Bedrock Valleys of the New England Coast as Related to Fluctuations of Sea Level

By JOSEPH E. UPSON *and* CHARLES W. SPENCER

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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Depths to bedrock in coastal valleys of New England, and nature of sedimentary fill resulting from sea-level fluctuations in Pleistocene and Recent time

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By Joseph E. Upson and Charles W. Spencer

ABSTRACT

Test borings for bridges crossing 14 New England rivers or bays near the coast (including Narragansett and Passamoquoddy Bays) reveal information on depths to thalwegs of buried bedrock valleys and on the nature of contained unconsolidated sediments. An attempt is made to infer from these data something of the time and rate of sea-level rise in late- or post-glacial time as one phase of the general problem of encroachment of salty ground water from the sea.

Thalweg elevations near the coast range from about −95 feet msl (mean sea level) to about −420 feet msl. Virtually level reaches on the Blackstone buried valley at about −200 feet msl and on the Charles at about −250 feet msl suggest at least local base levels. The bedrock valleys were formed before the Wisconsin Glaciation, and the thalweg elevations are not considered to be a measure of sea-level decline at the Wisconsin maximum.

The unconsolidated deposits within the bedrock valleys are of late and post-Pleistocene age, and differ systematically along the coast. In the valleys off the Connecticut coast, fluvioglacial outwash, possibly related to a stand of the ice at Middletown, Conn., is overlain in irregular contact by estuarine deposits extending to about present sea level. Valleys in the Boston area and in southern Maine contain mainly glacial-marginal marine clays, also overlain by estuarine deposits. Estuarine deposits of appreciable thickness apparently do not occur in eastern Maine. The deposits in Narragansett Bay have elements of both sequences.

The estuarine deposits probably represent the last major eustatic rise of sea level. The underlying surface was probably formed by subaerial erosion during a period of relatively lowered sea level accompanying the readvance of ice of late Wisconsin stade, such as Mankato (Port Huron) or Valders (Flint, 1957, p. 346–347, Leighton, 1960, p. 547–548).

If this explanation is correct, then the overall rate of rise of sea level along the southern New England coast, and also along coasts farther south, can be approximated by properly placing the period of low level in the late- and post-glacial chronology. If it is of Valders (Flint, 1957; p. 346–347) age, then the rise has taken place in about the last 10,000 to 11,000 years.

INTRODUCTION

The New England coast, from the New York State line to the Canadian border, is predominantly rocky. The igneous and metamorphic rocks, buried beneath the coastal-plain sediments of New Jersey and Long Island, emerge at about New York City. Thence, east and north, except for Cape Cod and for local accumulations at other places of glacial and marine deposits, these rocks occur along most shores, either exposed or thinly covered. Along all coastal stretches exposed to the open sea, these rocks are washed clean within the zone reached by high tides and storm waves. At the mouths of the streams and rivers, however, the bedrock lies some distance below sea level.

Nearly every stream enters the sea above or near the site of a buried or submerged bedrock valley which contains unconsolidated deposits. At the shore the deepest parts of these valleys, the thalwegs, lie from a few tens of feet to more than 400 feet below present sea level. The largest of these valleys are those of: the Housatonic, Quinnipiac, Connecticut, and Thames Rivers in Connecticut; Narragansett Bay in Rhode Island and Massachusetts; the streams entering Boston Harbor, Mass.; and the Portland Harbor area, Passamaquoddy Bay, and the Kennebec and Penobscot Rivers in Maine. This paper deals with the depths below sea level of the so-called buried bedrock valleys of these harbors and rivers and with the nature of the sediments deposited therein.

PURPOSE OF THE INVESTIGATION

This investigation is part of a broad program of research intended to determine the relationships between fluctuations of sea level in relation to the land in Pleistocene and Recent times, and the occurrence and movement of salty ground water (presumably marine) in coastal areas. This research is multifaceted; some of its chief aims are to determine the sequence and magnitude of the sea-level fluctuations themselves, as well as their rate of rise or fall particularly in the last

5,000 to 15,000 years. Much has been written about the eustatic declines of sea level that doubtless accompanied periods of glacial maximums. Many writers, including the present senior author (Upson, 1949), have ascribed the presence of coastal stream valleys at depths appreciably below present sea level to erosion during lowering of sea level accompanying the maximum of Wisconsin Glaciation. This explanation is somewhat too simple when applied to the valleys of New England, especially because some of the valleys have a veneer of Wisconsin till.

This study was undertaken to find evidence pertaining to the origin of the bedrock coastal valleys, to obtain data on the nature and age of the sedimentary fill within them, and to draw conclusions, if possible, on the time and rate of the last rise of sea level.

Data on the size and dimensions of the bedrock valleys and lithology of the contained sediments were also obtained and are useful in evaluating the buried valleys as ground-water reservoirs. Originally it was planned to obtain data on the occurrence of salty ground water in the deposits in the coastal parts of the valleys, but the records examined give practically no information on that subject. There are, of course, considerable data for a few small areas, such as New Haven and Bridgeport, Conn., which are considered as separate problem areas and which are not discussed intensively in this work.

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[1] In 1962, at Cornell University.

[2] In 1962, at California Institute of Technology.

PREVIOUS INVESTIGATIONS

A regional geologic picture of the New England coastal valleys has not been presented previously, although some detailed work has been done locally; and, in general, the existence of buried valleys has been known for many years.

Brown (1925, 1928) studied the occurrence of salt water in the unconsolidated deposits in the New Haven, Conn., area, and obtained data on New Haven Harbor and the lower end of the Quinnipiac River. Cushman (1960) gave a bedrock contour map of the Connecticut River valley in Connecticut north of Middletown. The significance of the Rhode Island buried valleys as a source of large volumes of ground water was noted by Roberts and Brashears (1945). Since 1945, most reports pertaining to ground-water resources in Rhode Island have included data on depth to bedrock and possible locations of buried or partly filled valleys.

Early workers concerned with these features in eastern Massachusetts were W. O. Crosby (1899, 1903) and F. G. Clapp (1901) who attempted to work out the preglacial drainage system. The ground-water potential of buried valleys in the Greater Boston area has been recognized and investigated in more recent years by I. B. Crosby (1937, 1939), Halberg and Pree (1950), and N. E. Chute (1959).

For New Hampshire and Maine, I. B. Crosby (1922) proposed possible alinements of the preglacial Androscoggin River, and Perkins (1927) suggested a possible history of drainage development for the Kennebec River in the vicinity of Waterville, Maine. Depths to bedrock, location of bedrock valleys, and nature of unconsolidated deposits in the Passamaquoddy Bay area of northeastern Maine have been studied (Smith, Upson, and others, 1952; Upson, 1954) as part of the proposed tidal-power project.

