Relationship between River-mouth Depositional Processes and Delta Architectures, Huangqihai Lake, Inner Mongolia, North China*

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Abstract

Huangqihai Lake, a modern lacustrine rift basin located in the south of Inner Mongolia, Northern China. The lake has an area of 110 km^2 and variable depth between 2 m to 15 m in the past, and dries out in present. Three small (4-8 km^2) deltas (Bawanghe, Luzimiao, and Dahewan) on the margins of Huangqihai Lake were surveyed to investigate differences in delta architectures produced by different river-mouth regimes using aerial photographs, field trenches, and sediment samples. Sedimentary logs and cores were collected from 37 trenches (grid spacing approximately 300 m on the top of the three deltas), allowing detailed mapping of sedimentary facies. Three dimension delta architecture models were generated utilizing Petrel software.

Sediment dispersal and accumulation patterns from the three deltas were governed by three basic river effluent regimes and by wave processes which have been recognized based on the delta morphologies. Dahewan delta, is friction-dominated, has a very shallow (2-3 m) front with 3 delta lobes and 6 distributary channels. Luzimiao delta front which is inertia-dominated has one elongated lobe, and exhibits limited lateral spreading resulting in narrow (100 m) river-mouth bars. Bawanghe delta front, is buoyancy-dominated, has 3 major lobes with a few elongate distributaries with parallel banks, and few bifurcations. Trenches on the top of the deltas and the 3-D models reveal common features such as small (1 m thick) channels with dm thick cross-strata, alternation of cm to dm thick sand and mud beds. However, there are also significant differences with the Dahewan (friction dominated) having the sandiest delta front and the Luzimiao (inertia dominated) the muddiest delta front. The morphology and facies differences between the three delta types coming in the same lake is most likely controlled by the river discharge characteristics and the sediment load type. The 3-D models of the lacustrine deltas despite being relative small in dimensions are at the scale of some of the lacustrine reservoirs and provide insights into the complexities if the deltaic reservoirs formed within the same basin.

Introduction

Deltaic depositional morphology and patters resulted from interacting of dynamic processes including river-mouth dispersal, wave and tidal reworking forces (Coleman and Wright, 1975; Galloway, 1975; Ethridge and Wescott, 1984; McPherson et al., 1987; Orton, 1988). The river-mouth is the point at which the momentum of riverine flow is diminished and diffused by interaction with an ambient water body and at which sediments which contribute to delta progradation are disseminated. River-mouths and deltaic lobes which show various plane and vertical configuration indicate different mechanisms and patterns of river effluents. These mechanisms and type of effluents depend upon river flow characteristics, density contrasts between issuing and water body, slope gradients, tidal and wave currents (Wright and Colman, 1974). Coleman and Wright (1971) used field observations and maps to analyze 34 major river systems, which suggested the existence of a finite number of river-mouth types. In addition, there have been numerous theoretical, laboratory, and field investigations of river-mouth processes and delta forming (Bates, 1953; Komar, 1973; Wright and Coleman, 1971, 1974; Olairu and Bhattacharya, 2006; Yu et al., 2012).

Huangqihai Lake, the objective of this study, is located within a modern lacustrine rift basin, Inner Mongolia, Northern China. The drainage of the basin is subdivided into seven major rivers which formed deltas around Huangqihai Lake (Figure 1). Three of these deltas showing different plane configuration were investigated by trenching. The purpose of this study is to (1) explore the influence factors for different river-mouth mechanisms; and (2) discuss the relationship between river-mouth processes and delta architecture.

Methods

This study includes two aspects, field study primarily for sample and data collection and laboratory experiments mainly for grain size determination and facies interpretation. The field program entailed trenching, profile describing, sampling, and photographing at selected locations on the three deltas. The laboratory work involved lithofacies and architecture classification, profile correlation and interpretation. In order to identify the sedimentary features of the deltas, a number of trenches were dug on the surface of each delta (15 on Dahewan Delta, 4 on Luzimiao Delta, and 18 on Bawanghe Delta). The space of trenches is approximately 300 m to 500 m, in response to the topographic variation.

