

3D Modelling of Longshore Bar Deposit in Modern Fluvial Dominated Delta: Case Study of Wulan Delta, Demak, Central Java Province*

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Abstract

Wulan Delta is a part of Java Island northern coast, which juts into the sea, with an approximate area of 25 km². Administratively, it is located in Wedung District, Demak City, Central Java Province. This is a delta which formed in Java in part of back-arc basin and is included in the Sundaland. The still-active delta system formed in humid, tropical climate under high-wave energy, large fluvial influx, and quite high tidal influences.

In the 2000s, the section around the mouth bar began to form sand deposit which grew laterally until 2015 and now continue to widen, forming longshore bar in northeast-southwest direction. The ocean waves control the distribution pattern of sedimentary material in the delta front. The deposition of longshore bar in fluvial-dominated delta are very rare; most longshore bar deposits are found in wave-dominated delta system.

The main purpose of 3D modelling study of longshore bar deposits in modern delta is to understand subsurface conditions and geometry of sand deposits, vertical stratigraphic pattern, facies changes, and, in this case, the northeast-southwest orientation.

The subsurface configuration was derived from core samples. The stratigraphic correlation shows facies changes around the longshore bar based on integration of vertical and lateral grain size distribution. Facies changes caused by the fluctuation of rapid sedimentation and wave processes can be shown by remote sensing analysis, using LANDSAT aerial photographs of Wulan Delta from 1975 to 2015.

The interpretation provides new information for understanding vertical and lateral continuity around the longshore bar deposit, vertical and lateral grain size distribution, wave movements and directional influence, prograding delta formation, sand distribution boundary in the longshore bar, and gross sand map distribution. All results have been combined into 3D modelling of the longshore bar. Thus, the 3D model

can be used to determine sand distribution in the longshore bar. This study will contribute to hydrocarbon exploration in determining the sand geometry in the deltaic system which has longshore-bar- facies reservoirs.

Introduction

The modern Wulan Delta formed in the northern coast of Demak City, Central Java Province, Indonesia ([Figure 1](#)). The delta formed in a back-arc basin and is included in the Sundaland. Its overall geometry shows a bird-foot shape dominated by the fluvial energy. The fluvial-dominated delta systems are rarely associated with wave-dominated bars. Longshore bar deposits develop lateral to the delta. Longshore bars deposited in Wulan Delta represent good modern sedimentological analogue for low-wave energy longshore-bar-sandstone reservoirs.

Methodology

The 3D modelling of longshore bar deposits is used to understand the sand distribution/geometry in Wulan Delta river mouth. The geometry of sand-body deposits has been determined from sediment distribution. This modelling also describes the sedimentary process of longshore bar deposition in Wulan Delta.

This study uses qualitative and quantitative analysis methods. Qualitative analysis was carried out, using field core samples and LANDSAT aerial photographs. There were 34 core samples obtained from Wulan Delta ([Figure 2](#)). Quantitative analysis methods utilized grain size distribution. For each core sample, 4 granulometry samples were analyzed ([Figure 3](#)).

Lithostratigraphy

The model was generated from stratigraphic correlation based on lithostratigraphy of each log. Some locations have different depositional characteristics and geometries ([Figure 4](#)). Longshore bar lithostratigraphy is as follows:

a) Tidal Sand-Mud deposit (LB-11, LB-01, [Figure 5](#))

These deposits are characterized by the alternation of mud layers and very fine sand layers. Mud drape-like flaser or lenticular lamination typical of tidal deposits formed at the bottom of the core samples. This deposit also contains bioturbation formed by burrowing organisms. Tidal sand-mud deposit, usually present in core samples, is 10-20 cm thick.

b) Interdistributary Bay Mud (LB-14, [Figure 5](#))

Interdistributary bay deposits are characterized by a very thick mud layer without alternation of sand layer. In this deposit organic material is commonly present, as the plant root, trunk, leaf, and mollusk shell. Interdistributary bay mud is present in the lower part of the core at STA LSB 2 and is 40-80 cm thick.

c) Lagoon Mud (LB-11, [Figure 5](#))

Lagoon deposit is isolated by barrier sand. The barrier sand in this case is the longshore bar deposit. The lagoon deposit, in the core samples, is in the upper part of the section. These deposits have grain size from muddy sand to mud. The sand thickness in the backshore area is about 20 cm. Therefore, lagoon deposit has interfingering relationship with longshore bar deposit laterally.

d) Offshore Mud

Offshore mud deposit is a sediment from the offshore, dominantly of mud. In the study area, this sediment is found far from shoreline, within 2 - 3 m depth.

e) Longshore Bar Sand ([Figure 5](#))

The longshore bar deposit is characterized by very fine sand to very coarse sand. Its stratigraphic pattern is coarsening upward; sedimentary structures are parallel lamination and swash-cross stratification, with low-angle cross-stratification. Sand is moderately well sorted and contains mollusk and planktonic foraminifera fragments. The lamination of sand deposit includes black laminae of heavy minerals, such as hematite, hornblende, and magnetite. Longshore bar deposit is present in the upper part of core samples, with tidal sand-mud deposit and interdistributary bay mud usually underlying it.

Prograding Wulan Delta

Wulan Delta has physiographic "bird-foot" form reflect the dominant by fluvial process. This is shown on LANDSAT photographs that demonstrate the development of Wulan Delta from 1975 to 2015. The delta formed branches, as the river, began rather significant progradation in 1975 to 1997 ([Figure 3](#)) due to rapid sedimentation in the Wulan Delta area. Development of the delta created Wulan Baru River, which has equal dimensions with Wulan Lama River. In addition, ocean waves were not dominant, so that material can be transported to the sea directly.

In the 2000s, Wulan Delta has not been depositing sediments directly into the sea because of high wave energy has led to sediment being transported back toward the land. Deposits in Wulan Delta river mouth are sand deposits distributed laterally to form longshore bar ([Figure 6](#)). The development of longshore bar deposits in the last 10 years has been quite broad and elongated in a northeast– southwest direction. These deposits developed in relation to both the Wulan Lama and Wulan Baru rivers. Besides the influence of ocean currents and high waves in the last 10 years in the Wulan Delta area, sediment brought into the sea is not equal to what it was in the two previous decades. Sand deposits are transported laterally around the river mouth, forming an elongated longshore bars.

