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Landscape Classification and Terminology for Marsh in Deficit Coastal Lagoons

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ABSTRACT

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Marsh development in coastal barrier lagoons is governed by sea-level fluctuation, sediment input and the antecedent character of the lagoon floor. Shores associated with the mainland and barrier island provide a variety of different platforms for marsh colonization. During the Holocene transgression, low marshes along the basin boundaries tended to be submerged into the lagoonal bays, whereas high marshes tended to spread over newly inundated surfaces.

Along the mainland side of lagoons, the distribution of fringe-marshes is primarily related to the complexity of terrestrial topography. When mainland boundaries are relict beaches, then mainland fringe-marshes tend to be linear and coast parallel. However, when the mainland shores form over mature drainage topography, serrated shorelines are produced with a variety of different marsh patterns. The degree of wave-exposure and variations in sedimentation rate produce different environments for marsh colonizations. The main marsh sites along the mainland are in stream valleys, on interfluves, at headlands, around hammocks and on intertidal islands. Maintenance of marshes is related to the relative rate of sea-level rise with respect to the rate of sediment accumulation on marsh surfaces.

The configurations of marshes in the centers of lagoons are primarily dependent on the submergence of locally high topographies and the degree to which sedimentation is able to offset submergence.

Fringe marshes along the backbarrier side of barrier islands are less dependent on antecedent topography. Cross-island sediment transfer is the main process providing platforms suitable for marsh colonization. The main sites for backbarrier marsh colonization are on washover fans, storm-surge platforms, swales between beach ridges, intertidal portions of flood deltas and antecedent highs.

ADDITIONAL INDEX WORDS: *Coastal barriers, sea-level change, coastal marsh, barrier island, storm surge, beach ridge, delta.*

INTRODUCTION

Barrier lagoons are basins formed by barriers separating the sea from the land. Early work on barrier lagoons was done in carbonate environments of the tropical seas around volcanic islands where lagoons formed behind barrier reefs (Darwin, 1842; Dana, 1885). However, along clastic coasts, barrier lagoons form behind barrier islands, barrier spits and bay-mouth barriers. While the environments of deposition associated with carbonate and siliciclastic lagoons are dissimilar, they are both "true" barrier lagoons in that they separate the inner and outer shorelines of a dual-shoreline coast. Barrier lagoons are transitional zones between the sea and land, and marsh evolution in these basins is influenced by characteristics of both environments.

The following discussion of marsh evolution and classification is for siliciclastic coasts and considers the relative importance of primary landscape features, sedimentation rate and sea-level rise.

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HYPSOMETRY AND MARSH DISTRIBUTION

Barrier lagoons with large open-water areas (bays) have been termed "open-water lagoons". Lagoons with large areas of marsh coverage have been called "marsh-filled lagoons" or simply "marsh lagoons" (Oertel and Dunstan, 1981). The terms marsh lagoon and open-water lagoon describe "end-member states" of lagoonal landscape and marsh distribution. In open-water lagoons, the lagoonal tidal prism is directly related to tidal range. However, in marsh lagoons with numerous tidal flats, marshes and intertidal channels, the "wetted" hypsometric relationship clearly changes when water spills out of the channels and over tidal flat and marsh surfaces (Oertel and Dunstan, 1981; Eiser and Kjerfve, 1986). It is as apparent that the terms describing the end-member states are inadequate to describe the

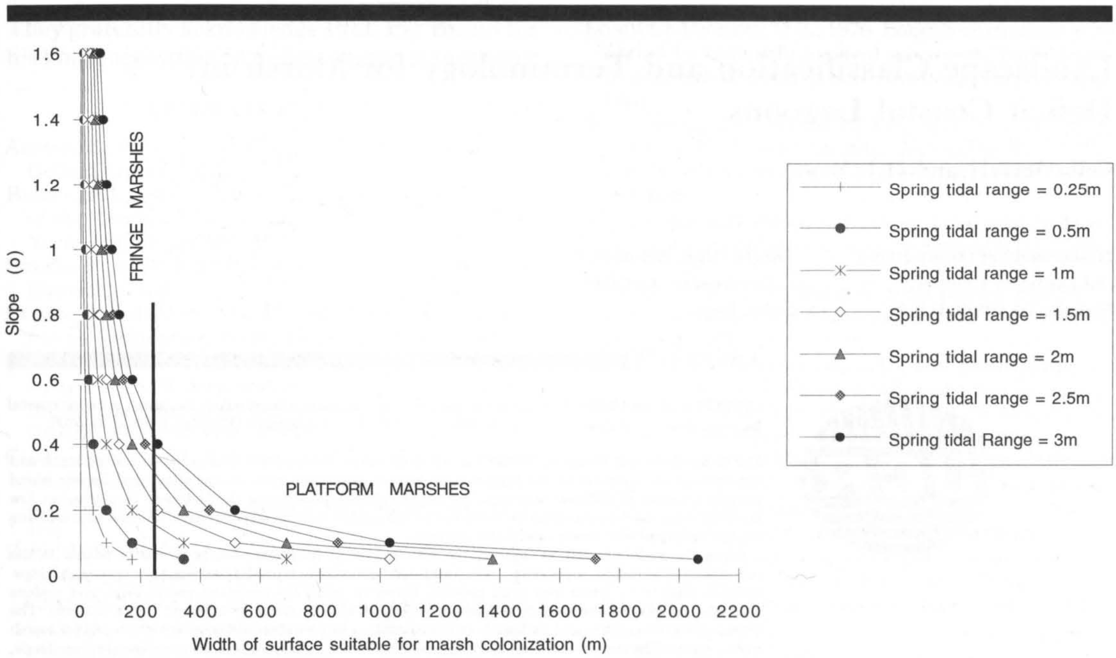

Figure 1. Graph showing the effect of tidal range and platform slope on marsh width.

many different marsh environments within a lagoon.

All wave protected surfaces between mean sea level (MSL) and highest high water (HHW) are potential surfaces for marsh colonization and the size of a lagoonal marsh is dependent on the hypsographic state produced by tidal range and slope (Figure 1). Microtidal marshes may be considerably smaller than mesotidal marshes because of limited surface area between mean sea level and highest high water. Large marshes in microtidal areas clearly require very low slopes. However, meso- and macro-tidal areas are less slope dependent (Figure 1).

