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Depositional controls on tidally influenced fluvial successions, Neslen Formation, Utah, USA

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ABSTRACT

The stratigraphic architecture of marginal marine successions records the interplay of autogenic and allogenic processes, and discerning their relative role in governing the morphology of the palaeoenvironment and the architecture of the preserved sedimentary succession is not straightforward. The Campanian Neslen Formation, Mesaverde Group, Utah, is a tidally influenced fluvial succession sourced from the Sevier Orogen, which prograded eastwards into the Western Interior Seaway. Detailed mapping in three dimensions of architectural relationships between sandstone bodies has enabled documentation of lateral and vertical changes in the style of channel-body stacking and analysis of the distribution of sedimentary evidence for tidal influence. Upwards, through the succession, sandstone channel bodies become larger and more amalgamated. Laterally, the dominant style of channel bodies changes such that ribbon channel-fills are restricted to the east of the study area whereas lateral accretion deposits dominate to the west.

Combined allogenic and autogenic controls gave rise to the observed stratigraphy. A temporal decrease in the rate of accommodation generation resulted in an upward increase in amalgamation of sand-bodies. Autogenic processes likely played a significant role in moderating the preserved succession: up-succession changes in the style of stacking of channelized bodies could have arisen either from progradation of a distributive fluvial system or from an upstream nodal avulsion of a major trunk channel; accumulation of tide influenced, wave dominated units likely record episodes of delta-lobe abandonment, subsidence and submergence to allow accumulation of near shore sand bars with associated washover complexes.

1. Introduction

The majority of published studies of tidally influenced systems are those associated with estuaries and incised valleys rather than non-confined coastal alluvial plains (e.g., Dalrymple et al., 1992; Shanley and McCabe, 1994; Plink-Björklund, 2005; Dalrymple and Choi, 2007). There are numerous published studies of the sedimentology of the tidal-to-fluvial transition zone in both ancient (e.g., Shanley et al., 1992; Bose and Chakraborty, 1994; Shanley and McCabe, 1995; Yoshida, 2000; Ghosh et al., 2005; van den Berg et al., 2007; Corbett et al., 2011; Flaig et al., 2011; Ashour et al., 2012; Bhattacharya et al., 2012) and modern (e.g., Choi et al., 2004; Lambiase, 2013; Nanson et al., 2013; Vakarelov and Ainsworth, 2013) settings. Few of these studies have integrated sedimentological relationships with detailed analyses of the style of stacking and hence connectivity of channel bodies that record different degrees of tidal-influence. However, the discovery and exploration of large oil reserves held in tidally influenced fluvial reservoirs, including the Cretaceous McMurray Formation, Alberta, Canada, have focussed attention on these successions (e.g., Hubbard et al., 2011; Fustic et al., 2012; Musial et al., 2012).

Conceptual models (e.g., Dalrymple and Choi, 2007; Fig. 1) identify a suite of dynamic processes that compete within tidally influenced environments. Recognition and characterization of tidally influenced fluvial deposits are challenging because the energy of the system changes both spatially (upstream to downstream) and temporally as a function of the relative roles played by competing tidal, wave and fluvial forces (Fig. 1). Fluvial discharge varies seasonally or in a pseudo-random manner in response to major flood events (Leopold, 1964; Miall, 2013). Tidal currents are modulated by the interplay of semi-diurnal (or diurnal), monthly (spring-neap) and annual cycles. Typically, the effects of these processes diminish upstream in the zone of tidal influence (Dalrymple and Choi, 2007; van den Berg et al., 2007). Furthermore, few sedimentary structures alone serve as unequivocal evidence for tidal currents; rather, the interpretation of such processes from outcrop successions is reliant on the occurrence of an assemblage of sedimentary structures, in combination with palaeontological and ichnological salinity indicators (Shanley et al., 1992).

The pattern of stacking of channel bodies on delta plains is controlled by extrinsic and intrinsic factors, in a similar manner to fluvial successions. Early analyses of such stacking patterns (e.g., Leeder,

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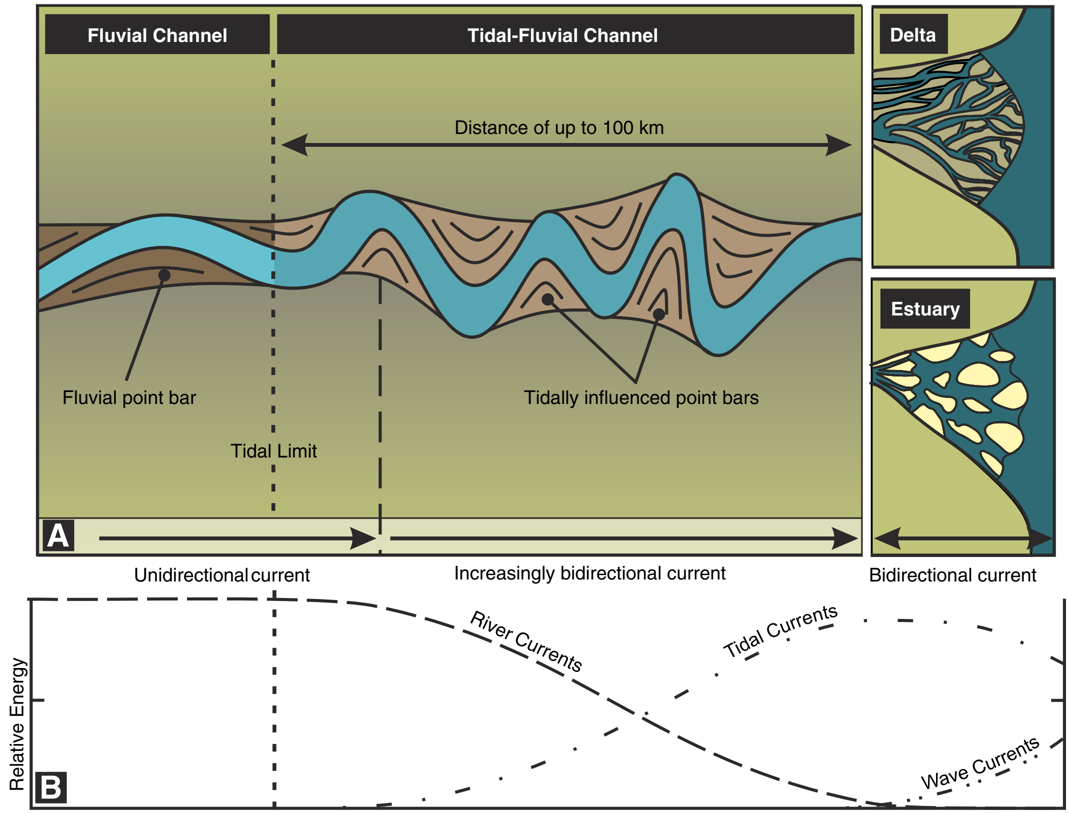

