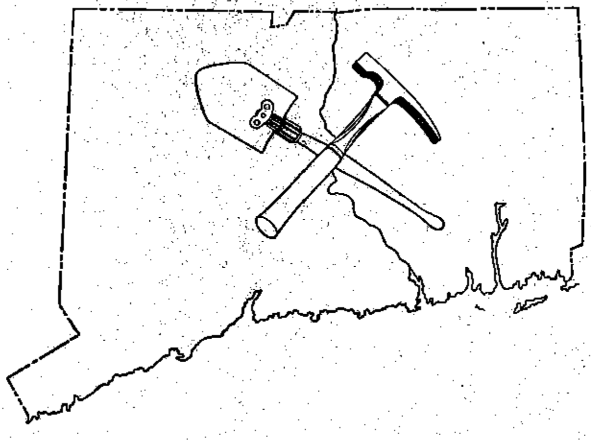
Postglacial Stratigraphy and Morphology of Coastal Connecticut

ARTHUR L. BLOOM
and
CHARLES W. ELLIS, JR.



STATE GEOLOGICAL AND NATURAL HISTORY SURVEY
OF CONNECTICUT

A DIVISION OF THE DEPARTMENT OF AGRICULTURE
AND NATURAL RESOURCES

1965

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ARTHUR L. BLOOM
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Sinclair Research, Inc.

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TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

Postglacial Stratigraphy and Morphology of Central Connecticut

by

Arthur L. Bloom and Charles W. Ellis, Jr.

This report originally appeared as the Guidebook for Field Trip No. 5 of the 1963 (New York City) Annual Meeting of the Geological Society of America (and Associated Societies). It was printed and distributed by the Department of Geology, Cornell University, Ithaca, New York. It is reproduced by the Connecticut Geological and Natural History Survey with the permission of the authors and of Cornell University.

PALUDAL STRATIGRAPHY AND MORPHOLOGY

Introduction

There were before human intervention an estimated 43 sq. mi. of tidal marsh along the 98-mi. straight-line length of the Connecticut coast. In the last decades B.P. (before physics) some work had been done on the paludal stratigraphy and morphology, but no regional study had been attempted. Brown (1930) described a section in a now-flooded clay pit near North Haven and discussed its significance. Knight (1934) described a small marsh in Branford that "revealed a section preserving the hitherto unrecorded early stages of a New England salt marsh developed in accordance with Shaler's classic theory, coupled with later stages developed in accordance with the theory first proposed by Mudge and later reproposed and elaborated by Davis."

In 1960, encouraged by preliminary work and the reports of Brown and Knight, a systematic study of the Connecticut coastal marshes was begun by Bloom. The initial goal was to collect sufficient samples for radiocarbon dating so that the age and rate of postglacial submergence could be determined. Field work was supported in part during 1960 by the Connecticut Geological and Natural History Survey, and since 1960 by the Office of Naval Research, Project NR 388-065. Since the initial goal was achieved (Bloom and Stuiver, 1963) the project has been modified to include research on sedimentation rates and shoreline erosion of the coastal marshes.

Consideration of the relationship between sedimentation and submergence pervades the interpretation of the Connecticut coastal marsh environment. Three significant paludal environments can be distinguished, wherein the interaction of the two variables has produced three distinct stratigraphic records.

(a) *The estuarine "fresh-water" marsh.* Where a sufficiently large river enters an estuarine marsh, the fall and rise of the tide causes alternate accelerated stream flow and slack water. The salinity is low, but the nutrient content of the water is apparently high. A dense growth of *Typha* (cattail), *Phragmites* (reed), and *Scirpus* (bulrush), commonly more than 6 ft tall, characterizes this environment. Harshberger (in Nichols, 1920, p. 540) likened these marshes to the British "fens." Production and accumulation of organic debris has kept pace with submergence, and a thick layer of sedge peat has been built up to the local high-tide level in the marsh.

(b) *The former deep (9-50 ft) bay or lagoon.* During rapid submergence, until about 3,000 years ago, the sea transgressed into coastal valleys and produced bays or lagoons. In an environment of generally low wave energy and low sediment supply, early submergence exceeded the rate of sedimentation, and open water of near-normal salinity persisted in the embayments. However, during the last 3,000 years submergence has been slow enough to be equaled by the sedimentation rate, and salt marshes have filled former bays and lagoons. A typical stratigraphic section of these salt marshes is composed of a veneer of muddy salt-marsh peat, 9 ft or less in thickness, overlying a thick wedge of mud that has an open-bay fauna. Below the mud in many marshes there is a thin layer of sedge peat in sharp contact with the substratum. This peat represents the fringe of "fresh-water" rushes and reeds that grew at the transgressing shoreline.

(c) *The shallow (less than 9 ft) coastal marsh.* A coastal embayment less than 9 ft deep below present high-tide level was not affected by submergence prior to 3,000 years ago. Many of the shallow marshes are on submerged coastal lowlands, especially outwash plains, which continue their gentle seaward slope up to a mile beyond the high-water line. Many of these low-relief areas were marshy even before submergence raised the water table. The vegetation on these marshes is zoned landward from salt marsh through belts of progressively lower salinity tolerance to either normal upland vegetation or fresh-water marsh. The stratigraphy of a shallow marsh is similar to that of the upper 9 ft of a salt marsh in a former deep bay, except that lenses and tongues of sedge peat complexly alternate with salt-marsh peat. The alternations reflect shifts of vegetation belts across the marsh as seasons of abnormal high tides or excessive fresh-water runoff displaced the zone of salt marsh respectively landward or seaward. Deeper parts of the marsh apparently represent former topographic basins that filled with sedge peat as a result of the rising ground-water table prior to marine inundation. A normal upland soil profile on glacial drift commonly underlies a shallow coastal marsh.

Three marshes (fig. 1) have been chosen to represent the three paludal environments outlined.

