The Modern Mahakam Delta: An Analogue for Transgressive-Phase Deltaic Sandstone Reservoirs on Low Energy Coastlines*

Joseph J. Lambiase[1] and Salahuddin Husein[2]

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Abstract

The modern Mahakam Delta on the east coast of Borneo has been traditionally characterized as a mixed river-dominated and tide-dominated delta that is presently prograding (e.g. Galloway, 1975; Allen and Chambers, 1998) and is commonly used as an analog to interpret subsurface reservoirs. However, a recent quantitative study demonstrates that the delta is presently in a transgressive phase (Salahuddin and Lambiase, 2013). Its distributaries are filling with sediment accompanied by relatively minor reworking of pre-transgression sediment. Quantitative hydrodynamic and sedimentologic data indicate that sediment flooring the distributaries is progressively finer downstream, which generates a fining-upward distributary-fill succession that also becomes more marine upward as transgression continues. Similar fining-upward distributary-fill successions that become more marine upward are relatively common in outcrops of the paleo-Mahakam Delta.

The depositional mechanism is a progressive decrease in current speed, sediment transport capacity and competence as ongoing relative sea level rise continually reduces water surface slope in the distributaries that, coupled with high sediment supply rates, fills accommodation with progressively finer, fluvially-derived sediment. Water surface slope decreases until the distributary becomes inefficient and avulses near the delta apex, causing back-stepping lobe switching. Very low wave energy in the receiving basin, plus rapid subsidence and burial, limits marine reworking to the uppermost pre-transgression strata. This preserves the pre-transgression, progradational distributary and inter-distributary morphology as well as the distributary-

fill successions. Sandy back-filled distributary successions are somewhat thinner and closer together in the upper delta plain than in the lower delta plain. As these sands fill the topographically low distributaries, they are laterally adjacent to slightly older, pre-transgression progradational strata. In contrast, inter-distributary areas are developing relatively thin, sandstones directly above pre-transgression progradational strata and separated from it by a transgressive erosional surface generated by marine reworking. Wave-dominant shoreline sandstones occupy equivalent stratigraphic positions in paleo-Mahakam Delta outcrops, where they are the first marine strata in transgressive successions.

The three dimensional geometry of the sandstones within a transgressive succession is expected to be complex and highly dependent on the pre-transgression delta morphology. The back-filled distributary sandstones are sinuous and oriented quasi-perpendicular to the shoreline while the transgressive shoreline sandstones are shoreline-parallel with a lateral extent that is determined by the distributary spacing. Ongoing transgressive lobe switching means that the back-filled distributary successions are not exactly contemporaneous and that they probably have highly variable thicknesses and lateral extent.

Recognition of distributary-fill sandstones can be problematic, especially where thin transgressive successions occur within sequences that are strongly progradational. Distributary-fill sandstones and fluvial point bar deposits fine upward over comparable thicknesses, which makes it nearly impossible to distinguish them on wireline data. The geometry and total volume of distributary-fill sandstone reservoirs is highly variable and determined by the number, size and three-dimensional connectivity of the distributaries. In addition, sandstone thickness is controlled by avulsion so there is no relationship between thickness and channel width in distributary-fill sandstones. Transgressive shoreline sandstones can be misinterpreted as fining-upward fluvial successions when they occur within sequences dominated by progradation. Their lateral extent is controlled by the pre-transgression delta morphology and width and thickness are a function of relative sea level history and wave energy. Although generally thin, transgressive shoreline sandstones can increase reservoir volume and connectivity significantly wherever they immediately overlie older sandstones.

Selected References

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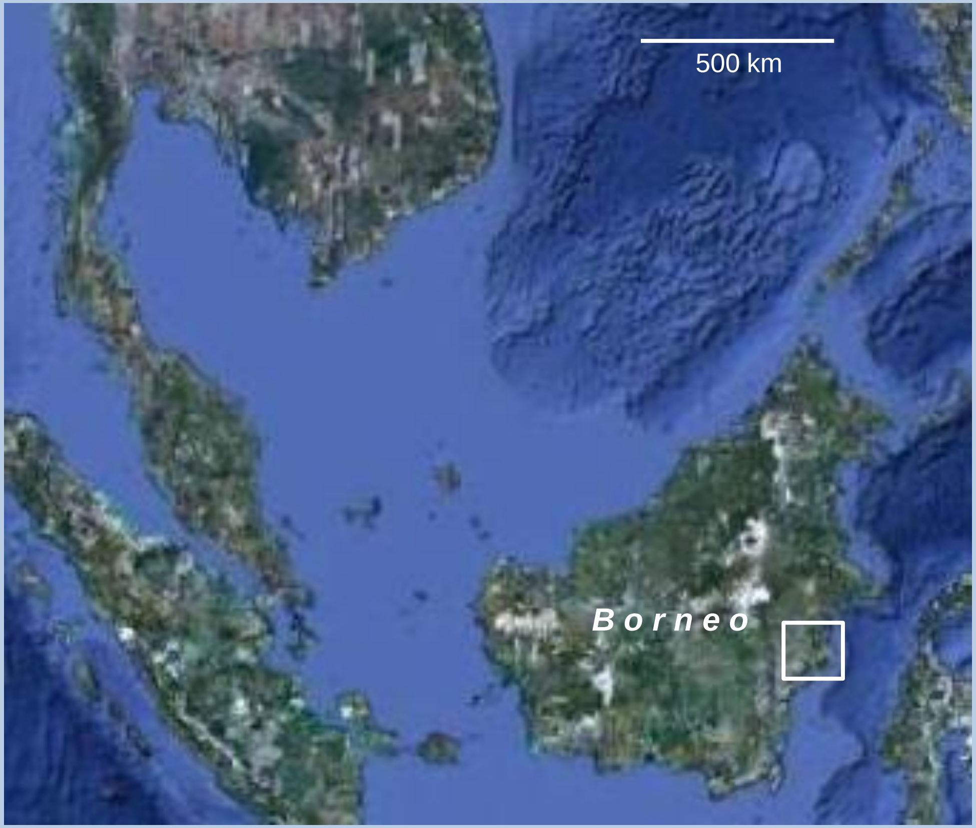
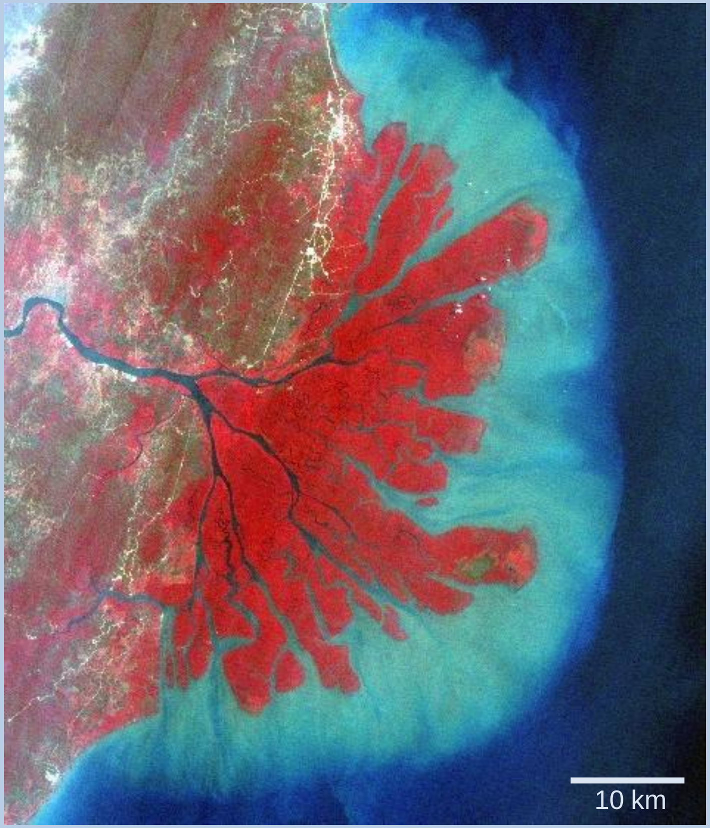
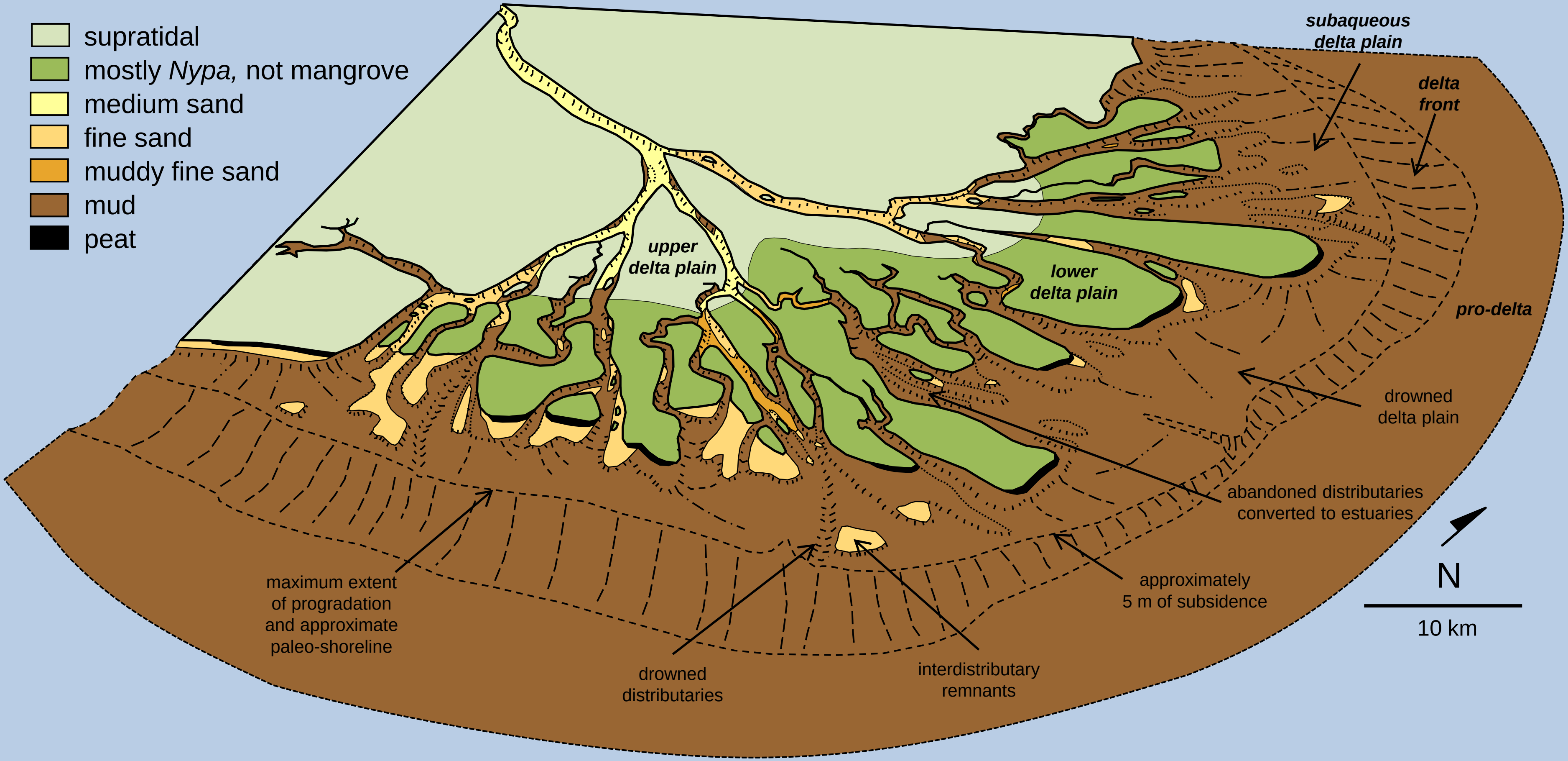
The Mahakam Delta

- Long regarded as a progradational mixed tide- and fluvial-dominated delta
- Mean tidal range is 1.2 m
- River floods are damped by the Kutei Lakes upstream of the delta
- Wave energy is fetch limited, mean wave height is 0.6 m