Longshore Bar

Longshore bar deposit is an elongate shape of sand deposit in the river mouth. At the beginning longshore bar deposit spread parallel to the coastline and will be exposed to the surface. As increasing sediment supply toward sea, a new longshore bar deposit will formed in front of previous deposit. This process will continue to form a parallel bar migrate towards shoreface because the influence of longshore current that brought sediment material toward land ([Figure 7](#)). In the section between two longshore bars were deposited muddy sand, this is due to the longshore bars, which form a barrier, blocking the ocean current toward the land. Longshore bar can only be reached by the flood tide. Additionally in the backshore of longshore bar is an isolated place because of the presence of the longshore bar. This is the dominant setting for deposition of suspended mud, in a lagoon ([Figure 8](#)).

Gross Sand Map

The longshore bar gross sand map shows that sand deposits in the middle part of sand body are thicker than on the edge. The thickness of sand deposits in the middle part is about 90-100 cm in the LSB STA 1 and 3 and is 40 cm in STA LSB 2 ([Figure 9](#)). This distribution was due to the

processes of longshore bar deposition influenced by tidal (and wave) action. Commonly in a vertical section, sandy-mud is in the lower part of the section, and sand is in the upper part.

Results and Discussion

Muddy sediment accumulated in deep areas, with pelagics; there depositional energy is low. The products of this deposit are designated as offshore mud ([Figure 10](#)).

Tidal sand-mud facies shows alternations (interbedding) of sand and mud deposits . Tidal-process influence developed after deposition of offshore mud during progradation. Sediment from the land was sand that became material affected by tidal processes.

In the next stage of sedimentation, at a specific locality, was depositon of material from Wulan River prograding towards the sea, but the depositional energy of the sea becamequite dominant. Longshore currents carrying sediment material distributed the sand in front of river mouth. The sediment was spread laterally in zig-zag pattern. This deposit extends laterally farther, and sand deposits are thicker in this specific area.

Longshore current direction influences the shape of longshore bar deposits. Sediments in the longshore bar migrate in such as way that longshore bar deposition will continue to prograde toward the offshore ([Figure 11](#)).

Conclusion

Longshore bar deposition formed laterally to the coast by the influence of ocean currents in the last 10 years. It was caused by longshore current reworking sand material from the river.. STA LSB 1 deposit has greater sand body thickness because of the accommodation space; it will continue to grow laterally. STA LSB 2 and STA LSB 3 have limited accommodation space because of their locations between distributary channels; therefore their lateral development is limited.

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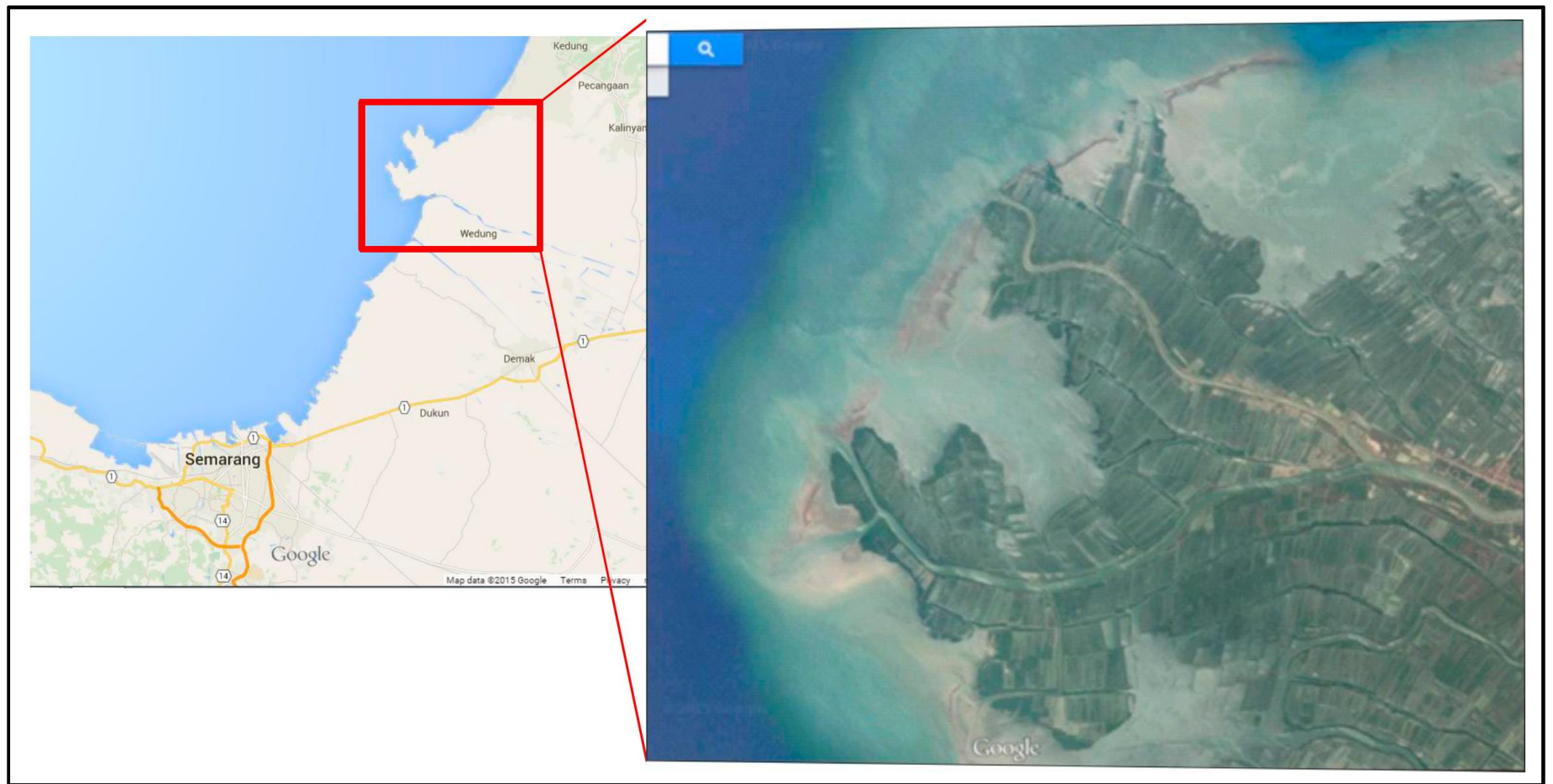


Figure 1. Location map of study area (Google Maps, 2015).