Facies and Architectural Elements

The depositional system within Huangqihai Lake consists largely of braided fluvial-deltaic facies, which distribute along margins of the lake. The deltas are comprised of very fine-grained to gravelly sediments of quartz, feldspar, debris, and abundant micas that characterize their terrestrial sources. The general color of the sediments is mainly light grey for sands and dark grey for muds. In proximal area, the delta plain mainly consists of massive or trough cross bedding, coarse sands of channel sediments, and laminated silts with plant roots of the flooding plain. In distal area, delta front predominately comprise of muds and fine to medium sands with coarsening upward sequence showing typical progradational configuration. The sand layers with wave ripples in delta front indicate the reworking of wave currents. Pre-delta primarily consists of grey to dark grey, organic rich mud which was deposited in subaqueous area of semi-deep lake (Figure 2).

Architectural elements of deltas in Huangqihai Lake were identified by observation of trenches (Figure 3). Channels (CH) which include the feed channel in delta plain and distributary channels in the delta front consist of cross-stratified or massive sand beds alternating with clayey

intervals. Typical fining-upward successions were formed due to the rapid deposition of coarse-grained sediments. Distributary mouth bars (DB) which formed by downstream accretions and lateral accretions present stacked planar cross beddings with coarsening upward grain size. Ephemeral flood sediments (EF) are characterized by the inter-bedded massive sand layers and mud beds which were mainly reformed from the delta flood plain or overbank. Laminated sand sheets (LS) are commonly composed of fine-grained sand layers with lamination beddings. These sheets were interpreted as the products of flash floods depositing sand under upper flow regime plane bed conditions. Wave sand sheets (WS) of the shoreline, immediately adjacent to the standing water, comprise plenty of wave ripples. These elements were typical wave reworked littoral sediments of delta front, and the sediments features are developed in response to river-mouth processes and wave effects.

Friction-dominated Effluent

Dahewan Delta is located on the southern margin of Huangqihai Lake. This delta has the largest area of 11 km^2 and highest annual river discharge, which provided huge amount of sediments toward the lake on the shallow margin. Under this condition, outflow velocities and bed shear stress were high during the delta development. Friction action controlled the delta deposition pattern of plane and vertical configuration. The delta which developed under this type of river-mouth effluent exhibits multiple channel bifurcations and distributary mouth bars.

The deposition response to plane-jet diffusion initiated a short-term positive feedback; shoaling lake-ward of the progradation caused an increase in the friction-induced deceleration and effluent spreading, which in turn increased the shoaling rate. In that case, the channels migrated frequently on the delta plain by developing crevasses, and delta prograded lake-ward with high sand content ratio (Figure 4).

Inertia-dominated Effluent

Luzimiao Delta is located on the steep margin of Huangqihai Lake, which shows an elongate plane view with area of 3 km^2. This delta mainly consists of fine to medium sands with a moderate annual feed river discharge. Steep slope gradients and turbulent jet caused the fluid and momentum exchange between the outflow and lake water. The deltaic deposition was responsible for the expansion, mixing, and deceleration of the effluent. The transporting capacities of the effluent are diminished, and sediment was deposited in a pattern showing the effluent spreading.

The depositional pattern resulting from inertia-dominated effluent is shown in Figure 5. Due to the low spreading angles, the lateral dispersion of delta was confined to a narrow zone, especially in the river-mouth region. The sediments from proximal to distal area show gradual deceleration of grain size by the constant velocity. Delta front is characterized by sigmoid progradation with moderate sand content ratio (Figure 5).

Buoyance-dominated Effluent

Bawanghe Delta is located on the shallow margin with gentle slope gradients, north of Huangqihai Lake. Due to the arid climate and human construction (dam built for agricultural irrigation) recently, discharge and transportation capability of the Bawanghe River have been decreased dramatically. Meanwhile, severe evaporation caused the shrinkage of the lake area and concentration of water density. Density contrast was

formed in the river-mouth area. Therefore, the outflow spread as a buoyant plume above the underlying salty water, and a buoyance-dominated depositional pattern occurred (Figure 6).

Flows with fine-grained sediments associated with buoyant effluent played a significant role in controlling the geometry of the river-mouth deposition and progradation pattern. Rapid deceleration of load capacity led the coarse sediments deposited around river-mouth area. In delta front, sheet sand layers fine progressively lake-ward, whereas the lateral extent and continuity of sediments increased as the result of expanding effluent. The pro-delta clays deposited from suspension in the slow-moving outer extremities of the effluent constitute the ubiquitous basal unit of the delta.

