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# Organic-Rich Facies in Paraglacial Barrier Lithosomes of Northern New England: Preservation and Paleoenvironmental Significance

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**ABSTRACT**

Geological controls on the origin and preservation of organic-rich facies in Holocene barrier sequences of northern New England are documented using sedimentological and geophysical databases. In addition to backbarrier marsh interfingering with washover/aeolian deposits, several distinct modes of organic accumulation are recognized in association with clastic barrier facies. These include: 1) basal lake gyttja or wetland peats (thickness: 0.1-2.5 m); 2) intra-barrier saltwater/freshwater horizons (0.01-1.2 m); and 3) foreshore peat exposures (up to 1.2 m). Freshwater peat and gyttja underlying barrier lithosomes below contemporaneous Mid-Holocene sea level suggest extensive backbarrier lake and wetlands, possibly due to a wetter climate. Present freshwater organics accumulate up to several meters below lake level, which is controlled by the elevation of groundwater table and, over the long term, sea level trends. In some areas, the saltwater-freshwater peat transition is attributed to cessation of long-term saltwater input into the backbarrier, commonly as a result of tidal inlet closure, rather than relative sea-level fall. The association of well-preserved tree stumps and saltmarsh peat exposed on the foreshore suggests drowning of the upland fringe by rising sea level around 2.5- 3.0 ka BP and subsequent barrier rollover.

Whereas basal ages of high-marsh peats are conventionally used for sea-level reconstruction, radiocarbon dates of the top portions of in-situ organic units may provide near-maximum ages of burial by barrier sediments. This information is independent of compaction and type of dated material and may be used to estimate the timing of barrier emplacement at or near its present position. Age estimates are less constrained when dating allochtonous organic material, but may still provide upper age limits for overlying clastic sequences. Similar to other mid- to high-latitude coastal settings, parts of maritime bogs and ponds in mid-coastal Maine have been buried episodically by storm overwash or dune migration over the past 5,000 years. The chronology of these events varies over a short distance along the coast as a function of barrier exposure and morphology, antecedent geology, and changes in sediment supply and vegetation cover.

**ADDITIONALINDEX WORDS:** *Maine, backbarrier, stratigraphy, GPR, preservation, peat, gyttja.*

## INTRODUCTION

Organic-rich lagoonal and coastal marsh facies have been recognized in association with a variety of modern and ancient barrier sequences, with high economic potential as hydrocarbon resources (HORNE and FERM, 1978; MCCUBBIN, 1981; REINSON, 1992) and sources of heat fuel and salt in historical times (MARSCHALLECK, 1973; PETZELBERGER, 2000). However, the stratigraphic context of these deposits within paraglacial barrier lithosomes has received relatively little attention (DUFFY *et al*., 1989; STREIF, 1989; DEVOY *et al*., 1996; BUYNEVICH, 1999; FITZGERALD and VAN HETEREN, 1999). The extent and diversity of coastal wetlands along the south-central coast of Maine (KELLEY, 1987) make the Kennebec Barrier Chain an ideal location for examining the distribution, stratigraphic relationships, and preservation of organic-rich facies (Fig. 1). In addition, a well-established sea-level chronology of the region allows for reconstruction of barrier behavior using the ages and stratigraphic position of organic horizons (BELKNAP *et al.*, 1989; GEHRELS *et al*., 1996; BARNHARDT *et al*., 1997).

The aim of this study was: 1) to document the occurrence and distribution of organic-rich facies associated with clastic barrier deposits; 2) to assess modes of preservation and paleoenvironmental significance of these facies in paraglacial barrier sequences, and 3) to examine the use of buried organic horizons as chronological markers of barrier dynamics.