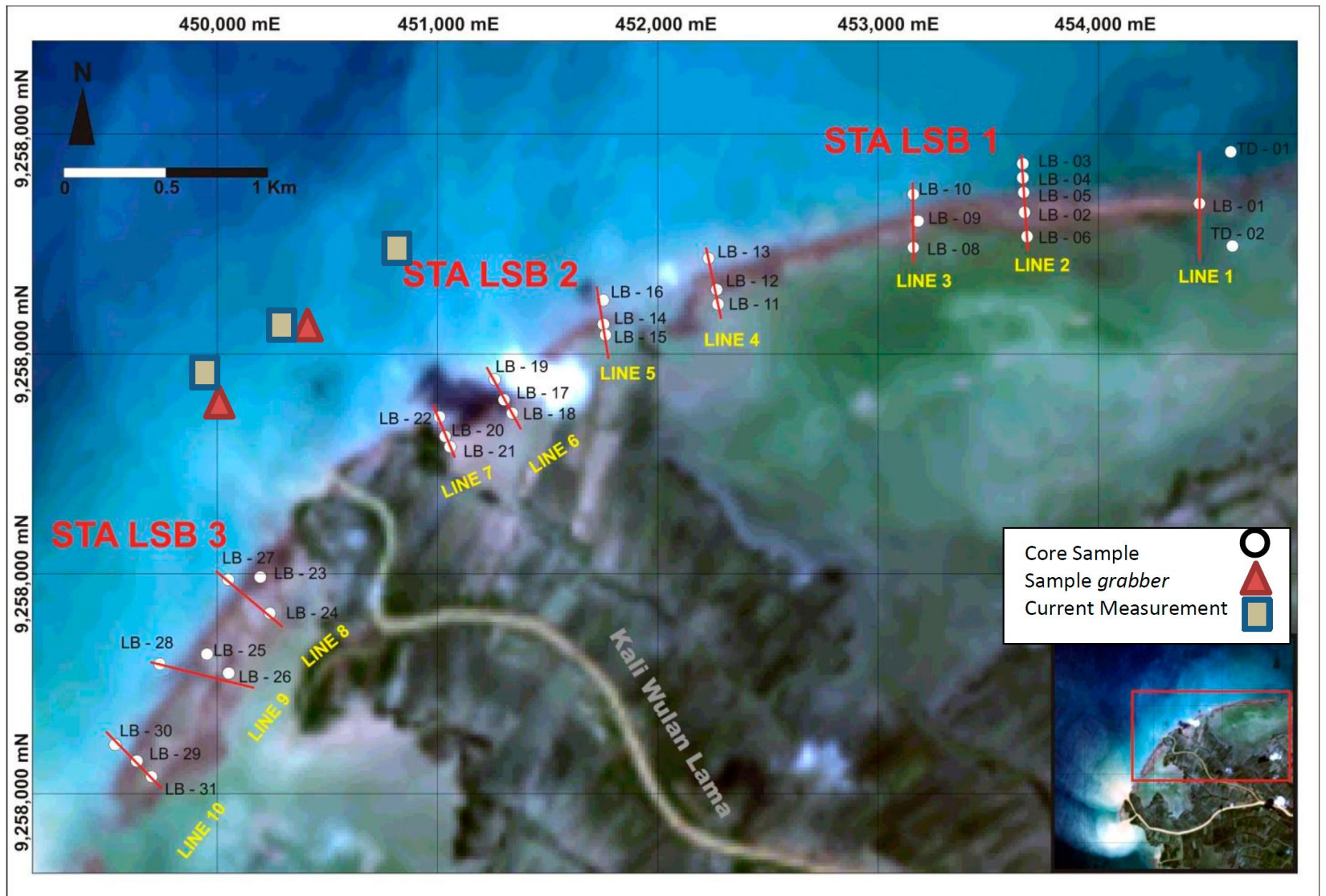


Figure 2. Area of study and sample locations in Wulan Lama River area, using LANDSAT 2015 Photograph.

