

## SEDIMENTOLOGY OF BONGAYA FORMATION, JAMBONGAN ISLAND, BELURAN, SABAH, MALAYSIA

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Received: 16 April 2026

Revised: 25 May 2026

Accepted: 26 May 2026

Published online:

26 May 2026

Doi :

10.51200/bsj.v47i1.7578

Keywords:

Bongaya Formation;  
Sedimentology; Facies  
Analysis; Geology Sabah.

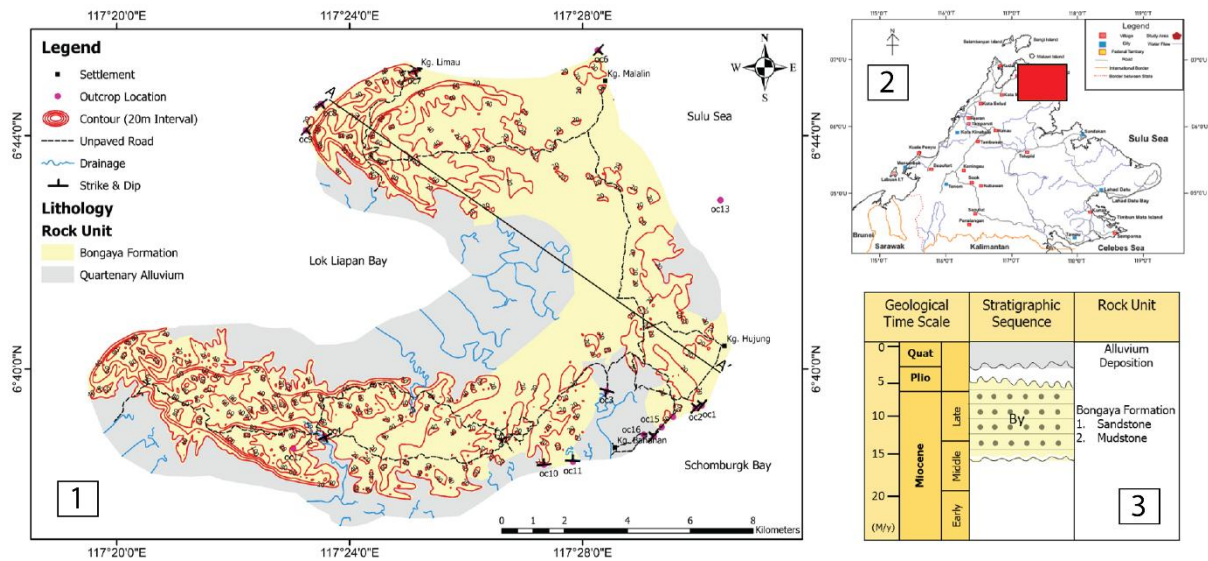
### ABSTRACT.

Jambongan Island is located at Northeast Borneo, Sabah. The exposed Bongaya Formation on this island is a Neogene siliciclastic succession characterized by sandstones, shales, and occasional conglomerates. The formation is Miocene aged, and the highly friable nature of the sandstones suggests an age potentially extending into the Early Pliocene. This study utilizes detailed sedimentary logging of 11 outcrops to refine the depositional framework of the formation. Six distinct facies were identified: Hummocky Cross-Stratified (HCS), Swaley Cross-Stratified (SCS), Horizontally Stratified (Sh), Flaser Bedded Sandstone (FF), Structureless Sandstone (Sm), and Mudstone (M). Three facies associations are identified to represent a progradational, high-energy shoreface model ranging from lower shoreface to foreshore environments. Notably, the absence of the distal shelf-to-transition zone suggests that fair-weather finer grained deposits were either bypassed or eroded by intense storm currents during rapid progradation.

## INTRODUCTION

The Neogene sedimentary rocks of Sabah, North Borneo, are primarily deposited within unique “circular” to sub-circular basins. These features, such as the Sandakan and Maliau basins, are often interpreted as pull-apart or extensional basins (Tongkul, 1991). High volumes of sediment filled these depressions throughout the Neogene period, resulting in thick, wave-dominated shoreface and deltaic system (Tongkul, 1991). The Bongaya Formation, prominently exposed in the Northeast Sabah Basin and across Jambongan Island, in the Beluran district (Figure 1). It is assigned Middle to Late Miocene in age with highly friable nature of the sandstones suggests that these units may be as young as the Early Pliocene (Sanudin Tahir and Baba Musta, 2007). Other Neogene units in Sabah are Tanjong, Sandakan, Kapilit, South Banggi formations. These formations are of great interest to the industry as they are considered potential onshore analogues to the oil and gas reservoirs found in the offshore Sabah basins. Detailed sedimentological studies are vital for establishing accurate onshore-to-offshore correlations. By analyzing the well-exposed outcrops across Jambongan Island, reservoir potential, sand-body geometry, and internal facies architecture can be estimated and compared to the formation located at the offshore subsurface. This research focuses on investigating the general geology and depositional settings of Jambongan Island by integrating new, high-resolution sedimentological data. The primary objective of this study is to characterize the localized facies architecture and establish a comprehensive depositional model for the area, thereby resolving existing ambiguities regarding its paleoenvironmental evolution. By refining the stratigraphic framework of the Bongaya Formation, this study provides critical insights into the spatial distribution and quality of high-energy shoreface reservoirs. These

findings also offer a valuable analogue for understanding similar progradational, high-energy wave-dominated systems globally. This enables predictive utility for hydrocarbon exploration, carbon capture storage (CCS) site characterization, and hydrogeological modeling. Furthermore, understanding these complex coastal facies distributions is vital for reducing subsurface uncertainty, as demonstrated by modern forward seismic and facies modeling approaches (Pelliccioli et al., 2025).



