TIDAL MARSHES OF CONNECTICUT AND RHODE ISLAND

David E. Hill and Arthur E. Shearin

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THE COVER PHOTO

The meandering Menunketesuck (left) and Patchogue (right) rivers drain more than 300 acres of tidal marsh in Westbrook before joining and emptying into Long Island Sound. Clearly seen traversing the marshes are U.S. Route 1 near the mouths of the rivers and, to the north, the Penn-Central Railroad. Farther north, the Connecticut Turnpike cuts through the wooded uplands. Houses surround most of the marshland, while marinas jut from the river banks and slice the marshes near the confluence of the rivers. The network of mosquito ditches was formerly the only evidence of man's intrusion there. *Photo by Keystone Flying Service.*

TIDAL MARSHES OF CONNECTICUT AND RHODE ISLAND

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INTRODUCTION

Soil surveys, originally designed to assist the farmer, have expanded to new uses in the last two decades. The soil survey now assists planners, developers, and land conservationists and encompasses all land irrespective of agriculture. Soil scientists knew little about the tidal marshes that border our coasts and estuaries. We have, therefore, examined the tidal marshes in our area and classified them.

Essentially, there are four types of tidal marshes in Connecticut and Rhode Island. Three of these types are along the coast and are segregated by total depth of the marsh peat and tidal sediments: deep, shallow, and very shallow. A fourth, the estuarine marsh, is found along rivers entering Long Island Sound and Block Island Sound and in segments of coastal marshes protected by tide gates. The properties of the sediments in the four marshes were studied in the field and laboratory, and quantitative measurements of them are reported in this Bulletin.

This study is especially appropriate today because renewed efforts are being made to protect the marshes, which are important in the lives of many creatures. A recent public act in Connecticut preserves all tidal marshes and estuarine systems. Future modification of tidal marshes, where permitted, must be in the public interest. Decisions in the future must be made, therefore, to preserve or modify. Public Act 695 defines tidal marshes by the plants that grow on them. The soil survey with its classification system considers not only the ephemeral surface features but the more durable properties of the marsh sediments as well.

In this report, earlier mapping and classification of tidal marshes by geologists and botanists are discussed because they are an integral part of the soil classification scheme. Next, we present the traditional elements of soil classification: acidity, salinity, organic matter, depth, particle size, and clay minerals. They are related to growth of plants, drainage, corrosion of metal and concrete, and strength and shrinkage of a sediment as well as classification. In addition, clay minerals also indicate whether the sediments of each layer in the marsh were deposited from the land or from the sea. Finally, the classification scheme is described and put to use in a general map that shows each marsh in Connecticut and Rhode Island that exceeds 15 acres.

TIDAL MARSH FORMATION

The deep, shallow, and very shallow coastal marshes and the estuarine marshes of Connecticut and Rhode Island have been shaped by such geological events as glaciers, rising sea level, and marine erosion by waves and longshore currents. To understand fully the properties of marsh sediments, we must first trace their history through the eyes of geologists.

Sudden geological events such as hurricanes and floods are recorded and well remembered by those who survive their wrath. But the slow balancing and adjusting of land and sea on the wrinkled skin of earth are scarcely perceptible in a lifetime. Geologists, however, digging into the margins of land and sea have traced, in an afternoon, the record of centuries of tides, erosion, and changes in the level of the sea. By studying the sediments and plant remains, they have been able to reconstruct the chronology of marsh formation. Let us trace these events because they have shaped the four types of marshes which we shall later identify and describe in detail.

Deep and shallow coastal marshes

These two marsh types have been shaped by a glacier and the subsequent rising sea acting on an irregular, rock-ribbed coast interspersed with glacial outwash plains. As we shall soon learn, their differences are due to age.

The last great glacier, which ground over New England 14,000 to 20,000 years ago, halted in its southerly push in the vicinity of Long Island. The heaps of soil and rock bulldozed along its front came to rest from Long Island northeastward across Fishers Island and eastward along the Rhode Island coast. Long Island Sound, covered by the glacier, did not begin to fill with water until the glacier finally yielded to a warming climate. Even after the last traces of ice had melted along the shore, 7,000 to 11,000 years ago, the seas of the New England coast and the waters of Long Island Sound lapped a shoreline that lay as much as 33 feet below its present level in some places (Bloom and Stuiver, 1963). At that time, Connecticut's irregular coastline was characterized by bedrock headlands thinly covered by glacial debris and interspersed with short stretches of sandy and gravelly plains covering shallow valleys (Sharp, 1929). Narragansett Bay in Rhode Island was similar.

As plants reappeared on the bare land, fresh-water sedges began to grow in many places along the early shoreline just above high tide. The sea level rose, presumably fed by water melting from the glaciers that still covered much of the northern continents. The fresh-water sedges were submerged by the rising sea and were covered by silt and clay deposited by tides. Their remains, buried centuries beneath the tidal sediment, record the rate of drowning of the land because many fringes of fresh-water sedges progressively migrated to higher land as the sea encroached. Radiocarbon dates of the buried remains of the fresh-water sedges revealed that the sea level rose as much as 0.6 foot per century (Bloom and Stuiver, 1963).

In western Connecticut the rate of submergence was so fast that the coastal valleys were drowned, forming calm, shallow bays and lagoons. In these backwaters, silt and clay accumulated. These fine sediments were winnowed from the bottom of Long Island Sound by the scouring of longshore currents and then carried to the shallow, protected basins by tides (Van Straaton and Kuenen, 1958).

About 3,000 years ago, or in the era when Agamemnon destroyed Troy and David became king of the Israelites, the Connecticut coast stood about 9 feet below its present level. Thus, the sea rose on the Connecticut coastline only 0.3 foot per century (Bloom and Stuiver, 1963). The slower rise of the sea permitted the open water in the protected bays and lagoons to fill with sediment carried by the tides. Eventually, grasses that could tolerate salt grew on the tidal flats. In the past 3,000 years, sedimentation in Connecticut has kept pace with submergence.

The deep and shallow marshes of the Connecticut coast have an interesting distribution. Deep marshes, averaging 16 feet thick, predominate west of the Connecticut River and shallow marshes, averaging less than 6 feet thick, predominate east of the river to Watch Hill, Rhode Island, and also in Narragansett Bay.

East of the Connecticut River the coastal depressions, which now contain shallow marshes, stood 25 feet or more above the earliest shoreline. These depressions finally fell under the influence of the rising sea less than 3,000 years ago and the vegetation has kept pace with submergence since plants first began to accumulate. The thick subsurface layers of silt and clay that accumulated earlier in open bays west of the Connecticut River during rapid submergence are absent east of the river. Drawing an analogy from Bloom and Ellis's description of marsh erosion at Chittenden Beach, Guilford (1965), the shallow marshes may be remnants of earlier, more extensive marshes. The older and deeper portions of the eastern marshes may have been eroded by waves in recent centuries. They are unprotected, for the most part, by barrier beaches.

Today, submergence continues and the surface of the marsh slowly builds with the remains of generations of plants and the silt and clay trapped by them at flood tide (Bloom, 1967).

Very shallow coastal marshes

This marsh type has also been shaped by a glacier and the rising sea, but it has also been shaped by severe marine erosion of a weak, unstable coast.

The Rhode Island shore from Watch Hill to Point Judith has few bedrock headlands. It is covered with thick glacial debris, called terminal moraine (Sharp, 1929). Open to the Atlantic Ocean and unprotected by Long Island, the sandy Rhode Island coast has been straightened by longshore currents as waves eroded the terminal moraine during the centuries as the sea rose. This erosion formed long stretches of sandy beach while on-shore winds formed dunes in front of shallow lagoons.

These shallow lagoons have filled with sand washed and blown from the beaches and dunes during severe coastal storms. Thus, the marshes from Watch Hill to Point Judith are mixtures of sand and peat. The sandy peat is seldom more than 2 feet thick.

Estuarine marshes

This marsh type has been shaped primarily by the rising sea but more recently by man's attempt to control mosquitoes. Tide affects not only the immediate shoreline but extends inland along rivers, notably the Connecticut, Housatonic, and Quinnipiac Rivers. As the coast submerged beneath the rising sea, the tide reached farther inland, up the rivers and streams. But inland, the tide only quickens or slows river flow, and the sediments of the estuarine marshes are carried from the hills and deposited during slack water rather than carried inland from the floor of Long Island Sound. In the section on clay mineralogy, the origin of these sediments will be discussed.

The estuarine marshes are not only distinctive in the origin of their sediments but their vegetation is reeds and sedges intolerant of strong salt concentrations. Thus the estuaries, where the rivers meet the sea, are mixing bowls where fresh water meets salt water and river sediment meets tidal sediment.

More recently, however, portions of the deep and shallow coastal marshes, now protected by tide gates for mosquito control, have taken the appearance of the estuarine marsh. Daily flooding ceased several decades ago and salt has partially leached from their surface and permitted invasion of tall reeds and sedges. In some protected coastal marshes, reeds and sedges now grow in pure stands, in others they are still replacing the salt grass as salt content diminishes.

VEGETATION

Botanists mapping the vegetation of tidal marshes recognized that plant communities are segregated by varying degrees of salinity (Niering, 1961). For our classification of marsh sediments, this is especially informative because the plants, used as indicators, can give clues to the salinity of the sediment in which they grow.

Studies of plant communities on the Mamacoke Island Marsh in the Thames River estuary, Waterford, reveal that three communities of plants typify three degrees of salinity. Along the water's edge and in shallow depressions on the marsh where salinity is greatest, salt water cord grass *(Spartina alterniflora)*, black grass *(Juncus gerardi)*, and spike grass *(Distichlis spicata)* abound. Other common species include sea lavender *(Limonium carolinianum)*, purple gerardia *(Gerardia maritima)*, aster *(Aster tenuifolius)*, seaside goldenrod *(Solidago sempervirens)*, saltwort *(Salicornia europaea)* and seaside plantain *(Plantageo juneoides)*. In higher and drier parts of the marsh, salt meadow grass *(Spartina patens)* often grows in pure stands. Where the marsh meets the upland and salinity is least, switch grass *(Panicum virgatum)*, sea myrtle *(Baccharis halimifolia)*, marsh elder *(Iva frutescens)*, and marsh mallow *(Hibiscus palustris)* commonly grow.

In the less salty estuarine marshes of tidal rivers and streams, and in parts of coastal marshes protected by tide gates for mosquito control, the plant communities are principally tall reeds and sedges. Here, cattails *(Typha angustifolia)*, reeds *(Phragmites communis)*, and bulrushes *(Scirpus robustus)* abound. Although it is not known what concentration of salt becomes limiting for reeds and sedges, salt seldom exceeds 10,000 ppm (parts per million) in the marshes where these plants grow.

PROPERTIES OF THE SEDIMENTS

Several properties of the sediments merit study because they are important elements of soil classification. Acidity, salinity, organic matter, particle size, and clay minerals inform us about the growth of plants, drainage, corrosion of metal and concrete, and strength and shrinkage of the sediment. Properties of sediments from each of the four types of marshes described in the section "Tidal Marsh Formation" are presented in Table 1.

Acidity

Measuring acidity is particularly useful because we can tell from pH whether the sediments are permeated with fresh water or salt water, whether they contain sulfides or sulfates, or whether large quantities of shells have neutralized the acid. Acidity, expressed as pH, was determined with a glass electrode immersed in a 1:1 soil-water paste.

The initial pH determined as samples in sealed containers were brought from the field, revealed that most samples from the coastal marshes were slightly acid to neutral; pH ranged from 6.1 to 7.2. This reflects the influence of alkaline salt water, which has a pH of approximately 8.0. In general, the organic-rich surface layers were more acid than the organic-poor layers below. A few surface layers were as low as 3.5.

In the estuarine marshes along the major rivers, the sediments are more acid, with pH ranging from 4.3 to 6.6. This acid pH corresponds to that in fresh-water marshes. The greater hydrogen ion concentration comes from organic acids produced by decaying plants in an environment deficient in oxygen. In the deep, coastal Great Island Marsh at the mouth of the Connecticut River, the pH is also acid. It ranges from 5.0 to 5.6. Here, sea water is often displaced or mixed with fresh water, and the sediments are as acid as in estuarine marshes even though we shall see that they are salty.

In the Clinton Marsh, below 36 inches, pH exceeds 7.5 in places. Beneath the organic layers, alkaline shells are abundant in the silt and clay (Bloom and Ellis, 1965), and the dissolving of carbonate in the shells raises pH.

