Evolution and Architecture of the Holocene Mitchell River Megafan and Delta, Gulf of Carpentaria, Australia

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ABSTRACT

Ancient fluvial and deltaic systems are estimated to host a large proportion of the world's remaining hydrocarbon reserves. Establishing links between processes and forms in similar modern analogue systems can improve our understanding of the architecture of such systems and thereby enhance hydrocarbon recovery from their ancient counterparts. Research attention has traditionally focused on fluvial-dominated river deltas. However, fluvial-dominated deltas constitute only 3% of the modern global coastline. Rather, the majority of the world's coastal zone is mixed-influenced (waves, tides, fluvial energy), with waves and tides being the two most dominant processes. To address this knowledge gap, this project has investigated process-form links in the mixed-process Mitchell River Delta, which has the additional benefit of being fed by a megafan, a characteristic that is now recognised to be well represented in the rock record, though under-represented in the literature.

The Holocene Mitchell River Delta and Quaternary Megafan is located in the shallow (less than 70 m deep), intracratonic basin of the Gulf of Carpentaria (GOC), in north-eastern Australia. The Holocene Delta was deposited in association with relative sea-level fall, the last of multiple cycles of sea-level fluctuation that have affected the greater Quaternary megafan system. The Mitchell River Delta and Megafan has been minimally disturbed by anthropogenic activity and provide a unique opportunity to examine the link between megafan channel avulsions and coeval deltaic evolution.

Detailed mapping, field and chronologic investigations were used to characterise the palaeo-distributary channel belts on the megafan, and to reconstruct architectural changes on the megafan and delta related to internal and external forcing factors.

The evolution of the Mitchell River Delta can be summarised into four depositional Phases: (I) Progradation was initiated during the maximum Holocene marine transgression, approximately 6 ka; (II) The fluvial-dominated Central Mitchell depocentre was deposited by avulsions on the upper delta plain during the peak of Holocene Effective Precipitation (EP); (III) The first major fan avulsion caused sediment supply to shift northwards, initiating the Main Mitchell Depocentre. Forced regression commenced

approximately 3 ka, as evidenced by the first subtle downstepping of this Depocentre; (IV) A second episode of accelerated sea-level downstepping at approximately 2 ka was recorded in the Main Mitchell River Depocentre and the Nassau depocentre. A second major partial avulsion on the megafan during this episode also resulted in the ongoing splitting of catchment flows between these two major depocentres.

Shifting of depositional loci is driven primarily by avulsion. Two types of avulsion have been described: (1) frequent (more than 16 per 1000 years; or an average of one avulsion every 60 years) backwater mediated avulsions on the delta plain, which have resulted in relatively small scale shifts in depositional loci in the order of 10 – 20 km alongshore. These are clustered at the backwater limit and define the megafan to delta boundary. Avulsion rate in the backwater zone also appears to be influenced by sea-level trajectory. Estimated avulsion rate has doubled from 11 per 1000 years in the Central Mitchell depocentre, (under highstand conditions) to 20 per 1000 years in the Main Mitchell depocentre (during sea-level fall) in spite of decreased EP following ~3.7 ka, and may be attributed to the relative sea-level fall causing the superelevation of the channels thus promoting avulsion conditions. (2) The second avulsion type are less frequent (approximately 3 per 1000 years; or an average of one avulsion every 330 years) avulsions on the megafan (upstream of backwater influence), which have resulted in shifts in depositional loci in excess of 80 km alongshore and the initiation of new depocentres.