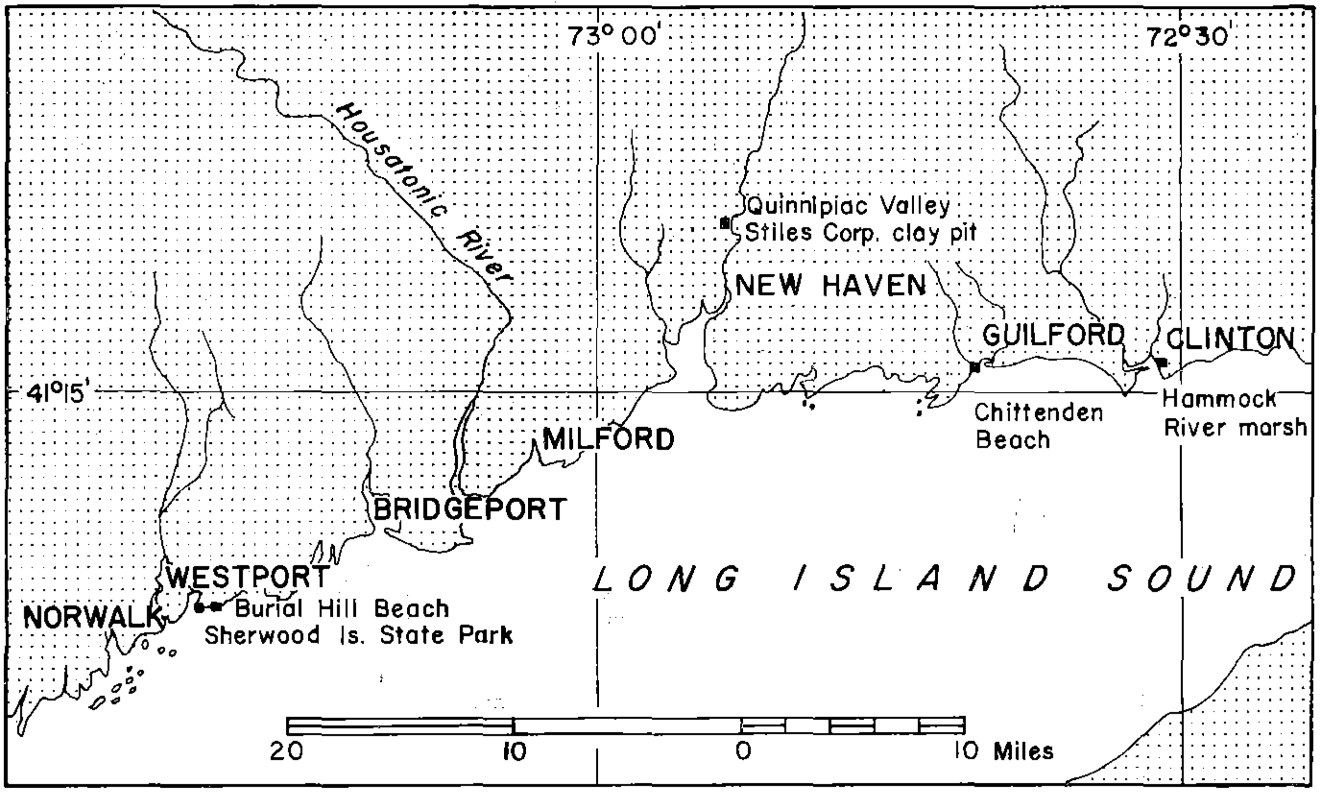

Fig. 1. Index map of the central Connecticut coast

Quinnipiac Valley, Hamden — an estuarine "fresh-water" marsh

Excellent exposures of late-glacial and postglacial deposits have been available for many years in the brickyard clay pits of the Quinnipiac Valley, near New Haven. The section described by Brown (1930, p. 263-266) was obtained from a now-flooded pit north of the Stiles Corporation brickyard. However, a similar section (fig. 2) is currently exposed in the pit south of the brickyard.

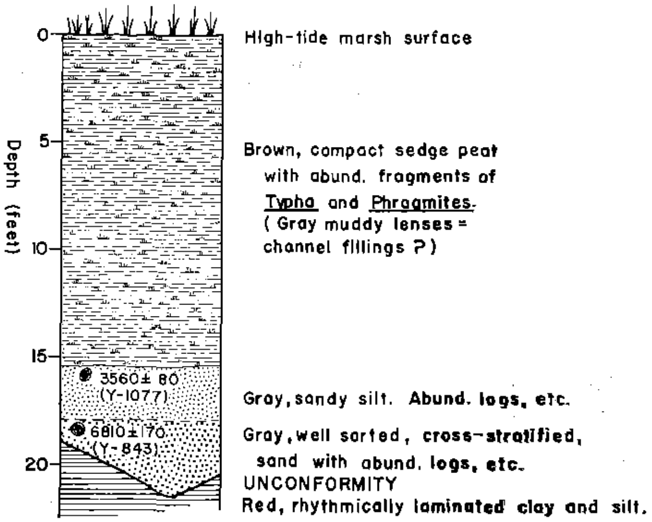

Fig. 2. Generalized stratigraphy of the Stiles Corporation clay pit, Hamden, Connecticut

The postglacial stratigraphy of the Quinnipiac Valley begins at the erosional unconformity between underlying glacial deposits and overlying alluvium. An episode of stream erosion to a lower-than-present base level followed deposition of the late-glacial lacustrine New Haven Clay. Erosion was followed or accompanied by fluviatile deposition of cross-stratified sand and gravel. In other parts of the Quinnipiac Valley yellowish-gray outwash unconformably overlies the channeled upper surface of the New Haven Clay (Porter, 1960, p. 18). The alluvium in the Stiles clay pit is not outwash, as is evidenced by (1) the arkosic composition of the alluvium, (2) the dominantly hardwood composition of the enclosed logs and leaf mats, and (3) a radiocarbon age of 6810 ± 170 years B.P. for a log from the alluvium (Y-843). Postglacial erosion in the southern end of the Quinnipiac Valley apparently not only removed the outwash that formed the final glacial deposit of the valley, but cut into the underlying reddish, arkose-derived ice-contact stratified drift and lacustrine clay and silt. This unconformity represents a hiatus of approximately 6,000-7,000 years prior to 6800 B.P.

The basal alluvium of the postglacial section exposed in the Stiles Corporation clay pit grades upward into gray sandy silt of questionable origin. The silt represents the loss of former stream transporting power. It is a slack-water deposit but whether it is a fresh-, brackish-, or salt-water deposit has not been determined. Foraminifera or sponge spicules are not present. The silt contains abundant logs, twigs, nuts, and leaf trash of species similar to those preserved in the underlying alluvium. A log from the top of the silt was radiocarbon dated at 3560 ± 80 years B.P. (Y-1077).

Brown sedge peat, 12 to 17 ft thick and similar to that which is presently accumulating on the marsh surface, immediately overlies the silt. The nature of the contact indicates an abrupt change in the depositional environment from the time of silt accumulation to the time of peat accumulation, although no erosional unconformity is apparent. Old reports (Davis, 1913, p. 700; Brown, 1930, p. 265) described a "forest soil" and tree stumps rooted in place beneath the peat of the Quinnipiac Valley, but no recent observers have verified these reports. At the Stiles Corporation clay pit, the transition from silt deposition to peat accumulation represents only a change in depositional environment without an interval of weathering and soil formation. This change took place shortly after 3560 B.P. Since then, the Quinnipiac Valley has had its present appearance, with a cattail, sedge, and reed marsh growing to high-tide level in an estuarine environment of low salinity. Salt-marsh grasses do not now enter the valley in significant quantity north of the railroad yards, 2 mi. south of the clay pit.

