Geological Oceanography of a Segment

of

Long Island Sound

J. R. Schubel
Marine Sciences Research Center
State University of New York
at Stony Brook
Stony Brook, New York
11794

The field trip will be conducted aboard the Marine Sciences Research Center's new 55 foot research vessel, R/V ONRUST. The ONRUST, completed in 1974, was designed specifically for work in coastal and continental shelf waters. It is well equipped for work on biological, chemical, geological, and physical oceanographic problems of the coastal environment.

The primary objective of this cruise is to introduce the participants to some of the tools and techniques used by oceanographers in their quest to understand, interpret, and predict the processes that characterize the coastal marine environment. A secondary objective is to use some of these tools and techniques to make a cursory examination of several different sedimentary sub-environments of Long Island Sound. The shortness of the trip precludes a detailed look at any particular area and requires that the cruise be concentrated in the Sound off Port Jefferson Harbor. The actual shiptrack will be dictated largely by weather and sea state, and therefore no specifics are given in this brief report.

After a variety of methods and instruments have been demonstrated by MSRC staff members, participants will be encouraged to use the devices to collect their own samples, and to make their own measurements. The methods and instruments to be employed; the measurements to be made; and the samples to be collected, fall into several broad categories:

I. Navigation

- A. Electronic
  - 1. Loran A
  - 2. Loran C
- B. Optical
  - 1. Horizontal Sextant

II. Shape and Structure of Coastal Basin

- A. Precise and Accurate Bathymetry
- B. Shallow Sub-structure
  - 1. High Resolution Continuous Seismic Profiler
    - a. E. G. & G. Uniboom

III. Sediments

A. Suspended Sediments
   1. Various water bottles and filtration techniques

B. Surficial Bottom Sediments
   1. Shipek grab smapler
   2. Van Veen grab sampler

C. Sub-surface Sediments
   1. Gravity corers
      a. Benthos
      b. Phleger

IV. Physical and Chemical Properties of Sea Water

A. Temperature
   1. Thermistor
   2. Reversing Thermometer

B. Salinity
   1. Electrical Conductivity

C. Nutrients
   1. Autoanalyzer

D. pH
   1. Electrode

E. Dissolved Gases
   1. Oxygen
      a. Winkler Titration
      b. O_2 electrode

F. Optical Properties
   1. Transmissometer
   2. Fluorometer

V. Circulation

A. Current Measuring Devices
   1. Eulerian
      a. ENDECO current meter with deck readout
   2. Lagrangian
      a. Drogues
      b. Dye Diffusion

VI. Plankton

A. Towed nets

B. Pumped samples

C. Water bottles

Each participant will be provided with a set of oceanographic data from Long Island Sound and a suggested reading list for possible classroom use in oceanography courses at the undergraduate and beginning graduate levels.

NOTES

TRIP A-6 AFTERNOON

SEDIMENTARY DYNAMICS OF A COASTAL POND:

FLAX POND, OLD FIELD, LONG ISLAND, NEW YORK

by

Karl W. Flessa, Glenn A. Richard and Mary K. Cushman
Department of Earth and Space Sciences
State University of New York at Stony Brook
Stony Brook, New York, 11794

INTRODUCTION

Flax Pond is a small estuarine marsh located on the north shore of Long Island, New York (Fig. 1). Since 1966 the Flax Pond marsh has been owned by the State of New York and administered by the Department of Environmental Conservation and the Marine Sciences Center of the State University of New York. Under this administration the marsh has been utilized as a research site for studies dealing with salt marsh flora and fauna, estuarine hydrology, nutrient cycling and coastal sedimentation. The protected nature of the Flax Pond marsh and its similarity to other intertidal marshes in the northeast make it a unique scientific resource for the region. In addition to the advantages conferred by state protection, the Flax Pond marsh is situated in an area which was settled early in the history of New York. Historical records which mention Flax Pond date back well into the 18th century, maps showing the pond date from 1797, and accurate coastal charts of the region were first issued in 1852. Thus, the existence of historical records and maps provides an opportunity to study the development of man's interaction with this coastal pond and permits the documentation of the natural and manmade coastal changes of the past 200 years.

The objectives of our research on the sedimentary dynamics of the Flax Pond marsh include the understanding of the processes, rates and environmental controls of sedimentation and marsh growth. We have, to date, utilized information derived from historical records, maps and charts, the stratigraphy of the marsh sediments, and marker bed studies to arrive at estimates of the rates of marsh accretion. A summary of this work is presented in this paper and will be illustrated while in the field. Future projects will utilize radiometric techniques and suspended sediment budgets to arrive at additional estimates of the rates and environmental controls of marsh growth.

Throughout the settlement and development of the coastal zone, marshes have been altered to varying degrees. Among these alterations are the physical changes resulting from ditching, bulkheading, dredging and partial or wholesale infilling. In recent years the value of marshes in providing food, sites for recreation, natural flood protection, and habitats for wildlife has been realized and many coastal wetlands are now protected by law from further alteration. Many previously altered marshes are now recovering from an era of abuse. Our studies will provide an estimate of the rate at which marshes can grow under natural conditions and may serve to predict the rate of recovery of disturbed marshes. Furthermore, an assessment of the relative importance of the factors governing wetland growth may indicate ways in which marsh growth and recovery may be initiated or stimulated.

THE FLAX POND MARSH: GENERAL FEATURES

The Flax Pond marsh is a small (0.5 km^2) salt marsh located on the north shore of Long Island, New York (Fig. 1). The marsh is a "pocket" marsh facing Long Island Sound and is situated between two long hills formed by the Harbor Hills moraine of Wisconsinan age. The two hills terminate in bluffs known as Crane Neck and Old Field Points.

The total drainage area of Flax Pond is only 1.68 km^2 (Woodwell and Pecan, 1973) and no substantial fresh water streams enter the marsh. The salinity in Flax Pond is about 26 ‰, approximately equal to that of Long Island Sound water in this region. The average tidal range in the marsh is 1.8 meters and the low tide is delayed by approximately two hours by a sill near the inlet. The marsh itself is predominantly intertidal. Further details on the hydrology of Flax Pond are given by Woodwell and Pecan (1973).

The dominant vegetation in the marsh is the tall form of *Spartina alterniflora*, a grass which is capable of colonizing intertidal mudflats and sandflats and which may form accumulations of peat. In the Barnstable, Massachusetts marsh *S. alterniflora* grows through two-thirds of the entire tidal range (Redfield, 1972). Small stands of the shorter, or "dwarf" form of *S. alterniflora* are present in the upper intertidal areas of the marsh. Essentially all of the peat in the Flax Pond marsh is formed by *Spartina alterniflora*. The other species of *Spartina*, *S. patens* is found associated with *Distichlis spicata* (spike grass) along the high water periphery of the marsh with especially extensive stands in the north-central parts of Flax Pond. Several species of *Salicornia* (marsh samphire or glasswort) are common in the sandier parts of the marsh near the high water line. At elevations slightly above mean high water, but in areas which are still subject to the influence of storm tides, are stands of *Juncus gerardi* (black grass) and *Iva frutescens* (marsh elder). This association is characteristic of the upland periphery in the north-central parts of the marsh.