Conclusions

(1) Various river-mouth depositional processes (friction-dominated, inertia-dominated, and buoyancy-dominated) occurred in Huangqihai Lake, which mainly depended upon sediment supply (discharge), slope (bed-form) gradients, and density of outflow and standing water. The morphology and facies differences between the three delta types coming in the same lake is most likely controlled by the river discharge characteristics and the sediment load type.

(2) Friction-dominated delta primarily exhibits multiple channel bifurcations and delta lobes with high sand content ratio; inertia-dominated delta presents an elongate or narrow lobe zone with typical sigmoid progradation in delta front; and buoyancy-dominated delta which commonly developed shingled progradation shows divergence expansion with fine sediments.

Acknowledgments

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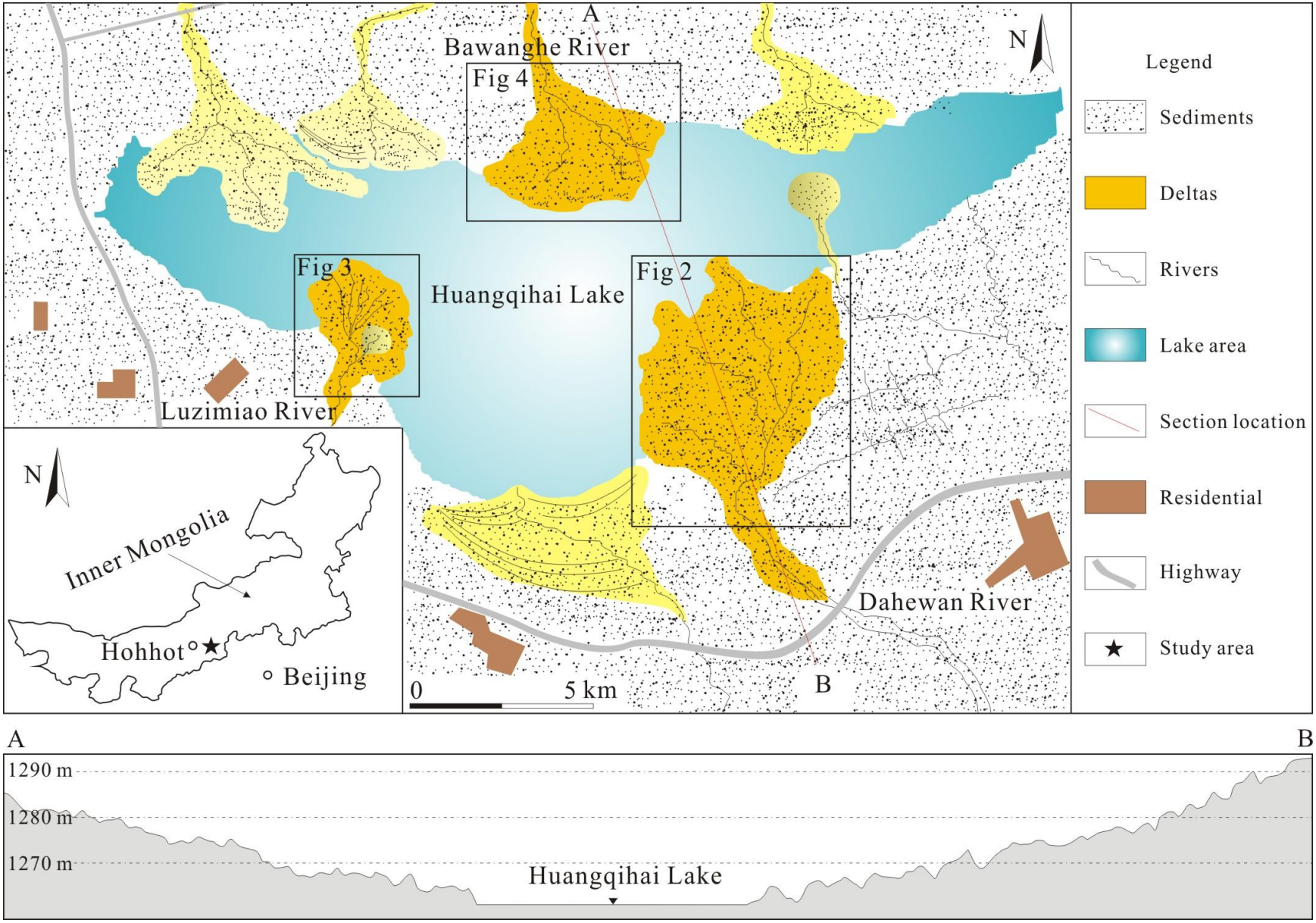

Figure 1. Geological setting of Huangqihai Lake showing topography and depositional systems.

