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Aggradation and lateral migration shaping geometry of a tidal point bar: An example from salt marshes of the Northern Venice Lagoon (Italy)

Lara Brivio [a,*], Massimiliano Ghinassi [a], Andrea D'Alpaos [a], Alvise Finotello [a], Alessandro Fontana [a], Marcella Roner [a], Nick Howes [b]

[a] Department of Geosciences, University of Padova, V. Gradenigo 6, 35121 Padova, Italy
[b] Shell Technology Center Houston, 3333 Highway 6, South Houston, TX 77082-3101, USA

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ABSTRACT

Although meanders are ubiquitous features of the tidal landscape, the architectural geometries of tidal point bar deposits are relatively unexplored and commonly investigated on the basis of facies models developed for their fluvial counterparts. The present study aims at improving current understanding of tidal point bar deposits developed in salt marsh settings, through a high-resolution investigation of an abandoned intertidal meander loop, located in the northern part of the Venice Lagoon (Italy). The study channel is 6 m wide and was active until the 1950s, when it was deactivated as consequence of a neck cut-off. A total of 150 cores was recovered from the associated point bar. The bar erosionally overlies a subtidal platform consisting of sand and mud and is covered by both channel fill and salt marsh mud. The bar, floored by a shell-rich sandy lag, consists of stratified fine sand, grading upward into sandy mud. The outer bank of the bend is characterized by well-developed, sand-rich levee deposits and absence of crevasse splays, which represent a distinctive feature of alluvial sedimentation. Sediment grain size distributions suggesting that seaward and landward sides of the point bar experienced comparable changes of bed shear stress due to alternation between flood and ebb currents, highlighting a remarkable difference with the classical downstream-fining characterizing fluvial point bars. Spatial interpolation between key stratal surfaces shows an overall thickening of the bar from 1.2 to 1.7 m in the direction of channel migration, associated with both lowering of the bar base and rising of its brink, which occurs in parallel with an increase in channel cross-sectional area, to progressively accommodate the increasing tidal prism. The bar top surface is characterized by a spoon-shaped geometry stemming out from a combination between lateral migration (8–10 cm/yr) and vertical aggradation (2.5–3.0 mm/yr) of the inner bank. In salt marsh settings, vertical aggradation plays, therefore, a major effect on point bar sedimentation, generating peculiar bar top geometries that are not common in fluvial meanders, where the high rate of lateral migration causes the cutoff to be reached before substantially thick deposits are accumulated on the bar top.

1. Introduction

Tidal channels play a key role in the evolution of coastal environments and facilitate the exchange of water, sediment, and nutrients within these environments (Perillo, 2009; Fagherazzi et al., 2012; Hughes, 2012). The morphodynamic evolution of these channels is governed by the interaction between the tidal prism, tidal asymmetry, sediment texture, sediment supply and presence of vegetation (Garofalo, 1980; Dalrymple et al., 1991; Fenies and Faugères, 1998; Gabet, 1998; Marani et al., 2002; Lanzoni and Seminara, 2002; Solari et al., 2002; Fagherazzi et al., 2004; D'Alpaos et al., 2005; Garotta et al., 2006). Although the sedimentary products deriving from the lateral migration of tidal meanders have been explored (e.g., Land and Hoyt, 1966; Bridges and Leeder, 1976; Barwis, 1978; de Mowbray, 1983; Choi et al., 2004; Choi, 2011), it is commonly assumed that stratal geometries of these deposits show marked similarities with those of their fluvial counterparts. Accordingly, the basic architectural and facies models developed for fluvial meander bends (Allen, 1963; McGowen and Garner, 1970; Brice, 1974; Jackson, 1976; Nanson, 1980) are commonly used to detect tidal point bars in the fossil record (Díez-Canseco et al., 2014), while acknowledging that the latter shows evidence for bidirectional currents along with a higher mud content and degree of bioturbation (Allen, 1982). Nevertheless, there are several key differences between the morphodynamics of tidal and fluvial meanders. Rivers are characterized by high-discharge flood events which overlap to

* Corresponding author.
E-mail address: lara.brivio@studenti.unipd.it (L. Brivio).

