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The tidal character of fluvial sediments of the modern Mahakam River delta, Kalimantan, Indonesia

R.A. GASTALDO*, G.P. ALLEN† *and* A.-Y HUC‡

**Department of Geology, Auburn University, AL 36849-5305, USA;*
†TOTAL, Centre Scientifique et Technique, Domaine de Beauplan, Route de Versailles, 78470 Saint-Rémy-les-Chevreuse, France; and
‡Institut Français du Pétrole, 1 & 4, av. de Bois-Préau, 92506 Rueil-Malmaison, France

ABSTRACT

The Mahakam River delta, Kalimantan, Indonesia, is a low wave-energy, mixed tide- and fluvially-controlled delta complex, situated at the eastern edge of the island of Borneo. The medium- to fine-grained terrestrial sediment originates from within a 75 000 km^2 drainage area. It is transported through the equatorial basin and debouches into the Makassar Strait. The Mahakam has two active distributary systems, directed north-east and south-east respectively, with an intervening interdistributary area consisting of a series of tidal channels and former fluvial distributary channels which today are no longer connected to the fluvial regime. A non-random sampling strategy was employed during a vibracoring programme conducted in 1988. The vibracores were collected along two transects: (i) cores from the first transect represent depositional environments within the tide-affected fluvial distributaries; and (ii) cores along the second transect were sampled from sites within the tidal interdistributary area. Sample sites of the distributary channel transect included lateral channel bars, distributary-mouth bars, and delta-front settings.

All the sediments recovered from subaqueous sample sites show varying degrees of tidal influence. Mud drapes and couplets of medium–very fine sands and mud are the most commonly encountered sedimentary successions in the active fluvial distributaries, being also characteristic of all tide-dominated distributary channels. Sand/mud ratios are variable, ranging from 90:10 to 30:70. The thickness of clay drapes is also variable. Sedimentary structures include wavy and lenticular bedding composed of asymmetrical ripples and trough cross-stratification. Ripples may be multi-directional within any one core, being inclined upstream, downstream or horizontally disposed. Sand and mud are mixed by bioturbation in the lower delta plain and delta front. Primary sedimentary structures in conjunction with the degree of bioturbation and the presence of phytoclast drapes appear to be useful criteria for the identification of ancient tide-influenced deltaic distributary channels.

INTRODUCTION

The sedimentological features of deltaic regimes have attracted much attention during the past three decades (e.g. Niger delta: Doust & Omatsola, 1990; Colorado River delta: Kames, 1970). It is a well-established fact that coastal delta morphologies are dependent upon the interplay between fluvial and marine processes. However, most data concerning the features of deltas are derived from studies detailing the end-member systems of a tripartite classification: fluvially-dominated, tide-dominated, or wave-dominated deltas (see e.g. Elliott, 1978a; Galloway & Hobday, 1983). Fewer studies have focussed on coastal regimes where this interplay is dominated by a combination of fluvial and marine processes (e.g. Allen *et al.*, 1979).

It is generally agreed that fluvially-dominated distributary channels are characterized by unidirectional flow with periodic stage fluctuations resulting from annual climatic oscillations. Bedload transport is inhibited only during episodic and/or anomalous events such as when waves are associated with strong onshore winds or river discharge is exceptionally low or high. As a result of this, sediments transported in suspension can be deposited within the distributary channels (Wright & Coleman, 1973). It is also believed that when marine influences dominate over fluvial processes, the sediments most affected are those debouched at the river mouth. In areas of moderate to high tidal range, where tidal processes are more effective, sediment transport may be significantly influenced in the lower parts of river courses (Elliott, 1978b). Tidal currents entering the distributaries during spring tides inundate the interdistributary areas. The tidal waters are temporarily stored at high-water slacks, to be released at the onset of the following ebb stage. This situation results in the sedimentation of suspended sediments, thus reflecting the tidal influence.

Vibracores collected within fluvially-dominated distributary channels of the Mahakam River delta, eastern Kalimantan, Indonesia, reveal that the overprinting of tidal features within this low wave-energy, mixed tide- and fluvially-controlled delta complex is not restricted to the mouth of distributaries. The purpose of this contribution is to describe in detail the tidal features and sedimentological variability within these distributary channels.