**Figure 1.** Geographic and geological framework of the study area: (1) Detailed geological map of Jambangan Island (QGIS 3.44); (2) Regional index map of Sabah, Malaysia, highlighting the location of the study area within the red rectangle; (3) Generalized chronostratigraphic and lithostratigraphic column showing the Miocene to Early Pliocene.

## MATERIALS AND METHODS

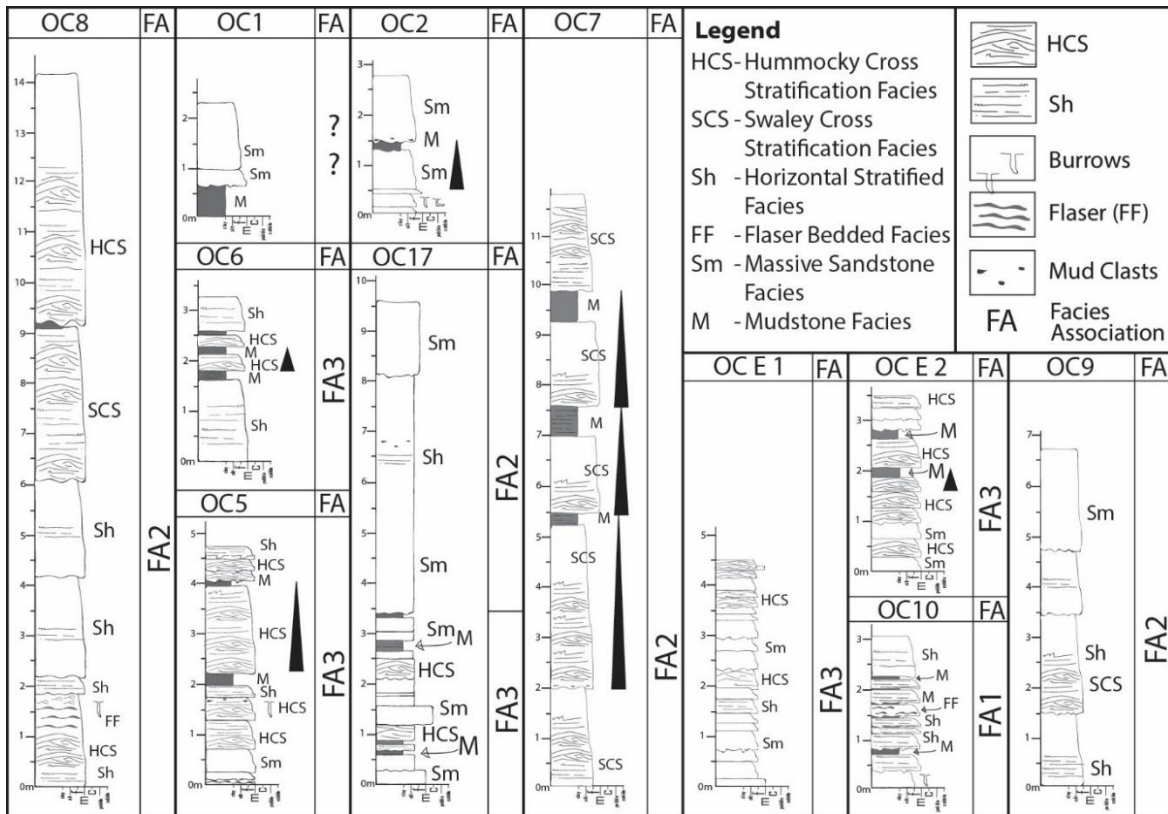
The research methodology collectively aims to achieve a comprehensive understanding of the geological characteristics, including sedimentology, stratigraphy, petrography, lithology, and geological history. The methodology integrates findings from previous research such as sedimentary logging, strike and dip measurements, and the assessment of faults and joints. An updated geological map was produced through the compilation of base maps, field data, information obtained from the Department of Mineral and Geoscience Malaysia (JMG). Additionally, stratigraphic correlation of the Bongaya Formation with the northeastern Sabah sequence was established by aligning sedimentary logs and sedimentary structures to refine the geological framework. Facies analysis and environmental reconstruction were done with accordance with Walker (1976) and Reading (1996).

