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Petrology and Petrography of Tuffaceous Sandstones from The Cipacar and Genteng Formations in the Kadurahayu Area, Lebak Regency, Banten Province

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Abstract
This study analyzes the petrological characteristics and depositional mechanisms of tuffaceous sandstones in the Genteng and Cipacar Formations, located in the Kadurahayu area, Banten Province. By integrating field observations with quantitative petrography based on Pettijohn (1975), the research identifies distinct mineralogical and textural variations between the two units. The Early-Middle Pliocene Genteng Formation is classified as a lithic wacke, comprising quartz (25%), lithic fragments (28%), and volcanic glass (10%). In contrast, the Late Pliocene Cipacar Formation is categorized as a greywacke, characterized by higher volcanic glass (13%) and clay matrix (22%) content. The presence of massive structures, matrix-supported fabrics, and poor microscopic sorting indicates that these deposits originated from sediment gravity flows and subsequent volcaniclastic reworking rather than primary air-fall processes. Early diagenesis is marked by the devitrification of volcanic glass into clay minerals, which significantly influenced rock porosity and overall properties. Regionally, the Genteng Formation exhibits higher textural maturity due to more extensive transport and reworking, while the Cipacar Formation reflects distal volcanic facies with a dominant primary volcanic input. These findings enhance the understanding of the depositional processes and volcanostratigraphic evolution within the Java volcanic arc.

1. Introduction

The Kadurahayu area and its surroundings in Lebak Regency, Banten Province, represent a region with relatively complex geological conditions influenced by volcanic activity and sedimentary processes. Regionally, this area is part of the Java volcanic arc, which developed as a result of the subduction of the Indo-Australian Plate beneath the Eurasian Plate. This tectonic setting has led to the formation of various volcanic and volcaniclastic sedimentary rock units distributed throughout southern Banten [1][2]. One of the rock units developed in the study area includes the Cipacar Formation and the Genteng Formation, which are generally composed of volcaniclastic sedimentary rocks such as tuffaceous sandstones and tuff. These rocks originated from volcanic materials produced during eruptions, which were subsequently transported and redeposited together with other sediments [3]. Previous studies have shown that the Cipacar Formation is characterized by tuffaceous sandstones that have undergone diagenetic processes, including compaction, cementation, and dissolution, based on petrographic analysis [4]. Meanwhile, the Genteng Formation is dominated by tuffaceous deposits associated with volcaniclastic sedimentation in littoral to terrestrial environments [5]. From a petrological and petrographic perspective, tuffaceous sandstones are typically composed of volcanic lithic fragments, feldspar, quartz, and volcanic glass embedded within a tuffaceous matrix. The mineralogical composition and textural characteristics of these rocks provide important information regarding the source of materials, transport processes, and depositional environment [6][7]. In addition, the presence of clay minerals and matrix plays a significant role in controlling rock properties and diagenetic processes [8]. Therefore, petrographic analysis is a crucial method for examining the characteristics of tuffaceous sandstones, particularly in determining mineral composition, texture, and provenance in volcaniclastic environments [9][10]. However, studies specifically focusing on the petrological and petrographic characteristics of tuffaceous sandstones within the Cipacar and Genteng Formations in the Kadurahayu area and its surroundings remain limited. As a result, detailed information regarding the mineral composition, texture, and origin of tuffaceous sandstones in this area is still insufficient. This research was conducted through field observations to identify lithological variations and to collect representative rock samples. Petrographic analysis was subsequently carried out through thin section observations using a polarizing microscope to determine mineral composition, grain characteristics, and rock textures. The objective of this study is to identify and analyze the petrological and petrographic characteristics of tuffaceous sandstones from the Cipacar Formation and the Genteng Formation in the Kadurahayu area and its surroundings, Lebak Regency, Banten Province. In volcaniclastic systems, sedimentation is commonly controlled by a combination of primary volcanic processes and secondary reworking mechanisms. Therefore, integrating petrographic characteristics with sedimentological interpretation is essential to understand depositional processes and volcanostratigraphic evolution.

