Maine Geological Survey
DEPARTMENT OF CONSERVATION
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OPEN-FILE NO. 83-8

Title: Evidence for Late Holocene Sea-Level Rise in New England: A Summary of Available Data Derived from Salt Marshes and Other Organic Materials

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Date: 1983

Financial Support: Preparation of this report was supported by funds furnished by the Nuclear Regulatory Commission, Grant No. NRC-04-76-291.

This report is preliminary and has not been edited or reviewed for conformity with Maine Geological Survey standards.

Contents: 15 page report

This three-part report summarizes all salt marsh information that has been obtained to date on late-Holocene and Recent sea-level rise along the Maine coast. Part I includes all data relevant to sea-level rise derived from the present Maine crustal warping study. Part II places this data in context with the information on the general Holocene sea-level rise in New England, with particular emphasis on northern New England. Part III details the significance and problems of dating salt marsh sediments.

PART I

This part of the report summarizes information obtained from examination of salt marsh sediments since the summer of 1979. Previous examination of salt marshes along the southeast coast of Maine showed that the deepest salt marshes consist of 3-4 m of peat which has accumulated over approximately the last 3,000 years (Thompson, 1973). Within this time, an adequate chronology of salt marsh growth, and thus the amount and rate of sea-level rise (see below), could be obtained. Since the accuracy of radiocarbon dating declines within the last few hundreds of years (Stuiver, 1978), an additional method of measuring salt marsh accumulation rates was applied. This method consisted of measuring salt-marsh encroachment on man-made structures which could be dated historically. Structures more than 200 years old are present on the Maine coast in many areas. Therefore, it has been our intention to utilize both methods, core studies with radiocarbon dating of sediments and salt marsh encroachment on historic structures, to provide a continuous record of sea-level change along the Maine coast.

Core Studies

Salt marsh floral assemblages are known to accurately indicate tidal levels (Miller and Egler, 1950), with low, middle, and high marsh zones dominated by *Spartina alterniflora, S. patens*, and *Juncus gerardi*, respectively. The upper limit of *Spartina patens* is approximately Mean High Water (MHW), whereas the upper limit of *Juncus gerardi* is termed Higher High Water (HHW). Sediment cores were collected from four locations in each of three marshes (Fig. 1), beginning with a deeper seaward core at each location and ending with a shallow landward core. We utilized a method similar to Scott (1977), which relates the Foraminiferal assemblages to the HHW datum, which was more easily recognized in a core than the MHW datum. Since Foraminifera live only in marine environments, the base of the Forminifera - bearing part of each core was radiocarbon dated to determine when sea level rose to that level. Sea-level curves for the three marshes were then constructed, by relating the HHW datum in the core to the present HHW datum of the marsh. Radiocarbon dating was performed by Robert Stuckenrath, Jr., Radiocarbon Laboratory, Smithsonian Institution.

Holt Pond marsh is located on the Stonington-Deer Isle, Maine, town boundary (Fig. 1). Linear regression of radiocarbon dates from three core segments containing the HHW datum (Fig. 2, SI-4596, SI-4595, SI-4768), including the present sea level, yield an average sea-level rise of about 8.8 cm/century since about 3,000 14-C years ago. SI-4767 was excluded from the curve because we believe it to be anomalously young (see below).

