J E M T
Journal of Earth and Marine Technology
homepage URL: ejurnal.itats.ac.id/jemt

Facies and Architectural Element Analysis of Braided Fluvial Succession : The Paleogene Cawang Member, Ogan Komering Ulu Selatan Area , South Sumatra

Sapto Kis Daryono *[1], Andi Kartika [1],Tridadi Saktiawan [2]
[1] Department of Geological Engineering, FTM-UPN "Veteran" Yogyakarta, Indonesia
[2] Department of Geological Engineering, FT-Universitas Akprind Yogyakarta, Indonesia
* corresponding author: saptokisdaryono@gmail.com

Article info
Received: Jul 30, 2025
Revised: Jan 7, 2026
Accepted: Jan 22, 2026
Published: Jan 25, 2026

Keywords:
Facies, Architectural elements, Fluvial, Cawang Member

Abstract

The Cawang Member of the Kikim Formation plays an important role in understanding the Paleogene sedimentary development of the Palembang Subbasin due to its presence as a pre-rift deposit that occurred before or simultaneously with the formation of the basin. Interpretations of the stratigraphic evolution of the Paleogene succession are based on detailed surface geological mapping, particularly through lithofacies identification and depositional environment analysis. These observations reveal that the lithological characteristics and facies distribution of the Cawang Member record dynamic sedimentary processes associated with early basin evolution. Facies analysis was conducted along measured stratigraphic sections encompassing conglomerate–sandstone 1 and sandstone 1-sandstone units exposed along the Bumi Agung and Batu Belang traverses in the South Ogan Komering Ulu area, South Sumatra. The conglomerate-sandstone 1 and sandstone 1-sandstone units attains a thickness of approximately 158.82 m, and about 177.50 m. A total of nine lithofacies were identified, including matrix-supported massive gravel (Gmm), matrix-supported, gravel (Gmg), massive gravel (Gm), massive sandstone (Sm), horizontally bedded sandstone (Sh), low-angle cross-bedded sandstone (SI), carbonaceous mud (C), massive fine sandstone-silt-mud (Fm), and massive siltstone and mudstone (Fsm). These lithofacies are grouped into four main facies associations: gravel bars (GB), sandy bedforms (SB), channels (CH), and overbank fine (FF). The assemblage of facies associations indicates deposition within a fluvial system dominated by braided river processes, with localized influence of sediment gravity flows.

1. Introduction

The research area is situated in Muara Dua Village, Muara Dua District within the South Ogan Komering Ulu Regency, South Sumatra Province (Figure 1). The area forms part of the South Sumatra Basin, one of Indonesia's major hydrocarbon-producing basins [1]. The stratigraphic interval investigated in this study corresponds to the Cawang Member of the Kikim Formation, which represents the earliest sedimentary record within the basin [2]. Despite its importance, the Kikim Formation, particularly the Cawang Member, has not been comprehensively studied in terms of facies architecture, sedimentary processes, and depositional environment interpretation [3]. This knowledge gap is largely attributed to the dominance of terrestrial Paleogene deposits within the basin, which complicates stratigraphic correlation and obscures constraints on depositional age, spatial distribution, and sediment provenance [4], [5]. The measured surface cross-section of the Cawang Member is still very limited, especially the key locations of Bumi Agung and Batu Belang so that control over vertical and lateral variations of gravel-dominated deposits is still weak, thus directly impacting the uncertainty in building the local braided-river gravel-dominated model, including understanding reservoir connectivity, channel geometry, and its implications for the petroleum system. This research examines the stratigraphy of Paleogene sedimentary rocks from surface samples, based on sedimentological analysis [6], [7]. The results of this study will provide an overview of the depositional environmental conditions that occurred during the formation of the Cawang Member of the Kikim Formation, as reflected in its lithological and facies characteristics.

2. Regional Geology

The South Sumatra Basin is located east of the Barisan Mountains, trending northwest-southeast. It is a back-arc basin, bounded by the Barisan Mountains to the southwest and the Pre-Tertiary Sunda Shelf to the northeast [8]. The basin is subdivided into several structural and depositional domains, including the Jambi Subbasin (North Palembang), Central Palembang Subbasin, and South Palembang Subbasin (Palembang Complex), with the present study area situated within the North Palembang Subbasin [9]. Stratigraphically, the South Sumatra Basin records a complex history of sedimentation from the Paleogene to the Neogene. The oldest succession comprises pre-Tertiary basement overlain by the Garba Formation, followed by the terrestrially deposited Kikim and Lahat Formations that rest unconformably on the Mesozoic basement (Figure 2) [10]. Subsequent marine transgression led to the accumulation of the Talang Akar and Batu Raja Formations, marking a shift from continental to shallow-marine conditions, which culminated in deep-marine sedimentation represented by the Gumai Formation. A regional regression phase followed, characterized by the deposition of the Air Benakat Formation in shallow-marine settings, the Muara Enim Formation in transitional environments, and finally the Kasai Formation under dominantly terrestrial conditions [2]. The tectonic evolution of the basin is closely linked to the broader development of Sumatra Island and involved multiple deformation phases. According to Pulunggono et al. [11] and Metcalfe [12], an early compressional phase during the Early Jurassic to Cretaceous resulted in metamorphism, folding, and faulting of Paleozoic–Mesozoic sequences, establishing the fundamental structural framework of the basin. This was followed by an extensional phase from the Late Cretaceous to Early Tertiary, which generated major N–S and WNW–ESE–oriented structural trends and provided accommodation space for sediment accumulation. Basin infill during this period was influenced by contemporaneous volcanic activity and the erosion of uplifted Paleozoic and Mesozoic source areas. A later compressional event in the Plio–Pleistocene reactivated earlier structures and coincided with the uplift of the Bukit Barisan Mountains, leading to the development of the Sumatran strike-slip fault system. As a result, northwest–southeast–trending structures dominate the present-day structural configuration of the South Sumatra Basin.

