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POSTGLACIAL CHANGE OF SEALEVEL IN NEW HAVEN HARBOR, CONNECTICUT*

JOSEPH E. UPSON,** ESTELLA B. LEOPOLD,† and MEYER RUBIN‡

ABSTRACT. Samples of organic material from three test borings for the Connecticut Turnpike bridge over the Quinnipiac River in New Haven, Connecticut, were taken from depths of 30 to 38 feet below mean sealevel. The material occurs near the base of estuarine deposits that rest unconformably on glacial outwash. Pollen content in samples from the three borings is all about the same and correlates with pollen zone B or C-1 of Deevey. The C-14 age of the sample (no. W-945) from one boring, at a depth of 30 to 31.5 feet below mean sealevel is 5900 ± 200 years B.P. This sample is thought to represent a position of sealevel not lower than 35 to 40 feet below present level, and hence suggests an average relative rise of sealevel since of between 1.7 and about 2 mm per year. Sealevel might have been as high as 20 to 25 feet below present level, but this is considered unlikely.

INTRODUCTION

Carbon 14 (C-14) and pollen analyses were made on samples of plant remains from a depth of 30 to 40 feet below sealevel at the edge of New Haven Harbor, New Haven, Connecticut. The C-14 age of one sample is approximately 5900 ± 200 years B.P. (Before Present); and the pollen analysis indicates that the material is probably in the B or C-1 pollen zone of Deevey (1939). The plant remains are believed to have accumulated within a few feet of the sealevel of the time. This together with the results of the analyses suggest a relative rise of sealevel with respect to the land since accumulation of the plant remains at an average rate of slightly more than half a foot per century, or about 1.8 millimeters per year.

The samples were selected from cores taken by contractors for the Connecticut State Highway Department in connection with the Connecticut Turnpike crossing of New Haven Harbor at the junction of the Quinnipiac and Mill Rivers. The geologic analyses of the samples were made by the U. S. Geological Survey as part of a study of the age and origin of bedrock valleys of the New England coast. The general results are given in a larger report, in preparation, by J. E. Upson and C. W. Spencer. In the present report, more detailed discussion is given of the Quinnipiac River crossing than in the larger report, and the suggested relative rate of rise of sealevel is elaborated more fully.

LOCATION

New Haven Harbor is on the north side of Long Island Sound and about 60 miles northeast of New York City. Figure 1 shows the location of the Quinnipiac and Mill Rivers at the head of New Haven Harbor and the crossing of the Connecticut Turnpike at which the samples were taken. Figure 2 is a more detailed map showing the location of the bridge itself and the plot of the borings. The samples were actually taken from along the Mill River, but the bridge is known as the Quinnipiac River Bridge, hence the use of that name in this report. The sample whose age was determined by C-14 was taken from boring 98, north of the center line of the bridge, adjacent to an area of filled land, probably a former tidal marsh, and approximately at the west edge of salt water. The location is at about lat 41°18′1″ N. and long 72°54′23″ W. Pollen

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** U. S. Geological Survey, 1505 Kellum Place, Mineola, New York.
† U. S. Geological Survey, Federal Center, Denver, Colorado.
‡ U. S. Geological Survey, Washington, D. C.