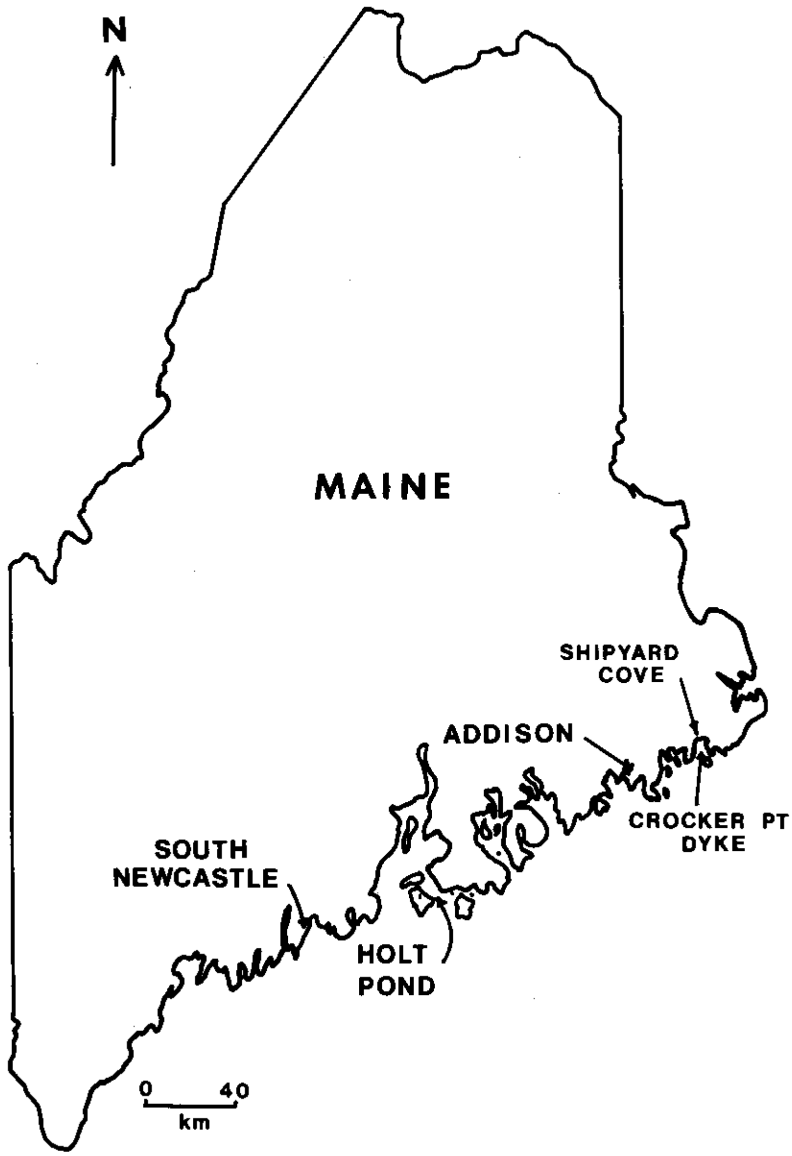

Figure 1

Location of salt marshes and historical structures studied as part of the Maine Crustal Warping Study.

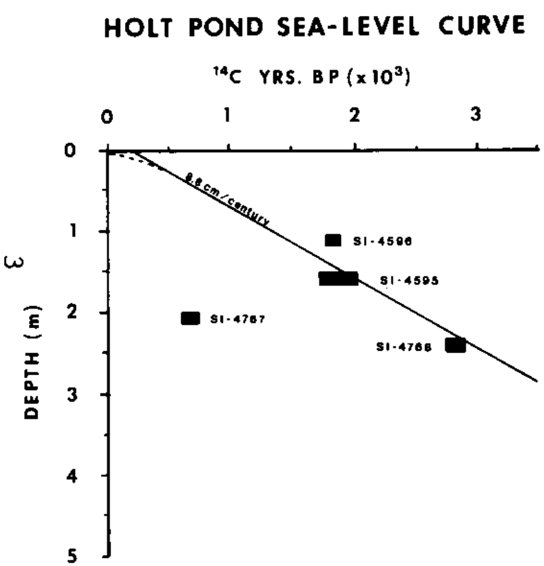

Figure 2

Sea-level curve for Holt Pond marsh, Stonington-Deer Isle, Maine.

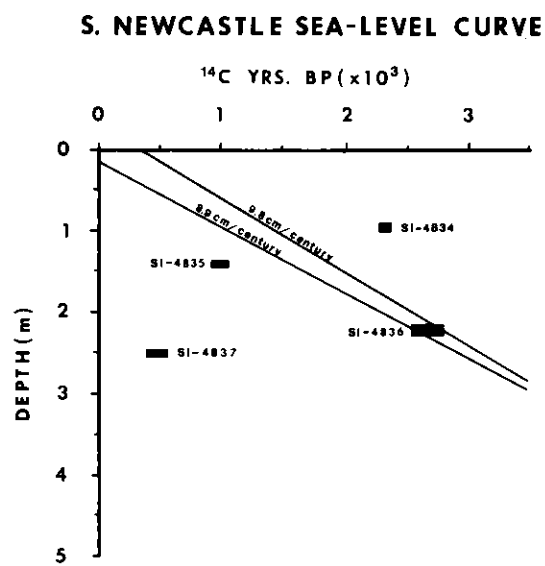

Figure 3

Sea-level curve for South Newcastle marsh, South Newcastle, Maine.

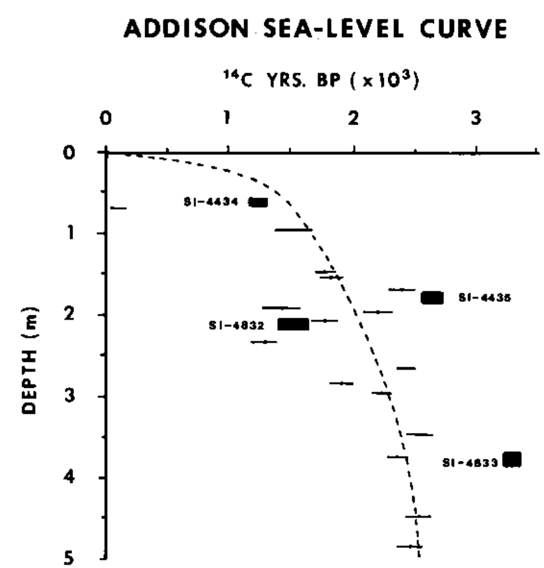

Figure 4

Sea-level curve for Addison I marsh, Addison, Maine (modified from Thompson, 1973).