3. Methodology

Facies analysis was applied to characterize lithological attributes that form the basis for interpreting depositional architecture [13]. The analysis is grounded in detailed observations of rock composition and sedimentary structures recorded in outcrop exposures. Facies classification follows the fluvial facies scheme proposed by Miall [14]–[16], in which sedimentary units are distinguished according to grain-size distribution, grain-support mechanisms, and the nature of primary sedimentary structures. This framework allows fluvial deposits.

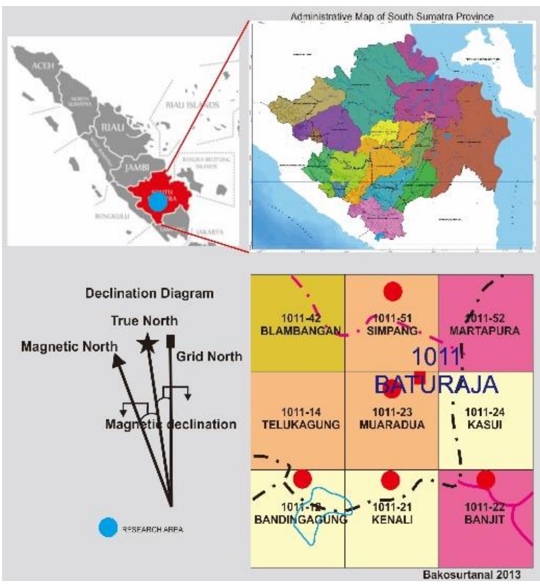

Figure 1. Map of Muaradua research location, South Ogan Komering Ulu Regency, South Sumatra Province

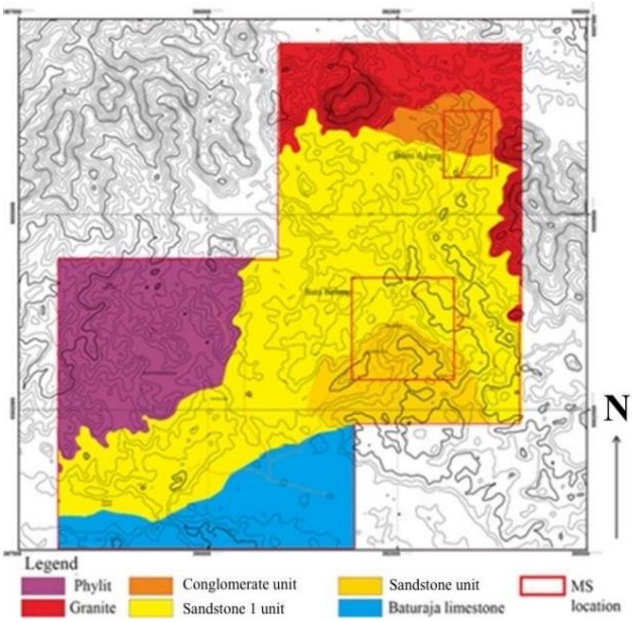

Figure 2. Geological map of the Muaradua research area, South Ogan Komering Ulu Regency, South Sumatra Province

Table 1. Lithofacies found in each unit (X indicating exist) (Figures 3 and 4)

Facies	Conglomerate Deposits	Sandstone Deposits
Gmg	X	X
Gmm	X	X
Gm	X	-
Sh	X	X
SI	X	-
Sm	X	X
Fsm	-	X
Fm	-	X
C	-	X

Explanation:
Gmg : *Matrix supported, gravel*
Gmm : *Matrix supported, massive gravel*
Gm : *Massive gravel*
Sh : *Horizontally bedded sand*
Sl : *Low-angle cross-bedded sand*
Sm : *Massive sand*
Fsm : *Laminated sandstone and mudstone*
Fm : *Massive mudstone-siltstone*
C : *Carbonaceous mud*

The facies determination of conglomeratic and sandy successions in the Ogan Komering Ulu area, South Sumatra, used primary data obtained from field mapping (Figure 2). Two stratigraphic sections were measured: one at the Bumi Agung site (Figures 3 and 5) and the other at the Batu Belang site (Figures 4 and 6). Two representative measured stratigraphic sections were documented, which expose laterally continuous and well-preserved outcrops of the studied units. Facies differentiation was initially carried out through lithofacies classification, using variations in grain size, grain-support framework, and primary sedimentary structures as diagnostic criteria. These lithofacies were subsequently grouped into facies associations that reflect recurring depositional patterns. Based on the facies associations found, interpretations are made regarding the depositional environment, the geometry of architectural elements, and the depositional mechanisms of the Cawang Member of the Kikim Formation.

