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Title: Evidence for Late Holocene and Recent Sea Level Rise Along Coastal Maine Utilizing Salt Marsh Data.

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INTRODUCTION

Field and lab work conducted during the summer of 1980 as part of the general investigation of evidence for Holocene and contemporary crustal warping along the Maine coast is described in this report. The work accomplished continues the project which began in the summer of 1979 (Anderson and Race, 1981). Last year we concentrated on locating and coring deep salt marshes as a basis for obtaining suitable locations for long (2-3000 year) records of sea-level change. This year's emphasis was placed on the investigation of structures built on or near salt marshes in eastern Maine. Salt marsh encroachment around and over these structures gives information on the rise in sea level during historic times. These structures included two salt marsh dikes - one designated "Pleasant River South Dike" in Addison, the other "Crocker Point Dike" in Machiasport - and the general area adjacent to Simpson's Wharf in Shipyard Cove, East Machias. By combining the two methods, ^{14}C dating of sediment deposited prior to European settlement and dating structures built by Europeans deduced from historical records, we hope ultimately to provide a continuum of sea-level change in Maine.

We have also investigated the stratigraphy of the land-marsh interface at the Addison I Marsh (Anderson and Race, 1981) as it relates to problems in radiocarbon dating, and cored Holt Pond Marsh, Stonington-Deer Isle, for determining a Recent sea-level curve for the mid-Maine coast.

HISTORIC STRUCTURES

Salt Marsh Dikes

The stratigraphy of two salt marsh dikes was studied in detail to investigate the Recent submergence of these features. Information on the history of salt marsh diking comes from oral and written sources compiled by Dr. David Smith and Anne Bridges, University of Maine at Orono History Department. The active period of dike construction was the late 18th and early 19th centuries, but continued on a local scale into the late 19th century. The dikes are widespread in eastern Maine and can be found wherever salt marshes have developed. They were built on the seaward side of salt marshes to exclude salt or brackish water from the marsh, allowing animals to graze on and/or machinery to cut the grass. Our experience suggests that the dikes were 0.5-1.0 m tall and most often included a one-way clapper valve at major drainage ways, allowing fresh water to pass freely out of the marsh into the sea at low tide, but remaining tightly closed by pressure exerted by the sea water during a rising tide. Salt marsh growth on the landward side of the dikes was thus impeded but continued on the seaward side.

Most of these dikes eventually fell into disrepair, and were subsequently breached by the tides. With this renewal of twice-daily flooding by salt water, salt marsh peat accumulation was again possible on the landward side. We hoped that stratigraphic studies of a profile perpendicular to the dike would show the amount of salt marsh accumulation on the seaward flank of these structures, which could be dated from historical records.

The procedure consisted of clearing a profile perpendicular to the long axis of the dike. This included portions landward and seaward as far as practical. Detailed stratigraphies were recorded every 0.5-1.0 m along this "transect". All depths were measured relative to an arbitrary leveled line above the dike with a transit and range pole. The location of each dike is shown in Figure 1.

Pleasant River South Dike, Addison

This dike along the south and east sides of the Pleasant River is one of the largest dikes constructed in eastern Maine. The section is about 100 m west of the Addison-South Addison road, where it crosses the Pleasant River (Anderson and Race, 1981). To cause minimal damage to the marsh and dike itself, our profile was located along a tidal stream at the former site of a clapper valve. The seaward side of the dike has been somewhat truncated by wave action. For this reason, little quantitative information on sea-level rise upon this dike was obtained and no stratigraphy is diagramed.

The lowermost strata consists of a gray silty-clay layer with a moderate amount of Spartina alterniflora rhizomes. A black, organic-rich, silty-clay grades into the gray silty-clay on the landward side. This is overlain by 15-25 cm of brownish silty-clay which contains more organics than the gray layer below. This layer can be traced continuously across the profile, and gently slopes downward towards the river. We believe that the top of the brown layer may be the surface on which the dike was constructed. The sequence is very analogous to present mudflats along the river. Compact gray silts are often overlain by a less compact, more organic, brown silty layer, often forming the substrate for plants of S. alterniflora.

The main part of the dike extends horizontally about 3 m. It most probably was wider when it was built, but has subsequently been eroded. Overlying the brown organic silts is a gray silt layer which is, in turn, overlain by another brown organic silt layer. The gray layer varies from 5.0-7.5 cm thick while the brown layer is 5-13 cm thick. The gray layer disappears toward the river and both layers become rather indistinct toward the landward side. Once again, these layers dip at a gentle angle towards the river.

Overlying this is a third and then a fourth gray-brown sequence. All layers dip toward the river. The top brown layer is probably truncated and occurs, in cross-section, as only two small lenses of material. It seems quite clear that three layers of mud, probably taken from either the S. alterniflora zone or adjacent mudflat, were successively placed on top of the former thatch zone to construct the dike. The mud layers may have been as much as 21 cm or more thick when laid into place.

On top of the dike is a rather heterogeneous layer of depth 5-22 cm consisting of a dark brown peaty soil on the landward side and a washed zone of gray and brown silts and clays on the river side. Spartina patens, the most abundant salt marsh grass, grows on top of the peaty soil. It is unlike other salt marsh sediments in that it is much less fibrous and is darker in color than the adjacent salt marsh. Colonization of the landward side of the dike may presently be proceeding, after exclusion of regular salt-water flooding by the dike.