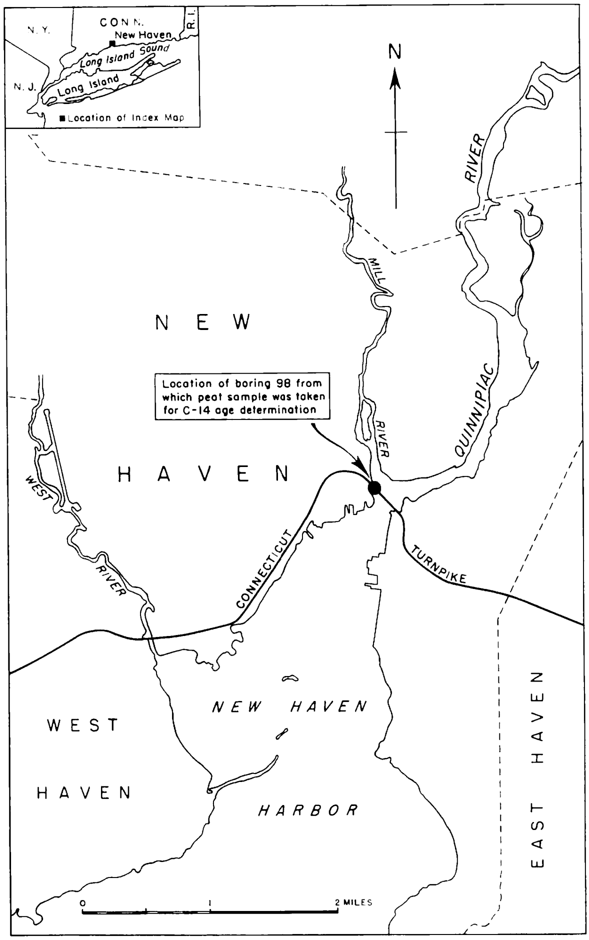

Fig. 1. Map of part of the New Haven area, Connecticut showing location of the Connecticut Turnpike crossing of the Quinnipiac River.

analyses were made on samples from borings 91, 95, and 98 (same material as for the C-14 analysis).

GEOLOGY

The Quinnipiac River enters Long Island Sound at the southernmost end of the Connecticut Valley Lowland which contains a structural depression formed by down-faulted and down-folded rocks of Triassic age. These are the sandstones and shales with interbedded basaltic rocks of the Newark Group and at New Haven probably the New Haven Arkose (Rodgers and others, 1956). From a study of the turnpike borings and other well and boring records in the area, it is inferred that the Quinnipiac River, or a precursor, cut a valley in the Triassic sediments, sometime before the mid- or late Pleistocene. This valley, perhaps deepened by glacial erosion, and now certainly more than 160 feet and perhaps more than 200 feet below present sealevel, was later partly filled with

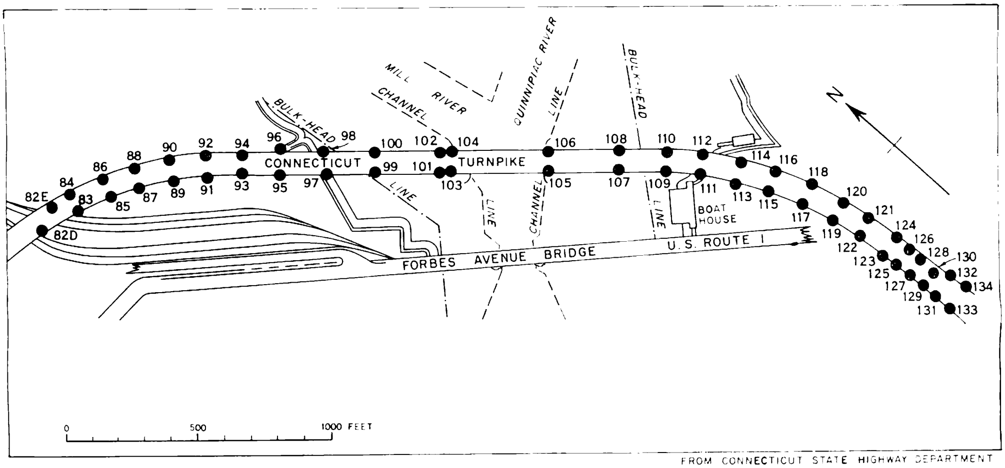

Fig. 2. Map showing crossing of the Connecticut Turnpike over the Quinnipiac River and location of test borings.

glacial outwash. The outwash, in turn, was trenched by the ancestral Quinnipiac, or perhaps Mill River, to develop a second and younger valley, when sealevel was below the land surface of the time, and doubtless substantially below present sealevel. This younger valley was invaded by the sea, evidently as the water rose after the last significant glacial stade. The rate of differential movement of the sea and land was slow enough and the slope of the erosional channel low enough so that, in the area of the present marine embayment, a marsh environment probably existed for a time, and plant remains accumulated, at least locally. These conditions were short-lived and changed to estuarine conditions with the deposition in brackish water of mud and silt containing shells.

This sequence of events is deduced from the stratigraphy shown by the cross section, figure 3, in which several depositional units are identified. This cross section was constructed from the records of borings made along the north side of the bridge, including boring 98 from which one of the peat samples was collected.

The deposits comprise four main recognizable units: (1) red or red-brown predominantly coarse sand considered to be glacial outwash; (2) discontinuous bodies of chiefly gray or blackish-gray sand which is probably also outwash; (3) a body of silt and clay with shell fragments, gray or black in color, considered to be mainly estuarine deposits but near the base containing lenses of peat and other plant organic material; and (4) local gravel and sand at the top, outside the present extent of the river, and probably mostly artificial fill.