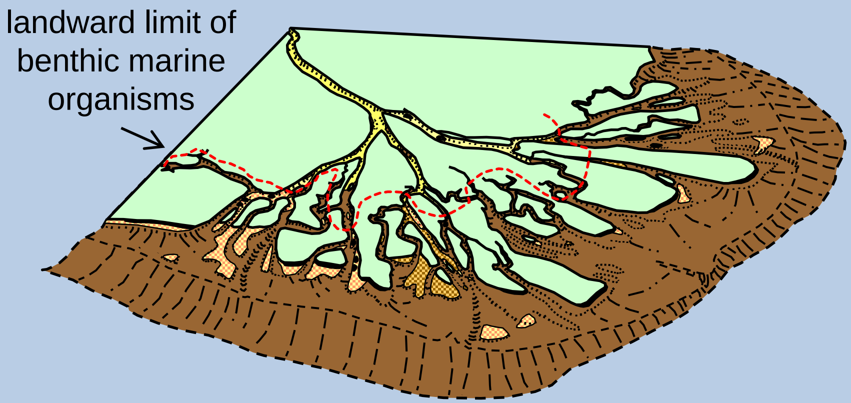


Lithofacies and Bathymetry



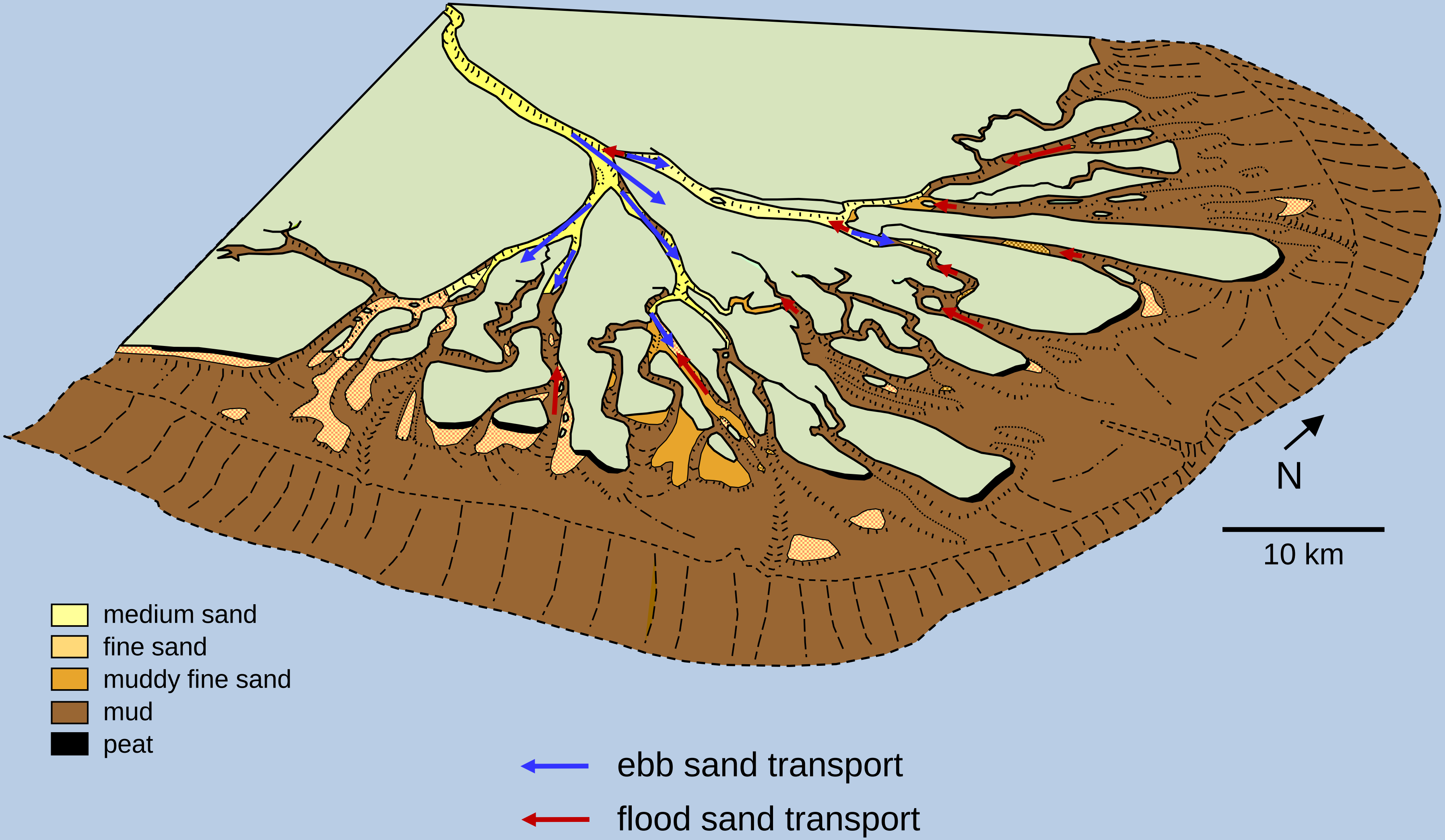
(after Salahuddin Husein 2008)

Marine Organisms



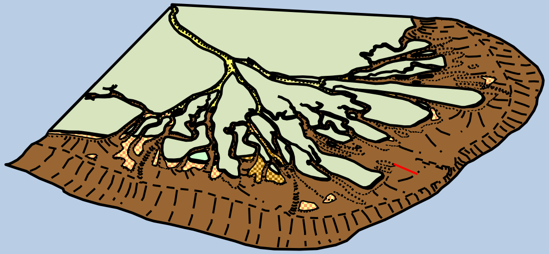
(after Salahuddin Husein 2008)

Bedload Sediment Transport

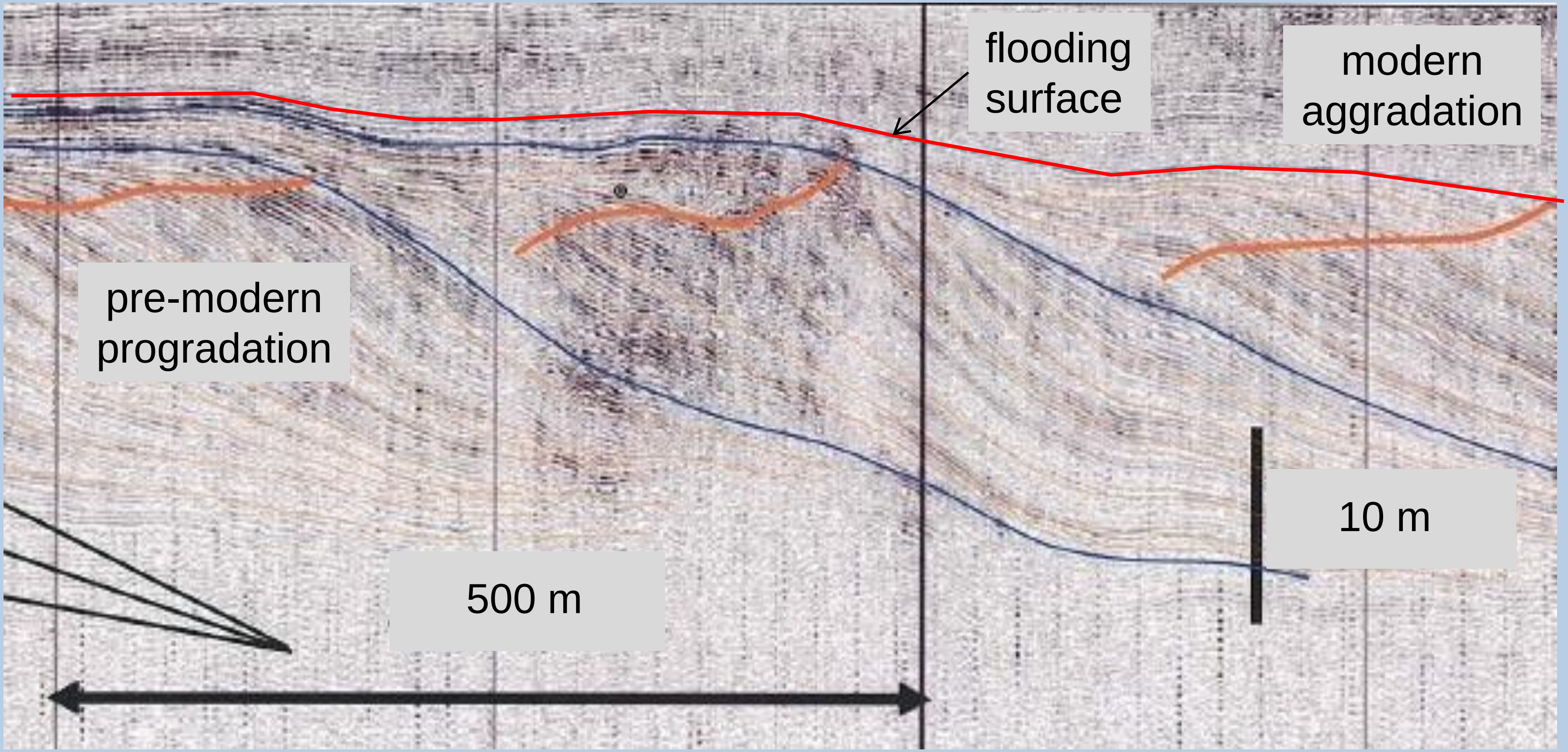


(after Salahuddin Husein 2008)