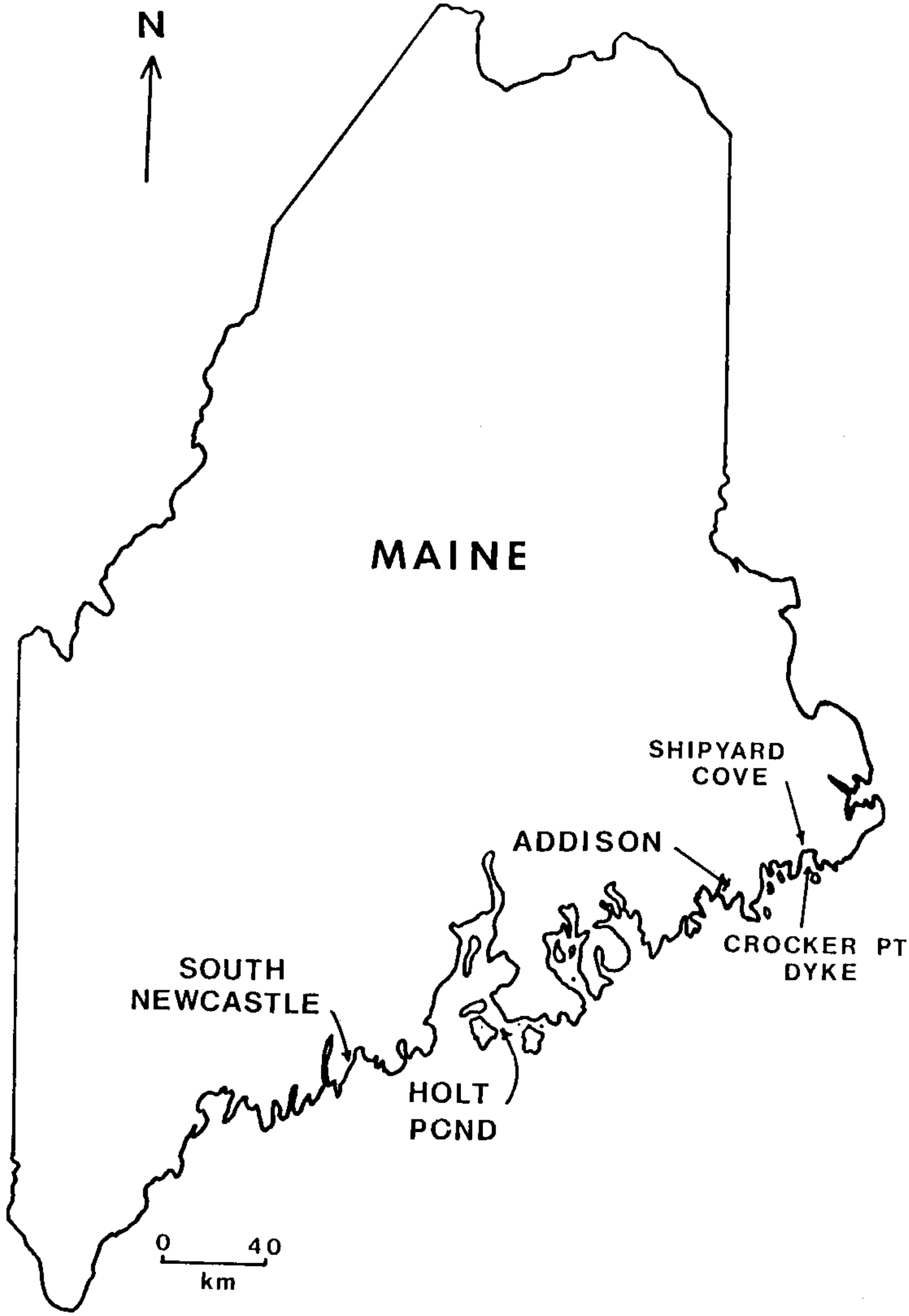

Fig. 1. Location of salt marsh sites and man-made structures.

Crocker Point Dike, Machiasport

The Crocker Point Dike in Machiasport is another large dike, believed to have been built in the 1820's (D. Smith, pers. comm.). This dike is located about 400 m east of a town road connecting Maine Route 92 and US Route 1 (Anderson and Race, 1981). Once again, to minimize damage to the dike and fragile salt marsh, we excavated a section perpendicular to the dike, close to the old clapper valve. In this case, however, the landward side of the dike was somewhat eroded, the seaward side was in excellent condition, providing a good record of sea-level encroachment (Figure 2).

The dike was built to a width of at least 4.5 m. Note that the vertical scale on Figure 2 has been exaggerated fourfold. The basal layer consists of a light gray organic silt which grades upward into a darker brown, slightly humified organic silt. We believe that this is the surface upon which the dike was constructed. Overlying this strata is a couplet of light gray-brown organic silt with roots of S. alterniflora, overlain by slightly humified dark brown organic silt. The contact within the couplet is gradational and has the same appearance as underlying strata. The thickness of the couplet varies from about 7.5 cm to 17.5 cm. On top of this is a layer of dark brown silty clays with little organic matter. The upper boundary of this layer consists of a distinct plane characterized by an orange stain (perhaps caused by oxidation of iron in solution) and contains roots and clay concretions. An unstratified mass of light gray silts with little visible organic matter rests on top of this sequence and forms a triangular (in cross-section) cap. Growing on the top of the dike is middle-marsh (S. patens assemblage) then high-marsh (Juncus gerardii assemblage) vegetation.

The most important observation here is that the dike is made almost entirely of silts and clay with little organic matter and that it also rests on silts and clay. Kaye and Barghoorn (1964) and Bloom (1964) have demonstrated the problems of interpreting sea-level changes in salt marshes due to autocompaction of the peat. The problem of compaction and settling is minimized in this dike because it is made up primarily of inorganic, relatively incompressible sediments.

We believe that much of the material used to construct the dike itself came from a trench that was dug on the seaward side of the dike (between stations 11 and 15). The trench subsequently filled with debitage - wood chips, sawdust, boards, silt and plant fragments. The random orientation of materials suggests that the trench filled in rapidly after the construction of the dike. On top of this is a 1-8 cm layer of peat with lots of sawdust and bark fragments. This layer extends both seaward on top of a light gray organic silt accumulation and up onto the dike in an onlap situation. On top of the sawdust surface is a layer of brown silty salt marsh formed primarily by Spartina patens. This also extends up onto the dike.

The sawdust and bark fragments were produced during lumbermaking operations in the Machias Bay area. The peat which has accumulated on top of the sawdust layer has done so since the 1820's at the earliest (time of dike construction) or the 1880's (end of active lumbermaking)(D. Smith, pers.

