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Sedimentology and ichnology of the fluvial reach to inner estuary of the Ogeechee River estuary, Georgia, USA

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ABSTRACT

Through the integration of sedimentological and ichnological observations, this paper explores the character of sediments deposited across the fluvio-tidal transition zone of the upper microtidal, mixed-energy, sand-dominated Ogeechee River estuary, Georgia, USA. A transect of tidally influenced to fluvial channel-bars and their facies variability is reported. Field and laboratory methods were employed, including observation of physical and biogenic sedimentary structures on the point-bar surfaces and in trenches, collection of grab samples, suction and box coring, grain size and total organic carbon analyses, optical microscopy, core logging, and daylight photography. The data presented in the paper can help in predicting facies changes across the fluvio-tidal transition of sand-dominated fluvio-tidal deposits in the rock record.

The lower inner estuary is characterized by medium-fine and fine-medium sand with planar and trough cross-bedding, small-scale ripple lamination, tidal sedimentary structures (flaser and wavy bedding, herringbone cross-stratification), abundant organic debris, and mud rip-up clasts. Bioturbation of the intertidal point bars is low, but cryptobioturbation is locally observed. Upper inner estuary deposits comprise coarse-medium- and medium-coarse-grained sand, and are characterized by faint high-angle planar and trough cross-bedding. Organic debris, mud rip-up clasts, herringbone and current-ripple lamination are rarely observed. Bioturbation is absent to sparse. The fluvio-tidal transition is represented by very-coarse- to coarse-grained sand and granules. Physical sedimentary structures constitute massive, graded planar and trough cross-bedding with abundant plant detritus. Except for rare *Siphonichnus*- and *Lockeia*-like traces, bioturbation is absent. The fluvial setting is characterized by coarse-medium sand with unidirectional cross-bedding, current-ripple lamination, and rare organic-rich mud clasts. Bioturbation is absent. Inner estuary and fluvio-tidal transition zones are bounded by supratidal marsh deposits, and may develop a substrate-controlled *Glossifungites* ichnofacies, comprising *Psilonichnus*-like burrows. The fluvial reach is surrounded by forested floodplain with crayfish domes and chimneys, forming *Camborygma*-like traces.

1. Introduction

With increasing interest in recognizing facies variability across the fluvio-tidal transition zone in the rock record, it is essential to provide analogs of modern estuarine systems, subject to variable fluvial and tidal fluxes. One analog is the Ogeechee River estuary, Georgia, USA. It serves as an excellent example of a sand-dominated, mixed-energy, upper microtidal to lower mesotidal estuary, where facies can be studied in detail from the inner estuary to the fluvial reaches. This paper focuses on establishing ichnological and sedimentological recognition criteria that can be used to better discriminate fluvial from inner estuary units in the rock record.

The fluvio-tidal transition zone (FTZ) within estuaries is defined at the inner end by the effective tidal limit and the bedload convergence zone at its outer end (Dalrymple and Choi, 2007). The FTZ is defined sedimentologically by Van den Berg et al. (2007, p. 289), who suggest that the FTZ is "the part of river that lies between the landward limit of observable effects of tidal-induced flow deceleration on fluvial cross-bedding at low river discharge and the most seaward occurrence of a textural or structural fluvial signature related to the high river stage". In this paper, the FTZ is determined by the predominance of fluvially supplied sediments, presence of freshwater (0–0.2 ppt) within the tidal backwater reach, and tidally modulated currents.

An understanding of sediment deposition across the FTZ is important to assigning paleo-environmental and sequence-stratigraphic interpretations of sedimentary successions (Dalrymple and Choi, 2007). The interest has peaked especially due to the exploration of large, bitumen-hosting, subsurface reservoir of the McMurray Formation

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interpreted to be deposited on fluvial and estuarine point bars (Stewart, 1963; Stewart and MacCallum, 1978; Pemberton et al., 1982; Wightman et al., 1987; Ranger and Pemberton, 1997; Hein et al., 2000, 2001; Hubbard et al., 2011; Musial et al., 2012).

