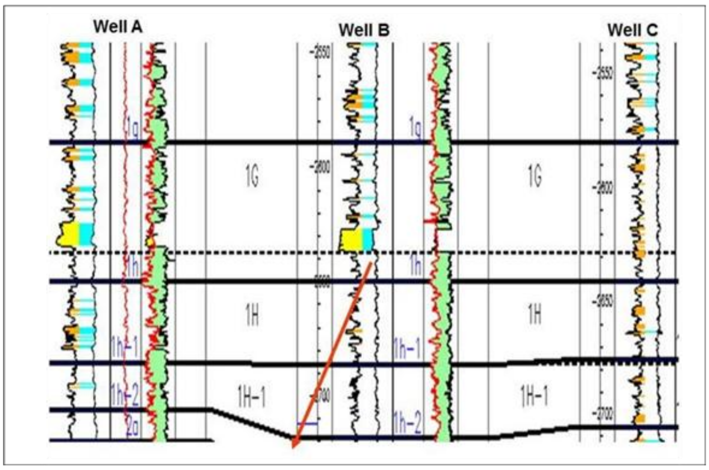

Figure 6. Well correlation illustrating channel facies and associated salinity variation in Group II.

C. Relation Between Facies and Salinity in Group III

In this group, the decreasing of salinity content along the increasing of depth is more visible. The decreasing of salinity content is contrary to the geological illustration of East Kutai Basin that indicates a pattern progradation from time to time which also shows the changing from marine to terrestrial environment.

Anomalies increasingly visible with the advent of channel sediment with high salinity and mouth bars sediment that has low salinity, both in proximal or distal position.

The channel sediment with high salinity value appears as described previously that this is caused by the deposition is in the distal position (adjacent to the mouth bar sediment), then the previous channel depositional environment dominated by the influence of the river turned into an ocean is most likely caused by a relative sea level rise (Figure 7 and Figure 8). This was shown by the change in sandstone sediment as channel facies becomes dominated by claystone. The depositional environment of channel that previously in lower delta plain, turn laterally into delta front depositional environment by the appearance of mouth bar and the claystone accumulation. The anomaly in the form of mouth bar sediment which has low salinity content is also more visible, both in proximal and distal of this East Kutai Basin.

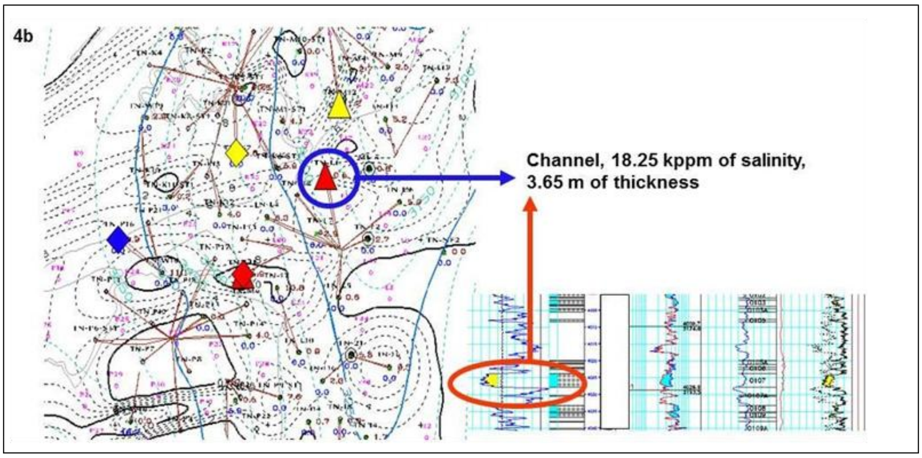

Figure 7. Example of channel facies with elevated salinity values in Group III stratigraphic interval.

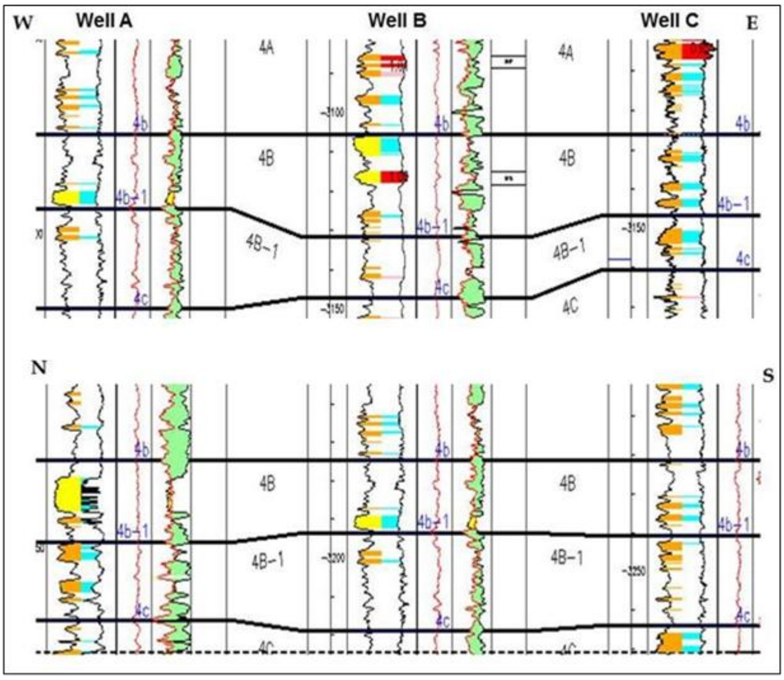

Figure 8. Well correlation panel illustrating channel facies with high salinity values in Group III.

Based on the geological interpretation, the anomalies emergence in the form of mouth bar sediment that has lower salinity content is caused by two main factors. The first factor is caused by channel influx dominated by the fluvial process in connection with progradation at East Kutai Basin (Figure 9 and Figure 10). This mouth bar formation causes the forming of branched river and created the new channel and mouth bar sediment toward the sea along with progradation. This process occurs continuously, which can be seen in the modern East Kutai Basin deposition today. The sediment of mouth bar that previously located in the distal position and has a high salinity content then changed into proximal or median sediment of East Kutai Basin today.