Depth measurements on the pit face are subject to error because of compaction of the clay-pit wall by an overlying earth dike. Figure 3 shows a section through the south face of the Stiles Corporation clay pit on June 16, 1962, shortly after the earth dike had been moved back for a new cut in the pit. A shallow sag pond parallel to the outer edge of the dike and tension cracks on the inner slope indicated that compaction was in progress. The peat at boring 1 had been compressed from an original thickness of 15.7 ft to 13 ft, or to about 83 percent of its original thickness. That much compaction was accomplished by earth fill about 12 ft deep on the boring site for an estimated 2 months. At the pit face, where the dike is believed to have lain through the preceding winter, the compaction was to about 63 percent of original peat thickness. To further complicate depth measurements, some "heave" or relaxation at the site of boring 1 seemed to have resulted from the removal of the dike. Vertical faults in the New Haven Clay, parallel to the pit face and upthrown on the pit side, suggested that both compression under the load of the dike and subsequent relaxation also may take place in the underlying silt-clay rhythmites. Thus, the depths of radiocarbon-dated samples from the clay pit are not considered as reliable as those of samples collected by coring undisturbed marshes.

Hammock River Marsh, Clinton — a former deep bay or lagoon

The Hammock River marsh in Clinton (fig. 4) has the appearance and stratigraphy typical of many Connecticut salt marshes. The surface is a thick mat of short, wiry salt-marsh grasses, especially *Spartina patens.* Along the banks of channels, the taller salt thatch, *S. alterniflora,* grows. Whereas *Spartina patens* can tolerate only a brief wetting by salt water at normal high tide, *S. alterniflora* can tolerate submergence of its roots for 5 to 16 hours daily. The combined effect of these two plants and similar species has been to build and maintain the marsh surface very close to the local mean high-water level.

(A tidal gate installed under the Hammock River bridge of Route 145 now inhibits the inflow of salt water to the northeastern part of this marsh, and reeds, shrubs, and weeds are rapidly destroying the smooth beauty of the salt meadow. The southwestern arm of the salt marsh is flooded by high tides through a drainage ditch extending through Hammock Point Beach to the southwest, and has not yet degenerated.)

Prior to submergence, the Hammock River probably flowed west on a flood plain about 38 ft below the present marsh surface. A tributary valley sloped northeast toward

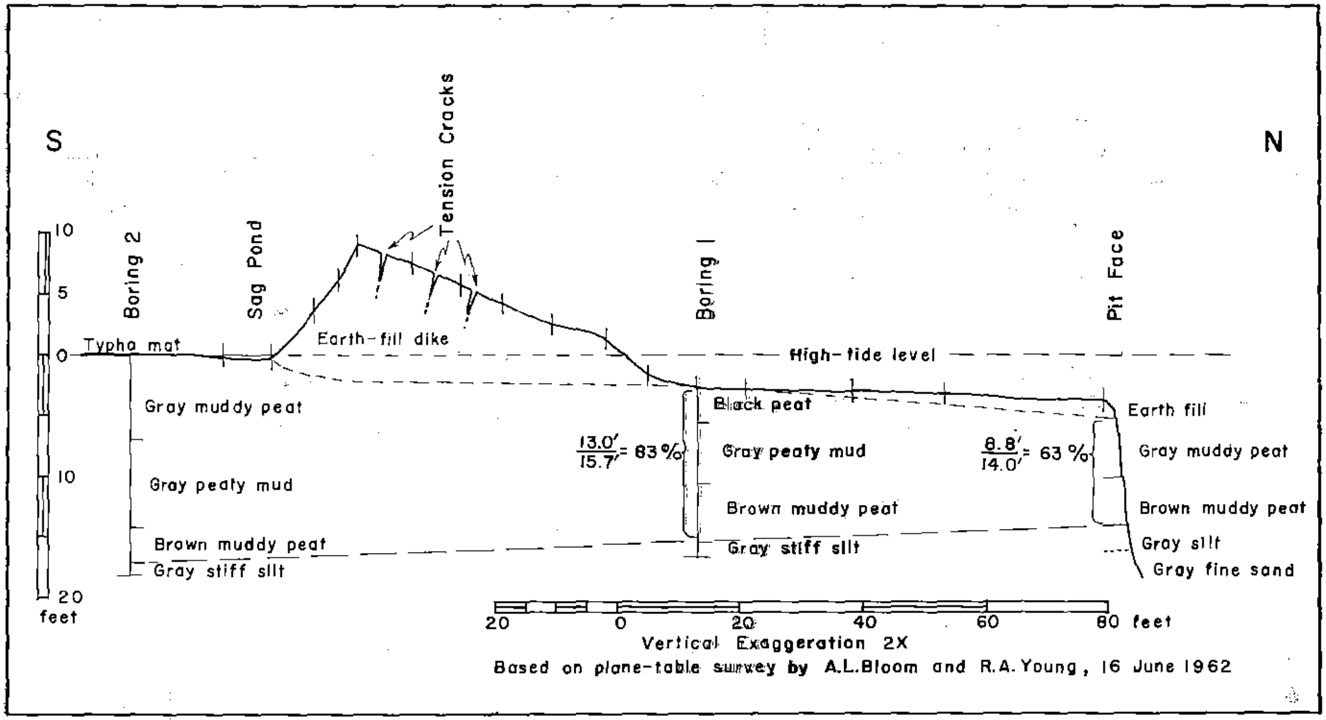

Fig. 3. Section through south face of Stiles Corporation clay pit, Hamden, Connecticut