The pH of the Hamden (1) sediments is particularly illuminating for it demonstrates that drainage of the marsh produces dramatic changes in acidity. This estuarine marsh on the Quinnipiac River was diked many years ago to prevent tidal flooding in order that the underlying clays could be mined (Brown, 1930). The entire thickness of marsh sediments is now exposed. The pH ranges from 3.6 at the surface to 2.2 in the underlying sediments. To demonstrate similar behavior in other marshes, we simulated drainage by slowly drying many samples of marsh peat and silty sediment. The pH of the organic layers decreased 0.5 to 2.0 units and the pH of the underlying mineral sediments decreased 0.5 to 3.0 units. After 18 days, pH was between 4.0 and 5.5 in most samples. We accelerated drying of some samples by placing them in an oven at 105°C. After 24 hours, the pH fell below 3.5.

The dramatic increase in acidity after draining and drying is caused by oxidation of sulfur, a process called sulfur acidity (Fleming and Alexander, 1961). The stage for oxidation was set earlier in a wet, oxygen-poor environment. Here, anaerobic sulfur-reducing bacteria extract sulfate from sea water, use it, and then concentrate it in the sediments. Thus, the sulfate of sea water is transformed biologically and chemically to black, hydrous iron sulfide (hydrotroilite) and hydrogen sulfide gas (Galliger, 1933). The blackish subsurface sediments and rotten-egg odor of the marsh are well known. The sulfides in the wet environment now lie ready to be transformed.

As marshes are drained or samples dried, oxygen permeates the sediment and sulfide is converted chemically to sulfate. Some sulfate combines with hydrogen and produces sulfuric acid and low pH.

If, however, the sediments contain abundant shells, the acid generated during oxidation and drying is neutralized by alkaline carbonate in the shells. For example, the alkaline pH of the shell-rich IIC layers in the Clinton Marsh decreased only slightly after drying (Table 1).

Thus, acidity can be used to distinguish between: (1) drained aerobic sediments containing sulfate and wet anaerobic sediments containing sulfide, (2) sediments containing salt water and those containing fresh water, and (3) sediments containing shells that can neutralize acidity and those containing few or no shells.

Salinity

The amount of salt a marsh sediment contains tells whether the sediment is permeated with salt water from the sea or fresh water from the land. We noted earlier in the section on "Vegetation" that salinity determines the types of plants that grow on a marsh. Further, salt in a tidal marsh can destroy man-made structures. Metal pipes and reinforced concrete structures embedded in marsh sediments corrode and soften due to electrolysis (Romanoff, 1957).

The amount of salt in marsh sediments is determined easily by instruments that measure electrical resistance. Sea water that contains much salt readily conducts electricity; hence, its electrical resistance is low. Fresh water, on the other hand, contains little salt; hence, its resistance is high. Resistance, measured in ohms, can be converted to parts per million (ppm) of salt in the sample.

Table 1. Properties of several representative marsh profiles in Connecticut and Rhode Island

Location	Layer	Depth	Acidity Initial	Acidity Dried 18 days	Organic matter	Salts	Sands	Silt	Clay
Deep coastal marshes; silty salt grass peat over deep, silty sediments (Westbrook series)									
		inches	pH	pH	%	ppm	%	%	%
Westbrook	Oi1	0-10	6.5	3.2	44.9	37,400			
	Oi2	10-40	5.7	4.5	44.0	22,200			
	Oi3	40-48	6.7	4.8	24.2	23,400			
	IIC1	48-64	6.6	4.9	12.0	18,200	2.5	75.6	21.9
	IIC2	64-192+	6.5	3.0	10.2	20,100	4.9	77.8	17.3
Clinton	Oi1	0-8	6.2	4.8	44.6	16,900			
	Oi2	8-36	6.9	6.4	28.6	18,200			
	Oi3	36-60	7.5	6.2	22.0	24,700			
	IIC1	60-96	7.5	7.0	18.6	16,900			
	IIC2	96-336+	7.7	7.0	8.4	15,600	16.1	65.1	18.8
Guilford	Oi1	0-8	6.2	5.1	62.1	26,000			
	Oi2	8-36	6.8	5.4	48.2	27,300			
	Oi3	36-50	7.0	5.9	19.6	31,200			
	IIC1	50-80	6.4	5.9	20.8	27,300			
	IIC2	80-300+	6.4	5.9	8.0	—	1.1	80.5	18.4
New Haven	Oi1	0-12	3.5	4.1	35.6	7,800			
	Oi2	12-24	5.8	4.2	23.5	24,300			
	Oi3	24-40	6.2	3.1	20.4	25,100			
	IIC	40-144	6.2	3.2	12.0	27,200			
Great Island Near mouth of Conn. River	Oi1	0-6	5.0	—	49.8	10,500			
	Oi2	6-14	5.0	—	34.8	11,700			
	Oi3	14-36	5.3	4.7	29.9	16,900			
	IIC1	36-56	5.3	3.9	19.2	17,500			
	IIC2	56-104	5.6	4.2	18.8	15,200	18.0	63.4	18.6
Milford	Oi1	0-10	6.6	4.9	48.9	13,000			
	Oi2	10-42	6.9	5.1	29.8	13,650			
	IIC	42-120	7.2	5.2	11.8	7,800	7.6	74.7	17.7
	IIIOib	120-192	6.1	3.1	32.7	2,900			
Stratford	Oi	0-10	6.2	5.2	28.8	19,500			
	IIC1	10-30	6.6	5.7	12.4	22,100	7.0	77.4	15.6
	IIC2	30-50	6.7	5.3	16.8	17,600			
	IIIOib	50-72	6.0	3.8	20.2	18,200			

Table 1. (Continued)

Location	Layer	Depth	Acidity: Initial	Acidity: Dried 18 days	Organic matter	Salts	Sands	Silt	Clay
Shallow coastal marshes; silty salt grass peat over sandy glacial till or outwash (Pawcatuck series)									
		inches	pH	pH	%	ppm	%	%	%
Barn Island, Stonington	Oi1	0-12	6.3	4.3	56.9	19,500			
	Oi2	12-40	6.4	5.6	22.8	22,900	13.4	70.4	16.2
	Oi3	40-46	6.3	4.9	26.8	18,800			
	IIC1	46-50	6.4	—	—	—			
	IIC2	50-60	6.3	—	—	—			
Palmer Neck, Stonington	Oi1	0-12	5.9	4.9	48.6	22,500			
	Oi2	12-36	6.1	4.4	52.9	24,700			
	Oi3	36-46	6.1	4.2	29.8	16,900			
	IIC	46-54	6.1	3.4	3.5	—			
Narragansett, R.I., Middle Bridge Rd.	Oi1	0-12	5.2	3.5	62.7	21,800			
	Oi2	12-30	6.6	4.4	53.6	24,700	23.2	54.4	22.4
	Oi3	30-54	6.1	5.5	43.6	26,000			
	IIC1	54-60	6.4	6.3	12.2	26,000	49.8	42.5	7.7
	IIC2	60-70	—	—	4.2	—	78.6	16.3	5.1
Conn. Arboretum[1] Waterford—6 miles north of mouth, Thames River	Oi1	0-12	4.3	3.6	63.4	8,800			
	Oi2	12-42	5.8	4.4	60.4	16,200			
	IIC	42-48	6.0	3.9	11.4	—			
Norwalk	Oi1	0-8	4.3	5.1	54.0	16,900			
	Oi2	8-24	6.7	6.3	29.1	23,400	2.3	72.2	25.5
	Oi3	24-50	5.7	5.3	32.6	27,300			
	IIC	50-56	—	—	—	26,000			
Very shallow coastal marshes; sandy salt grass peat over sand (Unnamed series)									
Galilee, R.I.	Oi	0-12	6.2	3.8	54.6	—			
	IIC1	12-18	6.6	3.2	2.3	—	95.3[2]	2.6	2.1
	IIC2	18-40	7.0	3.7	1.2	—			
Quonochontaug, R.I.	A11	0-18	6.2	3.0	8.9	26,000	71.6[3]	23.4	5.0
	A12	18-24	6.5	3.0	8.9	19,500			

[1] This marsh is in an estuary but is unlike most estuarine marshes. At a distance of 6 miles inland, water in the Thames River is apparently more salty than the water in the Connecticut River.

Table 1. (Continued)

Location	Layer	Depth	Acidity: Initial	Acidity: Dried 18 days	Organic matter	Salts	Sands	Silt	Clay
Deep or shallow estuarine marshes; silty brackish water sedge peat over deep silty sediments of sandy glacial till or outwash (Unnamed Series)									
		inches	pH	pH	%	ppm	%	%	%
Goose Island 4.5 miles north of mouth, Conn. River	Oi1	0-12	4.6	4.1	28.0	2,300			
	Oi2	12-36	5.1	3.1	71.8	3,400			
	IIC1	36-60	5.0	3.3	8.2	4,200	29.6	62.2	8.2
Oliver's Hole 5.6 miles north of mouth, Conn. River	A1	0-12	4.3	5.7	19.4	2,800			
	IIOib	12-50	5.4	3.3	44.2	4,600	22.5	59.1	18.4
	IIIC	50-72	5.3	—	—	4,400			
	IIIC2	72-84	5.4	—	4.0	—	57.4[3]	37.6	5.0
Deep River 9.0 miles north of mouth, Conn. River	Oi1	0-8	4.6	—	—	20			
	Oi2	8-54	4.6	4.2	24.8	20	8.4	79.3	12.3
	IIC	54-156	4.7	4.2	14.0	40			
	IIIOib	156-168	—	—	32.2	—			
Chester 10.4 miles north of mouth, Conn. River	Ap	0-6	5.0	4.6	13.4	—			
	C	6-24	5.0	4.6	19.8	30			
	IIOib1	24-36	5.2	—	36.2	30			
	IIOib2	36-192	5.2	—	—	20			
Hamden(2) 4.0 miles north of mouth, Quinnipiac River	Oi1	0-6	6.1	4.2	73.4	3,100			
	Oi2	6-20	6.0	4.7	37.0	2,500	13.4	69.2	17.4
	Oi3	20-36	6.1	4.5	71.0	1,900			
	Oi4	36-60	6.2	4.7	28.0	1,800			
	IIC1	60-108	6.5	—	13.8	3,200	3.4	77.7	18.9
	IIC2	108-144	6.6	2.5	21.4	2,900			
Hamden(1) Exposed cut in diked area	Oi1	0-9	3.6	—	42.0	1,700			
	Oi2	9-16	2.8	—	46.6	3,800			
	Oi3	16-36	3.2	—	40.2	4,400			
	Oi4	36-54	2.8	—	36.4	5,200			
	Oi5	54-72	2.8	—	23.2	7,300			
	IICI	72-90	2.6	—	12.1	8,400	6.2	76.6	17.2
	IIC2	90-108	2.2	—	6.0	10,700			
	IIC3	108-126	2.2	—	3.7	10,900			

[2] Mostly coarse, medium, and fine sand.
[3] Mostly fine and very fine sand.

Fig. 1. A coastal marsh in Guilford, Connecticut. Salt grass grows on deep silty sediments which have a high salt content. *U.S.D.A. Soil Conservation Service photo.*

All tidal marshes in Connecticut and Rhode Island, bordering Long Island Sound and Block Island Sound except those portions protected by tide gates have salt concentrations exceeding 15,000 ppm. Even the marshes in Milford and Great Island at the mouths of the fresh-water rivers have salt concentrations exceeding 10,000 ppm (Table 1).

As we ascend the large rivers, however, sea water is diluted with fresh water and becomes less salty. Thus, the estuarine marshes which border the rivers generally have salt concentrations lower than 10,000 ppm. For example, the marshes at Goose Island and Oliver's Hole, which lie 4.5 and 5.6 miles north of the mouth of the Connecticut River, have about 2,500 to 4,500 ppm salt; at Deep River and Chester, 9.0 and 10.4 miles north of the mouth, the marshes are nearly free of salt. Although the marshes far up the river are influenced by tides, the water that floods them is fresh, descending from the north.

Although the salts reported in Table 1 are from samples taken at one time, the concentrations in marsh sediments fluctuate slightly from day to day and season to season, especially at the surface of the marsh. Following heavy rains, the salt water at the surface of the marsh is diluted with fresh water; conversely, during summer drought, the higher parts of the marsh drain and become saltier. Thus, salt concentration at the surface depends on the frequency of flooding by the sea and rain and of summer drought.