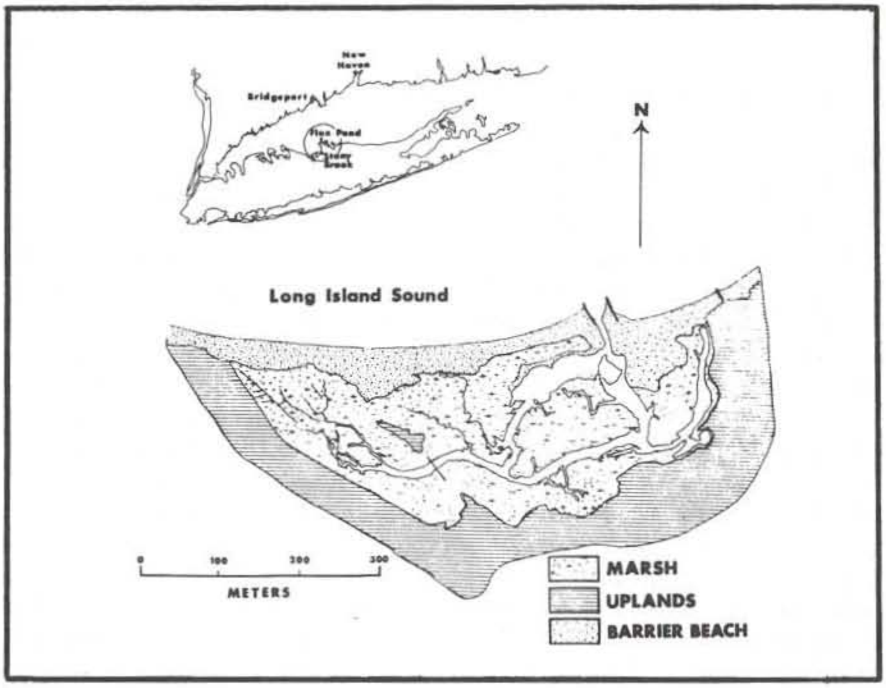


Figure 1: Location and physiography of the Flax Pond marsh

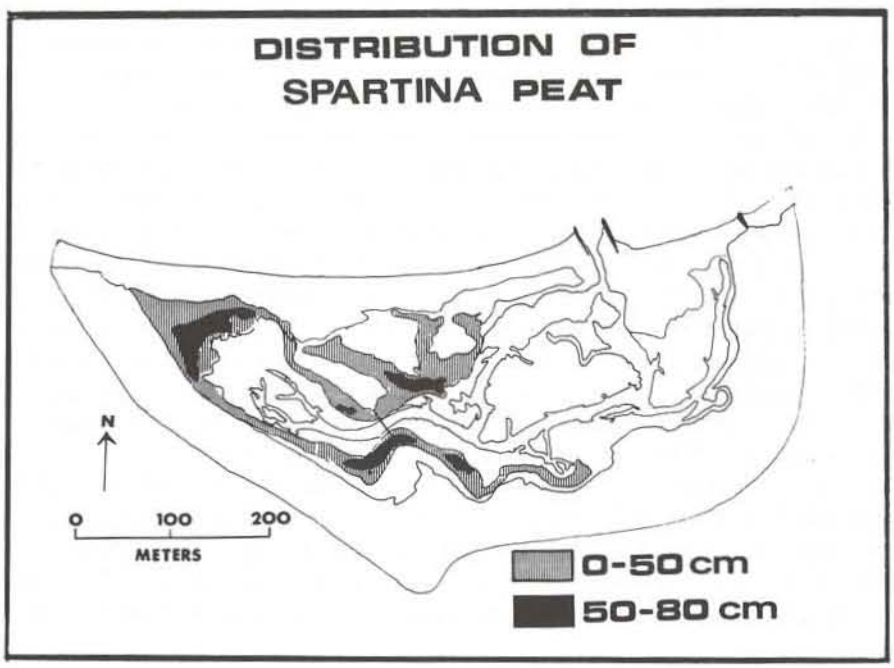


Figure 2: Distribution and thickness of Spartina peat in Flax Pond.

Surface sediments in the Flax Pond marsh range in size from coarse gravel to fine silts and clays. The beach facing Long Island Sound is composed of coarse sand and gravel derived from the cliffs of glacial sediment to the east and west of the marsh. In the central and eastern parts of the marsh a broad band of coarse sand and gravel, just slightly above the level of spring high water, forms the barrier between the marsh proper and the waters of Long Island Sound. The inner margin of this band is in the form of small lobes of gravel which appear to be encroaching upon the marsh surface. The movement of these lobes apparently takes place during severe storms. We have not yet been able to actually observe the movement of the lobes and do not know the rate at which this phenomenon occurs. Coarse sediments are also found inside the inlet to the marsh where an extensive tidal delta of sand and gravel is exposed at low tide. Within the marsh itself, sandy sediments are generally confined to the center of the tidal channels. The finer grained sediments, the muds and peaty muds, cover extensive areas in the eastern and western portions of the marsh. The finest grained sediments are located in the western parts of the marsh, the area farthest removed from the tidal inlet. The marsh peat is most extensive in the western and north-central parts of the marsh. Figure 2 shows the distribution of the Spartina peat.

The sediments within the Flax Pond marsh may be delivered by way of four mechanisms: stream inflow, aeolian input, sediment derived from storm washovers, and net tidal input of sediment. Only two small streams enter the Flax Pond marsh. The small area that they drain, and the fact that the salinity within the marsh is approximately the same as that of the open Sound indicates that sediment input from stream inflow is insignificant. The typically coarse beach sediment of the area and the absence of a dune field at Flax Pond argues against a significant aeolian input of sediment to the marsh. Because of the periodic nature of severe storms, the amount of sediment derived from storm washovers of the barrier beach is difficult to assess. The material thus delivered, however, is characteristically very coarse sand and gravel, easily recognizable in cores, and is generally confined to a relatively narrow strip behind the active beach. For the reasons cited above, we assume that the chief source of sediment is via net tidal input from Long Island Sound. Sediment delivered to the marsh by way of tidal exchange may be transported as either bottom load or suspended load. A gravel delta inside the mouth of the marsh is evidence of some contribution via bottom load, but because of the predominance of fine grained sediment within the marsh, we suspect that this transport mechanism plays a relatively minor role. The dominantly fine-grained nature of the sediments in the marsh supports the interpretation that the suspended sediment input controls the rate of sediment supply. Indeed, coastal wetlands are generally considered to be the major sink for suspended sediment on the Atlantic coast (Meade, 1972).

Further description and discussion of the marsh sediments may be found in the section on sedimentation rates.

FLAX POND: THE HISTORICAL RECORD

Town Records

Table 1 lists excerpts from the Brookhaven town records between 1712 and 1899 which mention Flax Pond. Many of the 18th century passages refer to Flax Pond as "freshpon" or "fresh pond". The 1751 excerpt reveals the origin of the name Flax Pond - the pond was used for the wetting of flax, a procedure which ideally requires "pure, soft water" (Anon., 1910). All of the historical references prior to 1801 clearly indicate that Flax Pond was a fresh water pond and was not connected to the marine waters of Long Island Sound. In 1801, however, the town sold a portion of the pond but reserved, for the town residents, all rights to fishing, clamming and oystering. This notation indicates that the pond was connected to Long Island Sound and that salinities in the pond were sufficiently high to allow the growth of clams and oysters. The pond is also referred to as a "Marsh" in 1801, but this term is ambiguous and does not necessarily imply a marine connection. The remainder of the pond was sold in 1819, also with the stipulation that fishing and clamming rights were to remain with the town trustees. In 1870 the first mention is made of a salt meadow in the Flax Pond area. By at least 1870 then, a stand of Spartina had become established within the marsh. Salt meadows along the north shore of Long Island are not especially unusual features and thus the Flax Pond "salt meadow" may have been in existence for some time prior to its mention in the town documents. In 1899 an individual applied for a permit to open an inlet to Flax Pond. Nautical charts from that same period, however (see next section), show a connection to Long Island Sound. We assume, therefore, that the intention was to deepen an existing inlet to allow for easier navigation or to increase tidal exchange in the marsh and thereby improve the fishing and clamming. A small area west of the inlet was dredged for sand and gravel, probably sometime during the 1940's.

The historical records pertaining to Flax Pond indicate that the pond contained fresh water through much of the 18th century. The pond was connected to marine waters sometime between 1751 and 1801. The first indication that the pond was connected with marine waters is a stipulation, made in 1801, that clamming and oystering rights were reserved for town residents. Town records do not, unfortunately, indicate whether the opening of the pond to Long Island Sound was a natural or man made occurrence.

Table 1: History of Flax Pond, 1712-1899.

1712-	Road laid "to ye freshpon in ye olde feild tu Rod wide" - Records, Town of Brookhaven, Book C, p. 62.
1725-	Purchase by the Trustees of "a cartayn dwelling Hows and home lot with ye garding orchard - ffencings and other Improvements there unto belonging or in any wise apertayning together with a three acre Lot in ye old field near ye ffresh pond..." - Documents, Town of Brookhaven (1693 - 1947) p. 1.
1728-	a highway 4 rods laid out "to ye flax pond" - Records, Town of Brookhaven, Book C, p. 131.
1738-	a road laid out from the mill dam (in Setauket) to the Clay hole and also a road to Crane Neck "and oute of that Rode to ye flack pon ass it was formerly layd out" - Records, Town of Brookhaven, Book C, p. 189.
1751-	"a highway to ye fresh pond in the Old Field two Rods wide" to be "laid open for publick use two Rods wide as it was laid outt and Entred on Record begining at and turning out of a road which leads from ye said Oldfield Gate unto Crains Neck", running "untill it comes to ye Common land and into said pond att the usuall place of wattring flex: We also order that all other roads hereto fore laid out to said pond shall be void and remain shut up Excepting this above Said roade as we have now Laid out to be and remain an open public free highway forever..." - Records, Town of Brookhaven, Book B, p. 481-482.
1801-	The Town Trustees sell to Richard Floyd, Vincent Jones, & Jonathan Mills, "the one equal undevided half part of a certain Pond or Marsh- in the Old Field- Fifty nine Acres one quarter and twenty one Rods," described according to a map and survey but reserving "the sole and exclusive right of Fishing, Clambing, & Oystering for ever unto said Trustees and their successors and the Inhabitance of said Town of Brookhaven for ever."- Records, Town of Brookhaven, 1798-1856, p. 49-51.
1815-	a record of the division of Flax Pond where by Vincent Jones, William Wickham Mills, and Stephen Hulse, deceased, are to have the west section and the Town Trustees the east sections. - Records, Town of Brookhaven, 1798-1856, p. 193-194.