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slowly varying discharges through the year, while velocities displaying high values can be maintained for relatively long time during floods (days). By contrast, tidal channels, in addition to experiencing reversal of flows during a tidal cycle, are characterized by highly variable discharges, even high in magnitude, limited in time (hours) and generally characterized by a defined range of possible values. Moreover, in fluvial channels the landscape-forming discharges occur when water is at bankfull stage, whereas in tidal channels high water level conditions occur at slack water where they are characterized by low velocities (Hughes, 2012).

Sedimentary facies models for tidal meanders are mostly derived from modern mudflats (de Mowbray, 1983; Bridges and Leeder, 1976; Choi et al., 2004; Choi, 2011), while scarce attention has been paid to meandering channels cutting through salt marsh surfaces. Salt marsh channels can resemble fluvial channels in low-energy floodplains (Nanson and Croke, 1992), where channels are characterized by low stream power and slow lateral migration rates, which is due to the presence of erosion-resistant, cohesive bank deposits. Vegetated, cohesive salt marsh mud resembles floodplain deposits and encourages a comparison between salt marsh meanders and their fluvial counterparts. In unconfined floodplains, fluvial meanders commonly evolve increasing their sinuosity ("expansional planform evolution" sensu Jackson, 1976), with a rate of lateral migration on the order of m/yr (van de Lageweg et al., 2016). In the fluvial realm, overbank aggradation is not expected to influence channel belt architecture, since the rate of channel migration (0.5–1.0 m/yr; e.g., Moody and Meade, 2014) is orders of magnitude higher than the rate of overbank aggradation (1–2 mm/yr; e.g., Walling et al., 1998). Nevertheless, numerical simulations show that high overbank aggradation rates (i.e., >10 mm/yr) can impact on the architecture of channel-belt deposits (Willis and Tang, 2010; van de Lageweg et al., 2016), with a significant increase in deposit thickness and preservation, which is also highlighted by outcrop evidence (Ghinassi et al., 2014). Salt marsh meanders are characterized by rates of migration which rarely exceed 0.5 m/yr (Garofalo, 1980; Gabet, 1998), therefore the rate of bed aggradation, which can also exceed 5–10 mm/yr (e.g., Temmerman et al., 2003), is expected to have major effects on point bar sedimentation.

Toward the goal of providing new insight into tidal meander-bend sedimentation, this present study investigates the morphodynamic evolution and the internal architecture of a point bar developed in a salt marsh of the Northern Venice Lagoon (Adriatic Sea, Italy; Fig. 1). The study site is represented by an abandoned meander bend, consisting of sandy point bar and related muddy channel fill. Using closely spaced sedimentary cores to define a high-resolution 3D model, the present study aims at investigating facies distribution and architecture of the point bar deposits. The geometry of the point bar body is analyzed here as a function of the ratio between vertical aggradation and lateral migration, and comparison with a fluvial bar of similar size is discussed.

2. Geological setting

2.1. The Venice Lagoon

The Venice Lagoon forms an elongated body oriented NE–SW, with a length of about 50 km and width of 10 km, and represents the largest Mediterranean brackish water body (total surface area of about 550 km^2). The lagoon is connected to the Adriatic Sea through three inlets (Lido—San Nicolò, Malamocco and Chioggia; Fig. 1B), where water depth can reach over 15 m while, inside the basin, the average depth of the tidal flats is shallower than 1.5 m. The tidal regime is semidiurnal, with an average tidal range of about 1.0 m and maximum astronomical tidal excursions of about 0.75 m (D'Alpaos et al., 2013) around mean sea level (msl). Maximum velocity generated by spring tides is around 1.0-1.5 m/s (Rinaldo et al., 1999), the highest tides elevate to 1.5–2.0 m msl and are generally reached during fall and winter, when high astronomical tides can coincide with strong southern onshore winds (Scirocco) (Bondesan et al., 1995). The highest water level was measured 1.92 m msl at the center of Venice in November 1966 (Pirazzoli and Tomasin, 1999).

