The Relic Fluvial-Dominated Morphology of Mahakam Delta

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Introduction

The Mahakam Delta lies at the mouth of the Mahakam River on the east coast of Kalimantan, about 50 km south of the equator. Geologically, the delta is located in the Kutai Basin, one of the major hydrocarbon provinces of Indonesia since the end of the 19th century.

Several sedimentological studies have been carried out on the modern Mahakam delta since the early 1970's. Pioneer works of Allen *et al.* (1976) indicated that the deltaic channel morphology is mainly the product of the interplay of fluvial and tidal processes, and is reflected well by the sedimentary facies distribution. Straight channels that are directly connected to the Mahakam River are typically identified as distributaries and are presumed to be dominated by fluvial processes. They are clearly different from the sinuous and flaring channels which are not directly connected to the distributaries and are presumed to be dominated by tidal processes (Allen *et al.*, 1976).

Attributed to those channel morphology, it has been speculated that different areas of the Mahakam Delta are in different phases of abandonment (Allen and Chambers, 1998). The northern area is assumed to be in the process of abandonment as it comprises primarily straight channels having flared mouths. The eastern area is presumed to be totally abandoned as it is occupied by sinuous and flared channels. The southern area is interpreted as more fluvially active as the channels are straight and several sand bars appear in the distal reaches of the channels.

Another assumption that has been generally agreed is that the delta is prograding (Allen *et al.*, 1976). The overall morphology of the Mahakam Delta is regarded as an example of a mixed fluvial-tidal delta in the classification of Galloway (1975).

