Stratigraphic models for microtidal tidal deltas; examples from the Florida Gulf coast

Richard A. Davis Jr. a,*, C. Kelly Cuffe b, Katherine A. Kowalski a, Eric J. Shock a

a Coastal Research Laboratory, Department of Geology, University of South Florida, Tampa, FL 33620, USA
b California Coastal Commission, 725 Front St., Suite 300, Santa Cruz, CA 95060, USA
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Abstract

Extensive vibracoring of both flood- and ebb-tidal deltas along the central Gulf Coast of the Florida peninsula reveals a strong overall similarity with subtle distinctions between flood and ebb varieties. Although the coast in question is microtidal, the inlets range from tide-dominated to distinctly wave-dominated. Both types of tidal deltas overlie a muddy sand interpreted to have been deposited in a back-barrier environment. The sharp contact at the base of the tidal delta sequence is typically overlain by a thin shell gravel layer. The ebb-tidal delta sequence is characterized by fine quartz sand with shell gravel in various concentrations; coarse and massive at the margins of the main ebb channel, and finer and imbricated at the marginal flood channels. The flood-tidal deltas are characterized by the same facies but with a small amount of mud. Shelly facies on the channels on flood deltas are not as well developed as on the ebb deltas. The combination of the stratigraphic sequence and the lithofacies make tidal deltas readily identifiable in the ancient record. The differences between flood and ebb varieties are subtle but consistent. © 2003 Elsevier B.V. All rights reserved.

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1. Introduction

Tidal deltas represent a primary sediment sink on barrier island coasts and are also among the most preservable depositional environments in the barrier island system. They are important elements in coastal management, and are reservoirs for production of oil and gas. Given their importance in both the modern coast and the ancient stratigraphic record, it is critical to have a good understanding of their stratigraphy and geologic development.

The Gulf Coast of peninsular Florida provides an excellent setting for studying these sediment bodies in detail because it contains tidal deltas having both variety and accessibility. The objective of this part of a comprehensive investigation of this barrier/inlet system is to produce stratigraphic models for tidal deltas that are applicable throughout the subject coast, and that can be applied to other parts of the Gulf Coast and be-
The synthesis of three separate investigations of both flood- and ebb-tidal deltas provides data from three flood-deltas and three ebb-deltas that can be summarized into models that represent this coastal regime.

1.1. Coastal setting

The barrier/inlet system of the Gulf Coast of peninsular Florida is a low-energy (Tanner, 1960), microtidal (Davies, 1964) coast that can best be described as mixed energy (Davis and Hayes, 1984). The coast to the north is a tide-dominated, open coast marsh system (Hine et al., 1988) and south of this barrier system is a tide-dominated coast characterized by mangroves (Davis et al., 1992). Although this coast experiences a maximum tidal range of about 90 cm, it displays the most varied barrier island/tidal inlet morphologies in the world (Davis, 1989). This system includes both wave-dominated and mixed-energy or drumstick barriers, and the entire spectrum of tidal inlet and tidal delta morphologies (Davis, 1997).

1.2. Coastal processes

Processes that influence this barrier/inlet system are dominated by tropical storms and by frontal systems that pass during the winter. Prevailing winds are gentle and have a southerly component; influenced by the Bermuda High over the central Atlantic (Henry et al., 1994). These southerly winds prevail from about April through October but are also present during the remainder of the year. Cold fronts move across the Gulf of Mexico from the northwest and pass over this coast from late October through mid-March. They range in intensity and periodicity but they typically pass at about 7–10 day intervals. These weather systems dominate the annual coastal process climate and produce a southerly regional longshore sediment transport (Hine et al., 1988; Davis, 1989).

Hurricanes are not frequent along the Florida Gulf Coast (Henry et al., 1994) but they have played a major role in the formation of inlets and associated tidal deltas. Although no hurricane has made landfall in the study area since 1921, the passage of these storms through the Gulf of Mexico has influenced coastal processes in this area. Examples are hurricanes Elena and Juan (1985), Opal (1995), and Josephine (1996). Each caused significant sediment transport and coastal change along the barrier/inlet system of the study area. The hurricanes of 1848 and 1921, while not documented in detail, were the most prominent storms of record along the study area. They opened tidal inlets, Johns Pass and Hurricane Pass, which have persisted to the present time (Mehta et al., 1976; Lynch-Blosse and Davis, 1977).

Mean annual wave height along the coast of the barrier system is only 30–40 cm and the mean period is 4–5 s (Tanner, 1960; Davis and Andronaco, 1987). Frontal systems during the winter produce breakers of 1 m or more. These storms also generate waves that move through the surf zone at angles of up to 20° with the shoreline (Wang, 1995; Wang et al., 1998) producing longshore currents that reach velocities of nearly 1 m/s. Such conditions cause rapid transport of sediment through the surf zone but the bimodal wind and wave approach directions result in a modest annual littoral transport; typically less than 50,000 m³ (Mehta et al., 1976).

