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Inclined heterolithic stratification in a mixed tidal–fluvial channel: Differentiating tidal versus fluvial controls on sedimentation

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ABSTRACT

Tidal and fluvial processes control deposition and determine the sedimentological and ichnological character of sediments in the mixed tidal–fluvial Middle Arm, lower Fraser River, Canada. Sedimentological trends that define the mixed tidal–fluvial zone include: 1) mud beds present from the intertidal zone to the base of the channel, 2) a downstream increase in the number of mud beds, and 3) a lateral mud–sand–mud profile developed in the intertidal zone of each bar. Non-rhythmic deposition of sand under conditions of elevated river discharge is apparent, although sand beds are interbedded with cm- to dm-scale mud beds deposited during periods of low river discharge and increased tidal influence. In rare cases, mm- to cm-scale rhythmically alternating sand and mud lamina are deposited in successions of 12–14 beds (tidal rhythmites).

Ichnologically, burrow density, trace size, and homogeneity in the vertical distribution of traces increase in the seaward direction. Burrows in all of the bars are evenly distributed in the vertical profile through substrates of similar grain size; however, infaunal distributions vary as a function of grain size and subaerial exposure. Muddier sediments and substrates that experience less subaerial exposure display a higher degree of bioturbation (bioturbation index [BI] 2–5). Sand beds are generally bioturbated to a lesser degree (BI 0–1) except in the lower delta plain, where higher degrees of bioturbation (BI 3–5) can be produced.

The sedimentological and ichnological character of sediments in the tidal–fluvial Middle Arm showcases subtle, but important differences between tide-influenced, river-dominated inclined heterolithic stratification (IHS) and mixed tidal–fluvial IHS. In particular, more homogeneous and diverse burrowing in both mud and sand beds, more rhythmic sand–mud interbedding, mud deposition to the base of the channel, and the development of a mud–sand–mud profile along the length of the bar are considered indicative of heightened tidal influence and sustained brackish-water conditions.

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1. Introduction

Inclined heterolithic stratification (inclined interbeds of sand and mud; IHS) is a common stratal architectural element in modern and ancient estuarine point bars and channel bars. Modern examples of IHS are recorded from river-dominated (Smith et al., 2009, 2011), mixed river and tide (Smith, 1985, 1987, 1988; Gingras et al., 1999; Sisulak and Dashtgard, 2012), and tide-dominated channels (Choi et al., 2004; Dalrymple and Choi, 2007; Choi, 2010), wherein sediment deposition is dominated by fluvial, mixed fluvial and tidal, and tidal processes, respectively. Hydrodynamic conditions not only differ between environments in which IHS is developed, but also vary significantly within a single channel and between branches and distributaries within the same depositional system. This can result in substantial within-system variability in IHS character.

Although published studies of IHS in modern environments are increasingly available, only a few of these studies link quantified measurements of hydrodynamic processes and water chemistry to the sedimentological and ichnological character of the resulting deposit (e.g., Sisulak and Dashtgard, 2012). Yet, to properly understand depositional controls across the tidal–fluvial transition (TFT), it is necessary to define changes in the character of the sediments relative to their position in the channel, and with changing hydrodynamic conditions and water chemistry (mainly salinity). In the lower reaches of the Fraser River, Canada, IHS is formed or is present where saltwater and freshwater mix. The sedimentology, ichnology, and architecture of three bars in the subequally mixed tidal–fluvial (i.e., tidal and fluvial processes equally impact sediment deposition) Middle Arm, lower Fraser River are compared to hydraulic and water chemistry data collected from this system. The results are then compared to a similar

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study conducted in the tide-influenced, fluvially dominated Main Channel (Sisulak and Dashtgard, 2012) in order to identify subtle and/or distinctive changes in the character of the IHS based on the relative influence of tidal versus fluvial processes. From these data, sedimentological, ichnological, and morphological criteria are defined for recognizing mixed tidal–fluvial IHS in paleo-estuarine and deltaic channels.

1.1. Study area

The Fraser River is the largest river that debouches into the Pacific Ocean (Strait of Georgia) on the west coast of Canada (Milliman, 1980; Monahan et al., 1993; Villard and Kostachuk, 1998), and is undammed along its entire 1200 km length. In its lower reaches, the Fraser River has four main distributaries: Canoe Pass, the Main Channel, the Middle Arm, and the North Arm (Fig. 1). In 1970, measurements of fluvial discharge during the spring freshet, indicated that the Main Channel carried 70% of the flow, whereas Canoe Pass, North Arm, and Middle Arm contained 18%, 7% and 5% of the flow, respectively (WCHL, 1977; FREMP-BEAP, 2006). The banks of the distributaries were diked between 1913 and 1919 (Johnson, 1921). Due to the fixing of the channels, large year-to-year changes in flow and sediment load within or between distributaries are unlikely, although small variations do likely occur (Dashtgard et al., 2012). Most of the Fraser River sediment load (80%), and almost all of the sand, is transported during the snowmelt-induced freshet from late May to July. Only 3 to 9% of the total Fraser River sediment supply enters the North Arm/Middle Arm distributaries (Church et al., 1990). River discharge is highest during the freshet, and ranges from 5130 to 15 200 m^3 s^{-1}. For the rest of the year, flow ranges from 1000 to 3000 m^3 s^{-1} (Kostaschuk and Luternauer, 1989). Tides are semi-diurnal, and in the Middle Arm tides range from 2 to 5 m with an average tidal range of 3.1 m.