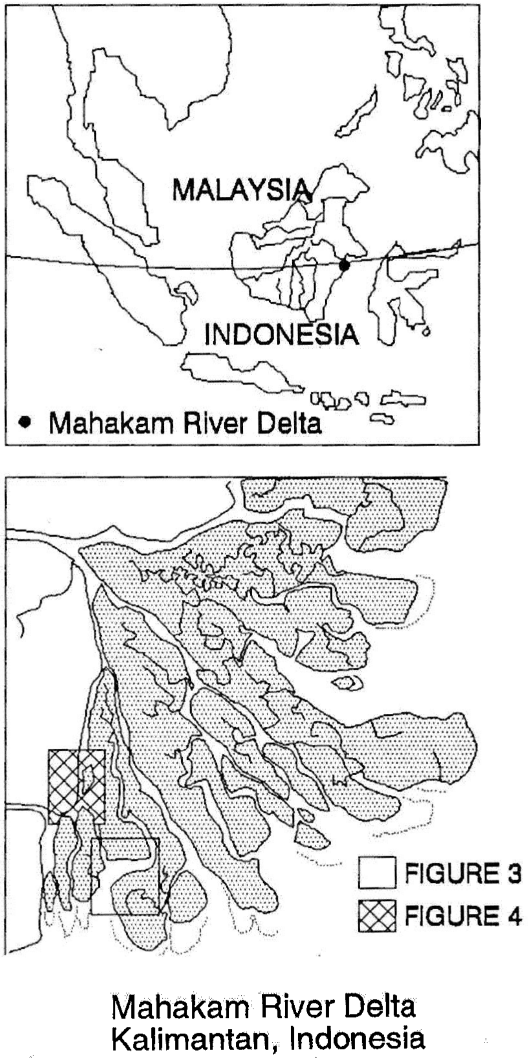

Fig. 1. Generalized locality map delineating the position of the Mahakam River delta on the eastern side of Borneo. Enlargement of the delta showing major channels and areas (Figs 3 & 4).

GEOGRAPHICAL SETTING OF THE MAHAKAM RIVER DELTA

The Mahakam River delta is located at the eastern edge of the island of Borneo (Fig. 1). Headwaters originate in the central highlands of Kalimantan and debouch into the Makassar Strait at the edge of the Kutei Basin (between 0°21′ and 1°10′ South Latitude and 117°40′ East Longitude). Deltaic sedimentation began in the Middle Miocene (LaLouel, 1979) and since then, several major deltaic complexes have accumulated. Each delta complex is separated by marine transgressions (Magnier *et al.*, 1975). The eastward prograding sedimentary wedge is 6000–8000 m thick. The Pliocene–Quaternary history of the delta has recently been reconstructed in the interdisciplinary MISEDOR project (Pelet, 1987).

The modern Mahakam River drainage system encompasses a 75 000 km^2 area. Sediments transported through the equatorial basin form a low wave-energy (mean wave heights are <0.6 m), mixed tide- (semi-diurnal tides with a mean range of 1.2 m and a maximum amplitude of 3 m) and fluvially-controlled delta (Combaz & De Matharel, 1978; Allen *et al.*, 1979). According to the shoreline classifications of Hayes (1979) and Nummedal & Fischer (1978), eastern Kalimantan would be considered a mixed-energy, low mesotidal coastline. The present delta comprises a thin sedimentary sequence, about 50–60 m thick, that overlaps older Pleistocene palaeodeltas (Roux, 1977). At present it is about 50 km 'long', as measured from the delta

; to the initial bifurcation of the river at ;a-Sanga, extending laterally along the coast for ly 100 km. It is composed of approximately) km^2 of wetlands in the subaerial delta plain 1800 km^2 of delta front and prodelta sedits.

ıe Mahakam has two active fluvial distributary :ms directed north-east and south-east respect-'. An intervening interdistribuary area (Allen , 1979) consists of a series of tidal channels that ıt present not connected to the fluvial sections ıe delta. Channel depths average 7–10 m, maxm depths attaining 15–18 m. The estimated ıarge is 1000–3000 $m^3 s^{-1}$ (Allen *et al.*, 1979). waters carry a high suspended load of silt and , whereas medium-fine sands are transported bedload. The estimated sediment load is .$0^6 m^3 yr^{-1}$ (Allen *et al.*, 1979). Tidal channels ;imilar in depth to river channels, with the base dal channels often in contact with underlying ı front sediments (personal observation, 1988). 'ace tidal currents can exceed 1 $m s^{-1}$ at channel ıths (Allen *et al.*, 1979). Medium to fine sands silt are localized in the distributary channels delta front (Allen *et al.*, 1979; Gayet & Legigan, 7). The remainder of the delta is characterized nud and clay which are distributed throughout ous depositional environments (Allen *et al.*, 7; Gastaldo & Huc, 1992).

he delta front, an intertidal to subtidal platform) km in width, fringes the delta plain (Combaz)e Matharel, 1978). Localized sand bars inter- a monotonous mud sequence in which a ine fauna is often preserved. Laterally extensive ɔsits of peat accumulate in form of beach ridges ıe delta front-delta plain boundary (Allen *et al.*, 7; Gastaldo *et al.*, 1993). These beach ridges can ıp to 2.5 m thick and are composed of river sported phytoclasts. They occur as far as 3 km nd and cover a total surface area of approxtely 50 km^2.

:odelta sediments accumulate on the outer t of the delta front, where water depth inses to 35 m within 1 km of the delta-front gin (Kartaadiputra *et al.*, 1975). The prodelta haracterized by massive homogenous muds rporating beds of carbonaceous clay and silt. ayed phytoclasts (*sensu* Gastaldo, 1994) are mon, palynomorphs are rare (Combaz, 1964; et, 1987) and phytoplankton is absent (Com- & De Matharel, 1978).

STUDY METHODS

Shallow subsurface sampling was conducted by vibracoring within the main organic-rich modern depositional environments (Gastaldo & Huc, 1992). The vibracore sampling pattern was nonrandom, being arranged in two transects. Cores from the first transect represent depositional environments within the mixed fluvial-tidal distributaries (Fig. 2). The second transect was designed to sample sites from within the tide-dominated interdistributary setting.