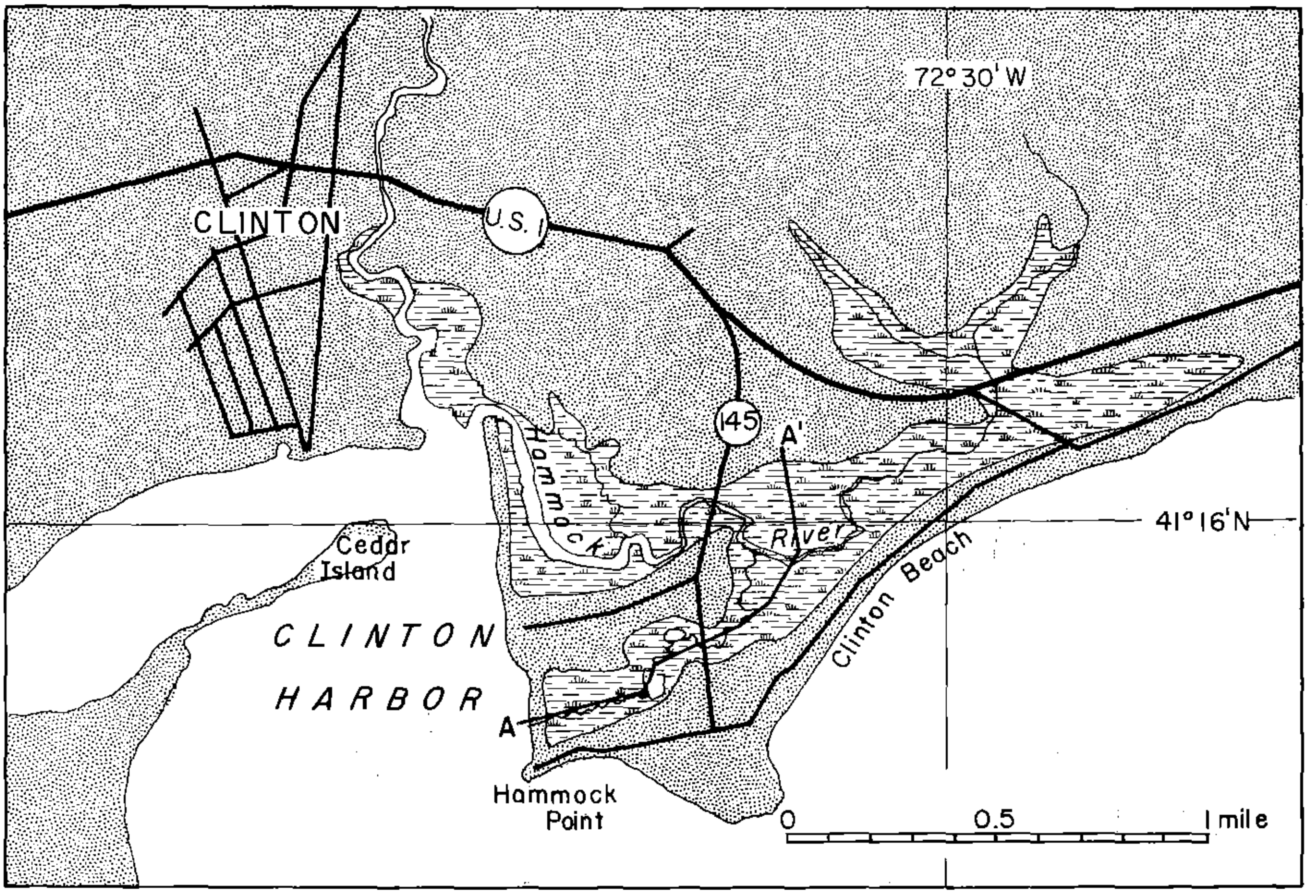

Fig. 4. Hammock River marsh and vicinity, Clinton, Connecticut

the river along line of section *A-A'* (fig. 4). Figure 5 shows the stratigraphy of section *A-A'*. The base of the section is the sand and gravel of the former valley floor, which had a northeastward gradient of about one percent.

As the sea transgressed eastward into the Hammock River valley, then southwestward into the tributary valley along the line of section, the shoreline was fringed by rushes and sedges. The basal unit of the stratigraphic section is a layer of sedge peat that accumulated at the transgressing high-tide shoreline. The sedge peat is overlain by mud of a shallow open-bay environment. The mud contains an abundant shallow-water, muddy-bottom fauna of snails, clams, and Foraminifera. Frances L. Parker (1962, personal communication) reported the following notes on the Foraminifera of boring 15 of the section:

> The upper 8 samples (8 ft.) contain a marsh fauna, either tidal marsh or shallow marsh pools. With sample 8, a rather meager bay fauna appears. I would guess that the

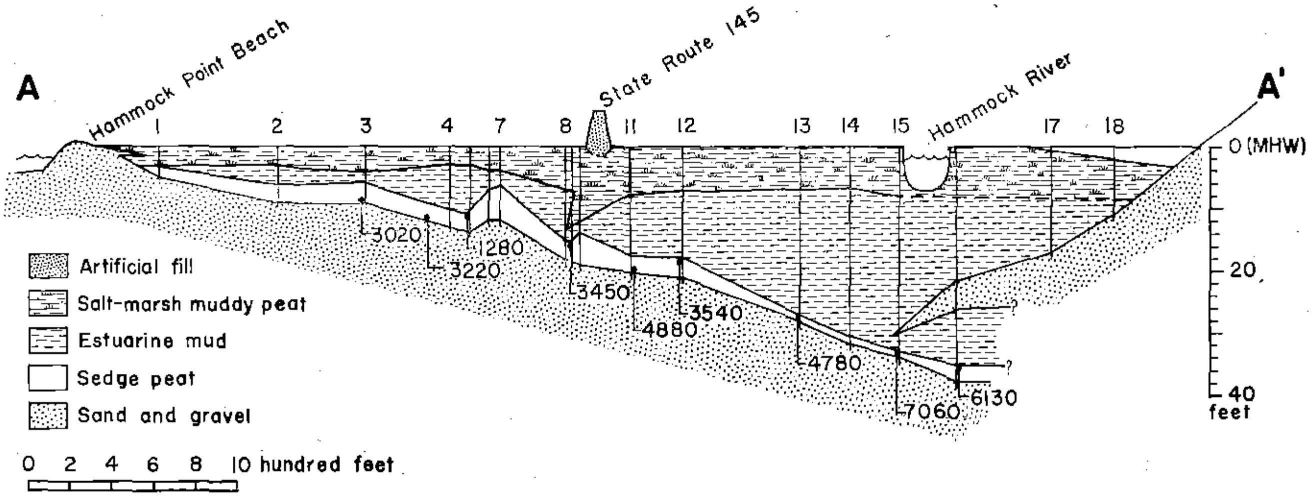

Fig. 5. Cross section of the Hammock River tidal marsh, Clinton, Connecticut

> water was probably shallow and conditions not too good for the Foraminifera. In one or two samples, there was evidence of solution of the $CaCO_3$ tests. The bay fauna is best developed at about samples 12-17. By bay, I don't mean a nice big open bay but rather some kind of semi-enclosed bay, probably with salinities somewhat lower than truly marine ones.

Sedimentation in the Hammock River estuary or lagoon (the nature of the embayment and the distribution of former barriers has not been determined) did not keep pace with submergence prior to 3,000 years ago, and open-water conditions persisted. However, when the rate of submergence decreased about 3,000 years ago, mudflats built up to the mid-tide level and were populated by *Spartina alterniflora.* The mid-tide marsh that developed was an efficient sediment trap, and in a short time the marsh surface had been built to high-tide level, where *S. patens* and related species became established. The lower third of the "salt-marsh muddy peat" of figure 5 consists of strawlike *S. alterniflora* fragments in mud, whereas the upper two-thirds consists of the fibrous roots of *S. patens* and similar high-tide species. Submergence of about 9 ft during the 3,000 years of marsh formation produced the thick section of peat derived from plants that live in a narrow vertical range near high tide (the "Mudge-Davis" type of salt marsh).