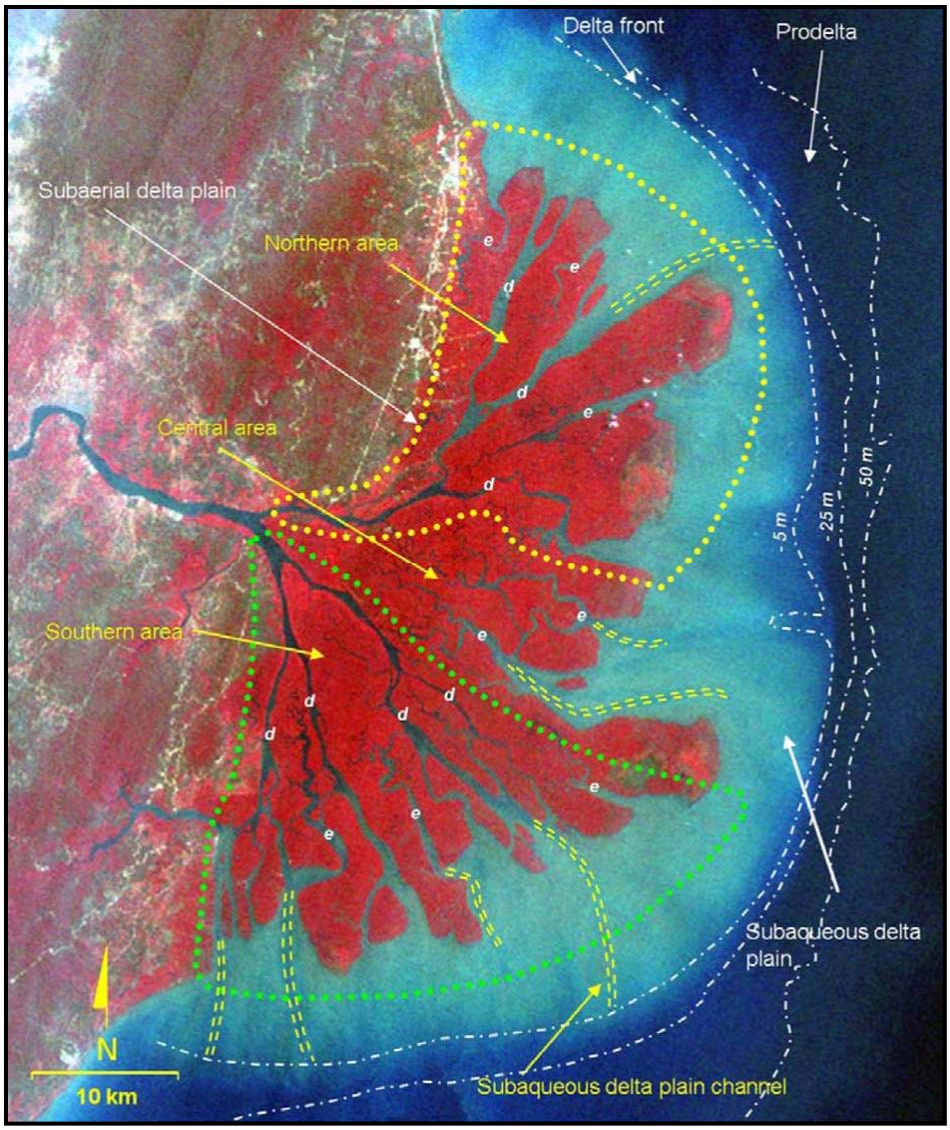


Figure 1. **Morphological components of the Mahakam Delta. The subaqueous delta plain ranges from the shoreline to 5 m water depth. The delta front comprises the area from 5 to 25 m water depth and the prodelta is from 25 to 50 m. Letters d stand for distributary and e for estuary.**

However, it was speculated recently that the present-day riverine sediment discharge is much smaller than in the past (Storms *et al.*, 2005).

The above mentioned assumptions were built on qualitative analysis of morphology and sediment facies distribution; but they have not been systematically mapped in detail. Recent studies on other deltas indicate that morphology, particularly coastline morphology does not reflect present-day depositional processes and that sediment facies distribution is not correlative to morphology (Dominguez *et al.*, 1992).

This short article attempts to present another sedimentologist's point of view on looking at the deltaic morphology, as supported by quantitative analysis of controlling

factors. Primary data on submerged morphology of the Mahakam Delta was detailed by 381 bathymetric echo-sounder (using a single frequency portable Raytheon DE719D MK2) survey lines that transversed all the channels as far as10 kilometers to the offshore, with an accuracy of about 0.5% of the indicated depth, collected during two years from 2003 to 2004.

Morphologic Elements

The delta plain of the Mahakam Delta comprises an area of about 2800 km², which is about 60% subaerial and 40% subaqueous. It has a lobate, fan-shaped morphology, and is dissected by numerous channels (Figure 1).

Two types of channels can be distinguished on the basis of their morphology, the first being relatively straight channels that have a distributive (i.e. seaward branching) pattern and are commonly considered as distributaries; the other has sinuous and flaring channels that form a contributive (i.e. seaward converging) pattern and commonly are considered as estuaries.

The distributaries branch from the Mahakam River at the delta apex. The width of the distributary channels is relatively constant and ranges between 0.5 and 1 km, while the depth varies between 5 and 20 m. Generally, distributaries are relatively straight with low sinuosity; some have distinctly flaring mouths. The transverse profile of the channels is asymmetric and the thalweg meanders occasionally between banks, creating poorly defined lateral bars. At the lower reaches and the mouths of the distributaries, the channels are shallower and elongate bars are present.

The estuaries are not connected to the Mahakam River. They are widely flaring trumpet-shaped inlets that decrease in width rapidly upstream and connect to the distributaries through narrow and sinuous tidal channels at their upstream end. Estuaries are very sinuous in their upper reaches with symmetrical cross-sections. In their lower reaches, they become less sinuous and more asymmetric in cross-section with flaring mouths. The depths of the estuaries are not much different from the distributaries, but they are narrower.