METHOD OF INVESTIGATION

Work was begun in late spring of 1958. Information on surface and subsurface geology was collected during parts of the summer and fall of 1958 and during the spring of 1959 at 39 sites on 14 rivers or bays near the coast. Narragansett Bay and Passamaquoddy Bay are each counted as a site. Many single wells are not included in the 39 sites. Twenty-three detailed geologic cross sections were prepared from engineering boring data on highways, bridges, and tunnels. Three detailed sections and simplified versions of 15 others are included in this report. Engineering boring data were found to be the best source of subsurface geologic information because the borings are generally closely spaced along the line of a proposed structure and are accurately located. The lithologic logs of these borings are usually very detailed and, because the samples taken from the borings of any one line were usually described by the same individual, the lithologic descriptions have a certain uniformity that was helpful in inferring stratigraphic correlations. On the other hand, not all borings penetrated the surficial deposits to bedrock, and a line of borings could not always be extended completely across a buried valley. (For example, see pl. 1*C*.)

The accuracy of the stratigraphic correlations shown on the sections depends, in part, on the quality of the original sampling procedures and the descriptions of samples. Sites of boring data and the bedrock valleys were visited in the field. Examination of bedrock outcrops and of exposures of surficial deposits facilitated subsurface stratigraphic correlations. Actual core samples from a number of borings, especially in Connecticut, were examined. Many plans of borings examined during the course of this study include data on the number of hammer blows required to drive a given sampling spoon a specific distance into the materials penetrated. These "blow counts" were often helpful in detecting lithologic changes and thus in correlating stratigraphic units.

GENERAL GEOLOGIC SETTING

Most of the New England coastal stream valleys occur in terranes underlain by relatively competent metamorphic and igneous rocks ranging from Precambrian to Paleozoic in age. A few of the stream valleys however, occur in or cross areas of less resistant sedimentary and low-grade metamorphic rocks that occupy downfolded or downfaulted basins. These rocks include some intrusive and extrusive igneous rocks. The principal basins are the Connecticut Valley Lowland, Narragansett Basin, and Boston Basin. (See fig. 1.) The rocks of the Connecticut Valley Lowland are of Triassic age; those in the Narragansett and Boston Basins are of late Paleozoic age. The Triassic sedimentary rocks are somewhat less resistant to erosion than the Paleozoic sedimentary and metasedimentary rocks. The igneous rocks in the Connecticut Valley Lowland and Narragansett Basin are substantially more resistant than the surrounding sedimentary rocks; those in the Boston Basin are about as resistant as the enclosing sedimentary and metasedimentary rocks. Of course, both the relatively resistant and the less resistant rocks have joints, faults, or interbedded weaker strata whose alinements follow the trend of the valleys locally.

This report is chiefly concerned with that part of the Connecticut River valley which lies across the resistant rocks downstream from where the river leaves the Connecticut Valley Lowland. The valley of the Quinnipiac River near New Haven, on the other hand, is cut in the less resistant Triassic sedimentary rocks of the lowland. Elsewhere, the deep valleys of Rhode Island were cut almost entirely in the sedimentary rocks of the Narragansett Basin; similarly, the deep valleys of Massachusetts were cut in the sedimentary rocks of the Boston Basin. Additional information about the relationships of the stream valleys to the areas of resistant and less resistant rocks is given in the discussion of the individual valleys.

Except for the Triassic rocks of the Connecticut Valley Lowland, most of the bedrock of coastal New England is nowhere younger than Permian. Thus, throughout the Mesozoic and Tertiary, this bedrock has undergone a long and complicated erosional history. Johnson (1931, p. 15–19) showed diagrammatically his interpretation of the evolution of various erosion surfaces. The most generally recognized of these surfaces is the Fall Zone peneplain (Sharp, 1929) of Cretaceous age, which probably formed prior to and contemporaneously with the deposition of the marine and continental deposits of Cretaceous age in the coastal plains area. Johnson believed that these coastal plain deposits extended a good many miles landward of the present shore and that superposition on the uplifted and tilted surface of this blanket of sediments accounts for the direction of the main stream courses. For example, the lower courses of the Housatonic, Connecticut, and Blackstone Rivers have a marked southeasterly alinement and are generally discordant with the alinements of the bedrock structure. The present authors discuss the subsequent erosional history no further than to point out that the interval between the Cretaceous Period and the Pleistocene Epoch was long enough to allow for the formation of sizable valleys in bedrock and that the erosion could well have occurred in more than one erosional stage. Flint (1930, p. 46–49) discussed the amount of glacial erosion in Connecticut and concluded that it was not great, and certainly not enough to form the bedrock valleys. The writers consider that the bedrock valleys were developed in about their present form and depth before the Pleistocene. The lowest parts however, may not have been formed until the late Tertiary or even the early Pleistocene.

The effect of glacial erosion, either scour by ice itself or erosion by subglacial streams, is unknown. In general, the amount of glacial erosion on upland areas is probably only a few feet except in local areas of weak or much-jointed rock. In mountain valleys, however, glacial erosion may at places be great (Flint, 1957, p. 92–97), although just how much of the erosion in any one valley is due to preglacial stream work and how much is due to ice usually cannot be determined. The same erosive processes presumably operate in valleys of nonmountainous areas. In southern New England, one of the most outstanding examples of probable glacial overdeepening is in the valley of the Connecticut River. At Middletown the bedrock valley appears to reach a minimum elevation of about −120 feet msl (mean sea level) (fig. 2), whereas about 15 miles farther north at East Hartford bedrock was penetrated in a well at more than −200 feet msl (Cushman, 1960, p. 104, 105). Tuttle, Koteff, and Hartshorn (1960, p. 1994) presented seismic and other data showing that near Springfield, Mass., some 40 miles north of Middletown, the bedrock in the Connecticut valley reaches an elevation of −118 feet msl.

These data suggest overdeepening of the valley, at least in the vicinity of East Hartford, amounting to about 100 feet. In the overdeepened reach the bedrock consists of Triassic sandstone and shale, rocks probably considerably less resistant than the crystalline granitic and metamorphic rocks that underlie most of southern New England and somewhat less resistant than even the sedimentary rocks of Paleozoic age that underlie the Narragansett and Boston Basins and parts of the New Hampshire and Maine coast. Some local overdeepening also may have taken place in other valleys, discussed in this report.

In general, however, the writers believe that the buried valleys here described were originally formed as stream valleys and that, although they may have been modified locally by glacial erosion, most of the depth is the result of stream erosion.

Pleistocene glacial deposits occur in all the bedrock valleys of the New England coast, completely filling and concealing a few of them but only partly filling the others. The deposits are probably almost entirely of one or another of the Stades of the Wisconsin, although locally there may be remnants of pre-Wisconsin drift. The sequence of late Wisconsin events has been summarized by Flint (1953) who suggested that the Long Island moraines were of Iowan and Tazewell age. More recently Denny (1956) suggested that the Valley Heads (Cary) ice margin reached Long Island where it formed the Harbor Hill moraine. At its maximum extent, the ice reached at least as far as Long Island and Cape Cod, and southeastward well beyond the present Maine coast. Certain features of the glacial deposits in the vicinities of Middletown, Conn., and of Boston, Mass., have been interpreted as a readvance of continental ice and considered to represent the Cary Stade (Flint, 1953, p. 898, and pl. 2). In more recent years, considerable systematic areal mapping of surficial deposits, as well as of the bedrock, has been done at scales of 1:31,680 and 1:24,000. Much is known in detail about the deposits that are exposed, particularly in southern Connecticut, the Narranganesett Basin, and at one or two localities in the Boston area. For example, Kaye (1961, p. B–75) described deep-lying glacial deposits at one locality in Boston, Mass., some of which he considered to be Illinoian and some of Kansan or Nebraskan age. Descriptions of the unconsolidated deposits that follow are not intended to summarize all that is known about the stratigraphy of the deposits, but rather to generalize the stratigraphy in units that are significant for this report.