South Newcastle marsh is located in South Newcastle, Maine (Fig. 1). The plot of date vs. depth (Fig. 3) does not lend itself readily to a simple linear regression. However, two regression lines have been calculated. SI-4837 has been excluded from both curves because of its anomalously young nature. Utilizing the present sea level, SI-4835, and SI-4836, we obtain an average sea-level rise of 8.9 cm/century for the last 3,000 radiocarbon years. The inclusion of SI-4834 yields a rise of 9.8 cm/century. Due to the scattered nature of the data points, interpretation of sea-level rise at this location should be done with caution.

Addison I marsh is located in Addison, Maine (Fig. 1). The date-depth plot for Addison I (Fig. 4) includes 15 radiocarbon dates (shown as horizontal lines with centered dots), along with a best-fit sea-level curve calculated by Thompson (1973). Thompson's curve suggests a 115 cm/century sea-level rise about 3000 years ago and a more recent 6 cm/century rise. Using the foraminiferal assemblage technique (Scott, 1977), we had hoped to improve the accuracy of this curve. However, our radiocarbon dates here (dark blocks) do not readily lend themselves to simple linear regression, and, for the most part, fall outside the envelope of dates which determined Thompson's curve for Addison Marsh. Therefore, we were not able to improve the data on sea-level rise for that area.

Encroachment on Historic Structures

To obtain an estimate of the more recent rise in sea level (over the past 100-200 years), we examined salt-marsh encroachment on historic structures of known age. These included two salt marsh dikes, in Machiasport and Addison, Maine, and an abandoned shipyard in East Machias, Maine.

Salt marsh dikes Agricultural dikes were built on salt marshes in Maine as early as the 1790's (David Smith, personal communication). Their purpose was to exclude salt and brackish water from the marsh, allowing harvesting of grasses. The dikes are widespread in coastal Maine and occur from southwest to southeast coastal locations.

The Crocker Point dike, Machiasport, was built in the 1820's (David Smith, personal communication). A profile of the dike (Fig. 5) shows a layer of sawdust and bark fragments, derived from lumbermaking in the area during the nineteenth century, on the flanks of the dike. This layer is overlain by a maximum of 32 cm of peat. The sawdust layer thus serves as a time-stratigraphic marker. Since the height of lumbermaking in the area occurred between 1820 and 1880 AD, (D. Smith, personal communication), the minimum rise of sea level at this location has been 20 cm/century, assuming the layer was deposited in about 1820 and that little or no autocompaction has occurred. The maximum rise could have been 32 cm/century, assuming the layer was deposited in about 1880 and no compaction occurred. Preliminary analysis of the stratigraphy of a dike along the Pleasant River in Addison, Maine, has shown that a minimum of 30 and maximum of 50 cm of peat has grown up onto the flanks of the dike since it was constructed, probably in 1795 AD. Calculation of the sediment accumulation rates in an analogous manner as for the Crocker Point dike above suggests a rise of 16-26 cm/century since dike construction.