Table 1, cont.

1819-	Town sells to some individuals "all the Right in the flax pond belonging to said town, excepting and reserving the right of fishing and clambing in said pond for the Inhabitance of said town to be under controul of said Trustees or their successors..." - Records, Town of Brookhaven, 1798-1856, p. 219.
1855-	Individual makes application to Town to lay down oysters in Flax Pond. Board appointed someone to view the premises and report at next meeting; appears no action taken. - Records, Town of Brookhaven, 1798-1856, p. 537.
1865-	Town agrees "to sell to highest bidder, the common land belonging to the Town, at or near the foot of Flax pond lane and adjoining said Pond." - Records, Town of Brookhaven, 1856-1886, p. 270.
1870-	reference to a "salt meadow" in this area. - Unrecorded Deeds and Land Papers in Brookhaven Town, North. (notebook, pages unnumbered).
1894-	Trustees deny individual oystering privileges. - Records, Town of Brookhaven, 1886-1900, p. 360, 364.
1897-	Capt. Daniel Smith applies for Flax Pond purchase, stating that there were 20 acres more or less, but the committee reports the pond was sold in 1819 but "the rights of fishing and clamming" were reserved to the people. - Records, Town of Brookhaven, 1886-1900, p. 360, 364.
1899-	Individual applies to open inlet to Flax Pond; Cannot be granted as property through which inlet would be cut is privately owned. - Records, Town of Brookhaven, 1886-1900, p. 437.

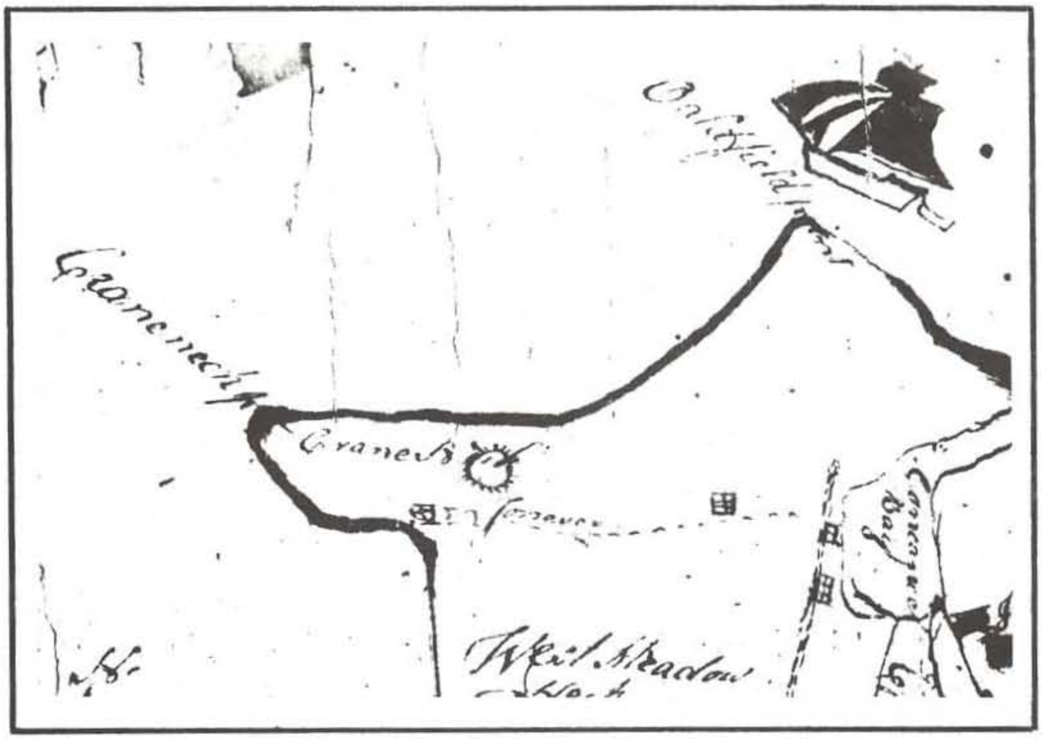
Maps and Charts

Three types of maps are available which illustrate the Flax Pond marsh:

1) Atlases and road maps - Although these maps constitute the longest and most continuous map record, road maps may not accurately represent shoreline features simply because the objective of the map is to illustrate the location of roads and villages. Even recent oil company maps show Flax Pond either connected to Long Island Sound, isolated from the Sound, or simply not there at all. Earlier, especially 19th century, maps were often copies of other earlier maps. This common practice resulted in out of date maps and maps which perpetuated earlier errors. For these reasons, we consider such maps to be the least accurate in their depiction of the Flax Pond marsh. 2) Topographic maps - these maps, published by the U.S. Geological Survey, are very accurate maps which show elevations, distances and landmarks. It is frequently not clear, however, in dealing with topographic maps which show tidal marshes, what stage of the tide is represented. The maps also have a relatively limited historical range. Flax Pond is depicted in topographic maps issued in 1922, 1955 and 1967. 3) Navigational charts - the coastal charts issued by the U.S. Coast and Geodetic Survey and its parent and daughter agencies are supposed to accurately show shoreline features and are, therefore, the most reliable source of information regarding coastal changes. The first of the charts which shows Flax Pond was issued in 1852. Subsequent editions were issued at intervals ranging from three months to ten years. Each edition, however, may not be a complete resurvey, but often merely updates the position of lights, buoys and other navigational aids. New base maps which show shoreline and depth changes were prepared at approximately 15 to 20 year intervals. Actual shoreline changes can take place during much shorter intervals and may not appear on the chart at all, or an ephemeral shoreline configuration may be shown on a chart for up to 20 years despite the fact that that shoreline configuration was very short-lived.

In addition to the information provided by maps and charts, aerial photographs provide direct, unequivocal information concerning the state of the shoreline. Aerial photographs which include Flax Pond were taken in 1938 and in 1969. The maps, nautical charts and photographs referred to in this paper were examined and copies from originals housed in the National Archives, the Library of Congress and the American Geographical Society.

Figure 3 shows 10 maps, charts or photographs which illustrate the major coastal changes which have taken place in the Flax Pond area since 1797. Figure 3-A is part of a 1797 survey of the town of Brookhaven and shows Flax Pond as a roughly circular pond isolated from the waters of Long Island Sound. This configuration is consistent with historical records which indicate that the Pond was fresh during much of the 18th century. This map's accurate depiction of other harbors and marshes in the area have convinced us that the 1797 map is a reliable one. Figure 3-B is a portion of an 1836 map which was designed to show the location of roads and villages. It, too, shows Flax Pond isolated from Long Island Sound, but in this case, the map is not consistent with records



<u>Figure 3-A</u>: The 1797 map.

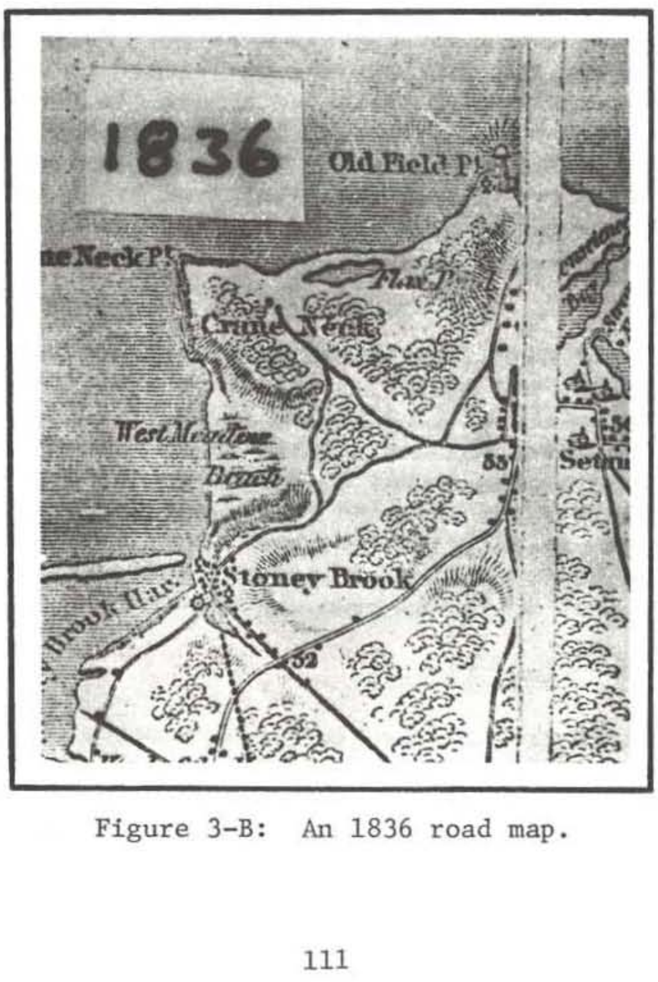


Figure 3-B: An 1836 road map.