The variety of different environments in barrier lagoons is primarily related to elevation and location within a lagoon. The deep open-water parts of the lagoons are tidal channels, bays and sounds. Shallow open-water areas with low relief form flats and shallow bays.

The tidal hypsography of a barrier lagoon is closely dependent on two different and distinct processes of lagoon formation and evolution (OERTEL *et al.*, 1992). Barrier lagoons occur in two major landscape groups that are related to the origin of barrier islands. The general distribution of marshes in these lagoons reflects their origin and evolution. Lagoons may form by the embayment of a portion of the nearshore zone by virtue of a migrating spit (see GILBERT, 1885). These lagoons which are initially too deep for colonization by marsh plants are generally bordered by narrow fringe-marshes (see SHALER, 1885; GARDNER and BOHN, 1980). The marshes generally represent less than 15% of the total surface area of the barrier lagoon and are confined to the margins of the basins (see HAYDEN and DOLAN, 1979; OERTEL and DUNSTAN, 1985). Expansion of these marshes is dependent on patterns of basin fill (LUCKE, 1934) and the relationship between basin capacity and the rate of sediment input (NICHOLS, 1989). At sediment-deficit basins, the percentage of open-water area increases with respect to marsh surface area. At sediment-surplus basins, the amount of open-water area decreases as marshes spread outward from the basin boundaries and shallow areas (LUCKE, 1934). At transgressive time scales, capacity is strongly influenced by relative sea-level rise and basin hypsometry (OERTEL *et al.*, 1992).

Lagoons also form by inundation of the coastal plain (HOYT, 1967; MCGEE, 1890). MUDGE (1858) initially described the growth of marsh over formerly terrestrial surfaces following slow submergence of the coastal plain (see description in GARDNER and BOHN, 1980). OERTEL *et al.* (1992) described the initial coastal lagoons as marsh-filled basins. Marshes covered a majority of the wetted surface behind the barrier islands, whereas open-water areas were limited to channels and shallow bays. The distribution of marshes is dependent on the submergence of the terrestrial surface by rising sea-level. Since global transgression is a characteristic of Holocene time, the formation of lagoons and lagoonal marshes by coastal inundation is extensive. A wide variety of hypsographic conditions are produced as the Holocene sea transgresses over the irregular terrestrial surface, and marshes may expand and shrink independent of sedimentation rate (see STRAHLER, 1952; BOON and BYRNE, 1981).

LAGOON TYPE AND HIERARCHY OF MARSH CLASSIFICATION

The barrier lagoon is one of the six major elements of a barrier island system (OERTEL, 1985). The distribution of subenvironments in barrier lagoons is primarily related to hypsometric conditions associated with water depth (Figure 1). Thus, viable models of marsh evolution must consider the evolving hypsographic characteristics of each of these subenvironments during transgression. The regional relationship between wave and tidal regimes establishes the initial framework for evolving lagoonal environments. Barrier lagoons formed by spit growth along wave-dominated coasts are initially relatively deep, with open-water features. They may get progressively shallower through upbuilding by rapid siltation. However, the rate of upbuilding must exceed the rate of relative sea-level rise before the basin floors can shallow to depths acceptable for marsh colonization. Along tide-dominated coasts, barrier lagoons are initially shallow and many surfaces are initially suitable for marsh colonization (OERTEL *et al.*, 1992). Rapid relative sea-level rise may cause the submergence of viable surfaces for marsh colonization.

A hierarchial classification of marshes is proposed which initially divides the lagoon into three zones that form and evolve by different processes (Table 1). Mainland fringe-marshes, mid-lagoon marshes and backbarrier fringe-marshes have distinct landscapes and facies. Expansion or contraction of marsh surfaces in each of these zones illustrates how, and whether a lagoonal basin is being filled with sediment or flooded with water.

Table 1. *Classification of marshes in coastal barrier lagoons.*

Landscape Setting	Marsh Name
Mainland fringe-marshes	Valley marsh
	Headland marsh
	Interfluve marsh
	Hammock marsh
	Tidal-channel marsh
Mid-lagoon marshes	Tidal-channel marsh
	Marsh islands
	Platform marsh
	Hammock marsh
Backbarrier fringe-marshes	Washover-fan marsh
	Storm-surge platform marsh
	Swale ("finger") marsh
	Flood-delta marsh
	Platform marsh

Mainland Fringe-Marshes

The shape of fringe marshes along the mainland side of a lagoon is controlled by the configurations of the antecedent mainland shoreline. This configuration is dependent on the origin of the associated barrier islands and lagoons. Along wave-dominated coasts, relict ocean beaches are embayed by migrating spits and barriers (HOYT and HENRY, 1967; KUMAR and SANDERS, 1974; FISHER, 1967, 1968). The mainland shorelines associated with these barrier lagoons are often linear and relatively steep ($\approx 1°$). The initial development of fringe marshes are usually contiguous with these straight shorelines. However, during the Holocene transgression, many of the mainland shores migrated landward of the relict shores and onto the drainage-scarred antecedent topography of the coastal plain (OERTEL *et al.*, 1992). In these areas, the mainland shoreline of the lagoon becomes very crenulated as the lagoonal water intersects valley and headland contours. The landscape characteristic of the antecedent surface is another important factor controlling the type of marsh that may form along the mainland boundary. The following discussion is a description of the various types of marshes that occur along the mainland boundary.

Valley marshes are located in the valleys of streams that drain into the barrier lagoon (Figure 2). The main characteristic of these marshes is that they are completely surrounded by the mainland, and are well protected from higher-energy lagoonal events. Since they trend parallel to drainage, they are generally elongate in the coast-normal direction. Relatively steep valley walls provide sources of sediment to the valley floor.