2. Methodology

Fieldwork was conducted in the Kadurahayu area and its surroundings, Lebak Regency, Banten Province, to identify lithological variations and geological characteristics of the rock units belonging to the Cipacar Formation and Genteng Formation. Field observations focused on outcrops of volcaniclastic sedimentary rocks, particularly tuffaceous sandstone. During the field investigation, several observation points were established to document lithological characteristics, including rock type, grain size, sedimentary structures, and the distribution of rock units. Representative rock samples were collected from each observation point to ensure that the samples adequately represented the lithological variations within the study area. Field documentation was carried out using standard geological field equipment such as a geological hammer, hand lens, GPS device, and camera.

Laboratory analysis was conducted through petrographic examination using thin section analysis. Rock samples collected from the field were prepared as thin sections and observed under a polarizing microscope to determine the mineralogical composition and textural characteristics of the rocks. Petrographic observations focused on identifying the main mineral constituents, including volcanic lithic fragments, plagioclase, quartz, and volcanic glass fragments embedded within a tuffaceous matrix. In addition, grain characteristics such as grain size, grain shape, sorting, and relationships between mineral grains were analyzed. The classification and interpretation of the petrographic characteristics were conducted based on sedimentological and petrographic classification schemes proposed by Pettijohn et al. (1987) [6] and Boggs (2006) [3]. The results of the petrographic analysis were then interpreted to determine the petrological characteristics and the origin of the volcanic materials that formed the tuffaceous sandstone within the Cipacar and Genteng Formations. Petrographic data were further interpreted to infer depositional processes, transport mechanisms, and diagenetic alterations, following standard sedimentological and volcaniclastic interpretation approaches.

3. Results and discussions

3.1. Genteng Formation

The Genteng Formation is interpreted to be of Early Pliocene age and represents an older stratigraphic unit compared to the Cipacar Formation. In the study area, this formation is represented by tuffaceous sandstone layers with a thickness of up to approximately 3 meters. Megascopically, the rock displays a greenish-gray weathered color and a gray fresh surface. The grain size ranges from fine to medium sand, with relatively good sorting and generally rounded grain shapes, suggesting moderate transport and reworking processes. The rock exhibits a matrix-supported fabric, indicating that fine-grained material dominates the framework. Petrographic observations, however, reveal poorer sorting at the microscopic scale, suggesting scale-dependent variation in grain distribution due to depositional processes and post-depositional modification. Sedimentologically, the rock is characterized by a massive structure. However, this feature alone is not diagnostic. The combination of massive structure, matrix-supported fabric, and moderate sorting suggests deposition from high-concentration sediment gravity flows or reworked volcaniclastic flows, rather than purely primary fallout deposits. (see Figure 1)