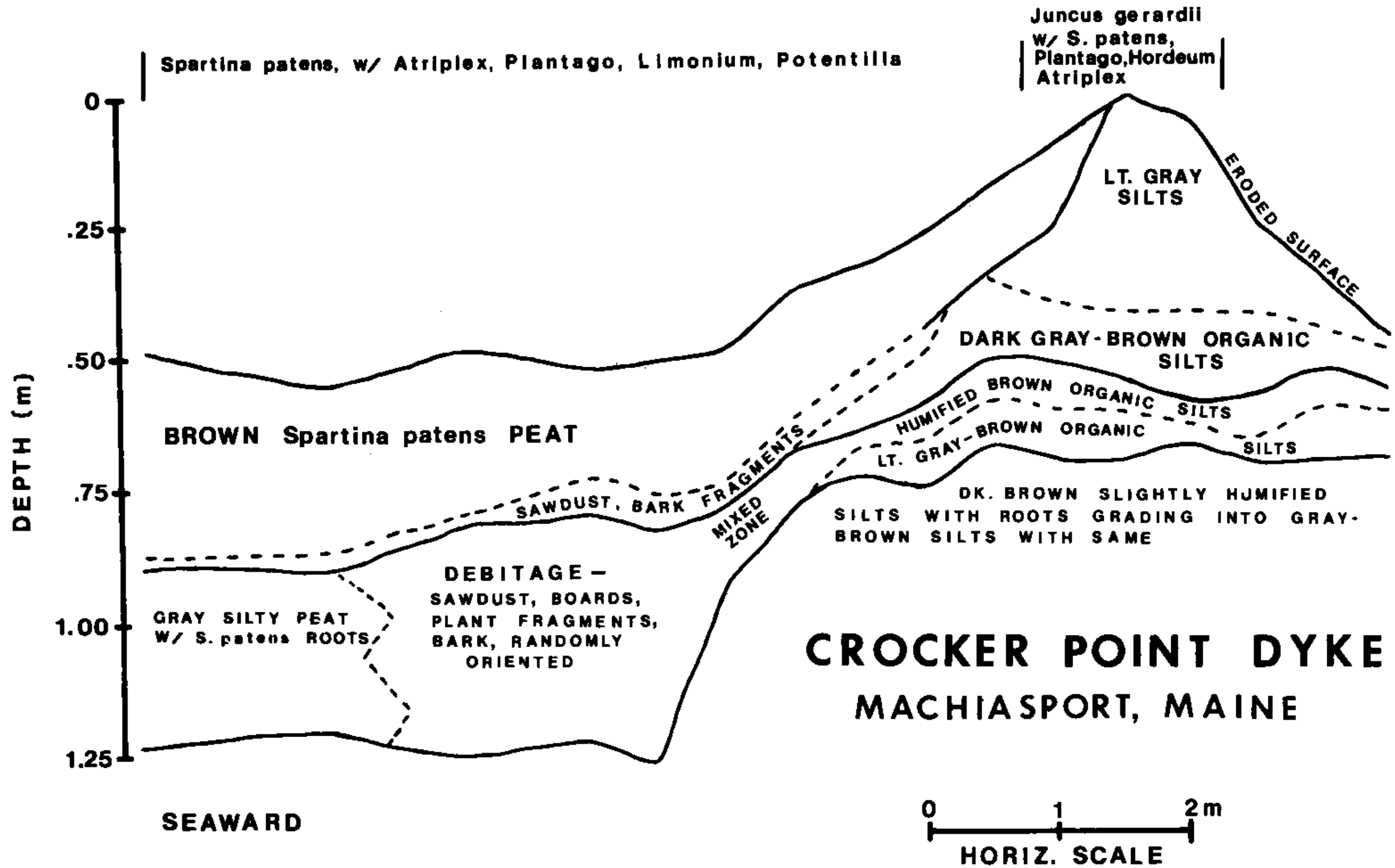

Figure 5

Schematic profile of Crocker Point dike, Machiasport, Maine.

Shipyard Cove Marsh Reconnaissance of salt marshes along the Machias and East Machias rivers show that boards and other pieces of lumber bearing obvious marks of manufacture are found at various depths in these marshes. Some boards contain drill holes or notches, or are burned. All have either axe or saw marks. One marsh with a particular abundance of these boards is adjacent to an abandoned shipyard in East Machias. Simpson's Wharf was a local center of shipbuilding from about 1820-1880 AD (David Smith, personal communication), roughly contemporaneous with the maximum period of lumbermaking. The seaward side of the marsh has a vertical face about 1-2 m high, and the major marsh-forming species is *Spartina alterniflora*. The depths of 41 exposed boards at 25 locations along the exposure were measured from the surface of the marsh. The boards ranged in depth from 51-136 cm. Frequency distribution of the boards by 10-cm intervals (Fig. 6) indicated that the majority of boards (63.5%) were deposited 70-99 cm below the marsh surface. If we assume that sediment deposited between these depths dates between 1820 and 1880 AD, a minimum sediment accumulation rate for this marsh of 40 cm/century and a maximum rate of 100 cm/century is inferred.

A vertical profile of this marsh was subjected to 210-Pb analysis, performed by Steven Johnston, Department of Geological Sciences, University of Maine at Orono. A more detailed treatment of the 210-Pb method can be found in Part III of this report. Figure 7 shows the 210-Pb profile for the peat section above a board deposited at 107 cm depth. Two interpretations of sediment accumulation rates were considered. In the first case, where background (supported) values of 210-Pb occur to the left of dashed line (a), and assuming a 210-Pb half-life of 22.2 years, the board was deposited in 1940 AD. In the second case, where the supported value occurs to the left of dashed line (b), the board was deposited in 1885 AD. This corresponds to a sediment accumulation rate of 260 cm/century and 100 cm/century, respectively. Rates of accumulation are somewhat higher as determined by 210-Pb activities than determined by historical inference. The discrepancy may be accounted for if sediment accumulation rates have increased substantially within the last few decades or if the boards were actually redeposited. In any event, both methods suggest a high sediment accumulation rate at this location.

Direct inference of sea-level rise of these magnitudes should be made with caution because the marsh is made primarily of *Spartina alterniflora* peat. This plant generally grows below MHW and is thus not an indicator of sea-level rise in itself. We believe that the high sediment accumulation rate is due primarily to elevated supplies of sediment. An increased supply of sediment may be related to sea-level rise, though, as rapid coastal erosion of the primarily silty coastal sediments is presently occurring in more exposed areas within the region.