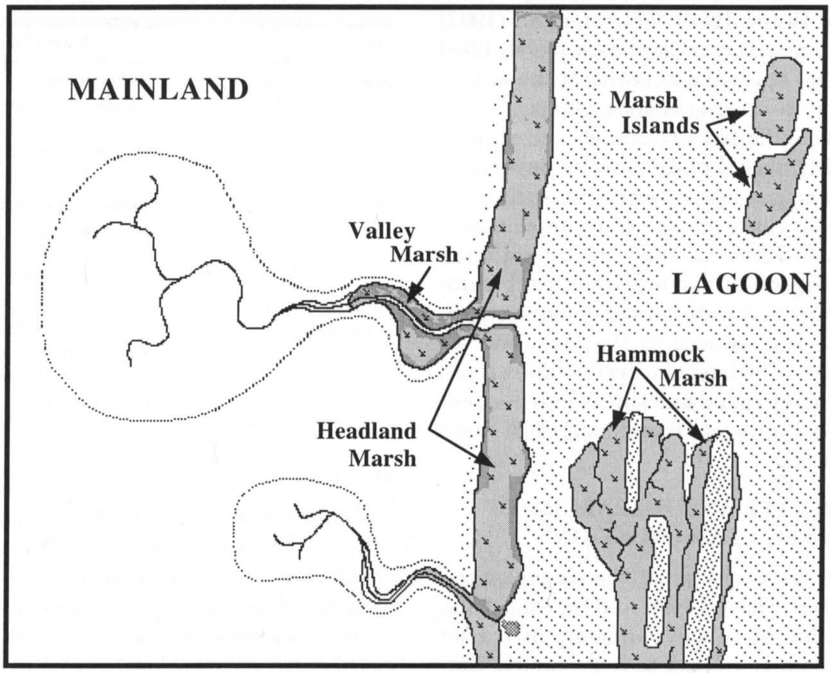

Figure 2. Schematic sketch of the mainland boundary of a hypothetical coastal barrier lagoon illustrating the landscape patterns of valley marsh, headland marsh, hammock marsh and marsh islands.

However, other significant sources of sediment come from organic accumulations and landward sediment transport caused by time-lag asymmetry in ebb/flood flow and grain settling (POSTMA, 1967). High rates of sediment input from the surrounding watershed result in fine-grained fill at valley margins forming platforms for marsh colonization. The size of the marsh is closely related to the topographic maturity of the part of the watershed that intercepts the upper part of the tidal zone. Near the tidal head of a stream, marshes are extensive and essentially fill the valley surface between the valley walls. Thus, the cross-sectional area of the tidal creek is considerably smaller than that of the antecedent valley. Tidal flushing and scour is confined to a narrow, steep-sided tidal channel in the center of the marsh-filled valley. Although very muddy, tidal channel walls on the stream margins can be very steep with slopes greater than 45°. This type of valley fill has been described by FLETCHER *et al.* (1990) for the upper parts of small tidal estuaries along the margins of the Delaware Bay. The rate of sediment input into these valley systems is generally equal to, or greater than, the rate of capacity increase caused by sea-level rise. As sea-level rises, relatively thick upbuilding sequences of marsh facies are possible between valley walls. The preservation potential of these fine-grained deposits is relatively good because sedimentation is rapidly forming thick sequences in valleys with relief of 5–15 meters. During transgression, the upper part of the sequence may be truncated and capped by coarser lagoonal/bay deposits.

Headland marshes are located on the headlands of necks (interfluves) between the valleys that drain into the lagoon (Figure 2). They are exposed or partially exposed to the open-water sections of the lagoon. Their orientation is dependent on the orientation of the mainland shoreline of the lagoon. Lagoonal shorelines formed on relict beaches are relatively straight and coast parallel. However, lagoonal shorelines formed by the inundation of youthful and mature drainage may be extremely irregular and crenulated. The degree to which marshes form a contiguous border along the mainland fringe of the lagoon is directly related to the drainage density of mainland watersheds. Low-order watersheds tend to be closely spaced and therefore the marshes that form on the headlands between these drains are "stubby". At small watersheds with only intermittently active drains, headland fringe-marshes often form across the mouths of the watershed forming a contiguous border along the mainland fringe of the lagoon.

The widths of headland marshes are primarily controlled by the slope of the mainland shore. Sediment runoff from the mainland and silt trapping in the marsh interior may also play an important role. Slopes may vary from 1° to 3° at scarps of relict beachfaces to less than 0.05° on terraces and plains. The resulting difference in the width of the marsh caused by inundation can be substantial (Figure 1). Steep slopes tend to increase the potential rate of coarse-grained sediment input, whereas gentler slopes tend to increase the extent of inundation by rising sea-level. The upper part of the fringe marsh often has lenses of coarse-grained silt and sand from soil runoff. The uppermost reaches of the headland marshes along the coastal lagoon of the temperate southern Delmarva Peninsula are bordered by *Distichlis* peats which achieve thicknesses of about 30–40 centimeters above the antecedent soils. These high-marsh areas support typical high-marsh flora, such as *Juncus* sp., *Spartina* sp., *Distichlis* sp., *Salicornia* sp., and short-form *Spartina a.* on a relatively firm sediment foundation. Peats are absent or far less common along the fringe-marshes of subtropical regions of Georgia and the Carolina's (FREY and BASAN, 1985). In the transitional areas between high and low marsh, lenses of coarse sediment runoff are inter-fingered (and biogenically mixed) with the muds that accumulate from suspended sediment settling at the more frequently wetted sections of marsh. The lower edge of the marsh is typically colonized by long-form *Spartina a.* in a very soft fluid mud.

In some areas, the combination of sediment runoff from the mainland and silt trapping in marshes has produced sedimentation rates approximately equal to local relative rates of sea-level rise. In these areas, the width of the marsh is maintained or may even increase during sea-level rise. Insufficient sediment input coupled with erosion by bay waves commonly produces a slow recession of the marsh shoreline. The seaward edge of the headland marshes often has a small step onto the adjacent tidal flats.