Although the fluctuations of salt due to the vagaries of weather are relatively minor, drainage of marshes and flood protection for mosquito control by man has a more permanent effect on salt fluctuation. For example, the estuarine marsh at Hamden (1) on the Quinnipiac River north of New Haven Harbor probably had salt concentrations of 4,000 to 5,000 ppm throughout its thickness. Diking and draining during excavation of the underlying clays caused leaching and translocation of salts. Thus, salts formerly in the surface organic deposits are now in the mineral sediments below, at concentration near 11,000 ppm. Complete removal is retarded by the impermeable clay beds below. Similar translocation of salt has been noted in drained tidal marshes in South Carolina (Fleming and Alexander, 1961).

Salt concentrations in parts of coastal marshes protected by tide gates have decreased since the gates were installed in the 1930's. Tide gates prevent daily flooding with salt water and the sediments have become progressively less salty. Tall reeds *(Phragmites communis)* have invaded these areas and replaced the species of grasses which tolerate high salt concentrations.

Organic matter

Two properties of organic matter are of special importance to a soil scientist; the amount and its degree of decomposition. The latter is seldom used to segregate marsh layers in this region because organic matter in the upper 5 feet of most marshes is relatively undecomposed. More than 70 per cent of the plant fibers can still be identified after centuries of burial. Knowing the amount of organic matter permits a soil scientist to segregate and identify layers rich in organic matter from those rich in minerals. For classifying, 20 per cent organic matter is arbitrarily used to segregate organic-rich (Oi layers) from organic-poor layers (IIC layers) in tidal marsh

Fig. 2. Estuarine marsh in Clinton, Connecticut. Tall reeds and sedges grow near brackish water which has a low salt content. *U.S.D.A. Soil Conservation Service photo.*

sediments low in clay (Soil Survey Staff, 1968). An engineer, on the other hand, is concerned with the behavior of soil for construction, with its strength and shrinkage. Organic-rich sediments are so weak that they do not even support fill that is used to cover them. They easily compress and shrink after draining and drying.

The amount of organic matter in a sample was determined by burning it away. The amount of organic matter in most coastal marshes varies with depth. It is greatest in the surface layers, ranging from 30 to 60 per cent. At 30 to 50 inches, organic matter decreases to less than 30 per cent.

Below 30 to 50 inches and extending to nearly 30 feet in some coastal marshes west of the Connecticut River, organic matter decreases to less than 10 per cent. These mineral sediments that contain little organic matter were deposited by tides in the protected bays more than 3,000 years ago.

At the bottom of several deep coastal marshes, we found another layer rich in organic matter. The Milford Marsh, Table 1, is an example. This layer, seldom more than 2 feet thick, is an accumulation of fresh-water plants that grew on the landscape soon after the glacier melted. The rapidly rising sea buried and preserved these organic layers beneath silt and clay.

The amount of organic matter in the very shallow marshes of Rhode Island is generally less than 10 per cent. Only the Galilee Marsh had as much as 50 per cent in the upper 12 inches. In most of Rhode Island's very shallow marshes, sand, washed or blown from the dunes during severe coastal storms, dilutes the organic matter.

Organic matter accumulates irregularly in the estuarine marshes. The marshes at Oliver's Hole and Goose Island, 5 miles north of the mouth of the Connecticut River, have their richest organic layers buried beneath 12 inches of silty peat. At Chester, 10 miles north of the river's mouth, the richest organic layers are buried beneath 24 inches of silt. The distribution of organic matter also varies in the Hamden (2) Marsh.

Depth

A soil scientist is concerned about the total depth of organic and inorganic layers in a marsh because it affects management of the land especially for drainage. An engineer is also concerned about the total depth because it tells him the volume of material that must be excavated or moved.

The deepest tidal marshes in our area are reported to be about 33 feet deep (Bloom and Stuiver, 1963). They are found only in a few marshes in Guilford, Clinton, and Westbrook. Most coastal marshes west of the Connecticut River are less than 16 feet deep. The shallower marshes less than 9 feet deep in Connecticut have formed on low coastal plains that sloped gently seaward before they became flooded by the rising sea 3,000 years ago (Bloom and Ellis, 1965). These plains are extensive east of the Connecticut River, hence, the marshes that now cover their seaward perimeters are dominantly shallow.

The coarse fibrous, organic surface layers in coastal and estuarine marshes range from 24 to 50 inches deep. The coastal marshes from Watch Hill to Point Judith, Rhode Island, however, range from 12 to 24 inches deep. The organic layer at the base of some of the deep coastal marshes seldom exceeds 12 to 24 inches thick.

Particle size

Particle size is important to soil scientists because the chemistry and physics of soil depend largely upon it. Sediments with abundant silt and clay have greater chemical activity than sediments with abundant sand and gravel. For an engineer, silt and clay mean instability and impermeability; sand means strength and permeability. In this study, particle size can also be used to distinguish between silt and clay deposited by tides and slowly moving rivers and sand and gravel deposited by glaciers and swiftly moving rivers.

The deep and shallow coastal marshes of Connecticut have formed in sheltered basins protected from the waves of coastal storms that buffet beaches and rocky headlands. The sheltered basin is therefore quiet, and small mineral particles settle gently to the bottom.

Silt and clay predominate in the inorganic sediments of Connecticut's coastal marshes. Mechanical analysis reveals that silt comprises 60 to 80 per cent and clay comprises 15 to 25 per cent.

Our samples were selected from a broad geographical area. Ellis (1960), studying Great Marsh in Norwalk in considerable detail, found clay more prevalent at the surface of the marsh and fine silt more prevalent 4 feet deep. Further, Ellis found that clay in the marsh increased with distance from Long Island Sound.

At the base of each marsh lies sandy and gravelly till or outwash deposited by the glacier. Although examples of the texture of glacial till are not given in Table 1, sample IIC2 from Narragansett, Rhode Island, is much like outwash.

Sand constitutes the major part of the inorganic sediments in the very shallow marshes of Rhode Island. Here, severe coastal storms have washed and blown sand from beaches and dunes onto the marshes which lie behind.

In the estuarine marshes, particle sizes are distributed erratically because river currents fluctuate with weather. A flooding river can move larger particles and sand often becomes an important component of its sediment. The amount of sand increases at Goose Island and Oliver's Hole several miles north of the mouth of the Connecticut River. The sand is mostly very fine and fine, sizes associated with relatively swift water, not with a raging torrent.

Clay minerals

The kind of clay in tidal marshes can tell us whether the sediment came from the land or the sea. Further, the structure of some clays alters if they are moved to a new environment, and these structural transformations are clues to past environments.

The clay minerals were identified by X-ray diffraction. The clay in marsh sediments is mostly illite and vermiculite with uniformly small amounts of kaolinite (Table 2). Traces of clay-size quartz and feldspar were also found in several marshes.

The relative amounts of illite and vermiculite in the marsh sediments present a clear geographical pattern. From it, we can infer the origin of the sediments and the changes that took place as the sea rose. The 35-to-45-per cent vermiculite content in the Hamden (2) and Deep River estuarine marshes is greater than the 5 to 25 per cent in the coastal marshes from Norwalk, Connecticut, to Galilee, Rhode Island. On the other hand, the 60-to-85-per cent illite content of the coastal marshes is greater than the 40 to 55 per cent in the Hamden and Deep River estuarine marshes.

The greater vermiculite content of the estuarine marshes is not difficult to understand if we assume that the sediment deposited by rivers was soil eroded from the land, which contains large amounts of vermiculite in its weathered surface (Sawhney, 1960; Sawhney, Frink, and Hill, 1962). Further, we can understand the large amounts of illite in the coastal marshes if we assume, as others have, that the silt and clay were winnowed from the bottom of Long Island Sound and Block Island Sound by longshore currents and deposited by tides in the marshes. Bottom sediments of Buzzard's Bay, Massachusetts, contain large amounts of illite (Moore, 1963). Thus, the geographical pattern of vermiculite or illite-rich sediments are well correlated with their sources on the land or in the sea.

The interesting geographical pattern of vermiculite deposited by rivers and illite deposited by tides led us to examine sediments throughout the depths of several marshes where we anticipated a change in the environment as the sea rose. Two marshes, Oliver's Hole (5 miles north of the mouth of the Connecticut River) and Narragansett, Rhode Island (1 mile north of the mouth of the Pettaquamscutt River), contain abundant vermiculite in deep, older sediments, and abundant illite in shallow, younger sediments. Both marshes are 6 to 7 feet deep and formed only in the last 2,000 years. The oldest sediment at the bottom of the marshes was probably deposited from fresh-water rivers that carried sediment from eroding land. As the sea level rose, the marshes were influenced by tides reaching farther inland and the source of sediment shifted from land to sea. The recent sediments at the top of the marsh became progressively enriched with illite. Thus, the distribution of vermiculite and illite within the marsh is consistent with the correlation between clay type and its source.

We must consider, however, an alternative explanation for the unusual distribution of illite and vermiculite in the two marshes at Oliver's Hole and Narragansett. The sediment may have always come from eroding land, and in recent centuries its vermiculite has been altered chemically to illite by the rising salty sea. Conversion of vermiculite to illite, called diagenesis, has been observed in salty marine sediments and in the laboratory (Weaver, 1958). We do not favor this alternative for two reasons. First, if salt water altered the recent sediment at the top of the marsh, it should have altered the bottom sediments also because the bottom sediments are also permeated with salty or brackish water (Table 1). Second, alteration of vermiculite to illite usually produces interstratified illite-vermiculite clay (Sawhney, 1967). We found none of this intermediate clay in the two marshes.

Regardless of the cause of vermiculite-rich and illite-rich sediments in the same marsh, we can use clay mineral analysis to distinguish between saline and fresh-water sediments if botanical means fail. Botanists have distinguished between these two environments for a long time by examining plant remains and pollen (Sears, 1963), but distinguishing is difficult if their remains are decomposed. Under these circumstances, clay mineral analysis reveals if the deposit is rich in vermiculite or illite, and along the shore of Connecticut and Rhode Island, vermiculite suggests a fresh-water origin and illite suggests a saline-water origin.

Table 2. Clay minerals in tidal marsh sediments

Location	Marsh type	Sample Depth	Clay minerals Vr	Il	Kl	Mt
		inches				
Hamden(2) (Quinnipiac Riv.)	Estuarine	6-20	40	50	10	—
		60-108	45	40	15	—*
Deep River (Conn. River)	Estuarine	8-54	35	55	10	—
Norwalk	Shallow	8-24	15	70	15	—**
Great Island (Conn. River)	Deep	56-96	5	85	10	—*
Clinton	Deep	96-336	25	60	15	—
Quonochontaug, R.I.	Very shallow	0-24	25	60	15	—
Galilee, R.I.	Very shallow	12-18	20	70	10	—
Oliver's Hole (Conn. River)	Estuarine	12-50	15	75	10	—
		72-84	35	55	10	—
Narragansett, R.I. (Pettaquamscutt River)	Shallow	12-30	20	65	15	—
		60-70	55	35	10	—
Buzzards Bay, Mass. (Moore, 1963)	Bottom sediments	—	10	80	10	—
Weathered Soil (Sawhney, Frink & Hill, 1962)		0-24	55	35	5	5

*Contains small amounts of clay-size feldspar.
**Contains small amounts of clay-size feldspar and quartz.

TIDAL MARSH CLASSIFICATION

History of tidal marsh classification

Soil surveying in coastal and estuarine marshes of Connecticut has been scant; consequently, little attention has been given to a system of marsh classification. Traditionally, soil survey has been oriented toward agriculture. Because the marshes are inundated by tides twice daily and are salty, they have been of little value for agriculture. Scattered areas mapped in Connecticut were called Tidal Marsh – Undifferentiated. An undifferentiated unit contains two or more taxonomic units which are not in regular geographic association; therefore, differences among tidal marshes were known to exist but their separation was not considered important.

In the soil surveys of Washington and Kent Counties, Rhode Island (Roberts, et al., 1939), and Newport and Bristol Counties, Rhode Island (Shearin, et al., 1942), two mapping units were used in the tidal marshes: (1) Tidal Peat and (2) Peat, salt marsh phase. These units were separated primarily according to the depth of the fibrous organic material. Tidal Peat was described as having a 6-inch, brown, fibrous mat of sedge and grass roots mixed with sand. The fibrous mat was underlain by dark gray sand which gradually changed to gray loose sand at 30 inches deep. It was described as having a firm subsoil, not springy. Peat, salt marsh phase was described as having a brown or dark brown fibrous, slightly decomposed surface layer over deep, darker colored, coarse fibrous, peaty material to 4 feet deep or more. The organic layer varies in color and degree of decomposition but contains coarser fibers than inland fresh-water deposits of peat and muck.