As shown in the section, the outwash, which rests on the bedrock, is the thickest unit. It consists predominantly of red or red-brown coarse to fine sand probably derived mainly from the Triassic rocks. Some cores contain fine gravel, others minor amounts of clay, but most of the material is fine sand silt. The greatest thickness of the material in this section is 112 feet at boring 100. It may be thicker at some of the other borings, but was not fully penetrated.

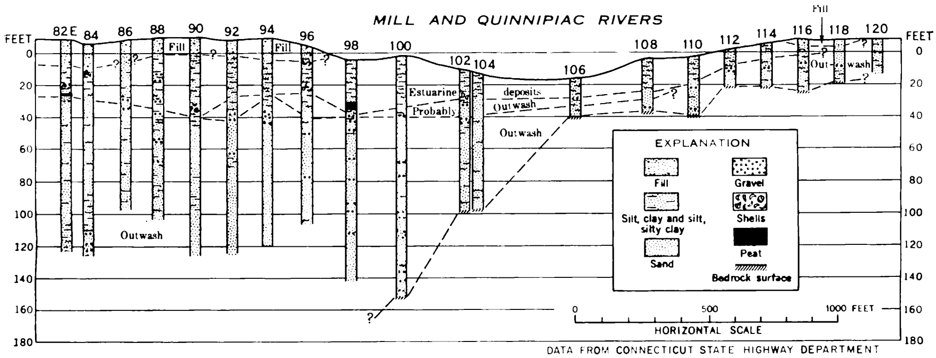

Fig. 3. Section across buried valley of the Quinnipiac River showing lithology of unconsolidated deposits and interpreted stratigraphic units.

Identification of this material as outwash depends in part on the general glacial history of the area, which has been more fully discussed in the larger report (Upson and Spencer, in preparation). It was deposited by meltwater streams from the last ice to reach southern New England. Possibly some till occurs at the base of the outwash, but it is not clearly recognized from the data on these borings.

At some borings, the red and red-brown sand is overlain by gray, gray-brown, or black-gray sand, which has a maximum thickness of about 14 feet (boring 96). This is generally fine grained, nearly silt size, but at several places has a little gravel. It is generally finer grained than the underlying unit. Because no organic remains are reported, it is considered to be part of the outwash, perhaps deposited by meltwater streams draining areas underlain by crystalline rather than Triassic sedimentary rocks.

The third unit is described as clay and silt, silt, or silty clay, generally dark gray or black in color, and organic, with minor amounts of coarse to fine sand and locally gravel. In several cores, shells and shell fragments are recorded, and near the bottom, where the clay and silt are the deepest, are beds that contain an appreciable portion of plant remains. The bulk of these deposits are considered to be estuarine deposits.

Peat or peaty material was reported in cores from three borings (91, 95, and 98) and was also seen by C. W. Spencer in samples from a fourth boring (99). The material and the depths at which it occurs are summarized below:

TABLE 1

Identification of samples and boring numbers, Quinnipiac River, New Haven, Connecticut

Boring	Sample Number	Material (Drill inspector's description)	Depth of core (feet)	Elevation below mean sealevel (feet)
90	2	Gray clay, trace of sand, peat and sea shells	40-41.6	31.0-32.6
91	4	Silt and sand, black, organic	40-41.5	34.9-36.4
95	5	Brown clay silt, containing peat	40-41.5	36.3-37.8
98	3	Dark brown peat	30-31.5	30.0-31.5
99	1	Dark brown peat	30-31.5	30.0-31.5

TABLE 2

Plants identified from megascopic remains

Plant Part	Megafossils identified	Common name	Habitat	Sample no.
Fruits	*Zannichellia palustris* L. cf. var. major (Boenninghausen), Koch	Horned Pondweed	Submerged aquatic, coastal	2
Seed	*Vitis* sp.	Grape	Costal and inland	4
Seeds	*Polyganum* section *Avicularia* Meisner	Smartweed	Coastal and inland strands	4, 5
Seeds	*Carex* cf. *lupulina* Muhlenberg	Sedge	Marshes	4
Seeds	*Carex* cf. *amphibola* Steudel	Sedge	Marshes	4, 5
Seed	*Scleria* sp.	Nutrush	Marshes and damp ground	5
Seeds	cf. *Sambucus*	Elderberry?		4
Seed	cf. *Viburnum*	Viburnum?		4
Seed	*Potamogeton* cf. *obtusifolius* Mertens & Koch	Pondweed	Submersed and floating aquatic in fresh or brackish waters	5
Stems and microphylls	Bryophyta undetermined	Mosses		2
Leaf fragments	Dicotyledonae undetermined			2, 4
Wood	Dicotyledonae undetermined			1, 3
Stems	Monocotyledonae undetermined			3