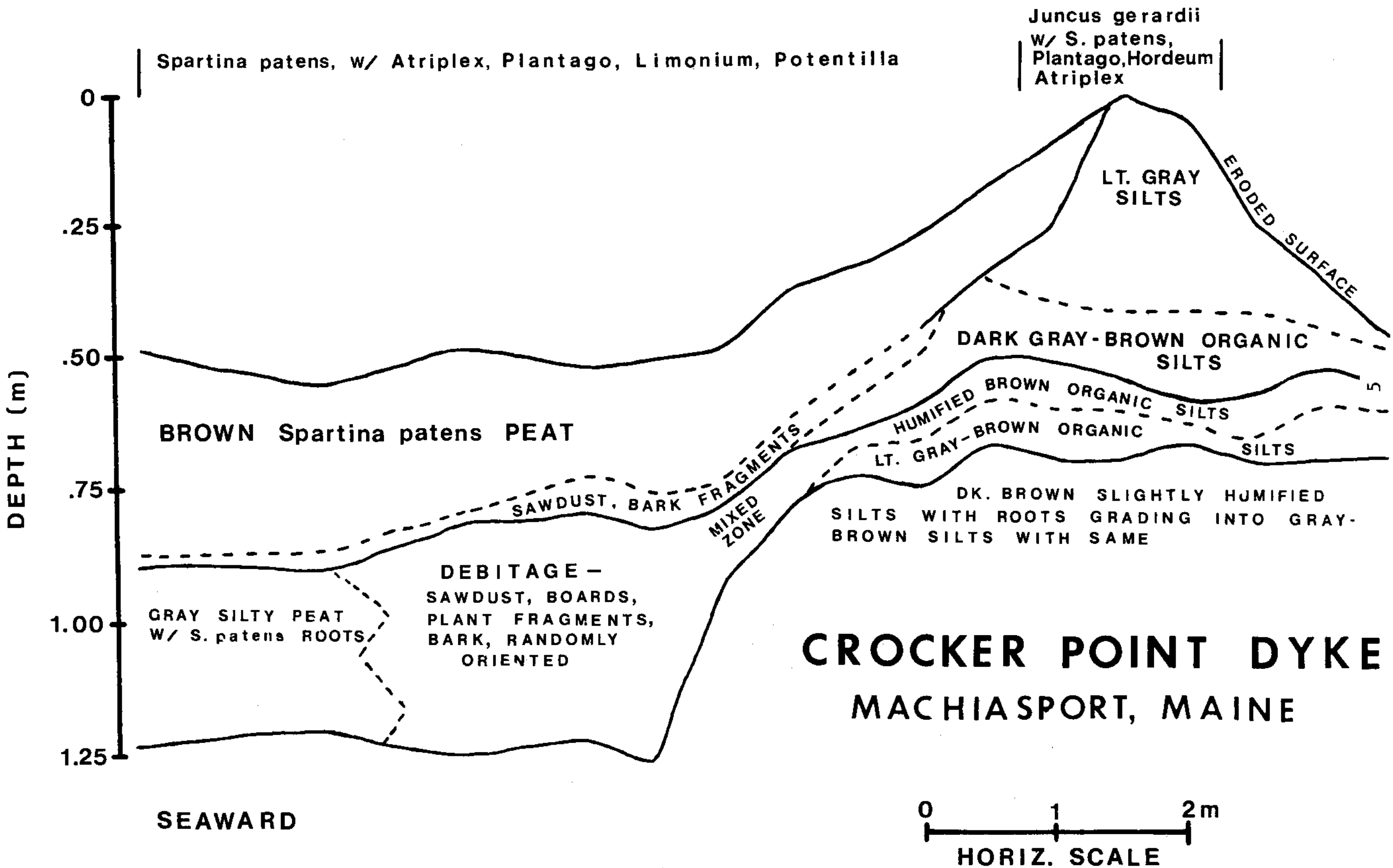
Spartina patens, w/ Atriplex, Plantago, Limonium, Potentilla
Juncus gerardii
w/ S. patens,
Plantago,Hordeum
Atriplex
DEPTH (m)
0
.25
.50
.75
1.00
1.25
LT. GRAY
SILTS
ERODED SURFACE
DARK GRAY-BROWN ORGANIC
SILTS
HUMIFIED BROWN ORGANIC SILTS
LT. GRAY-BROWN ORGANIC
SILTS
BROWN Spartina patens PEAT
SAWDUST, BARK FRAGMENTS
MIXED
ZONE
DK. BROWN SLIGHTLY HUMIFIED
SILTS WITH ROOTS GRADING INTO GRAY-
BROWN SILTS WITH SAME
DEBITAGE—
SAWDUST, BOARDS,
PLANT FRAGMENTS,
BARK, RANDOMLY
ORIENTED
GRAY SILTY PEAT
W/ S. patens ROOTS
CROCKER POINT DYKE
MACHIASPORT, MAINE
SEAWARD
0
1
2m
HORIZ. SCALE

Figure 2

comm.). Maximum depth of peat on top of this sawdust layer is about 32 cm. Therefore, a minimum rate of sea-level rise in this area would be

$$\frac{32\ \text{cm}}{1980 - 1820\ \text{AD}} = \frac{32\ \text{cm}}{160\ \text{yrs}} = 0.20\ \text{cm/yr or } 20\ \text{cm/century}$$

A maximum rate of sea-level rise would be

$$\frac{32\ \text{cm}}{1980 - 1880\ \text{AD}} = \frac{32\ \text{cm}}{100\ \text{yrs}} = 0.32\ \text{cm/yr or } 32\ \text{cm/century}$$

Shipyard Cove

The Machias area was a local center of lumber production and shipbuilding in the 19th century (D. Smith, pers. comm.). 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. They include small end and slab pieces of logs, wedge-shaped and lathe-like pieces, and wood chips, along with all manner and dimension of rectangular boards. Some contain drill holes or notches or are burned. All have axe marks or are rough sawn with both circular and/or straight sawmarks. The abundance of boards in the area, along with the known local history of lumbermaking and shipbuilding suggests that the boards are either by-products of the lumber manufacturing or shipbuilding processes. Assuming that these boards were lodged in the salt marshes soon after being discarded into the river, a simple measurement of the depth that the board occurs below the surface of the marsh gives a minimum value for the amount of sediment accumulation in the marsh since manufacture.