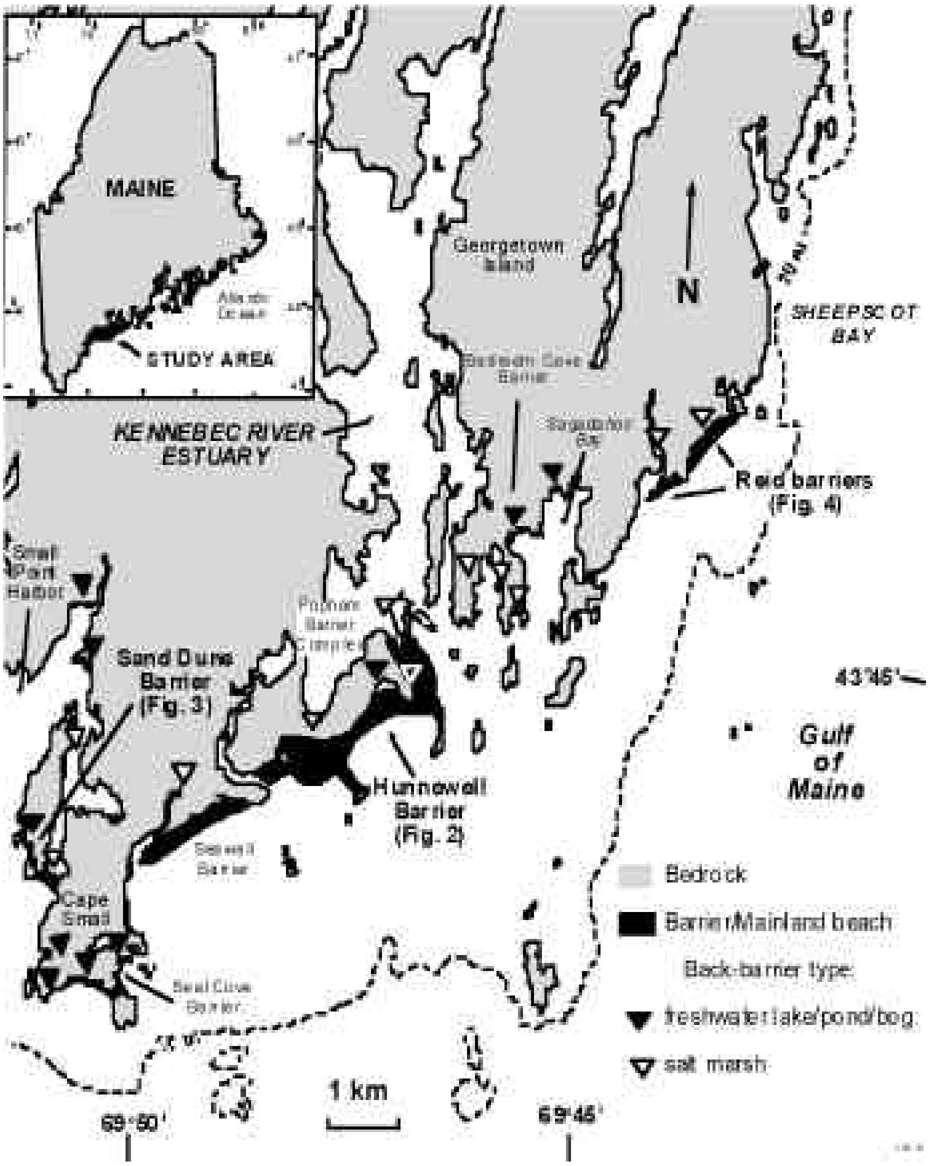


Figure 1. Location map of the study area. Triangles indicate the backbarrier types. Note the highly indented nature of this coastal region, with sandy barriers of variable length, width, and orientation. The largest barrier systems are located proximal and to the west of the Kennebec River estuary mouth.

## DISTRIBUTION OF BACKBARRIER TYPES

Among the total of 35 barriers and mainland beaches of the study area, 26 barriers have mappable backbarrier wetlands (the backbarrier types of the larger systems are shown in Fig. 1). Thirteen of these barriers (50% total) are backed by freshwater wetlands (Typha and sedge wetlands, cranberry bogs), 10 barriers (38%) front salt marshes of variable size and thickness of *Spartina* sp. peats, and 3 backbarrier settings (12%) are occupied by freshwater ponds, the largest of which is the 0.4 km-long Silver Lake (Figs. 1 and 2). The absence of open coastal lagoons along this shoreline is due to: 1) the majority of barriers having backbarrier regions throughout the mid-late Holocene that are too small to support tidal inlets, and 2) rapid infilling via flood-tidal deposition and saltmarsh growth where tidal inlets do exist (present mean tidal range is 2.6 m). There is, however, stratigraphic evidence that many freshwater wetlands evolved from lagoons and salt marshes that existed long enough to leave a sedimentary record (DUFFY *et al.*, 1989; BUYNEVICH, 2001; BUYNEVICH and FITZGERALD, in press).