Aluminium irrigation pipes, 6 m in length and 7.5 cm in diameter, were imported from Singapore. Pipe length was the limiting factor for the depth from which subsurface samples could be recovered. Depending on the depositional environment, core lengths varied from <3 m to >5 m. Three specially constructed 12-m tubes were used in fluvial channels where water depths exceeded 8 m (up to 7 m of core recovered). The cores were split longitudinally, one-half of the core being used for sedimentological description, photography and the fabrication of epoxy-resin peels (stored in the core warehouse, TOTAL Indonésie, Balikpapan, Kalimantan). The other half of the core was used for pH, E_H and temperature measurements (see Gastaldo & Huc, 1992) and the recovery of subsamples for phytological and geochemical analyses (see Gastaldo *et al.*, 1993; Huc & Gastaldo, unpublished). Selected phytoclasts were C^{14}-dated.

RESULTS

Channel morphology

The fluvial distributaries form a branching network of channels which radiate from the initial fluvial bifurcation at Sanga-Sanga (Fig. 2). The distributaries exhibit low sinuosity (Fig. 3), consisting of straight segments with channel bifurcations spaced 7–10 km apart. Bifurcations usually occur at sharp bends in the channels which result in deep scouring of the channel thalweg. Although the distributary channels do not exhibit any meandering, the thalweg within the channel exhibits a well-developed meandering pattern, resulting in an intrachannel network of side bars (Fig. 4). Channel cross-sections exhibit asymmetries similar to those observed in meander bends (Fig. 5).

The distributaries are incised into the flat inter-

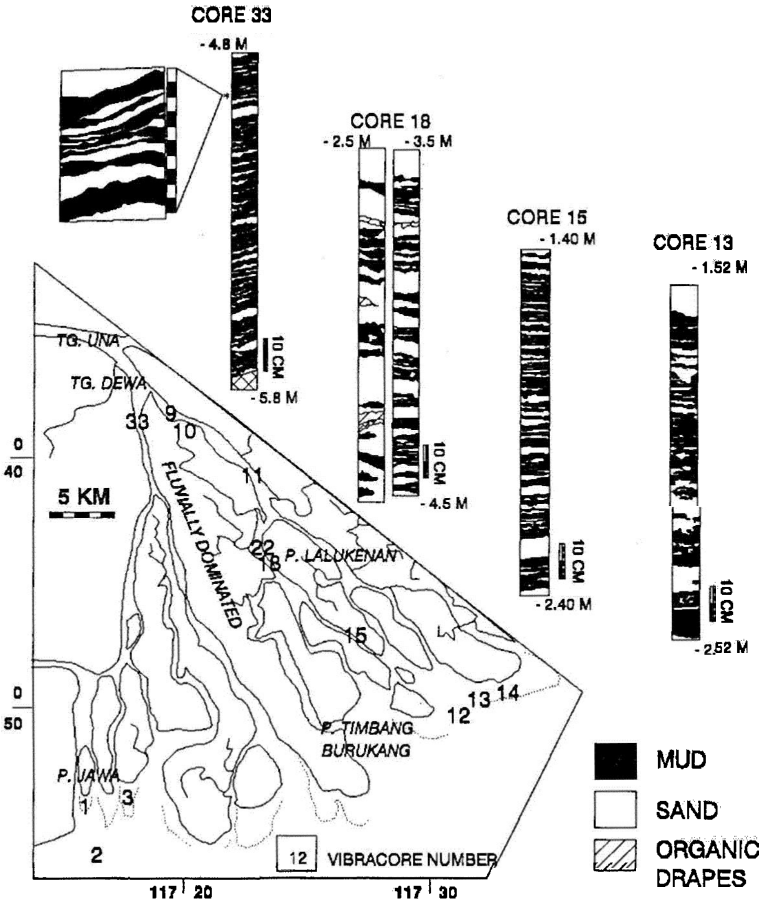

Fig. 2. Fluvially dominated transect in which vibracore sites are indicated by core numbers. Selected vibracore sections illustrate the prevalence of sand–mud couplet facies throughout the delta, including lateral channel bars more than 50 km inland. Facies variability is shown between the delta front (core 13, Fig. 7) and the lateral channel bar south of Tandjung Dewa (core 33; Fig. 8). Composition of organic drapes can be found in Gastaldo & Huc (1992).

tidal wetlands of the delta plain which are covered by a mixed hardwood and tropical palm forest in the interior subzone (Allen *et al.*, 1977) and a monoculture of the mangrove palm *Nypa fructicans* in the subtidal zone. Mangroves colonize newly formed tidal flats along channel margins and emergent channel bars in the subtidal zone, reflecting the upper limits of saline water influence. Channels are 0.5–1.5 km wide and do not exhibit any marked flaring at their mouths, in this respect contrasting to the more trumpet-shaped tidal channels. The positions of the distributaries have been stable during the past 50 years, there being very little or no lateral migration. Distributary thalweg depths vary from 6–>15 m (Fig. 5). The greatest depths occur at channel bifurcations (Fig. 4). In the straight channel reaches, the depth of the thalweg is relatively constant at 6–10 m.

Distributary channels are floored with sand brought in by the Mahakam River. Sand accumulates in form of elongate lateral bars along the channel banks (Figs 4 & 5). The lengths of these lateral bars vary between 2 and 3 km and the resulting sand deposits form elongate pods of similar length. Thicknesses may reach 7–8 m (Fig. 4; Allen *et al.*, 1977).