The Venice Lagoon (Fig. 1A) is located in the coastal sector of the Venetian Plain, a foreland basin that developed between the Apennine and South-Alpine chains since the late Oligocene (Massari et al., 2009). After experiencing deep-water deposition, during the early Pleistocene the basin was filled up with ca. 750 m of shallowing-upward deposits, spanning from turbidites to shallow marine (Massari et al., 2004). Since the middle Pleistocene, glacio-eustatic fluctuations led to the alternation of continental and coastal conditions (Kent et al., 2002) and during Last Glacial Maximum (LGM) the area of Venice was part of the distal sector of the Brenta river megafan (Fontana et al., 2014). At that time, the area experienced strong alluvial deposition, whereas sedimentation was almost lacking between the end of the LGM and the early Holocene, when paralic deposition started (Amorosi et al., 2008). The Venice Lagoon formed during the last 7500 years as a consequence of Holocene transgression, which promoted formation of lagoon – estuarine – barrier systems in the Northern epicontinental Adriatic shelf through flooding of the LGM alluvial plain (Zecchin et al., 2009). In the eastern sector of the Venice Lagoon, the Holocene lagoonal deposits have a maximum thickness of 14 m near the investigated area (Canali et al., 2007; Tosi et al., 2007). Salt marshes and tidal flats are drained by a dense network of sinuous channels, with a landward decrease in cross-sectional area. The Venice Lagoon is limited by the deltaic system of Piave River, to the northeast, and by the system of Brenta, Adige and Po rivers, to the southwest. The investigated area was partly affected by late Holocene activity of Piave River, that used to flow inside the lagoon basin until the 17th century, when it was artificially diverted out of it, with the aim of preventing siltation (Bondesan and Furlanetto, 2012).

2.2. The study site

The study site is located in the San Felice salt marsh (Fig. 1B, C), which is colonized by dense halophytic vegetation species (such as *Limonium*, *Juncus* and *Salicornia*) and represents one of the most naturally preserved portions of the Venice Lagoon (Marani et al., 2003; Roner et al., 2016). This area is characterized by mean temperature value of about 11 °C and water salinity around 32 psu (Venier et al., 2014). During winters, the Bora wind blowing from North-East (up to 18 m/s during storm events, Carniello et al., 2011), can generate waves, characterized by wave period comprised between 0.5 and 2.0 s and wave height up to 0.5 m, which impact against salt marsh margins and contribute to the flooding of salt marsh surfaces (Carniello et al., 2011; Marani et al., 2011). The average wind velocity is around 2.5 m/s, while turbidity values are about 22 FTU (suspended sediment concentration (SSC) around 20.7 mg/L; Venier et al., 2014).

The present study focuses on point bar deposits associated with an abandoned meander loop (Fig. 1D), that was formed by a 6 m wide channel cutting through the salt marsh. Analysis of historical photos reveals that the meander (neck) cut-off occurred during the 1950s (Rizzetto and Tosi, 2012) and caused progressive filling of the channel with muddy deposits, which started to accumulate on the seaward reach of the bend. The meander loop, oriented NW–SE, shows a "simple symmetrical planform" according to the nomenclature proposed by Hooke (2013) and has a radius of curvature of about 13 m (Fig. 1E). The inner bank area is characterized by a smooth topography (Fig. 2A), where scroll-bar morphologies are absent. The outer bank of the study channel is highlighted by a dashed gray line in Fig. 1E. Most of the channel fill-deposits are colonized by halophytic vegetation, although the landward reach of the bend is presently drained by a small rill, that cuts through the channel fill and bar top deposits (red line in Fig. 1E), converging into the main active channel.