2. Study areas

This report represents a synthesis of three master theses by Cuffe (1991), Kowalski (1995) and Shock (1994) at five different inlets. Three flood-tidal deltas and three ebb-tidal deltas are included. The inlets and their included elements are Hurricane Pass (flood and ebb deltas), Johns Pass (flood delta), New Pass (ebb delta), Big Sarasota Pass (ebb delta), and Midnight Pass (flood delta) (Fig. 1). Two of these inlets (Hurricane Pass and Johns Pass) were cut by hurricanes during historical time, but the origin and age of the other tidal inlets are unknown.

All of the flood-tidal deltas are multilobate. Only Johns Pass displays distinct channels that separate individual lobes and only Hurricane Pass has a completely subtidal flood delta. The ebb-tidal deltas range in configuration but all are significantly wave influenced with a distinct
asymmetry in the direction of dominant longshore drift. The area of the flood deltas ranges from $3.37 \times 10^5$ m$^2$ to $4.42 \times 10^5$ m$^2$, and that of the ebb deltas is from $4.4k \times 10^5$ m$^2$ to $31.05 \times 10^5$ m$^2$ (Table 1).

### 3. Data collection and analysis

The primary means for collecting stratigraphic data from these tidal deltas is through vibracores. The technique for coring and recovery followed modifications of that originally described by Lanesky et al. (1979). Most of the coring was accomplished utilizing a pontoon coring barge similar to that described by Stone and Morgan (1992). Core recovery ranged from less than 1 m to more than 5 m in length (Table 2). Coring of flood deltas was generally more efficient than on ebb deltas because of the tendency for waves to sort and pack sediments thereby making penetration difficult on the open coast. Flood deltas also tend to have more mud content which facilitates core penetration. This coring program resulted in a total of 89 cores, distributed as shown on Table 2.

Cores were split and visually described using standard techniques. They were photographed

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**Table 1**

<table>
<thead>
<tr>
<th>Tidal Delta</th>
<th>Type</th>
<th>Area (m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hurricane Pass</td>
<td>Flood</td>
<td>$4.42 \times 10^5$</td>
</tr>
<tr>
<td>Hurricane Pass</td>
<td>Ebb</td>
<td>$4.15 \times 10^5$</td>
</tr>
<tr>
<td>Johns Pass</td>
<td>Flood</td>
<td>$3.37 \times 10^5$</td>
</tr>
<tr>
<td>New Pass</td>
<td>Ebb</td>
<td>$9.65 \times 10^5$</td>
</tr>
<tr>
<td>Big Sarasota Pass</td>
<td>Ebb</td>
<td>$31.05 \times 10^5$</td>
</tr>
<tr>
<td>Midnight Pass</td>
<td>Flood</td>
<td>$4.13 \times 10^5$</td>
</tr>
</tbody>
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and sampled for textural analysis. Lacquer/fiber-glass peels were made of several cores to highlight sedimentary structures. These data provided the basis for the designation of the lithofacies described in the following section.

4. Lithofacies

The tidal delta sequences along the west-central Florida coast contain four lithofacies; three compose the tidal deltas themselves and the fourth underlies the tidal deltas (Table 3). The three facies of the tidal deltas are transitional among each other with the two major variable elements being fine quartz sand and shell gravel (SG).

4.1. Muddy shelly sand (MSS)

This facies has up to 25% mud and 20% shell mixed with fine, well-sorted quartz sand. Locally, in the basal portion of the facies, the mud includes up to 5% particulate organic matter. The shell is dominantly bivalves and consists of both fragments and whole shells which are randomly arranged (Fig. 2D). Shell material decreases upward in the facies and the shell material near the top is abraded and bored; not as fresh in appearance as that in the lower portion of the facies. The vast majority of this facies is characterized by bioturbated, MSS. Few distinct burrows are preserved and articulated bivalves are present but uncommon. Distinct shell beds are rare due to prevalent burrowing.

This facies is found beneath some combination of the three clean, tidal delta facies and reaches several meters in thickness. The contact with the overlying mud-free facies is sharp at all locations. Where this unit is completely penetrated the underlying unit is either iron-stained, Pleistocene sand or Miocene Tampa limestone.

4.2. Shell gravel (SG)

Although there is some gradation in abundance of shell in this facies as compared to the SS, the nature and fabric of the shell component is distinctly different. This facies has at least 25% shell and commonly it is about 50%. The SG is composed primarily of whole bivalve shells that are up to 3cm in diameter. The shells are neither sorted nor layered as viewed in the cores (Fig. 2C). It is possible that because of their size, the layering has been destroyed by the coring process. As in the other facies, the quartz sand is fine and well-sorted.