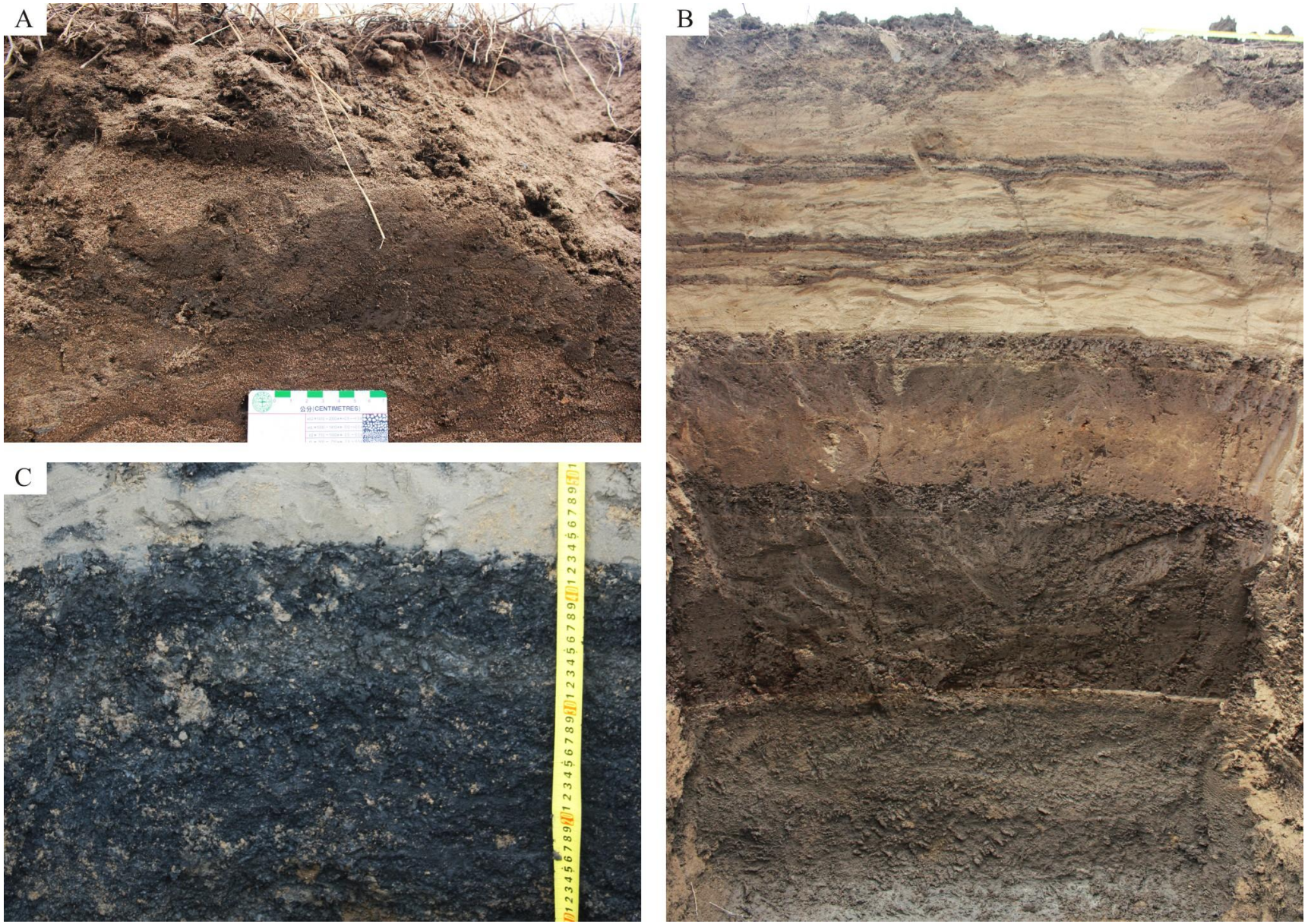

Figure 2. Sedimentary facies of deltas in Huangqihai Lake. Note that (A) delta plain showing massive or laminated, fine to medium sands with plant roots of flood sedimentation; (B) delta front presenting coarsening upward of progradational sequences with wave ripples; and (C) pre-delta exhibiting dark grey, massive and organic rich mud deposited in semi-deep lake.