PART II

Part II is a compilation of published and unpublished material on late-Holocene sea-level studies of New England, with particular reference to northern New England. We will include data from the present study in this context.

An examination of the literature on Holocene sea levels of New England reveals a large number of published 14-C dates used to construct local sea-level curves. Dates have been obtained on a variety of sediments including

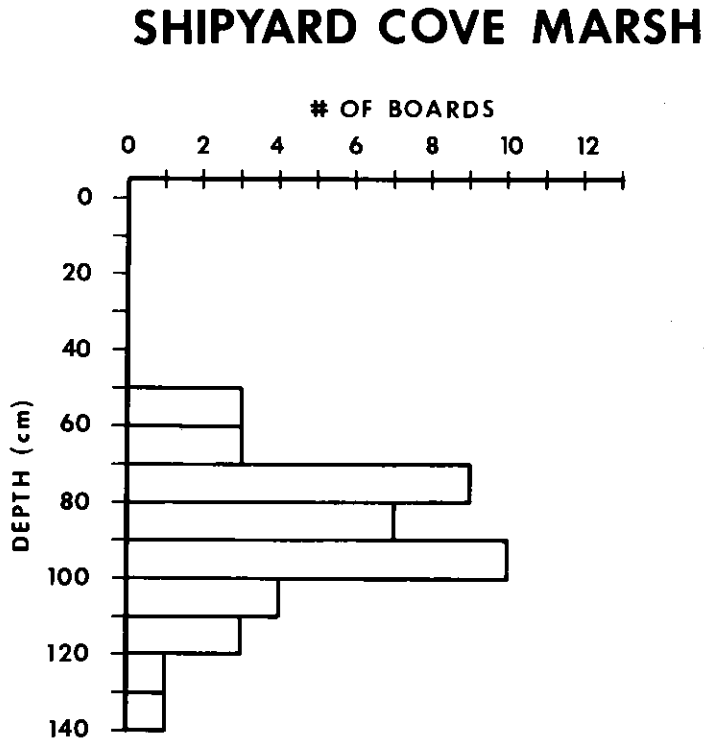

Figure 6

Distribution of exposed man-made boards by depth, Shipyard Cove marsh, East Machias, Maine.

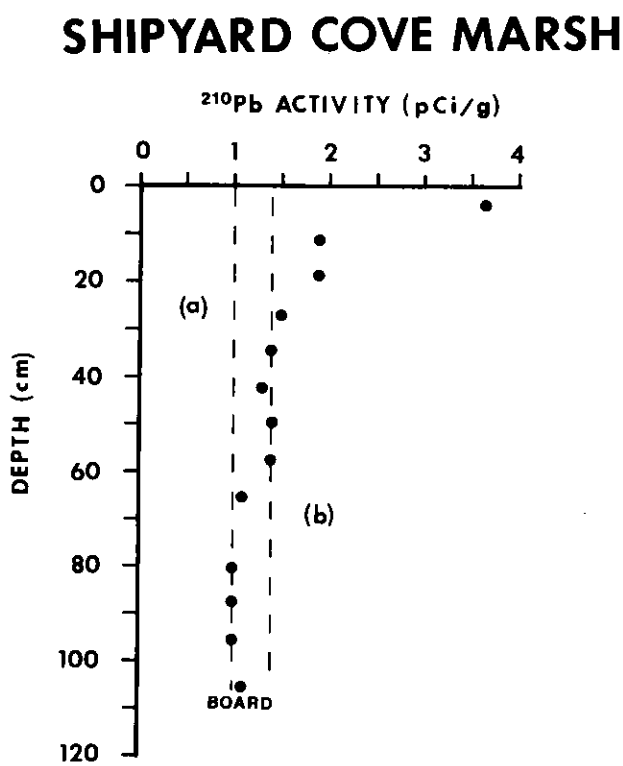

Figure 7

210-Pb activity profile for a vertical section of Shipyard Cove marsh, East Machias, Maine.

salt marsh peats, underlying freshwater peats, and wood. Dates obtained on marine sediments are preferred over non-marine materials for constructing local sea-level curves because dates on freshwater peats and wood provide only maximum dates for submergence of the particular area. In addition, freshwater organic materials characteristically have a higher organic content than salt marsh peats (personal observation) and thus are more easily autocompacted. This tends to maximize the apparent amount of sea-level rise in an area by depressing the absolute elevation of the sample subsequent to deposition. Thompson (1973) noted the possibility of this particular problem in his analysis of the Eastport, Maine, "drowned forest" site. The use of dates from freshwater materials thus creates a great deal of uncertainty in interpretation of sea-level curves.

