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Stratigraphic Evidence for Historical Position of the East Cambridge Shoreline, Boston Harbor, Massachusetts

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ABSTRACT

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Sediment cores were used to examine the stratigraphy at a site in East Cambridge, Massachusetts to ascertain its environment and the original shoreline position prior to artificial filling. Through the analysis of historical charts, sediment characteristics, and salt marsh plant species, it was determined that over 70% of the study area were above mean-high water prior to urban development. The fibrous nature of peat immediately underlying the fill material and the in-situ remains of *Spartina patens* and *Distichlis spicata* indicated a high marsh environment. The fact that the supratidal peat is below the present mean-high water is due to a combination of: (1) sea-level rise since the artificial infilling of the marsh in 1880–90s; (2) possible removal of marsh peat prior to filling; (3) compaction of peat by overlying anthropogenic fill, and (4) compaction and subsidence of underlying sediments. This study provided convincing physical evidence of the historic shoreline position that was necessary to establish former tideland boundaries.

ADDITIONAL INDEX WORDS: *Stratigraphy, mean-high water, sea level, peat,* Spartina *sp., rhizome, compaction, historical charts, Charles River.*

INTRODUCTION

Development of waterfront areas in the coastal zone requires by state laws that the boundaries and original elevations of both present and artificially filled historical tidelands be properly delineated. In Massachusetts and five other states, private ownership extends seaward to mean-low water, and the state maintains fishing, fowling, and navigation rights over intertidal and subtidal areas (tidelands). If these tidelands are proposed for development, the Commonwealth retains rights over the ultimate use of the developed area. The region above mean-high water (MHW) is classified as upland and does not fall under the jurisdiction of the state's Department of Environmental Protection (DEP).

The recent proposal by Cambridge Research Park proponents to develop a mixed-use project in East Cambridge, Massachusetts (Figure 1) required that the historical high water mark be delineated to define DEP's Waterways jurisdiction. This effort required an exhaustive review of historical maps, charts and other historical records. Using the 19th century survey charts, it was determined that the DEP jurisdiction extended to approximately one third of the project site (EPSILON, 1998). However, the shoreline position shown on the 1847 chart (Figure 2) was questioned because it was not specifically labeled as the high water line. Therefore, to confirm the location of the historic high water shoreline physical evidence was needed to ascertain the position of the shoreline prior to urban development and cores were taken to investigate the stratigraphy of the site.

In Massachusetts, the boundary between the high (supratidal) and low (upper intertidal) marsh grasses is considered the demarcation between the upland and private tidelands. Therefore, the presence of in-situ fragments of the high marsh plant species in salt marsh peat can be used to delimit the supratidal position of a particular coastal site. Due to the high elevation, this part of the marsh receives much less suspended sediment compared to the lower marsh. Consequently, these high marsh species form an organic-rich peat with a much lower mud content than the low marsh (FREY and BASAN, 1985). In general, along the New England coast, this boundary is near the open-coast mean high-water level (LEFOR *et al.,* 1987; ORSON *et al.,* 1987; GEHRELS, 1994). Therefore, if high marsh plant species are encountered beneath the artificial fill, it can be used as convincing evidence for the upland position of the site prior to filling (FITZGERALD *et al.,* 1994).

This paper discusses the stratigraphic and botanical evidence used to determine the paleo-elevation of the study site. Our study demonstrates how geological principles are used to corroborate the historical information on the position of the

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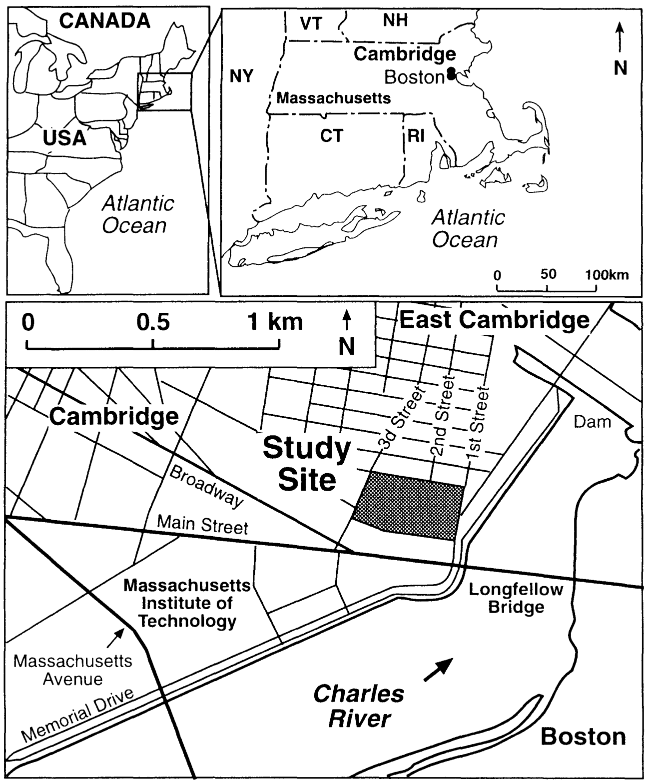

Figure 1. Location of the study site along the northern bank of the Charles River in East Cambridge, Massachusetts.

