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Channel Pattern and Deltaic-Estuarine Process in the Indo-Pacific Region

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Abstract

This paper explores the concept that deltaic-estuarine geomorphology is a function of the dominant processes. It has been traditional to recognize river, wave and tidal processes as the principal controls on the gross morphology of deltas. To a lesser extent, these processes are also recognized as significant controls on the shape of estuaries. The complex deltas of the Southeast Asian region contain active deltaic plains and often extensive abandoned deltaic plains which preserve an imprint of the processes which have shaped them. In northern Australia, where estuaries are more extensive than deltas, similar geomorphological features can be recognized and the relative significance of river, wave and tide processes assessed as these systems evolve. Channel pattern provides insights into the dominant process and the response of these systems to changes in boundary conditions as the system evolves. A better understanding of the natural morphodynamic adjustments of these systems to changing boundary conditions will provide some indication of the probable direction and magnitude of future adjustments on these systems, but discriminating natural change from human-induced changes will be a greater challenge.

Keywords

Channel, Pattern, Deltaic, Estuarine, Process, Indo, Pacific, Region, GeoQUEST

Disciplines

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Channel Pattern and Deltaic-Estuarine Process in the Indo-Pacific Region

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Abstract: This paper explores the concept that deltaic-estuarine geomorphology is a function of the dominant processes. It has been traditional to recognize river, wave and tidal processes as the principal controls on the gross morphology of deltas. To a lesser extent, these processes are also recognized as significant controls on the shape of estuaries. The complex deltas of the Southeast Asian region contain active deltaic plains and often extensive abandoned deltaic plains which preserve an imprint of the processes which have shaped them. In northern Australia, where estuaries are more extensive than deltas, similar geomorphological features can be recognized and the relative significance of river, wave and tide processes assessed as these systems evolve. Channel pattern provides insights into the dominant process and the response of these systems to changes in boundary conditions as the system evolves. A better understanding of the natural morphodynamic adjustments of these systems to changing boundary conditions will provide some indication of the probable direction and magnitude of future adjustments on these systems, but discriminating natural change from human-induced changes will be a greater challenge.

Introduction

The objective of this paper is to examine the extent to which channel pattern within Asian deltas might provide an important link between the longer-term geological processes of delta evolution, and the actively changing and dynamic deltaic environments associated with the numerous channels and delta distributaries. It is suggested that a greater insight into the dynamics of channels may form the basis for assessment of vulnerability and susceptibility of delta environments to change.

Earlier geomorphological studies of these deltas have mapped the deltas into an active delta plain and an abandoned delta plain (Wright et al., 1974). The active delta plain tends to contain channels that are river-dominated, whereas the abandoned delta plain is characterized by extensive systems that are tide-dominated. The Indus Delta, for example, has an active delta that is presumably actively prograding, and which has a channel that varies little in width with distance along it but with characteristic angular meanders. The coastline of the abandoned delta, by contrast, is covered with extensive mangrove forests and dissected by numerous channels that are tide-dominated, which are dendritic and highly tapering, narrowing rapidly upstream.

In order to demonstrate that channel pattern is related to process and provides a key to the dynamics of changing systems, several examples from the deltaic-estuarine systems of northern Australia are examined. The implications for Asian deltas are then considered.

Australian deltaic-estuarine systems

The north coast of Australia lies in a tropical monsoon region. There are extensive low-lying Holocene plains along the coastline, generally fringed by littoral mangroves (Chappell and Thom, 1986). Biogeographically these are similar to the deltaic systems of the southeast Asian region. The shallow water biota and the mangrove vegetation are a part of the Indo-Pacific region, whereas the characteristic ecosystems that occupy the plains away from the coast show a climatic gradient. These vary from saline mudflats in the arid to semiarid regions, such as Western Australia, to sedge and grasslands in the wet-dry tropics, such as the Australian Top End and parts of the Asian mainland, and culminate in forested peat swamp in perhumid areas such as Wallacea.