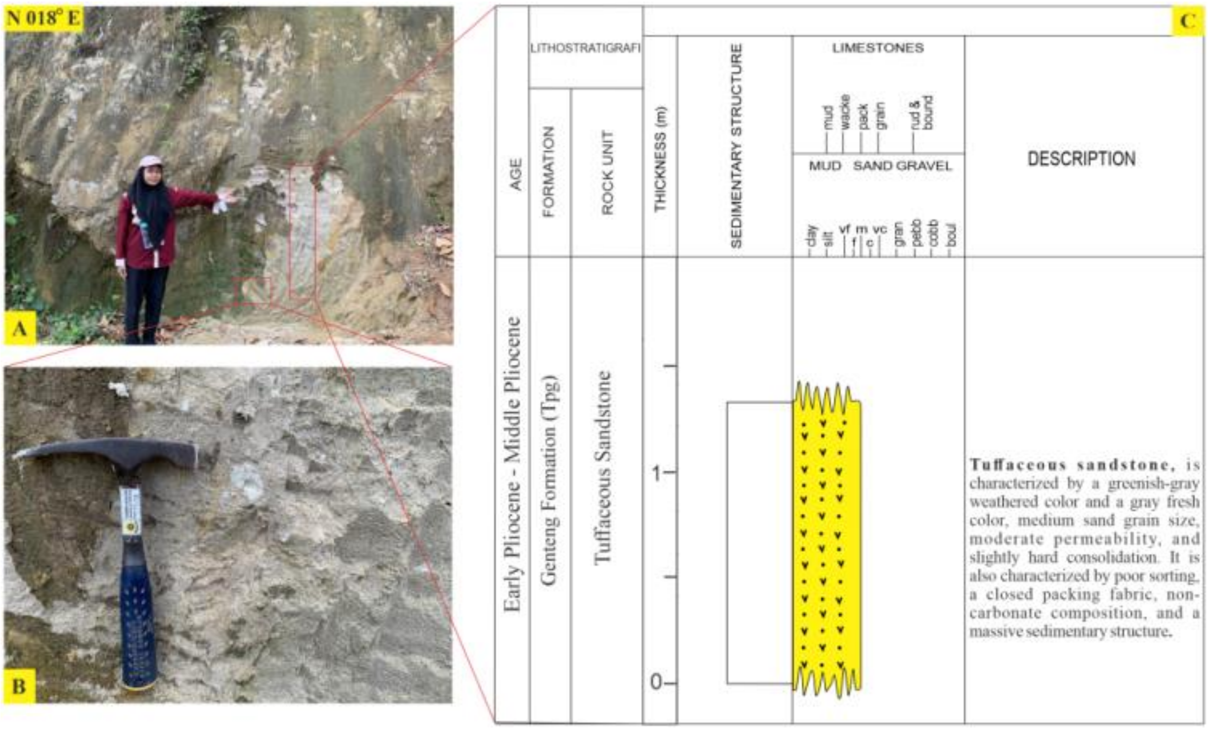

Figure 1. (A) Distant view of a tuffaceous sandstone outcrop of the Genteng Formation; (B) Close-up view of the tuffaceous sandstone outcrop of the Genteng Formation; (C) Lithological profile of tuffaceous sandstone of the Genteng Formation (scale 1:25).

To determine the mineral composition of the tuffaceous sandstone of the Genteng Formation (Tpg), a petrographic analysis was conducted using a microscope to examine thin sections of the rock (Figure 2). Observations were carried out at 10× magnification, using a 4× ocular lens and an objective lens, under both plane-polarized light (PPL) and cross-polarized light (XPL). This approach enabled a more detailed identification of the optical characteristics of the constituent minerals.

Petrographically, the sandstone is composed of quartz (25%), plagioclase (5%), biotite (15%), lithic fragments (28%), volcanic glass (10%), and clay minerals (14%). The relatively high proportion of lithic fragments and volcanic components indicates a strong volcanic provenance. Based on the matrix-supported texture and compositional characteristics, the rock can be classified as lithic wacke following Pettijohn et al. (1975).