Geomorphic investigation has resulted in a number of lateral relationships being determined between architectural units across both the megafan and delta. Channel belt distribution, morphology and sedimentary fill, are a product of the complex interplay of waves, tides and backwater dynamics. Backwater dynamics have an overriding influence on the position of avulsion nodes, hence exerting a major control on channel belt distribution. Channel belt spacing and channel belt segment length is reduced in the backwater zone compared to the purely alluvial portion of the megafan. Channel belt width and depth is also less in the backwater zone compared to upstream as a result of flow partitioning from partial avulsions. Although a general decrease in sediment calibre can be observed in a downstream direction from the apex of the megafan through the backwater zone, channel fill consists of predominantly gravel and sand. Silt and clay is typically confined to the top 1.5 m of the channel fills. On the lower delta plain, channels are affected by waves and tides. Waves suppress mouth bar development thereby reducing the number of smaller scale distributary channels. As a result, power-law distribution of decreasing channel length and width typical of fluvial-dominated deltas is not observed on the Mitchell River Delta. Conversely, channel belt widths on the lower delta plain are similar to those observed on the upper delta plain, and the channel segment length is typically greater on the lower delta plain than the upper delta plain as both avulsion and bifurcation is reduced in this zone. The degree of tidal influence (process category) is intimately related to delta evolution. Fluvial-dominated, tide-influenced (Ft) channel belts can transition to tide-dominated fluvial-influenced (Tf) and tide-dominated (T) channel Elements and belts. Such a change can occur both longitudinally (i.e. along channel length) and laterally, as channel belts become progressively abandoned with time. Channel fill on the lower delta plain has a distinct marine signature with the presence of shell material, marine bioturbation and inclined heterolithic stratification. The degree of tidal influence is the primary control on the ratio of sand to mud fill.

Depositional units on the Mitchell River Delta have been mapped and presented within the framework of the *WAVE* process and architectural classification. Element Complex (EC) units (equivalent to sedimentary facies associations) have been presented as a facies atlas. Sedimentary facies data are directly related to process category. *Parent-child* and *neighbour* statistics have also been generated for EC units. These statistics have predictive power in analogous subsurface settings. Geometric attribute data has also been presented for Element Complex Set (ECS) and Element Complex Assemblage (ECA) units, which represent depositional environments associated with pulses of shoreline migration. These data are presented in terms of their process category, shape, and in the context of delta evolution.

Non megafan-fed delta lobes are typically driven by backwater mediated avulsions. Results from this study depocentres in linked megafan shoreline systems are controlled by both backwater avulsions (ECS and ECA) and to larger scale avulsions that occur upstream of the backwater zone below the megafan apex (depocentre development). Detailed mapping of the megafan and delta, combined with geometric analysis of ECS and ECA units has led to a generalised linked megafan-delta model for the prediction of the autogenic evolution of a deltaic depocentre. Depocentre development is initiated with an avulsion on the megafan and the progradation of a fluvial-dominated, tide-influenced, wave-affected (Ft*w*) or a Tw*f* unit. Changes in shoreline orientation cause ECS development and are related to backwater mediated avulsions on the lower delta plain. ECS within an ECA increase in volume as flow capture increases. A second (partial) avulsion on the megafan causes the reduction of sediment supply to the active depocentre. The ECS in the active depocentre decrease in area and show a relative increase in tide or wave to fluvial influence thus defining an ECA boundary. The completion of flow capture on the megafan causes the abandonment of the depocentre and there is net erosion of the seaward ECS units. The depocentre terminates in wave-dominated ECA, whereby sediment is sourced primarily by longshore transported sand.

THESIS DECLARATION

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Tessa Lane (28 November 2016)

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EXPLANATION OF THESIS LAYOUT

The first chapter is a review of the state of knowledge of megafan and delta systems and provides an introduction to the geological problems addressed by this thesis. Chapter 2 provides description of the regional setting of the study area. The third chapter provides a detailed review of depositional Elements which form the building blocks of mapping and the subsequent levels of hierarchy. This Chapter draws heavily on the previous work of Nanson et al. (2012, 2013a, b, c) and is presented separately from the following chapters to clearly distinguish previous work from new data findings from this body of work. Chapter 4 details all stratigraphic methods and data upon which this dissertation is based. Chapter 5 describes the architecture and evolution of the Mitchell River Delta. Chapter 6 examines the links between fan and delta evolution and the downstream changes in channel geometry and sedimentology. A portion of the content of Chapter 6 has been published as a journal article (Lane et al., 2016). The final chapter (Chapter 7) summarises the study, details the conclusions and makes some recommendations for further work. Appendices 1 − 11 show stratigraphic logs, basic interpretations and photographs of vibracore obtained in this study. Dose equivalent distribution from OSL is presented in Appendices 12 – 32. Dose recovery test results for OSL samples are shown in appendices 33 – 36 and the journal article (Lane et al., 2016) is included as Appendix 37, prefaced by a statement of authorship form signed by all co-authors.