Sea-level curves based on radiocarbon dates on salt marsh sediments have proliferated over the past several decades. Although many problems with this method also exist, documentation of Holocene sea-level rise by this method is preferred since actual marine materials are being dated. Several published studies that utilize dates on salt marsh sediments also include dates on freshwater or terrestrial materials which immediately underlie the marine sediments. Our compilation of these studies begins with selected sites in southern New England and ends with sites in northern New England. Both sediment accumulation rate and sea-level rise are used in this report. The rate of sediment accumulation is correlated with sea-level rise, although the relationship is undoubtedly complicated by factors such as sediment compaction (see below). Many of the calculations from sites with "drowned forest" data are based on Nelson (1979), who made a compilation of such sites.

Bloom and Stuiver (1963) obtained 16 dates on wood and sedge peat occurring under salt marshes in the Clinton, Connecticut, area. The sedge peat was presumably analogous to that which is presently forming in primarily _Typha, Scirpus_ and _Phragmites_ marshes just landward of the salt marsh. Their sea-level curve suggests a rise in sea level of 18.5 cm/century from ca. 7,000 to ca. 3,000 yrs B.P., and 9.3 cm/century since ca. 3,000 years ago.

Redfield and Rubin (1962) utilized 17 dates from marshes in Barnstable, Massachusetts. Materials dated included not only _Spartina patens_ peat but also underlying freshwater peat and logs. Their data suggested a rise in sea level about 30.5 cm/century from ca. 3,700 to ca. 2,100 years ago and 10.2 cm/century since ca. 2,100 yrs B.P.

Redfield (1967) reported additional dates on peat obtained from _Spartina patens_ marshes along the northeastern coast of Massachusetts. The ten samples from salt marshes in Nantucket, Eastham, and Milton (Neponset River), Massachusetts, suggested to him an average rise in sea level at those locations of 18.3 cm/century from ca. 4,000 - ca. 3,000 years ago, and about 7.6 cm/century since 3,000 years ago.

Kaye and Barghoorn (1964) reported several dates on _Spartina patens_ peat, sedge peat, freshwater peat, and wood from marsh sediments that were exposed during construction of an underground parking garage in Boston. Recalculation from their sea-level curve suggests a rise of 35.5 cm/century from ca. 5,000 to 3,000 years ago, and 2.0 cm/century from 3,000 yrs B.P. to the present.

Keene (1971) produced a sea-level curve for Hampton, New Hampshire, from four dates on basal salt marsh peat (one date) and forest litter materials (three dates) buried by salt marsh sediments. His curve suggested a rise in sea level of 23 cm/century from ca. 6,850 to ca. 4,000 yrs B.P. with a rise of 11 cm/century since ca. 4,000 yrs ago.

Determinations of sea-level change in the Odiorne Point area of New Hampshire have been reported in two papers. Both have been made on tree stumps submerged beneath marine waters at high tide. A date from Deevey and others (1959) in Bloom (1963) suggested a minimum rise of sea level of 5.5 cm/century over the last 4,200 years, whereas Lyon and Harrison (1960) believed in a 9.5 cm/century rise between ca. 4,200 and ca. 3,200 yrs B.P.

Hussey (1959) reported submerged stumps from Wells Beach, Maine (dating to 2,810 years old, calculated minimum sea-level rise of 6.5 cm/century) and Kennebunk Beach, Maine (dating 3250 and 1280 years old, calculated minimum sea-level rise of 6.6-12 cm/century and 24-31 cm/century, respectively). Four 14-C dates on basal salt marsh peat collected by coring behind the Wells Barrier Beach by B. Timson (Rand 1978) suggested a rise in sea level of 3-4 cm/century there over the last ca. 3,000 years.

Dates on samples of salt marsh found buried under sand in Phippsburg, Maine, were reported by Nelson (1979). The date from the Atkins Marsh sample suggested a sea-level rise there of 3.4-5.5 cm/century since ca. 6,770 years ago. The sample from the Village Marsh suggested a sea-level rise there of 0-3.8 cm/century since ca. 2,900 years ago.

Data reported by Anderson and Race (1981 and this report) tentatively suggested a sea-level rise of 8.9-9.8 cm/century since ca. 3,000 years ago for a marsh along the Sheepscot River in South Newcastle, Maine.

Bradley (1953) provided an age of 4,150 yrs BP for a tree stump exposed in the intertidal zone at Robinhood (near Bath), Maine. From this date, Nelson (1979) calculated a minimum 6 cm/century rise in sea level since then.

Several dates have been reported for the Penobscot Bay region of Maine. Stuiver and Deevey (1961) in Bloom (1963) and Thompson (1973) reported dates on submerged tree stumps found in the Blue Hill area which suggested a minimum sea level rise of 13.9 cm/century since ca. 3,000 years ago and 11.2 cm/century since ca. 3,300 years ago, respectively. Anderson and Race (1981 and this report) constructed a sea-level curve from sediments of Holt Pond salt marsh in Stonington-Deer Isle. This suggested a sea-level rise of 8.8 cm/century since ca. 3,000 years ago.