which indicate that the Pond had been opened to tidal waters by 1801. We assume that this map is a copy of an earlier map made when Flax Pond was isolated from the Sound. Figure 3-C is from the first nautical chart of the region, issued in 1852. Although the quality of the reproduction is not good, it shows Flax Pond connected to the Sound via an inlet trending northwest-southeast and situated near the east central part of the barrier beach. The 1853, 1855, 1878 and 1880 editions of this chart are all essentially the same, differing only in information regarding the position of navigational markers. The 1890 edition (Fig. 3-D) shows two significant changes in the configuration of Flax Pond. The inlet is oriented in an east-west direction, due, presumably, to a persistent westerly longshore drift of beach sediment. The other change is the appearance of a tidal creek in the extreme eastern margin of the marsh which trends north-south and then turns abruptly to the west at the inner margin of the barrier beach. The configuration shown on this 1890 chart continues essentially unchanged through the 1931 edition. In 1933 a major change is evident in the outline of the marsh. The 1933 chart is not shown but is the same as the 1938 edition in Figure 3-F. Two inlets are apparent, one near the center of the barrier beach, the other situated on the extreme eastern margin of the marsh. Apparently, sometime between 1931 and 1933 a storm had broken through the beach on its eastern end and connected the tidal creek there with Long Island Sound. The 1938 chart does not, however, show the true state of the Pond at that time. Figure 3-G, an aerial photograph taken in July, 1938, shows the central inlet closed off and the eastern inlet extended in an east-west direction by the effects of the westerly longshore drift. The 1938 chart is apparently a largely unrevised version of the 1933 chart. The 1947 nautical chart (Fig. 3-H), while still a largely unrevised edition of the 1933 chart, shows two jetties, one positioned on each side of a central inlet. An artificial inlet had apparently been dredged by 1947 and the eastern inlet had been closed. The inlet has been stabilized by the jetties since 1947. The 1955 and 1967 topographic maps (Figs. 3-I and J) show the Flax Pond marsh essentially as it is today. Interestingly, however, the sand accumulations around the jetties indicate a predominantly easterly longshore drift, opposite that implied in the 1938 photograph.

The sequence of maps, charts and photographs illustrates three major facts about the Flax Pond marsh. 1) Prior to 1797, Flax Pond was isolated from the waters of Long Island Sound; 2) The position and orientation of the inlet changed several times between 1852 and 1947. Longshore drift and storms appear to have been the dominant natural processes responsible for the changing configuration of the inlet; 3) The direction of longshore drift has not been constant since 1852. Between 1852 and 1947 the dominant flow of littoral sediments was westerly. Since 1947 the direction of drift has been easterly.

Summary of the historical records

The information provided by historical records, maps and nautical charts indicates that Flax Pond was opened to marine waters between 1797 - the date of a map which shows the Pond isolated from the Sound - and 1801 - the date of a deed which reserves clamming rights for the town

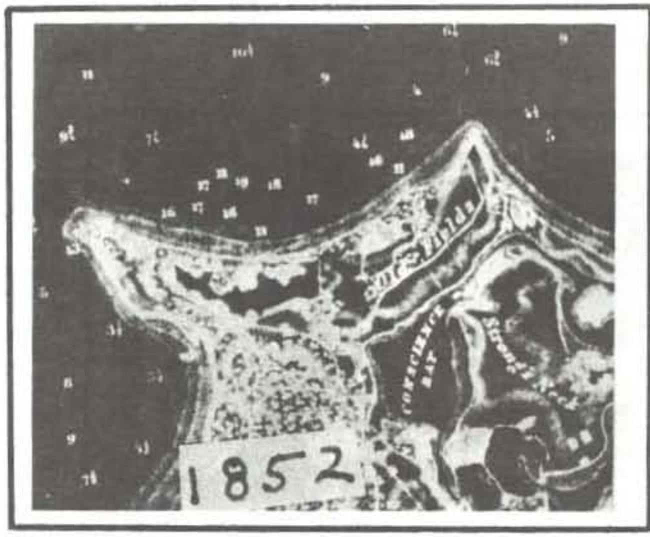


Figure 3-C: An 1852 nautical chart.

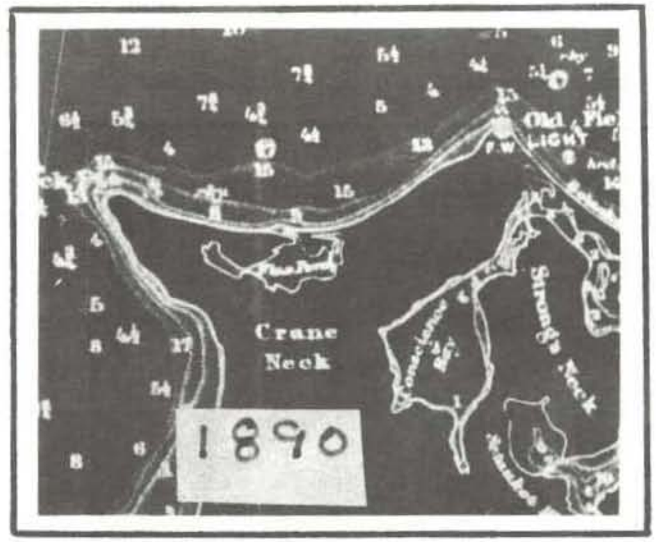


Figure 3-D: An 1890 nautical chart.

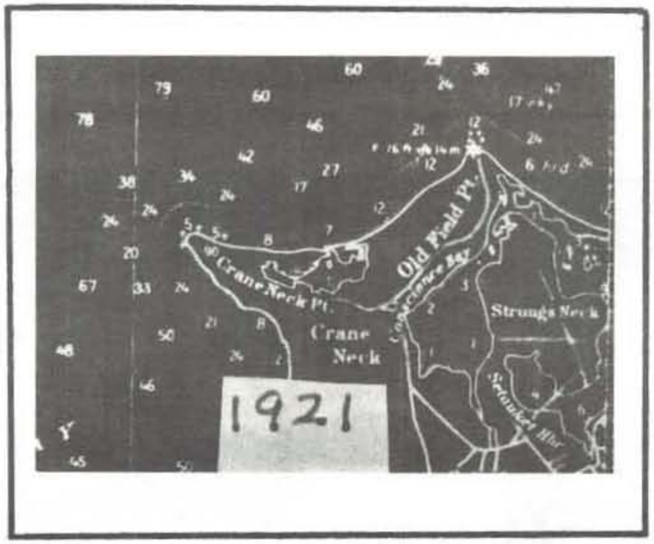


Figure 3-E: A 1921 nautical chart.

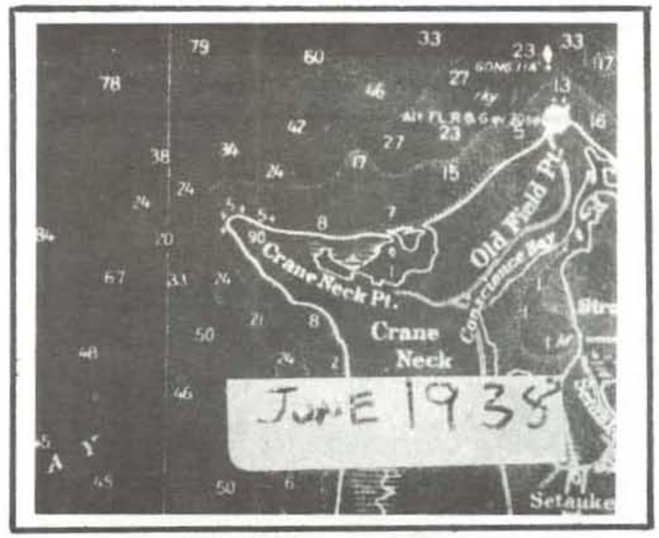


Figure 3-F: A 1938 nautical chart.