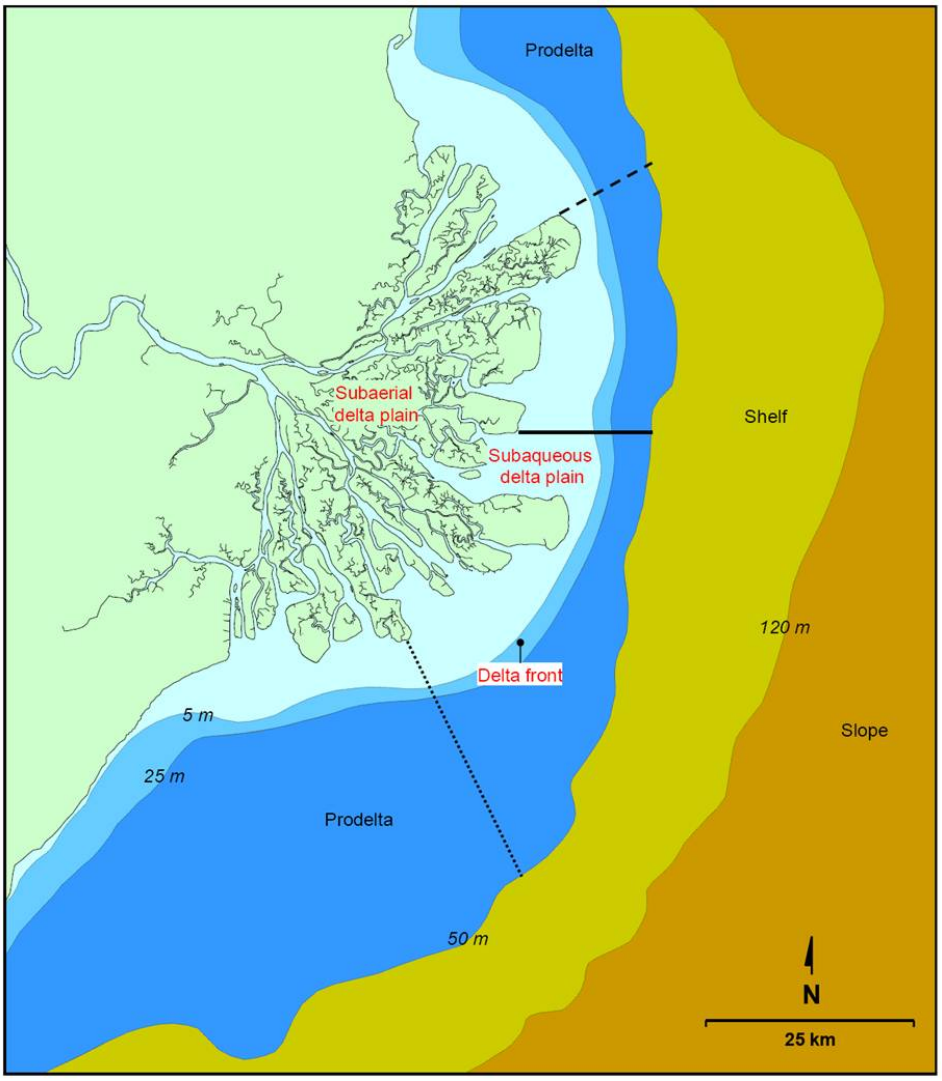


Figure 2. Symmetrical lobate geometry of the Mahakam Delta with a southward asymmetric bulge of the prodelta. The outer limit of the subaqueous delta plain forms a lobate deltaic geometry, suggesting that the location of the former coastline is now at 5 m water depth (Scruton, 1960; Coleman and Roberts, 1991). The coloured lines extending seaward from the coastline locate the bathymetric profiles in Figure 3.

Distribution of these channels on the subaerial delta plain is uneven (Figure 1). The southern area has more distributaries than estuaries, the central area has no distributaries and is only occupied by estuaries, while in the northern area both types of channel are equal in number. Morphologically, distributaries in the northern area are more flared and shallower than the southern area, as indicated by higher width/depth ratios. In contrast to the distributaries, the width/depth ratios of the estuaries do not vary significantly and are quite constant in the northern, central and southern areas. This evidence of channel distribution and morphology suggests that the three areas of the subaerial delta plain are different and can be distinguished.