The second factor is the influence of very high pressure that drives the discharge of water with low salinity content derived from prodelta shale otherwise known as expelled compaction water prodelta from shale. This phenomenon occurs mechanically and also chemically. The mechanical process that led to the expelling of water from prodelta shale is caused by the high pressure as the result of the progradation. The water that comes out must pass through the sand grain which is very fine (silt or sandy shale are not included in the criteria as a reservoir because it has a porosity of less than 5%), which acts as a semipermeable membrane that can filter water. Semipermeable membrane has the ability to trap the salt crystals and release the freshwater solution along with the presence of high pressure, then the water intruding the closest channel sediment or mouth bar sediment to the prodelta shale. The passed fresh water make the levels of salinity lowered in mouth bar sediment positioned at the distal.

Chemically, prodelta shale has water content with higher composition of salt than on mouth bar sediment. NaCl solution is then broken into molecules with different diameters, which is due to the very high pressure. Water molecule (H2O) has a smaller diameter than the Sodium metal (Na+). Therefore, the water molecule which has been separated from the salt crystals will be pushed out through the layer and intruded the nearest sand sediment. Ultimately, it reduces the content of salinity on such deposits.

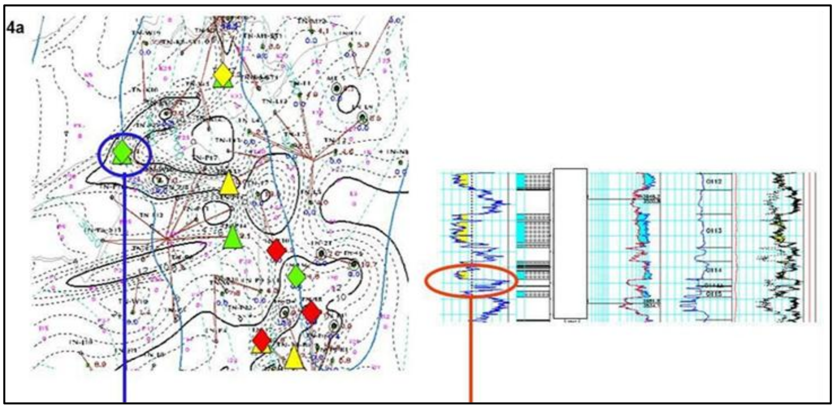

Figure 9. Example of mouth bar facies exhibiting low salinity values in Group III stratigraphic interval

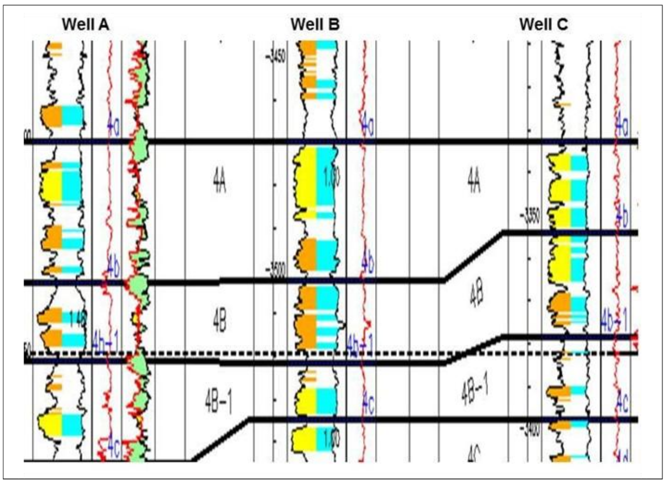

Figure 10. Well correlation illustrating mouth bar facies and associated salinity anomalies in Group III.

DISCUSSION

The observed salinity patterns in the East Kutai Basin reflect the combined influence of depositional processes and post-depositional fluid migration (Figs. 7–10). In Group I, the dominance of low-salinity water in the northern area is interpreted as the result of strong fluvial sediment influx, which supplied freshwater-dominated deposits even in relatively distal positions. The presence of high-salinity channel facies in some areas represents an anomaly caused by channel deposition occurring in positions influenced by marine conditions.

In Group II, salinity distribution is relatively uniform, indicating transitional depositional environments where fluvial and marine influences were balanced. The limited occurrence of anomalies suggests stable depositional conditions during this phase of basin evolution.

Group III exhibits the most pronounced salinity anomalies, with decreasing salinity observed with increasing depth (Figure 9–12). This pattern contradicts the expected progradational salinity model and is interpreted to result from the expulsion of low-salinity compaction water from overpressured prodelta shale. High pressure generated during progradation forced freshwater to migrate into adjacent sand bodies, reducing salinity in both channel and mouth bar facies. In addition, lateral migration of depositional environments due to continuous progradation caused formerly distal mouth bar deposits to become influenced by fluvial processes, further contributing to low-salinity anomalies.

The change of salinity has a basic pattern laterally from terrestrial (with lower salinity content) to marine (with higher salinity content), and this pattern can still be found in the research area. The effect of sedimentation is more dominant in the northern area of East Kutai Basin than in southern area of Group I. The salinity content decreases with the increasing of depth and is particularly evident in Group III as a result of the dominant influence of expelled compaction water from prodelta shale. The factors that cause the salinity anomalies in facies are as follows:

a. Channel sediment containing high salinity caused by its position in distal area of East Kutai Basin, which is dominated by the influence of the sea. Depositional environment of channel is also changed laterally from lower delta plain into delta front.
b. Mouth bar sediment that has low salinity content is a result of influx channel influence that is dominated by fluvial influence in connection with the process of progradation of East Kutai Basin, as well as the influence of expelled compaction water from prodelta shale.

CONCLUSION

Salinity distribution in the East Kutai Basin generally follows a lateral trend from low salinity in proximal fluvial deposits to higher salinity in distal marine deposits. However, significant lateral and vertical anomalies are present. Vertically, salinity decreases with depth in deeper stratigraphic groups, contrary to the expected progradational model. These anomalies are primarily caused by lateral shifts in depositional environments associated with progradation and by the expulsion of low-salinity compaction water from prodelta shale into adjacent reservoir sands. The results emphasize the importance of integrating sedimentological and hydrodynamic processes when interpreting salinity patterns in deltaic reservoirs.