Based upon extensive coring, stratigraphy and radiocarbon dating, the plains flanking the macrotidal estuarine systems of the Alligator Rivers Region are particularly well known (Woodroffe et al., 1993). Here several seasonally flooded rivers drain into van Diemen Gulf. There is a tidal range of around 6 m at the coast and tidal influence extends up to 100 km upstream. The channels of these rivers can be divided into several segments based on channel morphology. To seaward there is a rapidly tapering estuarine funnel fringed with mangroves, and the bare saline mudflats behind contain chenier ridges which mark former shorelines. The channel then becomes increasingly sinuous with distinct meanders that support mangroves on their inner bends. Several of the rivers show a segment in which meanders are cusped, and the channel contains sandy mid-channel bars and point bars. The plains contain paleochannels that are the former, generally sinuous, channel that has been cut-off. Upstream, the channel is flanked by levees and the plains behind those levees contain seasonally-flooded freshwater wetlands.

The coring, stratigraphy and dating results, undertaken in the greatest detail on the South Alligator River, but with supporting evidence from other adjacent river systems, indicate a three-stage model of estuarine evolution (Woodroffe et al., 1993). The first stage, commencing around 8 000 years ago, was a transgressive stage during which the valleys were flooded as sea level continued to rise. The second stage during the mid-Holocene, termed a big swamp phase, was characterized by widespread mangrove forests occupying much of what is now estuarine plain. This phase peaked around 6 000 years ago, when sea level stabilized at or close to its present level. This stage was replaced by the final stage during which the estuary became channelized as vertical sedimentation continued to infill the estuary and mangroves were replaced by sedge/grassland. This pattern of development, with a change from transgression to regression has been identified throughout much of the southeast Asian region, although many of the larger deltaic systems have filled in more rapidly and their shoreline may have prograded more extensively.

Estuarine channel dynamics

There have been considerable changes in channel pattern over the past six millennia in northern Australia as evident from the occurrence of paleochannels on the estuarine plains. In many cases these preserve channel forms which give clues to their behaviour.

For example, broad meandering channels near the coast; often tapering rapidly upstream, show that the position of the estuarine funnel has differed over time. In the case of one system, the Mary River, there is presently no active estuarine channel of the size of these paleochannels, and most of the monsoonal river flow of the Mary River evaporates from the Holocene plains surface. Over the past few decades two minor tidal creeks have cut back into the former estuarine plains. The history of expansion of these two dendritic systems (Knighton et al., 1991) provides a series of insights into regularities of tidal channel form which may elucidate how tide-dominated systems in Asian deltas may be expected to adjust.

The plains onto which the Mary River discharges are near horizontal and much of their surface lies below the height which high tide reaches at the coast. The two creeks have expanded exponentially; their history of expansion is recorded by the increase in magnitude of the creek system (Fig.1). As the tide has extended further inland, the width of the creek has increased in a regular manner to accommodate the additional tidal prism (Fig. 2). The tidal amplitude has increased as the creeks have widened (Fig. 3). In many cases these creeks have pre-

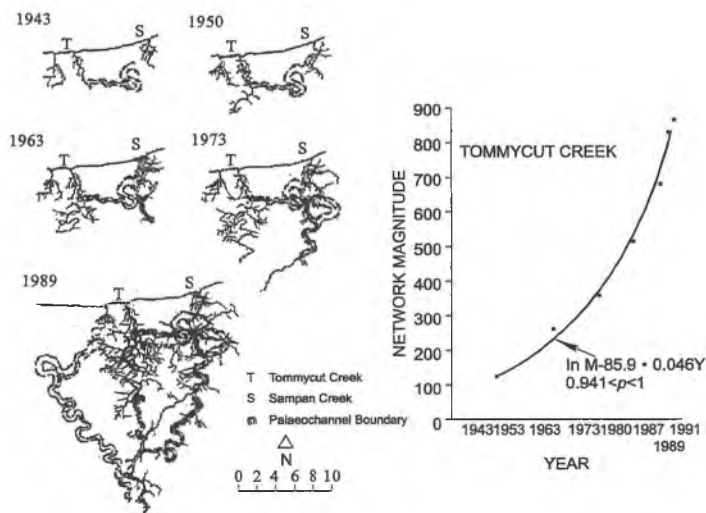


Fig.1 Expanding tidal creek network across the Mary River plains since 1943 and the increase in the magnitude of the Tommycut Creek system (marked T), based on Knighton et al., (1991)