One marsh was chosen for detailed study of the stratigraphy. The marsh is located adjacent to (east of) Simpson's Wharf in Shipbuilding Cove, East Machias (U.S.G.S. Machias Quadrangle, 7.5 minute, latitude 44°43'0", longitude 67°23'15"). Simpson's Wharf was a local center of shipbuilding from about 1820 to 1880 AD (D. Smith, pers. comm.), roughly contemporaneous with the maximum period of lumbermaking. The seaward side of the marsh has an exposed face, 1-2 m in height, and fronts a large mudflat along the East Machias River. The major marsh-forming species is *Spartina alterniflora*, although very appressed *S. patens* and *Juncus* zones (as defined by Miller and Egler, 1950) occur. All boards occur either in silty peat formed by *S. alterniflora* or on a contact zone between silty peat and silt with some organics.

The depth of each board exposed on the marsh surface was measured by cutting a vertical section from the marsh surface to the board. This was then related to a fixed point above the marsh using a transit and range pole. Sample boards were measured, described, and cataloged.

Forty-one boards were found at 25 locations along the exposure. Maximum depth below marsh surface of any one board was 1.36 m. None were found above 0.51 m. Frequency distribution of the boards by 10-cm intervals (Figure 3) indicates that the largest category, 90-99 cm, contains 24.4%.

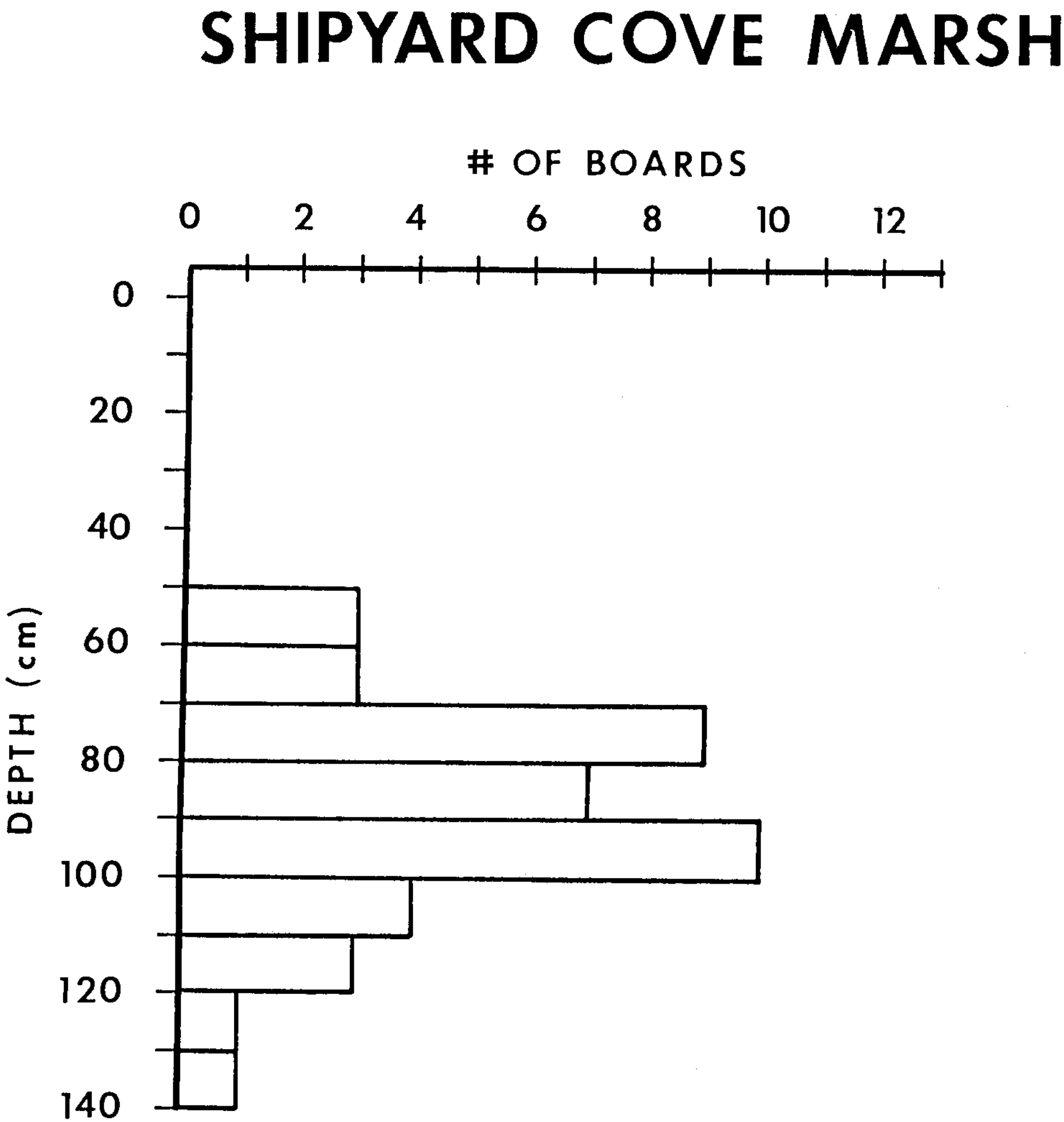

Fig. 3. Frequency distribution of man-made boards with depth, Shipyard Cove Marsh, East Machias, Maine.

Three categories, 70-79 cm, 80-89 cm, and 90-99 cm, account for the majority of boards (63.5%), while 22.0% are found lower than this and 14.6% are higher.

If we make the assumption that the depths containing the maximum number of boards (70-99 cm) correspond to the time of maximum lumbermaking and shipbuilding activity (1820-1880 AD) as shown from historical records, we can determine minimum and maximum values for peat accumulation rates at this site. A minimum rate of 0.4 cm/yr (40 cm/century) and a maximum rate of 1.0 cm/yr (100 cm/century) is inferred by this means.

