Drowned coastal deposits with associated archaeological remains from a sea-level “slowstand”: Northwestern Gulf of Maine, USA

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ABSTRACT
Drowned terrestrial wetland environments, such as lakes, marshes, and beaches, were thought to be rare in formerly glaciated regions like the Gulf of Maine (United States). In the northwestern Gulf of Maine, postglacial relative sea-level changes include a “slowstand” between 11.5 ka and 7.5 ka, when the ocean rose <5 m. This period of sea-level stability permitted erosion of glacial materials and concomitant construction of spits and sheltered wetland habitats, attractive to human occupation, between 17 m and 22 m below modern sea level. This work underscores the importance of a well-constructed sea-level chronology to predict the location of drowned terrestrial environments and associated cultural resources.

INTRODUCTION
Improvements in undersea remote sensing have led to new discoveries of drowned terrestrial environments associated with evidence of human occupation beneath lakes (O’Shea and Meadows, 2009) and on continental shelves (Bailey and Fleming, 2008; Fitch et al., 2005). Continued expansion of human activity into nearshore waters requires better prediction of previous seafloor environmental settings and location of submerged cultural resources.

The formerly glaciated continental shelf of northeastern North America was previously considered a location with poor archaeological site preservation. An earlier summary of archaeological significance reported that “limited subaerial exposure of the present shelf in the Gulf of Maine… inhibited the development of coastal land forms that typically are… high in archaeological site potential” (Stright, 1990, p. 461). Although sea level in the Gulf of Maine never descended to the full eustatic level, a large portion of the present inner continental shelf was subaerially exposed for thousands of years (Barnhardt et al., 1995). Numerous submerged shorelines and deltas exist, and were sampled to construct regional sea-level records (Oldale et al., 1993; Stea et al., 1994; Barnhardt et al., 1997; Kelley et al., 2003). Abundant glacial deposits provided sediment to construct coastal landforms during times of sea-level change. Bedrock topography aided in preserving drowned landforms by forming islands to shelter basins from erosive wave action. Many undiscovered lakes and wetlands that formed in these environments must exist offshore in the numerous bedrock-framed, mud-lined basins on the inner shelf (Rogers et al., 2006).

Predicting the location of submerged terrestrial environments requires an understanding of local relative sea-level changes. Here we describe a submerged locality with the morphology of a lake basin and/or a bar-built estuary that has yielded ancient cultural artifacts. The setting and chronology permit development of a temporal-spatial model for landform and site preservation in the Gulf of Maine and in similar rocky, formerly glaciated regions. Preservation potential is highest where erosion of glacial deposits during times of very slow sea-level rise created beaches to shelter wetlands that focused human activity. Timing and depths of slow sea-level change are the primary predictors of site preservation.

LOCATION AND SETTING
The study site of Bass Harbor is situated on the southwestern margin of Mount Desert Island, Maine (Fig. 1). Scallop draggers recovered Middle Archaic period stone tools (ca. 8–6 ka) from a submerged shoal in 20 m water depth (Price and Spiess, 2007). The site is sheltered from waves by islands and shoals on all but its west-northwestern side, the predominant direction of wind approach, though local waves are restricted by <20 km fetch.

Bedrock frames the coastline and exhibits hundreds of meters of relief (Gilman et al., 1988). Deglaciation of coastal Maine occurred ca. 15 ka, and glacial deposits mantle lowland areas (Borns et al., 2004), with recessional moraines trending northeast-southwest across Mount Desert Island (Gilman et al., 1988). During deglaciation, isostatic depression of the land permitted marine incursion to a local elevation of ~75 m. The Bass Harbor area is covered by coarse- and fine-grained glacial-marine sediments over till (Gilman et al., 1988). Following ice retreat, crustal rebound led to a local relative sea-level lowstand of ~60 m at 12.5 ka (Barnhardt et al., 1997) (Fig. 2; all dates in this study are calibrated to calendar years with a 400 yr reservoir correction; Reimer et al., 1993). After 12.5 ka, sea level rose rapidly to ~20 m below present level, and then slowed its rate of rise to <5 m between 11.5 ka and 7.5 ka. We informally refer to this period as the “slowstand” and speculate that it is the result of regional isostatic adjustments (Barnhardt et al., 1995) or meltwater events (Kendall et al., 2008). After 7.5 ka, sea level climbed rapidly, and then decreased its rate until historic time (Gehrels et al., 1996).