In the distributary mouths, tidal flow is more pronounced relative to river discharge and mid-channel bars separate ebb- and flood-dominant channels. In these zones the channel thalweg is non-erosive, the sediments being generally more muddy and the sands finer-grained.

A number of bore holes have been sunk within the distributary channels several tens of km landwards from the river mouth. These have shown that the sediments within the distributaries consist of 5–7 m thick erosive-based deposits of medium sand (Allen *et al.*, 1977, 1979). The sand bodies corres-

;. 3. Oblique aerial photograph, ·ected northwards, of the lower lta plain (Fig. 1). Distributary annels are of low sinuosity and nsist of straight segments with annel bifurcations occurring out every 7–10 km. Tidal annels exhibit high sinuosity and n be seen to cross swamps. angrove swamps can be seen to nge the monoculture *Nypa* amps, while juvenile mangroves n be seen to have pioneered tidal t deposits (lower left).

›nd to the side bars mentioned above. As in the se of fluvial point bars, they form deposits ughly equivalent to the thalweg depth, being verlain by 'mud-flat' silty clay and organic-rich ay with abundant plant detritus. The base of the annels commonly incise underlying delta-front nds and muds, the distributary channel sands verlying partly eroded delta-front mouth-bar de›sits.

ediment facies

x sediment facies can be recognized in the vibra›res recovered from the fluvially-dominated chan›l transect (Gastaldo & Huc, 1992), two of these ›ing particularly distinctive and serving to charac›rize all channel bars. These are the *sand–mud ›uplet facies* and the *bioturbated sand–mud couplet cies*. As the names imply, both are composed of ternating layers of sand and mud that appear to ive a couplet structure (Fig. 2). Sand grain size is ›riable throughout the transect. Medium sand ›minates in the upper reaches of the distributary annels (vibracores 9, 33), whereas fine–very fine nds are characteristic of the more distal parts of e river (vibracores 15, 18). The sand/mud ratio is ›riable, ranging from 90:10 to 30:70, again de›ndent on the location of the vibracores (see ›low). Sand colour varies from yellowish-tan to ive green-grey or dark grey-tan. Primary sedimen›ry structures include trough cross-bedding, small›ale ripples, and lenticular and wavy bedding. ipples may be asymmetrical or symmetrical, isolated or in sets (up to 7 cm thick, but averaging at 2 cm) and variable in their inclination (Fig. 6). Thus, ripples are inclined upstream, downstream or are horizontally disposed. Their orientation may be unidirectional, bidirectional or multi-directional within any single core.

Muds up to several centimetres thick and/or bedded phytoclasts up to 2 cm thick overlie the rippled sections, being generally horizontally disposed. Coloration of the mud fraction varies from grey-tan to grey-brown. No primary sedimentary structures are visible. Planar bedding can be seen in the phytoclast fraction, being accentuated by the disposition of plant litter. Plant detritus is composed of entire leaves or leaf fragments, woody and resistant fibrous clasts, as well as dammar (Gastaldo & Huc, 1992). In some instances, phytoclasts may occur scattered within mud drapes. In addition, a variety of insect remains have been recovered from all allochthonous assemblages and bivalve fragments or disarticulated shells occur locally (see below).

The principal difference between the two sediment facies is the considerable bioturbation of the one, ranging from nearly complete homogenization to the presence of discrete, isolated burrows. Homogenization is characterized by the incorporation of sandy sediment into the mud drapes (Fig. 7). Isolated burrows may be vertical, horizontal, or U-shaped. Burrow diameter ranges from <0.4 to 2 cm, and may be lined with faecal pellets. Most burrows are sand-filled and may be cemented by early diagenetic calcite (as verified by XRD).

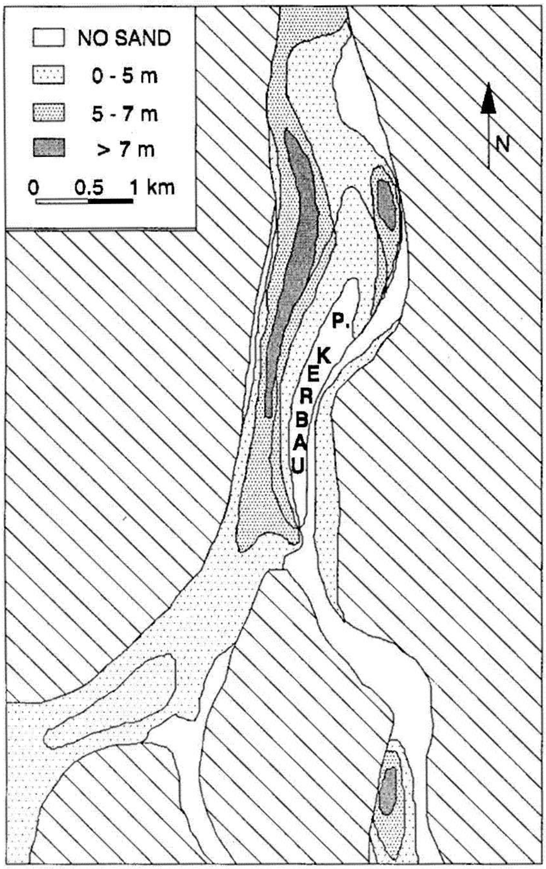

Fig. 4. Isopach of lateral channel bar configuration at P. Kerbau (Fig. 1). Lateral channel bars form a low sinuosity sand ribbon that consists of elliptical pods that result from the coalescence of individual lateral bars.