Offshore, the three areas have similar features, i.e. extensive intertidal flats, numerous isolated bars and several submarine channels as extensions of distributaries and estuaries. The geometries of intertidal flats and isolated bars vary between areas. They are commonly perpendicular to the shoreline in the northern and central areas. In the southern area, their geometry is slightly more triangular. The submarine channels vary according to the type of extended channels rather than the area. The extensions from distributaries gradually

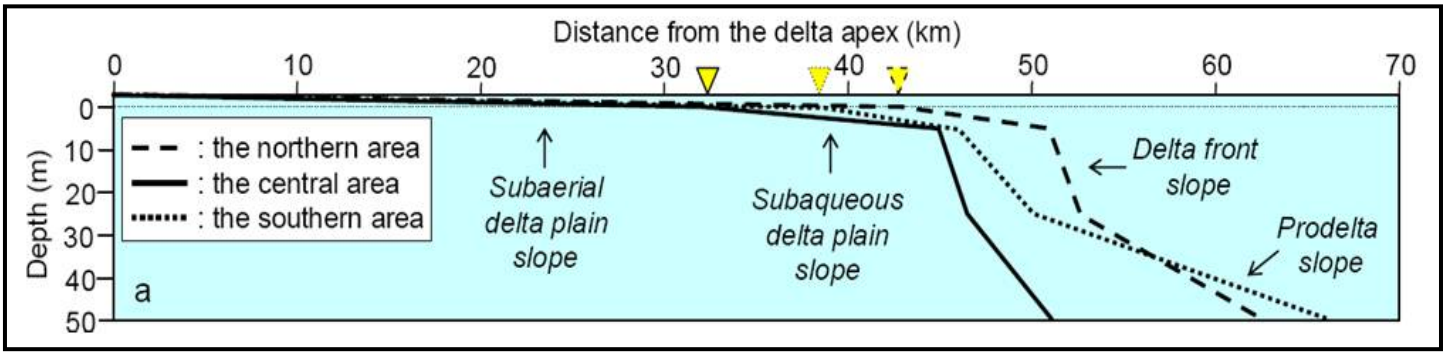


Figure 3. **Bathymetric profiles from the delta apex to the prodelta; yellow triangles are shorelines with outline style keyed to area (see the legend box). Profile locations are shown in Figure 2.**

shallow towards the slope break, while the extensions from estuaries rapidly shallow and die out before they reach the slope break.

The subaerial delta plain extends seaward about 42 km from the delta apex in the northern area, 30 km in the central area and 39 km in the southern area. It forms a nearly-flat swampy surface and has an extremely gentle slope of about 0.06 m/km. The proximal part of the subaerial delta plain is characterised by tropical lowland rain forest and a mixed hardwood and palm forest. These extend from the delta apex to the middle reaches of the distributaries, a distance of about 20–30 km in the north and south areas and about 10 km in the central area. The distal delta plain, which extends for about 20 km onshore from the shoreline, is characterised by Nipah palm (*Nypa fruticans*) and mangrove swamps.

The gentle delta plain slope persists offshore across the subaqueous delta plain, which is about 7 km wide, to a water depth of 5 m where the slope abruptly increases on the delta front (Figure 2). There are several subtidal channels on the subaqueous delta plain that are extensions of distributaries; some of them extend as far offshore as the delta front (Figure 1). A thin prodelta sheet extends seaward from the base of the delta front (Roberts and Sydow, 2003). It is 20 km wide on the southern shelf, 15 km wide on the northern shelf, and is confined to a narrow 3 km belt along the central part.