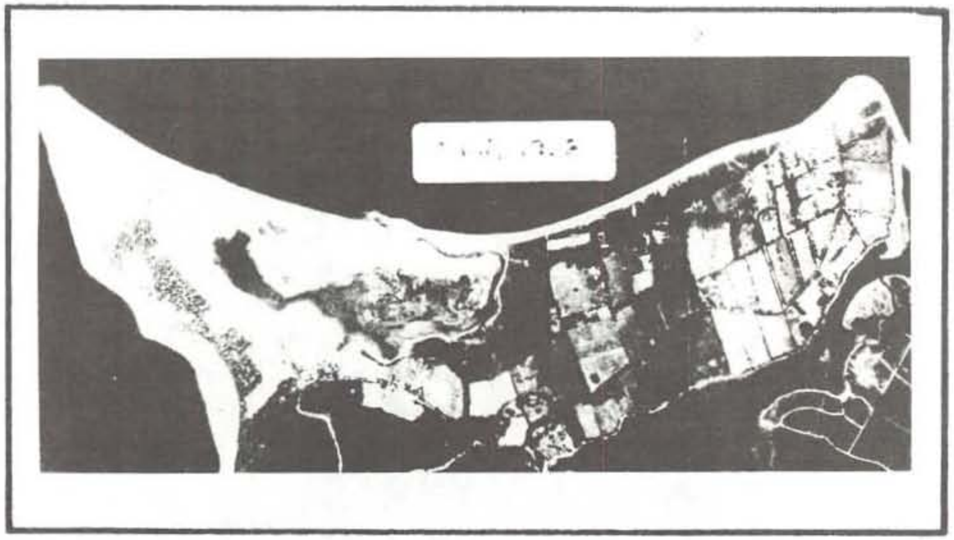


Figure 3-G:: A 1938 aerial photograph.

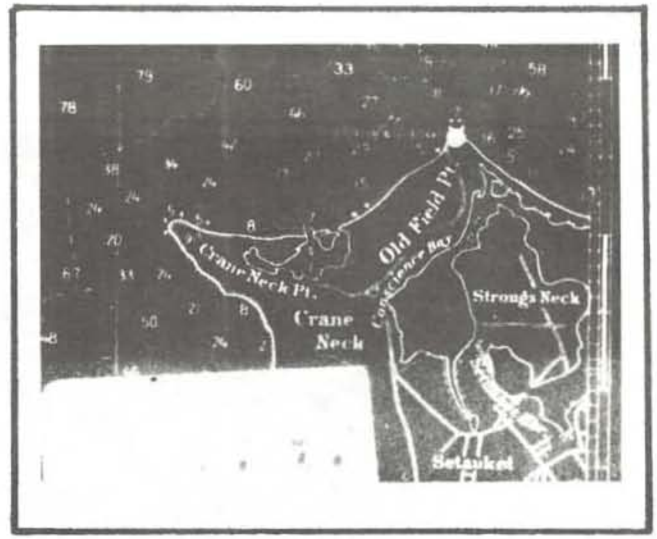


Figure 3-H:: A 1947 nautical chart.

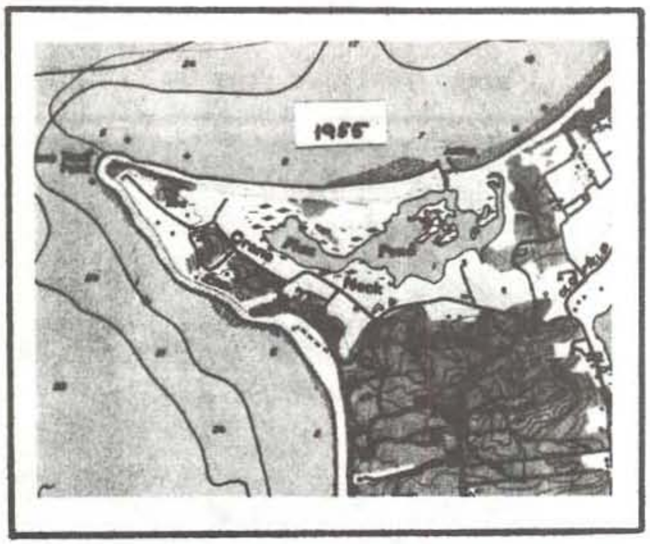


Figure 3-I: A 1955 topographic map.

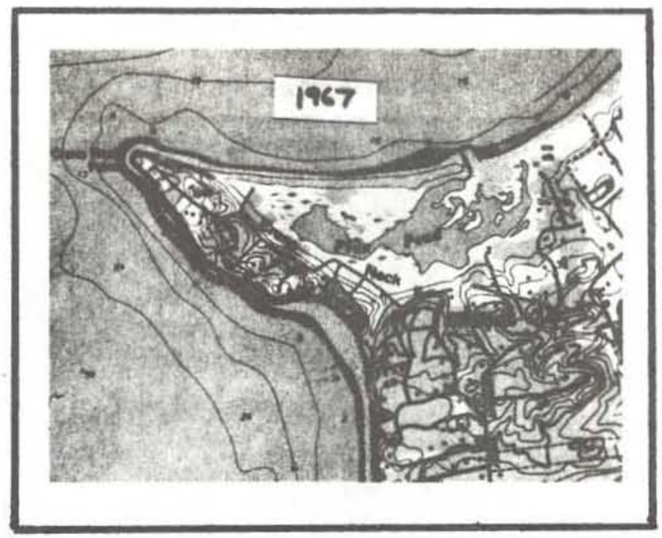


Figure 3-J: A 1967 topographic map.

residents. Subsequent to its connection with Long Island Sound the configuration and position of the inlet changed frequently as a result of longshore drift and storms. Since 1947 the inlet has been stabilized by the construction of two jetties.

SEDIMENTATION RATES

Introduction

The salt marshes of the east coast of the United States are the product of a distinctive interaction between the rate of rise of sea level, the rate of mineral sediment input, the rate of production of organic detritus and the rate at which the marsh grasses are able to trap and stabilize the sediment. In considering rates of accretion in coastal marshes it is important to distinguish between rates characteristic of the mature marsh, the elevation of which is adjusted to the level of mean high water, and rates typical of the young, immature marsh (Ranwell, 1972). The limiting factor in marsh accretion for the mature surface is the rate at which sea level rises: the marsh is at equilibrium with sea level. Studies of sedimentation rates in mature marshes have used the record of marsh peat as a tracer of sea level variation over the past hundred to seven thousand years (Redfield and Rubin, 1962; Bloom and Stuiver, 1963; Bloom, 1964; McCaffrey, 1975). In the immature marsh much of the surface is intertidal, thus the marsh can accrete at a rate faster than the rate of rise of sea level. Marker beds of various sorts (Richards, 1934; Steers, 1948; Ranwell, 1964; Bloom, 1967) and the recently developed lead-210 radiometric technique (Armentano and Woodwell, 1975) have been used to estimate accretion rates in immature marshes.

We report here on estimates of vertical and lateral rates of accretion in Flax Pond, a young, dominantly intertidal marsh. Our estimates are based on historical records which indicate the time of the marsh's first continuous connection with marine waters, an event recorded in the stratigraphy of the marsh sediments. We have also estimated vertical accretion rates through the use of marker beds located in three sedimentary environments within the marsh.

Sedimentation rates determined from historical records

Methods: During the summer of 1974 we used a 3.8 cm. (1.5 in) diameter extendable auger to sample the marsh sediments. We drilled over 340 boreholes of approximately one meter's depth every 12 meters along north-south transects spaced 75 meters apart. The sediment types and thicknesses encountered in each boring were noted in the field. A compensating polar planimeter was used to measure the area covered by *Spartina alterniflora* peat.

Stratigraphy: Four different sedimentary units were encountered during our sampling program. These units are shown schematically in Figure 4 and are described below.

Pleistocene Outwash

At the base of sections along the periphery of the marsh is a poorly stratified, poorly sorted, brownish-orange sand. Small pebbles are common in this unit. Fuller's (1914) map of Long Island shows the Flax Pond area underlain by the Manhasset formation, a unit dominated by sandy outwash deposits of upper Wisconsinan (Woodfordian) age (Mills and Wells, 1974; Sirkin, 1971). This Pleistocene deposit was encountered only along the upland margins of the marsh.

Sand and Gravel

Above the Pleistocene unit are deposits of moderately well sorted light gray sand and gravel. These sediments vary in thickness from zero near the periphery of the marsh to over one meter in the central parts of the marsh. We were frequently unable to penetrate the entire thickness of this unit because the walls of the borehole would collapse upon retraction of the auger. This layer may be the product of post-Pleistocene fluvial deposition in the small valley now occupied by the Flax Pond marsh or may represent a strand deposit laid down before the barrier spit closed off the Pond.