## RESULTS AND DISCUSSION

The sedimentary features observed are Hummocky Cross-Stratification (HCS), Swaley Cross-Stratification (SCS), parallel stratification, structureless sandstone and minor flaser bedding. Burrows are sparse and observed only at certain intervals and sandstone beds, particularly OC8, OC2 and OC10. The sandstone commonly shows a transition between HCS into parallel cross-bedding. Ripple cross-bedding can be observed topping the sandstone reflecting calm environment and transition to mudstone. Sandstone beds are thick, amalgamated and extend horizontally across the outcrops.

### Facies Characterization

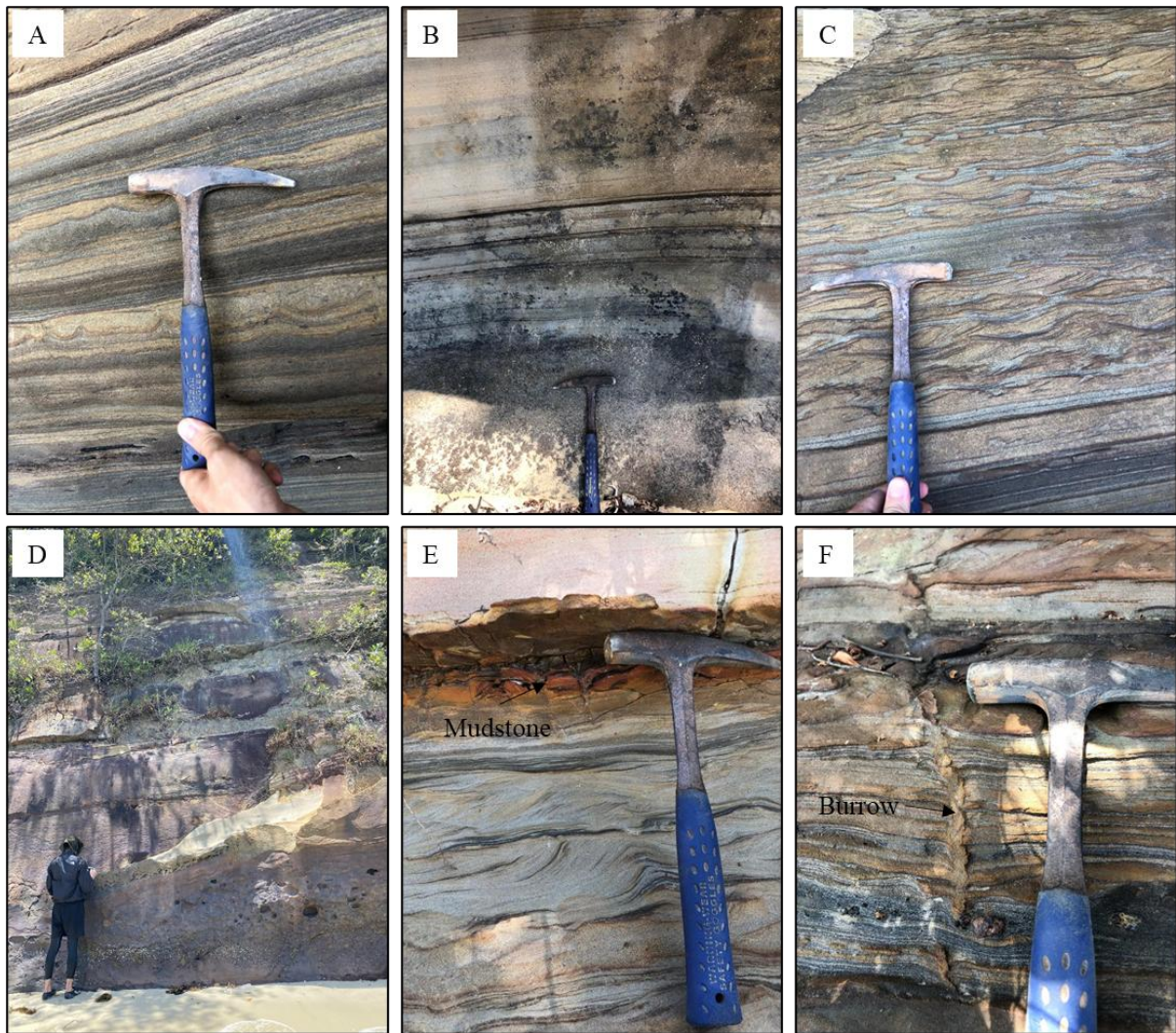
The six facies identified are 1) Hummocky Cross-Stratified Sandstone (HCS), 2) Swaley Cross-Stratified Sandstone (SCS), 3) Horizontally Stratified Sandstone (Sh), 4) Flaser Bedded Sandstone (FF), 5) Structureless Sandstone (Sm), & 6) Mudstone (M) (Table 1). The progradational nature of these sand bodies is evidenced by the distinct coarsening- and thickening-upward successions marked by the black triangles on the measured sedimentary logs (Figure 2). While Figure 3 shows the characteristics of these six identified facies.



**Figure 2.** High-resolution sedimentary logs from 11 measured outcrops of Bongaya Formation across Jambongan Island. Black triangles denote overall coarsening- and thickening-upward progradational trends.