Morphologic Responses to Hydrodynamics

Delta morphology, especially shoreline morphology, has long been accepted as an indicator of dominant hydrodynamic process (e.g. Galloway, 1975), but recent studies suggest that, in some deltas (e.g. the Sao Fransisco Delta; Dominguez, *et al.*, 1992), a significant component of the modern morphology is inherited from a pre-modern system so that present-day morphology is not necessarily a reliable indicator of hydrodynamic dominance.

The Mahakam Delta has a lobate geometry, which generally characterises fluvial-dominated deltas prograding into shallow water (Fisher *et al.*, 1969), although it has been described as a mixed fluvial and tidal morphology by several authors (e.g. Galloway, 1975; Allen *et al.*, 1976). The multiple distributaries that built the lobate morphology generally indicate a high fluvial discharge distributing the sediment load with a short recurrence interval of bifurcation and avulsion (Olariu and Bhattacharya, 2006). However, sediment transport data indicate that the present-day Mahakam Delta is tide-dominant and less fluvially-influenced than previously interpreted (Husein, 2008).

The volume of the Mahakam Delta is estimated to be 135 km^3, which is calculated based on the area of the subaerial delta plain (~ 1700 km^2) plus the subaqueous delta plain (~ 1100 km^2) multiplied by the average delta thickness (50 m for the subaerial delta plain and 45 m for the subaqueous delta plain (after Roberts and Sydow, 2003). If the Mahakam Delta is assumed to have developed in the past 5000 years (Allen *et al.*, 1976), then the average fluvial sediment discharge has been 2.7x10^7 m^3/year. However, the present-day fluvial sediment discharge of the Mahakam River is estimated to be 634,685 m^3/year (Husein, 2008) or 2.4 % of the discharge necessary to build the delta. This indicates that the present-day fluvial system delivers much less sediment than the pre-modern river, suggesting that there have been significant changes in the hydrodynamic environment. Although the Kutai Lakes system has been present throughout the Holocene, their influence on the downstream Mahakam River may have varied with time. At present, on-going subsidence in the Kutai Lakes region apparently traps most of the fluvial sediment and prevents its delivery to the Mahakam Delta.

The sediment transport patterns indicate that the southern area is more fluvially influenced than the northern area (Husein, 2008). However, the overall morphology of the two areas is virtually identical; the southern area has more outlets than the northern area, but both subaerial and subaqueous delta plains extend approximately the same distance from the delta apex. The only difference is that the delta front and prodelta slope more gently, and the prodelta extends farther seaward, in the southern area than in the northern area (Figures 2 & 3). This suggests that the present-day fluvial system has little influence on the delta plain morphology.

The wide southern prodelta is the result of greater suspended sediment discharge in the southern area relative to the northern area, as its distributaries have higher suspended

sediment concentrations (Husein, 2008). A small amount of suspended sediment drifts to the adjacent offshore water and is assumed to be influenced by the southward net current flow of the Makassar Strait (Eisma *et al.*, 1989) and carried hundreds of kilometres southeast of the delta.

The subaqueous morphology suggests that approximately 5 m of subsidence has shifted the shoreline landward from its former position near the offshore break in slope at the delta front and submerged part of the lower delta plain and the distal reaches of the distributaries, some of which remain as topographic features on the seafloor (Figure 1). The broad subaqueous delta plain causes waves to break, thereby reducing wave influence on the broad shallow platform.

The modern depositional processes and recent history of the Mahakam Delta indicate that its fluvial-dominated morphology is not a product of present-day processes, but reflects a phase of fluvially-dominant progradation that occurred prior to the present-day subsidence and transgression. The discrepancy between sedimentary facies and morphology developed because facies respond to changing hydrodynamic conditions much more rapidly than morphology, simply as a function of the much larger volume of sediment t hat must be transported to modify morphology (Husein, 2008). Essentially, the funnel-shaped estuaries and flared distributary mouths are ongoing tidal modifications to pre-existing distributary morphology.

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