The deposits are of varied lithology. They include the following: Till; gravel, sand, and silt formed both in valley trains and in contact with melting or stagnant ice; sand, silt, and clay of glaciolacustrine origin; marine silt and clay laid down in shallow-water estuaries and bays as the sea invaded low-lying land still depressed by the ice load; other estuarine deposits clearly postglacial in age; and fine sand, silt, clay, and peat in still younger tidal marshes. Table 1 summarizes the characteristics of the units and their occurrence in the several valleys.

Conclusions as to the origin of the bedrock valleys discussed in this paper are based in part on the lithology and sequence of the different deposits that occur in the buried valleys. These stratigraphic characteristics are interpreted from records of borings. The deposits are described in more detail and conclusions are drawn in the parts of this paper that deal with separate valleys or groups of valleys.

It is difficult to establish and use consistently a standard designation for the valleys, but for the most part the term "bedrock valleys" is used. Only in places where the valleys have no surface expression can they truly be termed "buried." Most of the valleys are merely the partly submerged or filled deep-lying near-shore parts of visible valleys that lead to the sea. Many of them are long, narrow estuaries in which the concealed bedrock valleys coincide with the observable topographic depressions. Where applied, the term "bedrock valley"

TABLE 1.—*Summary of stratigraphy of unconsolidated deposits in New England bedrock valleys*

Stratigraphic unit	Thickness (feet)	Lithology	Occurrence and remarks
Fluviatile and tidal marsh deposits.	[1] 0–20	Mud, silt, and sand. Tan to black. Contain shell fragments locally and layers of plant remains and peat generally.	Occur locally in all areas. Transitional downward with and interfingers with estuarine deposits.
Estuarine deposits	0–135	Mud, clay, silt, and sand; some gravel. Moderately well sorted; generally soft. Usually tan or brown, but locally gray. Contain considerable plant carbon, and locally shell fragments. At some places, include fresh-water peat or tidal marsh deposits.	Occur in Connecticut coastal valleys, Narragansett Bay, Boston area, and southern Maine. Appear to be progressively thinner northward; in eastern Maine deposits are thin and, locally, may be missing entirely. Recent age. Where present, rest unconformably on underlying glacial deposits.
Glacial-marginal marine deposits.	0–240	Clay, silt, and fine sand; contain some pebbles locally, probably ice rafted. At many places laminated, with individual layers very well sorted. Commonly stiff or tough. Gray to blue, but locally black; tan to brown where weathered. Contain fragments of shells, especially in upper part.	Boston area, entire Maine coast, and possibly Narragansett Bay. Not necessarily fully contemporaneous everywhere. Apparently entirely missing from the Connecticut valleys. Recent to mid-Wisconsin age.
Stratified drift	0–300±	Mostly sand, fine to coarse, and gravel; some clay and silt. Well to poorly sorted. Where exposed is evenly to crossbedded. Locally includes varved clay and other lacustrine deposits. Gray, tan, or red-brown.	Thickest in Connecticut valleys and Narragansett Bay area. Occurs also in the Boston area and locally in southern Maine. Includes deposits above and below the glacial-marginal marine deposits. Mainly middle and late Wisconsin in age.
Till	0–75±	Clay, silt, sand, gravel, cobbles, and boulders. Heterogeneous, poorly sorted, and—at places—compact.	Occurs in all areas. Where below sea level, it is mainly thin and lies discontinuously on bedrock. Locally, some till occurs interbedded with outwash or resting on glacial-marginal clay. May represent more than one glacial substage and is not necessarily contemporaneous everywhere. Middle and late Wisconsin in age.
Older glacial deposits	------------	------------	Till and stratified drift, possibly representing early and pre-Wisconsin glacial deposits, in a deep excavation in Boston have been described. They have not been recognized in other areas.

[1] Generally +10.

distinguishes the concealed part, the main subject of discussion, from the visible feature. On the other hand, the bedrock valleys of the Boston area are so deeply filled and covered by deposits that they are completely concealed throughout much of their length. In most older reports, these valleys are referred to as "buried," and one of them has the word "buried" as part of its name. Therefore, the bedrock valleys of the Boston area are generally referred to as "buried valleys."

LOCATION OF SECTIONS AND SOURCES OF DATA

The bedrock valleys are separated into four groups based partly on geographic location and partly on the types of contained deposits. These groups are: (1) coastal valleys of Connecticut, (2) valleys of the Narragansett Bay area, (3) the Boston Basin area, and (4) the Maine coast. The outline map, figure 1, shows the streams and areas referred to, and the locality numbers for sections along the Connecticut and Maine coasts. Locality numbers for Narragansett Bay and the Boston Basin area are shown on separate larger scale maps elsewhere in the text. Information on the localities and the sources of the data are given in tables in the parts of the text that deal with each group.

The names of highways and bridges, small towns, and topographic features mentioned in the tables and text and shown in plates 1, 2, and 3 and in figures 2, 5, and 8 are included, not for reference in this report, but primarily to aid readers who may wish to study more deeply the data for particular sections. For example, it is sufficient for this report and for the general reader to indicate that the section shown in plate 1*D* at locality 4 (fig. 1) is about at the mouth of the Connecticut River. The reader familiar with the area will recognize the Raymond E. Baldwin Bridge. Others can readily find Old Saybrook and Old Lyme on the appropriate topographic maps. Also, the name of the bridge and the highway route number will assist the student to search, for example, the files of the Connecticut State Highway Department for the original boring records.

The sections were all obtained from State, municipal, or private agencies, and the numbers of the boreholes are those that appear on the records of the agency under which the work was done. (See p. M2.)