Sedge Peat

In the central regions of the marsh and in a few other isolated locations, a bed of fibrous, dark reddish-brown peat overlies the sandy deposits. The organic content of this peat is approximately 50 percent (Armentano and Woodwell, 1975). Florer-Heusser et al. (1975) have identified the pollen and remains of such brackish and fresh water plants as Scirpus (sedge), Phragmites and Typha in this peat. Large wood fragments and roots of the marsh elder, Iva, are also common. This layer has an average thickness of 14 cm, with a maximum of 49 cm. Sedge peat may compact to between 13 and 44 percent of its original thickness (Bloom, 1964). However, the thin overburden of Spartina peat (average of 42 cm) suggests that compaction has been minor. The lateral distribution of the sedge peat is shown in Figure 5. The sedge peat does not extend laterally to the present high water periphery of the marsh and, where present, is always overlain by Spartina peat. The sedge peats described by Bloom (1964) are time transgressive units which mark the migration of brackish water plants near the high tide line as the sea level rises. Because the Flax Pond sedge peat does not extend to the high water line and because the plants which form the sedge peat are currently rare or absent in Flax Pond, we conclude that the sedge peat reflects the depositional conditions within Flax Pond prior to its opening to Long Island Sound. Flax Pond was most likely a small, swampy area dominated by the plants listed above, plants which are not able to tolerate open Sound salinities. Because of the proximity

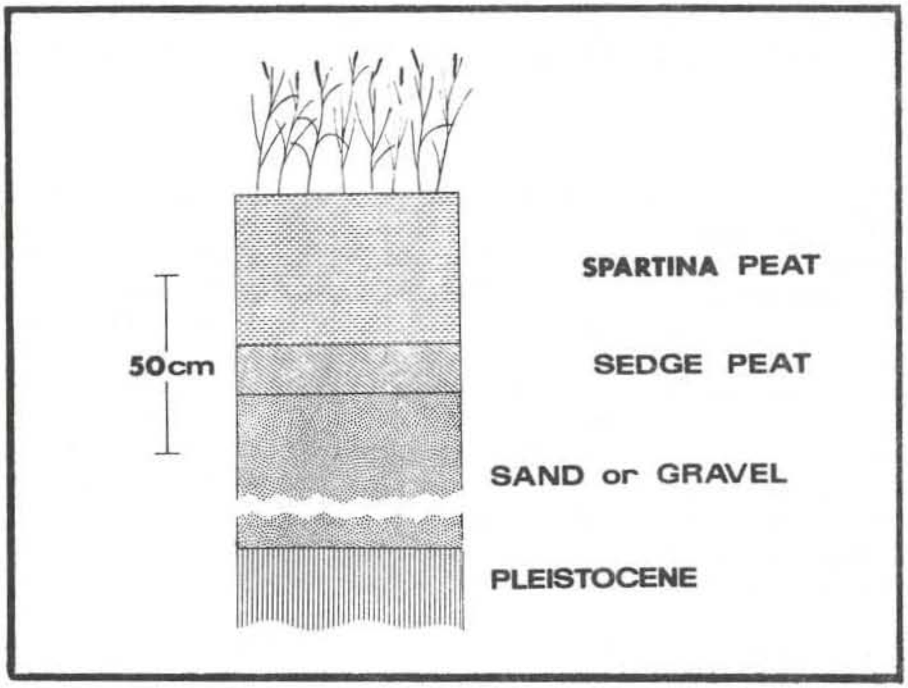


Figure 4: Schematic stratigraphic section of the Flax Pond sediments.

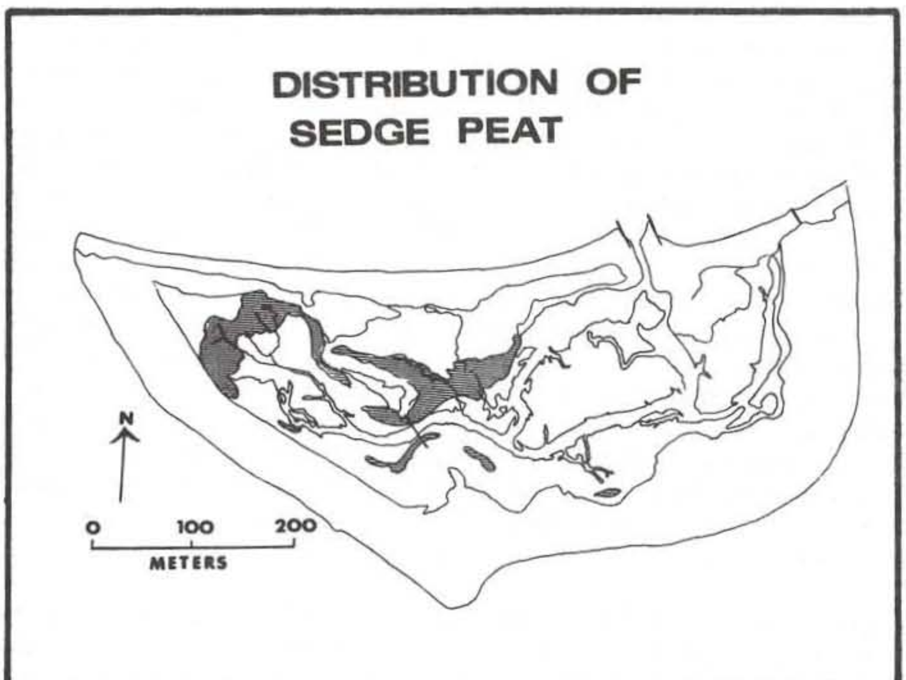


Figure 5: Subsurface distribution of sedge peat in the Flax Pond marsh.

of the area to the Sound and the likelihood of storm washovers, the water in the Pond probably ranged from fresh to brackish in character.

Spartina Peat

The Spartina, or salt marsh peat is a gray, fibrous mixture of clay, silt, Spartina alterniflora roots, rhizomes and stems and other organic matter. The organic content ranges from 20 to 30 percent (Armentano and Woodwell, 1975). The thickness of the salt marsh peat ranges from zero at the high water periphery and the newly colonized mudflats to 80 cm in the western part of the marsh. The lateral distribution and variation in thickness of this layer are shown in Figure 2. Armentano and Woodwell (1975) report no systematic variation of bulk density with depth, indicating that little compaction has taken place. Large areas in the eastern part of the marsh are not yet covered by a layer of Spartina peat, even though the region has a dense stand of Spartina alterniflora. Apparently, this area has only recently been colonized by the grass.

Vertical and lateral accretion rates: The boundary between the sedge peat and the Spartina peat marks the permanent opening of Flax Pond to marine waters. Taking 1801 as the year of the Pond's opening (the date of a document which stipulates that clamming rights were to be reserved for the local residents), 173 years had passed between the earliest possible time of deposition of Spartina peat and 1974, the year in which we measured the salt marsh peat's thickness. The average depth of Spartina peat which overlies the datable horizon is 42 cm. This yields an average accretion rate of 2.4 mm/yr. The maximum thickness of Spartina peat in the marsh is 80 cm, indicating a maximum accretion rate of 4.6 mm/yr. The rate of lateral growth of the salt marsh peat may be calculated by dividing the area now covered by Spartina peat (27,300 m^2) by the 173 years since the Pond's first connection to Long Island Sound. Lateral accretion of Spartina peat proceeds at the rate of 158 m^2/yr. These figures underestimate the actual accretion rates for several reasons: 1) Spartina alterniflora may not have become established in the marsh until a few years after its opening to the Sound; 2) peat may not have begun to accumulate immediately after Spartina colonization and; 3) erosion may have removed some of the salt marsh peat during the 173 years of net marsh growth. Some small amount of peat was undoubtedly removed by dredging operations during the 1940's. The figures of 2.4 mm/yr. and 4.6 mm/yr. for vertical accretion and 158 m^2/yr. for lateral accretion should be considered minimum rates of accretion over the past 173 years - rates during shorter intervals may have been quite different.

Discussion: Bloom (1967) and Harrison and Bloom (1974) used marker beds of metallic "glitter" to measure sedimentation rates in several Connecticut marshes. Accretion rates, based on an observation period of ten years, within the dwarfed S. alterniflora zone of two of the

Connecticut marshes are 6.5 mm/yr. and 6.7 mm/yr. (Harrison and Bloom, personal communication). These values are higher than the values we report for a marsh located on the opposite shore of Long Island Sound. The difference may be due to our underestimation of the actual rates (see above); the difference in vegetation type (Flax Pond is dominated by the tall form of S. alterniflora; or differences in the hydrology of the different marshes. Future work will evaluate the relative importance of elevation, vegetation, tidal range and rate of inorganic sediment input as determinants of marsh accretion rates.

Armentano and Woodwell (1975) have calculated sedimentation rates for two sections of Spartina peat from the Flax Pond marsh. They used the lead-210 method to date the sediments. One section of marsh peat yields a sedimentation rate of 4.7 mm/yr., while another indicates a rate of 6.3 mm/yr. The latter figure is suspect, however, because it is a rate computed from a regression line of lead-210 activities and depth which is based on only three points. Furthermore, other samples from the same section show unexpectedly constant levels of lead-210 activity. Their value of 4.7 mm/yr. is close to the range that we have calculated from our interpretation of the stratigraphy and the historical record. Any difference may be due to real differences in the sedimentary regime within the marsh. Curiously, however, the extrapolation of their sedimentation rate indicates that marsh growth began in approximately 1870, 18 years after a chart was made that shows Flax Pond connected to the Sound, and 69 years after clamming rights were ceded to local residents. Either peat accumulation at the site of their section was delayed up to 69 years or their analysis is subject to some unknown error.