Fig. 1. (A) Conceptual model of tidally influenced environments illustrating the variability and complexity present in the tidally influenced fluvial zone. (B) Graph showing the temporal variation of the energy regimes within tidally influenced systems.
Modified after Dalrymple and Choi (2007).

1977; Allen, 1978; Bridge and Leeder, 1979) argued that the degree of amalgamation of fluvial sandstone bodies is inversely proportional to the sedimentation rate. As such, changes in channel-body stacking patterns reflect the rate of change of subsidence within the basin (Heller and Paola, 1996).

Decryption of the controls on deltaic and fluvial architectures in coastal systems requires detailed analysis of continuous, laterally extensive outcrops that allows for the reconstruction of three-dimensional geometries and trends of architectural elements together with their relationship to one another. Studies based on one- or two-dimensional datasets (e.g., Holbrook, 2001; Hampson et al., 2012), with three-dimensional constraints (e.g., McLaurin and Steel, 2007; Pranter and Sommer, 2011; Trendell et al., 2013) or with control in one direction (e.g., Hampson et al., 2013; Legler et al., 2013) do not allow for channel bodies or channel belts to be accurately projected beyond the cliff line. Studies that do benefit from three-dimensional data sets, however, commonly examine vertical cliff sections for which it is not possible to gather detailed sedimentological information or palaeoflows (e.g., Deveugle et al., 2011).

The Neslen Formation of the Mesaverde Group, Book Cliffs, eastern Utah, USA (Fig. 2), however, benefits from three-dimensional outcrop expression that enables accurate reconstruction of channel-body and channel-belt orientations together with detailed facies analysis within settings representative of zones of transition from fluvial to tidal dominance (Fig. 3).

As such, the Neslen succession is well suited to determination of the relative roles of *allogenic* factors such as changes in relative sea-level, sediment supply and basin subsidence, tectonism and climate (Dalrymple and Choi, 2007; Gawthorpe and Colella, 2009; Hampson et al., 2013) and *autogenic* factors such as progradation of a distributive fluvial system, delta lobe switching and major nodal avulsion (Jones and Schumm, 2009; Hofmann et al., 2011; Blum and Roberts, 2012; Weissmann et al., 2013) each of which may act to control coastal plain and delta morphology and preserved architecture.

The aim of this study is to demonstrate the combined allogenic and autogenic factors that control the transition from tidally influenced to exclusively fluvial sedimentation in the marginal marine setting represented by part of the Neslen Formation. Specific objectives are: (i) document the lithofacies present; (ii) characterize the three-dimensional architecture of tidally influenced fluvial deposits; (iii) assess the controls on the pattern of stacking of fluvial, tidal and tidally influenced sand-bodies, and (iv) evaluate the degree to which a sequence stratigraphic framework can be applied to a relatively up-dip section of the Neslen Formation. Traditionally, the stratigraphy of the Mesaverde Group has been interpreted dominantly in terms of sedimentary response to allogenic processes. This work redresses the balance by identifying a range of autogenic processes that might alternatively have given rise to the preserved stratigraphic expression.

2. Geological setting

The Neslen Formation crops out along the Book Cliffs of eastern Utah as part of the extensively studied Upper Cretaceous Mesaverde Group (Lawton, 1985; Olsen et al., 1995; van Wagoner, 1995; McLaurin and Steel, 2000; Hettinger and Kirshbaum, 2003; Kirschbaum and Hettinger, 2004; Aschoff and Steel, 2011a, 2011b; Fig. 2) which forms the eroded southern margin of the Uinta Basin (Lawton and Bradford, 2011). The Mesaverde Group contains several siliciclastic wedges (Fig. 2) sourced from the Sevier Orogenic Belt that prograded eastward to the accompanying foreland basin occupied by the Western Interior Seaway (Armstrong, 1968; Krystinik and Blakeney DeJarnett, 1995; McLaurin and Steel, 2007; Miall et al., 2008; Aschoff and Steel, 2011b; Fig. 3). The Campanian Neslen Formation was deposited in a low gradient, low relief coastal plain system.