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Influence of system controls on the Late Quaternary geomorphic evolution of a rapidly-infilled incised-valley system: The lower Manawatu valley, North Island New Zealand

Alastair J.H. Clement [a,*], Ian C. Fuller [a,b]

[a] Physical Geography Group, Institute of Agriculture and Environment, Massey University, Private Bag 11-222, Palmerston North 4442, New Zealand
[b] Innovative River Solutions, Institute of Agriculture and Environment, Massey University, Private Bag 11-222, Palmerston North 4442, New Zealand

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ABSTRACT

The Manawatu incised-valley estuary was rapidly infilled between 12,000–4700 cal. yr BP. A combination of empirical measurements of sedimentation rates, a reconstruction of relative sea-level (RSL) change, and digital elevation models of key surfaces within the Holocene sedimentary fill of the valley were integrated to produce a numerical model to investigate the influence of the system controls of sea-level change, sediment flux, and accommodation space on the rapid infilling history of the palaeo-estuary. The numerical model indicates that sediment flux into the palaeo-estuary was greatest during the Holocene marine transgression between 12,000–8000 years BP. The average rate of sediment deposition in the estuary during this period was ~1.0 M m^3 yr^{-1}. This rapid rate of sedimentation was controlled by the rate of accommodation space creation, as regulated by the rate of sea-level rise and the antecedent configuration of the valley. By the time sea levels stabilised c. 7500 cal. yr BP, the palaeo-estuary had been substantively infilled. Limited accommodation space resulted in rapid infilling of the central basin, though sediment flux into the estuary between 7100 and 4500 cal. yr BP was at a lower rate of 234,000 m^3 yr^{-1}. The limited accommodation space also influenced hydrodynamic conditions in the estuarine central basin, driving export of fine-grained sediment from the estuary. Once the accommodation space of the estuarine basin was infilled sediment bypassed the system, with a consequent reduction in the sedimentation rate in the valley. More accurate partitioning of the sources of sediment driving the infilling is necessary to quantify sediment bypassing. Post-depositional lowering of RSL index points from the valley is driven by neotectonics and sediment compaction.

1. Introduction

The sedimentary fill of incised-valley estuaries preserves nearly complete records of the late Quaternary sedimentary and geomorphic evolution of these coastal environments in response to system controls such as hydrodynamics, sea-level change, sediment supply, accommodation space, tectonics, and antecedent geomorphology (e.g., Dalrymple et al., 1992, 1994; Boyd et al., 2006). The complexity in the sedimentary record of incised-valley estuaries reflects the initial formation of the incised valley by fluvial incision during periods of lower sea level, followed by the subsequent flooding of this depositional space as sea-levels rise, with the sedimentary infilling driven by fluvial and marine processes regulated by these system controls. Recognition of the strong influence of hydrodynamics on the morphostratigraphy of incised-valley estuaries (e.g., Bird, 1967; Klum and Byrne, 1967; Roy et al., 1980; Roy, 1984; Nichol, 1991; Reinson, 1992; Dalrymple, 1992) was ultimately refined into two distinctive, idealised tripartite facies models of wave-dominated and tide-dominated estuaries, with extant estuaries falling somewhere on a continuum between these two forms (e.g., Dalrymple and Zaitlin, 1989; Dalrymple et al., 1992; Zaitlin et al., 1994). The facies models of incised-valley estuaries have been widely utilised as a framework for elucidating how variations in system controls such as hydrodynamics, sediment supply, accommodation space, tectonics, and antecedent geomorphology have influenced the sedimentological and geomorphological evolution of estuaries that deviate from the classical forms (e.g., Heap and Nichol, 1997; Dillenburg et al., 2000; Cooper, 2001; Lobo et al., 2003; FitzGerald et al., 2005; Brothers et al., 2008; Burningham, 2008; Wilson et al., 2007; Abrahim et al., 2008; Kennedy et al., 2008; Chaumillon et al., 2010; Peterson and Phipps, 2016; Gregoire et al., 2017). This attention is apt, as the facies models were distilled from case studies of estuaries subject to particular system controls: estuaries of large extent (40–100 km in length) situated within large catchments (~13,000–85,000 km^2) on stable coastlines, though with comparatively low river discharges and limited sediment supplies (Wilson et al., 2007; Clement et al., 2010).