Maximum thickness of this facies is at least 3.0m and it is confined to areas adjacent to the main channel of ebb-tidal deltas.
4.3. Shelly sand (SS)

This facies is characterized by up to 25% shell mixed with fine, quartz sand (Fig. 2B). There is shell debris scattered throughout the unit but it occurs in highest concentrations as distinct shell layers. Nearly all shell is bivalve debris and is less than 1cm in diameter. The shell mode itself is well-sorted and shell fragments tend to be well-imbricated. There is more shell and the shell fragments are more bedded in the ebb-tidal deltas as compared to the flood-tidal deltas. This facies is up to 2.0 m thick and is not laterally extensive.

4.4. Quartz sand (WSS)

The most homogenous of the lithofacies is the quartz sand. It is composed of fine, well-sorted sand (Fig. 2A) that typically is free of mud and shell although both may be present locally in

Fig. 2. Photographs showing each of the lithofacies included in the tidal delta stratigraphic models; oldest to youngest: (D) muddy shelly quartz sand, (C) shelly quartz sand, (B) sandy SG, and (A) quartz sand.
small amounts. This shell component is present in distinct layers in which the shell fragments are less than 1 cm in diameter. Mud may be present as scattered flasers or as burrow linings in the lower portion of the facies. It is more abundant in flood deltas than in ebb deltas.

The uniform nature of the sand is such that no vertical trends in grain size are detectable. The appearance of the sand is massive to plane-laminated with the laminations being best displayed by the presence of minor amounts of fine shell. Thickness of this facies exceeds 5.0 m in the ebb delta at Big Sarasota Pass (Fig. 3) but is typically less than 2.5 m thick in the other ebb and flood tidal deltas (Fig. 4). This facies is found throughout both flood and ebb deltas and is the most widespread of the tidal delta facies.

5. Distribution and environmental interpretation of facies

Coring in modern tidal deltas provides direct information on the environmental significance of the lithofacies and their geographic and stratigraphic distribution (Figs. 5-10). The fact that two of these inlets were formed by hurricanes during historical time further permits the details of the environmental significance of the tidal delta facies to be documented. Aerial photographs also aided with these interpretations. This was particularly beneficial in the case of Hurricane Pass which was formed in 1921 and for which aerial
photography is available from 1926 to the present.

5.1. Muddy shelly quartz sand (MSS)

This basal Holocene facies is the most wide-

spread lithofacies throughout this barrier system (e.g. Davis and Kuhn, 1985; Evans et al., 1985; Gibbs and Davis, 1991; Davis et al., 1992). It is at least a few meters thick, it is continuous (Figs. 5-10) and various shells in it have been dated at 4-6 kyr BP (Gregory, 1984; Davis and Kuhn, 1985;
Gibbs and Davis, 1991), placing it about mid-Holocene in age.

The basal part of the unit contains, at most, a few marine shells and has a relatively high content of organic matter including recognizable plant fragments. This is interpreted to represent a paralic vegetated environment similar to the combined salt marshes and mangrove mangal habitats that inhabit some of the study area at the present time.

All of the characteristics of this facies suggest a protected, low-energy environment similar to the
present back-barrier environment along this coast. Although the radiometric dates obtained for this unit are much older than known ages for the barriers (Stapor et al., 1988), it is possible that older, more Gulfward barriers were present at this time or that the facies represents a low-energy open coast such as now exists to the north of the study area. New information on radiocarbon ages for beach and backbarrier deposits at Siesta and Casey Keys (Fig. 1) indicate that older barriers were present in that area (Spurgeon et al., 2003; Davis et al., 2003).

5.2. Shell gravel (SG)

This facies is the most geographically restricted of any of the lithofacies present in the tidal deltas (Figs. 5–7). It may be at least 3m thick and it decreases in thickness away from the ebb channel. It is present in both New Pass and Big Sarasota Pass but was not recovered in any of the cores from Hurricane Pass (Fig. 1). There is a thin layer of this facies on the floor of one of the channels in the Johns Pass flood delta (Fig. 9).

The nature and location of this facies within the ebb-tidal deltas indicate that it is a channel-margin lag deposit, primarily on the ebb deltas. The concentration of large pieces and whole shells, the thickness and the presence of similar deposits along the sides and floor of the present channels supports this interpretation. These shell concentrations are the result of tidal currents that remove the sand and fine shell thereby concentrating the larger shell material.

