Received: 20 Jan 2026| Revised: 26 Jan 2026| Accepted: 28 Jan 2026

Journal of Geological Sciences and Applied Geology
Open Journal System || Fakultas Teknik Geologi, Universitas Padjadjaran
GSAG
ISSN 2579 - 3136

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.

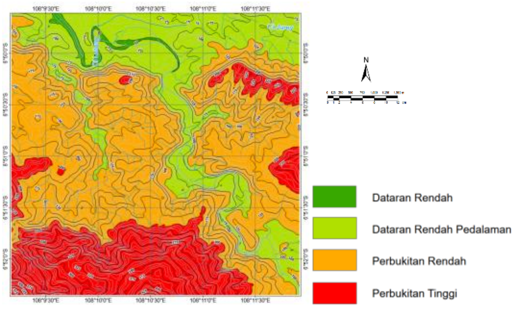

Figure 1. Morphography map

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).

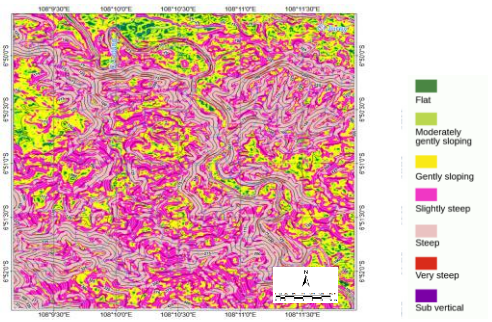

Figure 2. Morphometry map

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).

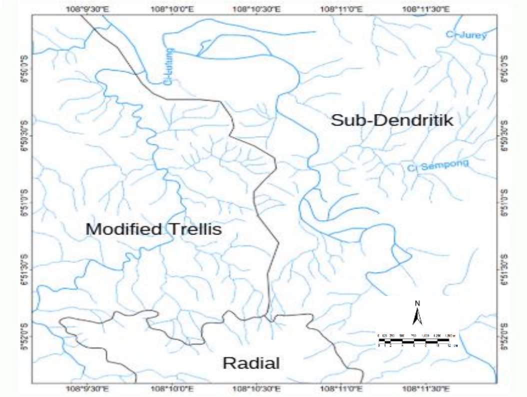

Figure 3. Drainage pattern map

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).

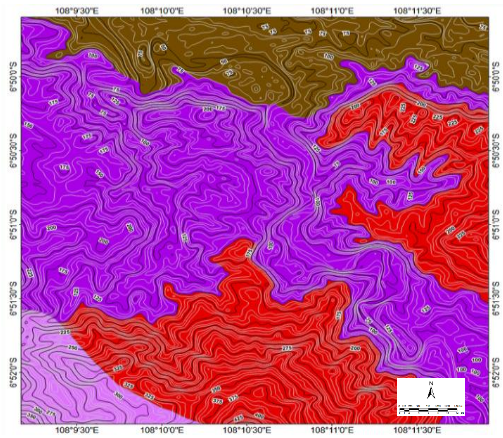

Figure 4. Geomorphology map

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).

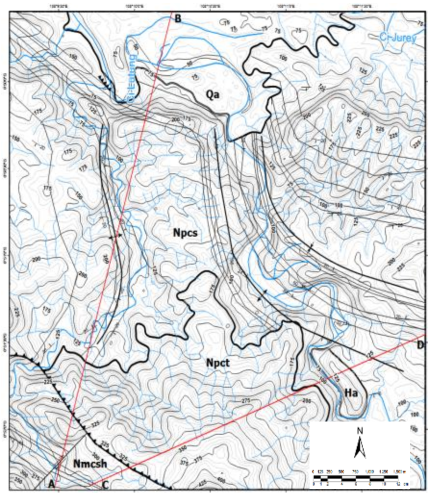

Figure 5. Structural/strike trend map

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.

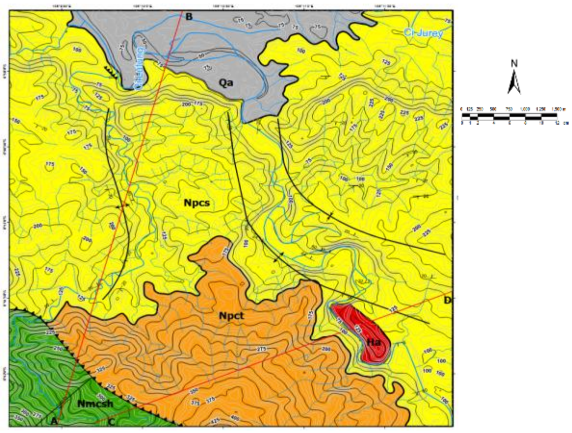

Figure 6. Geological map of research area

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.

ACKNOWLEDGEMENT

Thank you to Faculty of Geological Engineering, as the faculty in which the author studies at. The author also acknowledges the government of Majalengka and Sumedang district, specifically the Sidamukti, Lebaksiuh, and Kadu for their support. Thank you also to Prof Iyan Hariyanto for the valuable insight. Lastly I want to thank HMG (Himpunan Mahasiswa geologi), more specifically the class of 2022 for the support and accommodation throughout the mapping processes.

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