Table 3. Elements of the classification system

Marsh type	Thickness of surface peaty layer*	Texture of underlying mineral layer	Salt
	inches		*ppm*
1. Deep coastal marshes; silty salt grass peat over deep silty sediments. (Westbrook series)	30-50	silt loam	>10,000
2. Shallow coastal marshes; silty salt grass peat over sandy glacial till or outwash. (Pawcatuck series)	24-48	sandy loam or loamy sand or sand	>10,000
3. Very shallow coastal marshes: sandy salt grass peat over sand. (Unnamed series)	12-24	sand	>10,000
4. Deep or shallow estuarine marshes; silty brackish-water sedge peat over deep silty sediments or sandy glacial till or outwash. (Unnamed series)	36-50	silt loam or sandy loam or loamy sand or sand	<10,000

*Peaty layers contain more than 70 per cent undecomposed fibers.

The classification system

Now that we have examined the properties of tidal marshes, we can use them to establish a classification scheme. Three important properties can be identified readily in the field. They are: (1) thickness of the surface organic layer and (2) texture of the underlying mineral layers. The third, salt, can be used to differentiate the salty coastal marshes from the brackish and fresh-water marshes of the estuaries. Although salt content is determined in the laboratory, plants can be used in the field to estimate its concentration. We observed that tall reeds and sedges usually grow where salts are less than 10,000 ppm while salt grasses grow where salt is greater than 10,000 ppm. Hence, indicator plants can be used as a convenient tool to separate the tidal marshes of high and low salinity.

A fourth property, fiber content, is also important in marsh classification because the quantity of fibers in an organic layer reflects the degree of decomposition of the layer. Undecomposed layers contain many fibers; decomposed layers contain few fibers. Since almost all organic layers in the marshes of this region contain large amounts of undecomposed fibers, it is not used here as a differentiating characteristic.

Deep coastal marshes; silty salt grass peat over deep silty sediments. (Westbrook Series)

In this unit, the silty salt grass peat ranges from 30 to 50 inches thick. The amount of organic matter is highest in the surface layers, with a maximum of 60 to 65 per cent, and gradually decreases with depth. The underlying silty sediments have less than 20 per cent organic matter in the upper layers and less than 10 per cent in lower layers. These mineral sediments have about 60 to 75 per cent silt and 15 to 20 per cent clay. Salts range from 10,000 to 30,000 ppm. In some marshes, a thin layer of fresh-water sedge peat lies between the thick silty sediments and the glacial till or outwash below.

The thick silty sediments of this unit correlate well with Bloom and Ellis's (1965) former deep bay or lagoon sediments, deposited more than 3,000 years ago during the rapid rise of the sea.

This unit is extensive along the Connecticut coast west of the Connecticut River. A detailed technical profile description and range of characteristics are given in Appendix A. (See Westbrook series.)

Shallow coastal marshes; silty salt grass peat over sandy glacial till or outwash. (Pawcatuck Series)

In this unit, the silty salt grass peat ranges from 24 to 48 inches thick. The underlying glacial till or outwash lies 24 to 48 inches beneath the surface, but may be as deep as 60 inches in places. A thin silty layer may lie beneath the surface peaty layer but above the sandy till or outwash. Organic matter content is highest in the surface layer, with a maximum of

60 to 65 per cent; in the silty or sandy sediments below, the amount of organic matter is generally less than 10 per cent. The fine sediments trapped in the top 2-to-4-foot thick organic mat contain 50 to 70 per cent silt and 15 to 25 per cent clay. In the till or outwash below, 50 to 70 per cent of the mineral grains are sand.

Salts range from 10,000 to 30,000 ppm and are similar to the salt content in deep deposits.

This unit does not correlate exactly with Bloom and Ellis's (1965) shallow coastal marsh environment. They separated the shallow marshes from the deep marshes at a depth of 9 feet. This depth is important historically because it corresponds to the depth accumulated in the past 3,000 years since the rise in sea level slowed to 0.3 foot per century.

We chose to segregate deep and shallow marshes at 5 feet deep for two practical reasons. First, in mapping this seems to be the most practical depth for surveyors to distinguish between shallow and deep. Second, 5 feet deep is almost the same depth as the standard control section (51 inches) used by soil scientists in classifying all organic deposits. Thus, we can correlate the classification of marshes in Connecticut and Rhode Island with the national soil classification system.

This unit is extensive along the Connecticut coastline east of the Connecticut River and scattered in western Connecticut and Narragansett Bay, Rhode Island. A detailed technical profile description and range of characteristics are given in Appendix A (See Pawcatuck series).

Very shallow coastal marshes; sandy salt grass peat over sand. (Unnamed Series)

In this unit, the sandy salt grass peat is 12 to 24 inches thick. This layer is mixed with 25 to 50 per cent sand and 10 to 25 per cent silt. Organic matter exceeds 50 per cent, but in some places surface layers have less than 10 per cent. Below 12 to 24 inches, sand washed or blown from dunes predominates. It contains little organic matter.

Salts range from 10,000 to 30,000 ppm, as in the other coastal marshes.

This unit is commonly found along the Rhode Island coast from Watch Hill to Point Judith where dunes border the beaches. There are no large marshes of this type in Connecticut but small areas lie behind several small barrier beaches breached by tidal creeks. A detailed technical profile description and range of characteristics are given in Appendix A. (See Unnamed series—Very Shallow Marsh.)

Deep and shallow estuarine marshes; silty, brackish or fresh-water reed and sedge peat over deep silty sediments or sandy glacial till or outwash. (Unnamed Series)

In this unit, the reed and sedge peat ranges from 36 to 50 inches thick. Organic matter varies widely from 75 per cent to less than 20 per cent. Fine mineral sediments, mixed with the peat, contain 60 to 70 per cent silt and 10 to 20 per cent clay.

The mineral sediments below 36 to 50 inches are mostly silt but in some places fine and very fine sand. These grade to coarser sediments below.

Salt is less than 10,000 ppm in marshes that flood with brackish water and less than 100 ppm in marshes, 8 to 10 miles inland, that flood with fresh water.

This unit correlates well with Bloom and Ellis's (1965) estuarine marsh environment where tall reeds and sedges grow at low salt concentrations. The estuarine marshes in Connecticut are found along the Housatonic, Quinnipiac, and Connecticut Rivers. Estuarine marshes in Rhode Island are few and small.

Tall reeds and sedges, used to identify the estuarine marshes with low salt content, also grow in coastal marshes, but less extensively. They are common in the coastal marshes where marsh sediments abut adjacent uplands and also in parts of marshes protected by tide gates. They also grow where the natural grade of the marsh has been raised with deposits from mosquito control ditches, hydraulic landfill, and on fill for roads and railroads. These raised areas, which flood infrequently, are not extensive.

A detailed technical profile description and range of characteristics are given in Appendix A. (See Unnamed series—Estuarine Marsh.)

SUMMARY

1. The coastal and estuarine marshes of Connecticut and Rhode Island were formed as the coastline drowned beneath the rising sea fed by the melting continental glacier. The apparent sea level has risen as much as 33 feet in the last 7,000 to 11,000 years west of the Connecticut River.

2. Plant communities growing on the marshes are controlled by the salinity of water which floods them. Coastal marshes have become inhabited by salt-tolerant grasses and herbs while estuarine marshes have become inhabited by tall reeds and sedges that are less tolerant of salt.

3. Coastal marshes sediments with high salt contents are slightly acid to neutral: estuarine marshes sediments with low salt contents are more acid. Marsh sediment, rich in shells, is alkaline; that which has been drained or dried becomes extremely acid.

4. Salt in coastal marshes permeated with sea water exceeds 15,000 parts per million. Salt in estuaries, where sea water is diluted with fresh water, is less than 10,000 ppm. Ten miles inland, the salt content is less than 100 ppm.

5. Organic matter, produced by generations of plants, ranges from 30 to 60 per cent at the surface and decreases to less than 30 per cent at 2.5 to 4 feet deep. Below 4 feet, organic matter decreases to less than 10 per cent. In the estuaries, organic-rich layers are often buried beneath 1 to 2 feet of silt and clay.

6. Most marshes in Connecticut, west of the Connecticut River, are less than 16 feet deep but several marshes from Guilford to Westbrook are nearly 33 feet deep. The marshes east of the Connecticut River to the Rhode Island border are less than 6 feet deep and those from Watch Hill to Point Judith, Rhode Island, are only 2 to 4 feet deep.

7. Silt and clay predominate in Connecticut's coastal marshes. Silt comprises 60 to 80 per cent of the minerals and clay comprises 15 to 25 per cent. Sand predominates in the coastal marshes from Watch Hill to Point Judith and is often a major component in Connecticut's estuarine marshes and in the underlying glacial till and outwash.

8. Vermiculite and illite, the two major clay minerals, can be used as indicators to identify sediment deposited in fresh or salt water. Vermiculite-rich clay predominates in estuarine marshes and its source is probably eroding land. Illite-rich clay predominates in coastal marshes and its source is the eroded bottom of Long Island and Block Island Sounds.

9. A classification system can be developed from three important properties: thickness of the surface organic layer, texture of the underlying mineral layer, and salinity. If plants can be used to estimate salinity, all three properties can be readily identified in the field.

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APPENDIX A

PROFILE DESCRIPTIONS AND RANGE OF CHARACTERISTICS

Technical profile descriptions are an integral part of soil classification, hence, they are included in this report for the benefit of soil scientists and others interested in technical details of classification. The series descriptions and range of characteristics fully use all the properties studied in the field and laboratory. The descriptions and range of characteristics of the Westbrook, Pawcatuck, and Unnamed series are tentative and subject to change. As we learn more about the tidal marshes, our concepts of the series will change and we will have to redefine the series. The Unnamed series have not been named because there is not enough acreage of these types of marshes in Connecticut and Rhode Island.

Many of the terms in the technical descriptions will be unfamiliar. For those interested in definitions, the report, "Soil Classification–7th Approximation," published by the Soil Survey Staff, U.S.D.A., Soil Conservation Service, 1960, and recent supplements to this document are helpful.

WESTBROOK SERIES

(Tentative series for identification)

The Westbrook series is a member of the loamy, sulfureous (?), euic, mesic family of Terric Medifibrists. These soils are characterized by dark colored, fibric material high in salts underlain by loamy mineral sediments at 20 to 50 inches deep. The underlying mineral sediments contain 65-80 per cent silt and 15 to 18 per cent clay. Organic fibers are mostly herbaceous.

Typifying Pedon: Westbrook peat–salt water tidal marsh (Colors are for moist soil unless otherwise noted).

Oi1 – 0-10" – Very dark gray (10YR 3/1), dark gray (10YR 4/1), dry; about 80 per cent fiber, 65 per cent rubbed; dense mat of roots, stems and leaves; massive; slightly sticky; many large and fine roots; sodium pyrophosphate extract color light gray (10YR 7/1); fibers herbaceous; thin lenses and coatings of silt especially noticeable when dry; 45 per cent organic matter; pH in water, initial 6.5, dried 18 days 5.3; total salts 37,440 ppm; clear wavy boundary.

Oi2 – 10-40" – Very dark gray (10YR 3/1), dark gray (10YR 4/1), dry; about 70 per cent fiber, 50 per cent rubbed; massive; slightly sticky; few large to fine roots in the upper part; sodium pyrophosphate extract color light gray (10YR 7/1); fibers herbaceous; thin lenses and coatings of silt; 44 per cent organic matter; pH in water, initial 5.7, dried 18 days 4.5; total salts 22,100 ppm; gradual wavy boundary.

Oi3 – 40-48" – Dark olive gray (5Y 3/2), dark gray (10YR 4/1), dry; about 60 per cent fibers, 50 per cent rubbed; massive; slightly sticky; no roots; sodium pyrophosphate extract color light gray (10YR 7/1); fibers herbaceous; 24 per cent organic matter; pH in water, initial 6.7, dried 18 days 4.8; total salts 23,400 ppm; clear wavy boundary.

IIC1 – 48-64" – Very dark gray (5Y 3/1), gray (10YR 4/1) dry, silt loam; about 5 per cent fibers, 1 per cent rubbed; massive; slightly sticky; no roots; 12 per cent organic matter; pH in water, initial 6.6, dried 18 days 4.9; total salts 18,200 ppm; diffuse boundary.

IIC2 – 64-192" – Dark gray (N4/), gray (10YR 4/1) dry, silt loam; massive; slightly sticky; no roots; 10 per cent organic matter; few small shell fragments; pH in water, initial 6.5; total salts 20,100 ppm.

Type Location: Town of Westbrook, Middlesex County, Connecticut; north of West Beach, 1,375 feet northeast of the mouth of Patchogue River and 550 feet north of Long Island Sound.