4. Results

4.1. Fluvial unit division

Based on detailed measurements of the stratigraphic cross-sections, the conglomerate–sandstone 1 unit was identified in the Bumi Agung section and sandstone-sandstone 1 units from the Batu Belang section, all of which are part of the Cawang Member of the Kikim Formation. Both stratigraphic cross-sections are amalgamations of profiles at the observation locations. The measured stratigraphic section at Bumi Agung records a total thickness of approximately 158.82 m, whereas the Batu Belang section represents a thicker succession, reaching about 177.50 m.

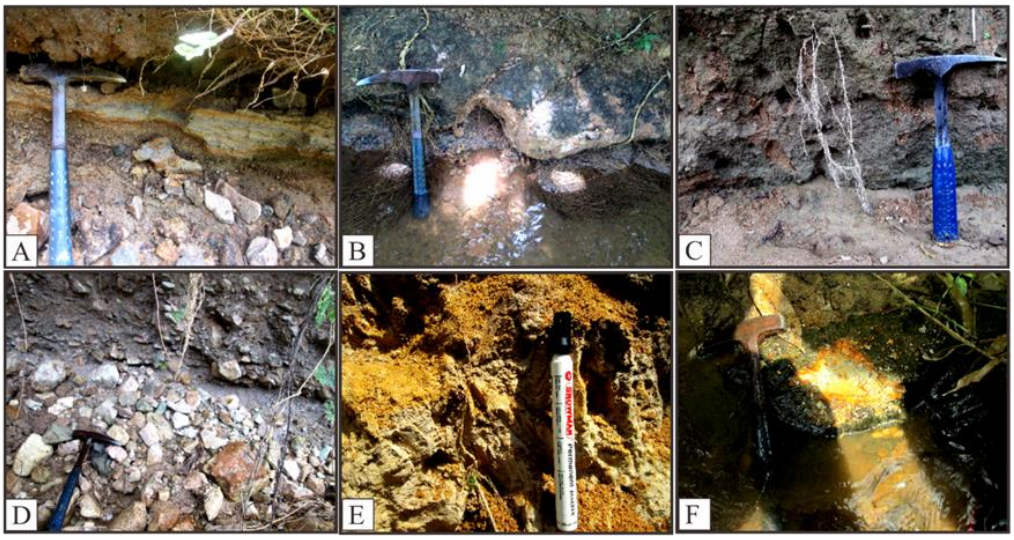

Figure 3. The measured section at Bumi Agung consists of: (A) Sandstone with layered structure with Horizontally bedded sandstones (Sh) facies, (B) Siltstone with laminated structure with Massive siltstones and mudstones (Fsm) facies, (C) Sandstone with Massive gravel (Gm) facies, (D) Conglomerate with Gravel matrix-supported (Gmg) facies, (E) Sandstone with Massive sandstone (Sm) facies, (F) Mudstone with Massive mudstone-siltstone (Fm) facies.

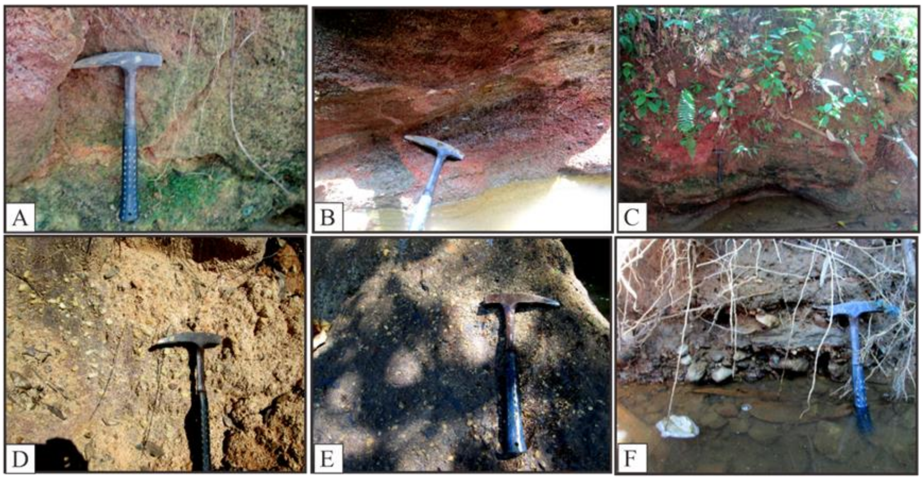

Figure 4. The measured trajectory of Batu Belang consists of: (A) Sandstone with Massive sandstone facies (Sm), (B) Sandstone with layered structure with Horizontally bedded sandstones facies (Sh), (C) Mudstone with Massive mudstone-siltstone facies (Fm), (D) Conglomerate with Gravel matrix supported massive facies (Gmm), (E) Sandstone with Massive sandstone facies (Sm), (F) Conglomerate with matrix supported graded gravel facies (Gmg).