Three bars in the Middle Arm are studied, including a channel-margin bar (CMB), an in-channel bar (ICB) and a semi-detached point bar (PB; Figs. 1, 2). The PB is situated within the lower delta plain tidal flats, and is bracketed by the Middle Arm to the north and a shallow tidal channel to the south (Fig. 2). Within the study area, the Middle Arm has an average depth of 5.3 m (relative to AMHT; Fig. 2) and an average width of 300 m. The average depths of the channel adjacent to the CMB, ICB, and PB, are 6.2 m, 4.3 m, and 5.4 m (relative to AMHT), respectively. The maximum depth of the channel is 8.5 m adjacent to the CMB, 6.1 m adjacent to the ICB, and 8.3 m off the PB (Fig. 2).

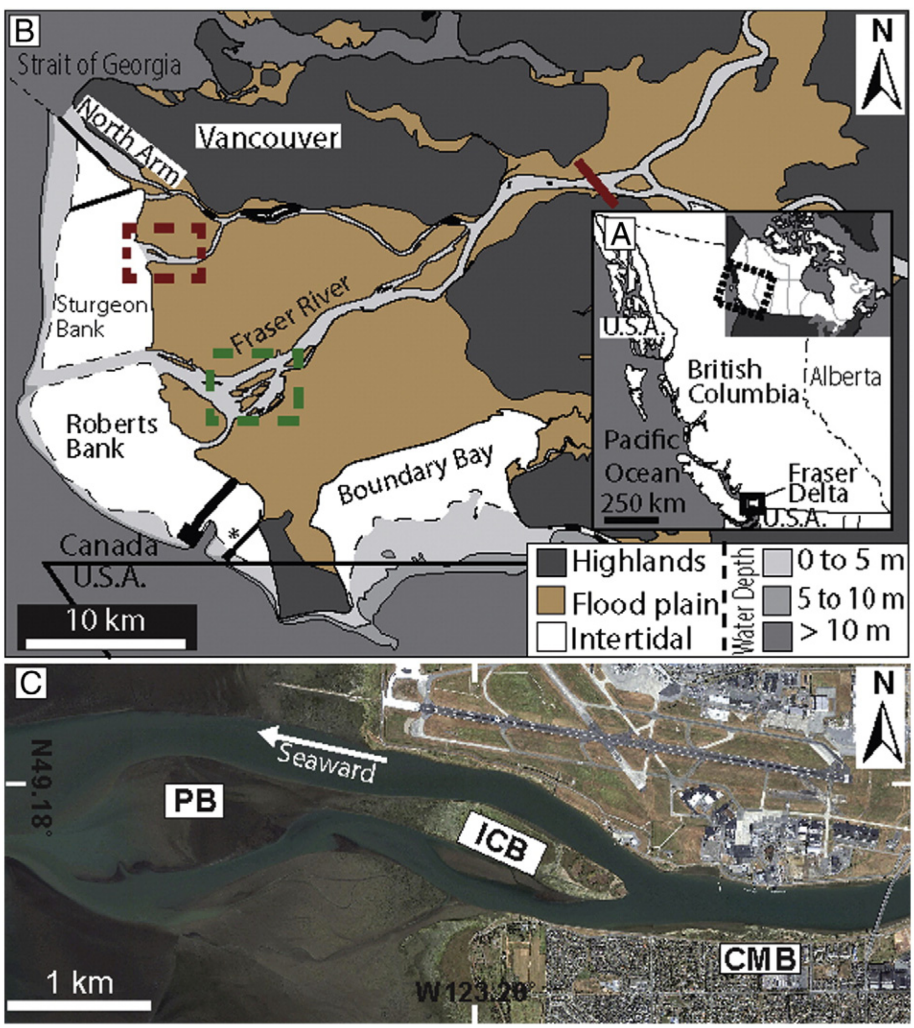

Fig. 1. A. (Inset map) Location map of the Fraser delta in British Columbia, Canada. B. Schematic map of the Fraser delta with the main geomorphologic features shown. The Middle Arm study area is defined by the dashed red box. The South Arm Marshes (SAM; dashed green box) is situated in the Main Channel and was studied by Sisulak and Dashtgard (2012). The maximum landward extent of saltwater incursion is indicated by the solid red line and is based on Kostaschuk and Atwood (1990). C) Satellite image of the three Middle Arm in 2000, with the three bars indicated: the channel-margin bar (CMB); the in-channel bar (ICB); and the semi-detached point bar (PB). (Image source: Google Earth).

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