Range in Characteristics: The organic layers range from 20 to 50 inches thick. This corresponds to the depth of the underlying silt loam sediments. Sandy material lies under the silty sediments ranging from 5 to more than 25 feet deep and represents the glacial till or outwash on which the marsh deposits lie. In many places a thin layer of black sedge peat separates the silt loam sediments from the underlying sandy material. Estimated fiber content in the surface tier is 75 to 80 per cent and in the subsurface and bottom tiers from 50 to 75 per cent. After rubbing, the fiber content ranges from 10 to 25 per cent less than in the unrubbed condition. The fibers are herbaceous. Organic matter content (loss on ignition) generally decreases with depth and ranges from 65 to 45 per cent in the surface tiers to 45 to 20 per cent in the subsurface and bottom tiers. In the underlying silt loam, the organic matter content ranges from 20 to 8 per cent. Initial pH values (in water) in the control section and upper mineral layers generally range from medium acid to neutral. After drying for 18 days, pH values range from 0.5 to 2.0 units lower in the Oi horizons and from 0.5 to 3.0 units lower in the IIC horizons. In cuts exposed for longer periods, pH values in water generally drop to less than 3.5. Pale yellow sulphur compounds are common on exposed surfaces after prolonged drying. Total salts in the organic layers and upper mineral layers generally range between 10,000 and 30,000 ppm, although the ppm in the surface layer may exceed the salt content of sea water. Moist colors in the organic layers are mainly of 10YR hue but range to 5Y, with values of 2 through 4 and chromas of 1 or 2. Dry colors are of the same hues with values of 4 through 6 and chromas of 1 or 2. In a few pedons, some fibers are one unit of value and one unit of chroma higher than in the matrix. Pressed moist colors are generally the same as unpressed colors but in some layers pressed color is one unit of value higher than unpressed. Lenses and patches of dominantly gray (10YR 6/1) silt are common in the organic layers, and are especially noticeable after drying. Moist colors in the contrasting mineral layers are in N 2/ through N 4/ or are in 10YR or 5Y hues, with values of 2 through 4 and chromas of 1. Dry colors are in these same 10YR or 5Y hues with values of 4 through 7 and chromas of 1. Texture is silt loam, with silt ranging from about 60 to 80 per cent and clay from 10 to 25 per cent.

Competing Series and their Differentiae: The Westbrook series is the only known series in this family. The Pawcatuck series is also located in tidal marshes, but it is underlain by sandy materials ranging from 24 to 48 inches deep.

Setting: Westbrook soils are on nearly level tidal flats bordering Long Island Sound and Block Island Sound and extending inland for short distances along the banks of the larger rivers. The soils are perpetually wet and flood twice daily. The regolith consists of partially decomposed fibric organic material from salt-tolerant herbaceous plants over mineral sediments high in silt at 20 to 50 inches. The climate is cool temperate. Mean annual temperature is 48°F to 50°F, and rainfall about 45 inches.

Principal Associated Soils: These include the competing Pawcatuck soils on salt water tidal flats underlain by sandy material at 24 to 48 inches, and unnamed estuarine organic soils along the banks of rivers extending inland from Long Island Sound or Block Island Sound. Fresh water carried by the rivers dilutes the sea water and the salt content of the unnamed estuarine organic soils is less than 10,000 ppm. Many mineral soils are on adjoining uplands and terraces along the margins of the tidal flats.

Drainage and Permeability: Very poorly drained. Surface runoff is very slow. Water table at low tide is within 6 to 10 inches of the surface. If diked and drained, permeability would probably be rapid to moderately rapid in the organic layers.

Use and Vegetation: This marsh type is a source of food for fish and shellfish, in addition to providing habitat for wild fowl. Small scattered areas are used for saltgrass hay. The most common grasses are salt meadowgrass *(Spartina patens)*, salt water grass *(Spartina alterniflora)*, and spikegrass *(Distichlis spicata)*. Other vegetation includes blackgrass *(Juncus gerardi)*, sea lavender *(Limonium carolinianum)*, saltwort *(Salicornia europaea)*, seaside goldenrod *(Solidago sempervirens)*, aster *(Aster tenuifolius)*, and purple gerardi *(Gerardia maritima)*. Skirting the edges of the marshes a few inches above normal high tide are switchgrass *(Panicum virgatum)*, marsh elder *(Iva frutescens)*, and groundsel tree *(Baccharis halimifolia)*.

Distribution and Extent: Connecticut, Rhode Island, and probably the states to the north and south. The series is probably of moderate extent.
Series Proposed: Middlesex County, Connecticut, 1969.

Remarks: In mapping, these soils were formerly called Tidal marsh, undifferentiated — a miscellaneous land type. Other related Histosols, although not competing, include the Adrian, Carbondale, Carlisle, Cathro, Chippeny, Dawson, Edwards, Greenwood, Houghton, Lupton, Markey, Palms, Rifle, Tawas, and Willette series. The Adrian, Cathro, Dawson, Markey, Palms, Tawas and Willette have mineral soil material within 51 inches, but they are not developed in salt marshes and the organic material is not fibric. Chippeny soils are underlain by bedrock and Edwards by marl within 51 inches deep. Carbondale, Carlisle, Greenwood, Houghton, Lupton, and Rifle soils developed in sapric or hemic deposits deeper than 51 inches. The values indicated in the typifying pedon for pH, dried 18 days, organic matter content, and total salts are from laboratory data. The drop indicated for pH values after drying, range in organic matter content, and total salts discussed under the Range in Characteristics are based on data from nine pedons.

PAWCATUCK SERIES

(Tentative series for identification)

The Pawcatuck series is a member of the sandy, sulfureous (?), euic, mesic family of Terric Medifibrists. These soils are characterized by dark colored fibric material high in salt underlain by sandy glacial till or outwash material at 24 to 48 inches deep. The sediments mixed with the peat are mostly silt and clay. Organic fibers are mostly herbaceous.

Typifying Pedon: Pawcatuck peat—salt water tidal marsh. (Colors are for moist soil unless otherwise noted.)

Oi1 – 0-12″ – Very dark gray (10YR 3/1), dark grayish brown (10YR 4/2) dry; about 75 per cent fiber, 60 per cent rubbed; dense mat of roots, stems and leaves; massive; slightly sticky; many large to fine roots; sodium pyrophosphate extract color light gray (10YR 7/1); fibers herbaceous; thin lenses and coatings of silt; 57 per cent organic matter; pH in water 6.3; total salts 19,500 ppm; clear wavy boundary.

Oi2 – 12-40″ – Black (10YR 2/1), very dark gray (10YR 3/1) dry; about 65 per cent fiber, 50 per cent rubbed; massive; slightly sticky; few roots in upper part; sodium pyrophosphate extract color light gray (10YR 7/1 or 7/2); fibers herbaceous; 54 per cent organic matter; pH in water 6.4; total salts 22,900 ppm; gradual wavy boundary.

Oi3 – 40-46″ – Black (10YR 2/1), same color dry; about 60 per cent fiber, 50 per cent rubbed; massive; slightly sticky; no roots; sodium pyrophosphate extract color light gray (10YR 7/1); fibers herbaceous; 27 per cent organic matter; pH in water 6.3; total salts 18,850 ppm; clear wavy boundary.

IIC1 – 46-50″ – Gray (N 5/), gray (10YR 5/1) dry, very fine sandy loam; about 5 per cent fiber; massive; slightly sticky; no roots; 10 per cent organic matter; pH in water 6.4; total salts about 20,000 ppm; clear wavy boundary.

IIC2 – 50-60″ – Black (10YR 2/1), dark gray (10YR 4/1) dry, loamy sand; massive; single grain; no roots; 10 per cent coarse fragments; pH in water 6.3; total salts about 20,000 ppm.

Type Location: Town of Stonington, New London County, Connecticut; Barn Island area, about one-half mile northeast of elevation benchmark on Barn Island and about three-fourths of a mile due north of elevation benchmark on Pawcatuck Point.

Range in Characteristics: Organic layers range from 24 to 48 inches thick, corresponding closely to the depth of the underlying sandy material. A thin silty layer is occasionally present just above the sandy material. Mineral sediments mixed with peat are mostly silt (50-70 per cent) and clay (15-25 per cent). Most pedons have a thin layer of black sedge peat just above the sandy materials and below the salt grass peat. Estimated fiber content in the surface tier is 75 to 80 per cent and in the subsurface and bottom tiers, from 50 to 70 per cent. After rubbing, the fiber content ranges from 10 to 25 per cent less than in the unrubbed condition. The fibers are herbaceous. Organic matter content (loss on ignition) generally decreases with depth and ranges from about 65 to 45 per cent in the surface tier to 45 to 20 per cent in the subsurface and bottom tiers. In the underlying mineral soil, the organic matter content ranges from 20 to 5 per cent. Initial pH (in water) in the control section generally ranges from medium acid to neutral. After drying for 18 days, pH values range from 0.5 to 2.0 units lower in the Oi horizon and from 0.5 to 3.0 units lower in the IIC horizons. In cuts exposed for long periods, pH values in water generally drop to less than 3.5. Total salts in the organic layers and upper mineral layer generally range between 10,000 and 30,000 ppm, although the ppm in the surface layer may exceed the salt content of sea water. Moist colors in the organic layers are mainly of 10YR hue with values of 2 through 4 and chromas of 1 or 2. Dry colors are of the same hues with values of 4 through 6 and chromas of 1 or 2. In a few pedons, some fibers are one unit of value and one unit of chroma higher than in the matrix. Pressed moist colors are generally the same as unpressed colors, but in some layers pressed colors are one unit of value higher than unpressed. Lenses and patches of dominantly gray (10YR 6/1) silt are common in some organic layers, and are especially noticeable after drying. Moist colors in the contrasting mineral layers are in N 2/ through N 5/ or are in 10YR or 5Y hues with values of 2 through 4, and chromas of 1. Dry colors are in these same 10YR or 5Y hues with values of 4 through 7 and chromas of 1. Texture of the underlying sandy material is dominantly sand or loamy sand.

Competing Series and their Differentiae: The Pawcatuck series is the only known series in this family. The Westbrook series is also in tidal marshes, but it is underlain by silt loam sediments ranging from 20 to 50 inches below the surface.

Setting: Pawcatuck soils are on nearly level tidal flats bordering Long Island Sound, Block Island Sound, and extending inland for short distances along the banks of larger rivers. The soils are perpetually wet and flood twice daily. The regolith consists of partially decomposed fibric organic material from salt tolerant herbaceous plants over sandy materials at 24 to 48 inches. The climate is cool temperate. Mean annual temperature is 48°F to 50°F, and rainfall about 45 inches.

Principal Associated Soils: These include the competing Westbrook soils on salt water tidal flats underlain by silty sediments at 20 to 50 inches, and unnamed estuarine organic soils along the banks of rivers extending from Long Island Sound or Block Island Sound. Fresh water carried by the rivers dilutes the sea water and the salt content of the unnamed estuarine organic soils is less than 10,000 ppm. Many mineral soils are on adjoining uplands and terraces along the margins of the tidal flats.

Drainage and Permeability: Very poorly drained. Surface runoff is very slow. Water table at low tide is within 6 to 10 inches of the surface. If diked and drained, permeability would probably be rapid to moderately rapid in the organic layers.

Use and Vegetation: This marsh type is a source of food for fish and shellfish in addition to providing habitat for wild fowl. Small scattered areas are used for salt grass hay. The most common grasses are salt meadowgrass *(Spartina patens)*, salt water grass *(Spartina alterniflora)*, and spikegrass *(Distichlis spicata)*. Other vegetation includes blackgrass *(Juncus gerardi)*, sea lavender *(Limonium carolinianum)*, saltwort *(Salicornia europaea)*, seaside goldenrod *(Solidago sempervirens)*, aster *(Aster tenuifolius)*, and purple gerardi *(Gerardia maritima)*. Skirting the marshes a few inches above normal high tide are switchgrass *(Panicum virgatum)*, marsh elder *(Iva frutescens)*, and groundsel tree *(Baccharis halimifolia)*.

Distribution and Extent: Connecticut, Rhode Island, and probably the states to the north and south. The series is probably of moderate extent.

Series proposed: New London County, Connecticut, 1969.