**Table 1.** Summary of identified facies.

Facies	Code	Grain Size	Thickness	Features	Fossils
Hummocky Cross-Stratified Sandstone Facies	HCS	medium to fine	0.3m – 1.8m	– Mud pebbles, fining upwards, irregular top and wavy bottom contacts	Ophiomorpha and skolithos linearis are common
Swaley Cross-Stratified Sandstone Facies	SCS	medium to fine	1.5m – 2.0m	– Fining upwards, wavy top and bottom contacts, transitional from and to Sh	Not observed
Horizontally Stratified Sandstone	Sh	medium to fine	~0.4m	Sharp bottom contacts, transitional from and to HCS and SCS	Not observed
Flaser Bedding Sandstone Facies	FF	medium to fine sand, mud flaser	~0.6m (OC8 & OC10)	Wavy top and sharp bottom contacts	Bioturbated
Structureless Sandstone Facies	Sm	medium to very fine	0.3m – 4m	Sharp contacts with overlying Sh, erosional base contacts with mud pebbles	Ophiomorpha and skolithos but uncommon
Mudstone Facies	M	clay	0.3m – 1.5m	– Carbonaceous laminations, sharp bottom and irregular to wavy top contacts	Not observed



**Figure 3.** Field photographs illustrating the diagnostic sedimentary facies and physical structures identified within the Bongaya Formation on Jambongan Island: (A) Amalgamated hummocky cross-stratified sandstone beds; (B) Sharp-based horizontally stratified sandstone; (C) Wave-influenced flaser bedded sandstone; (D) Thick, vertically stacked and continuous sand-rich intervals; (E) Symmetrical ripple cross-lamination capping a sandstone unit; (F) Vertical *Ophiomorpha* or *Skolithos* burrow within a stratified sand interval.

### 1) Hummocky Cross-Stratified Sandstone Facies, HCS

This facies ranges from 0.3 m to 1.8 m in thickness and is medium- to fine-grained. Fining-upward trends are common in this facies. The bottom contact is irregular and wavy. Both *Ophiomorpha* and *Skolithos linearis* are commonly found. Mud pebbles with diameters less than 5 cm are commonly observed to align at the top and bottom of the HCS facies.

### 2) Swaley Cross-Stratified Sandstone Facies, SCS

The SCS facies is defined as the stacking of two or more sets of HCS with visible toplap. This facies is fine- to medium-grained, with thickness ranging from 1.5 m to 2.0 m. It commonly shows fining-upward trends, wavy top and bottom contacts, and often transitions into the Sh facies. Fossils are not observed.

### 3) Horizontally Stratified Sandstone Facies, Sh

This facies shows horizontal stratification with a sharp bottom contact. It also commonly occurs within thicker SCS and HCS sandstones with transitional contacts. This facies is thinly bedded, with 0.8m being the maximum thickness observed.

#### 4) Flaser Bedded Sandstone Facies, FF

This facies is minimal and is only observed at OC8 and OC10 (Figure 4). Both occurrences are 0.6m thick. This signifies the presence of wave influence during deposition. However, it is common for wave-dominated facies not to be preserved in storm-dominated sequences due to intense erosion from wave action.

#### 5) Structureless Sandstone Facies, Sm

This facies ranges from 0.3 m to 4 m in thickness and is medium- to fine-grained. It is observed to fine upward into the Sh facies. Mud pebbles are occasionally present at the 6m to 7m interval at OC17. The structureless nature may be due to rapid deposition and high sediment supply. Parallel lamination is commonly present within this facies, signifying a decrease in sediment input or environmental energy. Ophiomorpha is present but not common.

#### 6) Mudstone Facies, M

Mudstone beds are subordinate and uncommon, with thicknesses averaging 0.3 m and not exceeding 1.5 m. Carbonaceous laminations are commonly present. Thin mudstone beds indicate low-energy conditions and sediment settling through suspension.