This study examines the influence of the system controls of sea-level change, accommodation space, sediment supply (littoral and fluvial),

* Corresponding author.
E-mail address: a.clement@massey.ac.nz (A.J.H. Clement).

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and antecedent geomorphology on the geomorphic evolution of the Manawatu incised-valley estuary system, on the southwest coast of the North Island, New Zealand (Fig. 1). Reconstruction of the morphostratigraphy and facies architecture of the Holocene incised-valley fill confirms that the estuary was infilled extremely rapidly – within 2700 years of the onset of the sea-level highstand (Clement et al., 2017). This contrasts with international examples of wave-dominated, incised-valley estuaries that are today in only early or intermediate stages of maturity (e.g., Dalrymple et al., 1992; Roy, 1984, 1994). The Manawatu valley therefore presents a unique opportunity to investigate the influence of system controls on the geomorphic evolution of a rapidly infilled system, compared to the relatively immature models constructed from comparatively less 'active' coastal landscapes.

This paper combines reconstructions of the facies architecture and morphostratigraphy of the incised-valley fill with empirical measurements of sedimentation rates, a reconstruction of Holocene relative sea-level (RSL) changes in the Manawatu valley, and digital elevation models (DEMs) of key surfaces and volumes within the sedimentary fill of the palaeo-estuary to produce a simple numerical model to investigate the effects of the key system controls of sea-level change, accommodation space, and sediment flux on the extremely short infilling history of the Manawatu incised-valley estuary.

2. Site description

The Manawatu River valley on the southwest coast of the North Island, New Zealand (Fig. 1), is a wave-dominated incised-valley system analogous to a drowned river valley estuary (Clement et al., 2010). The North Island, positioned on the Australian tectonic plate, is being underthrust from the east by the subducting Pacific Plate (Fig. 1; Walcott, 1978; Lamb and Vella, 1987; Cashman et al., 1992). Much of the strain of the plate collision is being transferred to the leading edge of the Australian Plate, and as a result the North Island is undergoing crustal shortening and is being actively deformed. The southeastern margin of the Manawatu valley is commanded by the Tararua-Ruahine Ranges, part of the axial mountain ranges that extend throughout the North Island. The ranges are essentially a series of horst blocks uplifted over the past 1–2 Ma (Lamb and Vella, 1987; Heerdegen and Shepherd, 1992), with uplift rates varying between 1 and 4 mm yr^{-1} along the length of the ranges (e.g., Wellman, 1972; Ghani, 1978; Pillans, 1986; Whitehouse and Pearce, 1992), reflecting the variable deformation histories of each of the constituent fault blocks (Heerdegen and Shepherd, 1992; Kamp, 1992a, 1992b). The Manawatu River rises on the eastern side of the ranges, but flows to the Tasman Sea on the western side of the ranges via the antecedent cutting of the Manawatu Gorge. The gorge marks the upstream limit of the 'lower' Manawatu valley.

West of the mountain ranges lies the 200 by 200 km ovoid-shaped back-arc subsiding Wanganui Basin (Fig. 1). Continental shortening across the Wanganui Basin has produced a number of northeast-striking reverse faults, many of which are buried at depth. At the surface these buried reverse faults manifest anticlinal folds in the landscape. The Himitangi and Pohangina anticlines are of particular significance to the late Quaternary evolution of the lower Manawatu valley (Fig. 1). The Pohangina Anticline diverts the passage of the Manawatu