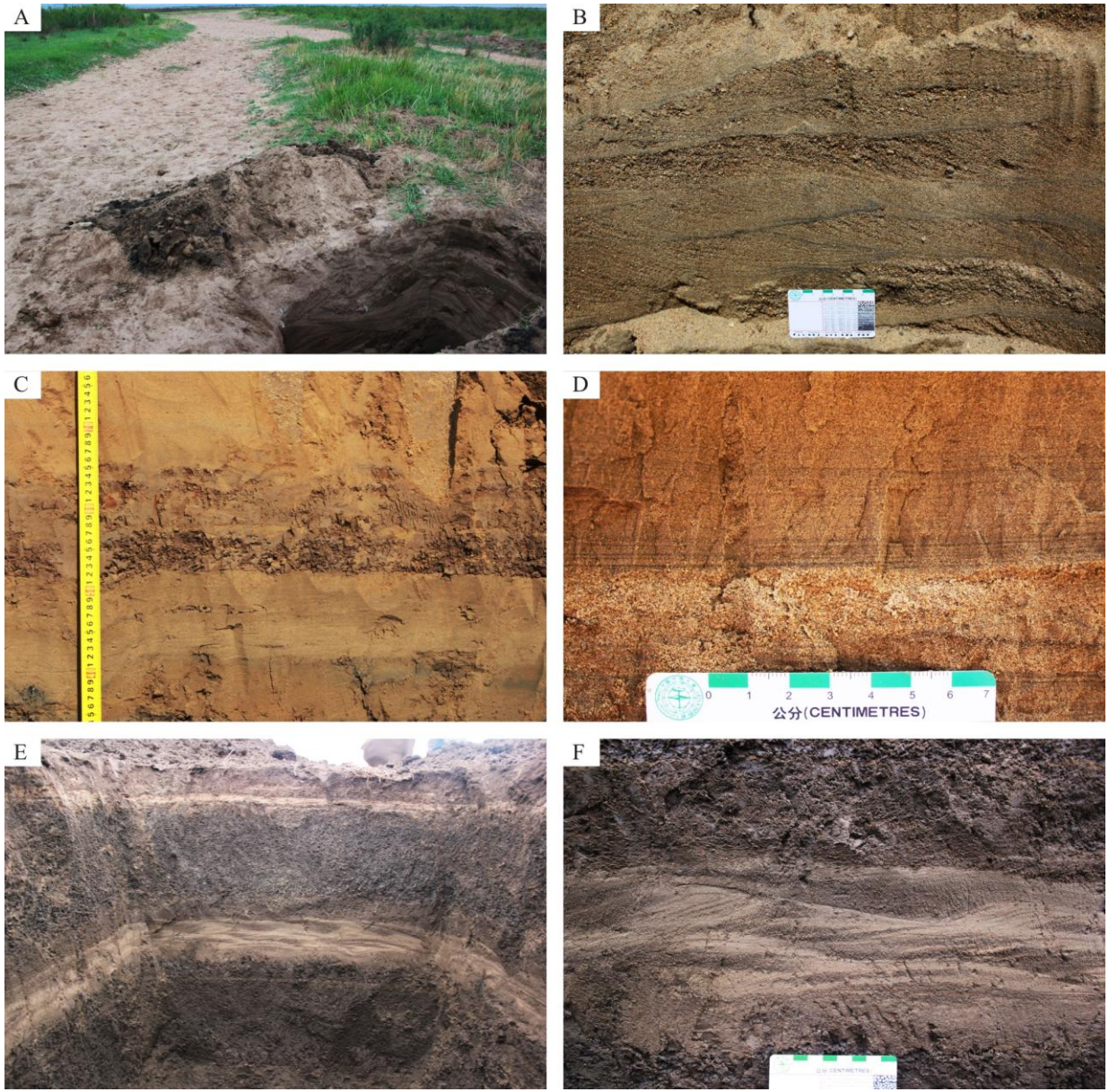

Figure 3. Architecture elements in deltas along margins of Huangqihai Lake. (A) Distributary channel and distributary mouth bar; (B) Distributary mouth bar with stacked planar cross beddings; (C) Ephemeral flood sediments with massive sand layers