As an independent measure of sediment accumulation rates, we subjected a core from the exposed face of this marsh, which contained a manufactured board, to ^{210}Pb analysis. The analysis was performed by Steven Johnston, Department of Geological Sciences, University of Maine at Orono. The method is explained in several papers (see for instance Johnston, 1981; Brugam, 1978; and Benninger, et al., 1975) 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 chronology of sediment accumulation can be determined by relating the ^{210}Pb activity at a specified depth in a sediment core to the ^{210}Pb activity at the surface. 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.

Figure 4 shows the ^{210}Pb activity curve for a profile taken from the exposed marsh at Shipyard Cove. The profile contains a board at 1.07 m depth. Two interpretations of sediment accumulation will be discussed. In the first case, the ^{210}Pb activity to the right of dashed line (a) is termed unsupported, that to the left is termed supported. Based on a semi log linear regression of the nine uppermost data points and a ^{210}Pb half-life of 22.2 years, the board at 1.07 m depth was deposited in 1940 AD. This represents a sediment accumulation rate of 2.6 cm/yr (260 cm/century). In the second case, the ^{210}Pb activity to the right of the dashed line (b) is termed unsupported and to the left is termed supported. Based on this linear regression of the top four data points, the board was deposited in 1875 AD. This represents a sediment accumulation rate of 1.0 cm/yr (100 cm/century). These two rates are the maximum and minimum values as determined by ^{210}Pb analysis. The actual sediment accumulation rate using this method probably lies somewhere in between the two extremes.

Rates of accumulation are somewhat higher as determined by ^{210}Pb activities than determined by historical inference. This was an initial attempt at dating salt marsh sediments by analysis of ^{210}Pb so conclusions as to the accuracy of the method on salt marsh sediments should await further trials. We hope to continue work on this. The discrepancy may be accounted for if sediment accumulation rates have increased substantially within the last few

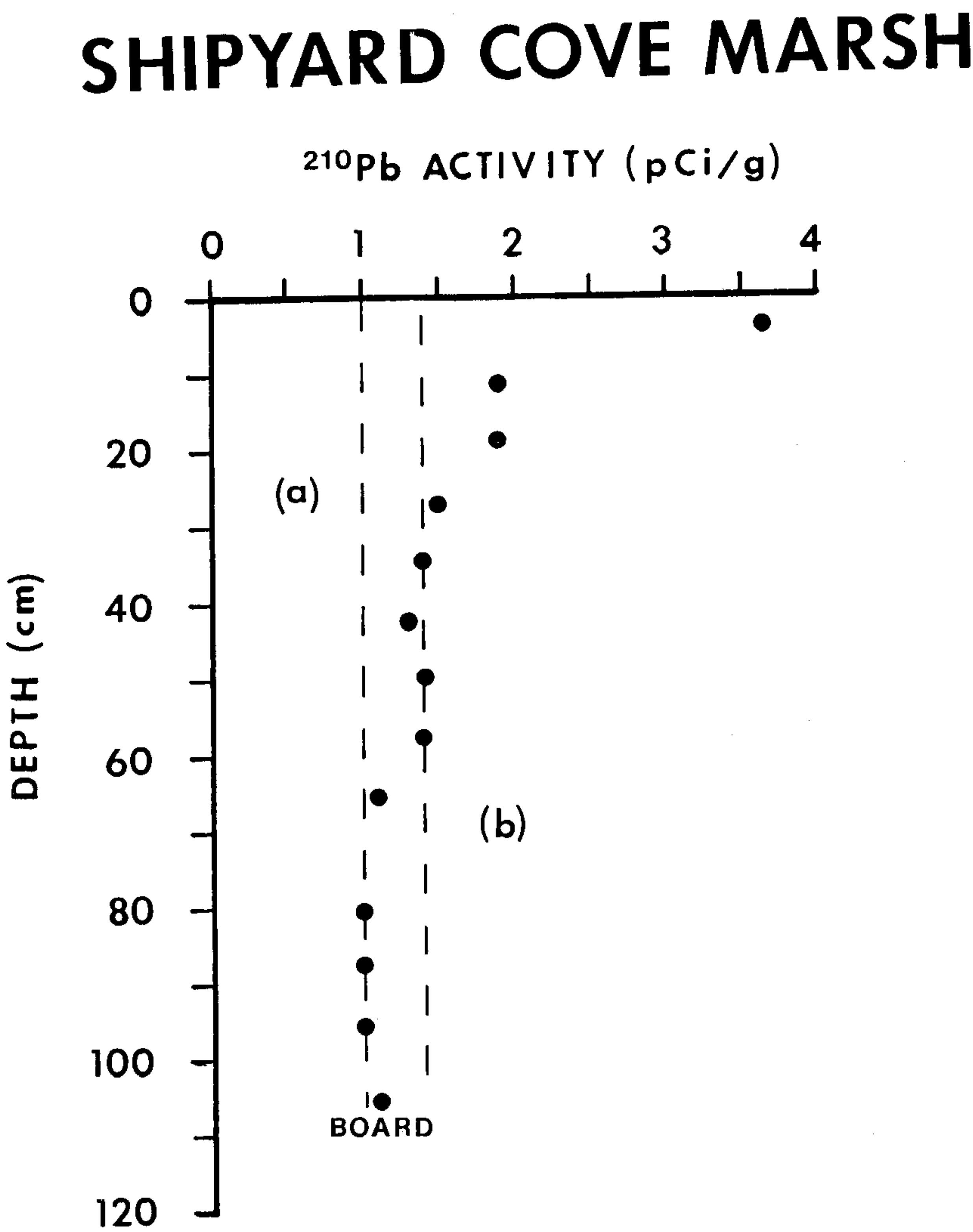

Fig. 4. Pb-210 decay curve for Shipyard Cove Marsh, East Machias, Maine.

decades or if the boards were actually redeposited. In any event, both methods suggest a high sediment accumulation rate.