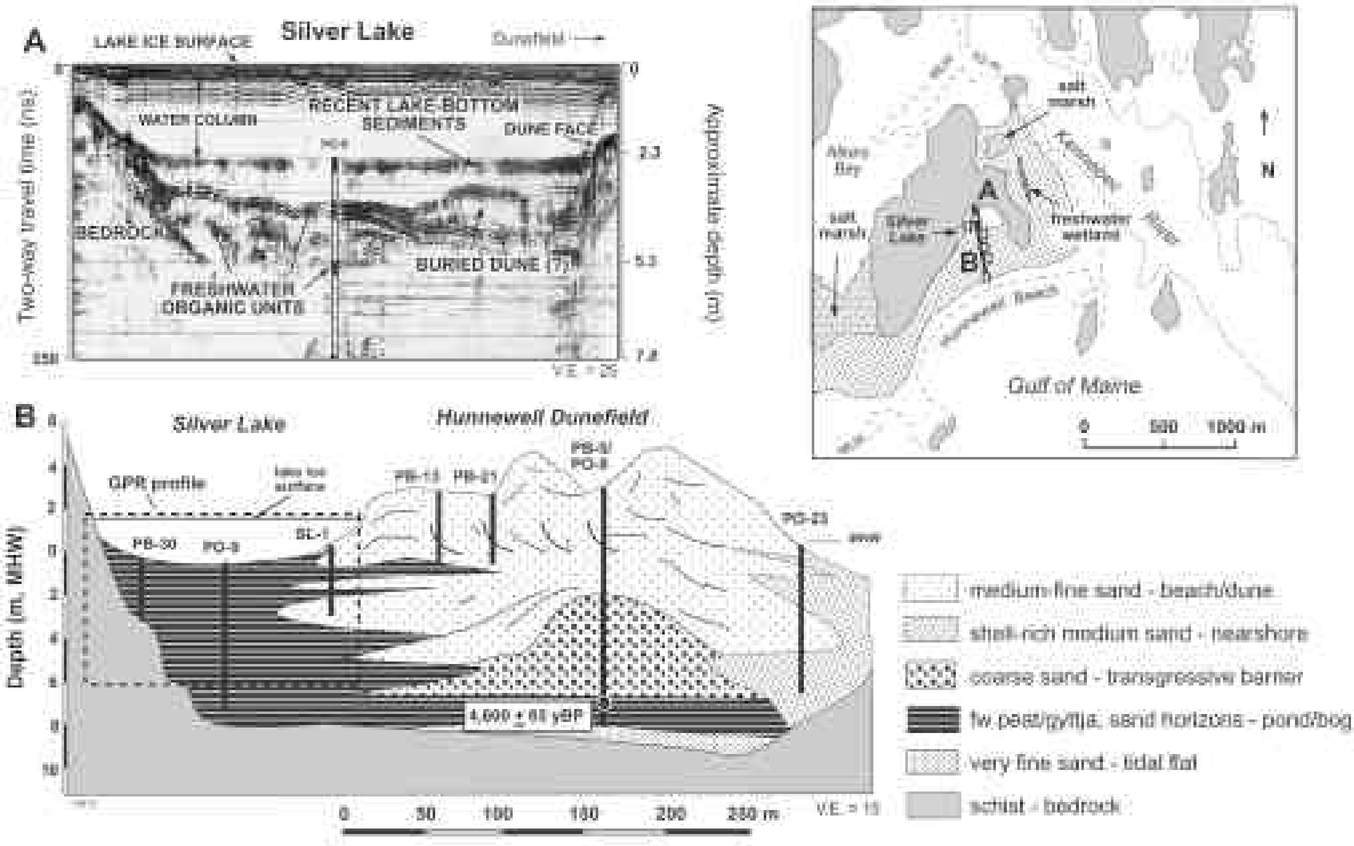


Figure 2. Shore-normal ground-penetrating radar profile over the ice-covered Silver Lake (A) and stratigraphic section across Hunnewell Barrier (B). Note the extent of the extensive organic-rich paleo-lake/bog unit beneath the barrier lithosome. Map on the right shows GPR transect, core locations, and backbarrier types.

## METHODS

This study involved an integrated high-resolution geophysical and sedimentological approach. The internal stratification of the barriers was investigated using a mobile, cart-mounted GSSI SIR-3 ground-penetrating radar (GPR) system with a 120 MHz transceiver. Despite the attenuation of the electromagnetic radar signal by saltwater, the GPR technique has been used successfully in a variety of coastal settings (JOL *et al.*, 1996; VAN HETEREN *et al.*, 1998; NEALand ROBERTS, 2000). Penetration of up to 15 m and resolution of 0.2-0.7 m is characteristic for New England barriers (VAN HETEREN, 1996; VAN HETEREN *et al.*, 1996). Topographic correction was applied to the profiles that had over 0.5 m variation in elevation along the trace.

Geophysical data were groundtruthed with vibracores and pulse-auger cores. Textural and compositional characteristics of core samples were analyzed using standard sedimentological techniques and provided a basis for interpreting barrier and associated backbarrier facies. The distinction between freshwater and saltmarsh/brackish peats was based on the plant remains and δ13C values, where available. Conventional radiocarbon dates on organic-rich sediments are reported as uncalibrated, δ13C-corrected ages.