The positions and radiocarbon ages of peat samples from the Hammock River marsh are shown in figure 5. Table 1 is a list of radiocarbon-dated samples from coastal Connecticut (after Bloom and Stuiver, 1963, p. 333). The dates are plotted against sample depth in figure 6 (Bloom and Stuiver, 1963, p. 333) and a curve is drawn through the samples whose depths have not been affected by compaction. The most reliable samples used in preparing the submergence curve came from the base of the sedge peat in the Hammock River marsh, where a nearly ideal combination of permeable substratum and sloping valley floor permitted the accumulation of sedge peat only very near the high-water shoreline of the transgressing sea. The depth of these samples below the present high-tide marsh surface in the same embayment is an accurate measure of the relative change of level since peat accumulation began. Samples collected from the top of the buried sedge-peat bed plot below the curve of submergence by an amount equal to the compaction of the peat. The displacement by compaction plus the present thickness of peat equals the original thickness, and the ratio of present to original thickness can be calculated. The sedge-peat bed beneath the Hammock River marsh has been compacted to between 13 and 44 percent of orignial thickness. Older and deeper samples (6,130 yrs. = 22 percent; 4,780 yrs. = 13 percent) show greater compaction.

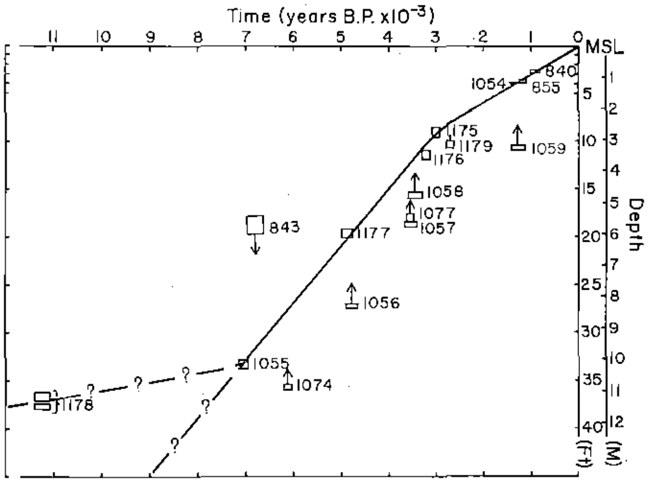

Fig. 6. Submergence of the Connecticut coast (Bloom and Stuiver, 1963). The line is the locus of a point now at mean sea level.

Table 1. Radiocarbon-dated samples from coastal Connecticut[1]

Laboratory No.	Locality	Sample	Depth (ft)	Age (years before present)
Y-840[2]	Branford	Cedar root	2.7 ± 0.2	910 ± 120
Y-843	North Haven	Log	18.5 ± 1.0	6,810 ± 170
Y-855[2]	Guilford	Oak log	3.8 ± 0.2	1,180 ± 80
Y-1054[2]	East Norwalk	Tree root	4.0 ± 0.2	1,400 ± 70
Y-1055[2]	Clinton	Peaty sand	33.3 ± 0.4	7,060 ± 100
Y-1056	Clinton	Sedge peat	27.2 ± 0.3	4,780 ± 130
Y-1057	Clinton	Sedge peat	18.6 ± 0.3	3,540 ± 130
Y-1058	Clinton	Sedge peat	15.6 ± 0.3	3,450 ± 160
Y-1059	Clinton	Sedge peat	10.7 ± 0.3	1,280 ± 150
Y-1074	Clinton	Sedge peat	35.7 ± 0.4	6,130 ± 90
Y-1077	North Haven	Log	18.0 ± 0.5	3,560 ± 80
Y-1175[2]	Clinton	Sedge peat	9.1 ± 0.6	3,020 ± 90
Y-1176[2]	Clinton	Sedge peat	11.4 ± 0.5	3,220 ± 90
Y-1177[2]	Clinton	Wood and bark	19.6 ± 0.5	4,880 ± 120
Y-1178[2]	Clinton	Sedge peat	36.6 ± 0.5	11,240 ± 160
		(combined)	37.7 ± 0.3	
Y-1179	Westport	Sedge peat	10.4 ± 0.4	2,710 ± 90

[1] Bloom and Stuiver, 1963, p. 333

[2] Samples whose depth range does not require correction because of compaction

Chittenden Beach, Guilford — a shallow coastal marsh

The small marsh at the back of Chittenden Beach formed on an outwash plain. The outwash appears to be thin, as numerous bedrock knobs protrude through it. The smooth profile offshore indicates that the outwash plain formerly extended at least a mile seaward of the present shoreline. Whether or not a barrier beach formerly protected the marsh has not been determined. The present beach is undernourished, and is little more than a fringe of sand and shells being "bulldozed" landward over the marsh by storm waves. The marsh in back of the eastern part of the beach is now only about half as wide as it was in 1960.

It is possible that the marsh formerly extended thousands of feet seaward, and at its outer edge a barrier beach extended from headland to headland. If so, the present marsh and beach remnants represent the final stage of landward retreat of a barrier beach across a filled lagoon. However, development of this marsh may not have been the result of a protecting barrier. Former glacial deposits, now submerged or eroded, may have provided protection for the early marsh. In that case, the present beach is only a reworked remnant of drift, rather than of a former barrier beach. As a third possibility, it may be that no more protection has ever been provided for this marsh than it now has. Erosional retreat of the marsh edge has been at the rate of 10 ft or more per year since 1960, and at least 2 to 3 ft per year during recent decades, according to local residents; however, these rates may not be typical of erosional retreat during the several thousand years of marsh history. The widespread destruction of eel-grass beds offshore in the early 1930s may have exposed this shoreline to more rapid erosion. Late spring storms of the past two years have been responsible in large part for the recent erosion, but their frequency in the past has not been investigated in this study. Furthermore, the submergence of the New York City tide gauge between 1893 and 1953 averaged 0.011 ft per year (Disney, 1955), about four times the average rate of submergence in Connecticut of 0.3 ft per century through the last 3,000 years. If submergence has accelerated in the past century, the effects would be most noticeable on exposed peat shorelines such as Chittenden Beach.