Other man-made objects found in the marsh include a triangular leather fragment found at 88 cm depth. Several distinct layers of sawdust, up to 2 cm thick, are found at almost all sites examined. Three locations, 7a-a, 7a-b, and 8, were chosen for more detailed stratigraphic analysis. Sawdust layers occur both above and below the boards at these locations. The uppermost sawdust layer at station 7a-a is 56 cm depth, at station 7a-b is 54 cm, and at station 8 is 42 cm depth. This is consistent with the minimum depth of boards found in the entire exposure.

Part of the marsh rests on a "beach" composed of native rock, coal, broken bricks, clinkers, pottery and glass, indicating possible human construction. The "beach" appears to run perpendicular to the shoreline, bridging the shore and a piling in the river. We suspect that the "beach" was constructed as part of a walkway connecting the boom with the shore. This exposure is 7.8 m long and is approximately 1.3 m below the top of the marsh surface. No further excavation of this feature was attempted.

CORE STUDIES

In addition to the studies described above, we have continued our investigation of salt marsh cores to extend the sea-level rise curve back in time (Anderson and Race, 1981), utilizing a method similar to Scott (1977). This method relates the foraminiferal assemblages in the core to the higher high water (HHW) datum. The HHW datum from each core is then radiocarbon dated and related to the present HHW datum. A sea-level curve can then be drawn. We have thus identified the HHW datum in each of four cores from three locations. Radiocarbon dates for all locations are listed in Table 1.

Holt Pond Marsh is located on the Stonington-Deer Isle town boundary (see map in Anderson and Race, 1981) and is our central-coastal location. Figure 5 shows the sea-level curve for this location. Linear regression of three points (SI-4596, SI-4595, SI-4768) plus the origin yield an average sea-level rise of about 8.8 cm/century since about 3000 ^{14}C years B.P. SI-4767 was excluded from the curve fitting because we believe it to be anomalously young.

South Newcastle Marsh is located in South Newcastle, Maine, and is our west-coastal location. Figure 6 shows the plot of ^{14}C dates vs. depth for that location. This plot of dates does not lend itself readily to a good linear regression and yields little information on sea-level rise. However, two linear regressions have been calculated. SI-4837 has been excluded from both curves because of its anomalously young nature. Utilizing the origin, SI-4835 and SI-4836, we obtain an average sea-level rise of 8.9 cm/century for the last 3000 ^{14}C years. If we include SI-4834, we obtain 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.

TABLE I

	Core	Date Number	Depth below HHW Datum (m)	^{14}C Years B.P.
Addison I Marsh	AID-1	SI-4434	0.60-0.68	1250± 65
	AIB-2	SI-4435	1.77-1.87	2610± 90
	AIA-2	SI-4832	2.07-2.17	1520±110
	AIC-3	SI-4833	3.75-3.85	3315± 75
Holt Pond Marsh	HD-1	SI-4596	1.01-1.07	1825± 55
	HC-3	SI-4595	1.55-1.61	1880±150
	HB-3	SI-4767	2.02-2.12	655± 75
	HA-3	SI-4768	2.37-2.47	2835± 70
South Newcastle Marsh	SNF-1	SI-4834	0.91-1.01	2280± 50
	SND-2	SI-4835	1.37-1.47	980±100
	SNC-1	SI-4836	2.19-2.29	2630±100
	SNB-1	SI-4837	2.48-2.58	435± 75