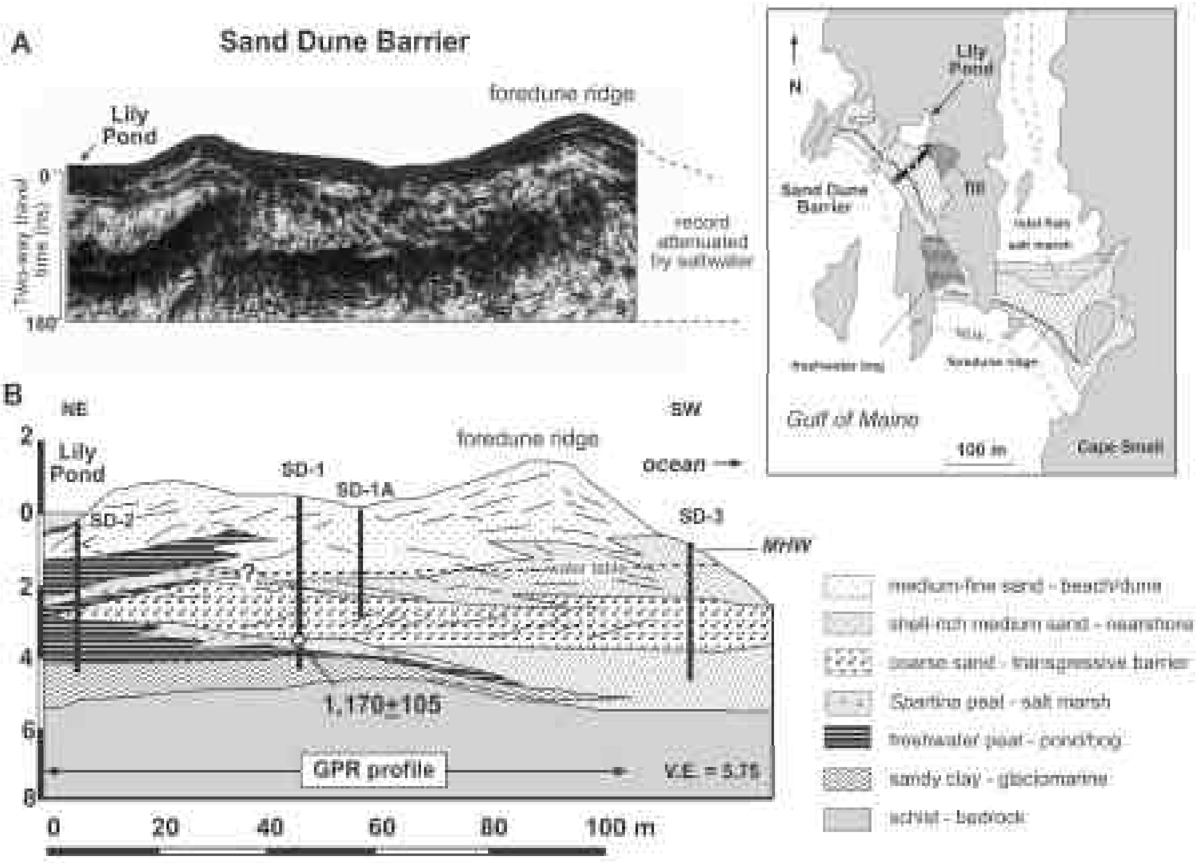


Figure 3. Shore-normal GPR profile (A) and stratigraphic section across Sand Dune Barrier (B). A succession of saltmarsh and freshwater peats is the result of backbarrier flooding with rising sea level and subsequent transformation of coastal lagoon into a freshwater pond. Map on the right shows locations of the stratigraphic section and sediment cores.

## RESULTS

Geophysical and sedimentological records from three barrier systems (Hunnewell, Sand Dune, and Reid barrier complexes) were used to examine the stratigraphic context of organic-rich deposits (Figs. 1-4).

### Hunnewell Barrier

On a shore-normal GPR transect, a series of subhorizontal reflectors within the lake-basin fill correspond to organic-rich lake sediment (gyttja) horizons interbedded with organic-rich fine-medium sands (Fig. 2A). Along the southern portion of the trace the margin of the dunefield is seen as a steeply descending surface reflection with several basinward-dipping beds. Below the flat lake-bottom reflector, a sequence of convex-up and wavy-parallel reflectors can be traced along the profile. A prominent convex-up reflector with a transparent core shown on the top right of the profile is interpreted as a submerged dune.

A sand-rich, basal freshwater peat unit 0.5-1.6 m in thickness has been traced from the Silver Lake seaward to underlie most of the Hunnewell Barrier lithosome (Fig. 2B). Above this unit is a series of freshwater peat horizons (0.01-0.5 m in thickness) that are interbedded with washover and dune sands. These intra-barrier organics extend approximately 100 m seaward of the lake and occupy a similar position to the present-day forested wetland.