The material whose age is here reported came from boring 98 (fig. 3). On the boring record, peat is reported from 30 to 35 feet below sealevel, but the core itself is only about 1½ feet long. So the elevation of the sample is taken as 30 to 31.5 feet below sealevel. Borings 91, 95, and 99 are beneath the south side of the bridge, but in the same area as boring 98 (fig. 2).

More precise information on the nature of the organic sediments is afforded by grain-size analyses, total organic carbon determinations, and study of contained plant megafossils. The grain-size analyses indicate that the predominant grain size in samples 1, 2, and 4 is silt and clay (<0.047 mm), and that sample 5 is mostly silt and very fine sand (<0.125 mm); sample 3 is mainly organic detritus of granule size and larger (>1 mm). The material in all samples is poorly sorted.

Total organic carbon determinations on the samples were made by Irving Frost of the U. S. Geological Survey Denver laboratory. The results, together with computations based on taking 51.5 percent as the carbon content of organic fractions of organic and peaty marine sediments (Bader, 1954), indicate that samples 1 and 4 contain about one-third and one-quarter organic material, respectively, and the other two contain less than one-tenth organic material by weight. On this basis the sediments can be classified as follows:

TABLE 3

Classification of sediments from carbon determinations and sieve analyses

Boring 90	Sample no. 2	Organic silt
91	4	Fine-detritus peaty silt
95	5	Organic sand
98	3	Coarse-detritus peat with sand and silt
99	1	Coarse-detritus peaty silt

Table 2 summarizes water plants and other megascopic remains identified. Fruiting parts of several water plants were identified from samples 2, 4, and 5, and wood fragments were frequent in samples 1 and 3. The plant megafossils found include a grape seed, moss stems, and wood that do not represent coastal swamp vegetation, but which probably were washed into the sites. The water plants identified could have been growing in shallow water at the sites, or their remains also could have been washed in. However, a shallow water environment is suggested by the relatively high percentages of organic material in samples 1, 3, and 4, and by the coarse-detrital nature of the peat fraction in samples 1 and 3.

The peaty material was encountered in recognizable thickness at several borings, within the depth range of 30 to 40 feet below sealevel, and at or a few feet above the top of the outwash. Organic material is known in similar stratigraphic situations in the Housatonic valley (Upson and Spencer, in preparation). Similarly, a layer of fresh-water peat underlying estuarine mud is reported by Bloom (1962, p. 178) in an embayment in Clinton, Connecticut, a few miles to the east. "Peat" overlying probable outwash was penetrated in a boring in the harbor at Mystic, Connecticut (p. 130). Thus, along the whole Connecticut coast there seems to be a buried zone marked by accumulation of plant remains. Because of the stratigraphic relationships, this organic material is believed to have been deposited in the shore zone as the sea encroached over the glacial outwash. The material accumulated, perhaps also grew at the sites, in swamps or shallow ponds, either in the backwaters of meandering streams or in depressions flooded by ground water rising together with rising sea level, or perhaps locally in tidal marshes. Because it occurs in a narrow zone between permeable glacial outwash and overlying estuarine deposits, the material probably did not accumulate in deep water. Analysis of the plant remains (p. 126) supports this interpretation (see also p. 130).

The fourth unit consists of gravel and sand and occurs at and above sealevel in both ends of the section. Some of this material is reported to contain cinders, and it is probably all artificial fill.

AGE DETERMINATION BY C-14 ANALYSIS

The sample of peat analyzed, obtained from boring 98, was acidified to remove any carbonates present, then boiled in NaOH to remove the humic acid fraction. The humic acid fraction is believed to be the more mobile and could have been brought in by ground water, contaminating the sample. Only the cellulose was burned for conversion to acetylene for counting. The radioactivity of the sample (W-945) was measured for two days in two counters and the age computed on the basis of a half-life of C-14 of 5568 years. The result, 5900 $\pm$ 200 years, is reported in years before present, present being arbitrarily agreed on as 1950.