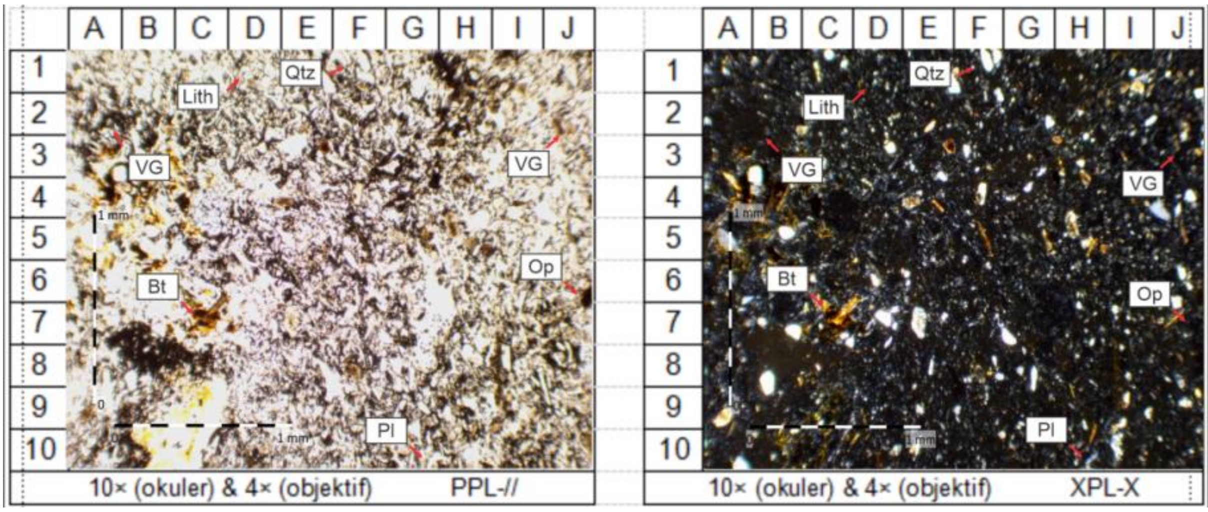

Figure 2. Thin section of tuffaceous sandstone from the Genteng Formation

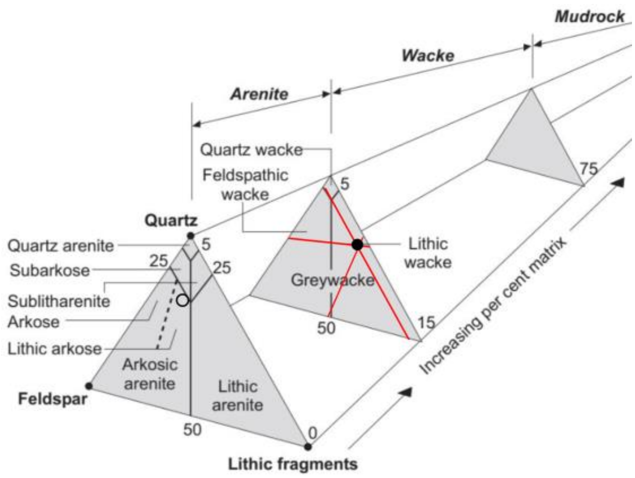

Figure 3. Classification Diagram based on Pettijohn (1975) [6]

The presence of volcanic glass suggests relatively rapid deposition and limited transport, allowing preservation of unstable volcanic materials. Partial alteration of volcanic glass into clay minerals indicates early-stage diagenetic processes, likely involving devitrification. These features collectively suggest that the Genteng Formation represents reworked volcaniclastic deposits influenced by sediment gravity flows in a volcanic arc setting.

3.2. Cipacar Formation

The Cipacar Formation is interpreted to be of Late Pliocene age and represents a younger stratigraphic unit overlying the Genteng Formation. In the study area, this formation is represented by tuffaceous sandstone layers with a thickness of up to approximately 2.1 meters. Megascopically, the rock exhibits a dark brown weathered color and a cream fresh surface. The grain size is generally fine to medium sand, with relatively good sorting and rounded grain shapes. Similar to the Genteng Formation, the rock exhibits a matrix-supported fabric. Petrographic observations indicate poorer sorting at the microscopic scale, reflecting depositional heterogeneity and possible reworking processes. The sandstone displays a massive sedimentary structure. When combined with the matrix-supported texture and high fine-grained content, this suggests deposition from high-density sediment gravity flows or reworked volcaniclastic materials, rather than direct air-fall deposition. (see Figure 3)