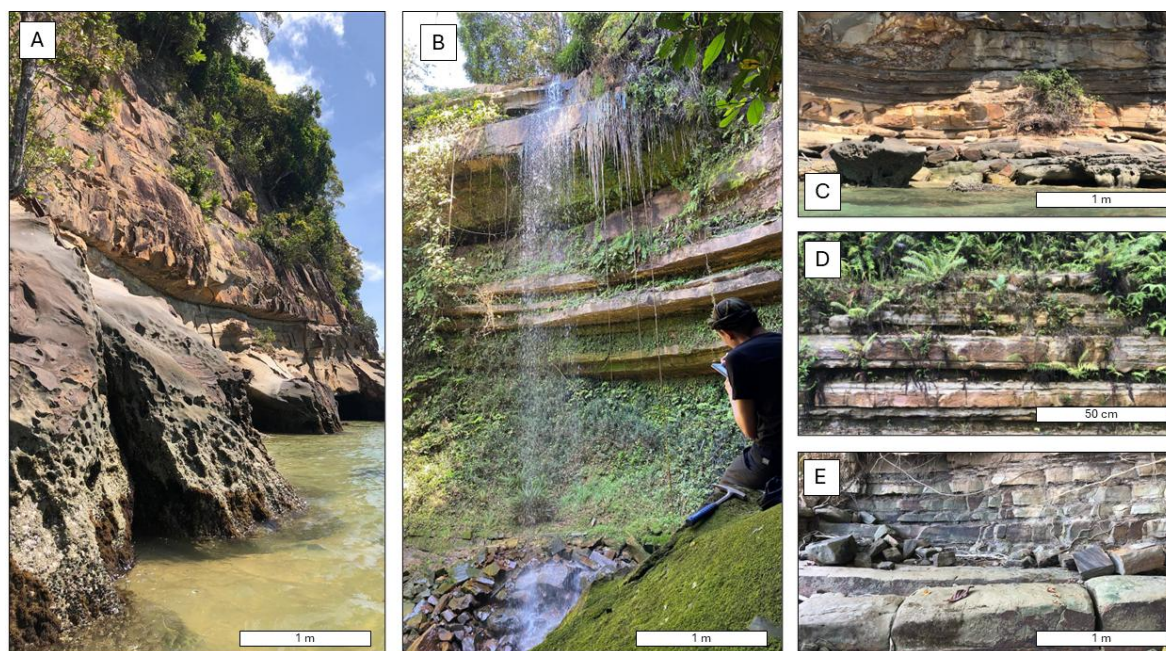
### Facies Association

Three distinctive facies associations are identified to represent a progradational, high-energy shoreface model ranging from lower shoreface to foreshore environments. These three facies associations are thinly interbedded, horizontally laminated sandstone and mudstone sequence (FA1; foreshore to backwash), thick sandstone sequence (FA 2; middle shoreface), and medium to thin sandstone sequence (FA3; lower shoreface). Notably, the distal shelf-to-transition zone of the shoreface succession is not observed in the study area, as the characteristic thick mudstone intervals and lenticular HCS sandstone beds are absent.

#### Facies Association 1: Thinly interbedded horizontally laminated sandstone and mudstone sequence (foreshore to backwash)

Facies Association 1 (FA1) consists of dominant, thinly interbedded horizontally laminated sandstones (Sh), with subordinate M facies and rare FF facies. Restricted to the middle section of Outcrop OC10, these Sh facies are interpreted as upper-flow-regime deposits characteristic of the swash and backwash zone. This facies association represents the highest energy reach of the shoreface, where constant winnowing by wave action yields well-sorted and often coarser sand fractions compared to the other shoreface units (Clifton, 2006). This is observable at outcrop cliff faces (Figure 4A and 4C), these high-energy boundaries are marked by internal erosional scour surfaces.

The minor mudstone and flaser bedding indicate localized and intermittent slack-water conditions. This suggests potential FF within a backshore runnel or a protected portion of the upper intertidal zone. As the crucial unit in a progradational shoreface succession, the foreshore is situated between the mean high-water and mean low-water marks, frequently incorporating fine organic debris from terrestrial vegetation (Di Celma *et al.*, 2017). Despite its high-energy origin, the preservation potential of this facies is typically low due to subaerial exposure and reworking by subsequent transgressive ravinement processes (Zecchin *et al.*, 2025). This low preservation potential is common in longshore currents preferentially redistributed shoreline fractions, eroding older beach barriers during subsequent sea-level changes (Frisicchio *et al.*, 2026).



**Figure 4.** Representative coastal and interior field exposures showing the structural and geomorphological expressions of the studied outcrops on Jambongan Island: (A, C, E) Massive and stratified cliff faces of outcrops OC7, OC8, and OC10 exposed along the wave-dominated eastern coastline; (B) Interior waterfall exposure at outcrop OC17 displaying a thick, aggradational sandstone succession; (D) Roadside exposure at outcrop OC4 revealing a highly rhythmically and thinly bedded siliciclastic sequence.

#### **Facies Association 2: Thick sandstone sequence (middle – upper? shoreface)**

Facies Association 2 (FA2) represents a prominent, sand-rich interval characterized by thick, amalgamated SCS and Sm sandstone beds. The succession exhibits a significant range in thickness, 6m to 16 m, suggesting a sustained period of high sediment supply coupled with sufficient accommodation to allow for vertical aggradation. The main sedimentary structure in FA2 is swaley cross-stratification (SCS) which indicates deposition in an environment subject to intense, high-frequency wave action. Unlike the HCS found in more distal settings, the prevalence of SCS suggests a position above the fair-weather wave base where the scouring of hummocky tops is common, leaving behind a record of amalgamated swales (Dumas and Arnott, 2006).

FA2 also contains structureless and massive sandstone beds. These are interpreted as the result of rapid sedimentation from high-density suspension clouds, likely during the peak major storm events where the deposition rate exceeded the time required for bedform development (Plint, 2010).