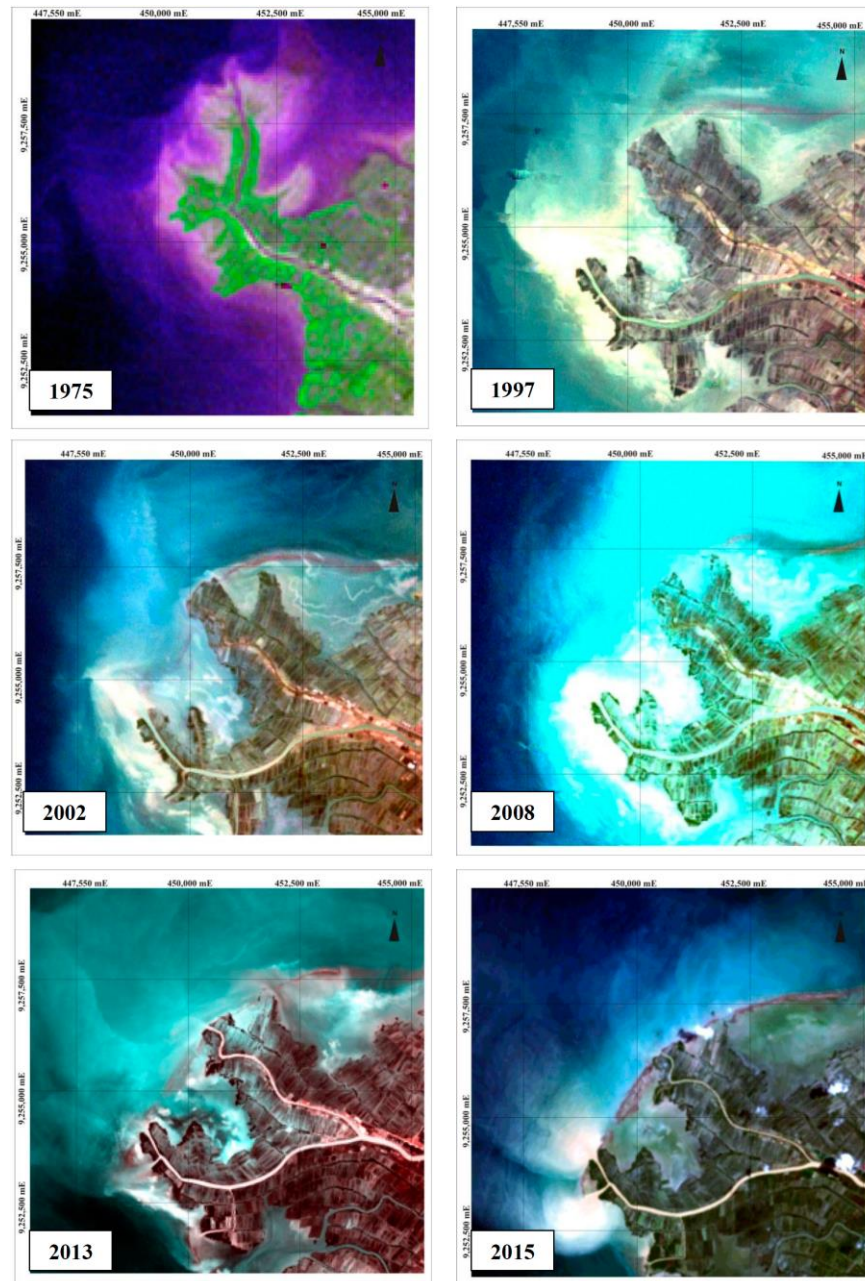


Figure 3. Comparison of Wulan Delta, showing its development from 1975 to 