Some indications of a change in shoreline development at Chittenden Beach appeared in 1963. Formerly, the wave-cut intertidal peat cliff fronted on a barren tidal flat, but in 1963 a heavy growth of *Spartina alterniflóra* covered much of the flat. If this vegetation persists, it may trap enough sediment from the river mouth and offshore to rebuild the marsh to high-tide level, leaving the present beach as a "chenier" across the marsh. Future years will determine the validity of this hypothesis.

The stratigraphy of Chittenden Beach marsh has been studied by coring, and is also exposed in the wave-cut cliff at low tide. The pollen profile of a 270 cm (9 ft) core from a site now beneath the beach was prepared by Sears (1963, p. 59). Figure 7 is reproduced from his report. The oxidized peat zone at the base of the section probably represents chemical activity by ground water from the underlying drift, but it could have paleoclimatic significance. The transition from underlying sedge peat to overlying salt-marsh peat was 95 cm (3.1 ft) below the marsh surface. The arboreal pollen content of the core shows a general shift upward from oak to pine and hemlock. Sears (1963, p. 59) interpreted this as a trend toward a cooler and moister climate during the time of marsh accumulation. Superimposed on the climatic change inferred from the arboreal pollen are a series of reciprocal alternations between sedge and grass pollen. Sears (1963, p. 59) interpreted these recurrent fluctuations as showing a pulsating rather than steady rise of the water table during submergence on the hypothesis that "slight rises in the water table normally favor sedges at the expense of grasses." However, in coastal marshes salt-marsh grasses normally displace sedges during growing seasons of abnormally high tides, the reverse of Sears' hypothesis. Most of the sedge-to-grass fluctuations are recorded in the sedge-peat part of the core, but some are shown in the upper salt-marsh peat as well. Because the environment has been in delicate balance with several variables, climatic interpretation is not easy.

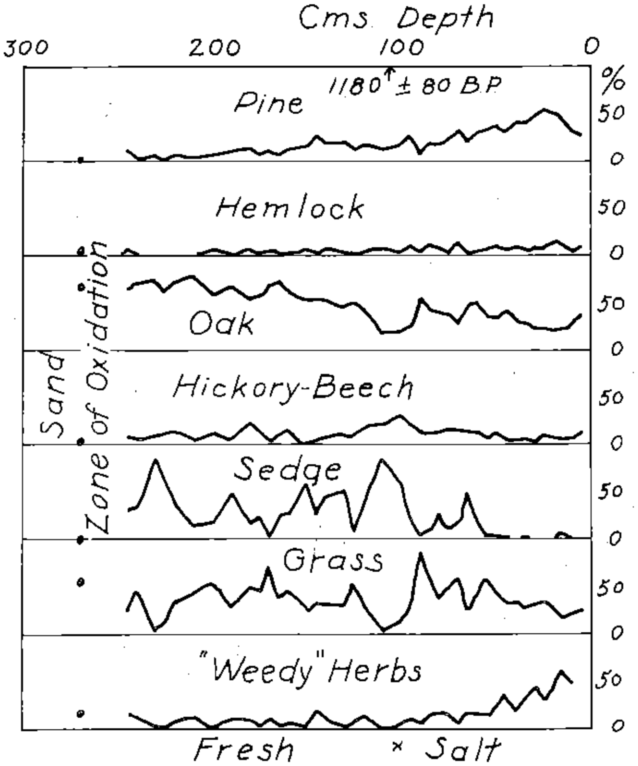

Fig. 7. Pollen diagram of important indicators in the Guilford, Connecticut, coastal marsh (Sears, 1963)

In the wave-cut cliff of peat, sedge peat is interbedded with salt-marsh muddy peat. The best indicator of accumulation in a low-salinity marsh is the distinctive curved-triangular culm of *Scirpus maritimus,* the common coastal bulrush. Fibrous, wiry mats of roots represent growth of *Spartina patens* and related high-salinity salt-marsh plants. An oak log from the base of the wave-cut bank at Chittenden Beach was 1,180 ± 80 years old (Y-855). It came from a layer of black "fresh-water" peat 115 cm (3.8 ft) below present high tide, nearly at the contact with underlying sand.

BEACHES OF THE NORWALK-WESTPORT AREA

Introduction

The embayed, irregular Connecticut coast of Long Island Sound trends ENE-WSW; rock headlands, bluffs of glacial till, tidal marshes, and small beaches form its most prominent geologic features. Although two rivers and numerous smaller streams enter Long Island Sound along the Norwalk-Westport segment of the Connecticut coast, none is actively carrying large quantities of sediment. The river mouths are characterized by estuaries rather than by deltas (Sanders and Ellis, 1961).

Marine sedimentary environments of the Norwalk-Westport area (fig. 8) were studied from 1958 to 1960 as part of a doctoral dissertation at Yale University. The published dissertation (Ellis, 1962) is concerned with the sediments and sedimentary processes in this part of the Sound. One of the more interesting aspects of the study proved to be the beaches. This is due to their variability and also to the beach "restoration" projects that provided opportunities for "before and after" investigations. In addition to the mainland beaches, there are several small natural beaches on the Norwalk Islands (a group of islets lying about 1 mi. offshore opposite the town of Norwalk).

General geology

Bedrock in the area consists of various metamorphic lithologies collectively called the Hartland Formation. Unconformably overlying this metamorphic complex, and derived in large part from it, is Pleistocene glacial drift. On the mainland the drift is mapped as ground moraine with small areas of ice-contact stratified drift. The islands, however, appear to be remnants of an arcuate end moraine. Erosion of the glacial deposits has furnished material of all size grades for postglacial sedimentation.

Gravel beaches and wave characteristics

Gravel is the most common beach sediment both on the islands and on several of the mainland beaches. This gravel is a lag concentrate left after removal of "fines" from glacial deposits. Two distinct sizes of gravel are found on the beaches: 1) small (2 to 10 cm) gravel, which is moved rather frequently, and 2) large (10 cm to 3 m) algae-covered gravel, which is seldom moved. The larger gravel is usually limited to the lower parts of the beach. The smaller gravel is consistently well sorted, with an average sorting value (σ_I of Folk and Ward, 1957) of 0.48. The sorting of this small gravel is better than that of any other sediment in the area except some of the lower foreshore