Interspaced within FA2 is marked by the presence of intraformational mud clasts occurring at the base of aggradational sets. These clasts represent the erosion and reworking of thin, fair-weather mudstone drapes by high-energy surges, a process typical of proximal and middle shoreface settings (MacEachern and Bann, 2008). The overall scarcity of preserved mudstone interbeds confirms a high-energy regime characterized by constant winnowing and amalgamation, where successive wave cycles remove finer-grained sediments, resulting in the characteristic clean, sand-dominated architecture of the middle shoreface (Walker and Plint, 1992). This structural amalgamation matches updated predictive models for ancient storm-dominated shallow-marine dynamics, where continuous high-energy storm events overprint fair-weather intervals (Hadi et al., 2025).

#### **Facies Association 3: Medium to thin sandstone sequence (lower shoreface)**

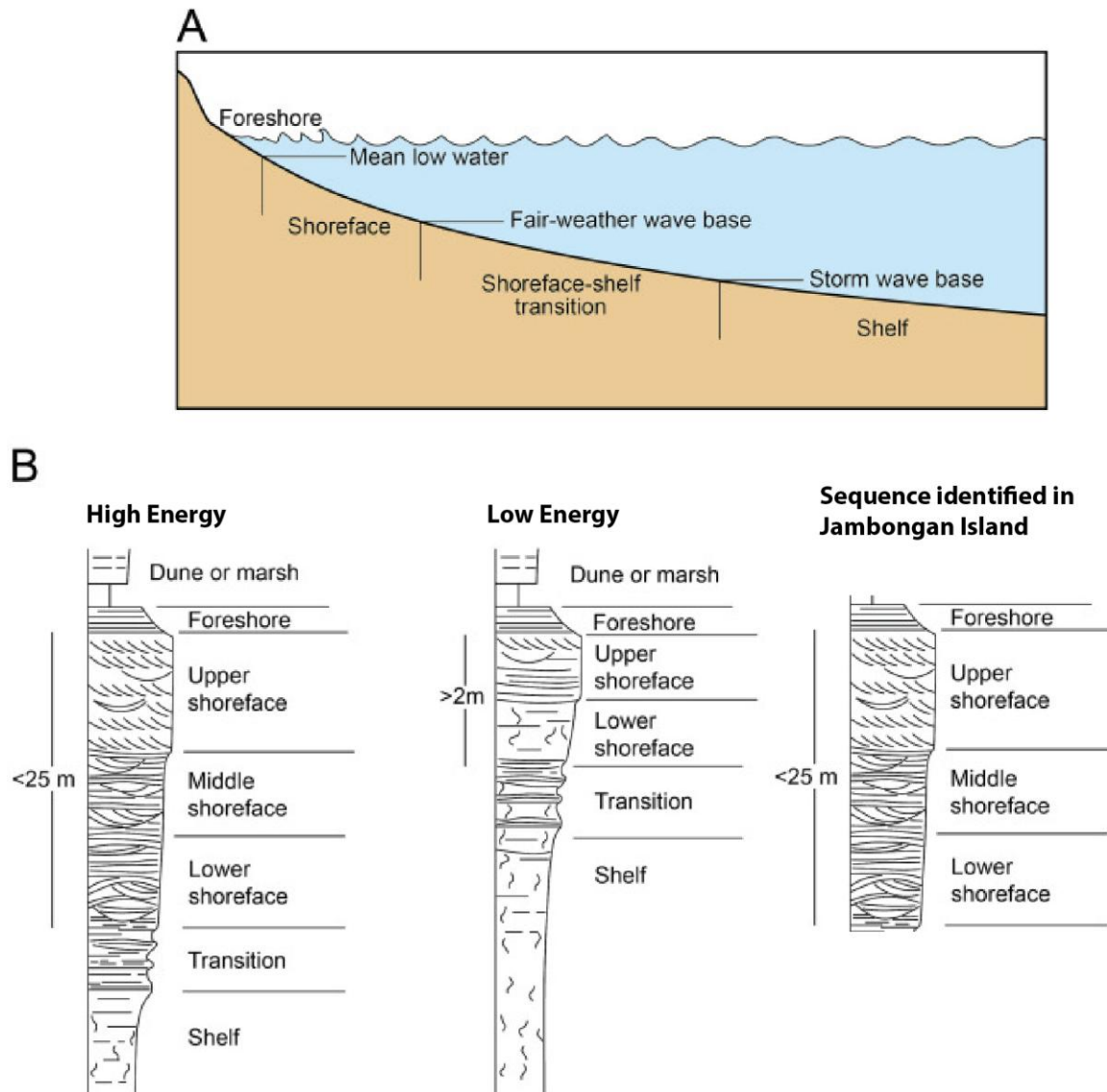
Facies association 3 (FA3) is characterized by a rhythmic succession of moderately thick, ~1m, HCS sandstones and structureless sandstones, with subordinate Sh and thin mudstone interbeds. This lithofacies assemblage is interpreted to deposit in lower shoreface environment, situated between the

fair-weather wave base (FWWB) and the storm wave base (SWB). In this setting, the depositional process is dominated by episodic, high-energy storm events that transport sand basinward with alternating protracted periods of low-energy fair-weather conditions (Dumas and Arnott, 2006).