### Sand Dune Barrier

The NE-SW oriented GPR profile LP-2 was taken from the edge of Lily Pond to the beach and groundtruthed with four cores (1, 1A, 2 and 3; Fig. 3). This section reveals a prominent, thick reflector extending beneath the pond and ascending in a seaward direction (Fig. 3A). This reflector is likely the result of amalgamation of freshwater and saltwater organic units penetrated in cores SD-1 and SD-2 (Fig. 3B). At least two separate saltwater peat horizons were identified in sediment cores. A deeper reflector was identified as bedrock overlain by glaciomarine clay and a thin regressive sand unit in seaward cores SD-1 and SD-1A

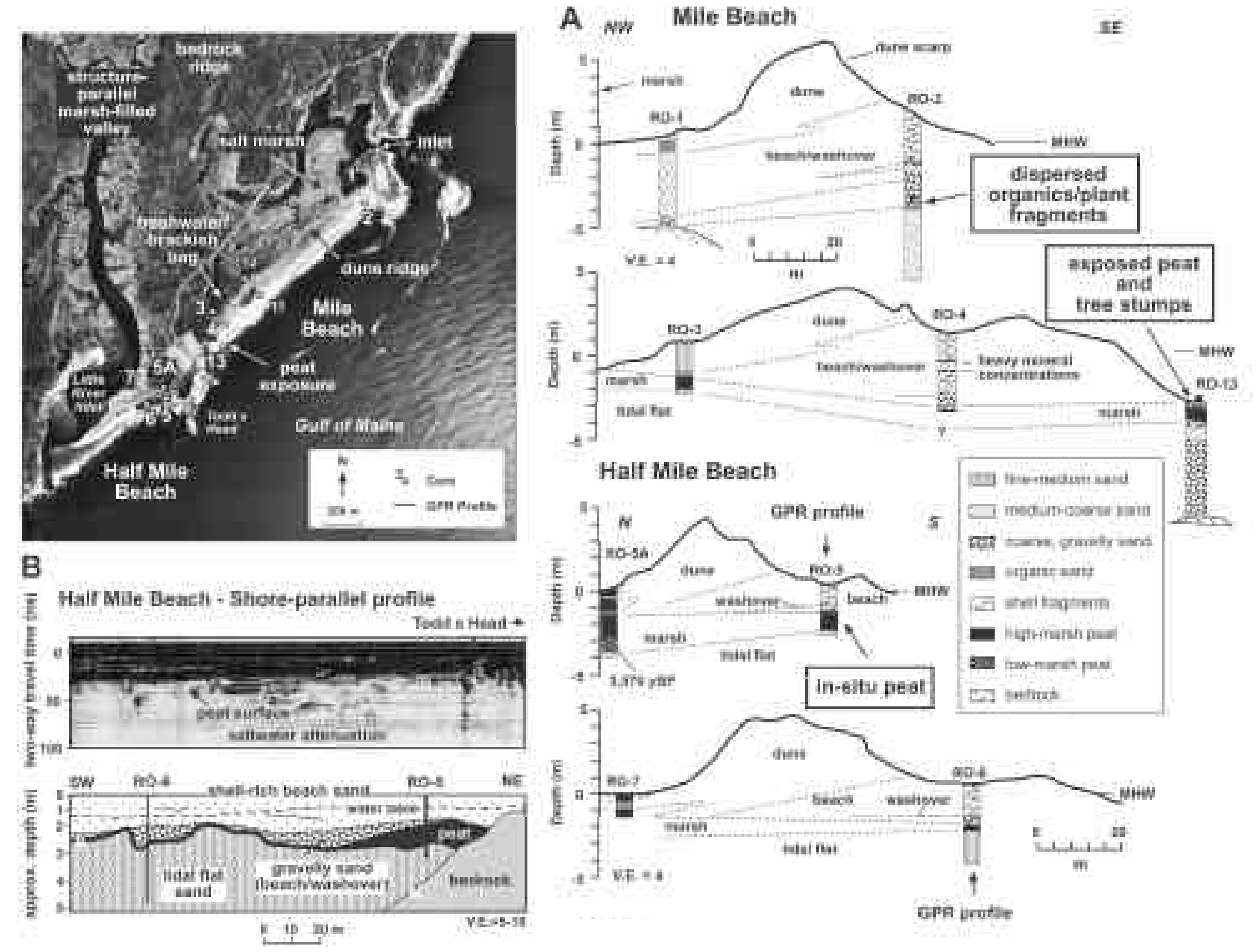


Figure 4. Stratigraphic sections from two barrier segments of Reid complex (A) and shore-parallel GPR profile along the eastern Half Mile Barrier(B). The occurrence and modes of preservation of organic-rich facies are indicated in boxes. Vertical aerial photograph shows locations of GPR transects and sediment cores.

(Fig. 3B). All cores contain a unit of coarse sand to sandy gravel that pinches out in a landward direction beneath the pond. This unit is interpreted as a washover deposit. A saltwater peat (δ13C= -17.9‰) immediately below this unit was dated at 1,170±105 14C years BP providing a maximum age for washover deposition.