POLLEN CONTENT

Sediments of three samples (nos. 3 through 5), collected from bore holes number 98, 91, and 95 (fig. 2) respectively, were boiled in 5 percent KOH

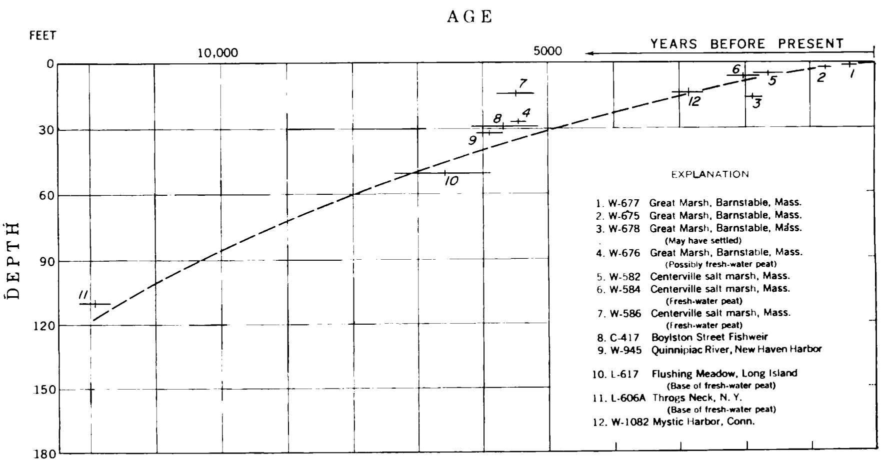

Fig. 4. Depths and ages of buried swamp and marsh deposits along the coast of southern New England.

and the organic residues floated off on $ZnCl_2$. Each sample was acetylated for four minutes. All three samples contained enough pollen for an adequate count. Results are given below.

TABLE 4

Plants identified from pollen examination (percent total pollen)

Sample no.	3	4	5
U.S.G.S. Paleobot. Loc.	D-1596	D-1597	D-1598
Depth (in feet) below mean sealevel	30-31.5	34.9-36.4	36.3-37.8
Core hole number	98	91	95
Picea	1.4	0.8	1.0
Pinus	30.5	29.7	32.6
Tsuga	40.4	22.5	26.6
Betula	0.7	1.4	1.0
Ostrya-Carpinus			0.5
Ulmus	0.4	4.7	1.5
Carya	5.7	3.3	3.6
Juglans	0.7	0.3	2.1
Tilia	5.3	5.0	4.7
Nyssa	0.4		
Quercus	5.0	19.7	15.8
cf. *Acer*			0.3
Fagus	0.7	0.8	
Platanus		0.3	
Corylus			0.3
Alnus	0.7	1.1	1.3
cf. *Impatiens biflora*		0.3	
Cyperaceae	1.0	1.1	2.5
Gramineae		0.3	0.8
Typha latifolia	1.8		2.5
Compositae	1.0	1.1	0.5
Chenopoliaceae	1.0		0.5
Anacardiaceae cf. *Rhus*		0.3	
cf. *Symplocos*		0.3	0.3
cf. *Petalostemon*		0.3	
cf. *Viburnum*			0.3
Unknown dicots	2.8	6.4	1.8
Total percent	99.5	99.7	100.5
Total pollen counted	(282)	(360)	(387)
cf. *Sphagnum*	(3)		
Lycopodium lucidulum	(2)	(3)	
cf. *L. complanatum*			(2)
Osmunda		(3)	(1)

All three samples contain a large percentage of hemlock (*Tsuga*) pollen which is frequent in early postglacial assemblages in Connecticut. If the samples are of postglacial age, which is indicated by the C-14 age, they can be assigned to pollen zones B or C-1 of Deevey (1939), judging from Deevey's Connecticut pollen chronology. The abundance of hemlock, the relative scarcity of spruce, and the rich assemblage of broad-leaved tree genera suggest a zone C-1 rather than a zone B age. The prominence of hemlock and pine pollen in the three samples examined suggests that they are of the same approximate age.

SIGNIFICANCE OF THE DATA

The data reported herein seem to be significant in two respects: (1) the relation between the pollen types and C-14 age; and (2) the rate of rise of sealevel in post-glacial time.