2015, with LANDSAT photographs.

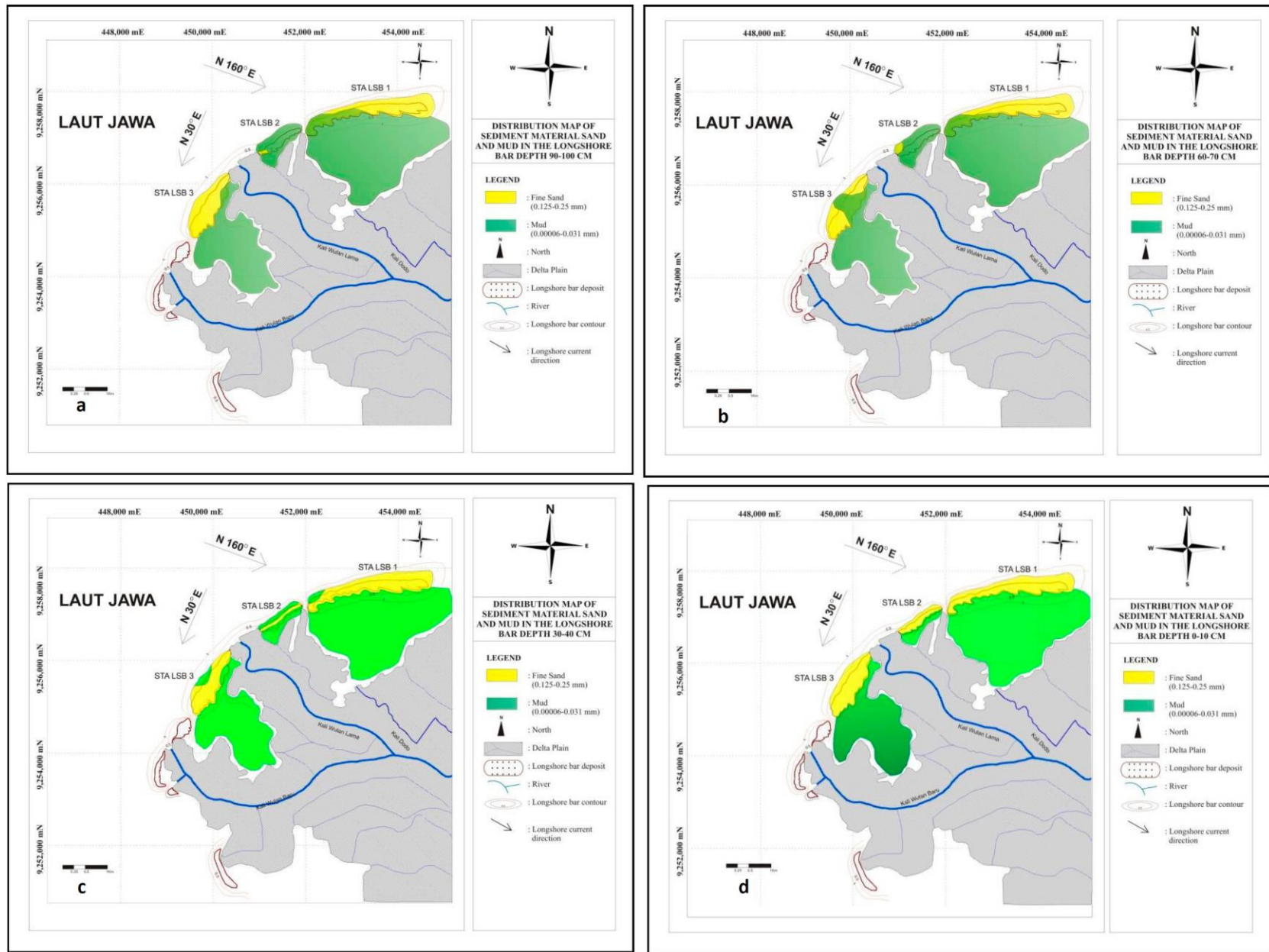
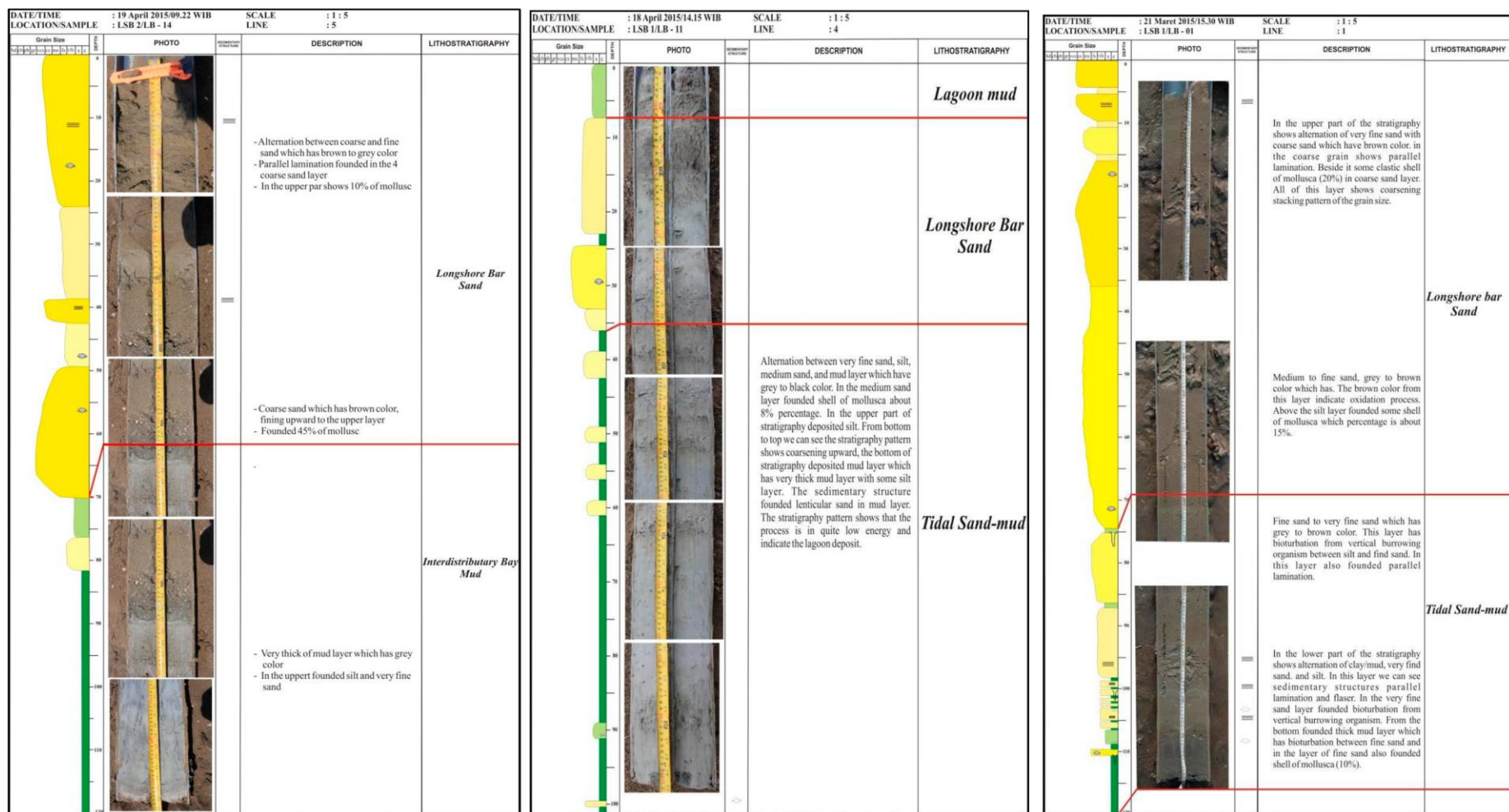