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GEOLOGY OF THE KADU AND SURROUNDING AREA, JATIGEDE AND JATINUNGGAL DISTRICTS, SUMEDANG REGENCY, WEST JAVA PROVINCE

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ABSTRACT

Administratively, the research area is located in Kadu and its surrounding areas, Jatigede and Jatinunggal Districts, Sumedang Regency, West Java Province. This study aims to determine the geological conditions and geological history of the research area. The research method consists of three stages: literature study, field observation for data collection, and studio observation combined with laboratory analysis. Based on geomorphological aspects, the research area is divided into three geomorphological units, namely moderately steep denudational low hills, steep structural elongated hills, and very steep structural sedimentary hills. Field observations indicate that the lithostratigraphic units are grouped into four units arranged from oldest to youngest: claystone unit (Sbl), sandstone unit (Sbp), tuff unit (St), and volcanic breccia unit (Sbv). The claystone and sandstone units were deposited simultaneously during the Middle Miocene in a deep marine environment. Subsequently, during a slightly younger period, the tuff unit (St) was deposited conformably with the sandstone unit. Geological structures developed in the study area include anticline and syncline folds formed in the Late Miocene due to compressional tectonic activity, with the principal stress direction trending northeast–southwest. Other structures such as joints and indications of strike-slip faults are also observed. The volcanic breccia unit (Sbv) was deposited from ancient volcanic eruptions in a disconformable relationship with the claystone unit (Sbl) during the Late Pliocene. Geological resources in the study area include andesite quarrying as well as tourism potential at Mount Jagat and the Pine Forest. The main geological hazard in the area is landslides.

Keywords : Anticline, Denudational, Sumedang, Syncline, Volcanic breccia

INTRODUCTION

Geology is the science that studies the Earth, including its constituent materials, physical and chemical processes occurring at the surface and subsurface, as well as the geological history of the planet and its life forms (Thompson & Turk, 1997). Geological processes operate slowly but continuously, producing significant changes over geological time, as proposed by Hutton (1785). Geological studies play an essential role in understanding natural phenomena such as volcanism and tectonic activity, managing natural resources, mitigating geological hazards, and supporting safe infrastructure development. Geological mapping is a fundamental method used to identify and document surface geological features, including lithology, geomorphology, stratigraphy, geological structures, and geological history, which are subsequently presented in geological maps.

The study area is located in Kadu, Cisampih, Cimanintin, and surrounding areas, Jatigede and Jatinunggal Districts, Sumedang Regency, West Java Province, it lies between 108°9'10.296" E to 108°11'55.295" E and 6°55'5.995" S to 6°52'20.996" S, covering approximately 5 × 5 km². Regionally, the area is composed of Miocene to Pliocene sedimentary and volcanicfigure rocks based on the Geological Map of the Majalengka Sheet at scale 1:50,000 (Isnaniawardhani et al.,2020). The geological context includes marine to terrestrial depositional environments and deformation related to regional tectonic activity. However, the regional-scale map provides limited detail and does not sufficiently describe local variations in lithostratigraphy, structural geology, geomorphological characteristics, and geological evolution. Therefore, a more detailed geological mapping is required to improve the understanding of local geological conditions, resource potential, and geological hazards.

This study aims to conduct detailed geological mapping to obtain comprehensive understanding of the geological aspects in the study area, including rock types and distribution, stratigraphic succession and relationships, structural geology conditions, geological history reconstruction, potential geological resources, and geological hazard assessment.

REGIONAL PHYSIOGRAPHY

Based on morphology, lithology, and geological structure, West Java is divided into five physiographic zones: the Jakarta Coastal Plain Zone, the Bogor Zone, the Bandung Zone, the Bayah Mountain Zone, the Southern Mountain Zone, and the Quaternary Volcanic Zone (Figure 1; Martodjojo, 2003).

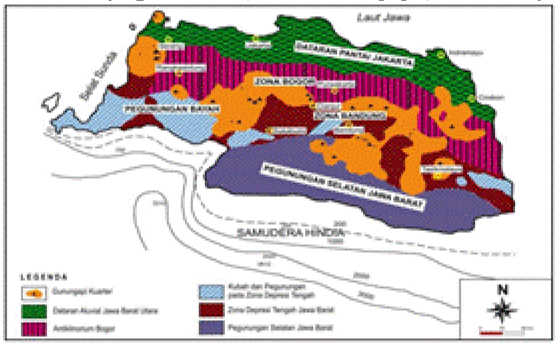


Figure 1. Physiographic Map of West Java according to Van Bemmelen (1949) as cited in Martodjojo (2003)

According to this division, the study area is located in the eastern part of the Bogor Zone. This area consists of folded hills formed from deep marine Tertiary sedimentary rocks that constitute an anticlinorium, with faulting in several places estimated to have occurred during the Pliocene-Pleistocene, contemporaneous with the formation of the Lembang Fault and the uplift of the Southern Mountains (Wardhana et al., 2016).

REGIONAL STRATIGRAPHIC SETTING

A regional stratigraphic study was conducted to obtain a comprehensive understanding of the rock formations closely related to the geological conditions of the mapped area. Referring to previous geological mapping, the study area is included within the Bogor Sheet coverage. The mapping area is based on the Geological Map of the Majalengka Sheet 1309-11 (Isnaniawardhani et al., 2020). This map provides information on lithological types, relationships between rock formations, their formation mechanisms, and the chronological sequence of formation from the oldest to the youngest units.

Based on the Regional Geological Map of the Majalengka Sheet, the study area is composed of five rock formations, as follows:

1. Shale Member of Cinambo Formation (Nmsch)

The Shale Member of Cinambo Formation is dominated by shale, interbedded with sandstone and limestone. Additionally, tuffaceous sandstone and calcareous sandstone are present. This formation is Middle Miocene in age (15.97 Ma - 13.82 Ma) and was deposited in a lower fan environment within a deep-sea fan system at depths of 500-2000 meters (upper bathyal bathymetry) (Sunarta et al., 2023). This rock formation is regionally the oldest formation in the Majalengka Regional Geological Map Sheet.

2. Sandstone Member of Cinambo Formation (Nmcs)

The Sandstone Member of Cinambo Formation is composed of sandstone, graywacke, calcareous sandstone, tuff, claystone, and siltstone. This formation is Middle Miocene in age (13.82 Ma - 11.608 Ma) but slightly younger than Nmcsh, deposited in a lower fan environment within a deep-sea fan system at depths of 200-2000 meters (outer neritic to upper bathyal bathymetry) (Sunarta et al., 2023).