3.2. Lithofacies

Lithofacies identification provides a basis for reconstructing the stages of sediment transport and migration within sedimentary successions, illustrating past sediment deposition processes. Based on the analysis, nine lithofacies were identified (Table 1). Most are dominated by coarse-to fine-grained sandstone. Facies dominated by conglomerate and clay-dominated facies are less common in individual outcrops. Each lithofacies is described below:

3.2.1. Matrix supported, gravel (Gmg) Lithofacies

The Gmg lithofacies is characterized by a dominant matrix-supported grain relationship, particularly in conglomerate and pebbly sandstone lithologies with massive sedimentary structures and graded bedding. Within the conglomerate–sandstone 1 units, bed thicknesses of about 60–100 cm. This lithofacies is found in the lower to upper portions of the stratigraphic section and is reflecting deposition under relatively high-energy flow conditions with high viscosity.

3.2.2. Matrix supported, massive gravel (Gmm) Lithofacies

The Gmm lithofacies is characterized by a dominant matrix-supported grain relationship, particularly in sandstone-conglomerate, pebbly sandstone, and conglomerate lithologies with massive sedimentary structures. The thickness of this facies in conglomerate or sandstone 1 units is 50-125 centimeters. This facies occurs repeatedly within the conglomerate–sandstone 1 units, indicating recurrent depositional events. It is interpreted to have formed from high-energy, high-viscosity debris flows.

3.2.3. Massive gravel Lithofacies (Gm)

The Gm facies is characterized by clast-dominated fabrics with predominantly grain-supported relationships and a lack of internal sedimentary structures, resulting in a massive appearance. Individual beds within the conglomerate unit approximately 50 to 125 cm in thickness. This facies is developed entirely within conglomeratic lithology and laterally continuous beds.

3.2.4. Massive sandstone Lithofacies (Sm)

The Sm facies feature medium-sized sand with massive structures. Within the conglomerate–sandstone 1 units, this facies occurs as beds with thicknesses ranging from approximately 14 to 200 cm. This lithofacies is a sedimentary gravity flow deposit.

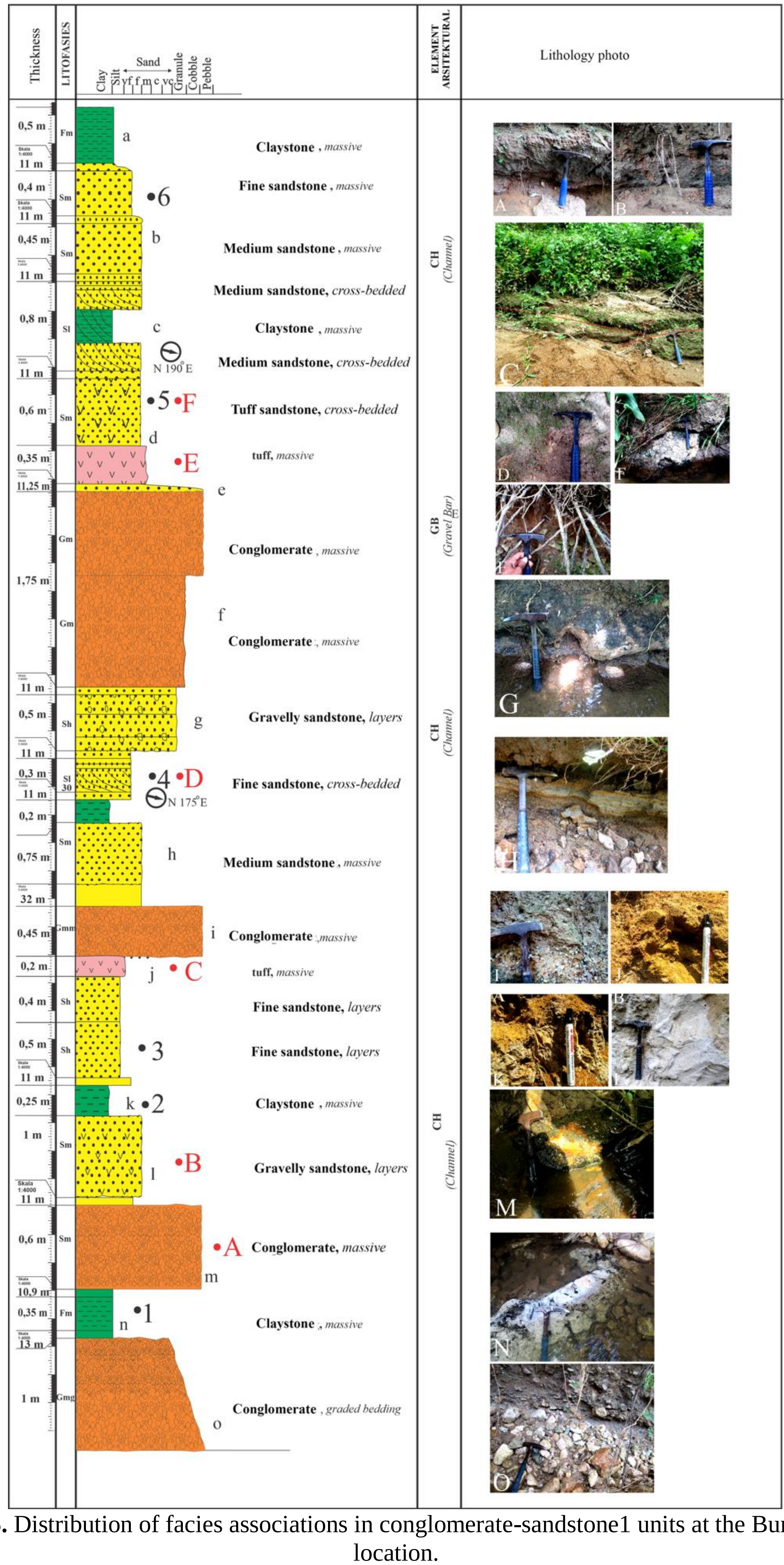

Figure 5. Distribution of facies associations in conglomerate-sandstone1 units at the Bumi Agung location.