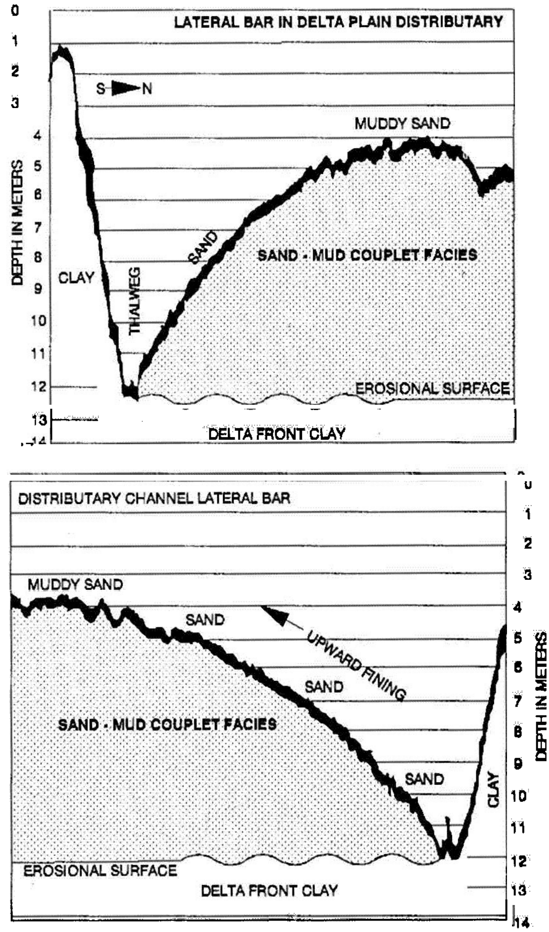

Fig. 5. Cross-sectional morphology of two distributary channels in the delta plain as reconstructed from echo soundings, surface sediment samples and vibracores.

In contrast to the distinctive sand–mud couplet facies and the bioturbated sand–mud couplet facies, the four other facies (i.e. the *bioclastic sand facies*, the *massively-bedded sand facies*, the *grey-black mud facies* and the *organic-rich mud facies*) identified in the vibracores form subordinate constituents, although one geographically localized facies delineates a delta-front setting (see below). The bioclastic sand facies is distinguished by the presence and incorporation of macrofaunal shell fragments (imbricated shell hash in asymmetrical ripples) in a medium-dark grey fine sand. The massively-bedded sand facies is oversaturated and not very common in the core records. Ripples may be present at the base of this facies, but otherwise it is devoid of any primary sedimentary structures. The only visible primary structures in the sulphurous, grey-black mud facies are defined by horizontally bedded phytoclasts. The same is true for the brown-tan to medium-dark grey organic-rich mud facies, but here phytoclasts do not undergo sulphur reduction (see Gastaldo & Huc, 1992, for details of these facies).

Transect variability

All lateral channel bars investigated are composed of the same sand–mud couplet facies. The only visual difference within the delta plain is an increase in the overall sand/mud ratio towards the delta front. Couplets in the upper delta plain (cores

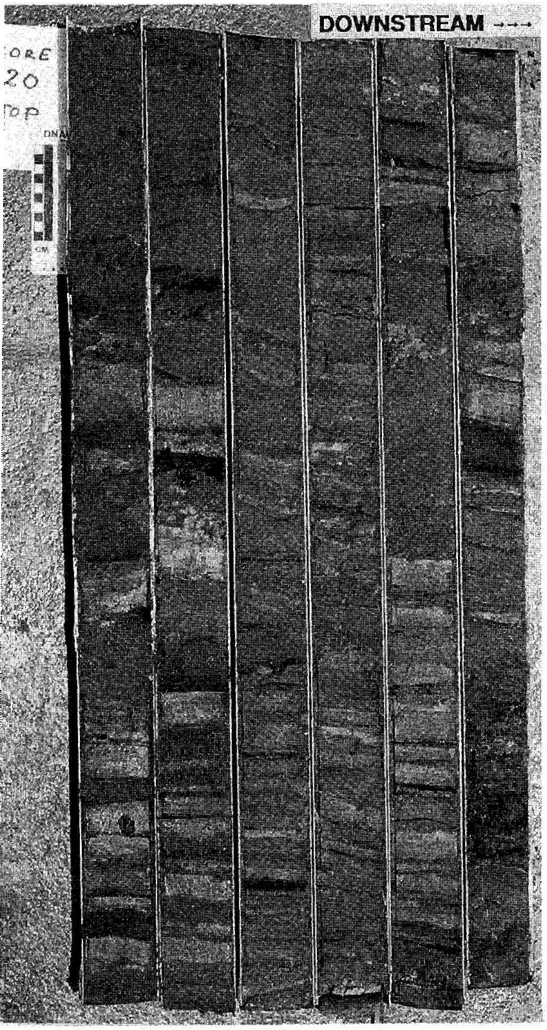

Fig. 6. Core 20: one of 10 vibracores recovered from a lateral channel bar near P. Lalukenan (Fig. 2). Note the interbedding of sand and mud, with sand disposed in isolated ripples, inclined strata and trough cross-bedded structures. Inclination of beds may be variously oriented. Core barrel is cut into 1 m sections. Top of core (sediment–water interface) is in the upper left; bottom of core is in the lower right. DNAG scale is in cm.

