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

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Abstract

The modern Mahakam Delta on the east coast of Borneo (Figure 1) 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.

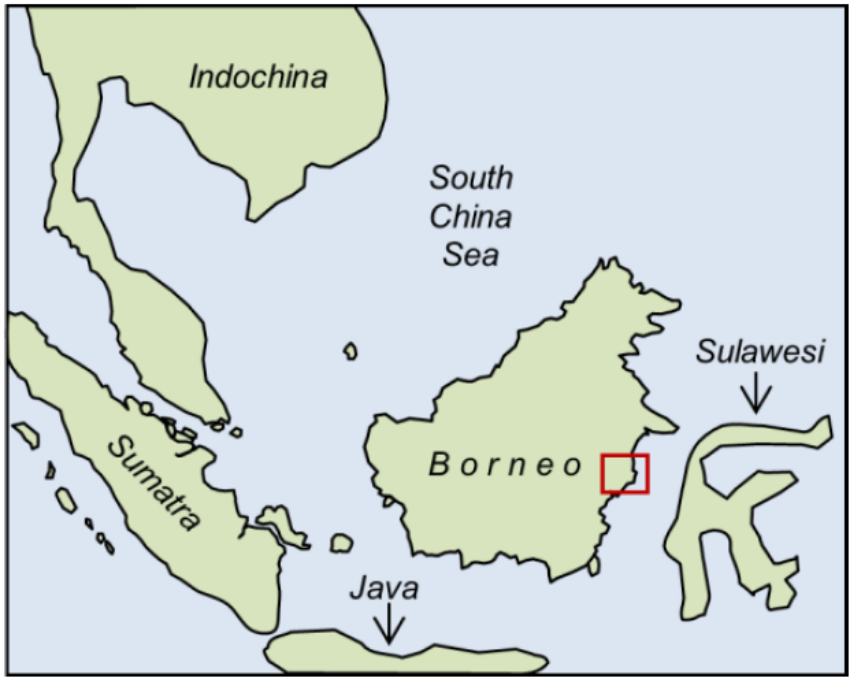

Figure 1. Location of the Mahakam Delta on the east coast of Borneo (red box).

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 (Figure 2).

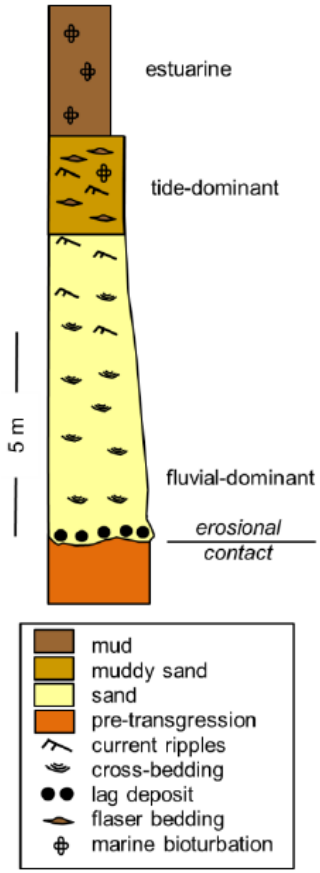

Figure 2. The distributary-fill succession that is presently being deposited on the Mahakam Delta.

Similar fining-upward distributary-fill successions that become more marine upward are relatively common in outcrops of the paleo-Mahakam Delta (Figure 3).