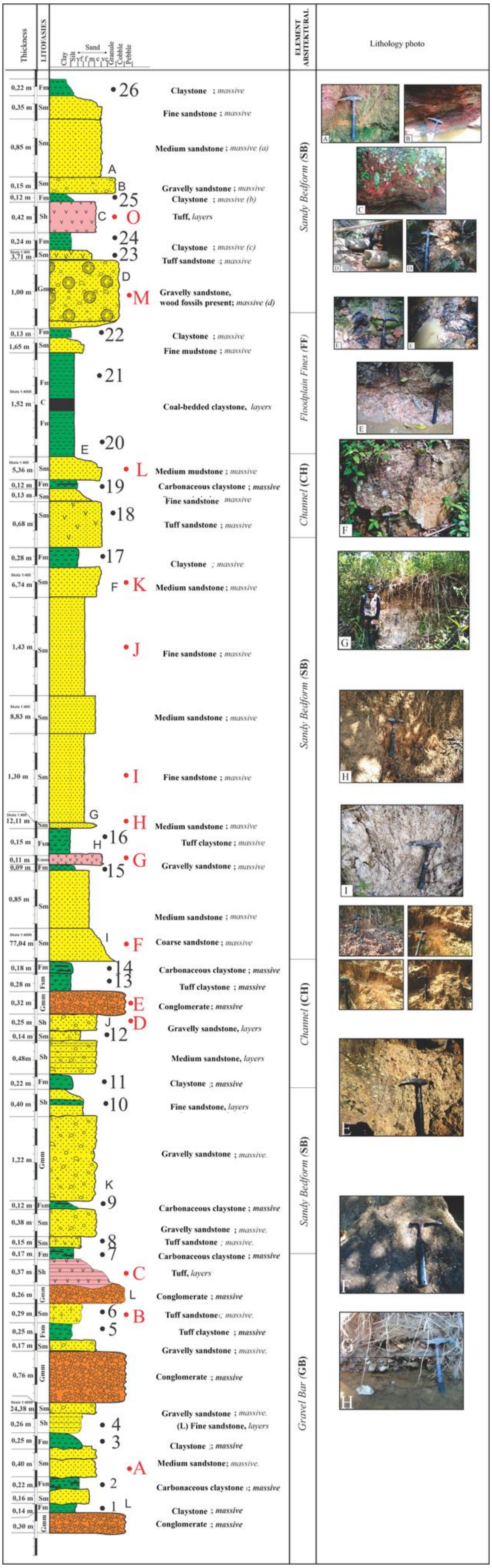

Figure 6. Distribution of facies associations in the sandstone 1 units at the Batu Belang location.

3.2.5. Horizontally bedded sandstones Lithofacies (Sh)

The Sh facies is composed of very fine- to very coarse-grained sandstone with a parallel bedding structure, are generally to the paleoflow direction. Individual beds within the conglomerate unit and sandstone 1 unit typically range in thickness from approximately 22 to 50 cm. This facies is developed within sandstone lithologies and occurs at multiple stratigraphic levels.

3.2.6. Low-angle cross-bedded sandtone (SI) Lithofacies

The SI facies has very fine to medium sand grains with a sedimentary structure consisting of low-angle cross-bedded sandstone (<15°). These facies have a thickness of 30 centimeters in conglomerate unit. These facies are found in sandstone and mudstone lithologies in the upper and middle parts of conglomerate unit.

3.2.7. Massive mudstone-siltstone (Fm) Lithofacies

The Fm facies is found in mudstone lithologies with a massive structure (Figure 3.c). This facies has a thickness of 10-150 centimeters. The Fm facies is interpreted as resulting from abandoned river or backwater swamp deposits.

3.2.8. Massive siltstones and mudstones (Fsm) Facies

The Fsm facies is found in massive mudstones and are 15-30 centimeters thick. This facies develops in mudstone lithologies in the lower, middle, and upper parts of the conglomerate or sandstone 1 units. The facies are interpreted as deposited by suspension processes in floodplain and abandoned channel environments.

3.2.9. Carbonaceous mud (C) Facies

The C facies consist of black mudstone and coal lithologies characterized by a massive structure. This layer can be 2-50 centimeters thick. This facies only develops in the central part of the conglomerate unit in the study area. Facies C is interpreted to represent deposition in overbank settings or abandoned channel environments.