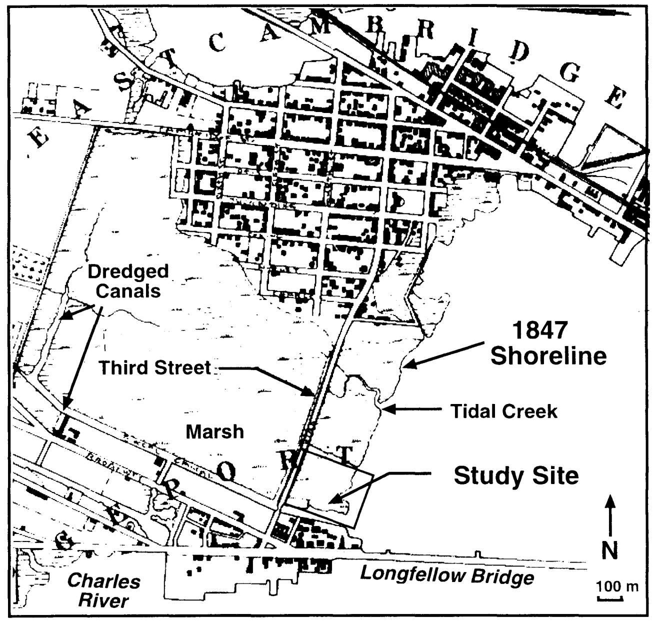

Figure 2. U.S. Coastal and Geodetic Survey chart depicting the 1847 shoreline in relation to the study site. Modified from Epsilon Associates Inc. Report (1998). Source: Roxbury, Cambridge and Medford, Massachusetts, 1847 U.S. Coast Survey. Note the relatively straight nature of the shoreline and the extent of the marsh pattern.

high-water shoreline along the lower position of the Charles River.

STUDY SITE

The study site is located in a parking lot in East Cambridge, Massachusetts and has a total area of about 50,000 m^2 (Figure 1). The 1847 U.S. Coast Survey chart, which is the most accurate representation of the historical shoreline position, shows that over 70% of the site were located landward of the marsh shoreline (Figure 2). The large-scale anthropogenic infilling of the area began in 1880–90s and in 1897 the filing of the area seaward of the 1847 shoreline was authorized (EPSILON, 1998). Today artificial fill of variable thickness overlies the 19th century coastal sediments. The mean tidal range in Boston Harbor is 3.0 m (spring tidal range is 3.4 m). The National Geodetic Vertical Datum of 1929 (NGVD-29) approximates the mean sea level for the region and was taken as a benchmark for elevation measurements. The present mean-high water level is on average 1.5 m above NGVD-29.

MARSH FORMATION

At the mouth of the Charles River estuary tidal marshes flourished prior to being filled for development. Marsh formation in this region is similar to the evolution of other New England salt marshes. In temperate, mesotidal coastal regions, saltmarshes infill backbarrier regions of estuaries, bays, and lagoons, form fringes along protected shorelines, and locally colonize abandoned supratidal sand accumulations (washovers, flood-tidal deltas; FREY and BASAN, 1985). When enough sediment has accumulated to form exposed areas during lower tidal stages, salt-tolerant plants begin to colonize the newly available substrate, with the intertidal zone occupied by *Spartina alterniflora* (smooth cordgrass). Throughout its growth, the stalks of the grass interfere with the flow of the tidal currents, slowing flow velocity and triggering deposition of sedimentary particles. This, in turn, elevates the surface of the substrate promoting further development of vegetation. The sediment of intertidal (low-marsh) areas is characterized by high percentage of inorganic particles with lesser amounts of organic remains including that of *Spartina alterniflora* (NIERING *et al.,* 1977; BELKNAP *et al.,* 1989). In New England, the inorganic fraction can range from clay to coarse gravel and it is not uncommon to find high percentage of sand in cores taken through the marsh (FREY and BASAN, 1985).