Thompson (1973) examined cores from two marshes in Addison, Maine, and constructed a sea-level curve based on a least squares regression. It suggested a sea-level rise of 115 cm/century about 3,000 years ago, tapering off to a more recent rise of 6 cm/century. Additional points were added to Thompson's curve by Anderson and Race (1981 and this report), who also reported a rise in sea-level of 16-26 cm/century since colonization of the area. Data from the Machias, Maine, region have been previously discussed in Part I of this report. Information from the historic period suggests a 20-32 cm/century sea level rise during the most recent centuries. Thompson's (1973) date on a "drowned forest" stump here suggested a minimum rise of 7.1 cm/century since ca. 2,500 years ago.

Perhaps the most revealing evidence of recent sea-level rise comes from Hicks and Crosby (1974) who compiled tide gauge measurements for seven New England locations (New London, Connecticut; Newport, Rhode Island; Woods Hole and Boston, Massachusetts; Portsmouth, New Hampshire; Portland and Eastport, Maine). All seven stations show a definitive trend of sea-level rise since the early decades of the 20th century. In each case, the change in sea level is measured on the order of 10's of cm/century. The data for the Maine locations clearly show that relative sea-level is rising faster at Eastport than at Portland.

Evaluation and comparison of all published and calculated sea-level curves for New England is complicated because of several reasons.

(1) Several methods of constructing curves have been attempted. These include curves determined from a) tide gauge data, b) salt-marsh accumulation on structures of known historical age, c) amount of salt marsh accumulation on top of radiocarbon dated basal peats, d) dates on peat materials obtained from below non-organic strata, and e) dates on underlying freshwater peat and/or on tree stumps from trees assumed to have been killed by the rising sea. The problems with dating non-marine materials have already been discussed.

(2) Several different time scales are represented. A corollary of this is that degrees of accuracy vary from method to method. Tide gauge data record sea-level changes on a yearly, or even more accurate, basis. Uncertainties in the method are in the range of individual years. Salt marsh accumulation on structures of known historical age record sea-level change over the past one to several centuries. Uncertainties in this method are on the order of decades. Methods which utilize radiocarbon dated materials record sea-level changes over thousands of years with uncertainties on the order of centuries.

(3) The datum for measuring sea-level changes in cores of salt marshes has been either Mean High Water (*Spartina patens* zone) or Highest High Water (*Juncus gerardi* zone). While both the MHW and HHW datum are readily discernable in many marshes, it is often diffuse in others. In actuality, the MHW datum represents a vertical range of 10-15 cm in elevation injecting additional error in depth measurements.

(4) Some curves include certain corrections on either the reported ages or depths, while others do not. Kaye and Barghoorn (1964) included a calculated correction for compaction of sediments at depth. The amount of apparent sea-level rise, if any, accounted for by compaction of salt marsh sediments in our study has not been investigated. Nelson (1979) included a correction for the difference in 13-C content of marsh peat.

Published sea-level curves discussed here and selected for inclusion in Bloom (1979) show sea-level changes measured over the past several thousands of years. Because of the time scale involved, small-scale changes in sea-level that might have occurred over that time period have been obscurred. This is especially true for areas with only one or two dates.

Even with the above limitations, a few generalizations can be made about late-Holocene sea-level changes in New England. The compilation of these data reiterates the fact that sea level is rising in New England. The actual amount of sea-level rise varies from place to place due to local effects. Sea-level rise over the past several thousand years is on the order of <10 to >30 cm/century. Several of the longer records show a reduced level of sea-level rise between ca. 4,000 and ca. 2,000 years ago (Bloom and Stuiver 1963; Redfield and Rubin, 1962; Redfield, 1967; Kaye and Barghoorn, 1964). This may be due to an actual decline in sea-level rise at that time or to mixing of younger salt marsh sediments with older soil horizons as the marsh migrates landward. This would make the shallower samples date older than expected and thus suggest a much slower rise in sea level. This phenomenon is suspected for the marsh at Addison, Maine (unpublished data of the authors of this report and Robert Stuckenrath, Jr.).

PART III

This part of the report summarizes the methods, problems and significance of dating salt marsh sediments in general, with particular reference to our results for the marshes along the Maine coast. Two categories of dating techniques for determining sediment accumulation rates and sea-level curves have been used by us and others. These include both radiometric methods (14-C and 210-Pb analysis of salt marsh cores and other materials) and non-radiometric methods (stratigraphic profiling and pollen analysis).

Radiometric Dating Methods

<u>14-C</u> Radiocarbon dating is useful in determining ages on the order of several hundred to ± 50,000 years. For determining sediment accumulation rates and rates of sea level rise, we have used a method similar to Scott (1977), which identifies the HHW datum from the stratigraphy of Foraminifera in the core. The sediment containing the first upcore occurrence of Foraminifera is dated.