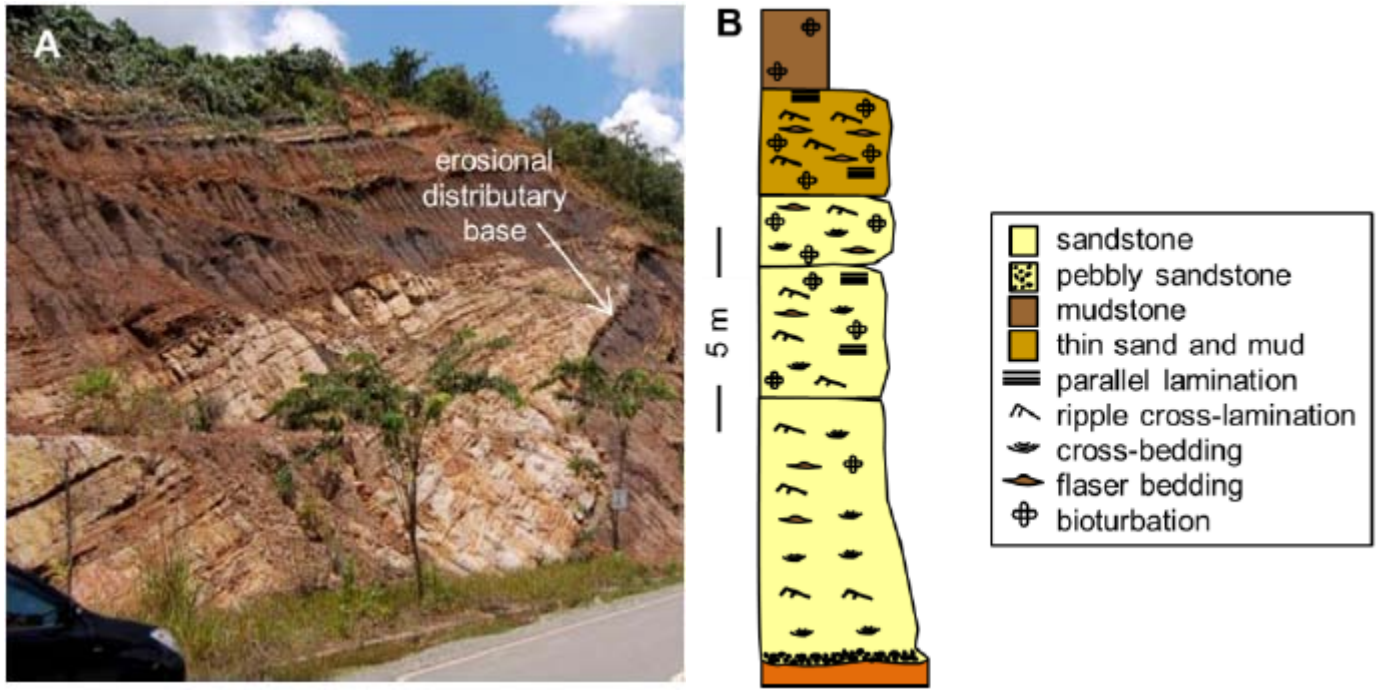

Figure 3. A) Outcrop photo and B) the stratigraphic column from a paleo-Mahakam Delta distributary-fill succession (after Nadia Nirsal, 2010).

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 (Figures 4, 5).

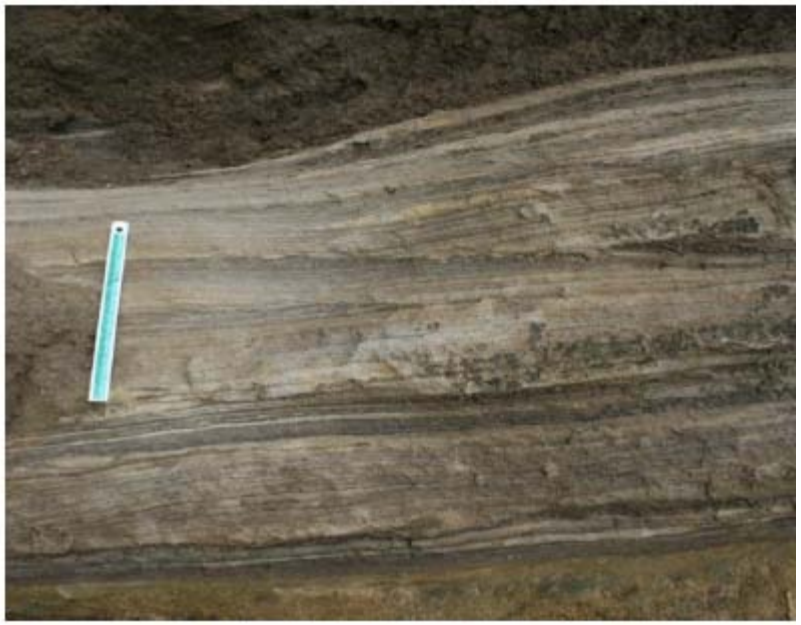

Figure 4. Wave-dominant shoreline sandstone in the paleo-Mahakam Delta succession. See Figure 5 for its stratigraphic context (after Riadi, 2013).

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 (Figure 6). 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.