When the marsh surface is elevated above mean high water level by sediment deposition and organic accumulation during spring high tides other grasses are established in this supratidal zone. These include *Spartina patens* (salt meadow cordgrass), *Distichlis spicata* (spike grass), and a stunted variety of *Spartina alterniflora.* The resulting supratidal sediments are more organic-rich than low-marsh deposits, consisting largely of fibrous peats formed by in-situ rootlets as well as other organic remains of supratidal vegetation. In an evolving salt marsh, the intertidal to supratidal succession is

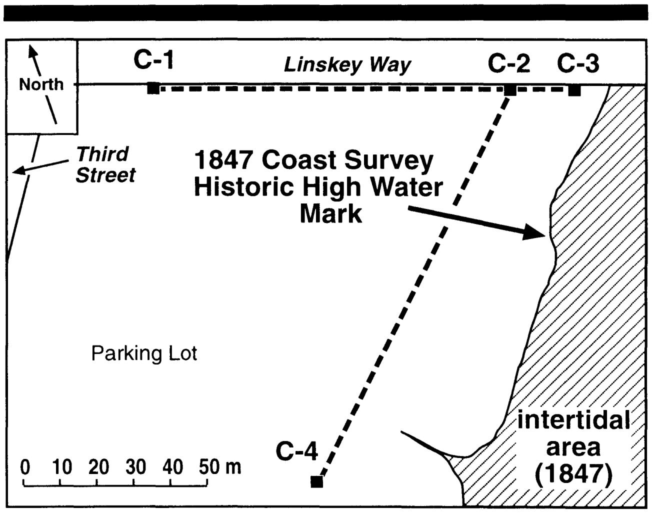

Figure 3. Map of the northern portion of the project site showing locations of cores C-1 through C-4. Dashed lines indicate stratigraphic sections shown in Figure 4. Note that all cores are landward of the 1847 high water mark. See Figure 2 for location of the site in relation to historic shoreline configuration.

expressed in high-marsh peats overlying the intertidal marsh deposits with an overall seaward thinning of high-marsh peats (REDFIELD, 1967). In areas of relatively slow sea-level rise, the surface of the marsh is able to maintain its elevation through time. Eventually, an elevation may be reached where inundation occurs only during the highest tides and the marsh accretion rates decrease dramatically (PETHICK, 1981). Over time, the intertidal marsh grows over the rising surface of the tidal flat, and high marsh gradually replaces the low marsh. The resulting surface is a high marsh that is flat over large areas, and interrupted only by tidal creek channels, salt pans, and local topographic highs. A typical stratigraphic sequence of a salt marsh produced during slow sea-level rise would consist of tidal flat sediments overlain by organic-poor low-marsh deposits and topped by organic-rich, fibrous high-marsh peat.

METHODS

To determine the stratigraphy of the site, an Edelmann hand auger was used for penetrating the anthropogenic fill. When fine-grained sediment was encountered, a Dutch auger was employed to collect undisturbed samples of peat and mud. The hole was re-entered as needed until the entire layer was sampled. A total of eighteen cores were attempted throughout the project site in October 1998, of which four penetrated the fill (Figure 3). The location of each core was determined using a tape measure. Core elevations were determined using detailed city maps with land base elevation accuracy of ± 1 cm. A description was made of the composition, thickness, and depth of each layer beneath the fill material. Sections of peat and organic-rich layers were photographed in the field and sampled for laboratory analyses.

The samples collected in the field were inspected under a binocular microscope. Plant rhizomes and other organic material were examined to identify the genus and species of the plant remains (NIERING *et al.*, 1977). It is primarily the rhizomes that are preserved in peats and muddy sediment as these parts are protected from destructive physical agents. In addition, the roots are commonly surrounded by muddy sediments that produce an anoxic environment and reduce the rates of oxidation and decomposition. Salt marsh plants have distinctive morphologies and the species occupying the high and low marsh have distinct root structures (JOHNSON, 1925; NIERING *et al.,* 1977). The low marsh is colonized by *Spartina alterniflora* which has relatively large diameter pale-yellow rootlets. Because this plant colonizes the lower intertidal zone which is often a region of high mud sedimentation, the remains of this plant form organic mud rather than a true peat. *Spartina patens* and *Distichlis spicata* have relatively thin yellow-brown rootlets and occupy the upper intertidal to supratidal portion of the salt marsh.