Brockenberry Creek and Cobb Mill Creek, Virginia, are small watersheds which drain into a barrier lagoon system on the southern Delmarva Peninsula. The headland marsh between these two creeks is exposed to open water of the coastal lagoon. OERTEL *et al.* (1989b) determined the sedimentation rates across this marsh using Pb-210 radiogeochronology from a transect of cores across the marsh. The average sedimentation rate was about 1.7 mm/yr. However, the rate varied from 2.2 to 0.7 mm/yr along the 200 meter long transect across the marsh. The variations appeared to be related to lenses of sand and organic detritus. The average sedimentation rate (1.7 mm/yr) is only about 50% of the local rate of sea-level rise estimated by GORNITZ and LEBEDEFF (1987), and BRAATZ and AUBREY (1987). During transgression, the distal edges of marsh facies are slowly inundated by rising sea-level and partially reworked into tidal flat facies. At the upper edge of the marsh (the marsh/terrestrial contact), inundation of the terrestrial landscape allows marsh to expand landward over the newly formed wetland.

The facies preservation potential for headland marshes is considerably less than valley marshes. The marshes tend to transgress landward at a greater rate than they accrete vertically, limiting the magnitude of vertical accretion. Subsequent exposure of relatively thin headland marsh facies to bay waves and the natural reworking into tidal flats decreases their preservation potential as a distinct marsh facies.

Interfluve marshes form over the interfluve surfaces between streams and rivers that have been flooded during transgression. The marshes are generally broad features between valley marshes. Since these interfluve areas are locally the highest surfaces, sediment runoff is limited and additional sediment accumulation is dependent on secondary supplies from the water. Without additional sediment sources, there is an inadequate sediment input for vertical accretion. The occurrence of interfluve marsh along the mainland fringe is primarily dependent upon inundation of the interfluve surface prior to open-water lagoon formation (OERTEL *et al.*, 1992). Inundation of the surface initially results in a broad high marsh on a firm antecedent substrate. High marsh flora is similar to that described above for headland marsh. If ambient suspended sediment concentrations are sufficient to trap substantial quantities of settling silts on the high-marsh surface, then a low marsh or even a high marsh may be maintained. However, vertical accretion is dependent on substantial quantities of fine-grained sediment trapping and accumulation. Maintenance of these marshes is controlled by the concentration of suspended sediment in the water column which is related to proximity to major watersheds. For example, the lagoons of the southern Delmarva Peninsula in Virginia are backed up against small first-order watersheds that drain relatively small areas of the coastal plain. This restricts the amount of fine-grained sediment available to the suspended load. Interfluve marshes in the southern lagoons of the southern Delmarva Peninsula were submerged during the Holocene transgression. Submergence has led to the formation of extensive tidal flats in the lagoons south of Quinby Inlet. Narrow lagoons north of Quinby Inlet have allowed the merger of mainland fringe marshes and backbarrier fringe marshes in the center of the lagoon.

Moderately large river systems, such as the Savannah and Altamaha Rivers in Georgia and the Santee River in South Carolina discharge large loads of suspended sediment into coastal barrier lagoons. The relatively large concentrations of suspended sediment in the water appears to have increased the fine-grained sedimentation rate sufficiently to offset the effect of rising sea level. GOLDBERG *et al.* (1979) found relatively high accumulation rates of fine-grained sediment (≈13 mm/yr) in distributary channels and interfluve marshes of the Savannah River. These sedimentation rates were 5–6 times higher then the local rate of sea-level rise estimated by GORNITZ and LEBEDEFF (1987) and BRAATZ and AUBREY (1987). Thus, during transgression sediment accumulation has kept ahead of relative sea-level rise producing a continuous marsh blanket (over the interfluve areas) between the mainland and barrier island shores.

Hammock marshes are marshes that occur adjacent to hammocks commonly along the mainland sides of the lagoons (Figure 2). Hammocks are shore parallel islands that are located in the lagoon, and are surrounded by marsh rather than water. Elongate basins between the ridges are protected from wave exposures and are excellent sites for marsh colonization. They are generally sections of landscape that have been separated from the mainland by relative sea-level rise and coastal inundation. The orientations of hammock marshes are controlled by the orientations of hammocks. Since many hammocks are sets of relict beach ridges or strand plain ridges formed during earlier sea level highstands, hammocks and hammock marshes are approximately parallel to the coastline. The occurrence of hammock marshes is dependent on the inundation of antecedent topography, and their characteristics are related to the stages of topographic submergence. In general, beach ridges and strand plain ridges do not have the same slope gradients and magnitudes of local relief exhibited by valley channels. Ridges generally have 2–3 meters of relief and slopes less than 5°.

On the Southern Delmarva Peninsula of Virginia, the Pleistocene Wachapreague Formation is a regressive strand plain sequence formed during the late Wisconsinan (MIXON, 1985). South of the Machipongo River at Fowling Point, swales between the regressive Wachapreague strand plain ridges have filled with transgressive hammock marshes. The marshes contain peaty bogs of *Distichlis* sp. on relatively firm foundations of silty muds with sand lenses. The progressive inundation by sea-level rise has transformed portions of these high marshes into low marshes with long form *Spartina a.* on relatively fluid substrates. Although continued submergence produces small tidal channels down the axis of the marsh (Figure 2), it may also allow the leading edge of the marsh to spread completely over the crest of the island's terrestrial landscape.

Phillips Creek, Virginia, is a watershed that drains through the hammock marshes of the Brickhouse Neck hammocks and continues into a barrier lagoon system on the southern Delmarva Peninsula (Figure 3). The lower portion of the watershed has marshes in the depressions between several hammocks. The sedimentation rate in one of these hammock marshes was determined using Pb-210 radiogeochronology. The sedimentation rate of 2.1–1.9 mm/yr was slightly higher than the average for the headland marsh described above but lower than the local rate of sea-level rise estimated by GORNITZ and LEBEDEFF (1987) and BRAATZ and AUBREY (1987).

Preservation potential of these marshes is controlled by the suspended sediment load in the water column and the depth of the infilled basins. Although the swales may become completely filled with fine-grained sediment, their maximum thickness is only 2–3 meters. This gives them a slightly better chance of preservation than headland and interfluve marshes, but preservation potential is still less than at valley marshes which often produce muddy facies greater than 8 meters thick.