Regarding the first, in recent years a postglacial chronology based on radiocarbon ages and pollen zones of Deevey has been developed. Beetham and Niering (1961), summarizing data from others, give an average age for the A-4 zone at about 10,460 years. Deevey (1958) gives an age of about 8320 years for the middle (?) of zone B at Upper Linsley pond, about 10 miles northeast of New Haven, and about 5960 years for the top of zone B from the same location. The bottom of C-2 at Linsley pond gave a date of 5230 years. The age of 5900 ± 200 years for pollen assignable to zone B or C-1 appears to be consistent with these other data in southern Connecticut.

Regarding the position of sealevel, the data suggest that sealevel in relation to the land rose about 35 to 40 feet in the last 5900 years. Figure 4 shows the depth plotted in relation to depths of similar samples from other parts of southern New England. Still additional depths are available for localities in New Hampshire, Maine, and Nova Scotia, but they are not plotted because they may not be strictly comparable.

Most of the depths plotted are for samples of peat taken from salt marshes or buried peat deposits believed to represent closely the sealevel of the time. Just how closely, of course, is the critical question. In the graph (fig. 4), the material for numbers 1 to 4 is from the Great Marsh in Barnstable, Mass. The ages are given in Rubin and Alexander (1960, p. 131-132), and the depths are measured from the present surface of the marsh. The material for numbers 5 to 7 is peat taken from the Centerville salt marsh, also Massachusetts. The dates are given by Rubin and Alexander (1960, p. 130-131), and the depths are from the marsh surface. The material for numbers 1, 2, 3, and 5 is salt-water peat, and, except for number 3 (see below), probably represented about mean high water at the time of deposition. Assuming that the materials had about the same relation to the sealevel of the time that a comparable material has to present sealevel and that there has been no appreciable change in the tidal range over the centuries, the present depths are an approximate measure of the rise in sealevel since the material was deposited or grew.

The material for number 3 (W-678) according to Redfield and Rubin (1962) is suspected of contamination, and the depth indicated may be too great. The material for number 4 (W-676) may be fresh-water peat and thus might have been somewhat above the sealevel of the time. Number 6, however, plots close to number 5. Number 7 seems to be unusually high and also is inconsistent with number 4 (W-676) which is within its possible age range, but is about 13 feet deeper. However, numbers 4 and 7 are not from the same marsh, and it is conceivable that number 7 indicates a short-lived episode of higher sealevel.

Number 8 is for the sample of lower peat at the Boylston Street Fishweir site in Boston, Mass. Johnson (1942a, p. 12, fig. 2) shows this peat at about 16 feet below Boston City base, which is 5.6′ below msl at Commonwealth Pier, U. S. Navy Yard, Boston, or 21.6′ below present msl. Johnson also (1942b, p.

161) states that the so-called Amorphous Layer of this peat was probably formed above mean highwater, although the Upper Layer of this same peat may have been formed in the intertidal zone or even at mean low water. Barghoorn later (1949, p. 73) writes that most of this peat is a fresh-water peat, overlain unconformably by a salt-marsh peat whose deposition rapidly gave way to marine or estuarine silt. The salt-marsh peat, then, probably was formed about at mean high tide level.

Arnold and Libby (1951, p. 113) give the age of a sample of this peat as 5717 ± 500 years B.P., but it is not certain which of these layers was dated. If the salt-marsh peat, it would have been 4 or 5 feet above the mean sealevel of the time, hence indicating a sealevel rise of around 26 feet; if the fresh-water peat, the rise would have been somewhat more. Point 8 is plotted at a depth of 29 feet in figure 4. On the other hand, if the peat formed as much as a few feet above the high tide of the time, the subsequent sealevel rise might be greater even than 30 feet. In any case, the exact amount is not very significant because the possible age range of the sample is so great.

Number 9 represents the material from the Quinnipiac River valley here reported. If the stratigraphic interpretation is correct, the date represents approximately the time of change from marsh conditions to a more rapid relative rise of sealevel which resulted in estuarine conditions. The position of the organic material in relation to the sealevel of the time can not be closely determined. The organic remains are believed to have accumulated in the shore zone of the encroaching sea. The evidence from the plant remains suggests that the organic material at least accumulated in shallow water. Thus, they may have formed a few feet below sealevel of the time, though this is considered doubtful, or a few feet above the sealevel as controlled by the ground water table not far landward. The outwash is medium to coarse sand and gravel, hence rather highly permeable, and no beds of clay are present that would particularly retard downward percolation of rainfall. Therefore the water table could not have been more than a few feet above sealevel. The sites of the plant accumulation also then probably were not more than a few feet above sealevel. The present-day tidal range at New Haven is about 6 feet, so if the material accumulated in a tidal marsh it might have been as little as 3 feet above the mean sealevel of the time; if in flood plain ponds, probably not more than 10 feet above. Thus the mean sealevel of the time probably was not more than about 35 or at most 40 feet below present level; and probably not less than 20 or 25 feet below. On figure 4 the point is plotted at about 31 feet below present mean sealevel.