The moderately thick HCS beds reflect combined-flow conditions where large-scale orbital wave ripples are modified by unidirectional currents during storm peaks. The presence of structureless sandstones suggests rapid deposition during surge of sediment input (Plint, 2010). While thin mudstone interbeds represent the background fair-weather sedimentation. Unlike in the amalgamated middle shoreface, storm events were not always erosive enough to entirely remove the fair-weather record (Pemberton and MacEachern, 1997). The overall bed thickness and sand-to-mud ratio in this FA are primarily controlled by the duration and intensity of storm currents and sediment supply (Walker and Plint, 1992).

### **Depositional Model**

Based on the sedimentary logs and facies analysis, the depositional environment is interpreted as a high-energy, wave-dominated shoreface system (Figure 5). The stratigraphic architecture is characterized by a progradational and coarsening-upward sequence that transitions from the lower shoreface (FA3) into the middle shoreface (FA2). This vertical stacking pattern suggests a seaward migrating shoreline, where shallower deposits gradually overlie deeper and lower-energy units. The succession follows a high-energy model because of the thick, amalgamated sandstone bodies, reaching up to 16 m as shown by the presence of storm-driven structures like hummocky and swaley cross-stratification. Notably, the distal shelf-to-transition zone is missing in the study area, which suggests that fair-weather muds and thin storm sands were either bypassed or eroded by powerful storm currents during rapid progradation. This confirms that high-energy overprinting routinely removes baseline faunal and physical stratigraphic records in wave-dominated basins (Dashtgard et al., 2026).



**Figure 5.** Paleogeographic reconstruction and depositional architecture models: (A) Idealized modern coastal profile defining the bathymetric distribution of the foreshore, shoreface, and shelf environment relative to FWWB and SWB; (B) Comparison between generalized high-energy and low-energy vertical stratigraphic successions (modified after Galloway & Hobday, 1996) alongside the specific sand-dominated, truncated sequence identified at Jambongan Island, highlighting the conspicuous absence of the distal shelf-to-transition zone.

The energy deposition is clearly seen in the transition from the lower shoreface, FA3, up into the middle shoreface, FA2, and foreshore, FA1. FA3 consists of repeating and moderately thick HCS sandstones with thin mudstone layers. This indicates deposition below the FWWB where calm periods allowed mud to settle. As the sequence progrades into FA2, the beds thicken and coarsen into amalgamated SCS and Sm, marking a shift to shallower water where constant wave action removed fine-grained sediments. The succession is then capped by the foreshore-to-backwash deposits of FA1, featuring Sh.

These findings align with the depositional model proposed by Galloway and Hobday (1996), which describes how high-energy shoreface systems produce thick and sand-dominated vertical successions. The shoreface is a seaward-sloping and wave-dominated wedge of sediment that extends from the low-tide mark down to the FWWB (Howell, 2005; Walker & Plint, 1992; Zecchin et al., 2025). In this environment, the water movement is very strong because of waves and longshore currents or storms. This environment is characterized by a high-energy hydrodynamic regime where sediment

distribution is primarily governed by the interaction of oscillatory wave currents, longshore currents, and episodic storm events. In a vertical stratigraphic succession, shoreface deposits typically manifest as a coarsening-upward sequence, reflecting the progradation of shallower and higher energy facies over distal deposits (Walker and Plint, 1992).

## CONCLUSION

This study established the depositional framework of the Neogene Bongaya Formation on Jambongan Island, identifying it as a high-energy, wave- and storm-dominated shoreface system. Detailed lithofacies analysis reveals a progradational, coarsening-upward stratigraphic architecture transitioning from rhythmic lower-shoreface sandstones (FA3) into amalgamated, wave-scoured middle-to-upper shoreface sandstones (FA2), capped by high-energy foreshore successions (FA1). The complete absence of a distal shelf-to-transition zone, along with thick sandstone packages reaching up to 16 meters, confirms a truncated shoreface geometry. This setup was shaped by strong storm-wave overprinting, continuous mud winnowing during fair weather, and rapid sediment bypassing as the shoreline moved forward. By characterizing the internal geometries of these clean, sand-dominated successions, this work provides a helpful onshore analogue. Future research should include systematic palynological and micropaleontological sampling to secure tighter age constraints.

## ACKNOWLEDGEMENT

The authors would like to express our profound gratitude to Universiti Malaysia Sabah (UMS), specifically through Grant SLB 2245 for funding this research. We would also like to thank UMS Geology staff for their support throughout this project. Finally, we extend our highest appreciation to the reviewers for their constructive comments, which greatly improved the manuscript.