and reddish mud bed; (D) Laminated sand sheet with fine to medium sands; (E) and (F) Wave sand sheet with ripples in delta front.

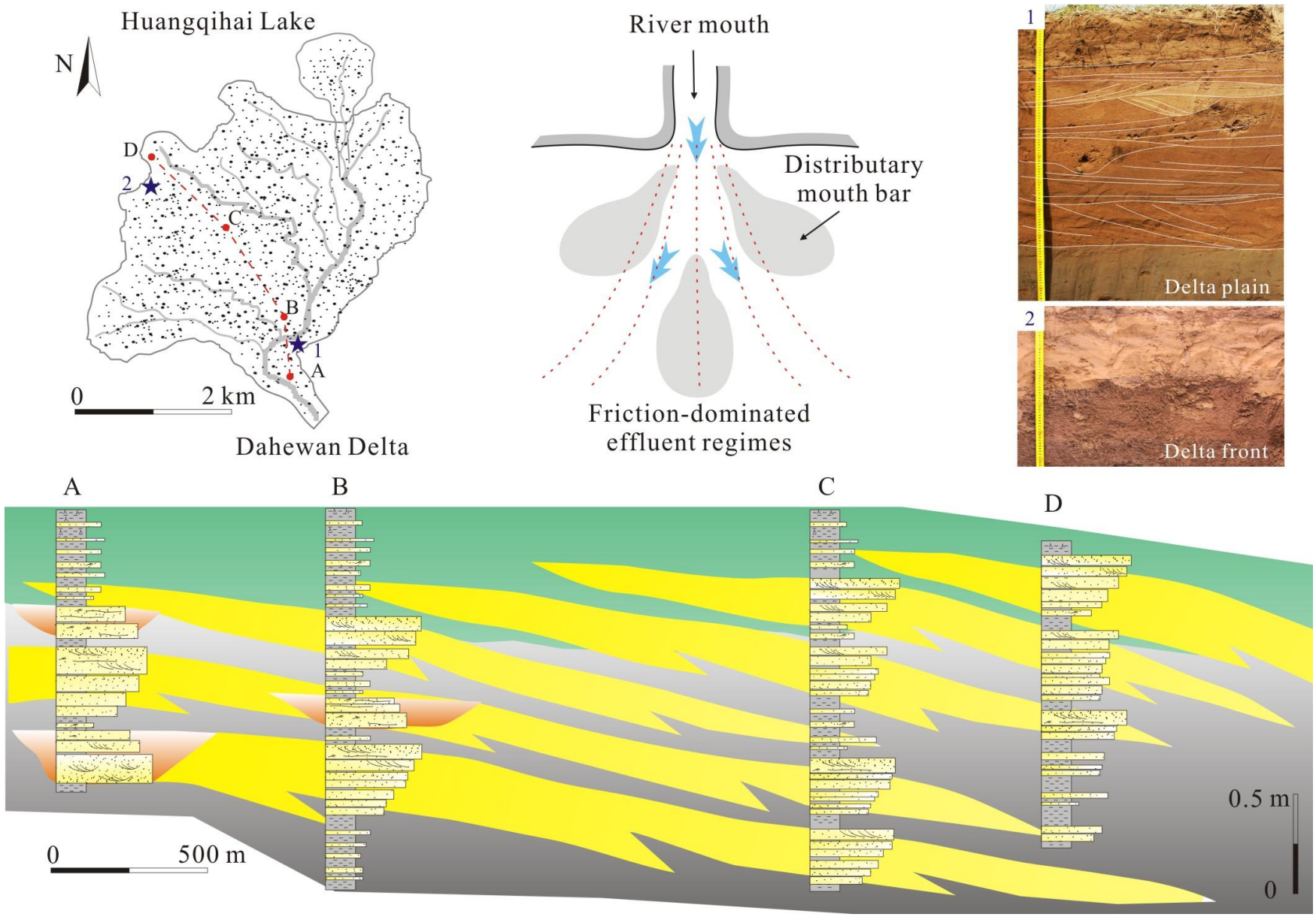

Figure 4. River-mouth depositional pattern and deltaic progradation related to friction-dominated effluents.