Number 12 (W-1082) is for a sample of peat from Mystic Harbor, Connecticut, nearly 50 miles east-northeast of New Haven. The material was cored by the U. S. Corps of Engineers in February 1960 and kept in a glass jar sealed with wax. The sample was obtained by the senior author in July 1961 through the courtesy of Carl G. Hard of the U. S. Corps of Engineers Office in Waltham, Massachusetts. The Carbon 14 age determination of 2850 ± 260 years B.P. was made in the laboratory of the U. S. Geological Survey in Washington, D. C. It is not known whether this material is fresh- or salt-water peat, but it occurs near the base of estuarine deposits resting on probable glacial outwash, in a situation similar to number 9 (W-945). The peat was probably formed not more than a few feet above mean sealevel. Similarly, the fresh-water peats for numbers 10 and 11 (Newman, W. S., personal communication, 1962) were considered to be not more than a few feet above the mean sealevel of their times.

The smooth curve drawn in figure 4 is believed to be at least a fair generalization of the relative rise of sealevel along the Connecticut coast based on the data presented. It is dashed to indicate that it is approximate. The zero line of the graph is present mean sealevel with respect to the curve. The depths for points 1 to 7 were actually measured from about present mean high water, but as explained on page 13, these are about the same depths as former mean sealevel was below present sealevel. For the remaining points, 8 to 12, the plotted depths are with reference to present mean sealevel. The material analyzed, however, represents at least the mean high water of the time, and possibly positions a few feet higher, as explained. The curve for mean sealevel then, is drawn somewhat below these points, except for number 10 which has a long possible time range. The curve at number 9 falls about 7 feet below the point.

For this curve, the data are fair back to about 2000 B.P. Redfield and Rubin, 1962, present newer and more complete data back to about 4000 B.P. which suggest a straight-line rise of sealevel from 4000 B.P. to 2000 B.P. The line is generally a little below and slightly steeper than the curve in figure 4. This leaves the interval from about 4000 to 5500 B.P. with essentially no data and from 4000 to 12,000 with some fair data, none of which fix closely the sealevel of the time. We hope that work by others now in progress will help fill these gaps.

Several other workers have prepared curves of sealevel rise or have plotted data on the basis of which such curves could be drawn. Chief among these are Jelgersma and Pannekoek (1960), Shepard (1960), Fairbridge (1961), and Jelgersma (1961). Without attempting to reconstruct or reproduce these curves, the Quinnipiac point, in general, would plot substantially below the Fairbridge curve, somewhat below the Jelgersma-Pannekoek data, and approximately on a curve based on data from Shepard (1960, p. 339, fig. 1). (Shepard did not draw the curve, but one can be approximated using primarily points for the Texas bays and Texas shelf probably outside the influence of the Mississippi delta which is known to be subsiding (Shepard, 1960, p. 343).) The data obtained by Jelgersma and Pannekoek are in the area of the Rhine delta and also of the North Sea structural basin, and therefore may be too low by a small factor of subsidence or crustal deformation (Jelgersma, 1961, p. 45-46, fig. 22). The Shepard data similarly may be slightly too low, because of deformation (Shepard, 1960, p. 344).

If the curves drawn by Fairbridge and by Jelgersma represent or are slightly below the true course of eustatic sealevel rise, the fact that the data on the southern shore of Connecticut plot even lower than these curves, suggests that this area is influenced by another factor. The Triassic or crystalline bedrock lies within a few hundred feet along the Connecticut coast. Accordingly, appreciable compaction of loose sediments or isostatic adjustment to load would seem to be negligible factors. Therefore, independent crustal subsidence may be the added factor.

The individual contributions of eustatic rise of sealevel and subsidence of the land which gave the relative change of sealevel observed at New Haven can not be separated by the data presented in this paper. However, the increased interest in sealevel changes and the many quantitative coastal studies being made at present, give one hope that this may be done soon.

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