Tidal-channel marshes are distinguished from adjacent marshes because of their potential for

Figure 3. Oblique aerial photograph (looking north) of the landward side of the lagoon behind Hog and Cobb Islands, Virginia. The photo illustrates the fringe marshes around the Brick House Neck Hammocks (located along the central axis of the photo). The arrow indicates the location of Phillips Creek, which drains seaward between Brickhouse Hammock (to the south) and The Hammocks to the north. The station for Pb-210 determination was just above the arrow.

preservation. Tidal channel fringe-marshes are on the margins of tidal channels that scour and fill other lagoonal facies. Tidal channels in marsh areas are either inherited from antecedent drainage or are cut into marsh surfaces by tidal streams. The margin of a tidal channel is commonly bordered by a natural levee topped by very tall forms of *Spartina a.* The "tall-form" *Spartina* is an effective baffle for accumulating sediment along the channel margins and enhancing the local sedimentation rate.

Tidal currents re-activate the antecedent and superimposed channels by providing energy for erosional and accretional processes. In most cases, the axis of a tidal channel scours toward one margin as the trailing-channel margin fills by point-bar advance and marsh progradation. This tidal-scour and fill process is not the quiescent siltation and upbuilding process often described for basins. Lateral accretion depends on the accumulation of fines by several processes. First, the separation of preferred pathways of ebb and flood flows at meanders creates backwater zones of "slack" water and mud settling. Second, filtration of suspended sediment from the water column by bivalves and other filter feeders is also an effective process of enhancing mud accumulation in point-bar backwaters. Third, densely spaced marsh stems along the crest of a natural levee are an effective baffle to current flow which also increases the settling rate of fines. The sediments on the scouring side of the channel generally have a firmer consistency than the more fluid muds on the accreting side of the channel.

The maintenance of tidal channel fringe-marshes is primarily controlled by accretional topography. During sea-level rise, marsh and lagoonal landscape are slowly submerged, and tidal channels broaden. Since the rates of fine-grained sediment accumulation at channel-margin levees are greater than the rates at interior marsh areas, the fringe marshes tend to survive inundation longer than the adjacent areas (see OERTEL *et al.*, 1992). As interior marshes are inundated to progressively deeper depths, the tidal-channel fringe marshes eventually become completely surrounded by water producing marsh islands.

Mid-Lagoon Marshes

The occurrence of marsh in the central sections of coastal barrier lagoons is dependent on the rate of relative sea-level rise with respect to: (1) relict antecedent surfaces that intercept tidal elevations and (2) accretional surfaces that maintain elevations between HHW and MSL. In deficit lagoons (see NICHOLS, 1989), the changing character of antecedent surfaces plays the most important role in determining marsh distribution patterns. The marshes are primarily a reflection of mainland fringe-marshes and topography that are slowly being submerged by the transgressing Holocene sea. Thus, hammock marshes which surround hammocks evolve into marsh islands as the marsh spreads over the surface of the hammock and distal edges of the marsh change into tidal flats.

Marsh islands are lagoonal islands with no terrestrial landscape. They may occur in bays or other open-water parts of lagoons. Early records of Big Piney Island, Delaware, show 15 acres of upland surrounded by fringe marsh. By 1990, rising sea level had transformed this former bay island into a marsh island with no upland acreage (KRAFT, 1991). Egg Island is a similar feature in a Virginia coastal lagoon that represents the last remnant of a hammock marsh in the middle of Hog Bay. The shape of a marsh island often provides a clue to its origin. For example, the Gull Island marshes in Cobb Bay, Virginia, are elongate, crescent-shaped islands that are the last remnants of tidal channel fringe-marshes.

In "surplus" lagoons, upbuilding by organic and fine-grained sediment accumulation allows an extensive coverage of marsh over accretional platforms. The shallow lagoon floor behind Assawoman and Metompkin Islands along the Virginia coast has maintained an extensive system of marsh islands that has formed a platform marsh extending from the mainland to the barrier islands. Groups of closely spaced marsh islands that cover broad portions of lagoon surfaces are platform marshes. The term platform marsh is less specific than marsh island and fringe marsh, because platform marsh generally refers to relatively large areas of marsh formed by the coalescence of the various other types of marshes described above. Tidal channel fringe-marshes are common along the margins of the extensive network of tidal channels separating closely spaced marsh islands. Platform marshes are very common in the "surplus" barrier lagoon systems of the southeastern United States where fine-grained sediment accumulation is enriched by major rivers such as the Altamaha and the Savannah Rivers in Georgia and Pee Dee River in South Carolina.

Mid-lagoon marshes are less common in open-water lagoons formed by wave-dominated processes of spit and barrier progradation (GILBERT, 1885; HOYT and HENRY, 1968). In these systems, the initial lagoon floor is a relatively deep engulfed shoreface, and upbuilding, by fine-grained sediment accumulation, is relatively slow compared to sea-level rise. During the Holocene transgression, the lagoon floor generally transgressed landward onto antecedent topography long before the basin was filled with sediment (OERTEL *et al.*, 1992). LUCKE (1934) presented a theory for barrier lagoon evolution that gives one explanation for marsh island formation in the middle of open-water lagoons. It involves the stranding of flood tidal deltas behind migrating barrier islands.

Backbarrier Fringe-Marshes

Backbarrier fringe-marshes occur between HHW- and MSL-shorelines on the lagoon side of the barrier island (Figure 4). They have distinct spatial configurations and facies related to backbarrier landscapes. The percentage of coarse-grained material in these fringe-marsh facies is generally higher than in mainland and mid-lagoon marshes. In fact, the percent of coarse-grained material may be used as a measure of cross-island sediment transfer and island stability. Intermittent storm-surges and overwashes are important processes transferring sediment from the fore-barrier to the backbarrier region. The aprons of sediment which spread from the backbarrier into the lagoon produce new platforms suitable for marsh colonization. Sand-rich facies in these fringe marshes are often banded with lenses of mud. However, muddy marsh facies are much more common than along the interior side of the lagoon.