3. Breccia Member of Halang Formation (Nmhbx)

The Breccia Member of Halang Formation is composed of breccia and sandstone. This formation is Late Miocene in age (11.608 Ma - 7.246 Ma), deposited in an upper fan environment within a deep-sea fan system (Sunarta et al., 2023).

4. Breccia Member of Citalang Formation (Npcbx)

The Breccia Member of Citalang Formation is composed of breccia and sandstone. This formation is Late Pliocene in age (<3.600 Ma - 2.588 Ma), deposited in a fluvial depositional environment as a braided river system (Al-Hakim & Rizal, 2021).

5. Sandstone Member of Citalang Formation (Npcs)

The Sandstone Member of Citalang Formation is composed of sandstone and tuffaceous sandstone. This formation is Late Pliocene in age (<3.600 Ma - 2.588 Ma), deposited in a fluvial depositional environment as a braided river system (Al-Hakim & Rizal, 2021)

RESEARCH METHOD

Geological mapping was conducted using the traversing method, defined as systematic geological data collection along predetermined routes (Lisle et al., 2011). Both open and closed traverses were applied to ensure comprehensive spatial coverage of the study area. Outcrops encountered along riverbanks, riverbeds, slopes, and road cuts were established as observation stations. Field methods included lithological description, measurement of structural orientations, documentation of geomorphological attributes, and sampling of rocks for laboratory analysis. Laboratory work involved petrographic analysis and micropaleontological identification to determine lithological characteristics, relative ages, and depositional environments. (Bermana. I, 2006)

The primary materials consisted of rock outcrops encountered along designated traverses. Rock samples were collected from representative outcrops for laboratory analyses, including petrographic and micropaleontological studies based on lithological variation, stratigraphic position, and structural significance. Petrographic analysis was performed through thin section preparation and microscopic examination to determine mineralogical composition, textural characteristics, and rock classification. Micropaleontological analysis involved fossil extraction, identification, and systematic classification to establish biostratigraphic age constraints and interpret paleoenvironmental conditions of the rock units. Additional observational data included geomorphological elements (morphography, morphometry, morphogenetics, and drainage patterns), sedimentary structures, geological structures (faults, joints, and folds).

Field and laboratory data were integrated and analyzed to delineate geomorphological units, lithostratigraphic units, stratigraphic relationships, and structural patterns. Sedimentological interpretations were used to infer depositional processes and environments. The results were compiled into geomorphological and geological maps and used to reconstruct the geological history and assess geological resource potential and hazards.

RESULT

Geomorphology

Geomorphology analysis starts with the morphography analysis with the landform aspects using the modified Van Zuidam classification by Bermana (2006). The research area consists of High hills, Hills Low hills, and Lowland (Figure 2). Moreover, the morphometry analysis shows that the research area consists of flat to very steep areas (Figure 3).

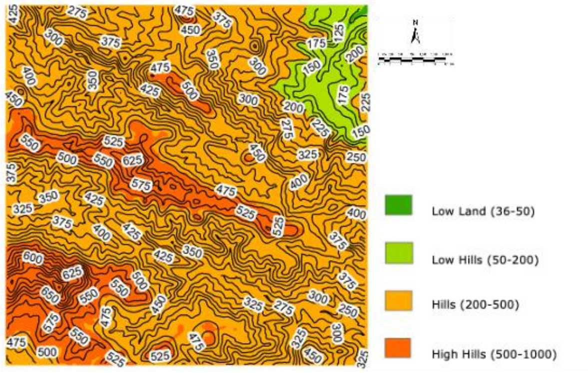


Figure 2. Morphography map

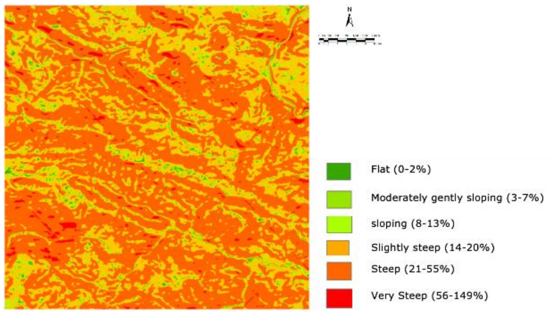
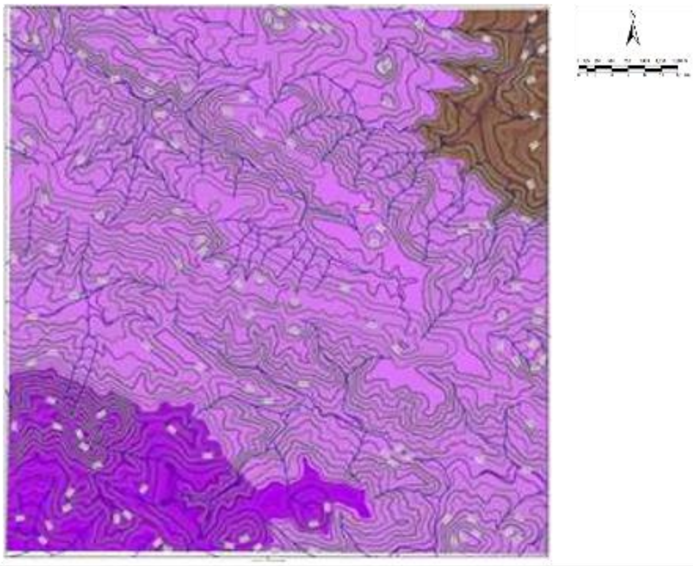


Figure 3. Morphometry map

Drainage Pattern is classified based on Howard (1967), and thus, the research area can be divided into three distinct drainage patterns, which is: dendritic, trellis, and rectangular (Figure 4).