Present-Day Offshore Aggradation

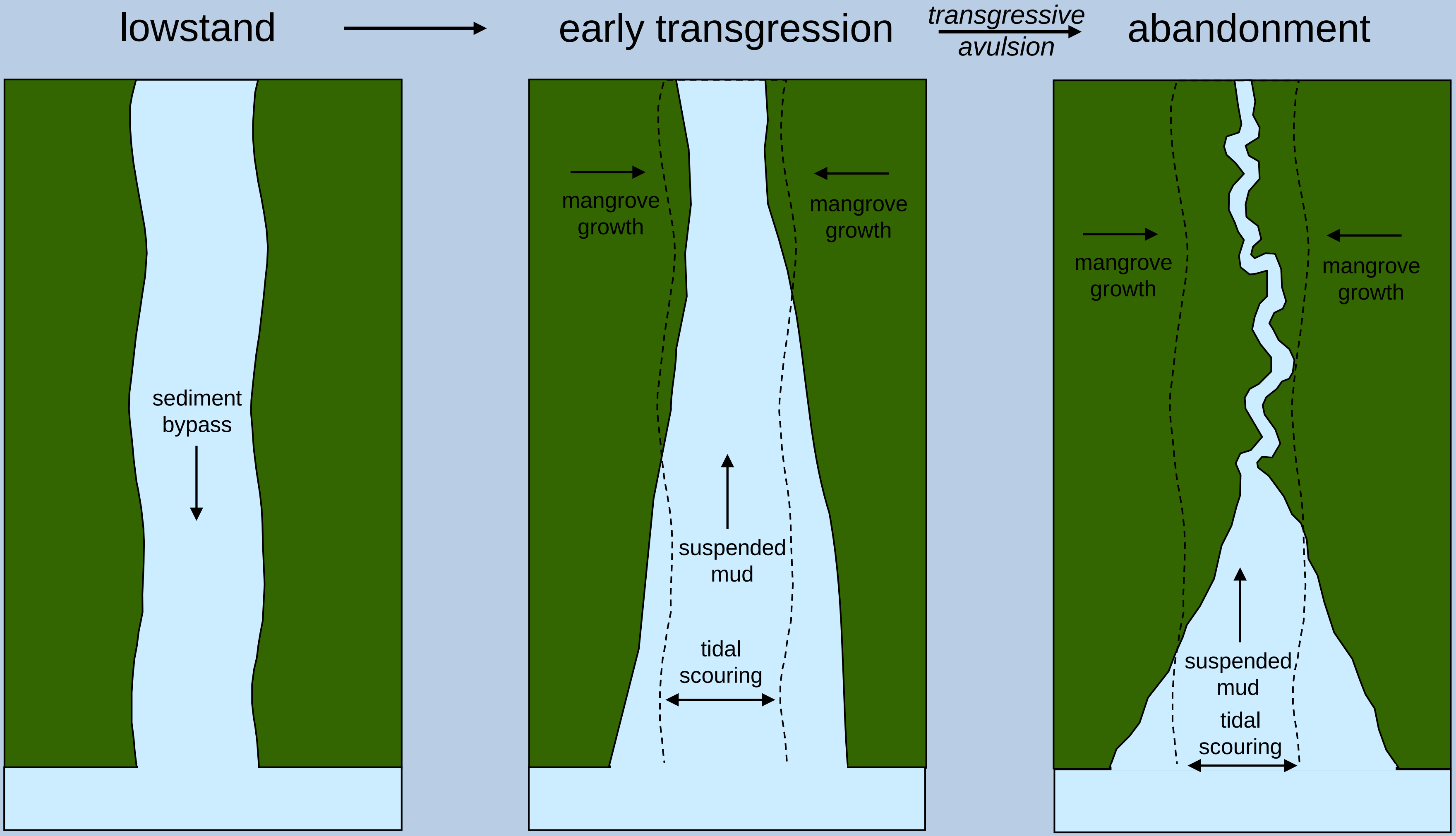


- Site survey line on the drowned delta plain
- Mud on the seafloor



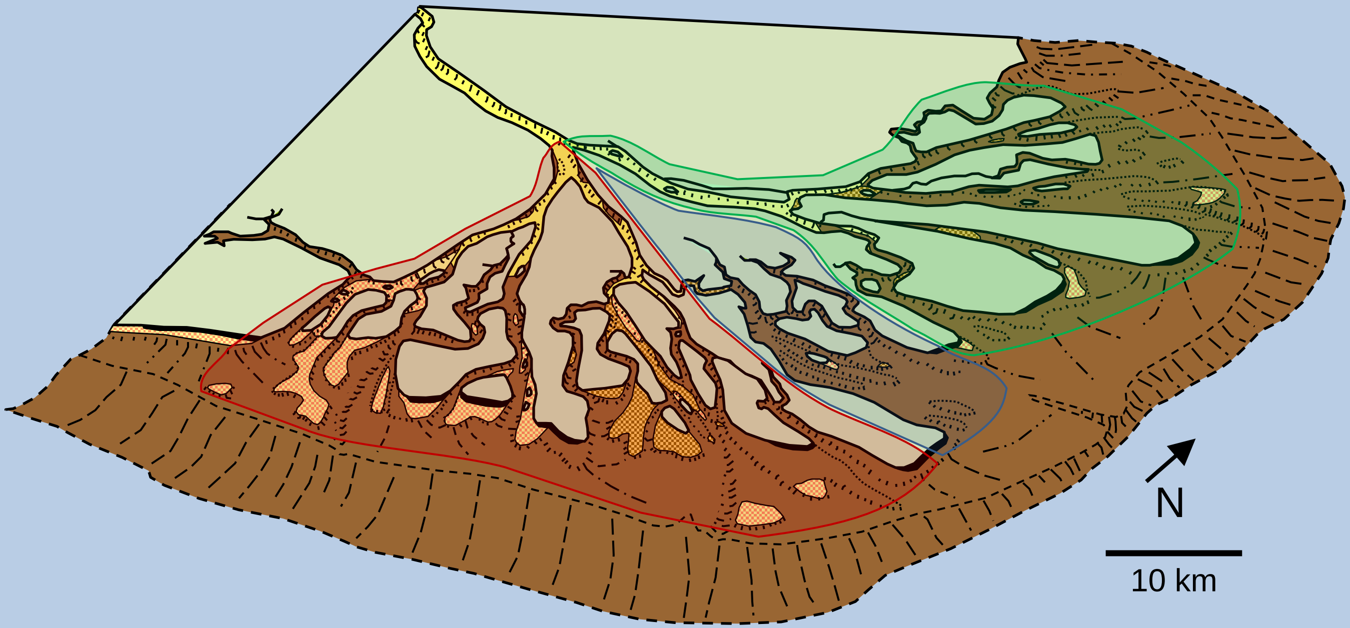
(after Cibaj 2007)

Distributary Evolution

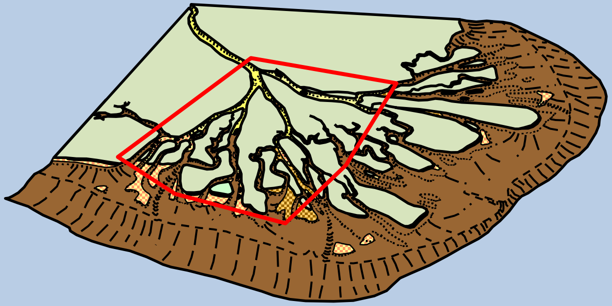


Transgressive Back-Stepping

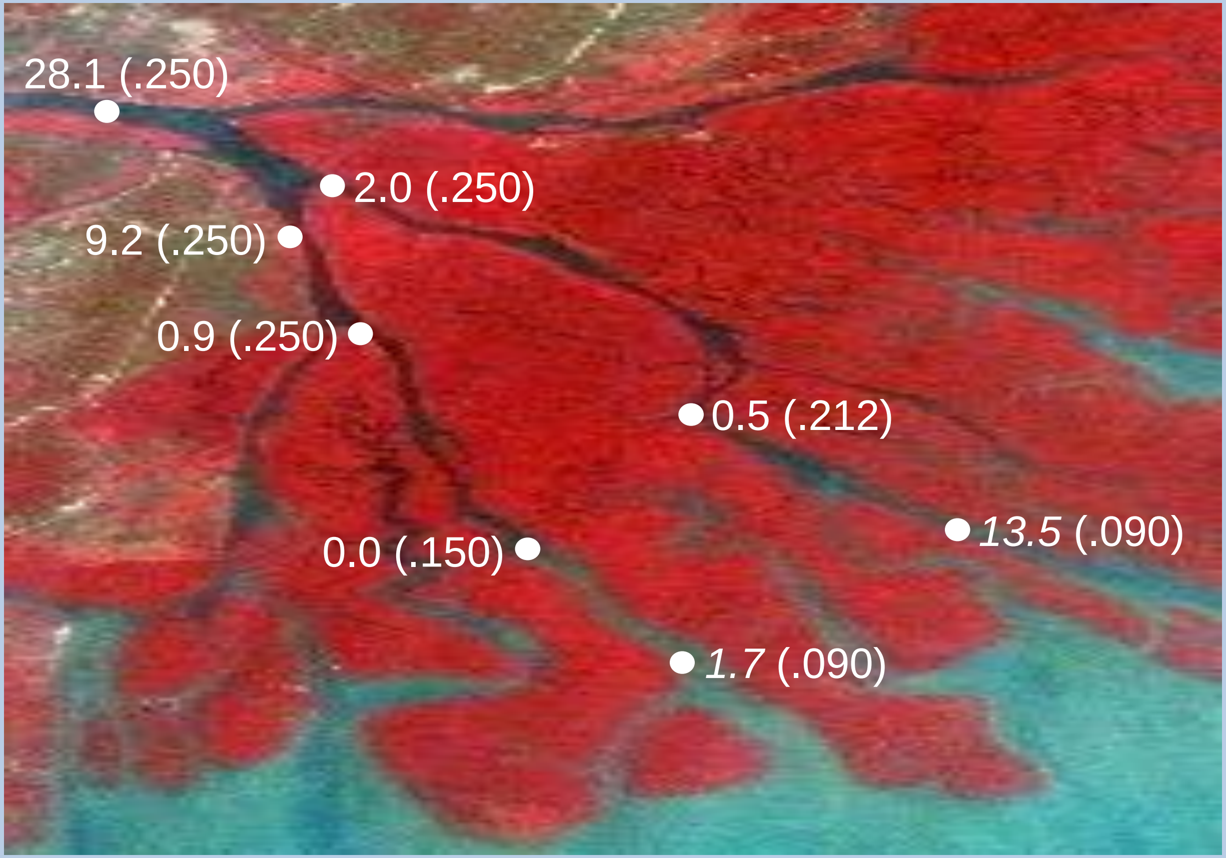
- The delta has fluvially active (red), partially abandoned (green) and abandoned (blue) areas
- Lobe-switching forced by avulsion of distributaries as water surface slope decreases during transgression
- Generates a back-stepping delta



Bedload Transport Rates



- Transport rate decreases seaward
- Grain size decreases seaward
- No river-derived sand reaches the sea coast

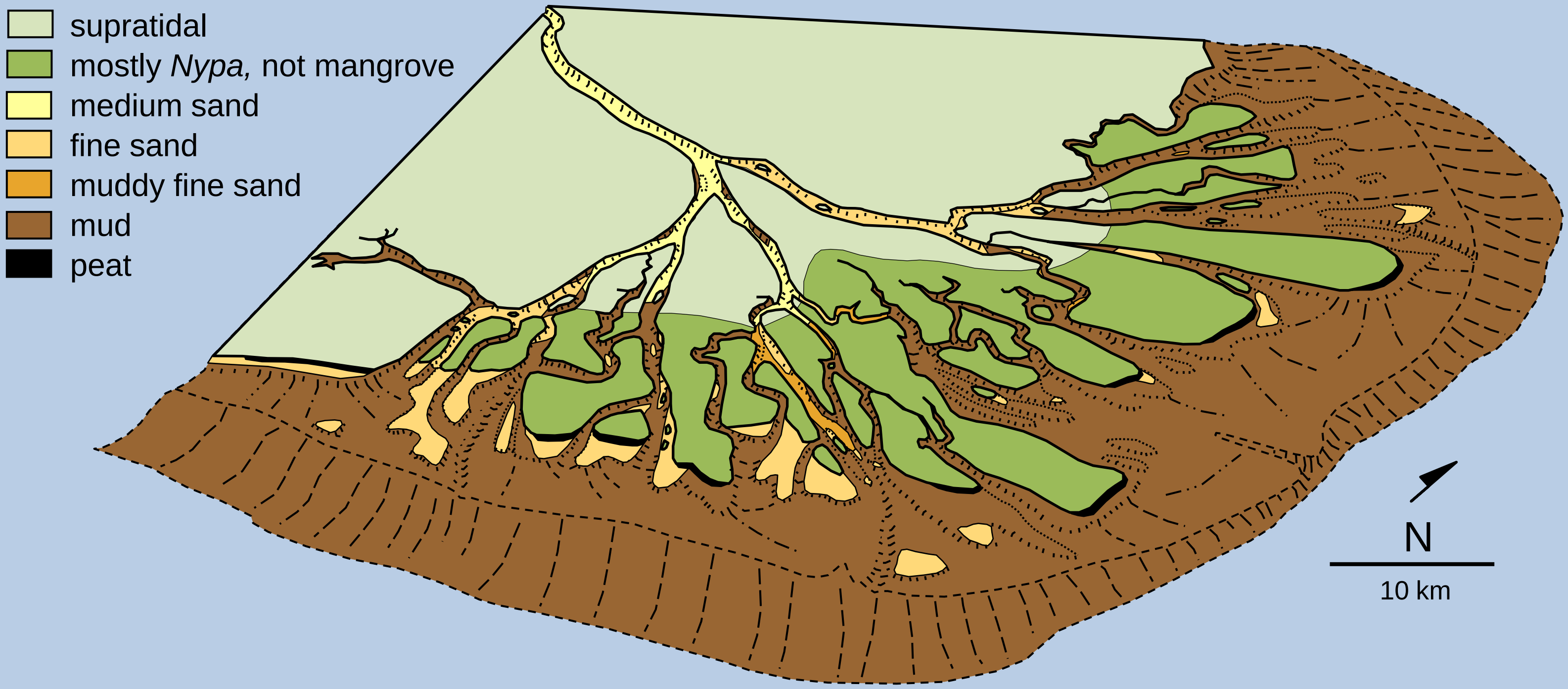


bedload transport rate (10^3 m^3/yr) → 28.1 (.250) ← median grain size (mm)