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RESULTS

Multibeam bathymetric mapping of the study area (Fig. 1) resolves two subparallel ridges trending northeast-southwest. The ridges are ~100 m long and 30 m wide, with scarps on the west-northwest side. The ridge scarps separate hummocky, boulder-littered surfaces to the northwest from a smoother bottom to the southeast. The boulders, to 1.5 m in relief, are very abundant right up to the sharp crest of the ridges, but do not continue to the east. The ridges have 4.5 m of relief on their northwest sides and slope down to the southeast with depths increasing from 18 m to 21 m. The two main ridges are connected by a smaller ridge with 1 m relief.

The basin east of the ridge complex has an irregular floor with a maximum depth of ~27 m, and includes localized depressions. It is encircled on most sides by a break in slope at ~24 m depth that cuts into the surrounding shallows, as well as into parts of the ridges. On the eastern side, another break in slope occurs at ~23 m. The basin has two openings, one on the eastern side that leads to shallower depths toward land, and another on the northwest side that connects to deeper water.

The 2 km² study area was crossed by 18 km of chirp and boomer seismic reflection profiles. Interpretation of the acoustic records was based on previous experience working in this region (Barnhardt et al., 1997; Kel-ley et al., 1992), and was verified with eight new vibracores. The western, boulder-covered parts of the ridges are underlain by a massive acoustic unit lacking coherent reflectors that we interpret as till. The northeast-southwest orientation of the till ridge conforms to the regional orientation of moraines. A well-stratified acoustic unit interpreted as glacial-marine mud is above the till. An articulated Mya arenaria shell from this unit dates to 13,593 ka, the time of glacial-marine sediment deposition in the region (Table DR1 in the GSA Data Repository¹; Fig. 2). Truncated reflectors of the glacial-marine unit crop out near the seafloor in the basin to the east (Fig. 3).

The morainal ridges are divided into boulder-littered northwest sides and finer-grained southeast sides by a 1-m-high scarp. Southeast of the scarp, the morainal ridges are buried beneath a well-stratified unit with eastward-dipping reflectors. Where the ridges project into the basin, they unconformably overlie glacial-marine sediment and have multiple reflectors in their upper 2.5 m (Fig. 3). Based on their connection to the till deposit, internal stratigraphy, and well-sorted sediment, we interpret the eastern ends of the ridges as spits developed from erosion of the till. Scallopers recovered artifacts from the southeastern portion of the southern spit (Price and Spiess, 2007).

All vibracores encountered sand and gravel at the seafloor. In the basin, the coarse sediment was <25 cm thick, unconformably overlying glacial-marine mud. The spits contained as much as 2.8 m of sand and gravel (Fig. 4), although cores did not reach the glacial-marine sediment. The seismic record over the spits displayed two reflectors at ~1 and 2 m

¹GSA Data Repository item 2010193, Table DR1. ¹⁴C data, is available online at www.geosociety.org/pubs/ft2010.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.
from 9.8 ka to 8.0 ka (Figs. 2 and 4). A transported fragment of peat was identified within the peat (not be identified, but numerous freshwater and brackish-water diatoms in this section of the core. The plant remains were degraded and could not be identified. Two organic-rich peat beds occurred one another in life position, and most of the shells were in pristine condition, showing no signs of transport. Two organic-rich peat beds occurred in this section of the core. The plant remains were degraded and could not be identified, but numerous freshwater and brackish-water diatoms were identified within the peat (Cymbella sp., Cyclotella sp., and Diplonis sp.). Radiocarbon dates from articulated and whole shells of lower intertidal–shallow subtidal animals in the bottom 60 cm of the core range from 9.8 ka to 8.0 ka (Figs. 2 and 4). A transported fragment of peat was dated to 10.3 ka.

At ~240 cm, shells become less abundant, transitioning to a muddy deposit (Fig. 4). The contact is irregular and may be erosional. The muddy unit is almost 1 m in length and contains many well-preserved Zostera marina fragments on bedding planes as well as many 3–5-cm-diameter pebbles (Fig. 4). There are no shells in this unit above an oyster at ~220 cm.

The muddy unit changes at ~130 cm in the core with an abrupt increase in the organic matter content of the mud (Fig. 4). At ~120 cm, there is an erosional contact with an overlying coarse gravel unit that grades upward. Numerous small blocks of peaty sediment and shell fragments occur throughout this material. The upper 1 m of the core is composed of shelly well-sorted coarse sand and fine gravel that fines upward. Radiocarbon dates of Zostera and Ilyanassa range from 8.0 ka to 8.3 ka (Table DR1; Figs. 2 and 4).