CONFIGURATION AND DEPTH OF BEDROCK VALLEYS AND STRATIGRAPHY OF FILL

BEDROCK VALLEYS OF COASTAL CONNECTICUT

GENERAL FEATURES

Bedrock valleys of coastal Connecticut here discussed are those of the large streams—namely, beginning on the west, the Housatonic, Quinnipiac, Connecticut, and Thames Rivers. The bedrock valleys all lie beneath the present valleys of the respective streams. The courses and bedrock valleys of the Housatonic and Thames Rivers are entirely within the terranes of the crystalline (predominantly gneissic and schistose) rocks of the western and eastern highlands of the state. (See Rodgers and others, 1956.) The Quinnipiac, on the other hand, is entirely within the structural lowland, called the Connecticut Valley Lowland, formed by the much less resistant red sandstones and shales that compose the various members of the Newark Group of Triassic age. (See Krynine, 1950.) The course of the Connecticut River north of Middletown is within this same lowland, but near the coast it is in the crystalline terrane. These streams, the location of detailed sections studied, and the position of the Connecticut Valley

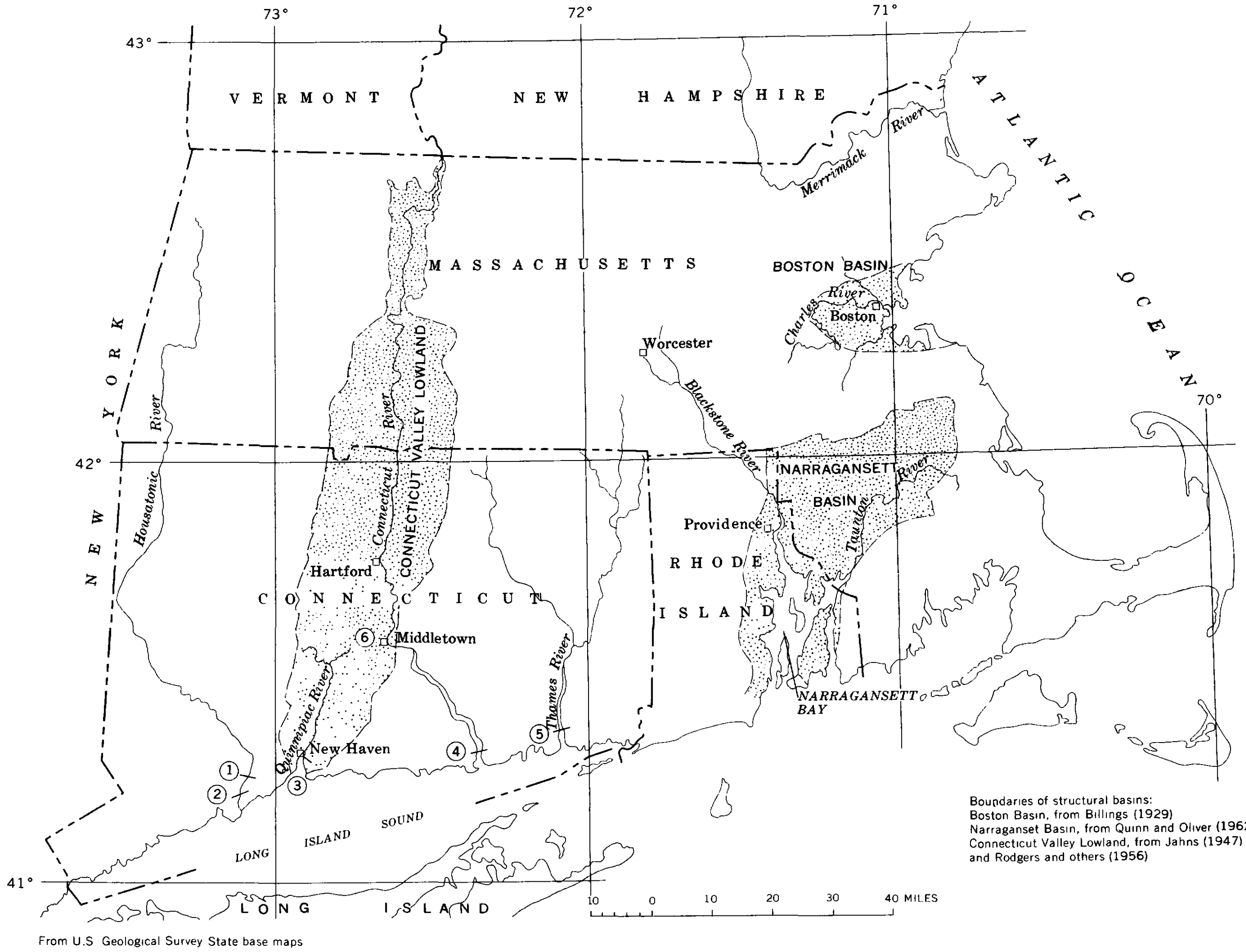


Figure 1.—Index map of New England showing rivers, location of sections, and major structural basins. Numbers in circles are cross-section locality numbers.

Lowland are shown in figure 1. Sections of the buried parts of these stream valleys are shown in plate 1.

Data were obtained on six crossings, two each for the Housatonic and Connecticut, and one each for the other two rivers. Table 2 identifies the valley, locality number shown in figure 1, and the structure and agency for which the borings were made. The data on distance of the site from the coast, the depth of bedrock thalweg, and depth of the base of estuarine deposits are summarized in table 6, page M37.

DEPTH OF BEDROCK THALWEGS

The lowest observed elevations of the bedrock surface in the valleys of the Connecticut coast range from −92 to at least −280 feet msl. The thalwegs, or actual lowest points, for the Housatonic and the Thames are fairly closely controlled, and the figures for approximate depth of the thalwegs at the crossings are probably

Table 2.—*Summary of information on bridge foundation borings at crossings of bedrock valleys in Connecticut*

Bedrock valley	Locality No. on fig. 1	Bridge	Date on which borings were made for Connecticut State Highway Dept.	Topographic quadrangle maps, Connecticut on which bridge and environs are shown
Housatonic	2	Connecticut Turnpike between Stratford and Milford, Conn.	1954, 1955	(1)
Do	1	State Route 15 between Stratford and Milford, Conn.	1938	Ansonia and Milford.
Quinnipiac	3	Connecticut Turnpike in New Haven, Conn.	1956	New Haven.
Connecticut	4	Raymond E. Baldwin Bridge (U.S. Route 1) between Old Saybrook and Old Lyme, Conn.	1946	Lyme.
Do	6	U.S. Route 6A between Middletown and Portland, Conn.	1936	Middletown and Middle Haddam.
Thames	5	Gold Star Memorial Bridge (U.S. Route 1) between New London and Groton, Conn.	1940	New London.

[1] Lies immediately south of and parallel to railroad bridge on Milford quadrangle.