5.3. Shelly quartz sand (SS)

The shelly quartz sand facies is present on both flood and ebb deltas but is most prominent in ebb deltas (Figs. 6–10). The distribution is fairly widespread but shows affinity for the small flood-dominated channels on ebb deltas such as in New Pass and Big Sarasota Pass (Figs. 6 and 7). It is also present on the flood deltas (Figs. 8–10). The environment of deposition combines wave-generated currents with shallow sandy areas causing plane bed conditions that produce isolated shell layers. These shell lag concentrations are associated with modest tidal currents in the small channels. These channels may be the flood-dominated channels of the ebb deltas or the numerous channels of the shallow subtidal flood deltas such as at Hurricane Pass.
Fig. 11. Stratigraphic model of (A) an ebb tidal delta, and (B) a flood delta. The ebb delta section shows relatively high concentrations of shell beds and mud is nearly absent as compared to the flood delta section.

5.4. Quartz sand (WSS)

The quartz sand facies is typical of both flood and ebb deltas and is the most widespread of the three, clean tidal-delta facies. It is commonly 1–2 m thick and continuous on individual tidal deltas but discontinuous on the Johns Pass flood delta where channels cut below its base (Fig. 9). This facies does, however, display some differences in its character between ebb deltas and flood deltas. The ebb deltas have no mud and shell material is rare. By contrast, this facies may have mud on the flood delta and shells are generally more common than on the ebb deltas. This facies represents the wave-dominated conditions of the ebb delta, and the combined wave and tidal conditions of the flood delta. Physical energy levels on the ebb delta are higher than on the flood delta as reflected in the presence of mud and the fact that there are some sea grass stands and mangrove mangals on the flood deltas (Fig. 11).

6. Stratigraphic models

Although there are many similarities in the distribution and character of the four lithofacies described above, there are enough subtle differences to justify separate stratigraphic models for the flood and ebb tidal deltas. The differences in geomorphology and in the dominant physical processes (waves or tidal currents) produce distinctly
different stratigraphy in the ebb and the flood deltas.

6.1. Ebb delta

All four lithofacies are typically present in the ebb tidal delta model. The basal unit is the MSS facies that is the pre-tidal delta unit. The contact at the base of the tidal delta sequence is typically sharp and typified by a shelly concentration. Although there is no physical evidence for scour at the base of the unit, the nature of the conditions at initiation of storm-generated tidal deltas and the presence of the shell concentration suggest such an origin for the contact.

Most of the volume of the ebb delta is composed of the quartz sand facies that represents the wave-dominated portion of the sediment body. Gravel size shell debris is rare and mud is absent as a result of these energetic conditions. The SG facies represents main ebb channel conditions and may be as thick as the entire sequence (Fig. 11). It may even exceed the combined thickness of the other facies if the ebb channel is deeply incised. The overall thickness of the ebb delta sequence is typically only a few meters but it can range up to at least 6 meters. The shelly quartz sand facies is typically present near the upper part of the sequence representing marginal flood channels. Thickness is typically less than 1 m but it may be completely absent in some ebb delta sequences.

These ebb delta sequences contrast to those described from the mesotidal South Carolina coast (Imperato et al., 1988) where mud is present and shells are not a common constituent.

6.2. Flood delta

The flood delta sequence contains at least two or three of the lithofacies discussed earlier; it is rare that all four are present. The thickness of the flood delta is typically only a few meters. There may be multiple lobes and multiple periods of activity shown in the stratigraphy of this sediment body complex. The SG facies is typically absent because physical energy in the channels is not high enough to concentrate large shells.

The base of the sequence is the muddy, shelly quartz sand on which rests the flood delta itself. The sharp contact is similar to that of the ebb delta and probably represents scour as the overlying flood delta sediments moved over the back-barrier environment. Most of the flood delta sequence is comprised of the quartz sand facies with some of the shelly quartz sand that represents the small channel areas where concentrations of shell debris are common. There is noticeable mud in several places in the form of flasers and burrow linings. The presence of these on the flood delta reflects the lower energy conditions. This is true of both the waves that are only those developed in the fetch-limited, back-barrier area, but also the tidal currents that are more sluggish on the flood delta than in the main ebb channel of the ebb delta (Hayes, 1975, 1980).

7. Summary

These simple but useful stratigraphic models are important tools for the overall management of barrier-inlet systems in that they provide us with information on the expected thickness and stratigraphy of the sand bodies. Such information is important in considering burrow areas for nourishment, dredging for navigational purposes and environmental characteristics related to various plant and animal communities and landfall of oil spills.

The models also provide a useful tool to enable researchers investigating ancient coastal depositional sequences to make decisions about environments of deposition, especially when comparing flood tidal deltas with washover deposits. The reader will find it very helpful to compare the flood delta model with the model presented in the paper on the stratigraphy of washover deposits presented in a companion paper (Sedgwick and Davis, 2003).

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