DISCUSSION

Formation of the Bass Harbor Drowned Site

Glacial conditions ca. 15 ka (Borns et al., 2004) in 75 m of water led to the formation of the Bass Harbor moraines and associated thick deposits of glacial-marine mud. Marine conditions supporting Mytilus edulis existed at least until 13.6 ka, but subaerial exposure resulted as sea level fell by 12.5 ka (Fig. 2). Erosion was probably minimal at that time due to the rapid sea-level fall and because nearby shoals provided protection from waves. Between 12.5 and 11.5 ka the moraines were subaerially exposed and the moraine-flanked basin probably supported a lake, stream, and/or freshwater wetland. The 1000 yr of freshwater conditions did not allow time for thick lacustrine deposits to collect, although some peat may have accumulated. The rising ocean probably reached the lowest opening into the basin between ca. 11.5 ka and 10.5 ka. Our oldest postglacial date from the site is 10.3 ka, but it is on a freshwater peat fragment found in subtidal flat sediments.

Between ca. 9.5 ka and 8.0 ka, a community with typical subtidal flat organisms, Crassostrea, Mya, and Ilyanassa, existed in the basin near the growing spit to the southeast. The excellent condition of the articulated shells in life position suggests limited transport. Freshwater peat fragments indicate the presence of a nearby eroding wetland. Small waves from the northwest continued to erode the moraines and wash some sand and gravel over the moraine crests. Longshore currents moved additional sand and gravel to the east, leading to spit development. The spits grew to the east and northeast as a consequence of the direction of wave attack and refraction around the moraines. Other spits grew between the moraines and likely connected them, with one extending as a tombolo from the southernmost moraine to the mainland, further isolating the basin. Shortly after 9.3 ka a more sheltered subtidal environment with abundant Zostera dominated the area until at least 8.0 ka.

Sand, gravel, and peat fragments began to wash into the quiet basin ca. 8.0 ka, suggesting the formation of a washer flat. The 8.0 ka date marks the transition to a shallow subtidal or intertidal washer flat with graded beds, with the 8.2 ka radiocarbon dates from organisms transported to the washer deposit. These graded beds probably mark storm events, and the final drowning of the coastal landforms.

Conditions for Preservation of Coastal Environments in the Gulf of Maine

Although local relative sea level reached a lowstand at less than half of the full eustatic depth (Fig. 2) (Clark et al., 2009), the antecedent geologic setting and sea-level history combined to preserve coastal environments and archaeological artifacts. The bedrock framework has tens of meters of relief, and differential erosion created numerous basins capable of impounding lake waters at times of lower-than-present sea level. Islands shelter many areas from direct exposure to storm-related waves and swells. Although the unconsolidated glacial materials overlying...
bedrock are subject to rapid erosion, and are unlikely to preserve an undisrupted surface, reworking by waves during transgression supplies material to form beaches and associated wetlands and lakes that may encase prehistoric archaeological sites. Because of wetland productivity, these environments focus human activity on their margins (Spiess and Lewis, 2001).

The sea-level history of the western Gulf of Maine is one of rapid excursions with a prolonged stable period. Periods of rapid sea-level fall and rise, between 13.5 ka and 11.5 ka, were unlikely to have led to the preservation of coastal habitats with in situ human artifacts. Although shorelines are recognized from this period, most are erosional features cut into glacial materials and contain patchy deposits or reworked sediment of varying thickness (Stea et al., 1994; Kelley et al., 2003). These shorelines persisted so briefly at any elevation that large beaches did not have time to accumulate material and grow, thereby limiting preservation potential. Exceptions to these are deltas that formed off the mouths of large rivers (Oldale et al., 1993; Belknap et al., 2005; Barnhardt et al., 1997).

During the slowstand between 11.5 ka and 7 ka, sea level rose only ~5 m. This slow rate of sea-level rise led to the reworking and redeposition of glacial deposits, especially coarse-grained moraines. Even in sheltered environments today, waves and tidal currents are able to move sediment and form spits attached to the eroding moraines and surrounding wetlands (Duffy et al., 1989).

**General Model for Preservation of Drowned Coastal Environments**

All radiocarbon dates from the study area are within the slowstand period, 11.5–7 ka, with the exception of one shell from glacial-marine sediments. The slowstand is recognized as the depth interval between 15 m and 25 m, and contains many potentially datable deposits identified as a guide. The depth range through which the slowstand occurred, from 15 m to 25 m, should serve as a high-priority target for locating ancient submerged archaeological sites here and in similar regions. Other glaci A.E., and Lewis, R.A., 2001, The Turner Farm fauna: 5000 years of hunting and fishing in Penobscot Bay, Maine: Occasional Publications in Maine Archaeology, no. 11, 177 p.


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