## REFERENCES

- Clifton, H. E. (2006). A re-examination of facies models for clastic shorelines. *SEPM Special Publication*. <https://doi.org/10.2110/pec.06.84.0293>
- Di Celma, C., Malinverno, E., Bosio, G., & Collareta, A. (2017). Sequence stratigraphy and paleontology of the Upper Miocene Pisco Formation along the western side of the lower Ica valley (Ica desert, Peru). *Rivista Italiana Di Paleontologia E Stratigrafia*, 123(2), 255-273. <https://doi.org/10.13130/2039-4942/8373>
- Dashtgard, S. E., Hsieh, A. I., Vaucher, R., & Löwemark, L. (2026). Controls on the ichnology of late Miocene-Pliocene shallow-marine strata during uplift of the Taiwan Orogen: A semi-quantitative approach. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 692, 113021. <https://doi.org/10.1016/j.palaeo.2026.113021>
- Dumas, S., & Arnott, R. W. C. (2006). Origin of hummocky and swaley cross-stratification during the combined-flow regime. *Journal of Sedimentary Research*, 76(1), 51-69. <https://doi.org/10.1130/G22930A.1>
- Frisicchio, V., Conforti, A., Kalb, C., Simeone, S., & De Falco, G. (2026). Morphosedimentary evolution of a sediment-starved coastal system in response to late Pleistocene sea-level oscillations: Structural and hydrodynamic controls (western Sardinian margin). *Frontiers in Earth Science*, 14. Article 1728707. <https://doi.org/10.3389/feart.2026.1728707>
- Galloway, W. E. & Hobday, D. K. (1996). *Terrigenous Clastic Depositional Systems – Applications to Fossil Fuel and Groundwater Resources* (2nd ed.). Springer. <http://doi.org/10.1007/978-3-642-61018-9>

- Hadi, M., Vinn, O., & Sedimentary Group. (2025). Storm-modulated ichnofabrics and taphomic windows: Synergistic archive for Upper Miocene shallow-marine dynamics (Dar Pahn Unit, Iran). *Journal of the Geological Society*, 182(2), jgs2026-136. <https://doi.org/10.1144/jgs2025-136>
- Howell, J. (2005). Sedimentary Environments: Shoreline and shoreface deposits. In R. C. Selley, R. M. Cocks, & I. R. Plimer (Eds.), *Encyclopedia of Geology* (pp. 580-579). Elsevier. <https://doi.org/10.1016/B0-12-369396-9/00494-9>
- Lim, P. S. (1981). Wullersdorf Area, Sabah, Malaysia. Geological Survey of Malaysia. Report 15.
- MacEachern, J. A., & Bann, K. L. (2008). The role of ichnology in refining shallow marine facies models. *SEPM Special Publication* 90, 90-116. <https://doi.org/10.2110/jsr2020.41>
- Nor Aainaa Farhana Azam, Khairul Azlan Mustapha, & Mohammed Hail Hakimi (2024). Organic geochemical and petrological investigations of the upper Miocene Bongaya formation in the pitas, onshore sabah basin, and its relevance for hydrocarbon potential. *Journal of Petroleum Exploration and Production Technology*, 14, 2669-2685. <https://doi.org/10.1007/s13202-024-01843-2>
- Pemberton, S. G., & MacEachern, J. A. (1997). The ichnological signature of storm deposits, the use of trace fossils in event stratigraphy. In C. E. Brett, & C. G. Baird (Eds.), *Paleontological Events, Stratigraphic, Ecology and Evolutionary Implications* (pp. 73-103). Columbia University Press.
- Plint, A. G. (2010). *Wave- and storm-dominated shoreline and shelf systems*. In N. P. James, & R. W. Dalrymple (Eds.), *Facies Models 4* (pp. 167-200). Geological Society of Canada.
- Reading, H. G. (1996). *Sedimentary Environments: Processes, Facies and Stratigraphy* (3rd ed.). Blackwell Science.
- Sanudin Hj. Tahir & Baba Musta. (2007). *Pengenalan Kepada Stratigrafi*. Penerbit UMS, Kota Kinabalu, Sabah.
- Tongkul, F. (1991). Tectonic evolution of Sabah, Malaysia. In G. Nichols, & R. Hall (Eds.), *Proceedings of the Orogenesis in Action conference London 1990* (pp. 395-405). Journal of Southeast Asian Earth Sciences.
- Walker, R. G. (1976). *Facies Models*. Geoscience Canada.
- Walker, R. G., & Plint, A. G. (1992). *Wave- and storm-dominated shallow marine systems*. In Walker, R. G., & James, N. P. (Eds). *Facies Models: Response to Sea Level Change* (pp. 219-238). Geological Association of Canada, Newfoundland.
- Widemann, T., Lasseur, E., Lofi, J., Berné, S., Grélaud, C., Issautier, B., Pezard, P. A., & Caballero, Y. (2025). Sedimentary Architecture Prediction Using Facies Interpretation and Forward Seismic Modeling: Application to a Mediterranean Land-Sea Pliocene Infill (Roussillon Basin, France). *Geosciences*, 15(10), 383. <https://doi.org/10.3390/geosciences15100383>
- Zecchin, M., Catuneanu, O., & Caffau, M. (2025). Sequence stratigraphy of wave-dominated and wave-influenced shoreface deposits: Systems tracts, stratigraphy surfaces and facies contracts. *Sedimentary Geology*. <https://doi.org/10.1016/j.sedgeo.2025.106980>