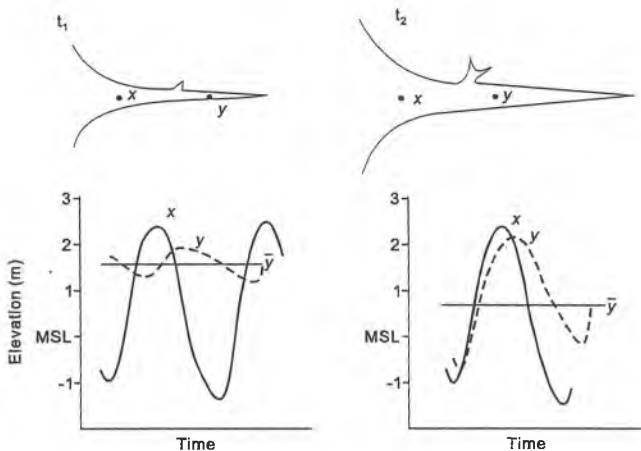


Fig. 2 Schematic representation of an expanding tidal creek system, showing the increase in width (and tidal prism), and tidal amplitude as the systems expands from t_1 to t_2 .

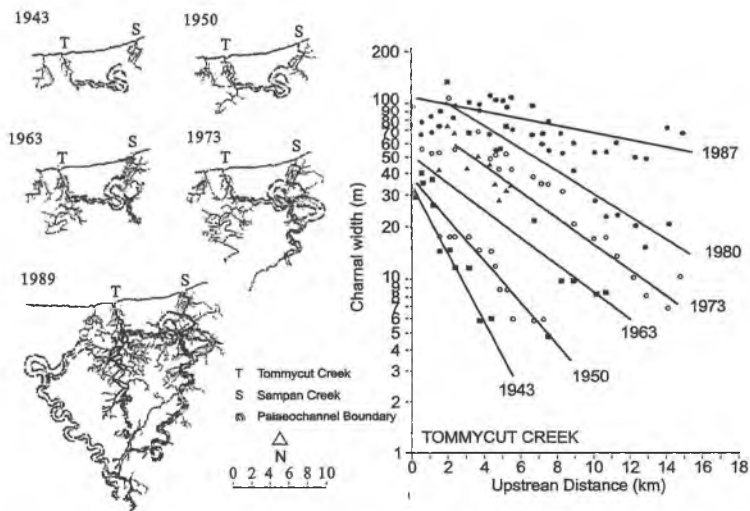


Fig. 3 Changes in tidal creek width over time as the Tommycut Creek system has expanded into the Mary River plains, based on Mulrennan and Woodroffe (1998)

stream, and their connection to the main channels at the upstream end is narrow and often un-navigable for much of the tidal cycle (Fig. 5). Aerial photographs show, however, that the mangrove forests which flank these tide-dominated channels, mark out a more uniform width (Jones et al. , 2003).

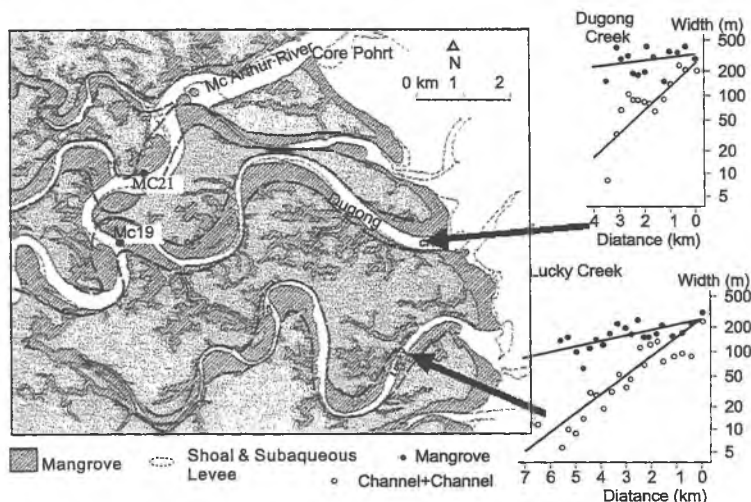


Fig. 5 The McArthur River delta showing rapidly tapering, tide-dominated distributaries, in contrast to the river-dominated channels, such as the McArthur River mouth itself, based on Jones et al. (2003)

The courses of several formerly active, river-dominated distributaries can be reconstructed and are marked by the mangrove forests. Coring has confirmed that there is a channel fill of sandy sediments which fills the former distributary paleochannel, and the base of the channel can be detected where shelly delta front sediments are encountered. The channel pattern apparent within the McArthur Delta indicates that in this relatively less tidal setting, former river-dominated distributaries have been infilled and now adopt a tide-dominated morphology.