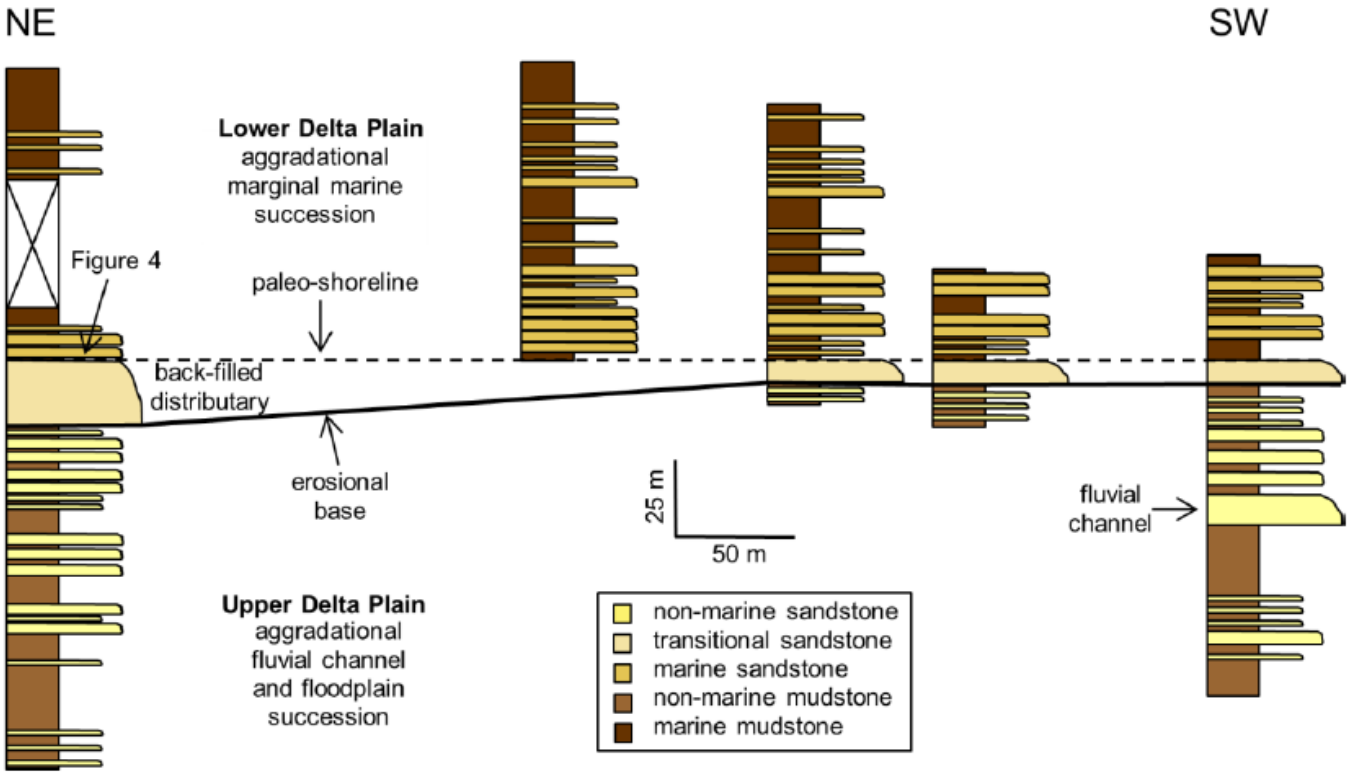

Figure 5. Stratigraphic context of the shoreline sandstone in Figure 4 within an outcropping transgressive paleo-Mahakam Delta succession (after Riadi, 2013).

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.

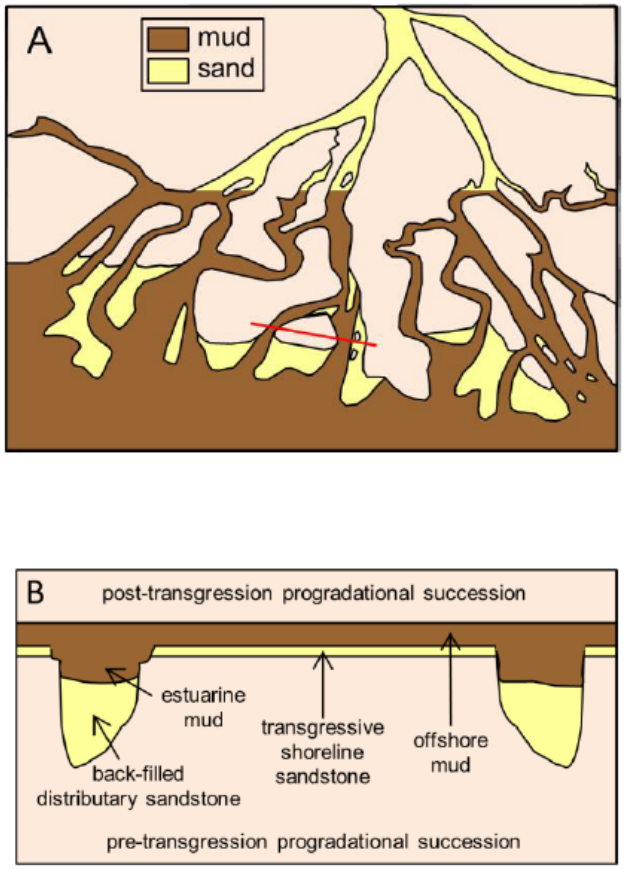

Figure 6. A) The distribution of distributaries and inter-distributary areas on part of the modern Mahakam Delta. The location of the cross-section in B is shown with a red line. B) A notional cross-section of the stratigraphic architecture of Mahakam Delta transgressive successions, assuming continuation of the ongoing transgression.

Acknowledgements

Joseph Lambiase thanks PTTEP and Chevron Thailand for research support. Salahuddin thanks Total E&P Borneo BV and Total E&P Indonésie for scholarship and field work sponsorship, respectively.

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