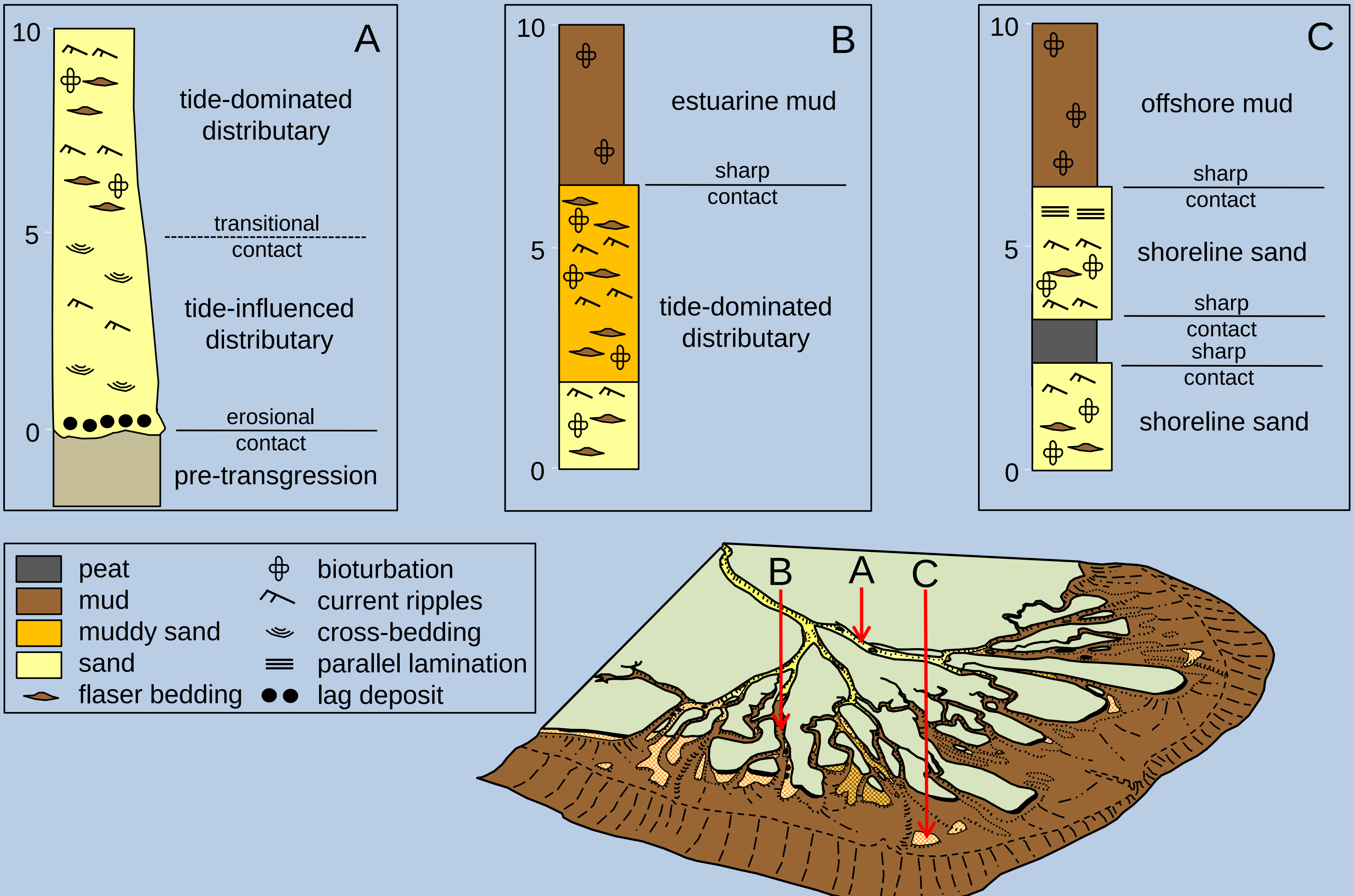
(Salahuddin and Lambiase 2013)

Sedimentary Processes

- Bedload transport rate and grain size decrease seaward
- Landward bedload transport in the lower distributaries
- Sand is being stored onshore, filling the distributaries
- Suspended sediment is transported seaward
- The tidal prism lifts fresh water out of the distributaries
- Waves strip off vegetation but cannot rework sand body geometry



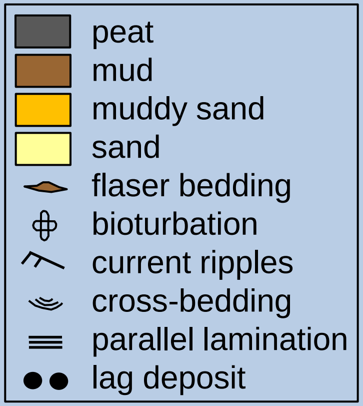
Stratigraphic Succession

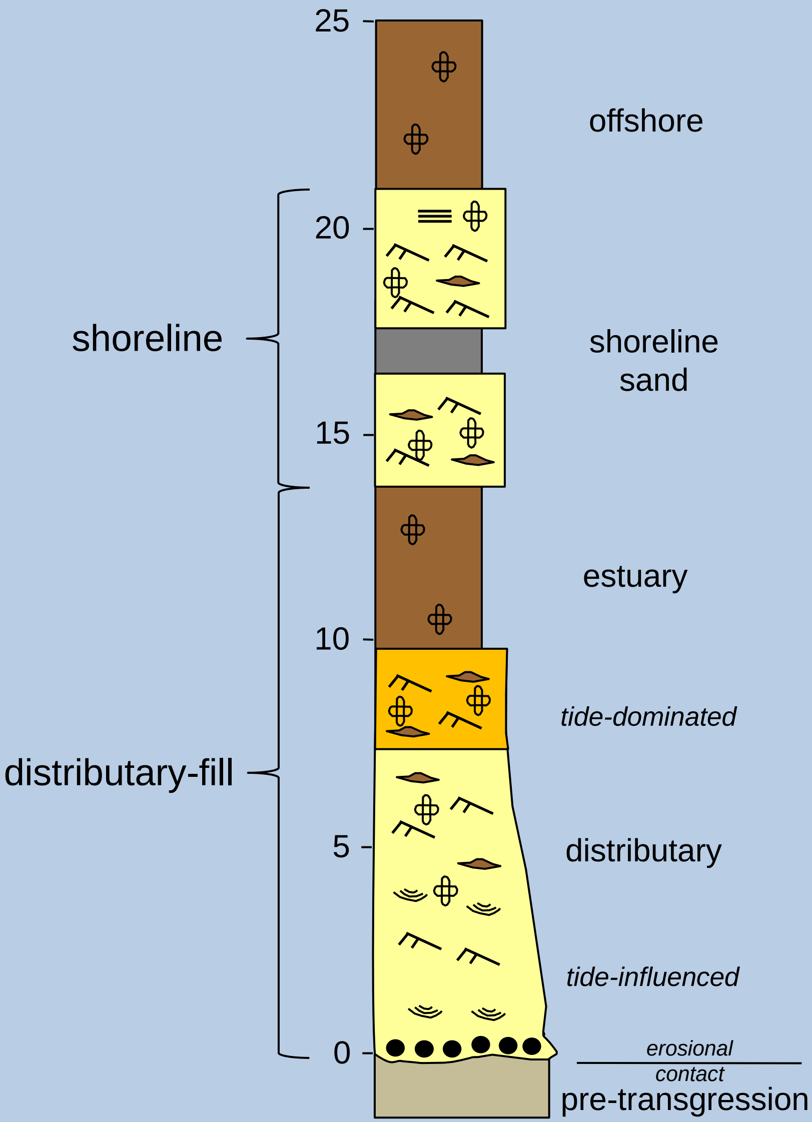


(after Salahuddin Husein 2008)

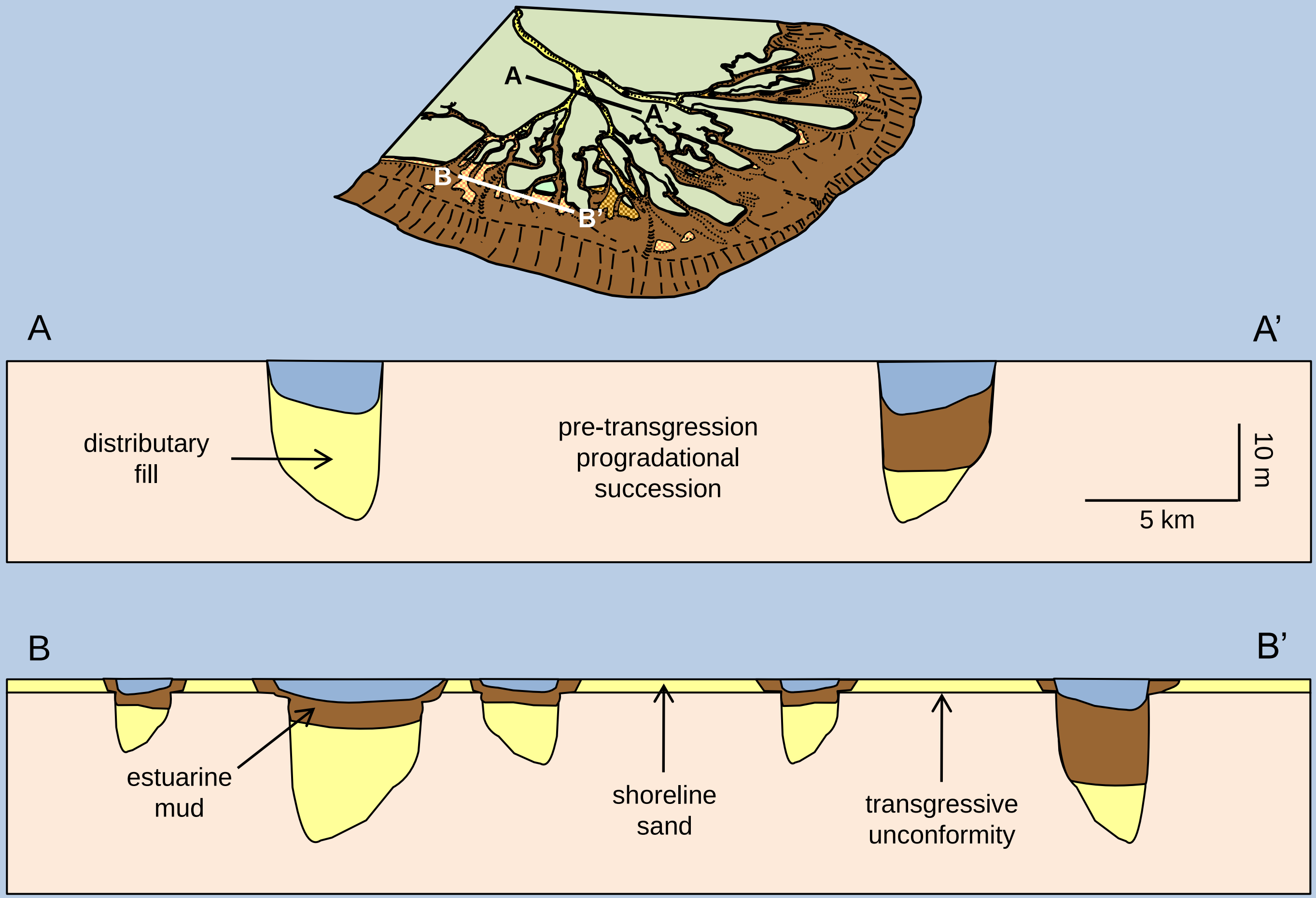
Composite Stratigraphic Succession

- Two types of transgressive sands are being deposited
- Fining-upward and increasingly marine upward distributary-fill
- Mixed wave- and tide-influenced shoreline sands