A number of studies on the sedimentological and ichnological characteristics of the estuarine point-bars have been conducted (Dorjes and Howard, 1975; Howard et al., 1975; Clifton et al., 1976; Thomas et al., 1987; Dalrymple et al., 1992; Gingras et al., 1999; Choi et al., 2004; Pearson and Gingras, 2006; Hovikoski et al., 2008; Hauck et al., 2009; Choi, 2011; Johnson and Dashtgard, 2014; La Croix and Dashtgard, 2014; Dashtgard and La Croix, 2015). Several geological and biological investigations have been undertaken on the Ogeechee River estuary (Gadow, 1972; Dorjes and Howard, 1975; Howard and Frey, 1975a, 1975b; Howard et al., 1975), which documented and interpreted animal–sediment interactions in the Ogeechee River estuary and Ossabaw Sound. Their area of investigation included the outer (i.e., lower) part of the Ogeechee River estuary up to 52 km upstream. Mineralogical studies of Ogeechee and other Georgia estuary sediments were reported by Windom et al. (1971). Further research was carried in the mid-1990s with the study of Eocene and Miocene paleochannels forming the coastal plain of the Ogeechee River (Leigh and Feeney, 1995), and organic matter dynamics in the Ogeechee River (Meyer et al., 1997). The Ogeechee River estuary was revisited in 2007 to study the subtidal deposits of the tidal-fluvial transition zone in detail in order to characterize the subtidal ichnological trend of the estuary (Gunn et al., 2007, 2008).

This paper examines the sedimentological and ichnological changes within the uppermost reaches of the Ogeechee River and for continuity, it partially overlaps with the studies presented by Dorjes and Howard (1975), Howard and Frey (1975b), and Howard et al. (1975). This case study shows facies variability in point and channel-bar deposits across the inner estuary to the fluvial reach of the sand-dominated, mixed-energy, micro-to mesotidal estuary. Moreover, this study adds to the currently constructed depositional model of the fluvio-tidal transition zone. The Ogeechee River estuary was chosen for this study due to its accessibility and owing to the rich scientific dataset outlined above.

2. Study area

The Ogeechee River rises in the outer Piedmont area and flows southeast across the coastal plain, entering the Ossabaw Sound at the Atlantic coast, USA (Fig. 1). The river is 400 km long (Benke and Meyer, 1988), and has a very low gradient (~0.0002 m/m) within the coastal plain area (Benke and Meyer, 1988).

The modern Georgia coastal plain stretches from the present beach of the Georgia coast to the Piedmont Province (Fig. 1). The rocks of the Piedmont consist of pre-Cambrian, Paleozoic sedimentary and volcanic rocks, and Paleozoic plutons comprising granite, gneiss and schist, and belts of marble and quartzite (Gadow, 1972). The Ogeechee River is an important coastal plain river, and 90% of its drainage comes from the coastal plain area (Windom et al., 1971; Gadow, 1972; Dorjes and Howard, 1975). The Ogeechee River meanders freely across the coastal plain and erodes large sandy paleochannel deposits. The coastal-plain sediments are late Cretaceous (upper coastal plain) to late Quaternary (lower coastal plain) in age (Leigh and Feeney, 1995).

The river bed consists of sand with isolated patches of silt and clay (Leigh and Feeney, 1995). The sediments of the modern Ogeechee River are dominated by fine to coarse sand (Gadow, 1972) with the predominant mineral being quartz with minor amounts of plagioclase and orthoclase (Windom et al., 1971). Coarse-grained material is primarily supplied from the incised Pleistocene deposits (Howard and Frey, 1975b). Finer-grained material such as montmorillonite is sourced from the coastal plain with lesser amounts of kaolinite supplied from the Piedmont (Windom et al., 1971). The river sediments also contain a suite of stable heavy minerals with preponderance of staurolite, sillimanite, tourmaline and zircon (Gadow, 1972). The virtual absence of unstable heavy minerals suggests presence of chemical alteration and dilution of the weathered material during sediment transport (Gadow, 1972).