Figure 4. Grain size distribution of sand and mud of longshore bar deposits in the following depth intervals: (a) 90-100 cm, (b) 60-70 cm, (c) 30-40 cm, and (d) 0-10 cm.



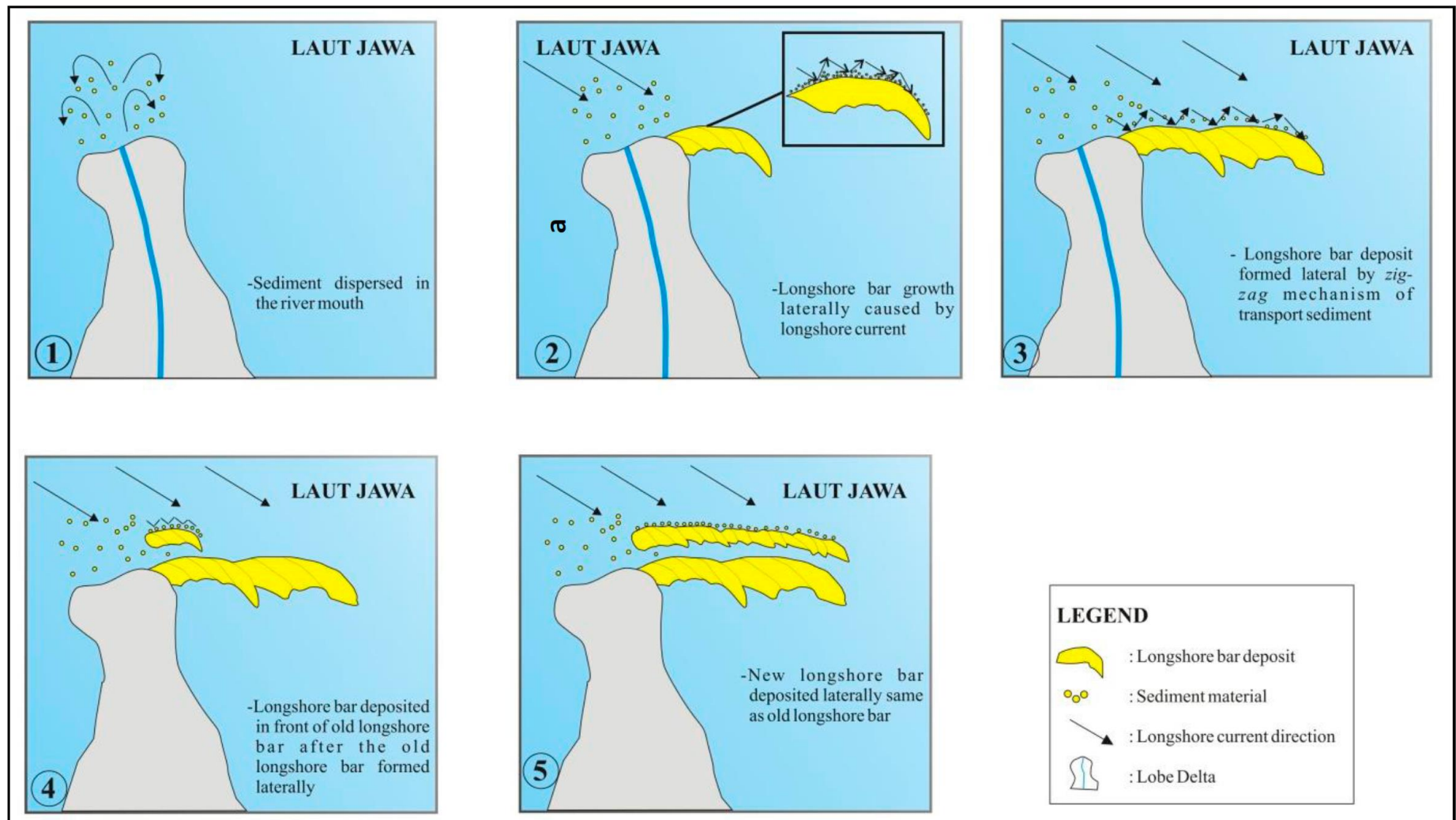


Figure 6. Lateral distribution of longshore bar deposits in Wulan Delta.

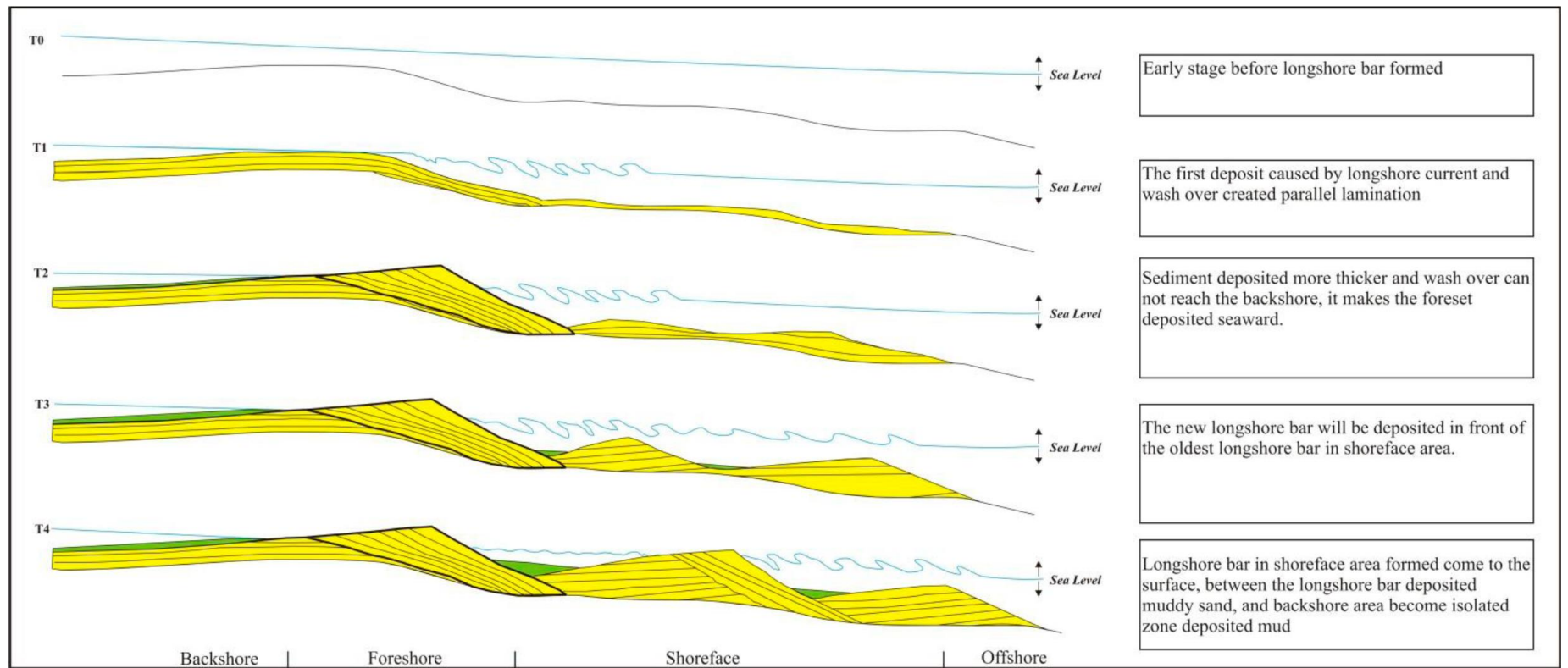


Figure 7. Schematic model of longshore bar migration.