Based on morphographic, morphometric, and morphogenetic analysis, geomorphological unit analysis was conducted and presented in a geomorphological map (Figure 4)



Geomorphological Unit	Symbol	Geomorphological Elements								
		Morphography			Morphometry			Morphogenetic		
		Drainage Pattern	Landform	Valley Shape	Slope Class	Elevation	Slope	Endogenous	Exogenous	Lithology
Moderately Steep Denudational Low Hills Unit		Dendritic	Low Hills	U-V	Gentle Steep	7-15%	4°-8°	Denudational	Weathering & Erosion	Sandstone,claystone, breccia, tuf
Steep Structural Elongated Hills Unit		Trellis,rectangular	Hills	V	Steep	15-30%	8°-16°	Structural	Weathering & Erosion	Sandstone, claystone,tuf
Very Steep Structural Sedimentary Hills Unit		Rectangular	High Heels	V	Very Steep	30-70%	16°-35°	Structural	Weathering & Erosion	Claystone

Figure 4. Geomorphological Map of the Study Area

According to these four aspects, the geomorphological aspects of the area is divided into 3 classes:

1. Moderately Steep Denudational Low Hills Unit

Presented in Figure 5A, this geomorphological unit occupies approximately 10% of the total study area and is located in the northeastern part of the area. Morphographically, it is characterized by low hilly landforms with elevations ranging from about 100 to 200 m above sea level, U–V-shaped valleys, and the presence of the Cilutung River, which exhibits a dendritic drainage pattern. Morphometric analysis shows slope gradients of approximately 4°–8° (7%–15%), classifying this unit as moderately steep slopes (Van Zuidam, 1985). The unit is composed of sandstone, claystone, breccia, and tuff lithologies and has been influenced by endogenous processes, including volcanic activity, as well as exogenous processes such as weathering and erosion.

2. Steep Structural Elongated Hills Unit

This geomorphological unit occupies nearly 70% of the total study area and is distributed throughout almost the entire study area (Figure 5B). Based on morphographic aspects, this geomorphological unit exhibits hill landforms with elevations of approximately 200-600 meters above sea level. Valleys in this unit have V-shaped forms and rectangular drainage patterns. Based on morphometric analysis, this geomorphological unit has slope gradients of approximately 8° to 16° or about 15% to 30%, classified as steep slopes (Van Zuidam, 1985). This geomorphological unit is composed of interbedded sandstone-claystone, claystone, sandstone, and tuff lithologies that have undergone endogenic processes in the form of tectonic activity including folding and exogenic processes including weathering and erosion.

3. Very Steep Structural Sedimentary Hills Unit

This geomorphological unit occupies nearly 20% of the total study area and is located in the southwestern and central parts of the study area (Figure 5C). Based on morphographic aspects, this geomorphological unit exhibits high hill landforms with elevations of approximately 400-750 meters above sea level. Valleys in this unit have V-shaped forms and trellis drainage patterns, whose formation is controlled by fold geological structures. Based on morphometric analysis, this geomorphological unit has slope gradients of approximately 16° to 35° or about 30% to 70%, classified as very steep slopes (Van Zuidam, 1985). This geomorphological unit is composed of interbedded claystone-sandstone lithologies that have undergone endogenic processes in the form of tectonic activity and exogenic processes including weathering and erosion.

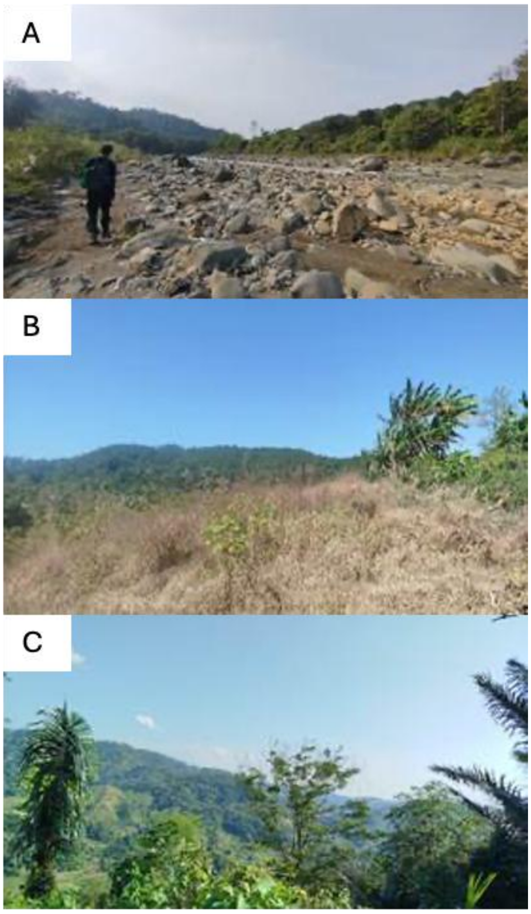


Figure 5. The geomorphological trend observed in study area: A. Moderately steep denudational low hills unit; B. Steep structural elongated hills unit; C. Very steep structural sedimentary hills unit.

Stratigraphy of the Study Area

The stratigraphy of the study area was classified into informal lithostratigraphic units based on field lithology distribution, following the Indonesian Stratigraphic Code (1996) criteria of rock type, combination, uniformity, and dominant properties. Rock unit boundaries were determined using stratigraphic position, topographic characteristics, bedding attitude, and stratigraphic principles including the law of superposition and cross-cutting relationships. Relative age and depositional environments were established through regional correlation and planktonic and benthic foraminifera analyses. The rock units in the study area are grouped into four groups as follows:

1. Claystone Unit (Sbl)

This unit is the most dominantly distributed unit, occupying nearly 70% of the total study area. It is located in almost all geomorphological units. Based on field observations, this unit consists of claystone, interbedded claystone with sandstone, claystone, sandstone, and volcanic breccia. However, overall it is dominated by claystone with shale, massive, and slump structures. Megascopically, this claystone has a fresh color of blackish-gray to light gray, and a weathered color of grayish-black to grayish-brown. One of the outcrop features is shown in Figure 5A-B. The grain size is clay with soft to hard compaction.

Microscopically, thin sections show a yellowish-brown color (//). It has a subrounded grain roundness degree. Open fabric (matrix supported), and well sorted. The rock composition consists of 7% fragments including carbonate, 87% matrix consisting of clay minerals (59%) and carbonate (28%), and 6% other fragments and minerals in the form of opaque minerals (1%) and skeletal fragments (5%). Based on Pettijohn, F.J. (1975), this thin section is classified as claystone.