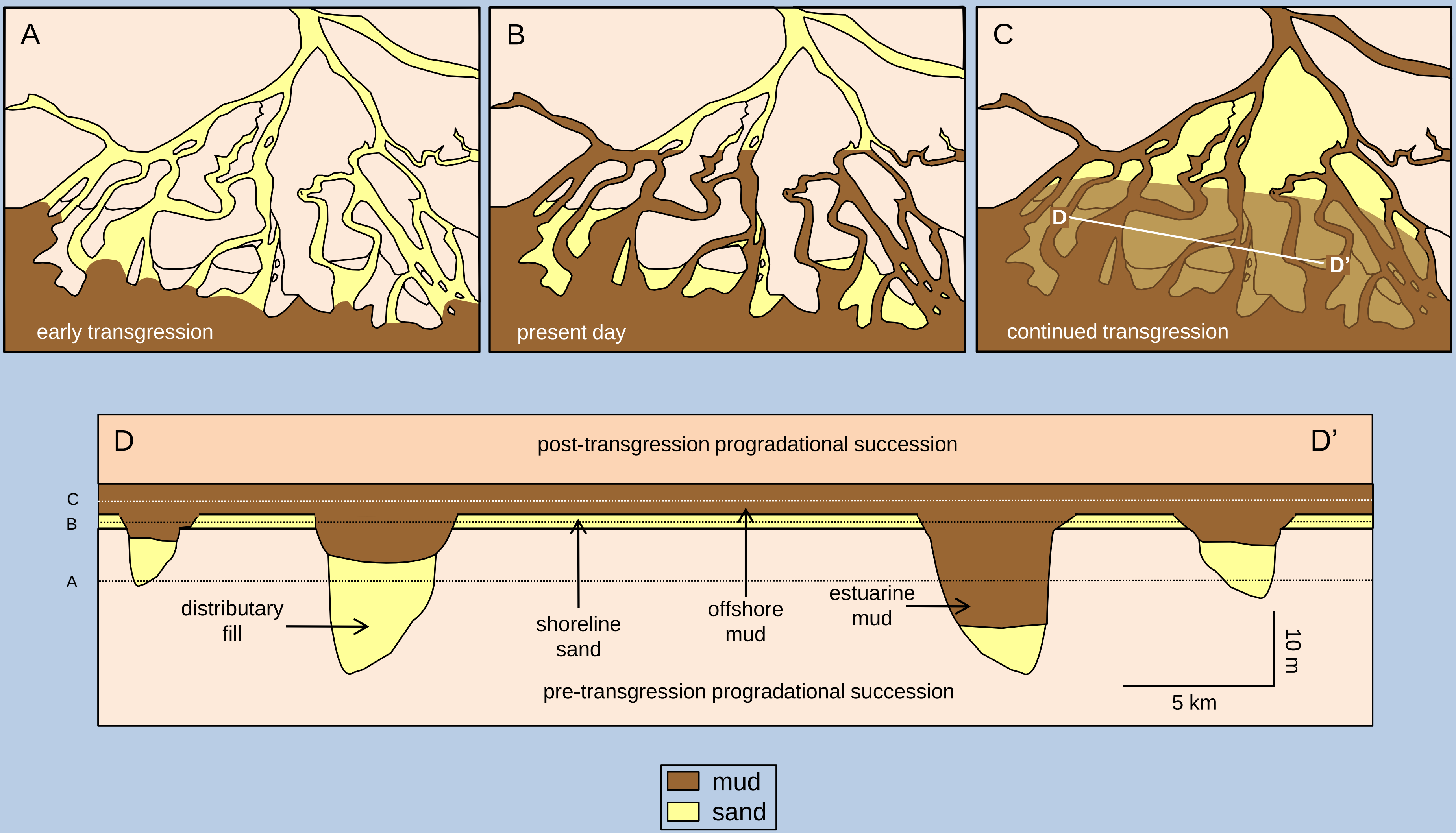




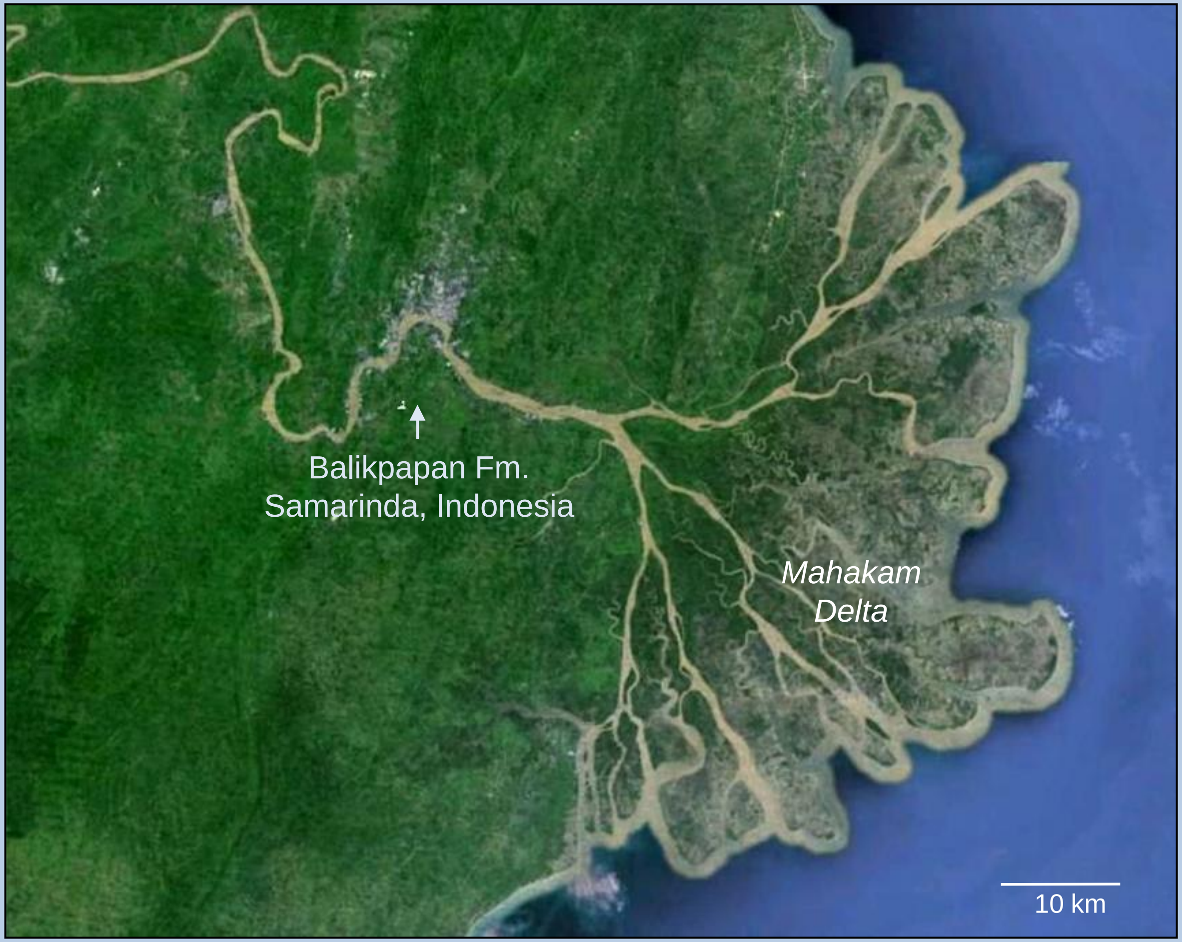
Distribution of Transgressive Sands



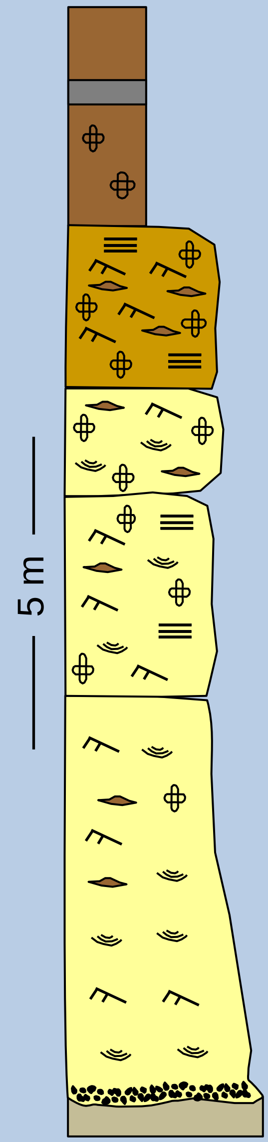
Sand Body Geometry



Paleo-Mahakam Delta Outcrops

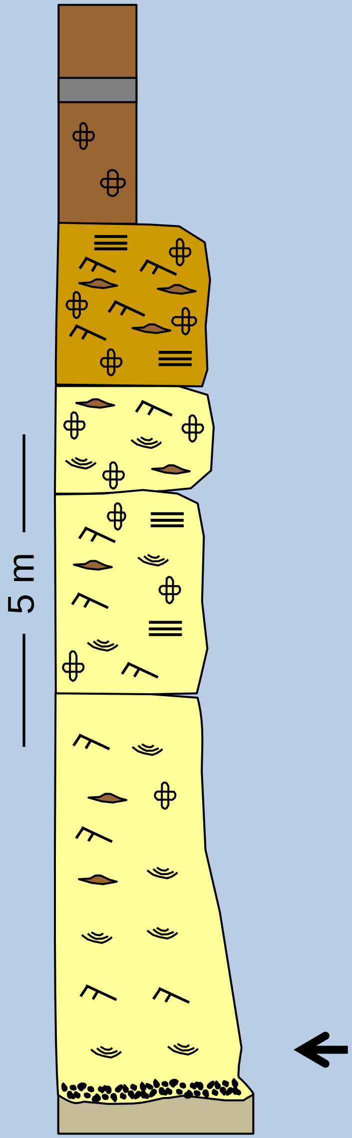


Stadion Utama Kaltim



- sandstone
- pebbly sandstone
- mudstone
- interbedded thin sand and mud
- parallel lamination
- current ripple cross-lamination
- cross-bedding
- flaser bedding
- bioturbation

(after Nadia Nirsal 2010)



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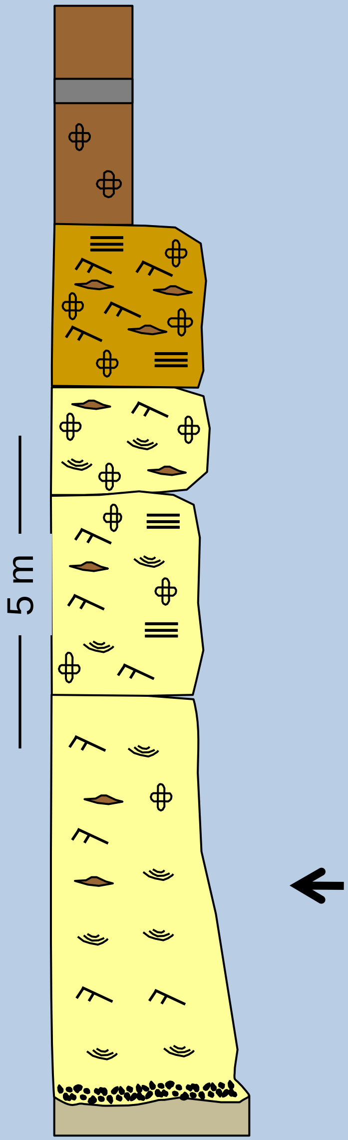