3.3. Architectural Elements

Four architectural elements were recognized in this study through analysis of rock texture and primary sedimentary structures [16]. These four architectural elements are gravel bars (GB), sandy bedforms (SB), channel (CH), and overbank fine (FF) (Figures 5 and 6). The following is an explanation of each architectural elements:

3.3.1. Gravel Bars (GB) Architectural Element

This element contains lithofacies of Gmm, Gmg, and Gm (Figures 3C, 3D, 4D and 4F). Gravel bars are composed of gravel-boulder-sized lithofacies. Its formation is influenced by transportation processes and indicate irregular transportation processes over time. The GB facies association is dominated by gravel- to boulder-sized clasts and is characterized by poor mixing between coarse and finer fractions, accompanied by the absence of primary sedimentary structures. These attributes indicate rapid sediment emplacement by gravity-driven processes, particularly debris flows.

3.3.2. Sandy Bedforms (SB) Architectural Element

This element contains lithofacies of Gmm, a relatively thick Sm, Sh, and Fm (Figures 3A, 3E, 3F, 4A, 4B, 4C and 4E). The architectural elements of Sandy Bedforms are typically layers of sandstone with a lens-like, layered, and wedge-shaped geometry. The SB facies association reaches a thickness of 80 meters. It was deposited by high-energy debris flows due to high sediment supply from upstream sources. The architectural elements were deposited in a low-sinuosity river environment.

3.3.3. Channel (CH) Architectural Elements

This element includes facies Gmm, Sm, Sh, SI, Fm, and Fsm (Figures 3A, 3B, 3E, 3F, 4C and 4D). The elements also exhibit a fining-upward pattern found in the lower, middle, and upper parts of the conglomerate or sandstone 1 units. These elements are approximately 5-12 meters thick. It predominantly consists of medium-grained sandstone, conglomerate, and siltstone intercalations.

3.3.4. Floodplain (FF) Architectural Element

This element contains the Fsm and Fm facies (Figures 3B and F) , consisting of massive mudstone and siltstone with ripple cross-laminated structures, ranging in thickness from 0.35 to 2 meters in conglomerate and sandstone 1 units (Figure 5). This element characterizes deposition in backwater or swamp environments, suggesting deposition under low-energy conditions. The FF facies association is also part of the overbank deposits of river systems.

4. Discussion

4.1. Conglomerate unit

Overall, the facies analysis of the conglomerate unit was taken from the stratigraphic cross-section at the Bumi Agung site (Figures 5 and 7). Conglomerate unit are dominated by sand-gravel-sized material, with eight types of lithofacies found. The facies that developed are Gmm, Gmg, Gm, Sm, Sh, SI, Fm, and Fsm.