In none of the cores did we find evidence of discontinuities of salt marsh growth. Therefore, under ideal conditions the oldest dates should be found in the deeper cores, with younger dates on shallower materials. This was not always the case, as has been discussed above (Part I, Figs. 2, 3, and 4). Three of the four samples from the Holt Pond marsh show an increase in age with depth. However, SI-4767, the second from the bottom, turned out to be the youngest of the series, and may be as much as 2,000 years too young. The four samples from South Newcastle show no progression of age with depth and the dates, in fact, appear to be randomly distributed. The distribution of dates from the Addison marsh nearly fits the expected distribution of increasing age with depth, but even here, deviation from the expected progression is found.

Several processes exist in salt marshes which may affect the sediments and produce anamalously old or young dates at a particular depth. We have hypothesized that one important mechanism which produces older dates than anticipated occurs as salt marshes grow upward and landward. Material from soils which have developed over long periods of time are incorporated into the marsh. In certain cases, the soil may contribute significant amounts of "old" carbon to the "new" marsh sediments. A test of this hypothesis is being conducted on Addison I Marsh sediment by Robert Stuckenrath, Jr., Radiocarbon Laboratory, Smithsonian Institution. Additionally, large rafts of marsh material are often torn from the front part of the marsh by ice action in winter and carried up onto other parts of the marsh by the tides. The marsh then grows up and over the block of older peat. This material is yet another source for old carbon.

The most common source for younger organic material at depth is probably the filling in of cracks in the marsh. These cracks can be enlarged by water movement during the tidal cycle with the subsequent movement and redeposition of marsh material. Drainage passages in salt marshes typically are meandering streams. As the stream changes course over time, an opportunity for mixing young with old sediment occurs. Chapman (1974) reported observing large amounts of trapped gas escaping from the vadose zone of the marsh during a flooding tide. The concomitant movement of material upward and downward may be significant.

A marsh in close proximity to a relatively active body of water, such as along a tidal river or in an unprotected area, might be more susceptible to these problems. Both South Newcastle Marsh and Addison Marsh are located along tidal rivers whereas Holt Pond Marsh is in a more protected cove.

210-Pb The second radiometric method that we have employed in these studies is dating by the 210-Pb method. The method is explained in several papers (for example, Johnston, 1981; Brugam, 1978) but will be briefly discussed here. 210-Pb is a natural radioisotope of the 238-U decay series and has an average residence time in the atmosphere of one week before falling to the ground with precipitation (Johnston, 1981). It is then adsorbed on clays and the organic fraction of soils. This fraction of 210-Pb is termed "unsupported". "Supported" 210-Pb is the fraction produced by in-situ decay of 226-Ra in the allochthonous inorganic fraction of the sediment. A chronlogy of sediment accumulation can be determined by relating the 210-Pb activity at the surface to values downcore. The values for supported, or background, 210-Pb must first be subtracted from the total 210-Pb activity from each level. The supported fraction is represented in the lower portions of a core by a relatively constant activity. The relatively short half-life (22.2 years) makes the use of 210-Pb dating attractive for sediments 100-150 years old.

Calculation of sediment accumulation rates based on the 210-Pb stratigraphy assumes a constant supply of sediment, with sediment size and percentage organic matter relatively constant over time. We have not evaluated this assumption in our study. Sediment accumulation rates determined at Shipyard Cove Marsh in East Machias, Maine (see above, Part I), measured by the 210-Pb method suggested a rate of 100-260 cm/century, but rates measured by historical inference were 40-100 cm/century. This discrepancy can be explained if sediment accumulation rates have increased in the past few decades. The method has not been used extensively on salt marsh sediments. However, sediment accumulation rates determined by the 210-Pb method have been satisfactorily evaluated against independent dating methods such as tide gauge data (McCaffrey, 1977) and pollen data (J.S. Clark, manuscript in preparation).

Non-radiometric Methods

For determination of the most recent (ca. two centuries) sediment accumulation rates in Maine marshes, we have measured salt marsh accumulation on top of stratigraphic markers which occur in the peat. This method was applied in the present study by measuring salt marsh growth on top of historically dated agricultural dikes in Machiasport and Addison, Maine, and measuring the depth of man-made artifacts of known age in a *Spartina alterniflora* marsh in East Machias, Maine.

Methods of determining sediment accumulation rates and sea-level rise include pollen analysis and other microfossil markers which may occur in the peat. By relating changes in percentage of certain pollen types to historically documented events, sediment accumulation rates can be determined with accuracies on the order of decades or less for the most recent several hundred years, and on the order of centuries for the past several thousand years. (A list of studies employing this method is cited in Carmichael, 1980.) We have not utilized this method in our studies thus far, but it would be possible to use it on a few sites in Maine.

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