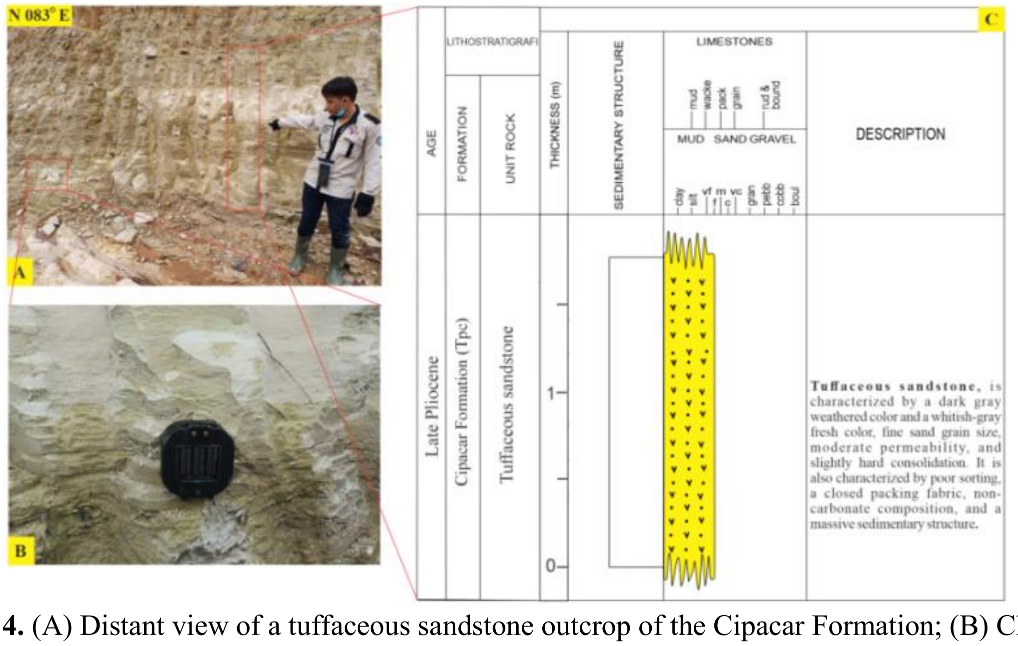

Figure 4. (A) Distant view of a tuffaceous sandstone outcrop of the Cipacar Formation; (B) Close-up view of the tuffaceous sandstone outcrop of the Cipacar Formation; (C) Lithological profile of tuffaceous sandstone of the Cipacar Formation (scale 1:25).

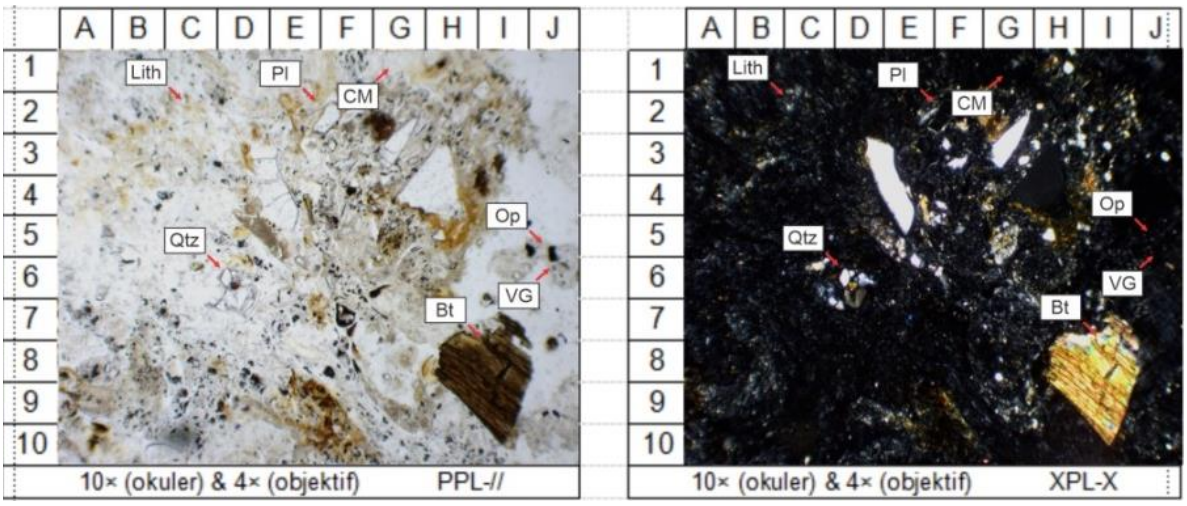

Figure 5. Thin section of tuffaceous sandstone from the Cipacar Formation

To determine the mineral composition of the tuffaceous sandstone of the Cipacar Formation (Tpc), a petrographic analysis was conducted using a microscope to examine thin sections of the rock (Figure 4). Observations were carried out at 10× magnification, using a 4× ocular lens and an objective lens, under both plane-polarized light (PPL) and cross-polarized light (XPL). This approach enabled a more detailed identification of the optical characteristics of the constituent minerals.