Implications for Asian deltas

Asian deltas show many of the same geomorphological and ecological characteristics that are shown in northern Australian deltaic-estuarine systems. However, the deltas are often larger, supplied by rivers which bring down larger volumes of sediment. A similar history of sea-level change means that their history of evolution has occurred over a similar period of time.

The broad division of delta plains into active and abandoned components is also often a division that differentiates channel pattern as well. The active part of the delta is characteristi-

cally river-dominated and the channel frequently varies little in width and meanders within a relatively narrow track. Former distributaries are abandoned and carry less, if any water. The coastline of the abandoned delta plain may be either wave or tide dominated. In some cases there are regions which show domination by particular factors. For example, the upper delta plain of the Red River delta is prominently river-dominated, whereas the southwestern section is wave-dominated with numerous shore-parallel sandy ridges, and the eastern section is tide-dominated with tapering channels (Mathers and Zalasiewicz, 1999). Even in the case of the Mahakam Delta, where there is only a small tidal range and where a lobate delta has built out from the coast, it is still possible to distinguish channels on the basis of morphology. The more active, and river-dominated channels carry most of the flow and vary little in width, in contrast to the formerly active distributaries which are now tide-dominated, muddy and prominently tapering (Fig.6).

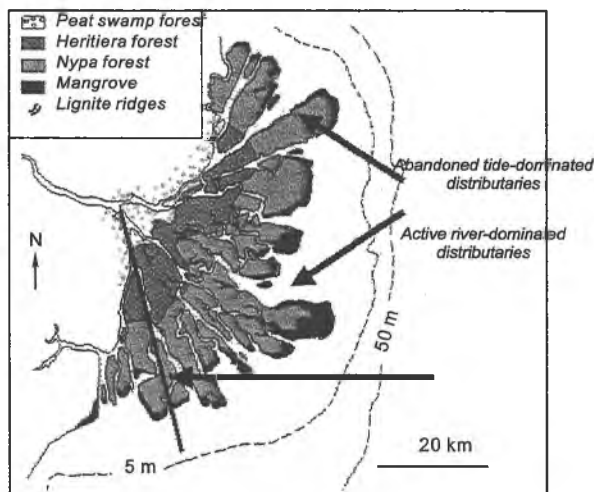
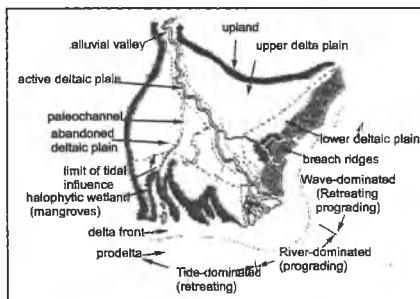


Fig. 6 The Mahakam Delta showing the active, river-dominated distributaries to the south and the abandoned tide-dominated distributaries to the east

The Ganges-Brahmaputra Delta complex contains a very prominent tide-dominated section across the Sundarbans, where it is clear that several former channels, such as the Gorai, were once active. The Sundarbans are characterized by distinctive tapering and meandering channels.

It is suggested that it might be possible to recognise regularities in channel pattern which provide insights to process and the pathway of evolution of Asian deltas (Fig. 7). This contrasts with the generally better-studied Mississippi Delta, where after abandonment of an active distributary there is a cycle of development of the shoreline under wave-domination. Wave domination results in sand being reworked, leading to development of barrier islands, transforming as a result of relative submergence into shelf sands. In the Indo-Pacific region, abandoned dis-

tributaries are likely to become tide-dominated and adopt a tapering morphology. A pattern of evolution is often instigated, with expansion and elaboration of tidal channels which are rapidly tapering and often tightly meandering. In the larger deltas, relative submergence of the abandoned delta is likely to accelerate retreat of the coast, and the inland penetration of tidal influence (Woodroffe, 2003). Further attention to the dynamics of these channels may reveal regularities that enable a greater degree of prediction, and which can be translated into an assessment of the relative vulnerability of different parts of the abandoned delta.



- Distributary abandonment
- Tide domination
- Channels taper
- Relative submergence
- Creek expansion
- Increased tidal inundation

Fig. 7 Schematic Asian delta (after Woodroffe, 2003) and suggested changes during tide domination after abandonment of distributary

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