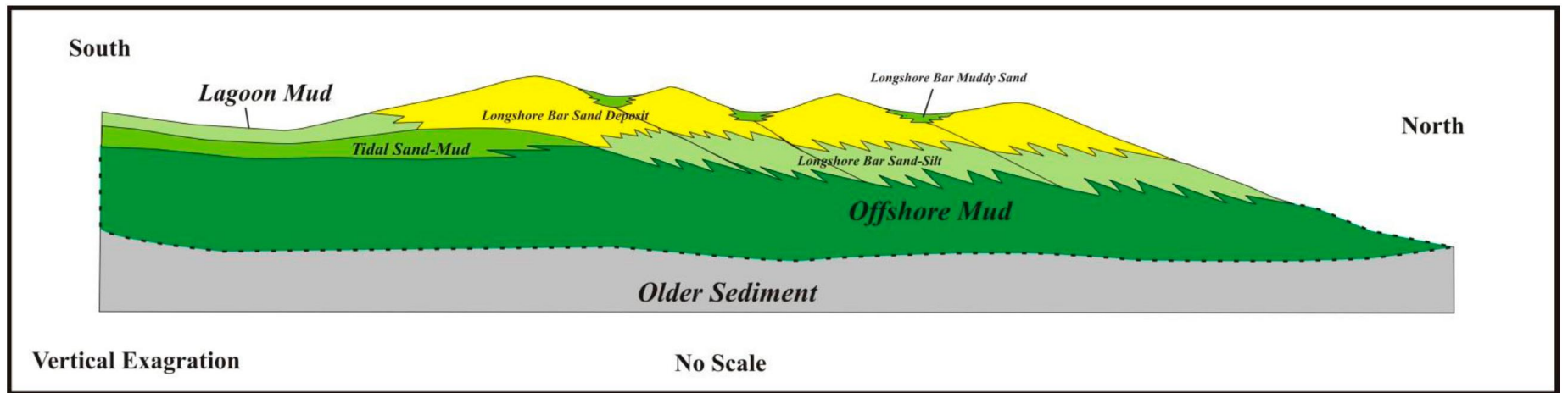


Figure 8. Longshore bar depositional facies.

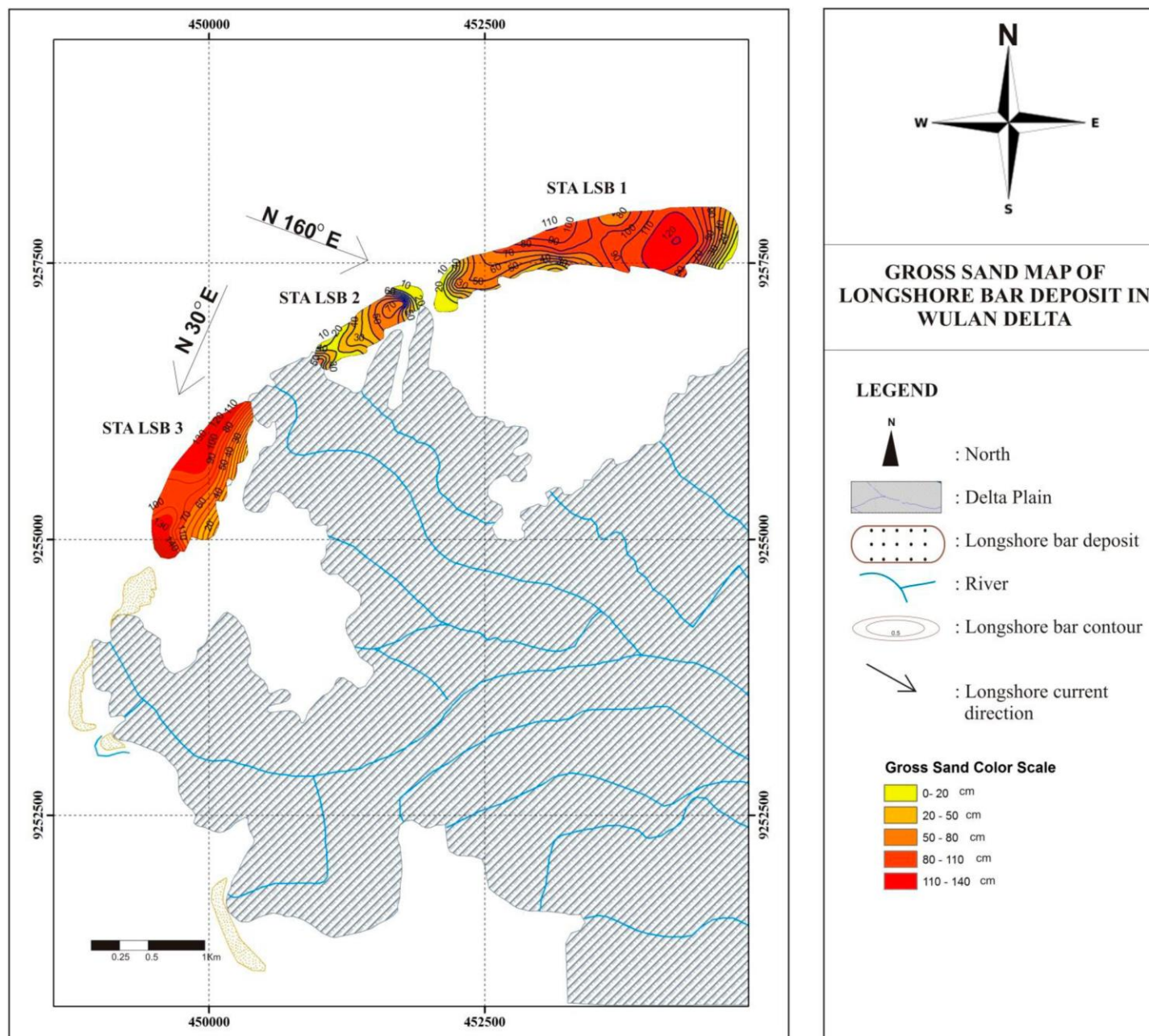


Figure 9. Gross sand map of longshore bar deposits in Wulan Delta.