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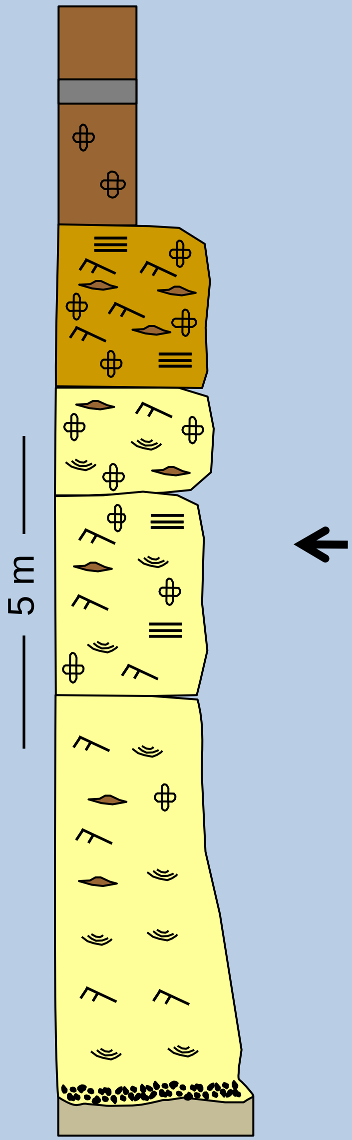

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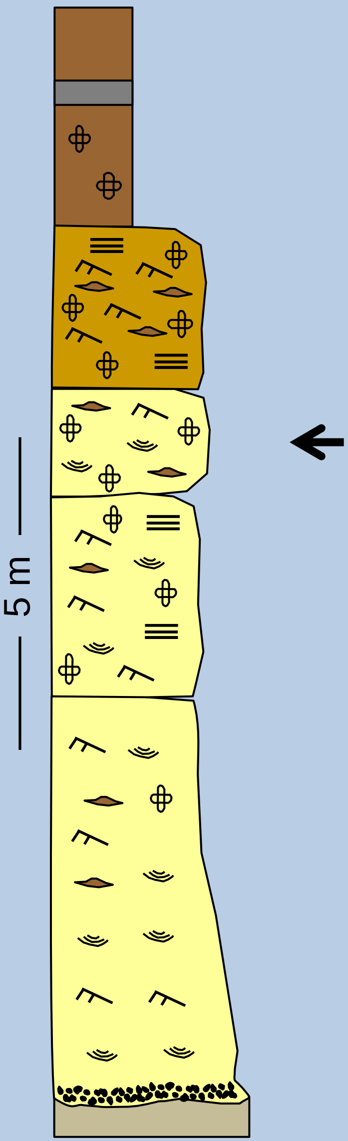

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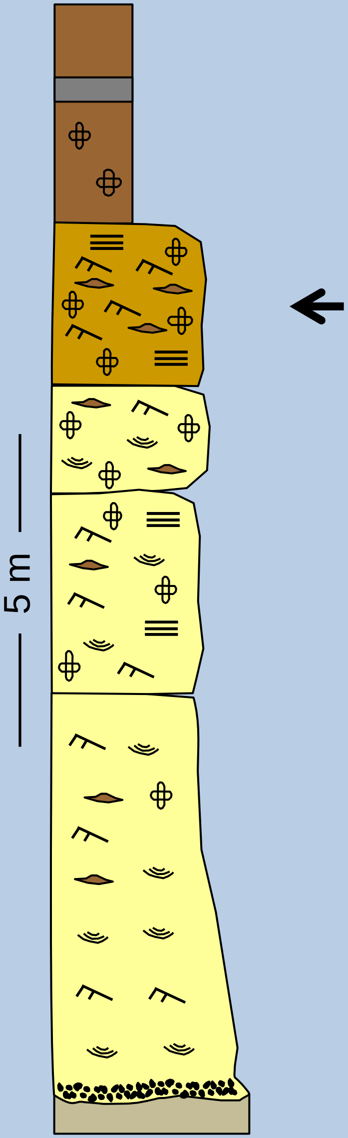

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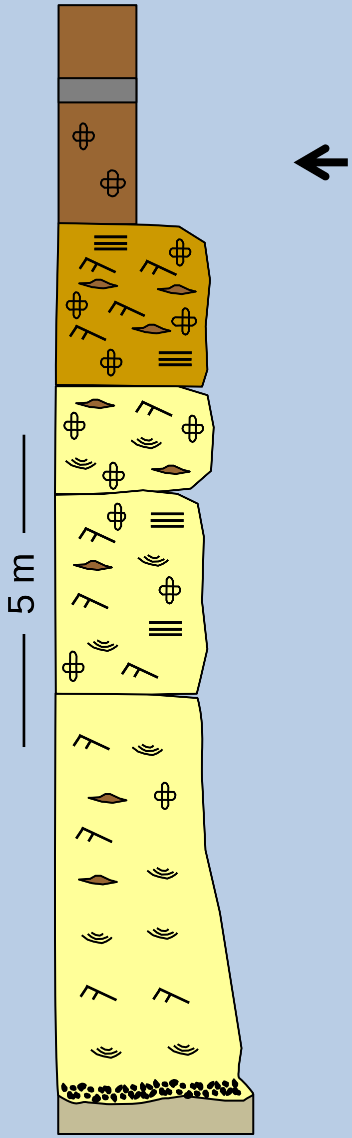

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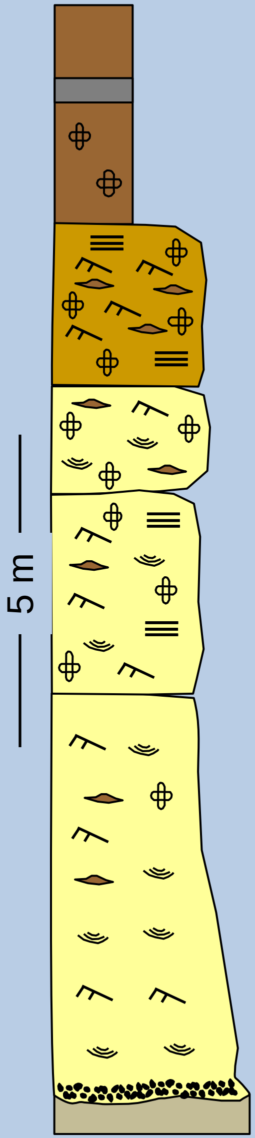

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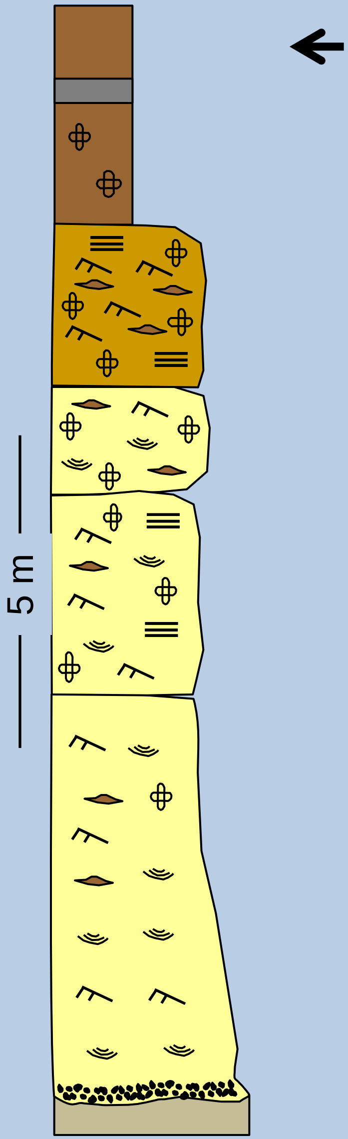

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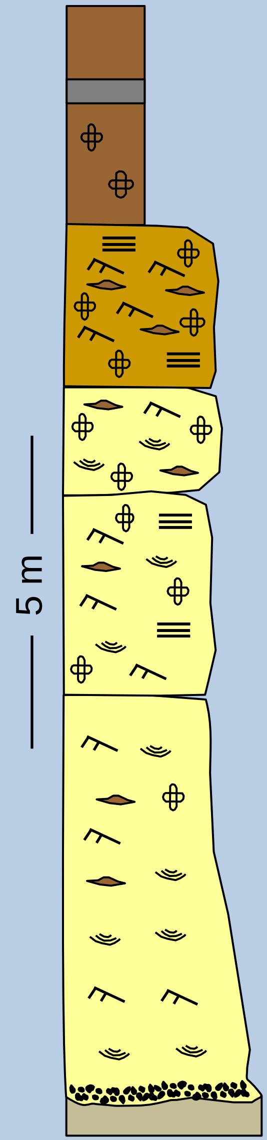
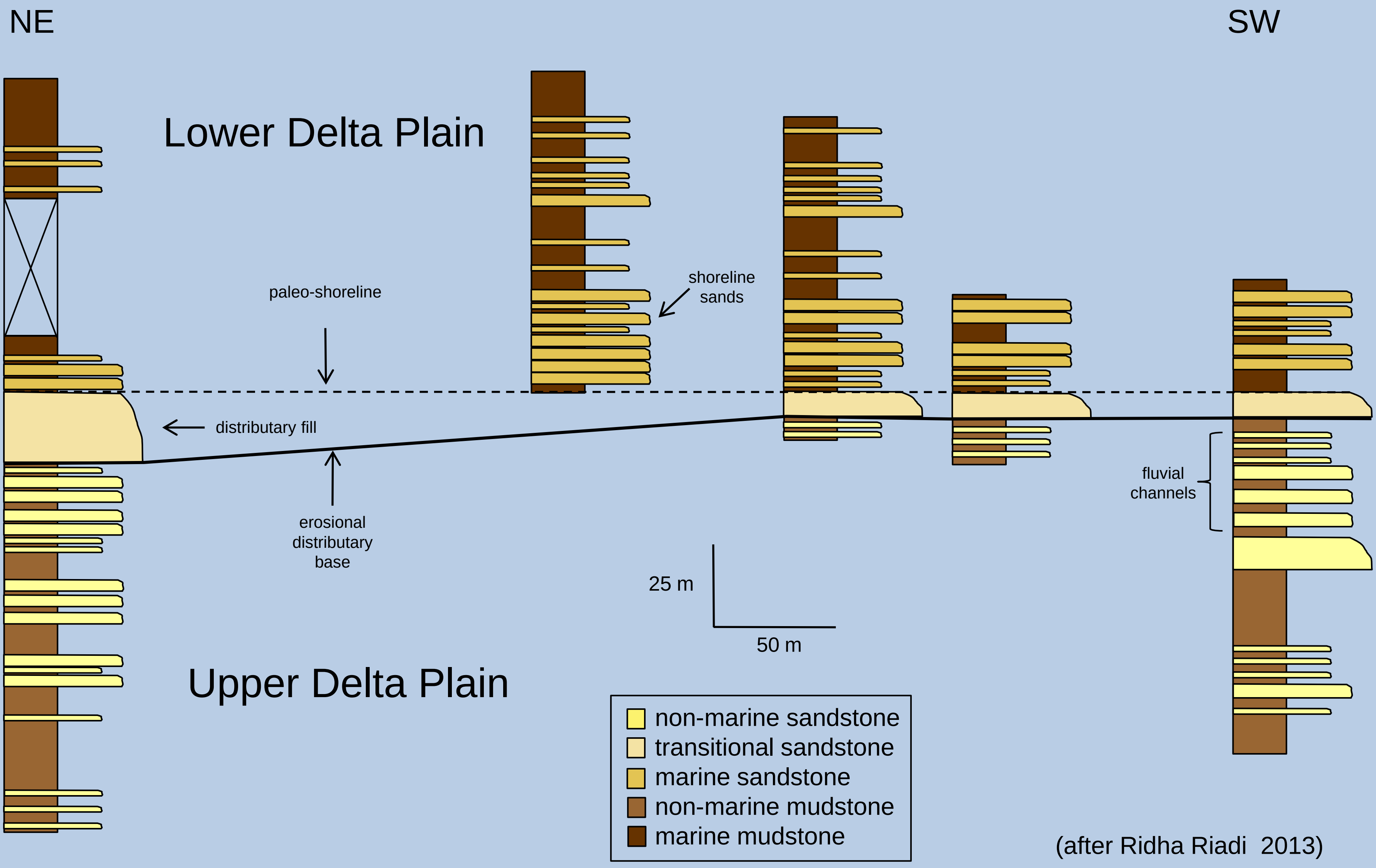
(after Nadia Nirsal 2010)

Stadion Utama Kaltim

- Fining-upward succession
- Onlapping bed geometry
- Increasingly marine upward
- Distributary filled during transgression