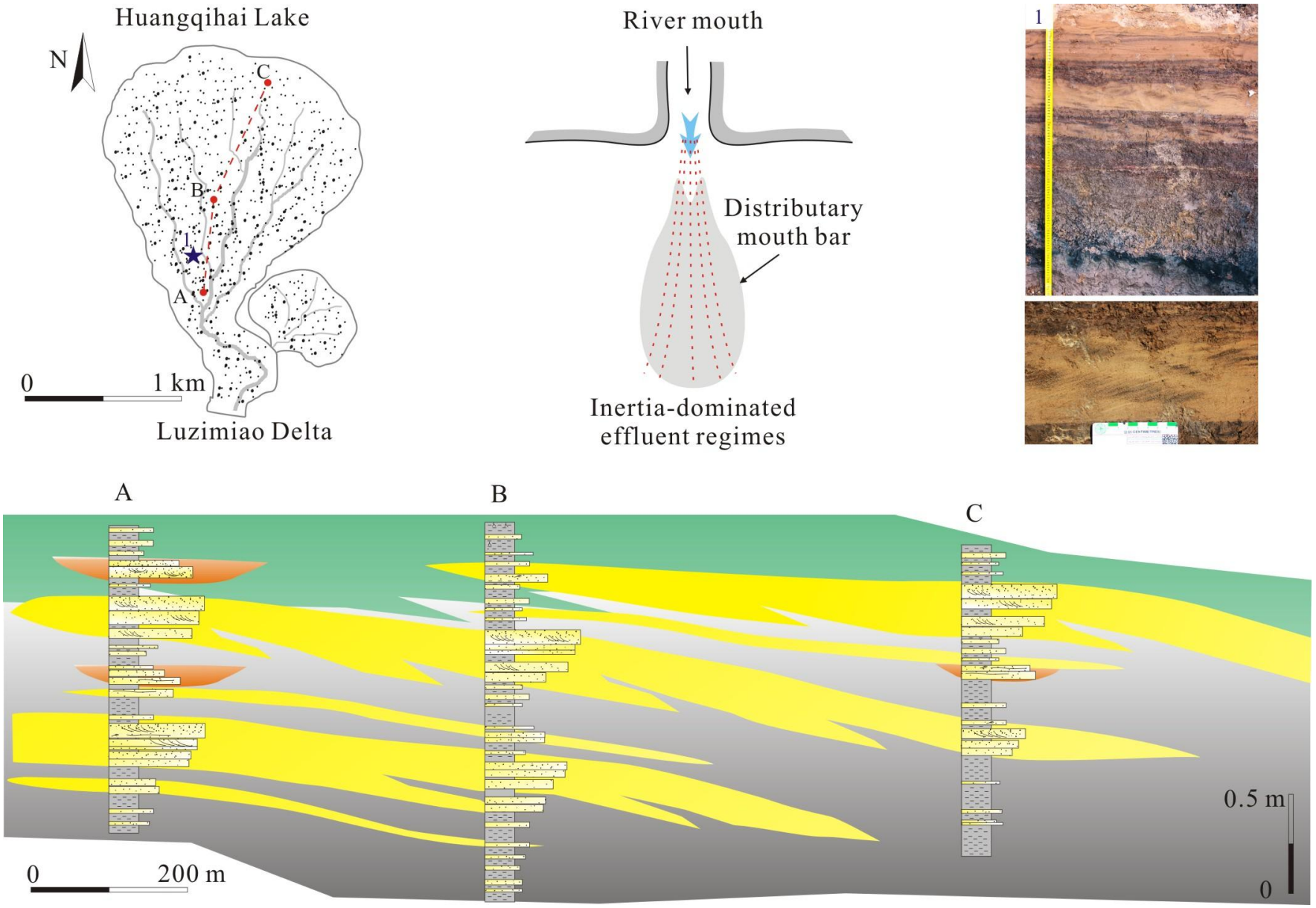

Figure 5. River-mouth depositional pattern and deltaic progradation related to inertia-dominated effluents.