Remarks: In mapping, these soils were formerly called Tidal marsh, undifferentiated—a miscellaneous land type. Other related Histosols, although not competing, include the Adrian, Carbondale, Carlisle, Cathro, Chippeny, Dawson, Edwards, Greenwood, Houghton, Lupton, Markey, Palms, Rifle, Tawas, and Willette. The Adrian, Cathro, Dawson, Markey, Palms, Tawas, and Willette have mineral soil material within 51 inches, but they are not developed in salt marshes and the organic material is not fibric. Chippeny soils are underlain by bedrock, and Edwards by marl within 51 inches deep. Carbondale, Carlisle, Greenwood, Houghton, Lupton, and Rifle soils developed in sapric or hemic deposits deeper than 51 inches. The values indicated in the typifying pedon for organic matter content and total salts (except horizons IIC1 and IIC2) are from laboratory data. The drop indicated for pH values after drying, range in organic matter content, and total salt discussed under the Range in Characteristics are based on data from five pedons.

Unnamed Series — Very Shallow Marsh

Typifying Pedon (Colors are for moist soil unless otherwise noted.)

Oi — 0-12" — Very dark gray (10YR 3/1), organic material dark gray (10YR 4/1) gray (10YR 6/1) dry; peat mixed with fine and medium sand; about 80 per cent fiber, 60 per cent rubbed; fairly dense mat of roots, stems, and leaves; massive; abundant roots; sodium pyrophosphate extract color light gray (10YR 7/1); fibers herbaceous; pH in water 6.2; total salts estimated 25,000 ppm; gradual wavy boundary (10 to 18 inches thick).

IIC1 — 12-18" — Gray (10YR 5/1), gray (5Y 6/1) dry, medium and coarse sand mixed with very dark grayish brown (10YR 3/2), gray (10YR 4/1) dry, pockets and lenses of fibrous organic material. About 75 per cent fibers in organic material; massive or single grain; very friable; plentiful roots; fibers herbaceous; pH in water 6.6; total salts estimated 20,000 ppm; clear wavy boundary.

IIC2 — 18-40" — Gray (2.5Y 5/1), gray (5Y 6/1) dry, medium and coarse sand; single grain; loose; no roots observed; pH in water 7.0.

Type Location: Town of Narragansett, Washington County, Rhode Island. 0.6 miles due east at the curve in the road at the Village of Galilee.

Range in Characteristics: The organic material mixed with sand or sand mixed with organic material ranges from about 12 to 24 inches thick. The proportion of fibrous organic material and sand in the upper 12 to 14 inches is variable ranging from 75 per cent organic material and 25 per cent mineral, which is mostly sand, to 50 per cent organic and 50 per cent sand. The lower part of the 24-inch section ranges from 75 per cent sand and 25 per cent organic material to 50 per cent sand and 50 per cent organic material. The underlying sands are dominated by medium and fine grains with some coarse sand. Estimated fiber content in the organic material ranges from 70 to 80 per cent and after rubbing 10 to 25 per cent less than in the unrubbed condition. The fibers are herbaceous. Reaction (pH in H_2O) generally ranges from medium acid to neutral. Total salt content ranges from about 10,000 to 30,000 ppm. Colors in the organic material in the upper 24 inches are in 10YR hue, value of 2 and 3 and chroma of 1 and 2. Dry colors are generally dark gray to gray (10YR 4/1 or 5/1). Color in the sand in the upper 24 inches and below ranges from very dark gray (10YR 3/1) to dark gray or gray (2.5Y, N5/ or N6/) moist and dark gray (10YR 4/1) to light gray (2.5Y, N7/) dry.

Unnamed Series — Estuarine Marsh

Typifying Pedon: (Colors are for moist soil unless otherwise noted.)

Oi1 — 0-6" — Very dark grayish brown (10YR 3/1), dark gray (10YR 4/1) dry; about 75 per cent fiber, 60 per cent rubbed; slightly sticky; abundant large roots; sodium pyrophosphate extract color (10YR 7/1); fibers herbaceous; 73.4 per cent organic matter; pH (in H_2O), initial 6.1, dried 18 days 4.7; total salts 3,120 ppm; clear wavy boundary (6-12 inches thick).

Oi2 — 6-20" — Dark brown (10YR 3/3), dark grayish brown (10YR 4/2) dry; about 70 per cent fiber, 60 per cent rubbed; massive; slightly sticky; plentiful medium to fine roots; sodium pyrophosphate extract color (10YR 7/1); fibers herbaceous; thin lenses and coatings of silt; 37 per cent organic matter; pH (in H_2O), initial 6.0, dried 18 days 4.5; total salts 2,535 ppm; gradual wavy boundary.

Oi3 — 20-36" — Black (10YR 2/1), very dark gray (10YR 3/1) dry; about 70 per cent fiber, 55 per cent rubbed; massive; slightly sticky; few large roots in upper part; sodium pyrophosphate extract color light gray (10YR 7/1-7/2); fibers herbaceous; 71 per cent organic matter; pH (in H_2O) initial 6.1, dried 18 days 4.5; total salts 1,900 ppm; gradual wavy boundary.

Oi4 — 36-60" — Essentially the same as Oi3 except that the organic matter is 58.4 per cent or slightly lower.

IIC1 — 60-108" — Dark gray (2.5Y 4/0) gray (2.5Y 6/0) dry, silt loam with 10 to 15 per cent fibers; massive; slightly sticky; no roots; 13.8 per cent organic matter; pH (in H_2O), initial 6.5; total salts 3,185 ppm.

IIC2 — 108-144" — Silt loam interbedded with coarse and medium sand.

Type Location: Town of Hamden, New Haven County, Connecticut. 4.0 miles north of mouth of Quinnipiac River.

Range in Characteristics: The fresh water tidal marshes are not as uniform as the salt grass tidal marshes. The organic layer of sedge peat with more than 20 per cent organic matter generally ranges from about 36 to 50 inches thick. One pedon at Chester, Connecticut, however, which is about 10 miles up the Connecticut River from Long Island Sound has about 2 feet of silt loam and fibrous peat mixed with woody material below 36 inches. The marsh sediments here extend more than 16 feet deep. Estimated fiber content in the surface tier ranges from 70 to 80 and in the subsurface and bottom tiers from 50 to 75 per cent. After rubbing, the fiber content ranges from 10 to 20 per cent less than in the unrubbed condition. Initial pH values (in H_2O) range from very strongly acid to slightly acid. After drying pH values drop depending on how long it has been exposed to the air. Total salts range from about 3,000 to 25 ppm. Moist colors in the organic layer are mainly in the 10YR hue but range to 2.5Y, with values of 2 to 4 and chroma of 0 to 3. Dry colors are in the same hues with values of 4 to 6 and chroma of 0 to 3. Pressed moist colors are generally the same as unpressed colors.

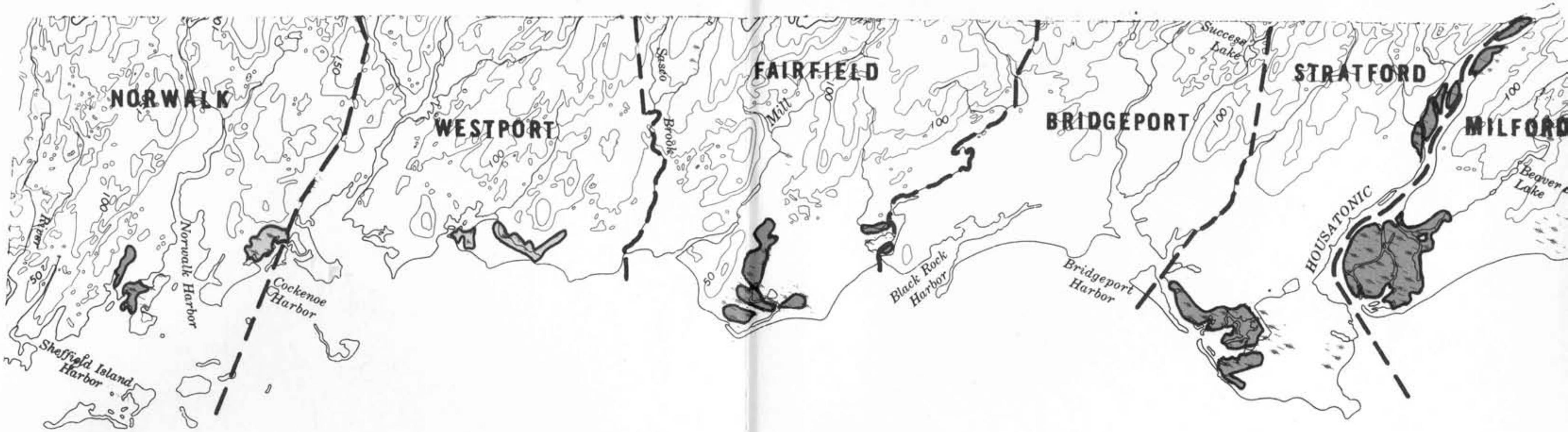
APPENDIX B – THE MAPS

All coastal and estuarine marshes in Connecticut and Rhode Island larger than 15 acres were delineated on the maps. The boundaries that appear on the maps are estimated from 1965 aerial photographs supplemented by field reconnaissance in 1968 and 1969. The base map used for Connecticut is an intermediate print of the State of Connecticut Map published by the U.S. Geological Survey. The scale of the map is 1:125,000. The base maps used for Rhode Island are U.S. Geological Survey Quadrangle Maps—7½ Minute Series. The scale of these maps is 1:31,680.

Each marsh was classified according to the criteria of Table 3. Classification decisions were based on dominant characteristics determined by 3 to 6 borings in each marsh. Reconnaissance revealed several marsh types in most marshes. For example, in deep marshes, the perimeters are often shallow to very shallow and may contain tall reeds and sedges, indicating low salt content. Perimeter variations could not be shown at this map scale.

Several estuarine marshes along the Connecticut River between Haddam Neck and Hartford are not shown on the Connecticut map. These are fresh-water marshes influenced by coastal tides.

Borings were made with a standard ¾-inch bore peat sampler with 4-foot extension rods. Location of each boring was recorded on U.S. Geological Survey Quadrangle Maps. These, together with the boring records, are on file at the Department of Soils, Climatology, and Forestry, The Connecticut Agricultural Experiment Station, New Haven.