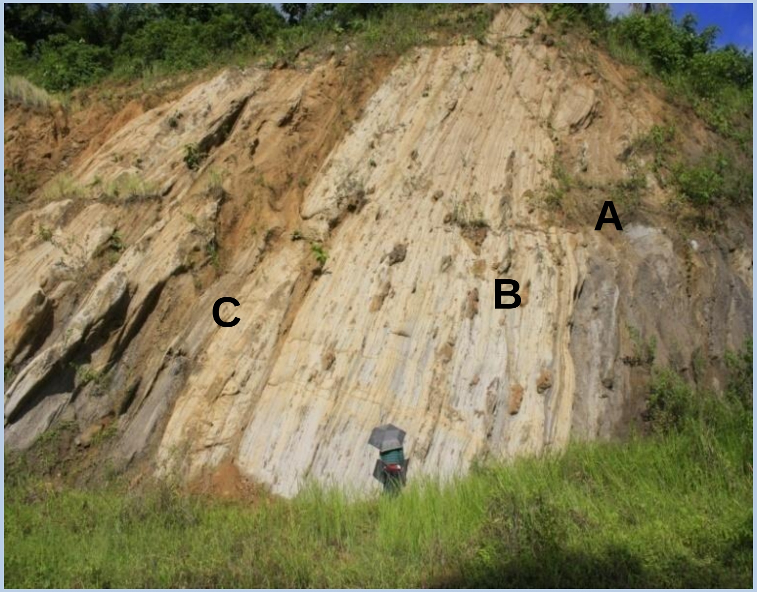


Grand Taman Sari Circuit



(after Ridha Riadi 2013)

Fluvial Sandstones



(after Ridha Riadi 2013)

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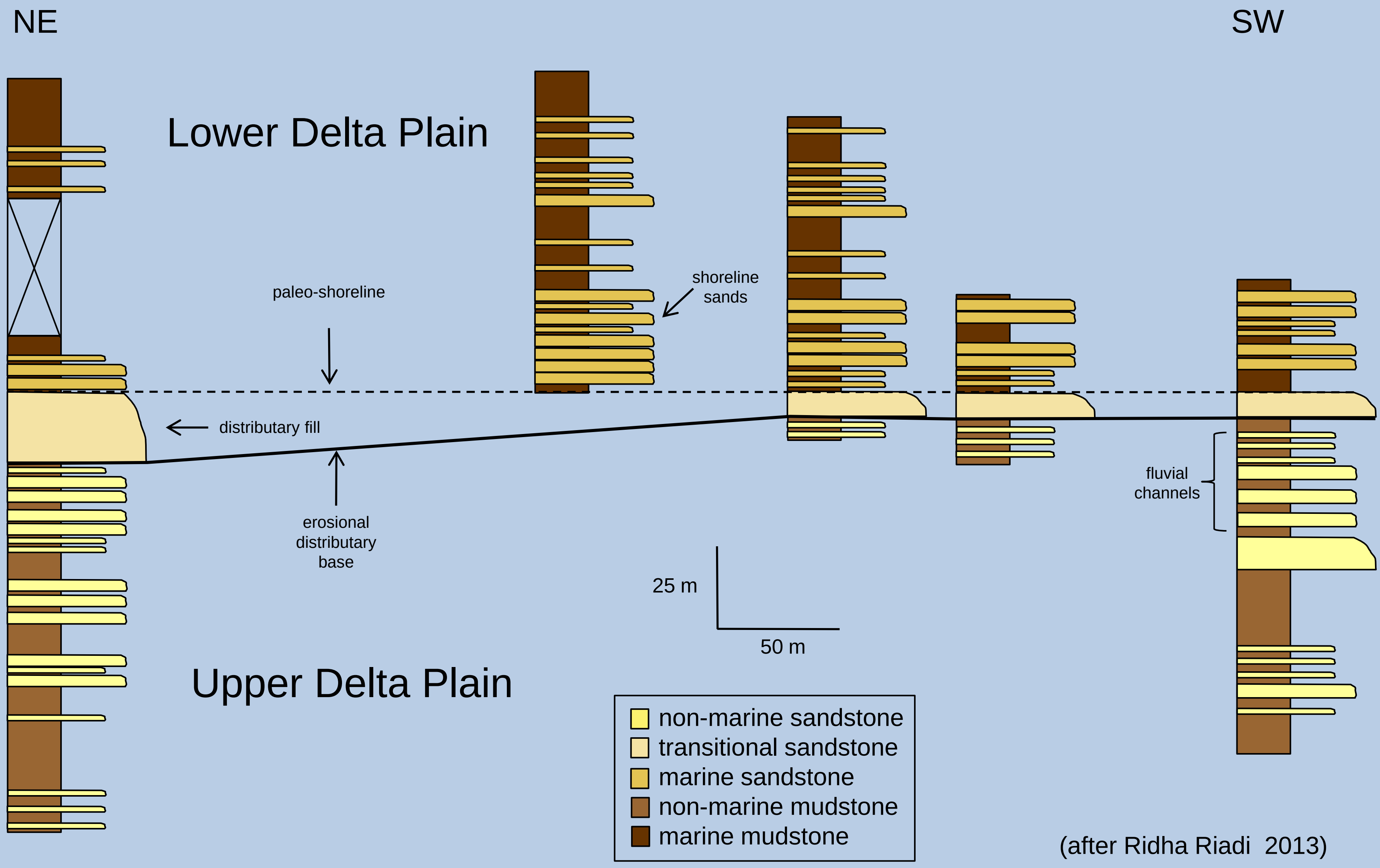
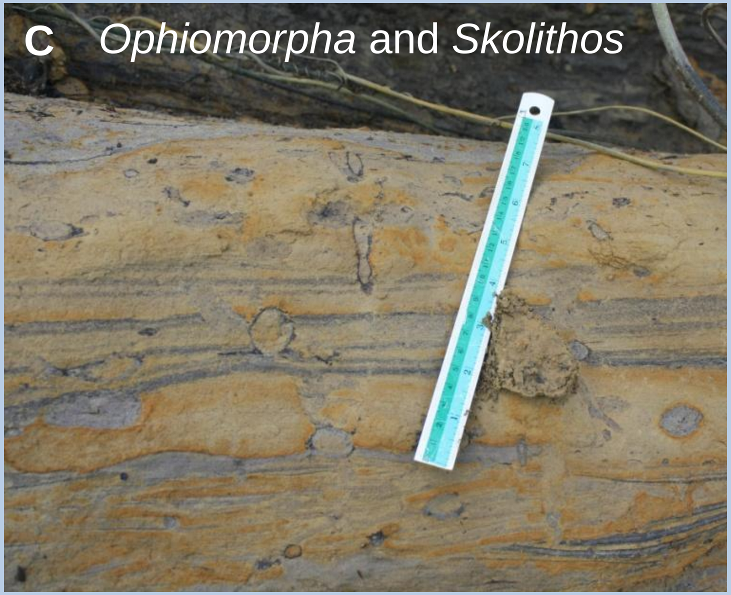


(after Ridha Riadi 2013)

Distributary Fill Sandstones



(after Ridha Riadi 2013)

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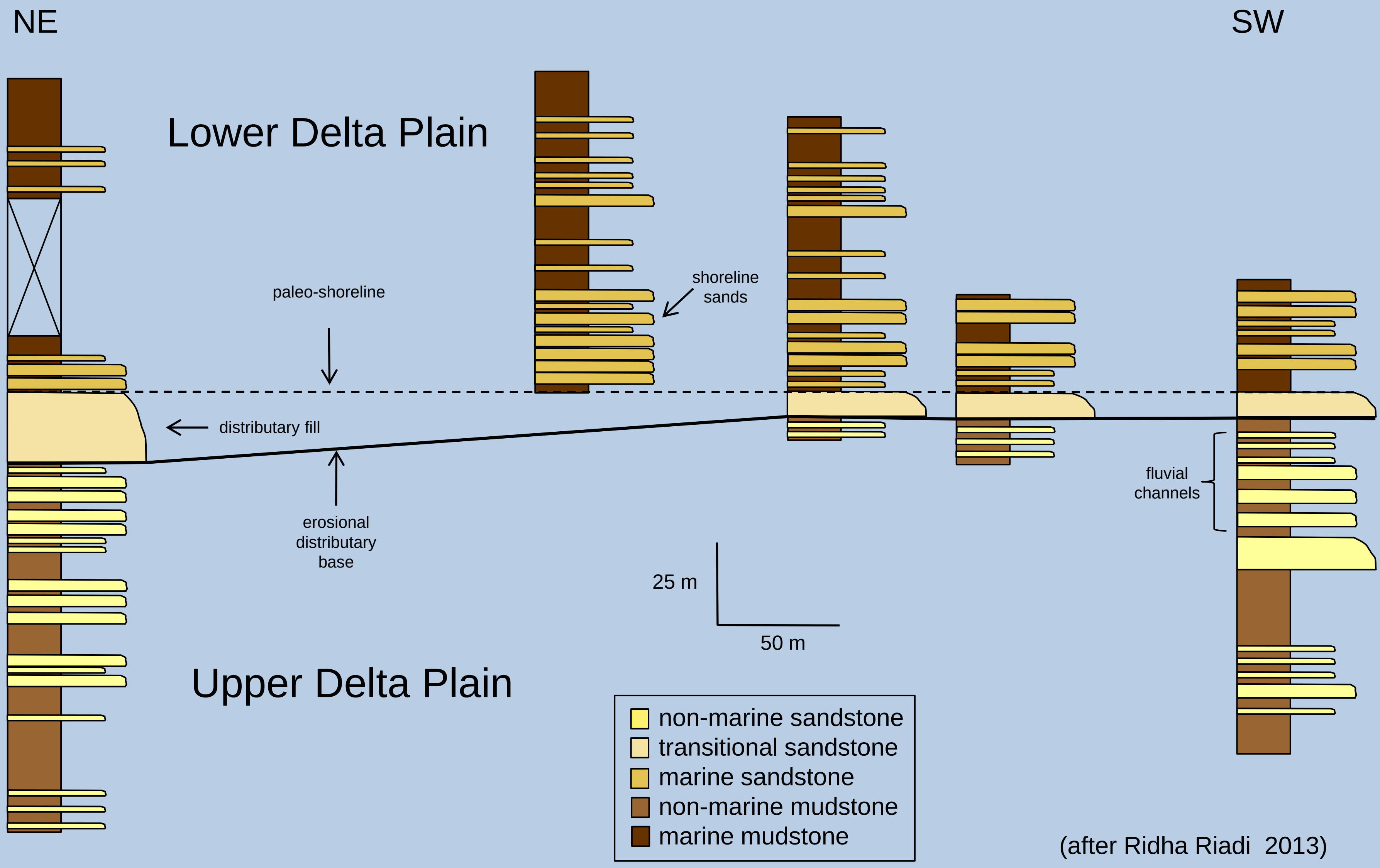
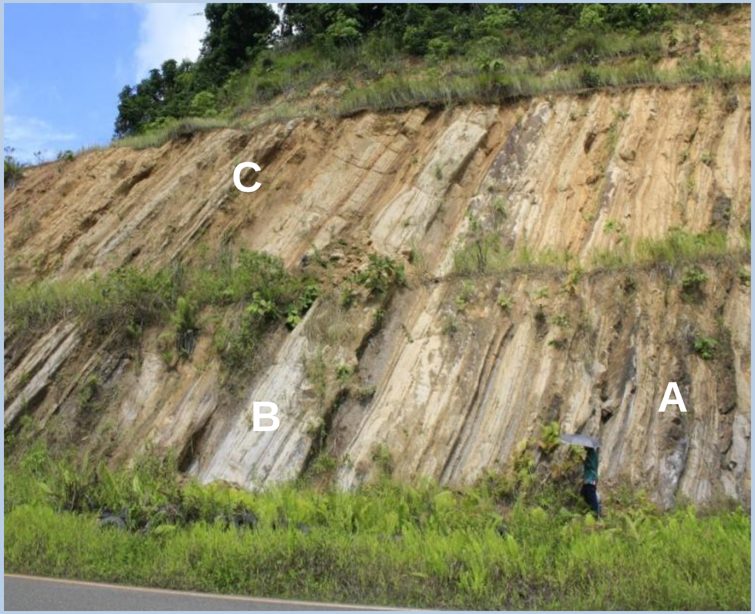
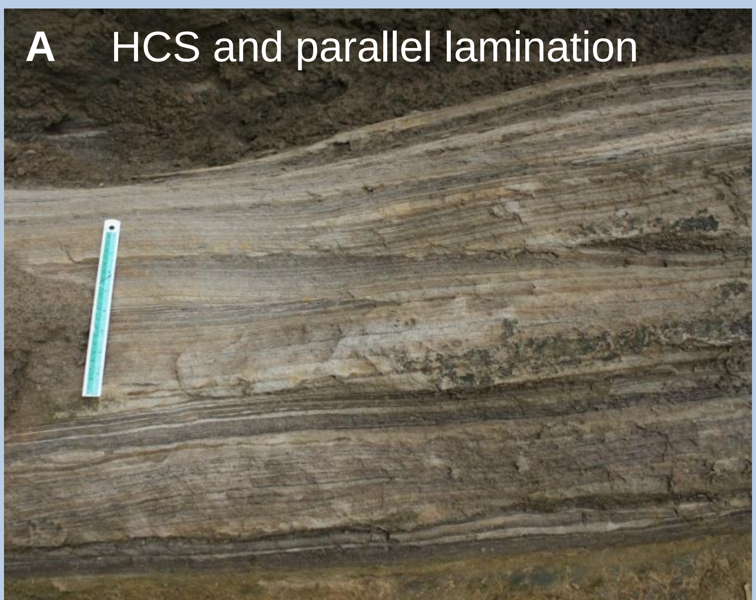