Washover-fan marshes are relatively common on the backbarrier of low-elevation barrier islands (Figure 3). Rapidly transgressing islands such as those along the southern Delmarva Peninsula have numerous marshes on washover fans. In fact, all barriers that illustrate the "rollover" processes of barrier movement (PIERCE, 1970; GODFREY and GODFREY, 1973; LEATHERMAN, 1979) commonly have washover fan marshes. During relatively small storms, high-water levels partially submerge barrier islands and the swash of breaking waves reaches and overwashes the island crest. As sediment-rich water leaves an overwash throat, it spreads and flows down the backbarrier into the lagoon. The resultant washover fans are primarily subaerial although distal parts of these sand bodies form the "scalloped-shaped" backbarrier shorelines at their boundary with the subaqueous deltas. The upper intertidal portions of the fans are rapidly colonized by marsh vegetation. Thus, the initial facies of the marsh is very sandy. However, the densely spaced stems of new marsh plants enhance the accumulation of fine-grained sediment during non-storm periods, and beds of mud accumulate rapidly until the next overwash event.

The barrier islands and spits along wave-dominated coasts are generally long, narrow, and illustrate characteristics of rapidly migrating inlets (HOYT and HENRY, 1967; KUMAR and SANDERS, 1974; FISHER, 1967, 1968). The lagoons embayed by these islands have relatively large open-water areas with narrow fringe marshes along the backbarrier shorelines. Narrow sections of islands that are easily breached during storms may produce numerous overwashes along the backbarrier. Backbarrier marshes are common on the sedimentary platforms that have been built up by overwash and other cross-island transport processes.

Storm-surge platform marshes (BOOTHROYD *et al.*, 1985) also form along the backbarrier margins of lagoons (Figure 4). During large storms, super elevation of water completely submerges portions of barrier islands allowing wave bores to pump water and sand directly onto the lagoon floor (MCGOWEN and SCOTT, 1975; GODFREY and GODFREY, 1974). Cross-barrier flow persists only for a short period during storms and often storm cuts and ephemeral channels become inactive when water levels return to normal. If the cut is large enough, a significant amount of the lagoon water may be captured and drained into the sea. Subsequent tidal exchanges through the cut may produce a "true" tidal inlet with NTD-flow (OERTEL, 1988). However, most cuts heal rapidly following storms, and flood jets and ebb drains never develop. The record of these events is only recorded by the remnants of a subaqueous storm-surge platform on the lagoon floor. Between storm events, lagoonal processes rework the lagoon floor mixing lagoonal mud with the storm-surge sands. Although storm-surge deposits are primarily subaqueous lagoonal features, proximal portions of the deposit are intertidal backbarrier surfaces where marsh colonization is rapid. Backbarrier fringe marshes on storm-surge platforms form broad bands behind the low-lying sections of islands. The facies of these marshes are sandy and very similar to washover fan marshes. Banded lenses of mud and sand reflect the intermittent nature of deposition related to storms and quiescent periods.

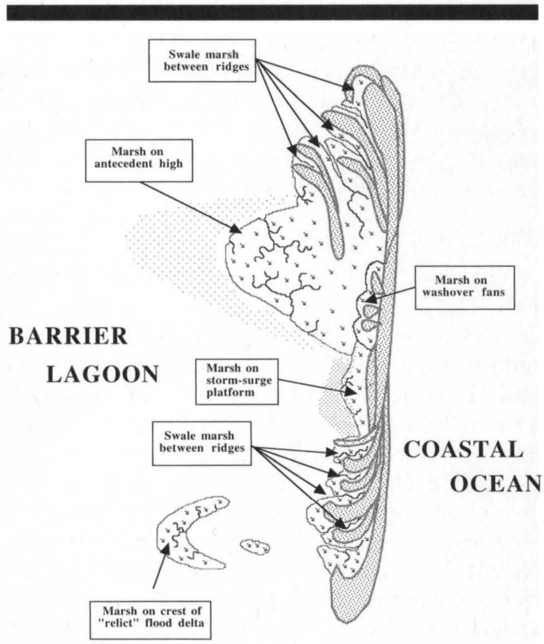

Figure 4. Sketch of a hypothetical barrier island illustrating five different types of marsh along the backbarrier.

Swale ("finger") marshes are more typical of prograding barrier islands that have multiple beach ridges (Figure 4). At stable sections of the backbarrier margin, fringe marshes may occur in swales between beach ridges that are oblique to parallel with the shoreline. Fringe marshes which occur in swales between beach ridges produce elongate muddy facies.

When beach ridges form on an accreting shore, the swales between the ridges are subaerial surfaces colonized by meadow grass (*Spartina p.*)