## Reid Barriers

The two barrier segments, Mile and Half Mile Beaches, exhibit contrasting stratigraphies, particularly in terms of the nature and thickness of backbarrier units. Mile Beach consists of a thick sequence of medium-to-coarse sands with occasional reworked organics in the northeastern section and peat exposures along the southwest end (Fig. 4A). At a depth of 5.3-5.6 m in core RO-2, a layer containing scattered organics (clumps of sandy peat and disseminated plant fragments) was penetrated. Berm core (RO-4) at the western end of Mile Beach shows a stratigraphy similar to the RO-2 with refusal at 4.7 m, possibly on a log or a tree stump. Core RO-13 penetrated a total of 1.2 m of high-marsh peat overlain by low-marsh peat, with occasional tree stumps exposed along the lower intertidal area (Fig. 4A).

The barrier lithosome at Half Mile Beach is relatively thin (2-5 m above MHW) and consists of shell-rich medium-to-coarse sands underlain by saltmarsh peat that has built over fine-grained tidal flat sands. GPR profiles from the eastern Half Mile Beach indicate a slightly undulating topography of the peat surface (Fig. 4B). In contrast to relatively thin and young saltmarsh peats to the east of Todd's Head ridge, the backbarrier sequence here is over 4 m thick, and possibly much thicker in the landward region of the Little River valley (GEHRELS, pers. comm.). Cores taken along the dune-marsh boundary show a transition from low to high-marsh peat with increasing number of sandy horizons toward the surface. A basal saltwater peat sample from core RO-5A taken at 3.2 m below MHW gave an uncalibrated $^{14}C$ date of 3,570 ±140 years BP ($\delta^{13}C$ = -17.4‰). The backbarrier stratigraphy can be correlated with the sequence of facies recovered in foreshore cores (RO-5 and RO-6), where the peat horizon is much thinner (Fig. 4). Here, the shell-rich barrier sands overlie a thin saltmarsh peat horizon. A gravelly layer, possibly a washover deposit, overlies peat in RO-6 (Fig. 4).

## DISCUSSION

Occurrence, Preservation, and Paleoenvironmental Significance

Based on geophysical records and sedimentological evidence, three modes of occurrence of organic facies seaward of the present barrier-backbarrier boundary have been identified. These include: 1) basal lake gyttja or wetland peats; 2) intra-barrier saltwater/freshwater horizons, and 3) foreshore peat exposures (Fig. 5). Basal organics may overlie bedrock, till, or glaciomarine deposits and may form the base of the Holocene coastal sequences in the region (DUFFY *et al*., 1989; GEHRELS *et al*., 1996; VAN HETEREN, 1996; FITZGERALD and VAN HETEREN, 1999). They range in thickness from 0.1 to over 2.5 m, and may contain upland vegetation in their basal portion.

The second facies type, intra-barrier organic horizons may occur throughout the barrier lithosome. They range in thickness from thin (cm-scale) discontinuous horizons to relatively thick 0.5-1.6 m backbarrier units buried by washover or aeolian sands (Fig. 5).