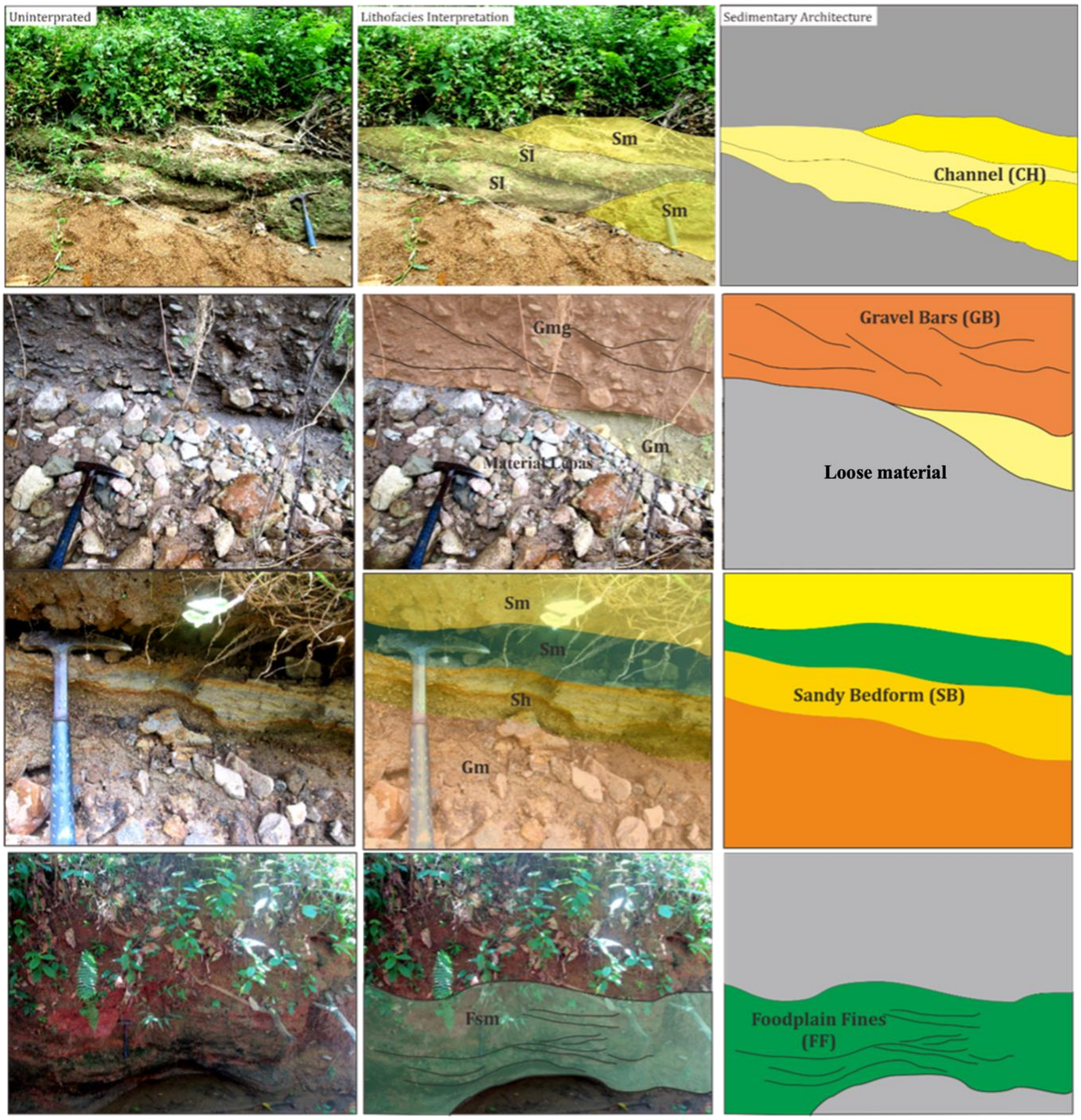

Figure 7. Interpretation of architectural elements in conglomerate and sandstone 1 outcrops: Bumi Agung section

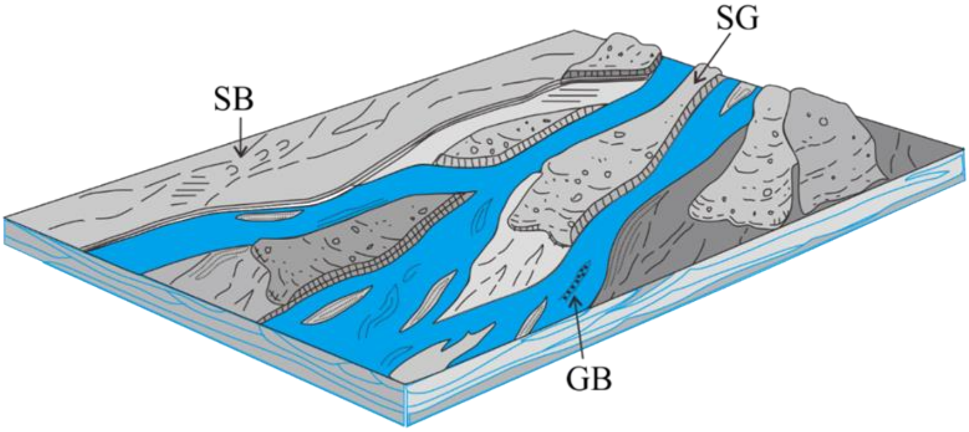

Figure 8. River model gravel braided rivers with sedimentary gravity flows [16].

Channel architectural elements are part of channel fill deposits. These elements exhibit fining-upward pattern and a scouring pattern at the base. Channels can be composed of lithofacies ranging in size from cobble to clay. In the study area, channel elements are composed of lithofacies Gmg, Gmm, Sm, Sh, and Fm. The Gmg and Gmm lithofacies indicate deposition from debris flows, where the resulting deposits can be massive or graded. The Sm lithofacies (massive sand) indicates deposition by gravity flow.
Gravel bar architectural elements are also part of channel fill deposits. Gravel bars are composed of gravel-sized lithofacies and indicate variable transportation processes over time. In the study area, this architectural element is composed of the Gm lithofacies. The floodplain (FF) architectural elements indicate a decrease in current energy.

4.2. Sandstone 1 unit

Overall, the facies analysis of sandstone 1 unit was based on the stratigraphic cross-sections at the Bumi Agung and Batu Belang sites (Figures 5, 6 and 7). Seven types of lithofacies were found in the sandstone 1 unit. The facies that developed were Gmm, Gmg, Sm, Sh, C, Fm, and Fsm.

The exposed portion of the sandstone 1 unit is dominated by sandstone lithofacies (Sm, Sh) and clay (Fm and Fsm). Conglomerate lithofacies (Gmm, Gmg, and Gm) are present in small amounts. The most common architectural elements are Channel (CH), Sandy Bedform (SB), Floodplain (FF), and Gravel Bars (GB). The presence of a facies dominated by coarse-to-fine sandstone, resulting in changes in grain size and stacking patterns observed in the study area, represent a typical facies interpreted as a transition from predominantly gravel-sized material deposited under high energy conditions to clay-sized material deposited under low energy conditions.

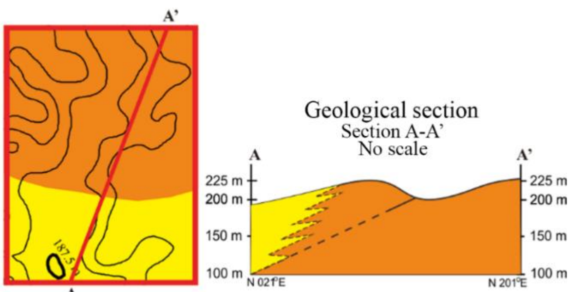

Figure 9. Geological section of conglomerate and sandstone 1 units: Bumi Agung section