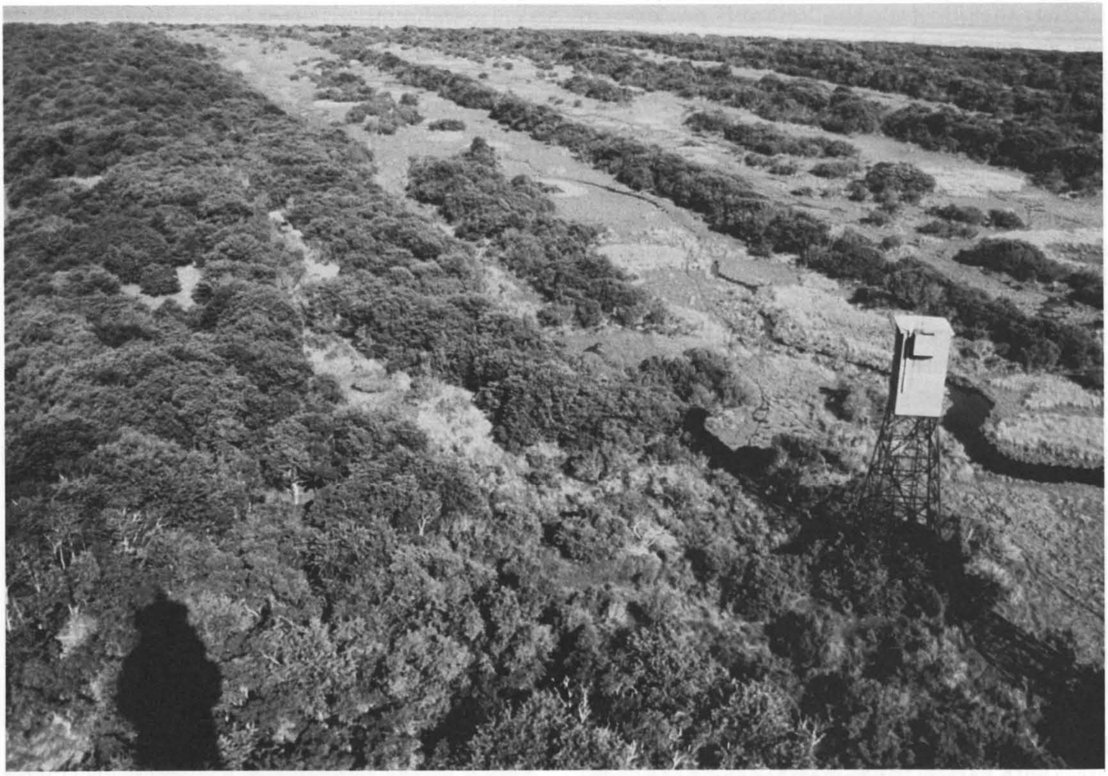

Figure 5. Photograph from the Cape Charles Light looking seaward across Smith Island, Virginia. Oblique beach ridges (covered with thickets of *Myrica*) are truncated by the ocean shoreline. The marshes between the ridges illustrate a variety of different high marsh plants which reflect subtle changes in elevation.

and other pioneer vegetation. Relative sea-level rise initially causes the water table to rise and intercept these topographically low areas producing fresh ponds, fresh/brackish wetlands, and local peat bogs. Numerous shore-oblique swale marshes are present between the swale on the south end of Smith Island, Virginia (Figure 5). *Distichlis, Cyperus,* and *Spartina p.* are common; *Juncus* and *Typha* are patchy (Figure 5). Continued sea-level rise and inundation result in the progressive transition from high- to low-marsh flora. Swale marsh with the tall form of *Spartina a.* is common between beach ridges on many of the Georgia Sea Islands. This is primarily the result of the 2–3 meter tidal range in this region.

At laterally migrating barrier islands, beach ridges are curved into the inlets as the island progrades. The trend of these ridges and intervening "finger" marshes is oblique to the oceanic coastline. The proximal ends of the finger marshes have peats and high-marsh vegetation, while the distal ends have low marsh of primarily *Spartina a.*

Since relief between ridges and swales is generally less than 2–3 meters, the preservation potential of these features is moderate under regressing conditions. Under transgressing conditions, the ridge crests are generally reworked into washover deposits, and the shallow facies of the finger marshes are exhumed on the retreating beachface.

Backbarrier fringe marshes may also colonize the antecedent highs of pre-Holocene surfaces along the backbarrier barrier islands. These marshes develop directly over relict soils and are very similar to their counterparts on the mainland margins of the lagoon or platform marshes over other pre-Holocene surfaces. They start as high marshes and slowly evolve into low marshes during progressive sea-level rise. Their continued existence is dependent on sediment input; however, because of their location behind barrier islands, coarse-grained input is limited and fine-grained input is dependent on the flux of suspended sediment between the bed and the water column. Large sediment discharge regions along the Georgia Bight have maintained marsh over these antecedent platforms; whereas, regions with only moderate suspended sediment loads along the middle Atlantic have resulted in a landscape "state" shift from marsh to tidal flats in these sediment deficit lagoons.

Flood delta marshes are marshes that colonize the upper intertidal zone on the shields of flood tidal deltas. The presence of a flood delta documents that a lagoon once had a large open-water area behind the inlet. Large open-water areas (behind the inlets) are necessary to allow a flood jet to spread into the lagoon. A confined channelized flow will not allow this to occur. During the ebb, flow in the open-water lagoon converges toward the inlet in a relatively symmetrical pattern. The net flow field after a complete tidal cycle produces a flow pattern inside of the inlet where the flood is enhanced along the inlet axis, and the ebb is enhanced along the island shores. This resultant Net Tidal Delta Flow (NTD-flow) is necessary for flood tidal delta formation on the lagoon floor (see OERTEL, 1988). Flow that is channelized (confined within the walls of a channel) cannot develop flood deltas landward of inlet channels. Once a flood delta is formed, it further shields the ebbing currents from the central part of the far field and enhances the segregation of flow into ebb and flood dominated zones. Sediment accumulates on the flood delta, and the crest of the ebb shield builds above MSL. If the surface is sufficiently protected from wave activity, marsh plants may colonize the surface. At wave-dominated coasts, rapid inlet and island migration causes flood deltas to become stranded in the lagoon behind the barrier islands. Marsh-covered remnants of flood deltas are present along many wave-dominated regions of the mid-Atlantic and Gulf coasts (PIERCE, 1970; MCGOWEN and SCOTT, 1975; LEATHERMAN, 1979). Marsh-covered remnants of flood deltas are relatively obvious subaerial features; however, major portions of inactive flood-tidal deltas are subaqueous (KRAFT *et al.*, 1979; OERTEL and KRAFT, in press).

In general, the formation of backbarrier fringe-marshes on washover fans, storm-surge platforms, flood tidal deltas and between beach ridges is dependent on both lateral and vertical development of a platform. This is in contrast to mainland fringe marshes which are primarily dependent on the presence of pre-existing antecedent platforms. The facies of backbarrier fringe marshes are rich in sand from cross-island processes and are generally very thin (< 2 meters). Their close proximity to a retreating shoreface inhibits preservation potential. It is common to see exhumed backbarrier marsh facies on the coastal beaches along the Atlantic shoreline.