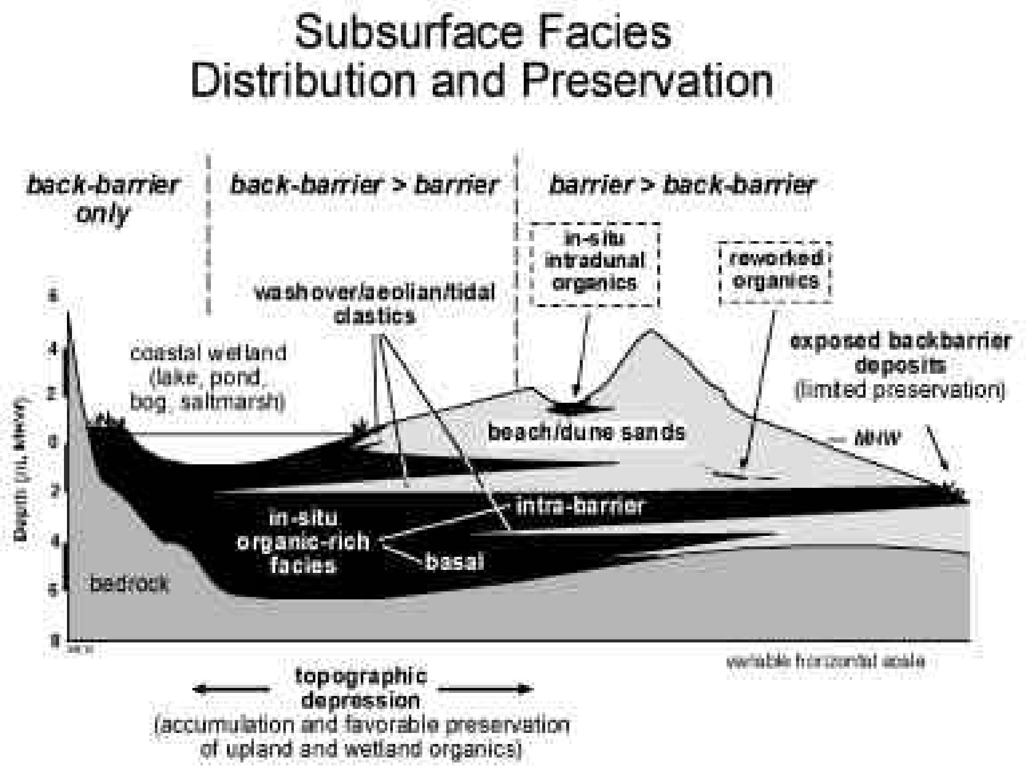


Figure 5. Schematic diagram illustrating the stratigraphic context of organic-rich facies within coastal lithosomes. The relative importance of barrier and backbarrier facies in a shore-normal stratigraphic section is emphasized. Boxes highlight the types of preservation discussed in the paper. Note the favorable conditions for preservation in antecedent backbarrier depressions.

The basal freshwater peat beneath Hunnewell barrier lithosome indicates that the paleo-Silver Lake wetland was much larger ~ 4.6 ka BP, possibly due to increasingly humid conditions during this time (DELCOURT and DELCOURT, 1984; WEBB *et al*., 1993; Fig. 2). The low elevation of the freshwater organic layer relative to contemporary sea level (Fig. 6A) may be explained by the existence of a welded Hunnewell proto-barrier since the Mid-Holocene. This transgressive barrier has subsequently prograded and migrating dunes encroached episodically into the Silver Lake (Fig. 2). In contrast, a succession of freshwater and saltmarsh peats beneath Sand Dune Barrier reflects the existence of tidal inlet and backbarrier saltmarsh prior to ~ 1.2 ka BP (Fig. 3). Despite rising sea level, subsequent return to pond/bog conditions indicated by upper freshwater organic units (Fig. 3B) is a response of this system to inlet closure and onshore barrier migration.

The third type of occurrence - the exposure of backbarrier deposits on the seaward side of the barrier - has only been documented in one location along the study area, where it consists of high-marsh peat, overlain by low-marsh peat with up to 1.2 m in total thickness (Fig. 4). This stratigraphy reflects drowning of backbarrier by rising sea level with associated tree stumps suggesting a temporary upland environment (BUYNEVICH and FITZGERALD, 1999). A number of sites along the northern New England coast where backbarrier and upland facies crop out on the seaward side of the barriers have been documented by KELLEY (1987), KELLEY *et al*. (1988), HILL and FITZGERALD (1992), and FITZGERALD *et al*. (1994). The preservation potential of the outcropping backbarrier units is a function of deposit thickness and induration, incident wave energy, foreshore-nearshore sediment dynamics, and the rate of relative sea-level change. Long-term preservation of these deposits is unlikely, unless large sediment influx causes the barrier to aggrade or prograde, or a pulse of rapid sea-level rise drowns the outcrops (DAVIS and CLIFTON, 1987).

Other modes of occurrence of organic facies include in-situ intradunal pond-bottom organics and bog peats (Fig. 5), which have been used for reconstructing the chronology of dune migration and stabilization as a function of Holocene climate changes (WINKLER, 1992). In addition to in-situ horizons, reworked (dispersed or disseminated) organic fragments are common in high-energy barrier settings (Figs. 4 and 5), and although they can not be used as accurate chronological markers, they may provide approximate maximum ages for the overlying barrier deposits.

The thickness, lateral extent, and preservation potential of organic-rich facies are, in large part, a function of sediment fluxes, backbarrier accommodation space, and the rate of relative sea-level change (NICHOLS, 1989; COOPER, 1994; DEVOY *et al*., 1996). Antecedent topography has been shown to be a key factor in coastal evolution, although its role in backbarrier development is often difficult to assess from the stratigraphy alone (BELKNAPand KRAFT, 1985). For example, along formerly glaciated regions, bedrock depressions may be sites of long-term sediment accumulation and favor the preservation of backbarrier deposits. The recognition of the preservation criteria of organic-rich facies in coastal lithosomes will improve our understanding of other marginal marine sequences. In addition, shifts in pollen and macrofossil records within organic-rich deposits provide high-resolution records of local and regional environmental shifts and sea-level changes through the late Quaternary.