Age determination and bathymetric zone analysis were conducted by analyzing foraminifera fossils in one of the samples from this unit, and from the analysis results it can be concluded that the Claystone Unit (Sbl) has a relative age of Middle Miocene (N9-N15) with an Upper Bathyal to Abyssal depositional environment (200 m-4000 m) (Blow, 1969). Based on its stratigraphic position, the Claystone Unit has a conformable relationship with the Sandstone Unit (Sbp), and has an unconformable relationship with the Volcanic Breccia Unit (Sbv). The type of unconformity between the Claystone Unit and the Volcanic Breccia Unit is a disconformity.

2. Sandstone Unit (Sbp)

This unit occupies nearly 20% of the total study area. It is located in the Steep Structural Elongated Hills geomorphological unit. Based on field observations, this unit consists of sandstone and tuff. Megascopically, the sandstone in this unit has a fresh color of light gray to blackish-gray, a weathered color of grayish-brown to blackish-brown, grain size of fine sand (1/8-¼ mm) to fine sand (1/8-1/4 mm), rounded roundness, closed fabric, no sedimentary structures, well sorted, non-calcareous, and moderately hard to hard. One of the outcrop features is shown in Figure 5C-D.

Microscopically, the rock thin section shows a yellowish-brown color (//), has a subangular grain roundness degree, closed fabric (grain supported), and well sorted. The rock composition in this thin section consists of 57% fragments in the form of quartz (54%); feldspar (1%); and rock fragments (2%), 5% matrix in the form of clay minerals, and 38% other fragments and minerals in the form of carbonate minerals (35%) and opaque minerals (3%). Based on this analysis, it can be concluded that the rock is Quartz Arenite (Pettijohn, 1975).

Based on age determination and bathymetric zone analysis from microfossil analysis, it can be concluded that the Sandstone Unit (Sbp) has a relative age of Middle Miocene (N9-N15) with a Middle Bathyal to Abyssal depositional environment (700 m-5000 m).

3. Tuff Unit (St)

This unit is the smallest unit of the total study area, occupying only about 2% of the total study area. It is located in the Steep Structural Elongated Hills geomorphological unit. Based on field observations, this unit consists only of tuff. Megascopically, this rock has a fresh color of brownish-white and a weathered color of blackish-brown. One of the outcrop features is shown in Figure 5E-F. This rock has a coarse ash grain size, subangular grain shape, moderate sorting, open fabric, and hard consistency. This rock has a composition of minerals, vitric, and lithic components.

Microscopically, the rock thin section shows a yellowish-white color (//), grain relationship (fabric) is open (matrix supported), with poor grain size uniformity/sorting. The matrix is composed partly of volcanic glass (15%), secondary quartz (2%), and clay minerals (5%). It consists of 1% glass/vitric fragments, 2% rock/lithic fragments, and 65% crystal/mineral fragments in the form of secondary quartz (43%) and chlorite (22%), with additional opaque minerals present. This rock has undergone alteration as indicated by the presence of chlorite and secondary quartz minerals; based on Lagat (2009), this rock is in the propylitic alteration zone. Based on Schmidt's (1981) classification, this rock is an Altered Crystal Tuff.

Age determination and depositional environment of this rock unit were determined using regional correlation, namely with the Sandstone Member of Cinambo Formation. From this, it can be concluded that this rock unit is Middle Miocene in age (13.82 Ma - 11.608 Ma) and its depositional environment is a lower fan environment in a deep-sea fan system at depths of 200-2000 meters (outer neritic to upper bathyal bathymetry).

4. Volcanic Breccia Unit (Sbv)

The Volcanic Breccia Unit occupies the northeastern part of the study area, representing approximately 8% of the total study area within the Moderately Steep Denudational Low Hills geomorphological unit. Megascopically, this rock exhibits a blackish-gray fresh color, blackish-brown weathered color, angular grain shape, open fabric, poor sorting, and moderately hard consistency. The matrix consists of tuff with ash-sized grains dominated by coarse components. Fragments comprise andesite igneous rock with medium crystallinity (1-5 mm), aphanitic granularity, holocrystalline crystallization, equigranular crystal uniformity, predominantly subhedral crystal form (hypidiomorphic granular), and massive structure. One of the outcrop features is shown in Figure 5G-H.

Microscopic analysis of the matrix reveals 17% volcanic glass, 8% quartz microlites, and 13% clay minerals, with 3% vitric fragments, 35% lithic fragments, and 17% crystal/mineral fragments including chlorite (10%), pyroxene (3%), plagioclase (2%), and carbonate (2%). Based on Schmidt's (1981) classification, this is Altered Lithic Tuff. Fragment samples show porphyritic and trachytic textures with hypocrystalline crystallinity, containing 52% phenocrysts (pyroxene 23%, chlorite alteration 29%), 44% groundmass (plagioclase microlites 32%, clay minerals 5%, glass 7%), and 4% opaque minerals. The highly altered nature and porphyritic-trachytic texture indicate this is Altered Andesite.

No benthic or planktonic foraminifera were found in this unit due to its volcanic origin, which is incompatible with foraminiferal habitat. Age and depositional environment determination was based on regional correlation with the Breccia Member of Halang Formation, indicating a Late Pliocene age (<3.600-2.588 Ma) and terrestrial fluvial depositional environment in a braided river system. This unit has a disconformable relationship with the Claystone Unit (Sbl), representing a depositional hiatus without clear evidence of erosion or structural changes between the rock layers.