Petrographic analysis shows that the rock is composed of quartz (16%), plagioclase (3%), biotite (15%), lithic fragments (17%), volcanic glass (13%), and clay minerals (22%). The higher proportion of volcanic glass and clay matrix indicates a greater contribution of primary volcanic material and lower compositional maturity compared to the Genteng Formation. Based on its matrix-supported texture and low lithic and volcanic content, the rock is classified as greywacke.

The relatively high volcanic glass content suggests rapid deposition with limited transport, while the abundance of clay minerals indicates alteration of volcanic materials during diagenesis. This alteration likely occurred through devitrification processes, influencing porosity and overall rock properties. These characteristics indicate that the Cipacar Formation represents relatively less reworked volcaniclastic deposits, likely deposited in a more distal setting but still strongly influenced by volcanic input.

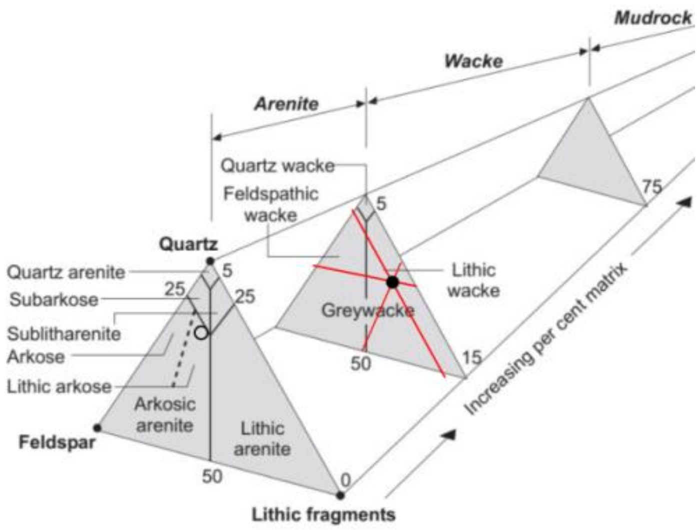

Figure 6. Classification Diagram based on Pettijohn (1975) [6].

3.3. Depositional Interpretation

Based on field observations and petrographic analysis, the tuffaceous sandstones of the Genteng and Cipacar Formations indicate deposition within a volcaniclastic system influenced by both primary volcanic processes and secondary reworking mechanisms. The matrix-supported texture, poor microscopic sorting, abundant volcanic lithic fragments, volcanic glass, and massive sedimentary structures observed in both formations suggest deposition associated with sediment gravity flows and subsequent volcaniclastic reworking.

Although both formations share similar petrographic characteristics, differences in mineral composition and textural maturity indicate variations in depositional processes. The Genteng Formation contains a relatively higher proportion of quartz and better-developed grain rounding, suggesting more extensive transport and reworking before deposition. In contrast, the Cipacar Formation is characterized by a higher volcanic glass content and greater clay matrix abundance, indicating a stronger contribution of primary volcanic material and relatively limited transport. These petrographic and sedimentological characteristics suggest that volcaniclastic sedimentation in the study area was controlled by volcanic input accompanied by varying degrees of sediment gravity flow and secondary fluvial reworking. Consequently, the depositional system is interpreted as a volcaniclastic basin where sedimentary processes subsequently redistributed primary volcanic deposits.