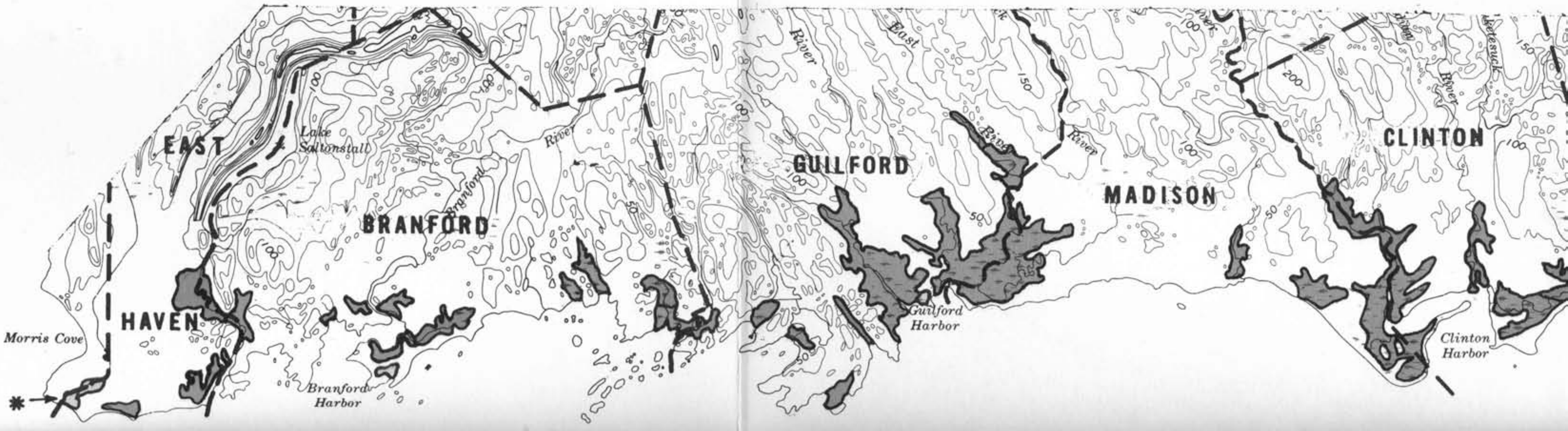
TIDAL MARSHES — CONNECTICUT

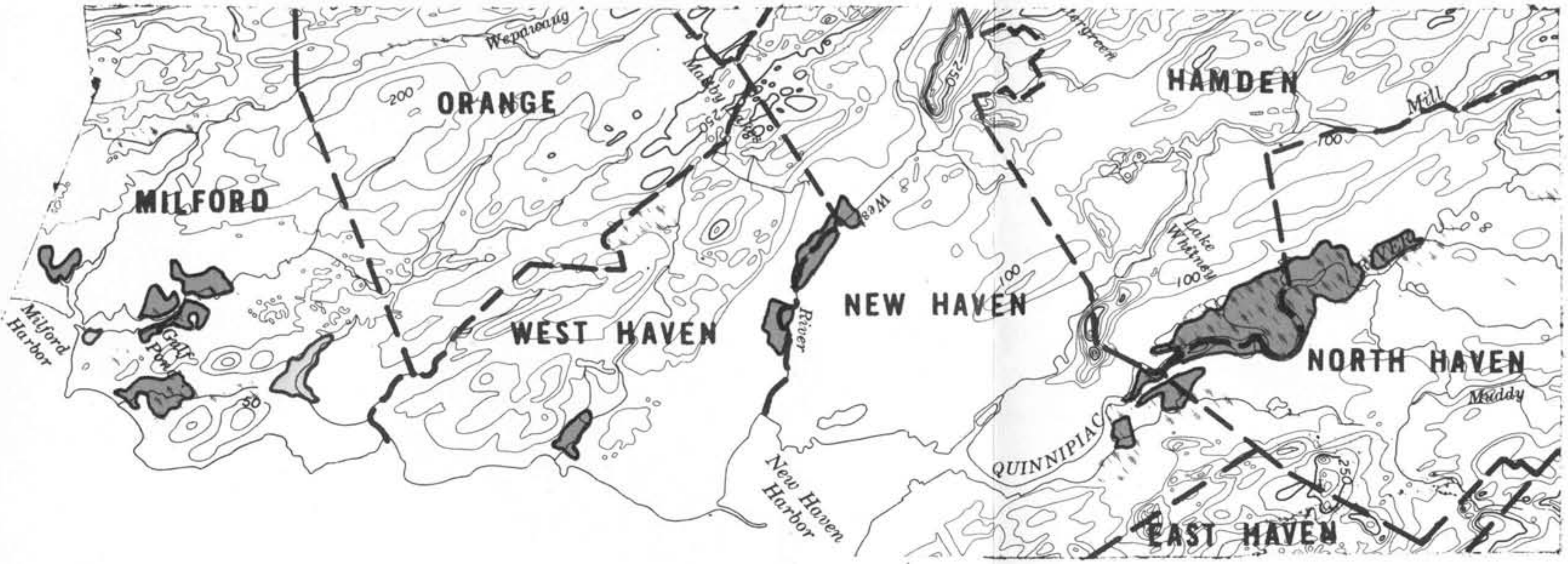
DEEP COASTAL >5 FEET

SHALLOW COASTAL 2–5 FEET

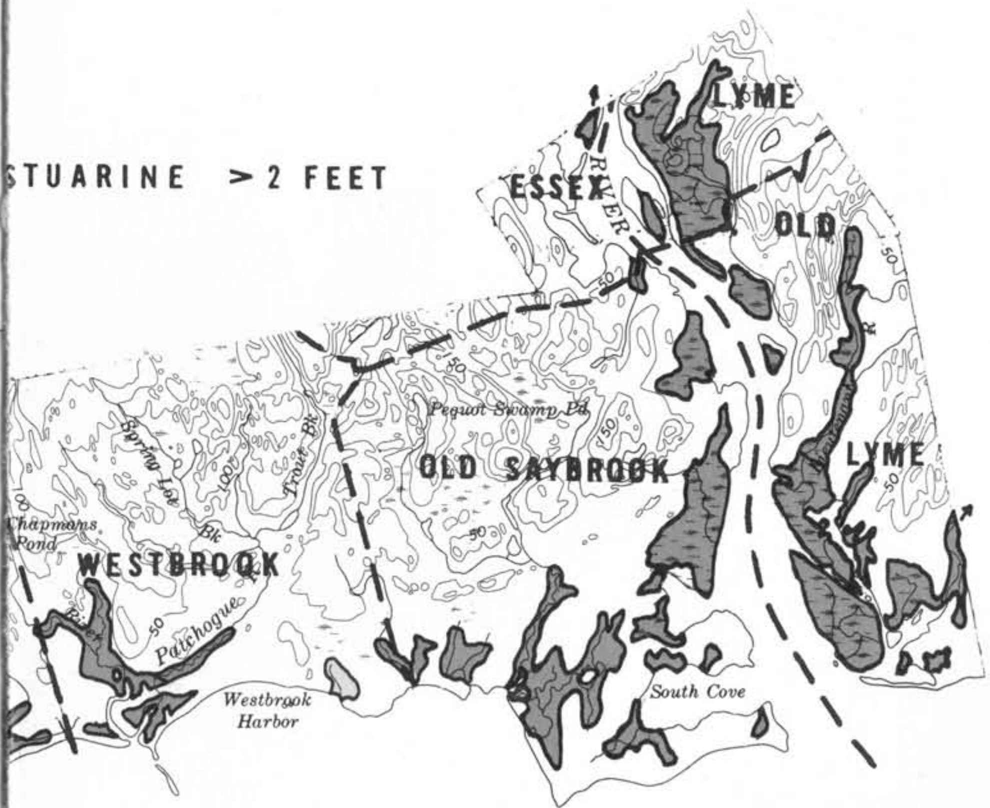
E

* VERY SHALLOW COASTAL <2 FEET

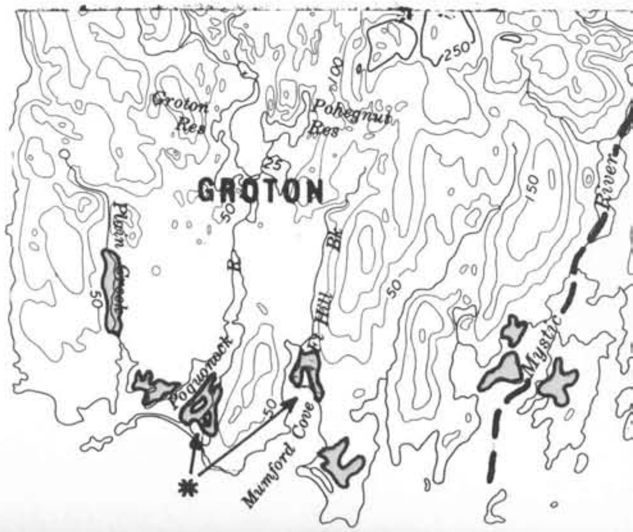


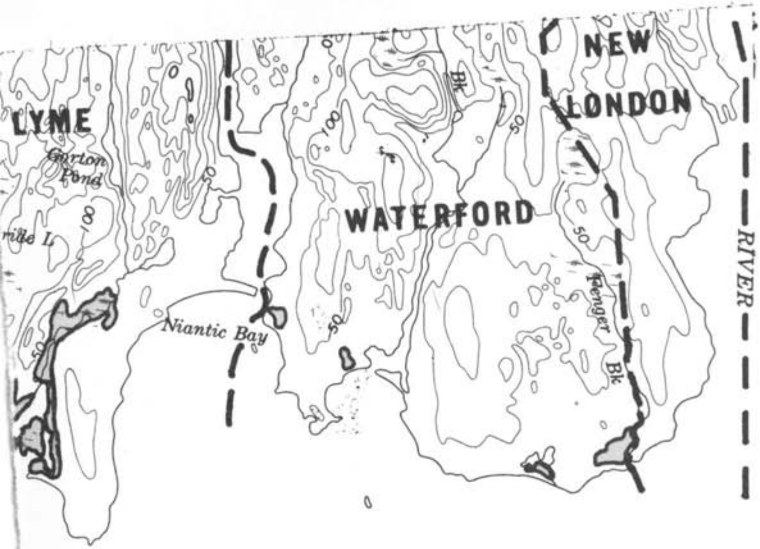


STUARINE >2 FEET

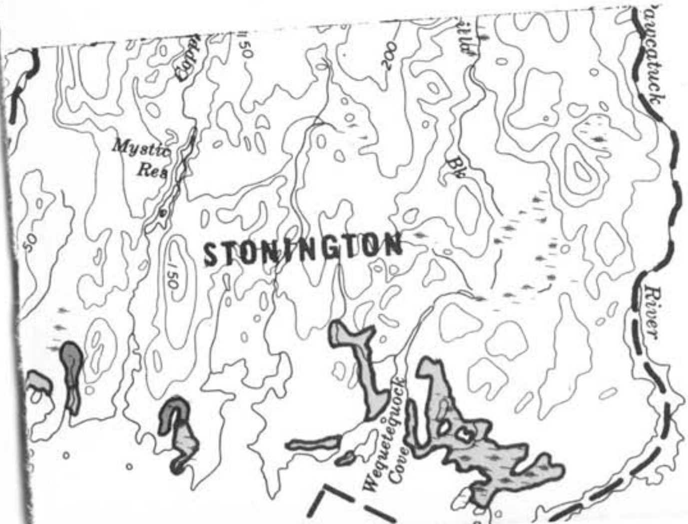


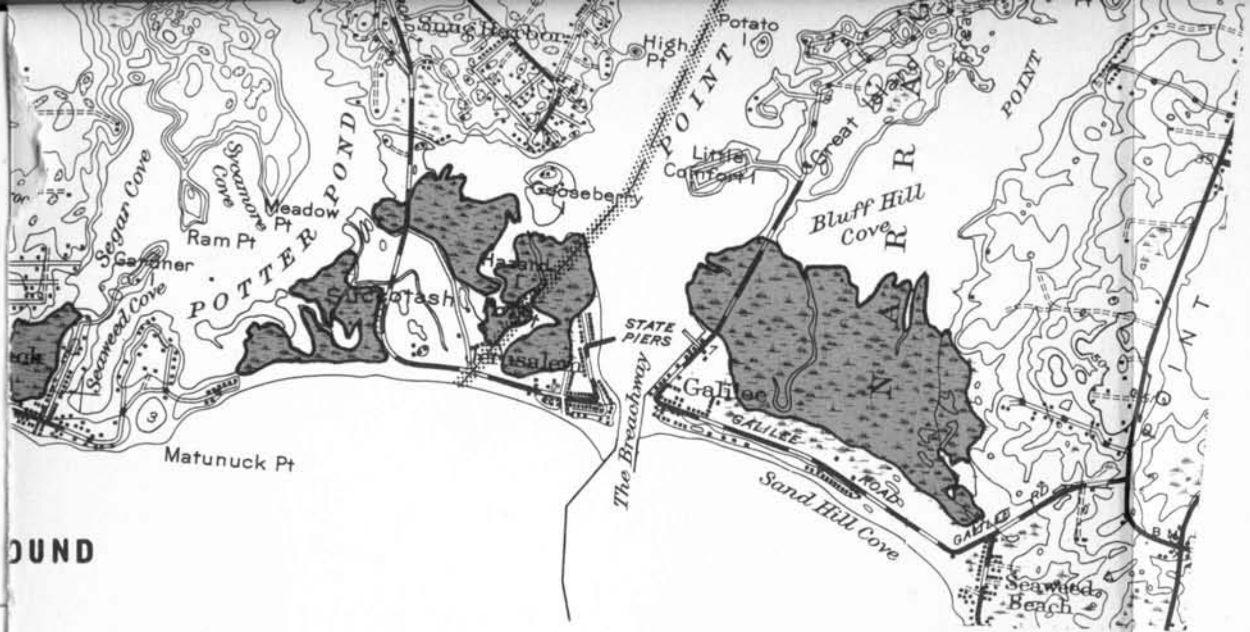
SCALE 1:1




LYME
Gorton Pond
100
NEW
LONDON
WATERFORD
Bk
50
Niantic Bay
Fenger Bk
RIVER

25,000

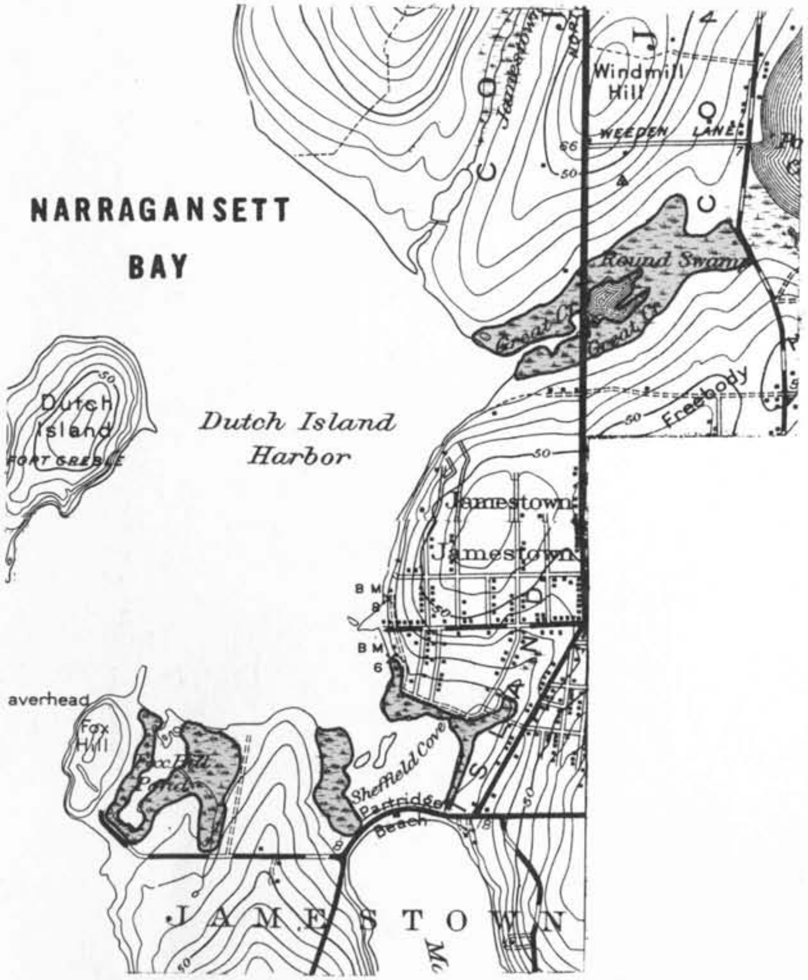

50
200
Mystic Res
Bk
STONINGTON
150
River
Wequetequock Cove