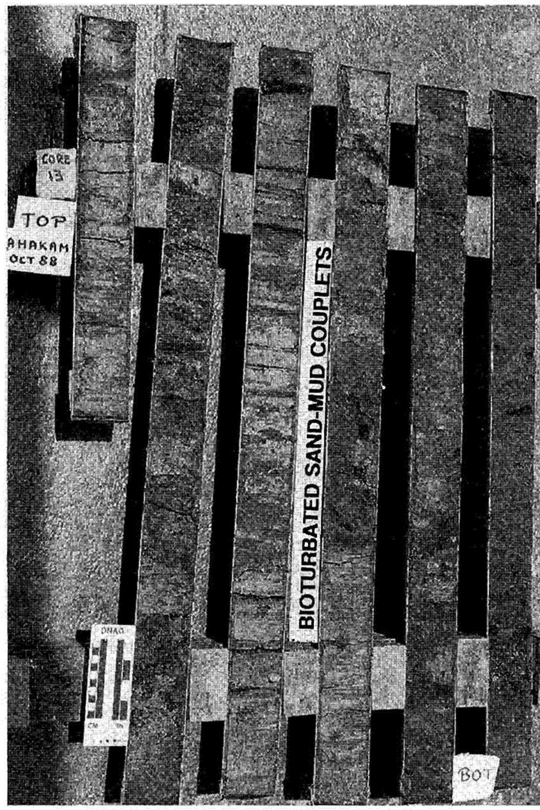

Fig. 7. Core 13: one of seven recovered from the delta front (Figs 2 & 9). Bioturbation from sand into mud is evident in the middle setion of the core. Entire and fragmentary invertebrate bioclasts are interspersed within the facies of the lowermost delta plain and delta front. DNAG scale is in cm.

9, 33) reflect minimum sand and maximum mud components, with sand/mud ratios lying between 15:85 and 25:75 (Figs 2 & 8). Sediments in vibracore 11, taken approximately 25 km downstream of the bifurcation at Tg. Una, reflect a marked increase in the amount of sand, the sand/mud ratio approaching 50:50. Ratios of the sand component in the lateral channel bar deposited adjacent to P. Lalukenan, approximately 38 km from Tg. Una, vary considerably depending on the positions of the vibracores within the bar. Ten vibracores (cores 18–23, 29–32) were extracted in close proximity to each other from the bar top (Fig. 6). Sand/mud ratios within these cores ranged from 80:20 (cores 18, 21) to 40:60 (core 20), with higher sand/mud ratios near the bar top. The higher proportion of sand in this bar is not due to an increased number of couplets, but rather to the deposition of cross-bedded and massive (up to 25 cm thick) sand (Fig. 2). Couplets observed in vibracore 15, over 50 km from Tg. Una are composed mainly of alternating silt and mud layers. Where sand–mud couplets exist (> −4.0 m depth), the sand/mud

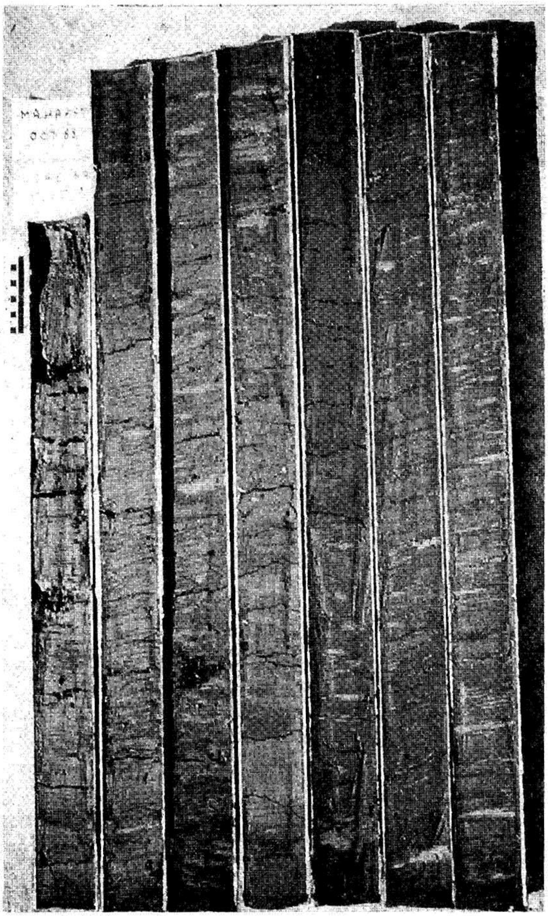

Fig 8. Core 33: recovered from the lateral channel bar immediately south of Tandjung Dewa (Fig. 2). Note the presence of sand and mud couplets in which thinner and thicker packages of sand–mud can be seen to alternate throughout the length of the core. Sand is concentrated in laminar, ripple and flaser-bedded structures primarily oriented downcurrent. DNAG scale is in cm.