We know of no studies which quantitatively estimate lateral rates of marsh accretion. Redfield (1965) shows, by a series of maps, the growth of the Barnstable, Massachusetts marsh during the past 3300 years. Redfield (1972) also compared a Coast and Geodetic Survey chart made in 1859 to one issued in 1957. Erosion and accretion appeared to be equal in the intertidal parts of the marsh during that interval.

Sedimentation rates determined from marker bed studies

Methods: Three sedimentary environments were chosen for a study of short term sediment accretion at Flax Pond: 1) bare mud flats; 2) areas where Spartina alterniflora is beginning to colonize, but has not yet formed a dense stand; and 3) areas where S. alterniflora has established a dense stand and a layer of peat has accumulated. Two one meter square plots within each environment were covered with a marker layer of either brick dust or aluminum glitter. Since mid-November, 1974, cores of sediment have been taken monthly at each plot, frozen and cut lengthwise. The position of the marker beds in relation to the upper surfaces of the cores has been used as an indicator of the total amount of sediment accretion that occurred in each environment during each month since October, 1974.

In June, 1975, four dowels were marked with millimeter scales and were placed in the plots representing the colonizing Spartina and the mud flat environments. Four metal plates were buried on the contact between the mud and the underlying sand, two plates in the mud flat environment and two in the colonizing Spartina environment. Mud depth above each plate is determined by lowering a thin cylindrical ruler into the sediment down to the level of the plate. Data on sediment accretion determined by these two methods will be compared with the data obtained by coring to determine whether the three methods yield consistent results.

Results and discussion: Monthly increments of sediment accretion are shown in Figure 6, and Figure 7 shows the cumulative sediment accretion up to July, 1975. Sediment accretion is most rapid on the bare mud flats and the least rapid where *S. alterniflora* has established dense stands, with intermediate values occurring where *S. alterniflora* is still colonizing. This pattern can be explained by elevation and distance effects. The peat surface on which the established *S. alterniflora* grows is at an elevation only slightly below mean high water. The other sedimentary environments are at lower elevations and therefore may receive suspended sediment for a longer time period. Mud flats are generally lower in elevation than areas where *S. alterniflora* is beginning to colonize and, therefore, show a higher rate of sediment accretion. The established *S. alterniflora* is also more distant from the main tidal channel than the other two environments, and a large portion of the suspended sediment load may become deposited on the mud flats and areas of colonizing *S. alterniflora* before it can reach the established *S. alterniflora*. Therefore, in spite of the fact that *S. alterniflora* aids in trapping and binding sediment (Redfield, 1972), the lowest accretion rates occur where Spartina growth is densest.

Previous studies of sedimentation rates at Flax Pond have concentrated on determining average sedimentation rates over much longer time periods. Armentano and Woodwell (1975) estimated, through Pb-210 dating, a peat accumulation rate in the western end of Flax Pond of 4.7 to 6.3 mm/year. Flessa and Constantine (1975) calculated an average rate of peat accumulation of 2.4 mm/year and a maximum rate of 4.6 mm/year by measuring the thickness of Spartina peat that has accumulated since Flax Pond was opened to marine waters in 1801.

The marker beds in the areas of established Spartina growth indicate that 3.5 mm of peat have accumulated during the past 9 months. If this rate is extrapolated to a period of one year, an annual accretion rate of 4.7 mm/year is calculated, which is slightly higher than the range of sedimentation rates reported by Flessa and Constantine (1975) and is at the lower limit of the range reported by Armentano and Woodwell (1975).

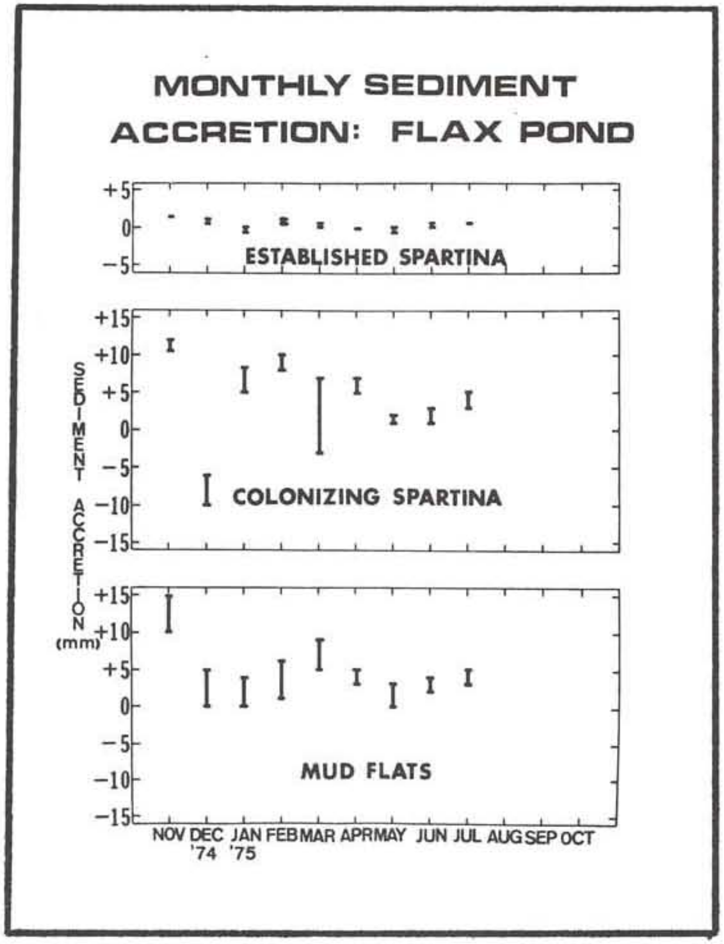


Figure 6: Monthly sediment accretion at Flax Pond. Bars indicate the range of accretion measured at the two stations in each environment.

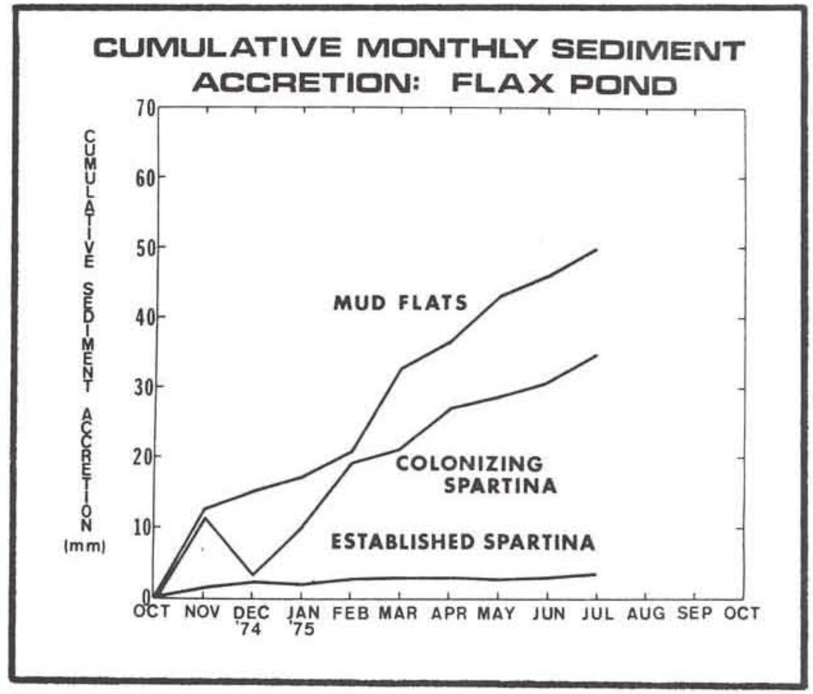


Figure 7: Cumulative monthly sediment accretion at Flax Pond since October, 1974. Values plotted are the mean of the two stations in each environment

The apparent discrepancy has a number of possible explanations, including intermittent periods of erosion and deposition, peat compaction, or a recent increase in the sedimentation rate brought about by an increase in the rate of sea level rise.

Long term peat compaction at Flax Pond was ruled out by Armentano and Woodwell (1975) who found no large-scale increase in peat density with depth. However, if compaction occurs rapidly in the top few centimeters of peat, a sedimentation rate of 4.7 mm/year may result in a much lower true accretion rate.

Bloom (1964) found that sea level rise during the past 3000 years averaged 1 mm/year. However, Meade and Emery (1971) found that the rate of rise in sea level increased to 3 mm/year since 1930 and Harrison and Bloom (1974) determined a sea level rise of 1 cm/year from 1964-1970. The recent rise in sea level may have resulted in a recent increase in the rate of peat accumulation.