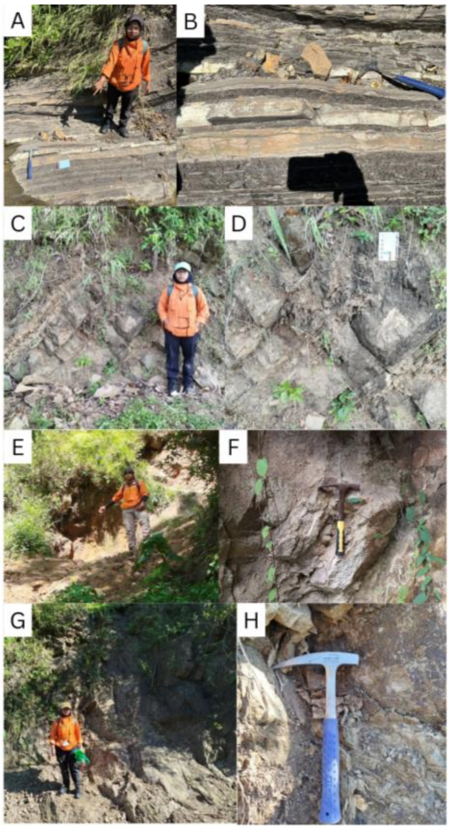


Figure 6. The Field photographs in study area: A-B Claystone Unit (Sbl) outcrops; C-D Sandstone (Sbp) outcrops; E-F Tuff Unit (St) outcrops; G-H Breccia Unit (Sbv)

Geological Structure of the Study Area

Structural geology analysis was conducted through a combination of field data and studio analysis in the mapping area. Interpretation of geological structures in the study area was based on various aspects including strike-dip anomalies, rock unit ages, and lithostratigraphic positions. As supporting data, the presence of structures in the study area was also confirmed through lineament pattern analysis on ridges visible in the DEMNAS (National Digital Elevation Model) map, drainage network patterns, and topographic lineament patterns. This ridge lineament analysis provides estimated information regarding the presence of weakness zones (geological structures) and their associated stress orientations.

Lineament

Lineament pattern interpretation of ridges and valleys was conducted using Digital Elevation Model (DEM) data to identify potential weakness zones related to geological structure formation, particularly faults. Lineament analysis indicates dominant stress orientations and fracture planes. Based on lineament pattern analysis using Rockworks software, the relative lineament orientation reflects tectonic processes with a northeast-southwest stress direction.

Folds

Folds represent curved structures formed through two main mechanisms, namely bending and buckling. Fold analysis was processed using the Dips software to obtain three classification parameters based on Fleuty (1964), including plunge, interlimb angle, and dip of the axial plane. These parameters were derived from opposing strike–dip data on synclinal folds or from strike–dip data with opposite directions on anticlinal folds. As the area is characterized by elongated anticlinal–synclinal hilly landforms, the presence of numerous fold structures of varying types and scales can be anticipated. Based on field observations, a total of 10 folds were identified and classified into four different fold names, namely:

1. Upright Horizontal Fold (Fluety, 1964)
2. Steeply Incline Horizontal Fold (Fluety, 1964)
3. Steeply Incline Gentle Plunging Fold (Fluety, 1964)
4. Upright Gentle Plunging Fold (Fluety, 1964)

Folds

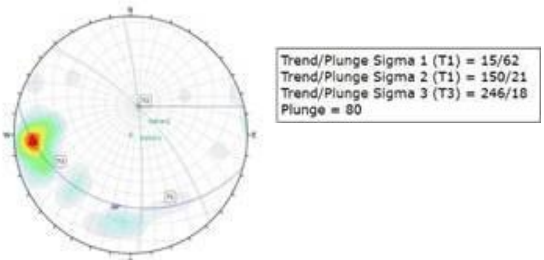


Figure 7.Stereographic projection of joint data

Based on the stereonet analysis of the joint data (Figure 7), it can be concluded that there are indications of extensional tectonic forces (normal fault regime) in the data acquisition area.

DISCUSSION

The geological history of the study area, reconstructed through integrated analysis of stratigraphic relationships, geochronological data, paleoenvironmental interpretations, and structural geology, reveals a complex evolution spanning from the Middle Miocene to the Late Pliocene. This evolutionary history reflects the dynamic interaction between sedimentation processes, volcanic activity, and tectonic deformation in the region. This output can be represented on the geological map (Figure 8).

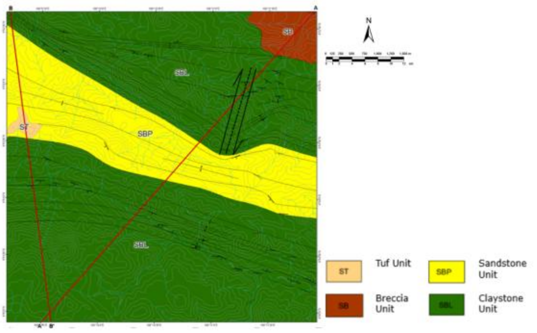


Figure 8. Geological Map

During the Middle Miocene (N9-N15), the study area was characterized by deep marine conditions where the Sandstone Unit (Sbp) and Claystone Unit (Sbl) were deposited contemporaneously and conformably through turbidite mechanisms in middle bathyal to abyssal environments, specifically within the lower fan setting of a deep-sea fan system (Sunarta Et al. 2023). The textural variations and grain size differences between these two units reflect changes in depositional energy related to either basin deepening or reduction in coarse sediment supply. This turbidite deposition represents a period of active sediment delivery from continental sources into a subsiding marine basin.

Subsequently, during the slightly younger Middle Miocene interval (N12-N15), the Tuff Unit (St) was deposited conformably over the Sandstone Unit. The deposition of this volcanic material occurred nearly contemporaneously with the turbidite sedimentation of the underlying units, indicating active volcanism in the region during this period. Volcanic ash from explosive eruptions settled through the water column and accumulated as tuff layers, demonstrating the influence of volcanic processes on the sedimentary record.

A significant tectonic event occurred during the Late Miocene, characterized by compressional convergent tectonism between two lithospheric plates moving toward each other with a relative stress orientation trending northeast-southwest. This compressional regime caused intensive deformation of the Sandstone Unit (Sbp), Claystone Unit (Sbl), and Tuff Unit (St), resulting in the formation of northwest-southeast trending fold structures. The structural analysis indicates the presence of both synclines and anticlines with consistent axial orientations, demonstrating a unified deformational episode. Additionally, evidence of dextral strike-slip faulting suggests that the compressional system generated lateral displacement components during deformation, possibly related to rotational movement of crustal blocks or partitioning of strain during fold development.

The geological evolution concluded with a dramatic environmental change during the Late Pliocene (<3.600-2.588 Ma), when the Volcanic Breccia Unit (Sbv) was deposited unconformably (disconformity) over the Claystone Unit (Sbl). This unconformity represents a significant hiatus and environmental transition from marine to terrestrial conditions. The volcanic breccia, composed of fragmental volcanic material from ancient volcanic eruptions, was deposited in a terrestrial fluvial environment, likely representing a braided river system transporting volcanic debris from nearby volcanic centers. This shift to subaerial deposition indicates regional uplift and emergence of the study area above sea level, transforming the former marine basin into a terrestrial volcanic-fluvial setting.