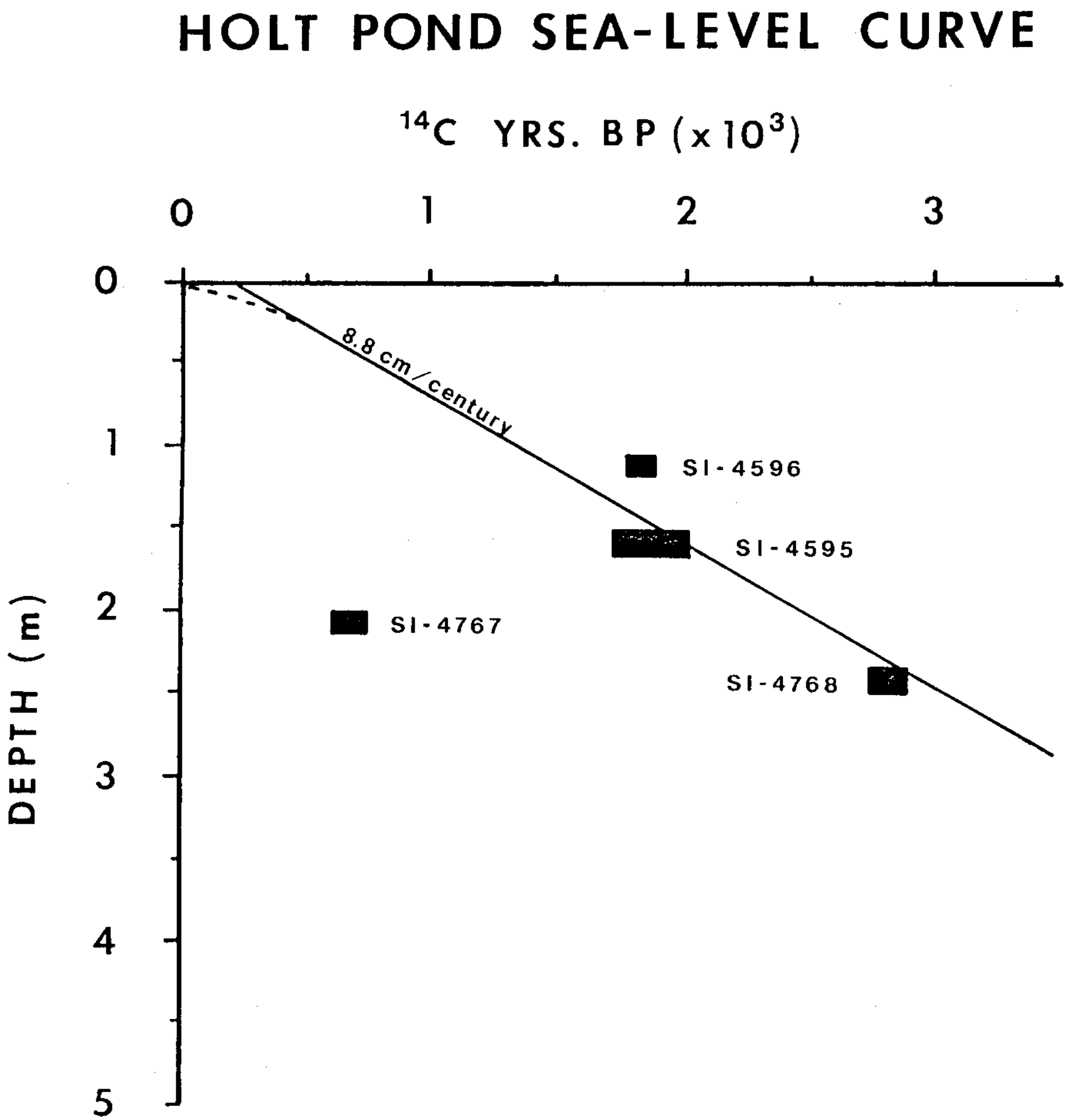

Fig. 5. Radiocarbon dates and sea-level curve for Holt Pond Marsh, Stonington, Maine.

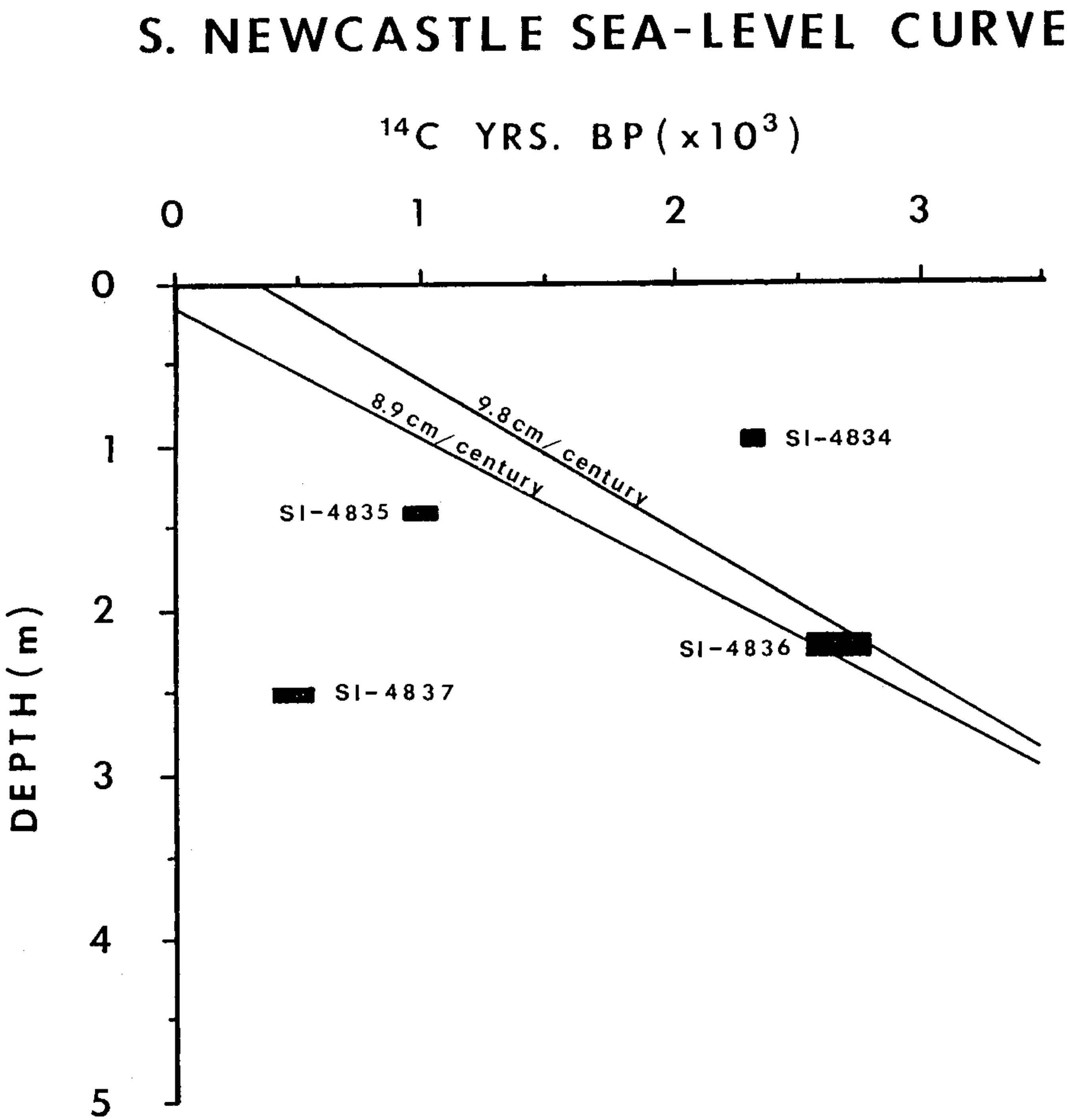

Fig. 6. Radiocarbon dates and sea-level curves for South Newcastle Marsh, South Newcastle, Maine.

Addison I Marsh is located in Addison, Maine, and is our east-coastal location (Anderson and Race, 1981). Figure 7 shows the date-depth plot. Included is a date-depth plot of 15 ^{14}C dates (shown as horizontal lines with centered dots) and a best-fit sea-level curve calculated by Thompson (1973) for that marsh. Thompson's curve suggested a 115 cm/century rise about 3000 ^{14}C years ago and a more recent 6 cm/century rise. We had hoped to be able to "fine-tune" this curve utilizing the foraminifera technique. Since the technique was in the developmental stage at that time, Thompson could not have used the method.

As with the dates from South Newcastle Marsh, our ^{14}C dates here (dark blocks) do not readily lend themselves to simple linear regression, and, for the most part, fit outside the envelope of dates which determined Thompson's (1973) sea-level curve for Addison Marsh. Therefore, we were not able to substantially improve the data on sea-level rise for that area.