MARSH PRESERVATION AND GEOLOGIC INTERPRETATION

Geologists often use the distribution of marshes and marsh facies as tools for analyzing transgression and basin fill. Marsh facies are commonly used for identifying former sea levels because of their association with mean sea level. For example, basal peats which are assumed to be produced by mainland fringe marshes have been used as a tracer of the Holocene transgression along the middle Atlantic coast of North America (KRAFT, 1971; FINKELSTEIN, 1986; FINKELSTEIN and FERLAND, 1987; BYRNES, 1988; PSUTY, 1980). The facies record of the fringe marsh is believed to be the base (and beginning) of the sedimentary sequence of basin filling. Thus, extensive marsh coverage (platform marshes) in barrier lagoons in the middle Atlantic area has been interpreted as the last or climax stage of basin infilling (LUCKE, 1934; FINKELSTEIN and FERLAND, 1987; ASHLEY and ZEFF, 1988). OERTEL *et al.* (1992) have shown that many barrier lagoons transgress landward long before they are able to fill by fine-grained accumulation. Considering the many different forms of modern marshes and the large variation in their preservation potential, the paleogeographic reconstruction of marshes during different lagoonal states is particularly difficult. In fact, detailed microfossil analysis may be the only way to distinguish between the various types of marshes (KRAFT and MARGULES, 1971; WOO, 1992).

In a transgressive setting, the basal peat is often depicted as an inclined layer which originates at the mainland fringe marsh and dips seaward under the barrier lagoon and barrier island. This reconstruction is accurate for lagoons that have seaward dipping planar floors. The buried marsh deposits (referred to as peats) form a continuous layer that gets progressively deeper and older in the seaward direction. Stratigraphic studies (NEWMAN and MUNSART, 1968; FINKELSTEIN and FERLAND, 1987; OERTEL *et al.*, 1989a; VAN DER

PLASSCHE, 1990) verified that relatively thick (up to 12 meters) fine-grained sequences occur in the lagoons of the southern Delmarva Peninsula. However, as seen above, the preservation potential of the different marsh facies is quite variable. As a result, marsh facies are often only preserved in the deeper depressions related to the margins of stream valleys and other channels. Thus, the probability is low that a continuous peat layer or marsh facies blankets the floor of a barrier lagoon. Instead, patches of peaty material and marsh facies occur in patches related to the deeper channel marshes described above. OERTEL *et al.* (1989a) determined that much of the mud in the lagoons of the southern Delmarva Peninsula is pre-Holocene and the Holocene sediment below tidal flats was often less than 1–3 meters thick. RIGGS (*personal communication* 1991) noted similar findings for the Albermarle and Pamlico Sound lagoons of North Carolina. Deep peats along the mainland side of Virginia lagoons (VAN DER PLASSCHE, 1990) are believed to be associated with buried valleys of relict shoreface scarps.

Shallow seismic reflection and vibracore data also suggest that the primordial floors of the lagoons on the southern Delmarva Peninsula are not planar surfaces (OERTEL *et al.*, in press). The stratigraphic record of marsh facies is discontinuous and often there is more than one Holocene marsh facies found at different horizons within the same core (OERTEL *et al.*, 1992). On the northern Delmarva Peninsula, Kraft and his colleagues (KRAFT, 1971; KRAFT *et al.*, 1979; BELKNAP and KRAFT, 1985) found buried marsh mud below Rehoboth Bay that was associated with the fringe of buried channels and backbarrier environments. During transgression, the channel marsh migrated up the channel walls. At channels oriented parallel to the modern shoreline, fringe marsh on the seaward side of the channel migrates in a seaward direction. In these cases, younger peat dates were found seaward of older peat dates. Similar findings of progressively younger and seaward dates also are found in the lagoons of the southern Delmarva Peninsula. In a transect across the Metompkin Bay, lagoon dates progressed from 2,200 YBP at 200 meters from the mainland; to 1,660 YBP about 1 kilometer from the mainland; 4,620 YBP about 1.6 kilometers from the mainland and 1,180 YBP at 2.8 kilometers (FINKELSTEIN and FERLAND, 1987). FINKELSTEIN and FERLAND (1987) attributed this difference to two different marsh types, a basal peat of a mainland (2,200 YBP to 4,620 YBP) and a modern platform marsh (≈1,700 YBP to present). In Cobb Bay lagoon, Virginia, the deepest records of Holocene marsh mud were from the central parts of the lagoons associated with the margins of channel fill (OERTEL *et al.*, 1989a). At tidal flats, traces of marsh mud were often missing in the sequence between the thin veneers of Holocene sediment over the pre-Holocene. The patchy distribution of buried marsh facies in the lagoonal sediments supports the suggestion that a large variety of marsh types were separated by irregular topography.

CONCLUSIONS

Lagoons that develop over complicated drainage of antecedent landscapes have complicated hypsography. Mainland shorelines are irregular and the thickest marsh facies form along the margins of stream valleys. Moderately thick marsh facies form in the swales between lagoonal hammocks. Inundation of the low-relief interfluves forms thin marsh facies. Coastal inundation rather than sedimentation is the principal process producing hypsometric surfaces suitable for marsh colonization.

In major estuarine systems (for example the Hudson, Delaware and Chesapeake estuaries) fine-grained sediment is primarily retained in the estuary before it reaches the coast. Therefore, coastal headland areas between the major estuaries receive relatively limited supplies of sediment, particularly during transgression and coastal inundation. When siltation in barrier lagoons is unable to keep pace with sea-level rise, many of the fringe marshes become progressively submerged and change to tidal flats and shallow bays. Only the fringe marshes that migrate up the valley walls of streams and tidal channels form sequences thick enough for potential preservation. Although initial marsh surface areas may be moderately extensive, marsh landscape with relatively thin sedimentary sequences are extensively reworked during transgression, and preservation of marsh facies is often confined to filled valleys. Since the Holocene transgression is globally extensive, many of the world's coastal barrier lagoons have transgressed landward without leaving a continuous basal peat blanket. The basal peat is instead limited to the patchy distribution of marsh facies that have filled the valleys of stream and tidal channels.

In coastal areas (such as the southeastern United States), the fluvial fine-grained sediment input to coastal lagoons is relatively high. As a result, the sedimentation rate of mud on marsh surfaces has been able to keep pace with sea-level rise (GOLDBERG *et al.*, 1979), and marsh-filled lagoons have been sustained during the late Holocene transgression.

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