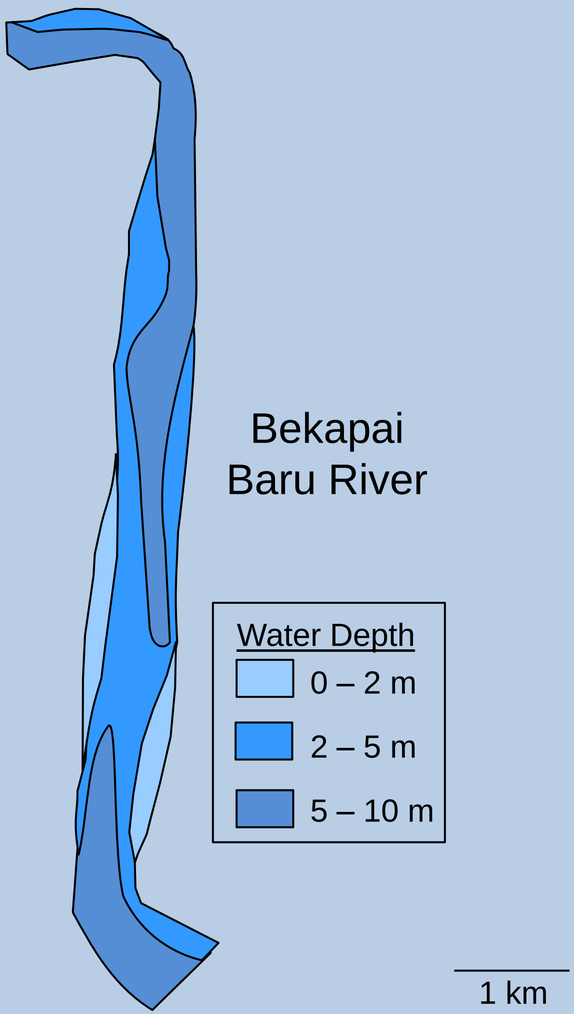
Shoreline Sands

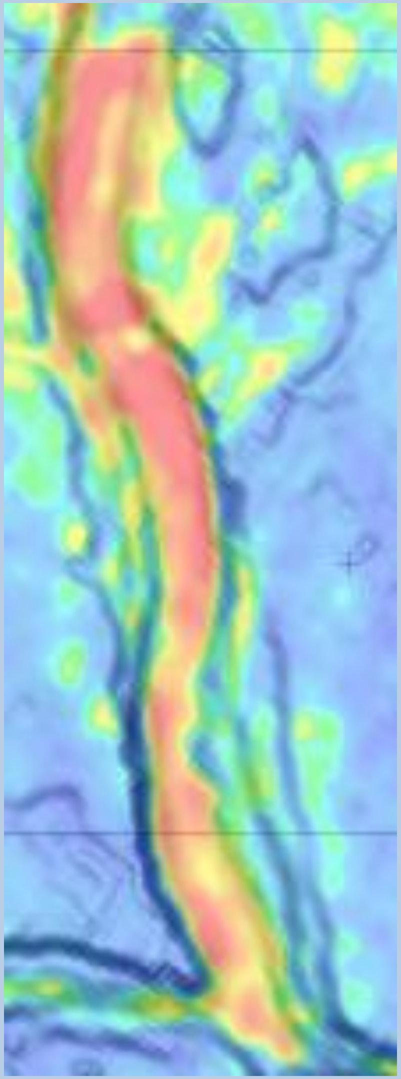




(after Ridha Riadi 2013)

Sand-Filled Distributaries

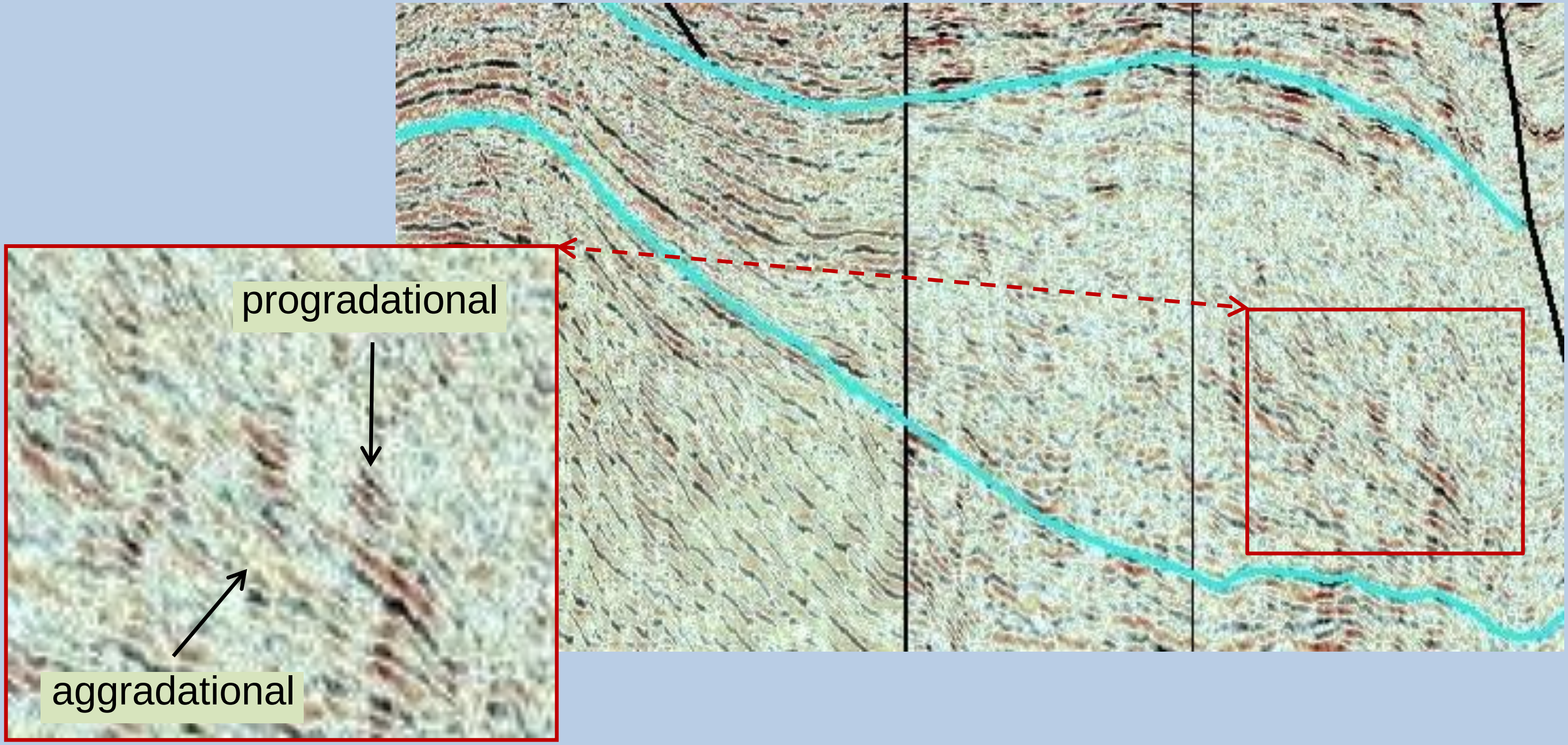




Seismic
Slice

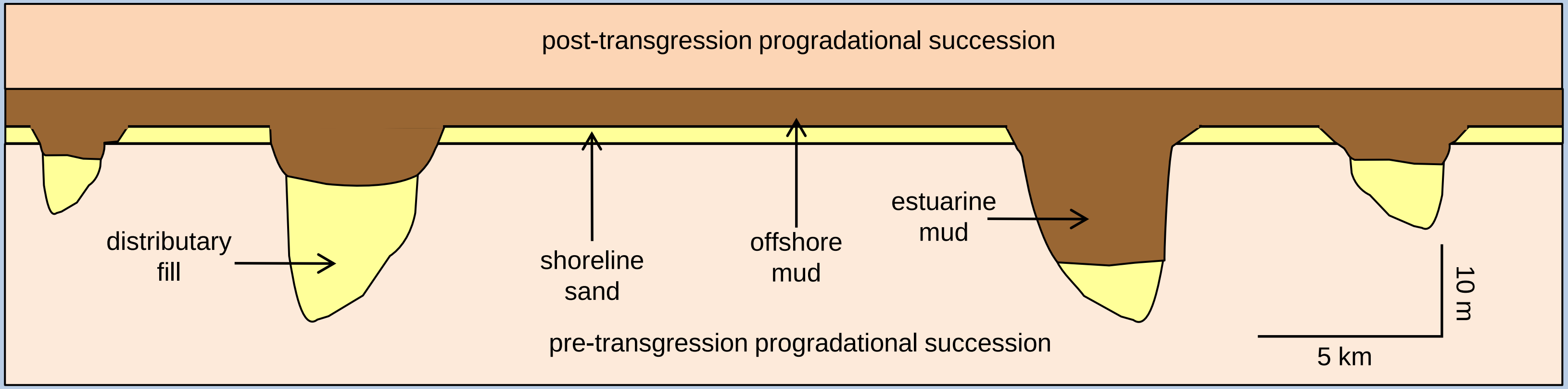
Subsurface Transgressive Successions

- Relatively thin, aggradational units
- Common within major progradational successions



Reservoir Implications

- Distributary-fill and shoreline sandstones have very good reservoir potential
- The thickness of distributary-fill sandstones is independent of channel width
- Distributary-fill sands can connect with pre-transgression sands
- Shoreline sands are laterally extensive and can connect with pre-transgression sands
- Sand body geometry is controlled by inherited topography
- Transgressive sandstones are typically 5 – 15 m thick and therefore below seismic resolution



Conclusions

- The modern Mahakam Delta is in a transgressive phase
- It is depositing distributary-fill and shoreline sands with very good reservoir potential
- Similar transgressive successions are common in outcrop and in the subsurface
- Sand body geometry is controlled by inherited topography
- The thickness of distributary-fill sandstones is independent of channel width

Acknowledgements

- Former students Nadia Nirsal and Ridha Riadi who completed the outcrop studies
- PTTEP, Chevron Thailand, Total E&P Borneo and Total Indonesia for financial support