The reconstructed geological history provides crucial insights into the broader tectonic and sedimentary evolution in the study area. The turbidite deposition observed in the Middle Miocene units demonstrates the operation of gravity-driven sediment transport mechanisms characteristic of deep-sea fan systems, where sediment-laden density currents flow down submarine slopes, depositing coarse-grained material in proximal fan settings and fine-grained sediments in distal environments. The grain size distribution patterns and sedimentary structures preserved in the Sandstone Unit (Sbp) and Claystone Unit (Sbl) reflect fluctuations in flow velocity and sediment concentration during turbidity current events, controlled by factors including source area uplift rates, sediment supply volumes, and basin subsidence patterns.

The contemporaneous volcanic activity, evidenced by the Tuff Unit (St), indicates the presence of an active volcanic arc system proximal to the basin, with explosive eruptions generating ash plumes that dispersed volcanic material across the marine basin. The Late Miocene compressional deformation represents a critical phase of mountain building directly linked to the convergence and collision of the Indo-Australian Plate with the Eurasian Plate, a tectonic process that continues to shape the geological architecture of the Indonesian archipelago (Van Bemmelen, 1949). The observed northwest-southeast axial trend of these fold structures directly reflects the perpendicular orientation to the northeast-southwest directed compressional stress field, consistent with the regional stress regime during the Late Miocene collision between the two major plates.

The Late Pliocene unconformity and shift to terrestrial deposition signifies a fundamental change in tectonic regime from active subsidence to regional uplift, driven by continued plate convergence and crustal thickening processes that elevated the former marine basin above sea level. This transition from deep marine to terrestrial environments was accompanied by progressive shallowing of depositional settings, likely influenced by a combination of tectonic uplift associated with the ongoing plate collision and eustatic sea-level fluctuations during the Pliocene (Satyana & Armandita, 2004). The uplift mechanism enabled the development of fluvial drainage systems capable of transporting coarse volcanic debris from newly emerged volcanic edifices, depositing the Volcanic Breccia Unit (Sbv) through high-energy braided river processes characterized by rapid lateral channel migration and continuous sediment aggradation.

The study area contains natural resources classified as Class C minerals according to the Indonesian Mining Law No. 4 of 2009 concerning Mineral and Coal Mining. Class C minerals consist of non-metallic materials including sand, river stones, and igneous rocks utilized for construction materials, road infrastructure, and bridge development. Field observations identified several sites where igneous rocks are extracted through traditional small-scale mining operations conducted by local communities. These extracted materials serve as essential construction resources for infrastructure development and various industrial applications in the region. The presence of these geological resources provides economic opportunities for local communities while requiring appropriate management to ensure sustainable extraction practices.

Beyond mineral resources, the study area possesses potential for geotourism development, particularly at Mount Jagat and the Pine Forest areas. These locations offer opportunities for educational tourism focused on geological and environmental features, which could contribute to local economic development while promoting geological conservation and public awareness of earth science.

Morphometric analysis reveals that the study area is predominantly characterized by moderately steep to very steep slopes, as demonstrated in the slope gradient classification map. This topographic configuration, combined with the lithological characteristics and structural geological features, creates significant susceptibility to mass movement processes, particularly landslides and soil displacement. The presence of claystone units with inherently low shear strength, coupled with steep slope angles and potential structural weaknesses such as joints and fractures, increases the landslide hazard potential in the region.

Given these geological hazard considerations, infrastructure development planning and implementation within the study area must incorporate comprehensive geotechnical assessments. Site-specific investigations should evaluate slope stability, rock mass characteristics, groundwater conditions, and potential failure mechanisms to ensure that constructed facilities meet appropriate strength and safety standards. Proper engineering geological evaluation is essential to mitigate risks associated with ground instability and to protect both human safety and economic investments in the region. Recommendations include detailed geotechnical site investigations prior to construction, implementation of slope stabilization measures where necessary, and establishment of early warning systems for landslide-prone areas to enhance community resilience to geological hazards.

CONCLUSION

This geological mapping study has successfully achieved its objectives of characterizing the detailed geological conditions of the study area. The research identified three geomorphological units: gentle denudational low hills, steep structural elongated hills, and very steep structural sedimentary hills, which reflect the combined influence of lithological characteristics and tectonic processes in shaping the present-day landscape.

The stratigraphic framework comprises four informal lithostratigraphic units deposited from Middle Miocene to Late Pliocene. The succession begins with the Claystone Unit (Sbl) and Sandstone Unit (Sbp), both of Middle Miocene age (N9-N15), deposited in deep marine environments (upper bathyal to abyssal zones) through turbidite processes. These are conformably overlain by the Tuff Unit (St) of Middle Miocene age (13.82-11.608 Ma), deposited in a lower fan setting of a deep-sea fan system. The succession is unconformably capped by the Volcanic Breccia Unit (Sbv) of Late Pliocene age (<3.600-2.588 Ma), representing terrestrial fluvial deposits from ancient volcanic eruptions in a braided river system.

Structural geological analysis reveals a compressional tectonic regime dominated by northwest-southeast trending synclines and anticlines, accompanied by joints and fault indications. These structures record northeast-southwest oriented compressional stresses during the Late Miocene, which produced dextral strike-slip faulting and folding patterns that significantly controlled the geological architecture of the region.

The geological evolution reconstructed from this study demonstrates a transition from deep marine turbidite sedimentation in the Middle Miocene to terrestrial volcanic deposition in the Late Pliocene, punctuated by significant tectonic deformation. This study contributes to a more comprehensive understanding of the Miocene-Pliocene geological evolution in the Sumedang area, providing detailed lithostratigraphic, structural, and paleoenvironmental interpretations that refine existing regional-scale geological frameworks. The detailed geological maps and stratigraphic data generated from this research provide essential baseline information for future geological investigations, natural resource exploration, and geological hazard assessment in the region. Further research integrating geochemical analysis and radiometric dating would enhance the understanding of the volcanic history and tectonic evolution of this area.

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