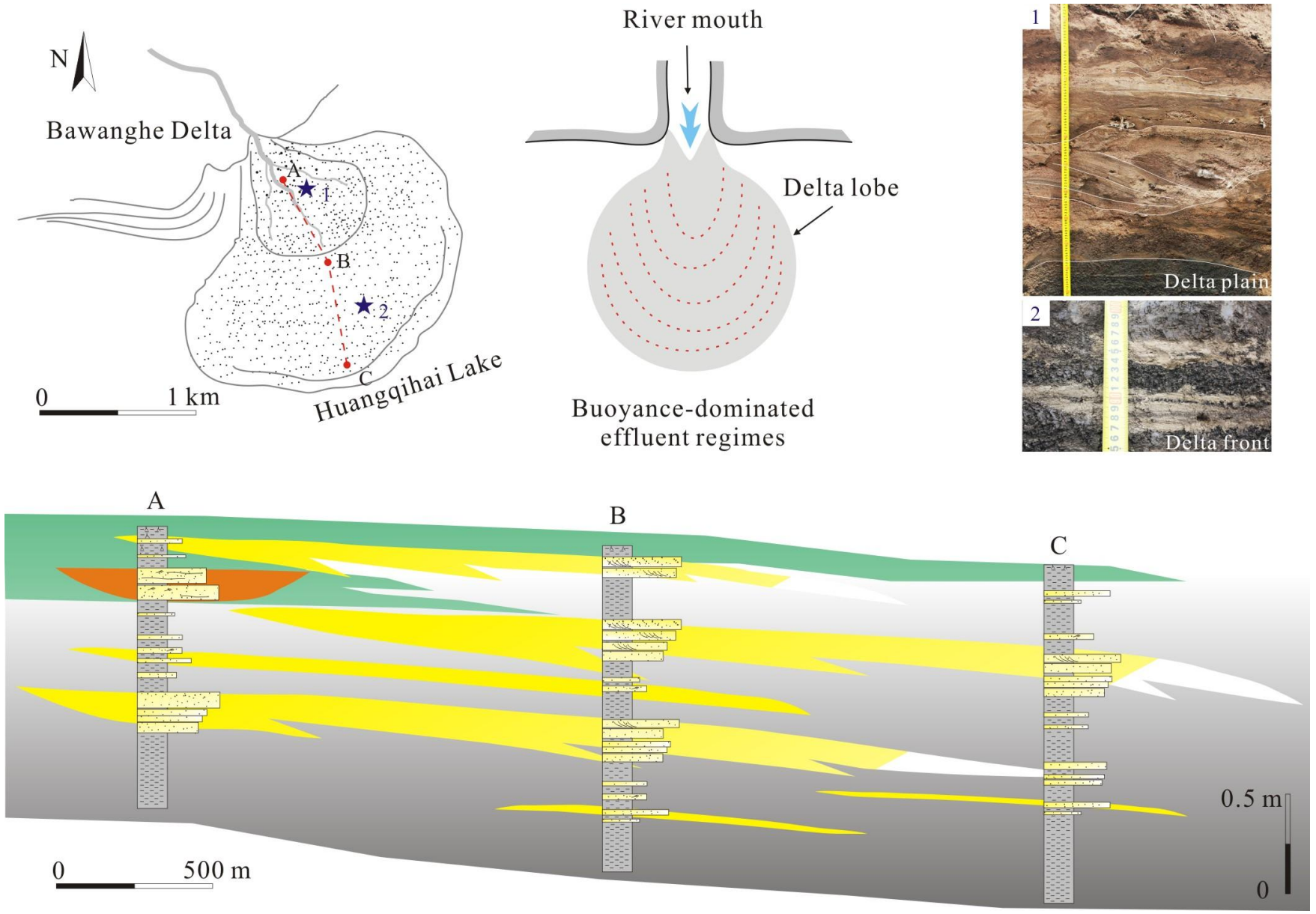

Figure 6. River-mouth depositional pattern and deltaic progradation related to buoyancy-dominated effluents.