We believe that the problem with ^{14}C dating lies less in the foraminifera method of Scott (1977) than in the manner in which the salt marsh grows. Several processes exist in salt marshes which may affect the sediments and produce anomalously old or young dates at a particular depth. Perhaps the most important mechanism in producing older dates than anticipated is that salt marsh growth is both upward and landward. In most cases, material from soils which have developed over thousands of years are incorporated into the marsh. The soil may contribute significant amounts of old carbon to the marsh. 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 and small drainage passages in the marsh. These cracks can be enlarged by water movement during the tidal cycle with the subsequent movement and redeposition of marsh material. Chapman (1974) reports observing large amounts of trapped gas escaping from the unsaturated zone of the marsh during a flooding tide. The concommitant 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 I Marsh are located along tidal rivers whereas Holt Pond Marsh is in a more protected cove. Our experience suggests that more analysis of these problems should be performed.

SUMMARY

From data using salt marshes, we can conclude that relative land subsidence has occurred and is presently occurring along the Maine coast. Our evidence suggests that at the mid-coastal site, Holt Pond Marsh, an average sea-level rise of 8.8 cm/century has occurred during the last 3000 years. In eastern Maine, our data did little to change the earlier conclusions of

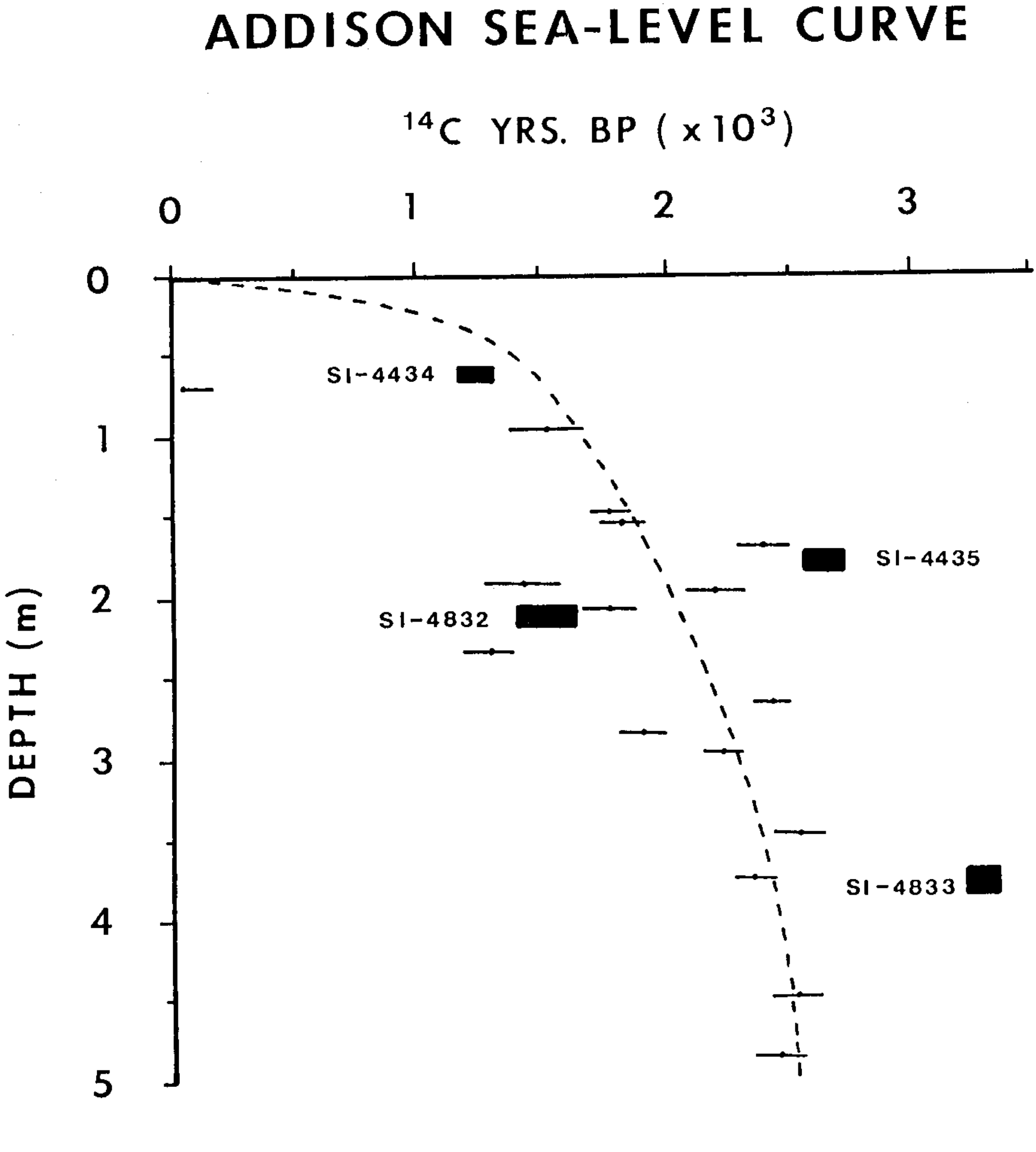

Fig. 7. Radiocarbon dates and sea-level curve for Addison Marsh, Addison, Maine.

Thompson (1973) on sea-level rise from about 3000 years ago until historic times. However, excavation of a salt marsh dike in Machiasport suggests a recent sea-level rise of 20-32 cm/century there since European colonization of the area. At the western site, South Newcastle Marsh, and to a lesser extent at the Addison site, we have examples of the problems in ^{14}C dating salt marshes and conclude that more investigation should be done on the incorporation of older or younger organic material in the marsh.

In addition, we have isolated an area in East Machias with an anomalously high sediment accumulation rate - 40-260 cm/century. Undoubtedly there is sea-level information built into the system, but it may be obscurred by problems with sediment redistribution in the area. We also believe that ^{210}Pb dating is a promising tool in determining the amount of recent encroachment of salt marsh (caused by sea-level rise) onto historic structures.

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