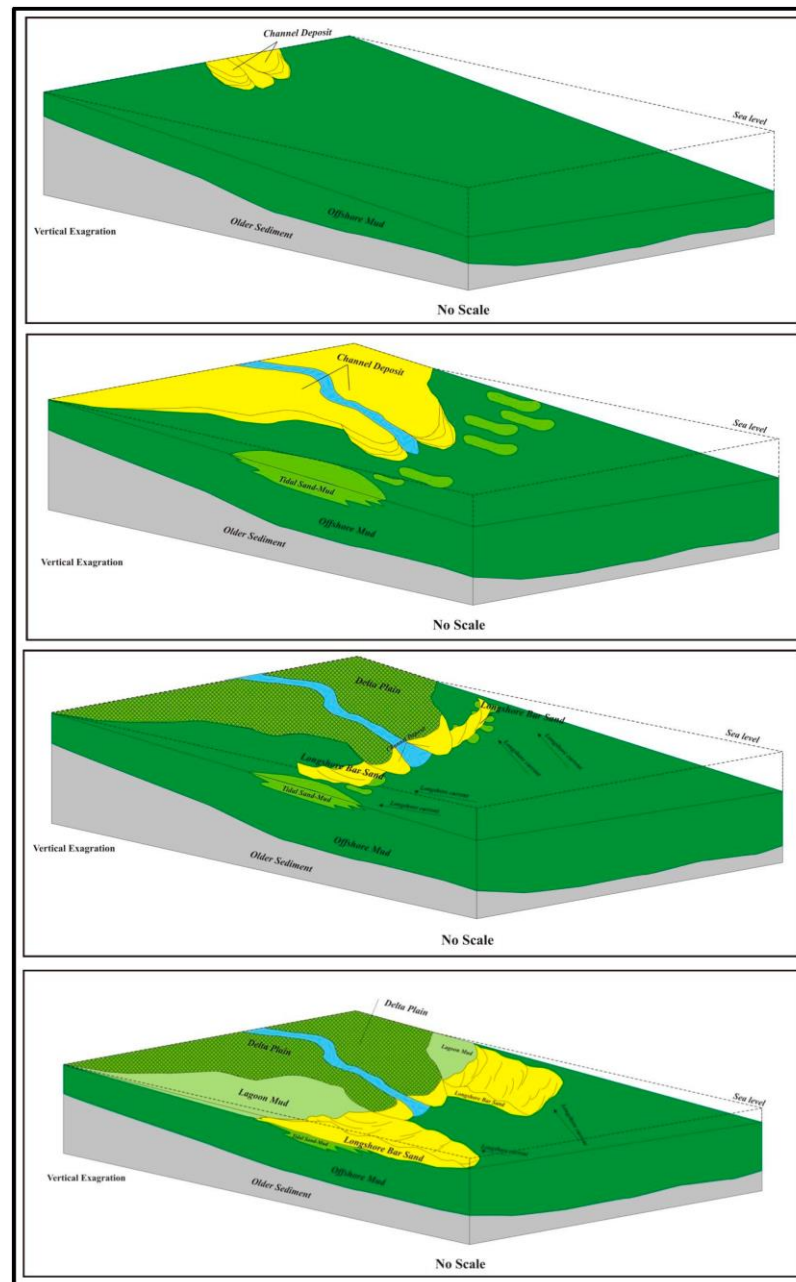


Figure 10. 3D model of depositional system in the Wulan Delta.

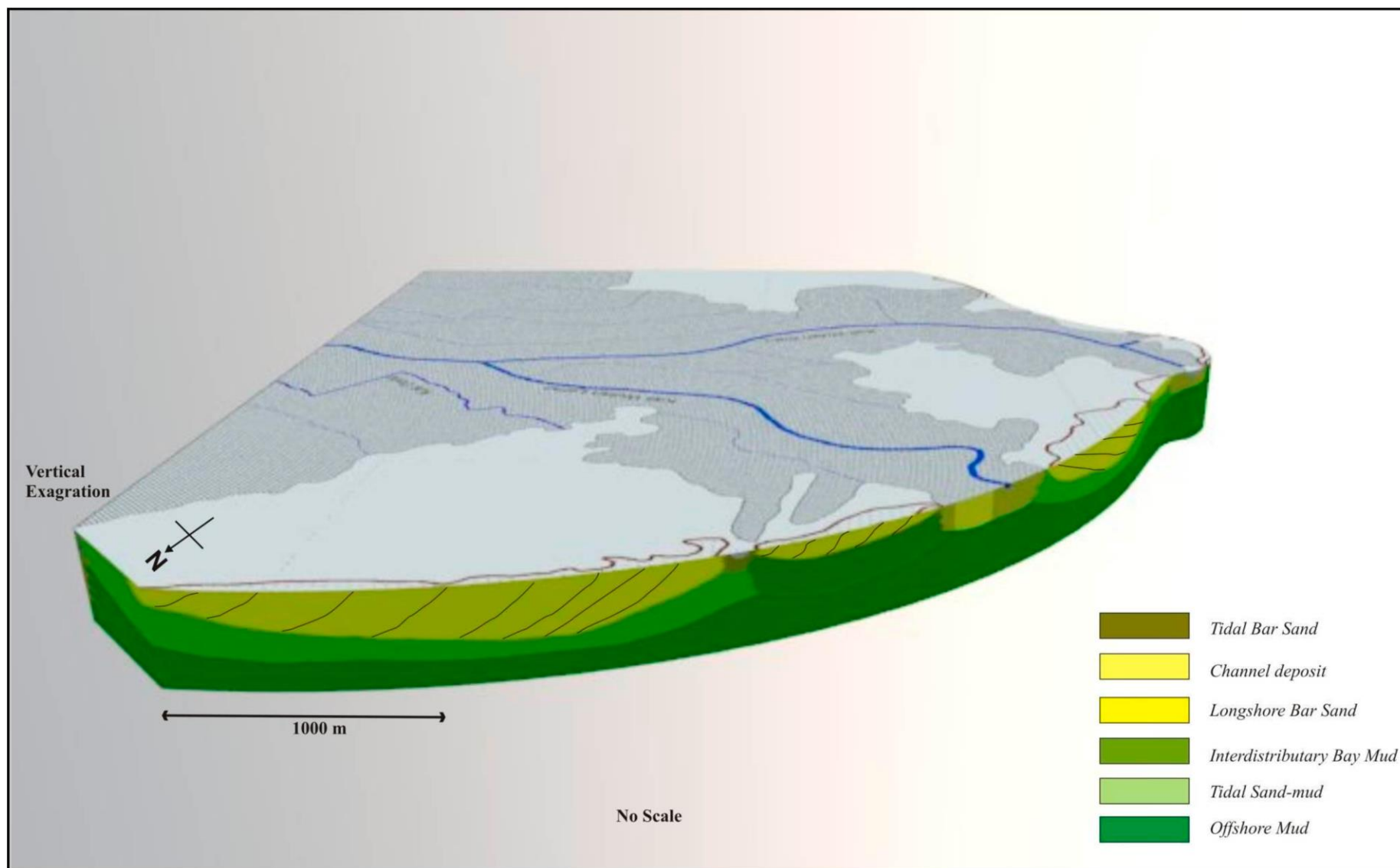


Figure 11. Block diagram of depositional facies in Wulan Delta.