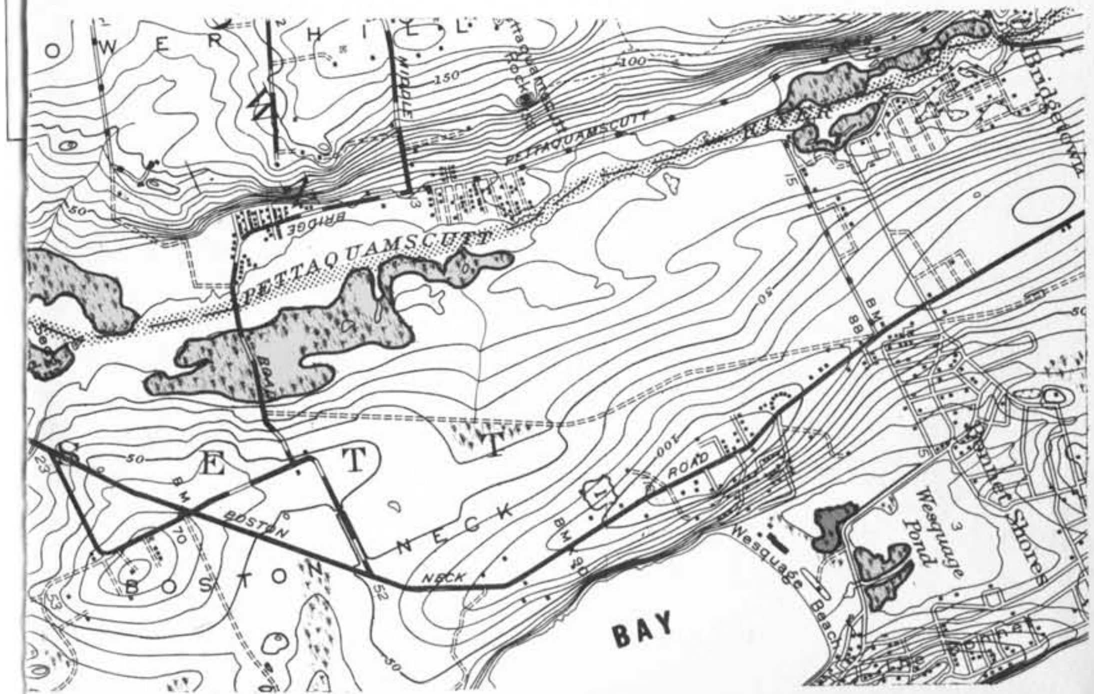
OUND

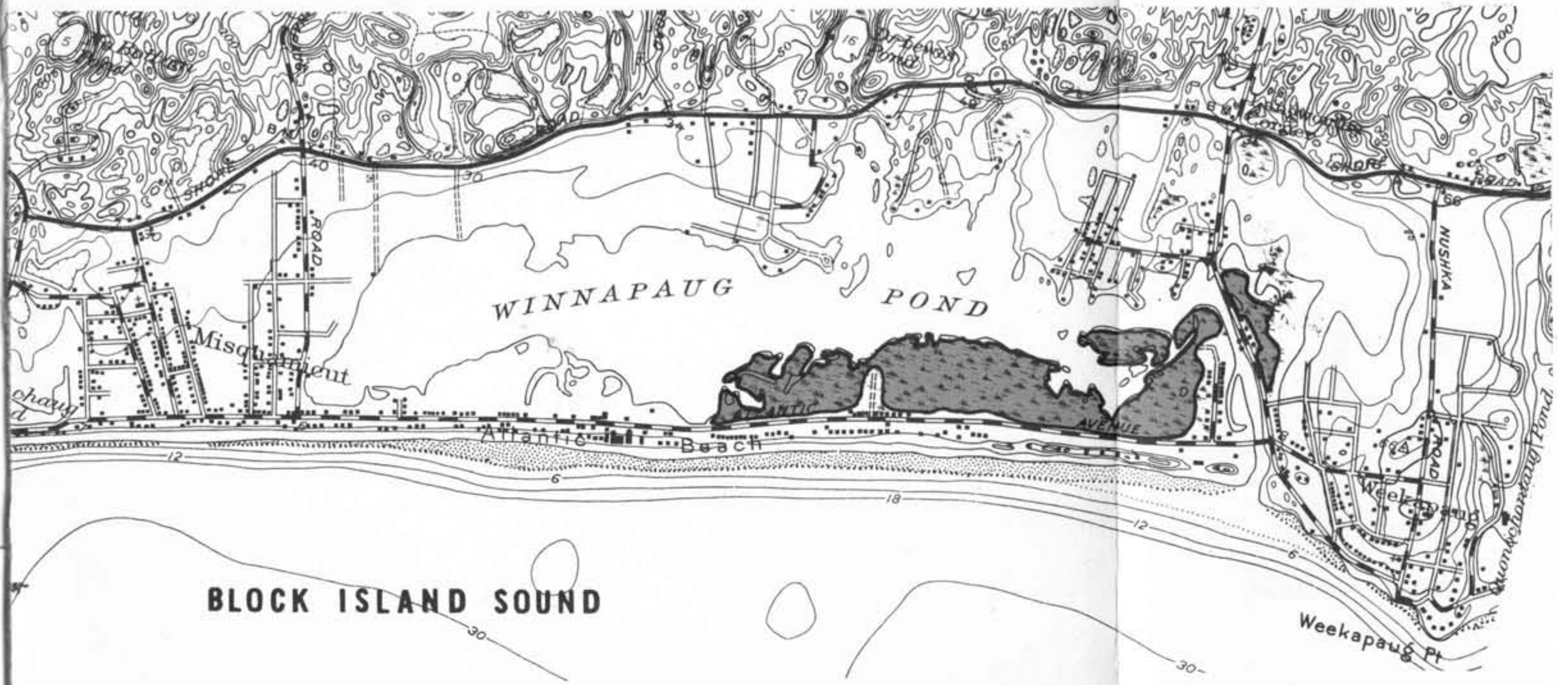
NARRAGANSETT

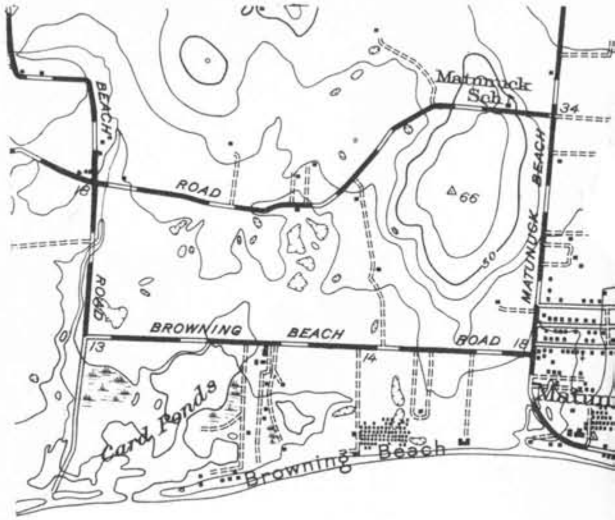
BAY



2 FEET







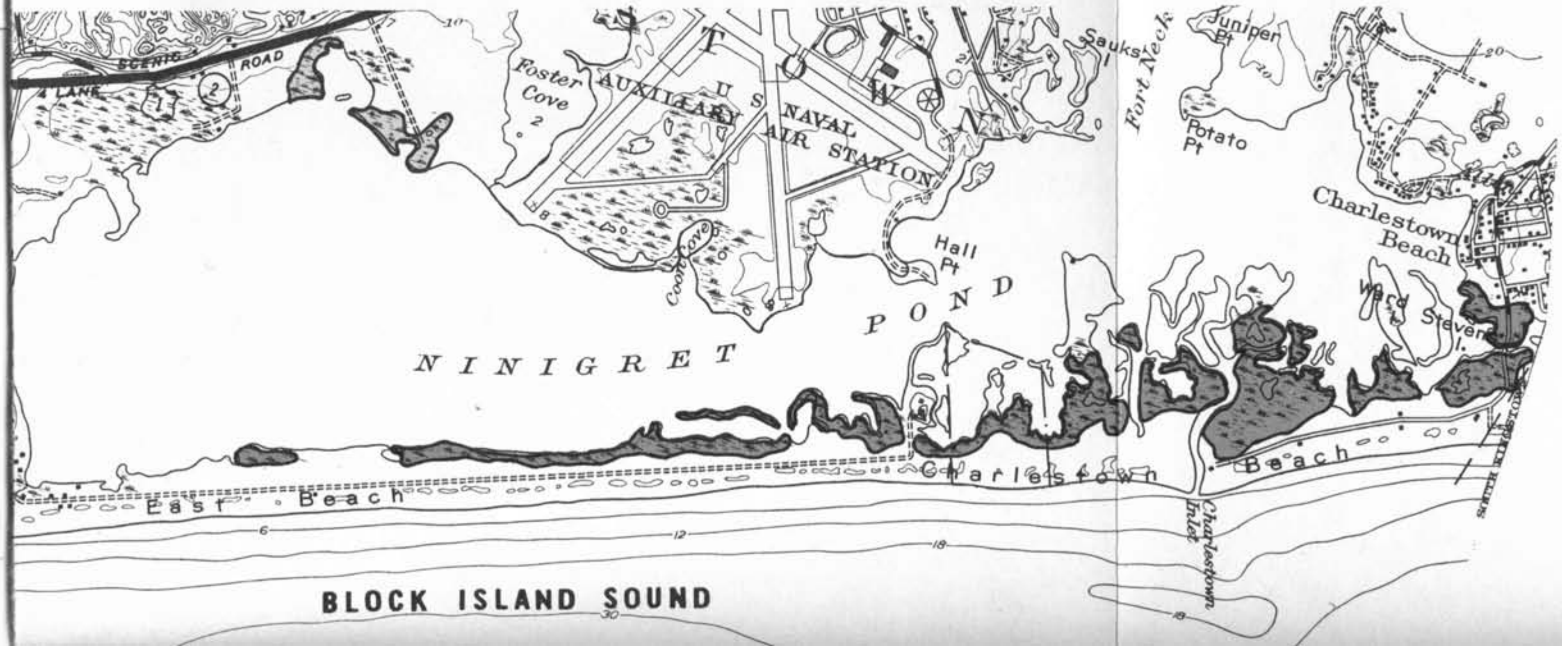
BLOCK ISLAND SOUND

TIDAL MARSHES — RHODE ISLAND

SHALLOW COASTAL 2—5 FEET

VERY SHALLOW COASTAL <2 FEET

ESTUARINE >




Hall I
Avondale
Graves Neck
CONNECTICUT
RHODE ISLAND
Colonel Willie Cove
Horace I
Rhodes Pt
Potter Cove
WATCH HILL ROAD
MISQUAMICUT CLUB GOLF COURSE
HIGHWAY
OCEAN VIEW
Maschaug Pond
Watch Hill


LANE
OCEAN
POST ROAD
Quonochontaug Neck
QUONOCHONTAUG ROAD
EAST BEACH ROAD
POND
Bills I
Quonochontaug
Beach