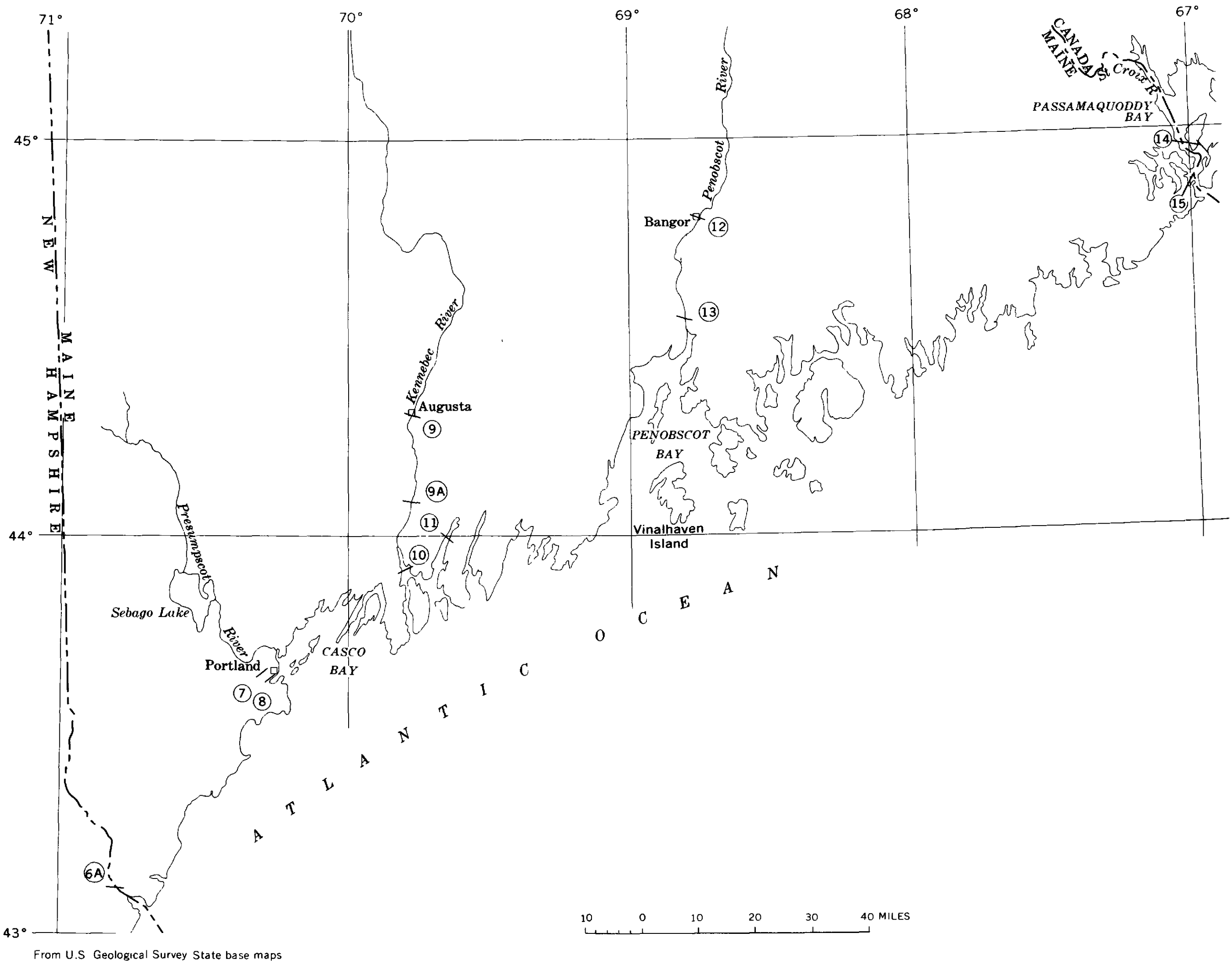


FIGURE 1—Continued.

accurate to within 10 feet. The data on the Quinnipiac River and on the Connecticut at the coast are not definitive; the thalweg depths are probably appreciably greater than the greatest observed depth at which the bedrock was penetrated. Some detailed comments follow.

HOUSATONIC RIVER

Data are available for several bridges across the Housatonic. The best are for State Route 15 (loc. 1, fig. 1) and for the Connecticut Turnpike (loc. 2, fig. 1), about 3.5 miles farther south. Some information on borings for the Washington Bridge, next bridge to the south, is available but is not used here because it adds little additional data.

Plate 1*A* shows a section based on selected borings made for the State Route 15 Bridge (connecting the Merritt and Wilbur Cross Parkways) across the Housatonic between Stratford and Milford, Conn. The crossing is about 6 miles above the river mouth. The section extends across only about half the valley, but probably includes the buried thalweg. The deepest point in the section is −79 feet msl at boring 106–B. The deepest known point at this crossing is at boring 107–A, 60 feet north of 107–C, where the bedrock was penetrated at about −92 feet msl.

Plate 1*B* shows the subsurface conditions as interpreted from logs of borings for the Connecticut Turnpike bridge. For this section, the borings are numerous, and the bedrock is cored. The bedrock profile is considered to be well controlled. The greatest known depth to bedrock is at boring 34–HR (about 80 ft north of boring 33–HR shown in the section), where the bedrock surface lies at −115 feet msl. Accordingly, the bedrock is shown at this depth in plate 1*B*. In addition to this main bedrock valley, borings numbered 9–HR through 21–HR, near the west end of the section, delineate a subsidiary buried bedrock channel.

QUINNIPIAC RIVER

Plate 1*C* shows the bedrock surface and lithology of unconsolidated deposits on the eastern side of the Quinnipiac River bedrock valley at New Haven, Conn. The bridge is 350 feet northeast of the old Forbes Avenue-Water Street bridge and just south of the confluence of the Mill and Quinnipiac Rivers.

The depth of the thalweg here is not known. The deepest bedrock shown in the section was penetrated at boring 99, where the surface lies at −171 feet msl. The best data on the deepest position of bedrock in the New Haven area were obtained from a log of a well drilled for the New Haven Clock Co., about 2,000 feet N. 21° W. of boring 82–D. Here the well went to 280 feet below sea level without reaching bedrock. Data on two other drill sites in the vicinity of Wallingford, about 12 miles west-northwest of New Haven, suggest that the bedrock is at depths of 243 and at least 190 feet below land surface, which is a few feet above high tide level. Thus, it is likely that this buried bedrock valley is considerably deeper than the maximum observed depth shown in plate 1*C*.

CONNECTICUT RIVER

The Connecticut River heads in northern New Hampshire, and flows generally south between New Hampshire and Vermont. It crosses about the middle of Massachusetts, and continues south in Connecticut about to Middletown. (See fig. 1.) Here it changes abruptly to a nearly due easterly course, which it follows for about 5 miles, and then changes to a sinuous but generally south-southeasterly course for about 22 miles to Long Island Sound. The course across Massachusetts and as far as Middletown in Connecticut lies in the structural basin, where here is underlain mostly by sandstones and shales of Triassic age. Just below Middletown the river crosses the eastern boundary of the basin. Thence downstream, the Connecticut occupies a rather narrow gorge cut in the much more resistant crystalline rocks, mainly gneisses. Because it is tidal as far upstream as Hartford, the lowermost 15 to 20 miles of the stream is more like a long, narrow estuary than a river.

The Connecticut River also has a buried bedrock valley which locally departs somewhat from the position of the present stream. Within much of the Connecticut Valley Lowland, the thalweg of the bedrock valley lies a short distance east of the present stream (Flint, 1933; Cushman, 1960, fig. 2). Near Middletown the thalweg of the bedrock valley may swing eastward in a broad curve that cuts off the sharp right-angle bend of the present course. Thence to the southeast, the bedrock valley lies beneath and is part of the present Connecticut River gorge.