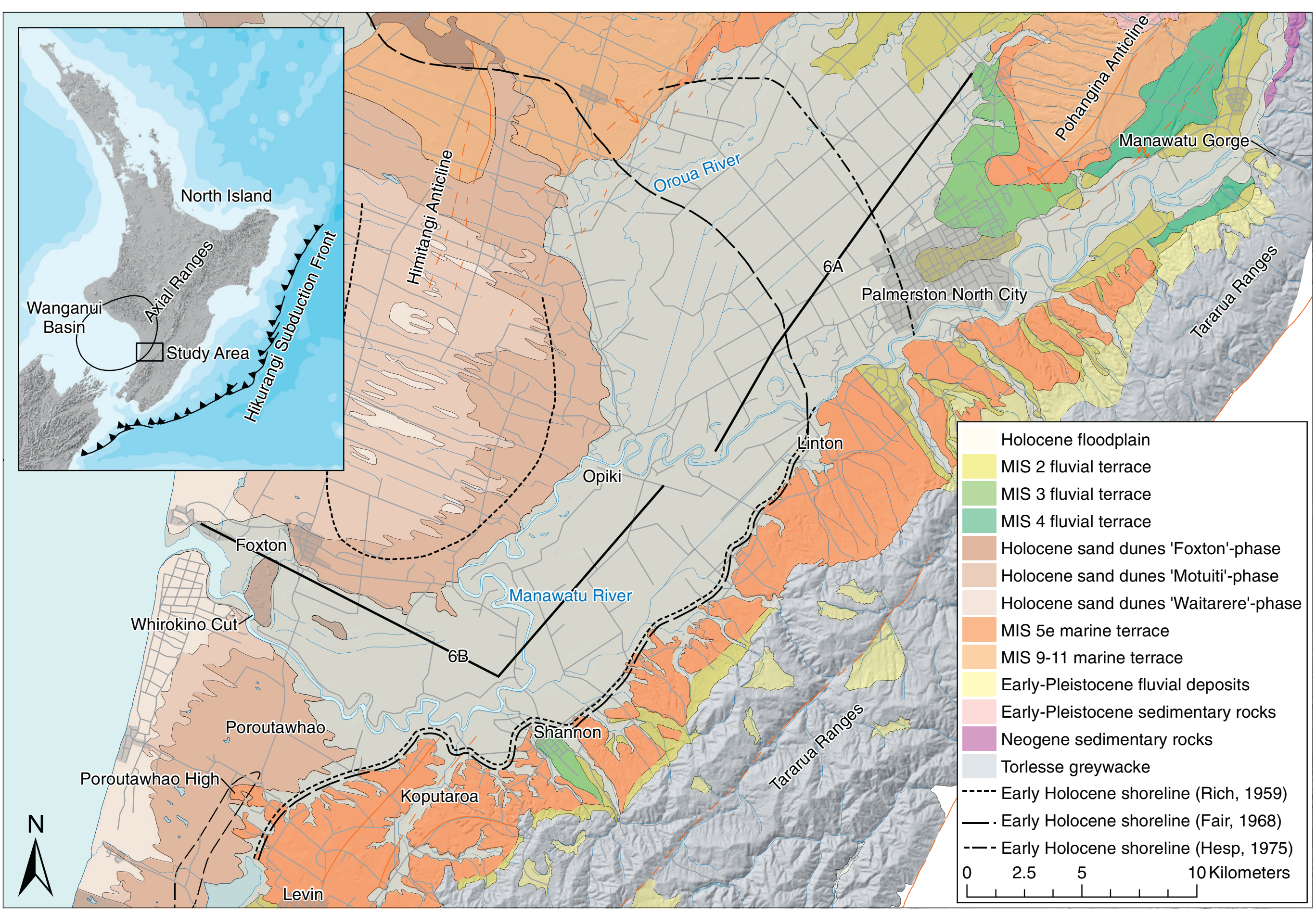

Fig. 1. Geological/geomorphological map of the lower Manawatu valley at 1:300,000 scale, showing localities and major geological features. Previous estimates of the extent of the Holocene palaeo-estuary by Rich (1959), Fair (1968), and Hesp (1975) are shown as dashed lines. The solid black lines marked 6A and 6B show the position of cross-sections of the sedimentary fill of the Manawatu valley depicted in Fig. 6. Base geological map data from Heron (2014).