Ranwell (1964) found seasonal variations in sediment accretion rates at Bridgewater Bay in southern England. Accretion rates were highest at most of Ranwell's sites from August to October, 1960. In this study, most of the accretion where Spartina has become established has, thus far, occurred between October and December, with almost no peat accumulation between February and June. Since accretion is seasonal, cores taken in October, 1975 may show that annual accretion is not actually 4.7 mm/year. Ranwell (1964) found that erosion occurred at most sites at some time during the year. In this study the only pronounced incidence of erosion, thus far, has occurred between November and December where Spartina is colonizing.

Final interpretation of the data obtained in this study must await collection and examination of the October, 1975 sediment cores. The sediment above the marker layers in these cores will represent a full year's accretion. Comparisons can then be made of seasonal and spatial differences in sedimentation rates. An attempt will then be made to devise a quantitative model of sedimentation at Flax Pond which incorporates changes in sedimentation rates that occur as the marsh surface is built upward.

CONCLUSIONS

Historical records and maps indicate that prior to 1801 Flax Pond was a fresh water pond isolated from the marine waters of Long Island Sound. Since 1801 the Pond has been connected to tidal waters by an inlet whose orientation and position have changed as a result of longshore drift and storms.

The opening of the Pond to marine waters is recorded in the stratigraphy of the marsh sediments by a sharp transition from Sedge (brackish or fresh water) peat to Spartina (salt marsh) peat. This dated horizon was used to calculate minimum estimates of vertical accretion ranging from 2.4 to 4.6 mm/yr. Lateral accretion of the marsh peat proceeds at the rate of 158 m^2/yr.

Marker bed studies show that sedimentation is most rapid on mudflats, slightly lower in areas newly colonized by Spartina alterniflora and slowest on the peat surface. On the peat surface vertical accretion proceeds at the rate of 4.7 mm/yr. These estimates may predict the rate at which Spartina marshes are able to recover from physical disturbance.

REFERENCES

Anon.,1910, The Encyclopedia Britannica 11th ed. 1910-1911 vol. 9, p. 484-488 New York, Encyclopedia Britannica, Inc.

Armentano, T.V. and Woodwell, C.M., 1975, Sedimentation rates in a Long Island marsh determined by ^{210}Pb dating. Limnol. and Oceanog. 20: 452-456.

Bloom, A.L., 1964, Peat accumulation and compaction in a Connecticut coastal marsh. Jour. Sed. Petrology 34: 599-603.

Bloom, A.L., 1967, Coastal geomorphology of Connecticut. Final Report, ONR Contract Nonr-401(45) Task No. 388-065, 72p.

Bloom, A.L. and Stuiver, M., 1963, Submergence of the Connecticut coast. Science 139: 332-334.

Flessa, K.W. and Constantine, K.J., 1975, Sedimentation rates in a coastal marsh determined from historical records. Submitted for publication.

Florer-Heusser, L.E., Heusser, C.J. and Weiss, D., 1975, Man's effect on the development of an estuarine marsh: Flax Pond, Old Field, New York Abstract, 7th Long Island Sound Conference, Jan., 1975.

Fuller, M.L., 1914, The geology of Long Island, New York. U.S. Geol. Survey Prof. Paper 83, 231p.

Harrison, E.Z. and Bloom, A.L., 1974, The response of Connecticut salt marshes to the recent rise in sea level. G.S.A. Abstracts with Programs 6: 35-36.

McCaffrey, R.J., 1975, A record of sediment accumulation in a Connecticut salt marsh as determined by Pb^{210} dating. Abstract, 7th Long Island Sound Conference, Jan., 1975.

Meade, R.H., 1972, Sources and sinks of suspended matter on continental shelves. In: Swift, D.J.P., Duane, D.B. and Pilkey, O.H., eds., Shelf Sediment Transport: Process and Pattern. Stroudsburg, Pa., Dowden, Hutchinson and Ross, 249-279.

Meade, R.H. and Emery, K.O., 1971, Sea level as affected by river runoff, eastern United States. Science 173: 425-428.

Mills, H.C. and Wells, P.D., 1974, Ice-shove deformation and glacial stratigraphy of Port Washington, Long Island, New York. Geol. Soc. America Bull. 85: 357-364.

Ranwell, D.S., 1964, Spartina salt marshes in southern England. II Rate and seasonal pattern of sediment accretion. J. Ecol. 52: 79-94.

Ranwell, D.S., 1972, Ecology of Salt Marshes and Sand Dunes London, Chapman and Hall, 285p.

Redfield, A.C., 1972, Development of a New England salt marsh. Ecol. Monographs 42: 201-237.

Redfield, A.C. and Rubin, M., 1962, The age of salt marsh peat and its relation to recent changes in sea level at Barnstable, Mass. Proc. Nat. Acad. Sci. 48: 1728-1735.

Richards, F.J., 1934, The salt marshes of the Dovey Estuary. IV the rates of vertical accretion, horizontal extension and scarp erosion. Annals of Botany 189: 225-261.

Sirkin, L.A., 1971, Surficial glacial deposits and postglacial pollen stratigraphy in central Long Island, New York. Pollen et Spores 13: 93-100.

Steers, J.A., 1948, Twelve year's measurement of accretion on Norfolk salt marshes. Geol. Mag. 85: 163-166.

Woodwell, G.M. and Pecan, E.V., 1973, Flax Pond: an estuarine marsh Brookhaven National Laboratory Report #BNL 50397, 7p.

FIELD TRIP GUIDE

You will be picked up near the pier in Port Jefferson harbor and taken to the Flax Pond marsh in a bus. The trip to the marsh is a short one and passes through the hilly topography characteristic of the Pleistocene Harbor Hills moraine.

The bus will park near the Department of Environmental Conservation's research lab and we will walk west along the road for about 0.25 mi. to reach the trail to the marsh. Beware of the Rhus radicans (poison ivy) at the trail entrance.

STOP ONE: The footbridge over the main channel provides an overview of the marsh and its geologic setting. The lighthouse to the ENE is situated atop Old Field Point, a bluff composed of the morainal sediments of the Harbor Hills moraine. The hills to the WNW, terminating in Crane Neck Point, are also composed of this glacial sediment. These bluffs are the source of the sediments on the barrier beach. Topographic, vegetation and surface sediment maps will be displayed on posters at this stop and will provide an opportunity for a description and discussion of the general features of the marsh. See also the section in the paper entitled "The Flax Pond marsh: general features".

Proceed to the northeast through a stand of Iva (the marsh elder) and Juncus (black grass), across a sandy patch which shows how the common marsh grasses spread via rhizomes, and onto a stand of Distichlis spicata and Spartina patens. Note how sharply these vegetation zones are bounded. Continue SINGLE FILE (to minimize the damage to the marsh) across the Spartina alterniflora zone to the bank of a small tidal creek. The far bank exposes the stratigraphy of the marsh sediments.

STOP TWO: Note the three distinct strata that are exposed here: the Spartina peat at the top, the reddish-brown, finely textured sedge peat, and the underlying coarse sand. Historical records indicate that the transition from sedge peat to Spartina peat took place in 1801. This datable horizon permits the calculation of sedimentation rates for the Spartina peat. Calculated estimates for vertical accretion range from 2.4 to 4.6 mm/yr. Lateral accretion proceeds at the rate of 158 m^2/yr. At this site a poster which summarizes the historical information in Table 1 will supplement the discussion of the environmental significance of these strata. Additional background information for this stop is in the article sections entitled "Flax Pond: the historical record" and "Sedimentation rates determined from historical records". Proceed back along the trail toward the footbridge. Instead of crossing the bridge turn to the northwest and walk along the periphery of the wooded upland (probably a submerged kame) to Stop Three.

STOP THREE: To the south and west of this stop are bare mudflats, hummocks of Spartina alterniflora, mudflats newly colonized by

S. alterniflora, and areas with well established stands of the grass. These areas include the sites of our marker bed studies. A poster showing monthly increments of sediment accretion since October, 1974 and cumulative accretion since that time will provide the basis for a discussion of the rates, environmental controls and seasonal patterns of marsh accretion. For additional information regarding this stop see the text section entitled "Sedimentation rates determined from marker bed studies".

Proceed to the east along the margin of the wooded area. We will pass through an extensive stand of Juncus and Iva. On the inner margin of the barrier beach you should note the lobate appearance of the gravel deposits. These lobes appear to be encroaching upon the marsh surface. Their movement is presumably due to extreme storm waves. The area immediately to the west of the inlet was dredged during the 1940's for sand and gravel. Present depths in this area are about 3 meters at low water.

STOP FOUR: The inlet, stabilized by jetties since 1947, has not been a stable feature of the Flax Pond marsh. Longshore drift and storms have been responsible for changes in the character and position of the inlet. The maps and charts also indicate a change in the dominant direction of longshore drift from westerly prior to 1947 to easterly since that time. A series of maps, charts and photographs dating from 1797 to 1969 will illustrate the major changes in the configuration of the inlet over the past 178 years. For further discussion see the section titled "Maps and charts".

Return to the bus by walking back along the trail to the footbridge and the road.

NOTES