Data for two crossings of the Connecticut River and its bedrock valley are considered here. One crossing is at Middletown at the Middletown-Portland Bridge (loc. 6, fig. 1), and the other is near the river mouth at the Raymond E. Baldwin Bridge for U.S. Route 1 between Old Saybrook and Old Lyme (loc. 4, fig. 1). The bedrock configuration is fairly well delineated at the Middletown-Portland Bridge, but most of the borings for the Baldwin Bridge did not reach bedrock. The stratigraphy of the deposits in the bedrock valley at these two sites is markedly different. The difference sheds some light on the glacial history of the lower Connecticut River that is pertinent to the present paper. (See p. M12.)

Figure 2 shows the configuration of the bedrock and lithology of the fill as interpreted from borings for the U.S. Alternate Route 6 and State Route 17 bridge between Middletown and Portland, herein called the Middletown-Portland Bridge (loc. 6, fig. 1). The lowest known elevation of bedrock here is −118 feet msl in boring 13–S. The bedrock may lie somewhat deeper because there is considerable area between boring 12–S and 13XS and between boring 12–S and STA 110+18 that is unexplored. However, a conservative estimate is −120 feet msl.

The Middletown-Portland bridge may not be over the thalweg of the main Connecticut bedrock valley which may follow the possible eastern cutoff of the sharp bend at Middletown. If the main bedrock valley follows the cutoff, it would pass about 3 miles east-northeast of Middletown. (See the Middletown and Middle Haddam quadrangles, Connecticut, scale 1:31,680, and Cushman, 1960, fig. 2.) In the cutoff the lowest known elevation of bedrock is −112 feet msl, but it may be as low as −120 feet msl (R. V. Cushman, personal communication, 1959). This is comparable to the inferred elevation at the Middletown-Portland Bridge. Even if that bridge were over a tributary to the main valley, as Bissell (1925, p. 235) suggested, the maximum depth would still be about the same as on the main thalweg because the point of junction can not be more than a few miles away and the gradient is low.

Plate 1*D* shows subsurface geology of the Connecticut bedrock valley as interpreted from lithologic logs of borings made for the Raymond E. Baldwin Bridge that crosses the river near Long Island Sound. This bridge, about 25 miles below Middletown, carries highway traffic for U.S. Route 1, Interstate Route 95, and the Connecticut Turnpike over the Connecticut River between Old Saybrook and Old Lyme, Conn. (See loc. 4, fig. 1.)

This section, unfortunately, shows comparatively little about the depth and configuration of the bedrock.

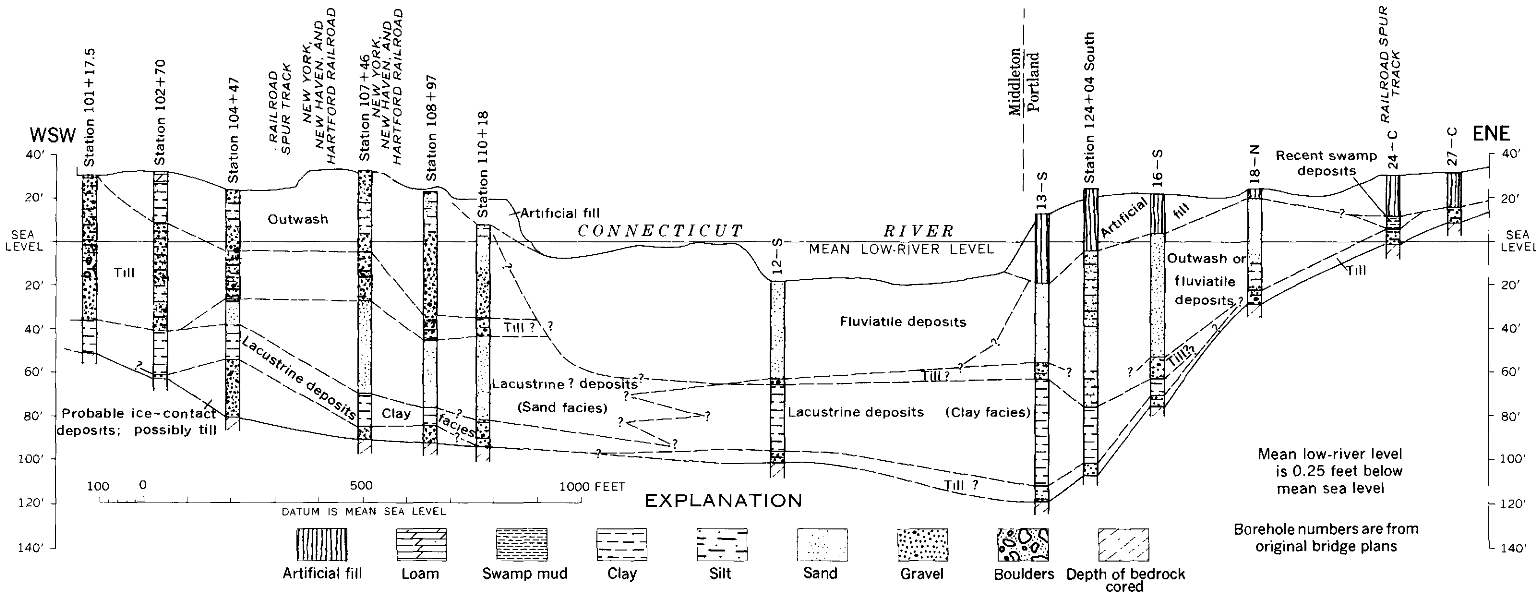


Figure 2.—Section of the Connecticut bedrock valley at highway bridge between Middletown and Portland, Conn. For location of section see locality 6, figure 1.

Bedrock is close to the land surface at the east abutment of the bridge. The west abutment of the bridge is probably about over the middle of the bedrock valley because the nearest exposed bedrock on the west side of the river is about half a mile to the west. Within the bedrock valley, bedrock was penetrated in the following five borings: 8–SW, 8–NW (not shown; about 85 ft north of 8–SW), 9–SE, 9–NE (not shown; about 85 ft north of 9–SE), and 5–B, all on the east side. The lowest observed position of the bedrock surface is at boring 8–NW (about 85 ft north of 8–SW), at an elevation of about −132 feet msl. At boring 8–SW, the elevation is about −130 feet msl.

The depth of the thalweg is not known. In the vicinity of East Haddam, which is along the river about 10 miles upstream from the Baldwin Bridge, data on a few water wells suggest that bedrock there is more than 100 feet below sea level. Another well drilled in the southeastern part of Middletown on the west side of the river and about 20 miles upstream from the Baldwin Bridge penetrated unconsolidated deposits to 155 feet below sea level without reaching bedrock. The thalweg beneath the Baldwin Bridge probably lies deeper than 200 feet below sea level.

THAMES RIVER

The Thames River is a narrow estuary that extends about 15 miles northward from Long Island Sound. Several streams come together at the head of the estuary. The bedrock beneath the tributaries is generally shallow, and the thalweg of the valley system apparently deepens abruptly at the head of the estuary.

Fairly complete data on the bedrock surface are available from borings taken at the U.S. Route 1 bridge near the mouth of the estuary at New London. (See pl. 1*E*.) The bedrock surface in this section is well controlled because nearly all the borings penetrated to bedrock. The present Thames is approximately centered over its bedrock valley whose profile is roughly symmetrical, although locally irregular, as shown at borings 9–K, 10–A, and 10–B. The lowest known elevation of the bedrock surface was found at boring 9–J, where the bedrock surface is −174 feet msl. On the basis of a projection of slopes, the minimum inferred elevation is about −190 feet msl, although a somewhat lower elevation would be reasonable.