RESULTS

Cores C-1, C-2, and C-3 were taken along Linskey Way at the north end of the property and were used to construct a stratigraphic section with approximately shore-normal orientation (Figure 3). Cores C-2 and C-4 make up a shore-parallel section that extends through the middle of the project site along a northeast-southwest trend. A fence diagram of the project site was constructed using four cores (Figure 4). Similar stratigraphy was exhibited in all of the cores, however, the thicknesses and depths of layers varied as did the composition of the units underlying the peat layers. Core C-1 was bottomed in silty organic sand. In cores C-2 and C-3, the fibrous peat was underlain by organic-rich mud containing *Spartina alterniflora* remains. Organic-rich sand and fine gravel were encountered underneath the peat in core C-4. As we were primarily interested in the peat layers, the sediment beneath the peat was not sampled to any great depth. In all cases the peat is overlain by fill material of highly variable composition (brick, glass, concrete fragments) and thickness (1.8 to 2.5 m).

The peat was present in all four cores and ranged in thickness from 7 to 40 cm (Figure 4). The black color in some samples was due to tar staining of otherwise brown fibrous peat. The surface of the high marsh peat in the cores ranged in elevation (relative to NGVD-29) from a low of 0.68 m at C-3 to a high of 1.30 m at C-1.

The results of lithological and botanical analyses of six samples are presented in Table 1. Remains of high-marsh grasses, *Spartina patens* and *Distichlis spicata,* were identified in each of the four cores directly underlying the fill material (Figure 4, inset). In cores C-3 and C-4, samples taken beneath the high-marsh peat containing *Spartina patens* and *Distichlis spicata* rhizomes mixed with *Spartina alterniflora* suggested a transition zone. In all cases plant remains were in growth position which allowed their use as indicators of depositional environments.

DISCUSSION

Originally, the supratidal position of the large portion of the site was based on the 1847 U.S. Coast Geodetic Survey

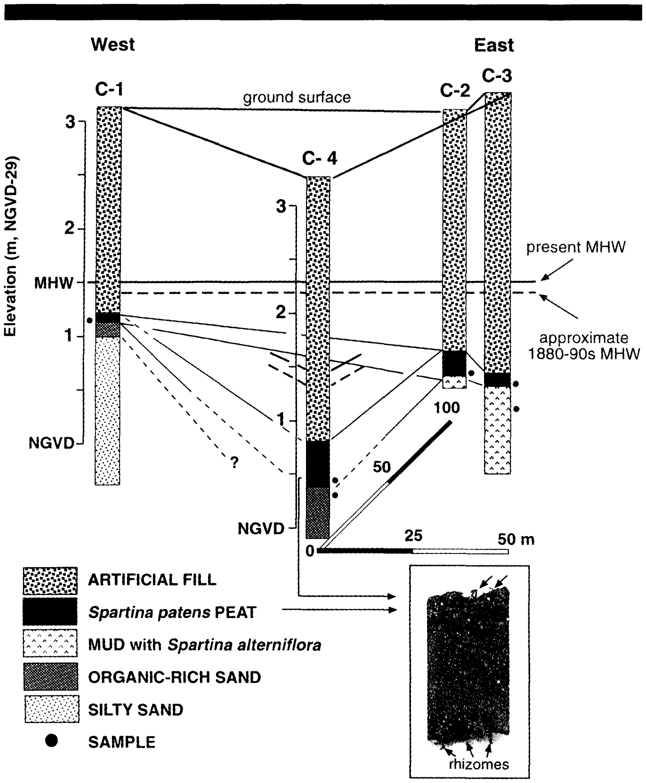

Figure 4. Fence diagram based on four sediment cores. Note the consistent stratigraphic relationships where high-marsh peat is overlain by anthropogenic fill of variable thickness and underlain by different lithologies including organic low-marsh mud and silty sand with variable amounts of organics. Also shown are the present mean-high water level and its approximate position in 1880–90's, when the infilling of the area began. See Figure 3 for core locations. The inset shows a fragmentof high marsh peat with in-situ *Spartina patens* rhizomes (core C-4, sample depth - 2.65–2.70 m).

chart of East Cambridge and the Charles River region (Figure 2). Although the accuracy of the shoreline position was challenged, this chart clearly shows the position of the roadway now known as Third Street East surrounded by an extensive marsh. Along the Charles River side, the edge of the marsh is almost linear and is cut by a number of tidal creeks. The edge of the marsh shown on this chart is depicted to coincide with the high water shoreline at that time. The marsh indicated on the 1847 chart is similar to other marshes in the region, such as nearby Belle Isle marsh located in Winthrop and East Boston and the Neponset marsh comprising parts of Boston, Quincy and Milton. On today's U.S. Geological Survey topographic maps these marshes are shown as flat surfaces and are also indicated as being above mean high water. Therefore, if the chart is accurate, the cores taken landward of the historical shoreline are expected to encounter high-marsh peat, unless it was completely removed prior to development of the area (FITZGERALD *et al.,* 1994).