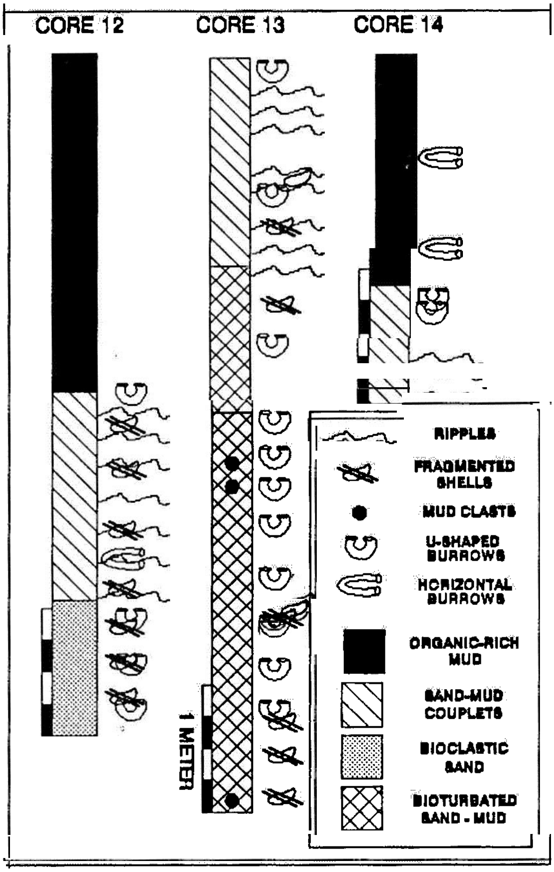

Fig. 9. Schematic representation of variability in the delta front environment between three cores recovered in close proximity to each other (Fig. 2). Organic-rich mud is characteristic of a tidal flat environment, whereas bioclastic sands characterize distributary mouth bars. For details of sediment facies see Gastaldo & Huc (1992).

ratio is 90:10. The upsection change to silt–mud couplets is due to the channel margin location of the core. Bioturbation first appears in these lower delta plain sites.

Facies diversity increase in the lower delta-plain channels, where there is more interaction between marine and fluvial processes. The delta front (cores 1–6, 12–14) is the depositional environment exhibiting the greatest diversity of sediment facies (Gastaldo & Huc, 1992; Fig. 9). The sand–mud couplet facies is still distinctive, but may be severely bioturbated. Macrofaunal shell fragments are often present and semi-lithified mud clasts can be found. The sand–mud couplet facies often overlies a bioclastic sand that is representative of distributary mouth bar deposits. It may be overlain by organic-rich muds signalling a tidal flat environment.

DISCUSSION

There is general agreement that couplets of alternating sand and mud result from the regular succession of currents and slackwater characteristic of tidal regimes (Reineck, 1972; Terwindt & Breussers, 1972; Visser, 1980; Boersma & Terwindt, 1981). The alternation between deposition from bedload and suspension is most effective in meso- to macrotidal environments. It is controlled by the relative volumes of sand and mud, current velocity, as well as the duration of the bedload and suspension load depositional phases (Elliott, 1978a; Klein, 1985). When the amount of sand is small relative to that of the mud (Reineck & Wunderlich, 1968), a large variety of wavy, lenticular and flaser bedding occurs. Their presence are but some of the criteria used to distinguish sedimentation originating from tidal processes (Klein, 1985). Such processes have been ascribed to the lower parts of distributary pathways (Elliott, 1978b).

The sedimentology of the Mahakam distributaries is controlled by the diurnal tidal current reversal and the lunar neap-spring cyclicity in amplitude. Field measurements in the southernmost distributary (Allen *et al.*, 1979) indicate that the duration of slackwater varies with tidal amplitude. During neap tide, for example, the period of zero bottom current can last for more than 1 h. Tidal current reversal occurs throughout the entire delta plain. During periods of heavy rainfall, however, the flood currents are strongly reduced at neap tide in the proximal reaches of the distributaries.

The hydrology of the distributaries is also affected by the existence of a pronounced salt wedge which can extend landwards up to the proximal delta plain (approximately 20–30 km from the distributary mouth bars). Salinities recorded in these zones range from 0‰ at the surface to 20–30‰ near the bottom (Allen *et al.*, 1979, p. 68). The resulting density stratification creates a stratified density circulation regime comprising landward moving bottom water that converges with seaward moving riverine water landwards of the salt intrusion. This creates a density current node that traps suspended sediment within a turbidity maximum in the zone of salt intrusion. The turbidity maximum migrates with the tides, affecting practically the entire delta plain. Suspended mud concentrations within the turbidity maximum can exceed 1000 mg l^{-1} (Allen *et al.*, 1979), such that a mud lamina can be deposited during a current slack lasting several hours.

The combination of tidal current reversal with high suspended sediment concentrations results in the accumulation of clay laminae during tidal slack. The potential for slackwater mud sedimentation is greatly enhanced during neap tides when the tidal currents are too weak to resuspend the deposited mud, particularly during waning tidal amplitudes. The presence of strong bottom currents would probably impede the preservation of slackwater mud laminations during spring tides. Therefore, as in most tide-dominated estuarine or distributary channel deposits, the sand–mud cycles that represent semi-diurnal slacks would be preserved mainly during neap tides.