UNCONSOLIDATED DEPOSITS

The unconsolidated deposits in the valleys of the Connecticut coast include for the most part three units which, from the base up, are identified as till, outwash, and estuarine deposits. These units each occur with slightly different characteristics or with somewhat different thickness or extent in the valleys, but they are all present. Their characteristics and relationships are described in more detail in following paragraphs. In the section at the Middletown-Portland bridge are more units; these deposits are discussed separately (p. M12).

TILL

In all the sections many of the borings penetrated a layer of coarse-grained material at the base. This material is poorly sorted, generally consisting of coarse gravel, boulders, cobbles, and some clay. Many records indicate a high blow count for penetration of this layer, and in some sections the material is described as "hard." The coarse grain, poor sorting, and high blow count indicate that the layer is till. As it is not reported in all borings (see, for example (pls 1*C* and 1*D*)), the layer is probably discontinuous.

At some sections, for example on the Thames (pl. 1*E*), the till is clearly distinct from overlying material. In others, as on the Housatonic (pl. 1*B*), the overlying material is also coarse grained and the distinction is not clearcut. Where doubtful material is believed to represent till, it is indicated by "till?" on the section shown in plate 1. In exposures near all the sections, a layer of till ranging from 1 to 20 feet in thickness can be observed locally resting on the bedrock. This basal till probably extends, at least discontinuously, down the sides of the concealed parts of the bedrock valleys.

OUTWASH

Above the till is better sorted material, consisting of sand and silt, some gravel, and a little clay. In the Houstatonic valley this unit is mostly sand and gravel, but the gravel is finer grained than the material below. Although this unit contains some clay locally, it is not described as "hard."

Some clay also occurs in the unit in the Quinnipiac valley, as indicated by some boring records which report layered sand and clay and some sand partings. Although traces of bedding do not appear in most samples examined, one sample from boring 84 (70 ft northeast of boring 83, pl. 1*C*) is well-stratified pink-brown silt and clay interbedded with some very fine sand. The position of other reported stratification is shown on plate 1*C* by the lines indicating clay at several borings in the western part of the section.

In the Connecticut and Thames valleys, this outwash unit is predominantly sand, although at some places it is gravelly in the upper part. Borings 1, 2–N, and West Abutment (pl. 1*D*) start in sand, gravel, cobbles, and some silt; similar materials make up the stratified drift, which is exposed nearby. At greater depth some of these borings penetrate uniform sand and silt, as do borings 3, 4, 5, 6, 7, and 8–SW. This material, although fine-grained, is considered to be part of the outwash unit. Exposures of this unit farther upstream also have coarse-grained deposits in the upper part and fine-grained deposits in the lower (J. A. Baker, written communication, 1959).

This unit underlies and forms terrace remnants whose surfaces are 20 or 30 feet above sea level at the Baldwin Bridge (pl. 1*D*), and which are traceable for several miles upriver. In the vicinity of Middletown the terrace surface stands at about 200 feet above sea level, and is the surface of the outwash mentioned by Flint (1953, p. 899) as marking the terminus of the readvanced Cary ice tongue. Therefore, at least the upper part of this outwash is of the same age as the ice tongue at Middletown, which is Cary.

In the Thames valley this outwash is predominantly sandy on the east side as shown by borings 10–E, 10–F, 11–A, and 11–B (pl. 1*E*) but contains some clay and gravel in the west side of the section. Clayey sand and sand with some clay was found in borings 11–E, 11–F, and 12. The heterogeneous material may have been deposited near ice, and the predominantly sandy material may have been deposited some distance from the ice by melt-water streams or in lakes. No organic remains are reported to occur in this unit.

Insofar as its characteristics are revealed by the records of borings, the outwash seems to be in each valley a single unit. However, its manner of deposition was probably complex. For example, Richard Goldsmith (1962) in discussing the surficial geology of the New London quadrangle indicated that the outwash deposits as exposed at the east end of the bridge are older than those that form lower terraces, as for example at about sea level in New London, Conn. Although not differentiated in the section, the deposits that are the highest and the farthest from the river may have been deposited in part against stagnating ice that occupied the central part of the bedrock valley. The lowest, central parts were deposited therefore after the ice had melted away. Thus, there may be local unconformities within the outwash. However complex its deposition, the outwash in the Connecticut valleys probably represents a single glacial retreatal episode.

The complexity of deposition is shown in the logs of borings 97 and 99 in the Quinnipiac valley (pl. 1*C*) where a few shells are reported. The log of boring 97 reports, "shells and mica in brown coarse to fine sand with little fine gravel" between −65 and −70 feet msl. This sample was not examined. A sample from boring 99 in the interval −105 to −106.5 feet msl was examined and found to consist of very fine to coarse red-brown sand and to contain several white flakelike calcareous fragments. The largest fragment was 2×3 mm. These fragments are not clearly pieces of shell. Furthermore, because they occur at only one place in each of two borings, they may have been carried down from above during the drilling. Except for the shell fragments, the material is predominantly sand like the rest of unit 2. Therefore, although the shells may mark an unconformity within the deposits (as indicated by the queried (?) dashed line in pl. 1*C*), they are all considered to be outwash.

The full thickness of the outwash is not penetrated by the borings, but it is certainly more than 100 feet in the Quinnipiac and Connecticut valleys.

ESTUARINE DEPOSITS

Above the outwash is the third unit, which is predominantly fine grained and contains organic matter. The material is only slightly resistant to coring, and hence is "soft." In the Housatonic valley, it varies somewhat in grain size because it contains a good deal of sand, as well as some soft clay or mud. In the Quinnipiac valley, the unit is also sandy at some places, but the sand is mainly fine to medium. The material is gray in contrast to the brown or tan of the underlying outwash. Farther east the unit is predominantly of loose mud, clay, and silt.

At most borings the clay and silt are described on the boring records as "dark" or "organic;" and in all the valleys the unit contains shells and shell fragments, and locally wood and woody organic matter. In the Connecticut valley, for example, the boring logs record the presence of "organic silt," "grass roots," and "rotted vegetation." Because of the fine grain, softness, and content of organic matter, these deposits are considered to be estuarine deposits. The basal few feet locally may be fresh-water swamp material.

Material reported as "peat" is particularly conspicuous in the Housatonic (pl. 1*B*) and the Quinnipiac (pl. 1*C*) valleys. In the Quinnipiac valley the peat occurs at the base or in the lower layers of the estuarine deposits. This basal peat probably represents swamp conditions shortly prior to the beginning of estuarine deposition at this place.

In the Thames valley section (pl. 1*E*) the estuarine deposits range from 0 to about 110 feet in thickness. The deposits rest on an irregular surface which in the section appears to be channeled. This evidence suggests that this surface is an erosion surface formed on the underlying outwash. This topic is discussed more fully on page M13.