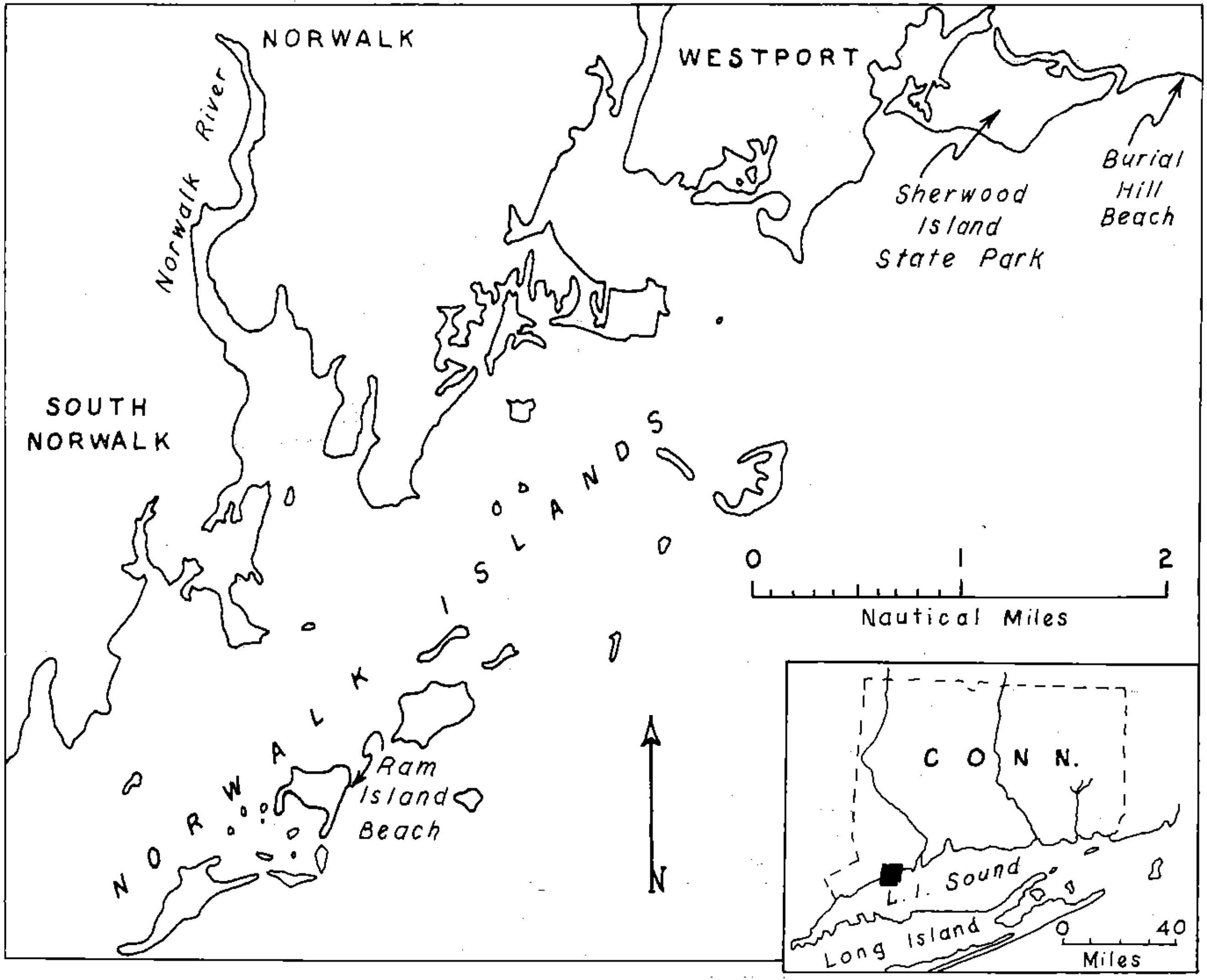

Fig. 8. Norwalk-Westport area, Connecticut

sands. Marked cobbles and pebbles placed on one of the gravel beaches indicated a movement of from 0.17 to 12 ft per week. The movement of the marked stones was not unidirectional along the beach; stones were found scattered in several directions from their point of origin. It seems somewhat surprising that the gravel moves at this rate because the average breaker height in this part of the Sound is less than 1 ft. Table 2 shows the average breaker height and wave period for the summer months at three of the mainland beaches.

Storm waves greatly exceed the values given on table 2. During the hurricane of 1938, waves at Bridgeport, Connecticut (12 mi. to the east) were reported to reach 30 ft in height. However, these are exceptional waves, for as table 2 shows, the limited fetch of the Sound ordinarily allows only small, steep, short-period waves to be generated. In spite of their size, these waves are capable of a surprising amount of erosion. During a year with no particularly large storms, the high tide shoreline on the point at Sherwood Island State Park was eroded landward more than 100 ft! This points to one of the biggest engineering problems in the area — beach restoration.

Table 2. Average wave heights and periods for three Westport and Norwalk beaches during the summer of 1959

Beach	Average wave height	Average wave period
Compo	10.9 in.	2.7 sec.
Burial Hill	9.3 in.	2.9 sec.
Calfpasture	9.2 in.	2.4 sec.

Restoration of sand beaches

The beaches at Sherwood Island State Park and the town beaches at Norwalk and Westport are a valuable community asset, providing recreation facilities for many people. These beaches are being rapidly eroded and covered by a lag concentrate of gravel that is undesirable from a recreation standpoint. In an attempt to restore sand to the beaches, hundreds of thousands of dollars were spent on dredging offshore material and pumping it directly onto the beaches. An effort was made to dredge only sand, but invariably gravel was also included. The pumping changed the beach profile to a flatter, more or less "convenient" slope.

Compo Beach at Westport and Calfpasture Beach at Norwalk were surveyed and sampled prior to the pumping as well as periodically thereafter. These beaches furnished an interesting "before and after" picture of the effects of restoration. Burial Hill Beach in Westport and Sherwood Island State Park Beach had been altered prior to the study, but surveys by the Connecticut Water Resources Commission coupled with some additional surveys during the study period provided valuable information on beach-profile changes associated with the restoration. The Burial Hill Beach profiles provide the longest time record of beach changes, and for this reason several of these profiles are plotted together in figure 9. Ram Island Beach, a natural beach on one of the Norwalk Islands, was surveyed and sampled several times during 1958-1959 in order to provide a background study of a sandy, unaltered beach. It is interesting to note that *while the "restored" beaches were being badly eroded, the natural beach on Ram Island actually gained sediment.* As the study progressed, the reasons for this became clear. In the first place, the slope of the natural beach was not changed, and hence it remained in equilibrium with the existing wave and sediment regimes; secondly, laterally adjacent glacial drift deposits (and to some extent offshore deposits) furnished a continuing supply of sand.