3.4. Reconstruction of the geological history of the study area

The Genteng Formation was formed during the Early to Middle Pliocene as a result of increased regional volcanic activity, which supplied significant amounts of volcanic sediments into the depositional basin. This formation is characterized by dominant lithologies consisting of volcanic breccia, tuffaceous sandstone, and sandstone, reflecting variations in distance from the volcanic source, ranging from proximal to distal depositional environments. Volcanic breccia indicates the deposition of coarse, angular, and large-sized fragments that generally accumulated relatively close to the eruption center, such as on volcanic slopes or within pyroclastic flow zones. In contrast, tuffaceous sandstone represents finer volcanic ash material that has undergone transportation and reworking by water, leading to its deposition in moderate-energy environments located relatively farther from the volcanic source [3]. Following the deposition of the Genteng Formation (Tpg) during the Early to Middle Pliocene, sedimentation continued, leading to the development of the Cipacar Formation (Tpc) in the Late Pliocene. The Cipacar Formation is interpreted to overlie the Genteng Formation conformably. This conformable relationship is inferred from the observed lithological continuity in the study area, although detailed measured stratigraphic sections are not available. The transition between these formations suggests relatively continuous volcaniclastic sedimentation, despite noticeable changes in lithological characteristics and depositional facies. In terms of facies, the Cipacar Formation is interpreted as a distal volcanic facies, representing volcanic deposits that accumulated relatively far from the eruption center. This condition resulted in dominant lithologies of tuff and tuffaceous sandstone, which reflect fine- to medium-grained volcanic ash materials that were transported and subsequently reworked before deposition. These lithological characteristics indicate relatively lower depositional energy compared to proximal volcanic facies and were influenced by reworking processes driven by water and gravity [11]. (Figure 5)

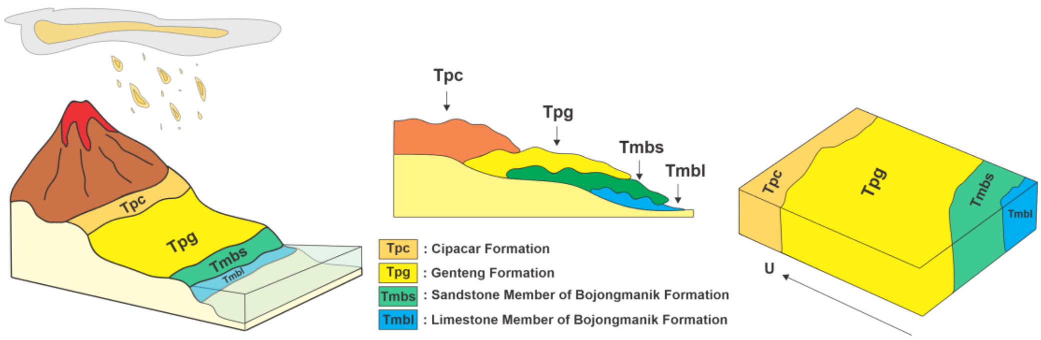

Figure 5. Depositional model for the Genteng Formation (Tpg) and Cipacar Formation (Tpc)

4. Conclusion

Petrological and petrographic analyses indicate that the tuffaceous sandstones of the Genteng and Cipacar Formations in the Kadurahayu area are derived from volcaniclastic materials but exhibit differences in mineralogical composition, texture, and depositional characteristics. The Genteng Formation is characterized by relatively higher quartz and volcanic lithic fragment contents, better grain rounding. It is classified as lithic wacke, indicating relatively greater textural maturity and more extensive transport and reworking. In contrast, the Cipacar Formation contains higher proportions of volcanic glass and clay matrix, is classified as greywacke, and represents a relatively less mature volcaniclastic deposit with a stronger contribution of primary volcanic material.

The integration of field observations and petrographic analysis suggests that the deposition of both formations was controlled by volcanic input, sediment gravity flows, and subsequent volcaniclastic reworking. Differences in mineral composition and textural maturity reflect variations in transport intensity and depositional conditions between the Genteng and Cipacar Formations. These findings contribute to a better understanding of the depositional processes and volcanostratigraphic evolution of the Genteng and Cipacar Formations in the Kadurahayu area, Lebak Regency, Banten Province.

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