The tidal regime of the Ogeechee River estuary is upper microtidal to lower mesotidal with a mean tidal range of 2.4 m. The tidal range can reach 3.4 m during spring tides (Howard and Frey, 1975a). The estuary is mixed-energy with a large tidal prism and wave-generated shoals at the mouth (Greer, 1975; Gingras et al., 2012), oriented perpendicular to the coastline and is bordered by extensive salt marshes in its lower expanses and areas of pine and deciduous/cypress trees in its upper region (Dorjes and Howard, 1975; Howard and Frey, 1975b). The waters are turbid due to the abundance of organic detritus derived from the marshes and forested areas (Odum and De la Cruz, 1967). Howard et al. (1975) reported that the turbidity maximum is located within the middle reaches of the Ogeechee River estuary at all times (Bars 3–4, refer to Fig. 2). This zone is situated outside of the study area, and results from increased flocculation of fine sediment in the mixing zone where the salinity rise becomes apparent (Howard et al., 1975). Maximum turbidities shift downstream during ebb tide (Howard et al., 1975).

The climate in the area is subtropical with annual average water temperatures around 18.5 °C.Minimum water temperatures occur in January (7 °C), and maximum temperatures (28 °C) during July to August (Benke and Meyer, 1988). Mean annual precipitation ranges from 1000 to 1300 mm/year (Meyer, 1992; Leigh and Feeney, 1995; Meyer et al., 1997). The highest precipitation values occur between February and April, whereas the months of September to November have the lowest rainfall (Cuffney, 1984; Meyer et al., 1997). Due to heavy rainfall from February to April and more rarely in July (caused by the moist air masses coming from the Gulf of Mexico), the floodplain is often under water and in hydraulic communication with the channel itself, readily sourcing abundant organics to the river channel (Edwards and Meyer, 1987; Benke and Meyer, 1988; Cuffney, 1988; Meyer et al., 1997). The river pH is approximately 6.5 (Meyer et al., 1997). Its mean annual discharge is 66.8 $m^{3/}s$, and ranges from 3.7 to 850 $m^{3/}s$ (Benke and Meyer, 1988; Meyer, 1992). During the year of investigation (2014), the river discharge varied between 0.85 $m^{3/}s$ and 190 $m^{3/}s$, and was 28–55 $m^{3/}s$ during the period of fieldwork (Fig. 1c). The Ogeechee River bedload was estimated at 13 t/day, with the suspended sediment concentration of 25 t/day (Kennedy, 1964).

The focus of the study is the inner estuary and the fluvio-tidal transition zone into the fluvial reach. The inner estuary inclusive of the fluvio-tidal transition is located 20–63 km landward from the estuary entrance. Fourteen study locations were investigated during the course of the fieldwork (Fig. 2). Dorjes and Howard (1975) and Howard et al. (1975) study locations and transects are marked in Fig. 2.

During the course of the fieldwork, the tidally influenced channel bars were accessed by road and boat for the sedimentological and ichnological investigations. For the purposes of the study, the Ogeechee River estuary is subdivided into the lower inner estuary (Locations 1–3), upper inner estuary (Locations 4–7), fluvio-tidal transition (Locations 8–11), and fluvial reach (Locations 12–14). Surface water salinity measured within the study area varies from freshwater (0–0.5 ppm) to oligohaline (0.5–4 ppt). Salinity changes with the tidal cycle and seasonally, depending on fluvial discharge. Additional salinity and current data for the inner estuary are available in Dorjes and Howard (1975), where it is reported that within the lower inner estuary (Transect II, Fig. 2) salinity ranges between 0.3 and 12 ppt: salinity at the surface varies between 0.3 and 2 ppt, whereas salinity near the channel bottom increased from 0.3 ppt at low tide to 12 ppt at high tide. The upper inner estuary (Transect I, Fig. 2) is characterized by the predominance of freshwater, where salinity ranges from 0 to 0.2 ppt with no difference between the surface and bottom waters (Dorjes and Howard, 1975). Flood–current velocities within the lower inner estuary (Transect II, Fig. 2) reach 0.41 m/s and are 0.51 m/s during the maximum ebb tide (Dorjes and Howard, 1975). Flood–current velocities within the upper