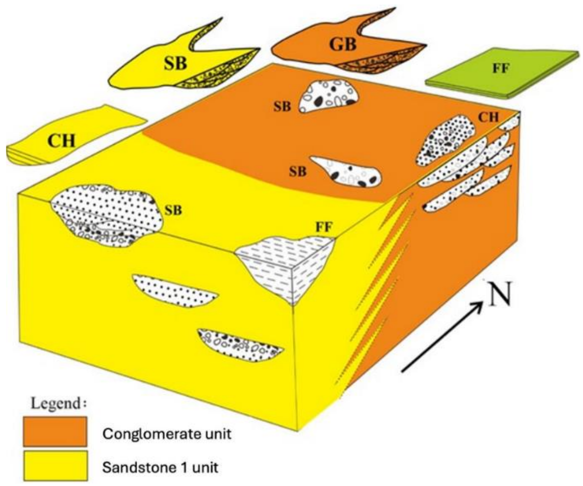

Figure 10. Block diagram of conglomerate-sandstone 1 units: Bumi Agung section

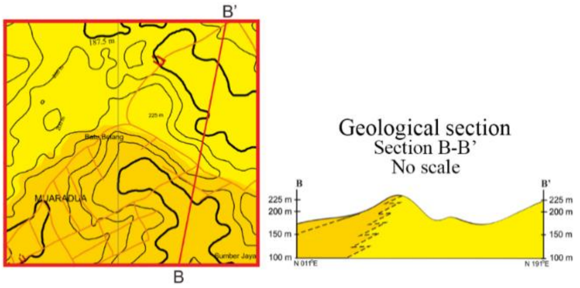

Figure 11. Geological section of sandstone-sandstone 1 units: Batu Belang section

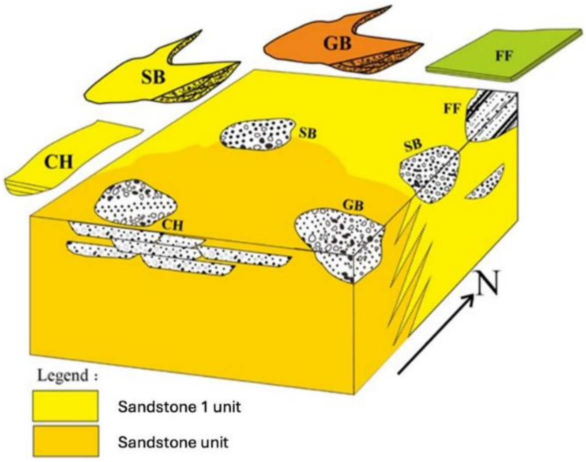

Figure 12. Block diagram of sandstone-sandstone 1 units: Batu Belang section.

4.3. Sandstone unit

The facies analysis of the sandstone unit is based on stratigraphic section at the Batu Belang site. Six lithofacies types are found within the sandstone unit. The facies developed are Gmm, Gmg, Sm, Sh, C, and Fm.

The exposed sandstone unit is dominated by sandstone (Sm, Sh) and clay (Fm and Fsm) lithofacies. Conglomerate lithofacies (Gmm, Gmg, and Gm) are present in minor amounts. The most common architectural elements are channels (CH), sandy bedforms (SB), floodplains (FF), and gravel bars (GB). Coarse to fine sandstone facies dominate in this unit, resulting in the changes in grain size and assemblage patterns observed in the study area. This is a typical facies interpreted as a transition from predominantly gravel-sized material deposited under high-energy conditions to clay-sized material deposited under low-energy conditions.

4.4. Depositional environment of conglomerate, sandstone 1 and sandstone deposits

The description above indicates that the depositional environment of the study area is fluvial. Furthermore, considering the large sediment grain size, large sediment load, high flow velocity, and rapid deposition, it can be described as a depositional environment that fits the Braided River model (Figures 8-12). The dominance of coarse sedimentary material and the abundance of GB and SB facies associations indicate a large number of river bars, which are characteristic of braided rivers (Figures 10 and 12). Braided river systems are characterized by sediment transport dominated by bedload movement, in which coarse material is conveyed primarily by rolling, sliding, or short-distance hopping along the channel floor. These systems typically develop in settings with relatively steep gradients, wide channel belts, and high channel slopes, resulting in some of the highest energy conditions among fluvial environments. Based on these characteristics, the depositional model inferred for the study area corresponds to a gravel-dominated braided river system, with sediment accumulation locally influenced by sedimentary gravity flows (Figure 8).

5. Conclusion

Based on profile observations conducted in the study area, the conglomerate, sandstone 1 and sandstone units represent a fluvial depositional environment. Facies analysis identified nine lithofacies: matrix supported, gravel (Gmg), matrix supported, massive gravel (Gmm), massive gravel (Gm), massive sandstone (Sm), horizontally bedded sandstone (Sh), low-angle cross-bedded sandstone (SI), carbonaceous mud (C), massive fine sandstone-silt-mud (Fm), and massive siltstone and mudstone (Fsm). Facies associations include gravel bars (GB), sandy bedforms (SB), channels (CH), floodplain (FF). The depositional system represents a braided river environment, specifically a gravel-dominated braided river model with sedimentary gravity flows.

Acknowledgment
The author would like to thank the Dean of FTME UPN "Veteran" Yogyakarta, Dr. Ir. Basuki Rachmat, M.T., for granting permission to conduct this research. Special thanks are also extended to Akbar Maulana, and M. Samih for their assistance in data collection and rock sampling in the field during the research on June-July 2025.

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