The slope changes that normally occurred on the restored beaches following their "restoration" are shown in figure 10. These idealized profiles are based on examination of more than 90 actual profiles. The first change to the beach profile after pumping is that the waves reshape the profile to match the slopes that existed prior to the alteration. This is accomplished by eroding material from the upper part of the tidal range (making this part of the slope steeper) and depositing material on the lower part of the foreshore (making this part of the slope flatter). Once the original slope is re-established, erosion continues at a reduced rate by landward retreat of the whole slope without

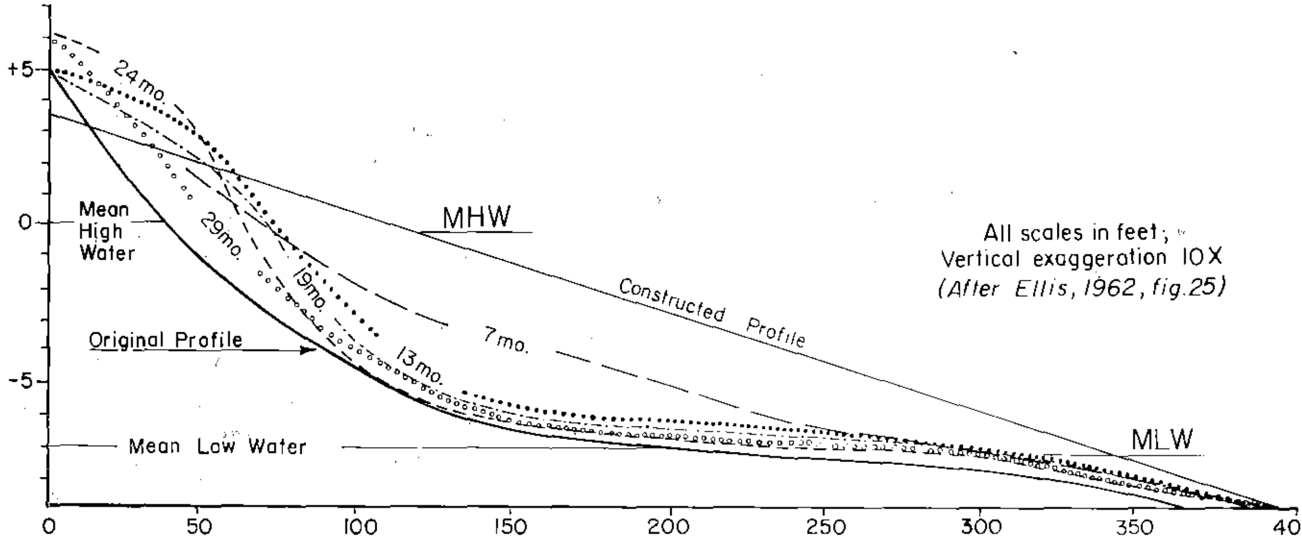

Fig. 9. Slope changes on Burial Hill beach, Westport, Connecticut, June 1957 to November 1959

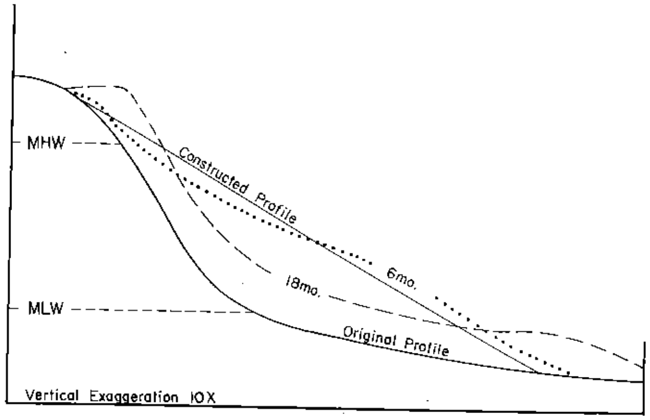

Fig. 10. Slope changes after alteration of a natural beach profile by direct placement of fill. Schematic diagram, modified from Ellis (1962, fig. 26)

alteration of its basic form. In some areas the proximity to groins affected the profiles. The development of berms sometimes altered the upper part of the profile, but most of the changes of beach slope closely approximated those shown in figure 10. The constructed profiles are modified much more quickly in exposed locations than in sheltered ones. Beaches on either side of the point at Sherwood Island State Park (the one that retreated more than 100 ft in one year) did not erode rapidly as long as they were being supplied with material eroded from the point. As soon as a lag gravel formed on the point, erosion spread laterally.

It seems, then, that the direct placement method of beach restoration is not satisfactory for these Connecticut beaches. A much better method would be to build the beaches at their natural slope and then stockpile sand in the updrift areas of each beach where erosion is most rapid. Stockpiling has been very successful on many beaches in other areas. The sand eroded from the beaches is largely accumulating in sheltered coves and embayments along the shoreline. Perhaps the best solution to the erosion problem would be to recycle this clean sand back to the stockpile areas on the beaches. Material could be supplied as fast as it was eroded, and the beach should remain stable. The use of clean sand is important because whatever gravel is pumped onto the beach along with the sand quickly forms a thin lag veneer over the surface, which for most purposes has the same effect as if the beach were made entirely of gravel.

Changes in grain-size-distribution parameters

Although our main concern here has been with beach erosion and adjustments of the beach profile, it will perhaps also be of interest to note briefly the changes in grain-size-distribution parameters that occurred in the beach sediment after the restoration processes. The parameters measured (by sieving) were those described by Folk and Ward (1957, p. 12-14); sorting (σ_I), skewness (Sk_I), kurtosis (K_G), and mean grain-size (M_Z).

These grain-size-distribution parameters do not follow as distinct a pattern of readjustment as do the beach slopes. The dominant prerestoration trend was a decrease in M_Z down the beach. This trend was not destroyed by the direct placement process, however, and there is no way to determine how quickly the trend might be re-established if it were destroyed. There is a trend with time toward coarser sediment on the foreshore, but because gravel was omitted from the sieving, the trend does not show as strongly as it should. Another dominant prerestoration trend was an increase in sorting down the foreshore. This trend is re-established almost instantaneously. The sorting of the entire foreshore continues to improve (again excluding the gravel) over a period of approximately two years after the restoration. This sorting improvement depends on the amount of beach erosion and the availability of sand. Availability of sand is also an important factor in the postrestoration skewness changes. Immediately after the restoration, the grain-size distributions of sands from the foreshore became nearly symmetrical and remained only slightly negatively skewed as long as there was an abundant supply of sand. Availability of sand seems to also affect the kurtosis values of the foreshore: they were mesokurtic ("normal") after the alteration, but in the later stages of readjustment these values range from mesokurtic to leptokurtic as they approach their "natural" condition which is leptokurtic. Sands from the backshore areas showed little uniformity of change in these grain-size-distribution parameters.

Conclusion

Detailed beach slope and sediment studies have led to the conclusion that the gravel beaches and natural sand beaches of the Norwalk-Westport area are in a state of equilibrium with existing wave conditions and sediment supply. In contrast to this, beaches restored by the direct placement of fill disturb the equilibrium conditions and lose almost all traces of their "restoration" within two or three years.

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