**Chronology of Barrier Development**

In addition to their role as archives of coastal environmental change, organic-rich facies may be used to estimate the timing of their burial by washover, aeolian, or tidal inlet and related facies. Ages of the uppermost portions of in-situ organic units may be used to estimate the timing of barrier emplacement at or near its present position. Such estimates are largely independent of compaction and type of dated in-situ material. The ages of basal peats, on the other hand, would provide minimum ages on barrier establishment or migration that allowed for protected backbarrier environment. In addition, using the relationship between the elevation of modern freshwater wetlands relative to sea level, the ages of buried organic horizons may be estimated using existing sea-level records, where available (STREIF, 1989; DEVOY *et al*., 1996). For example, a sea-level envelope of GEHRELS *et al*., (1996) was used in this study (white boxes in Fig. 6B).

The radiocarbon ages of the uppermost portions of in-situ organic horizons from Hunnewell and Sand Dune barrier systems indicate that the barriers were established at or near their present positions approximately 4.6 and 1.2 ka BP, respectively (BUYNEVICH, 2001). Ages older than 5.0 ka BP have been obtained from basal peats at the heads of marsh valleys by GEHRELS *et al*., (1996), where protected environments may have become established in the absence of a coastal barrier. The 3.5 ka BP age of basal saltmarsh peat behind Half Mile barrier and the lower intertidal position of exposed saltmarsh peats and tree stumps along western Mile Beach, suggest establishment of a proto-barrier by 3.5 ka BP and subsequent barrier rollover ~ 3.0-2.5 ka BP (Fig. 6). The proto-barrier was attached to Todd's Head headland seaward of the present barrier position, allowing for accumulation of peat now found in the intra-barrier and foreshore outcrop positions (Fig. 5). Figure 6 illustrates the spatial variability in the chronology of barrier emplacement at or near their present position, with the systems proximal to the Kennebec River having older ages. Although the timing of barrier stabilization is generally

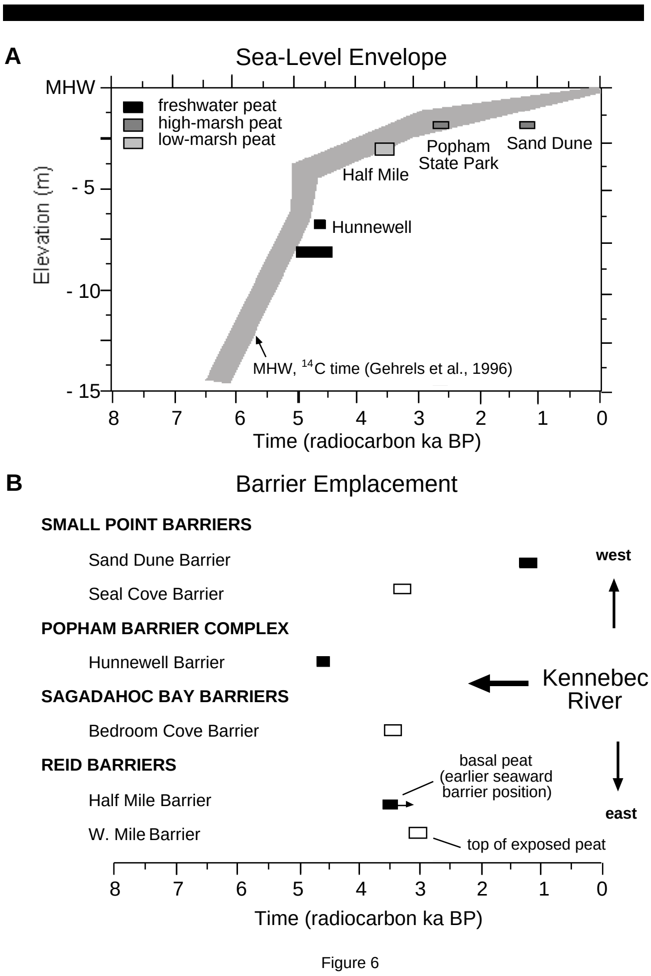


Figure 6. A) Comparison of radiocarbon dated samples from this study with the regional mean-high water level envelope of GEHRELS *et al*. (1996) (uncalibrated 14C time scale is shown). B) The timing of barrier emplacement at or near their present positions is based on ages of the uppermost portions of buried organic-horizons (black boxes) and elevations of organic units and existing sea-level envelope (white boxes). The age of Half Mile Beach proto-barrier is based on the basal backbarrier peat date, which reflects the initiation of saltmarsh development and pre-dates the migration of the barrier to its recent position. The estimated minimum age of saltmarsh peat exposed in the low intertidal area along the western Mile Beach approximates the timing of the initiation of barrier rollover process. Note the earlier establishment of large barrier complexes proximal to Kennebec River mouth (see Fig. 1 for barrier locations).

related to deceleration in relative sea-level rise ~5,000 years ago, the proximity of barrier complexes to an active fluvial sediment supply system and the relative elevation of abandoned inner shelf deltaic depocenters is the likely explanation for the observed trends.

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