The predominance of sand–mud couplets in all vibracores recovered from fluvial distributaries, even at sites over 50 km inlands from distributary mouth bars, indicates that tidal influences play a significant role in the development of within-channel deposits in such mesotidal settings. The distribution and quantity of sand that accumulates within any particular channel bar appear to be related to location within both the delta and the bar. For example, the sedimentological features observed in the ten vibracores (cores 18–23, 29–32; Fig. 6) extracted in close proximity to each other are highly variable. Sediments accumulate in bars along the margins of straight channels. One might expect that under such circumstances single depositional events (e.g. neap tide-generated mud laminae) should be traceable throughout the bar. However, it was not possible to find any correlation between particular beds, couplets or stratigraphical intervals, not even between two cores taken within 5 m of each other. Furthermore, these cores displayed a higher percentage of thick, clean sand. This feature may be explained by, amongst other things, the bar being located immediately downstream of a bifurcation and/or bar development occurring in a wide and straight part of the distributary (e.g. at the upstream end of a relatively linear channel).

Alteration of the sedimentological fabric within the bars occurs where conditions favour infaunal colonization. Bioturbation is restricted to the lower part of the delta, particularly within the delta front. This is probably related to the salinity gradient along the channel bottom and salinity tolerances of the burrowing organisms. Bottom salinities seawards of zones located about 10 km from the channel mouths are always greater than 10–20‰, whereas salinities measured landwards of a line about 30 km from the mouth are very low or zero (Allen *et al.*, 1979). The degree to which the sediments are homogenized may also be a function of increased substrate availability. The absence of bioturbation in the upper reaches of fluvial channels is primarily due to chemical barriers to infaunal colonization.

Because of the limitation imposed by the restricted number of vibracores, it is not possible to fully explain sediment variability and distribution within the bars, nor to accurately reconstruct bar development. Couplet generation is probably sporadic, related to neap–spring or equinoxial cyclicity rather than to daily fluctuations in tidal regime. The bundles of couplets observed within the vibracores do not exhibit the same rhythmic features as those described from daily deposition in other estuarine settings (Tessier, 1992; Tessier *et al.*, 1992, in press). In addition, a C^{14}-date of 765 ± 200 yr BP was recorded in an organic bed at -2.0 m depth (core 32—Krueger sample GX-14772 described as woody; Gastaldo & Huc, 1992). Leaves recovered from this organic drape were mostly intact. There was no indication that they had undergone mechanical fragmentation, a feature commonly associated with re-entrainment (see Gastaldo *et al.*, 1993; Gastaldo, 1994). However, since the litter bed was analysed in a bulk sample, it is possible that the C^{14}-date was biased by the presence of woody detritus in the litter. Gastaldo & Huc (1992) note that C^{14}-dated wood recovered near the top of this bar was at least 5200 years older than the organic drape that was dated at 765 ± 200 yr BP. The wood recovered near the top of the bar thus represents recycled organic material of high mechanical resistance. With this in mind, the C^{14}-date of the organic drape may not be an accurate reflection of the actual age of the horizon in the bar and may hence provide a misleading estimate of sedimentation rate. Even so, if these couplets had resulted from daily tidal cyclicity, we would have expected to find much younger leaf litter at this depth. In spite of the fact that the C^{14}-date may be biased towards an older age, the presence of entire leaves as organic drapes supports the contention that couplets are deposited intermittently and that deposition must be related to as yet unknown changes in flow conditions.

CONCLUSIONS

One of the characteristics of tidal deposits is their cyclic nature and, in particular, the rhythmic alternations of sand and mud deposited in response to current velocity cycles that occur with different periodicities. Lateral channel bars up to 15 m thick form a low sinuosity sand ribbon that consists of coalesced elliptical pods representing individual lateral bars. The sedimentary structures within these bars would generally be ascribed to tidal processes but, contrary to common opinion, these characteristic 'tidal features' are not restricted to the lower parts of deltaic distributary channels. These features may be the primary, and even unique, sedimentary structures in distributary channel deposits where tidal ranges are of at least mesotidal amplitude. Such sedimentary structures (e.g. alternating sand/mud layering, trough cross-stratification, asymmetrical ripples, and wavy, lenticular and flaser bedding) can be found in thick accumulations within lateral channel bar deposits some tens of kilometres inland. In the Mahakam, these features are found just below the first bifurcation of the river at Tg. Una. In the upper delta plain, these deposits are unaffected by bioturbation. Bioturbation associated with lateral channel bars is restricted to the lower reaches of distributary channels and distributary-mouth bars. The absence of bioturbation within wavy-, lenticular- and/or flaser-bedded sediments, along with the presence of thick organic drapes composed of phytoclasts within a thick (10 m or more) 'tidal' accumulation may represent useful criteria in ascribing deposits in the rock record to tidally-influenced fluvial distributary channels rather than to tidal flat environments.

Distributary mouth bars (Mayor Jawa, Tandjung Bukan and Mayor Bujit) are not as thick as lateral channel bars. They exhibit facies similar to lateral channel bars, except that there is more bioturbation and that fragmented macro-invertebrate shells occur together with phytoclasts. Bivalves, gastropods and echinoids are of allochthonous origin, transported into these shallow-water areas by waves and tides. The delta front is the most complex setting of fluvial sediment deposition. Rapid facies changes occur in response to fluctuations in the balance between fluvial discharge and marine processes, resulting in an interplay of facies that may characterize either fluvial, transitional or fully marine depositional settings.

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