A similar sequence of units within each of the four cores suggests a fairly homogeneous environment and a uniform sedimentation pattern within the project site. In all cores, the presence of in-situ *Spartina patens* rhizomes in fibrous peat indicates a supratidal environment. Transition zones of cores C-3 and C-4 reflect a change in environment brought about by an alteration in the duration of tidal submergence. As sedimentation builds the tidal flat vertically, the length of time that the grasses are submerged by salt water gradually diminishes. The duration of tidal submergence dictates the type of plant that can live in that environment. Thus, in a vertically accreting marsh, it would be expected that transitional marsh facies would exist beneath a high marsh supratidal community.

In all cases the high marsh peat surface is below the present mean high water mark which is at an elevation of 1.50 m. If we assume that prior infilling the marsh surface was above mean high water as indicated by the *Spartina patens* peat, then some of the elevation difference can be explained by the rise in sea level that occurred since it was buried by fill in 1880–90s. Using a sea-level curve for Boston, Massachusetts with a period of record from 1930 to 1990 (LYLES *et al.,* 1998) and extended sea-level record for New York City (pre-1930s; STEVENSON *et al.,* 1986), a conservative estimate of the MHW at the site at that time is 0.2 m below present (dashed line in Figure 4). Another reason for a lower peat elevation in the cores is a possible removal of the top portion of the peat prior to filling. Thus the upper surface of the

Table 1. *Lithologic description of sediment samples. Plants are listed in order of decreasing abundance.* Sp—*Spartina patens,* Ds—*Distichlis spicata,* Sa—*Spartina alterniflora. See Figure 4 for sample locations.*

Core	Sample Depth (m, NGVD-29)	Lithology	Color[1]	Plant Remains	Environment
C-1	1.23–1.29	sandy peat	10YR 2/2 very dark brown (tar-stained)	Sp	High Marsh (disturbed)
C-2	0.71–0.81	fibrous muddy peat	10YR 2/2 very dark brown	Sp, Ds	High Marsh
C-3	0.57–0.67	fibrous muddy peat	10YR 2/2 very dark brown	Sp, Sa[2]	High Marsh
C-3	−0.08–0.07	sandy organic mud	10YR 4/2 dark grayish brown	Sa, Sp	Transitional—Low Marsh
C-4	0.58–0.67	sandy peat, oyster shell fragments	10YR 2/1 black (tar-stained)	Sp, Sa[2]	High Marsh
C-4	0.42–0.53	organic-rich muddy sand & fine gravel	10YR 2/2 very dark brown (tar-stained)	Sp	Transitional—High Marsh (reworked?)

[1] Munsell® Soil Color Chart (hue, value/chroma) match and description
[2] Trace amounts (probably stunted variety)

marsh layer represents the minimum elevation. Finally, and most importantly, subsidence and compaction would be responsible for a lowering of the high-marsh peat surface. It is reasonable to expect that when 2.0–2.5 m of dense fill are placed on top of the peat, it will dewater and compact, especially if there were buildings and facilities constructed on top of the peat, it will dewater and compact, especially if there were buildings and facilities constructed on top of the fill. In addition, continuous vehicular traffic would further compact the peat and underlying muds and muddy sands. In addition to the thickness of overburden, the degree of compaction is related to a number of factors including the original peat thickness, water content (up to 90%; TEICHMÜLLER and TEICHMÜLLER, 1967, and composition of material underlying the peat (KEARNEY and WARD, 1986; CAHOON, *et al.,* 1995).

The peat surface attains its highest elevation at C-1. In contrast to cores C-2 and C-3, where peat is underlain by mud, core C-1 bottomed in sand which undergoes little compaction when loaded. Thus, the depth of the high marsh pat layer appears to be closely related to the thickness and type of underlying sediments and the response of these sediments to dewatering, compaction, and subsidence.

CONCLUSIONS

The consistence of the stratigraphy and the presence of fibrous *Spartina patens/Distichlis spicata* peat in the cores indicate that the large part of the project site was once a high marsh environment with a supratidal elevation. The variability in the present elevation of the high marsh peat surface is explained by sea-level rise since mid-1800's, possible removal of the upper portion of peat before the placement of the fill, differences in the amount of compaction by overlying fill, and subsidence of the peat and underlying sediment. This interpretation is consistent with the coastal charts of this region, which indicate that the mean high water shoreline extends through the property in a general north-south trend.

This study illustrates how standard geological techniques can be used to ground-truth and corroborate the existing historic data. Our investigation aided in delineation of state tideland boundaries. This was critical in determining where public rights and development standards are applied in a historically filled coastal area and led to the approval of the new development plan.

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