The presence of peat at the base in the Quinnipiac valley (pl. 1*C*) and in the marginal part of the estuarine deposits in the Housatonic valley (pl. 1*B*) suggests that swamp or tidal marsh conditions prevailed at least locally throughout much of the deposition of the estuarine deposits and, therefore, that the deposits were formed at the margins of a rising sea.

DEPOSITS AT MIDDLETOWN-PORTLAND BRIDGE

The deposits penetrated by the borings for the Middletown-Portland Bridge across the Connecticut River (loc. 6, fig. 1) are somewhat more varied than those near the coast. They appear to comprise six main units and two minor ones. These are, from bottom to top: (1) a basal till which may include some ice-contact deposits, (2) a unit of clay constituting lacustrine deposits, (3) a body of sand, which is probably a coarse-grained facies of the lacustrine deposits, (4) till, (5) a body of glacial outwash, and (6) present-day river deposits. The two minor units are a local body of swamp deposits, penetrated by one boring (24–C), and artificial fill. These two units are shown on the section (fig. 2) but are not further discussed.

The basal till is doubtless the clay, sand, and gravel penetrated at the bottoms of borings 12–S, 13–S, STA, 124+04 south, and 16–S. Borings 18–N, 24–C, and 27–C also penetrated material described as clay and gravel just above bedrock, which is considered to be till. This material, however, may not all belong to the basal till. The sand and gravel at the bottom on the west side of the river penetrated at borings 102+70, 104+47, 107+46, and 108+97 may be till, but the fact that the records do not mention clay suggests that the material may be stratified drift. If this material is drift, because it is directly on the bedrock, it is probably of ice-contact origin and only slightly younger than the basal till.

Every boring west of and including 16–S penetrated a variable thickness of nearly uniform red clay. One boring reportedly contained some gravel, and one contained some sand in the clay. This red clay is considered lacustrine, and probably represents the Middletown clay of Flint (1933, p. 968), which was deposited in a lake or lakes left when the retreating ice withdrew to some point north of Middletown.

Above this lacustrine clay in the western part of the section is a body of material described in the logs of three of the four borings as "fine red sand, hard." In the fourth, it is simply "red sand." This unit is either a coarse-grained facies of the lacustrine deposits, glacial outwash from ice that lay to the north, or both. The unit is designated as a sand facies of the lacustrine deposits.

The unit above is probably younger till. All the borings west of the Connecticut River penetrate a variable thickness of poorly sorted clay, silt, sand, gravel, and boulders. The description of part of the material as "gravel hard pan"—a term indicating compactness—and the heterogeneity of the material suggest that this unit is till. The unit overlies the sand facies of the lacustrine deposits at most borings but rests on the clay facies at the two westernmost borings. This unit reaches its greatest thickness, about 65 feet, at boring STA 101+17.5 and thins eastward. Similar, though more clayey material was penetrated at borings 13–S and 16–S on the east side of the river, where it rests on the clay facies of the lacustrine deposits. A 3-foot thickness of "gravel and red clay" was penetrated at boring 12–S at the top of the lacustrine clay. This unit also probably represents the younger till layer. East of boring 16–S the unit disappears or cannot be distinguished from the basal till.

This younger till may have been deposited by the readvancing ice, which according to Flint (1933) overrode and deformed the Middletown and Berlin lake clays. Its stratigraphic position above the lacustrine deposits is in accord with this view. As shown in the section, the younger till thickens westward and is exposed at the surface. West of the section it rests upon the bedrock and is indistinguishable from the basal till. Also, certain wells a short distance north of the line of the section (R. V. Cushman, oral communication, 1960) apparently did not penetrate till at intermediate depth. Thus this material might be interpreted as a mass of the basal till that became detached from a larger body to the west and slid out across the lacustrine deposits. The body, however, seems to extend across almost the entire valley, and the writers tentatively consider it to represent the readvancing ice. Flint (1953, p. 898) suggested that this ice was of Cary age. Later Flint (1956, p. 277) presented evidence to show that the readvance took place more than 12,700 years ago, which is compatible with a Cary age.

Above the younger till is a unit of varied stratified material. On the west side of the river, it is mostly sand and gravel with some clay; and on the east side it is predominantly sand. This material forms and underlies a terrace at an elevation of about 30 feet above sea level. It was evidently laid down during a late stage in the retreat of ice from the Connecticut valley.

The sixth unit is known only from boring 12–S, in the middle of the river, which penetrated about 45 feet of material described simply as "coarse sand." This unit extends to a depth of about 63 feet below mean low river level at the boring cited and is probably channel deposits of the present-day stream. This sand probably grades into the estuarine deposits that underlie the river farther downstream. (See pl. 1*D*.)

SUMMARY OF FEATURES OF CONNECTICUT COASTAL VALLEYS

The Connecticut bedrock valleys coincide with the present stream valleys and their extensions into estuaries. Near the coast the observed range in minimum elevations of these bedrock valleys is from about −115 to −174 feet msl; the inferred range is from about −120 to more than −280 feet msl.

The deposits within all the valleys have three recognizable stratigraphic units. At the base, discontinuous patches of till rest on the bedrock. Till also extends beyond the immediate vicinities of the bedrock valleys and at places forms thick or extensive ground moraine on the side of the valleys about sea level and on the adjoining uplands. This till is probably the same stratigraphic unit everywhere throughout the Connecticut coastal region, at least within a few miles of the shore.

The till is overlain mainly by fine- to coarse-grained sand and gravel that make up a unit of glaciofluvial outwash. Locally, this outwash extends above sea level and underlies terraces. These terraces are most clearly discerned along the Connecticut River, where they rise discontinuously upstream and terminate at a former ice border near Middletown. Along the other streams, the terraces are not so readily traceable, nor are their upstream terminations so clearly marked. These terraces were deposited during ice retreat, and are probably generally contemporaneous and of Cary age (p. M11).

The outwash is overlain by estuarine deposits. Upstream from the coast, the estuarine deposits are replaced by fluviatile deposits. The estuarine deposits grade upward and laterally into present-day tidal marsh deposits, and probably formed during the last general rise of sea level in Recent time.

Low points at the base of the estuarine deposits range from about −40 feet msl on the Quinnipiac to −130 feet msl on the Thames.

In his discussion of the outwash terraces along the Thames River, Goldsmith (1960) said that sea level was low until late in the depositional sequence, and suggested that the irregular surface of the outwash may be due to subaerial erosion, to collapse upon melting of the underlying ice, or to both before the sea rose to its present position. In this view, the now submerged surfaces at the base of the estuarine deposits are not necessarily erosional and may not have been formed after an interval of higher sea level. However, the low points on this surface at the two crossings of the Housatonic and corresponding points in the other stream valleys of Connecticut do fit a pattern suggestive of subaerial erosion. Such erosion might have taken place either during a final phase of ice retreat and outwash accumulation and before completion of a sea-level rise, or later after some epidode of higher sea level, traces of which either have been obliterated or are now submerged.

NARRAGANSETT BAY AREA

GENERAL FEATURES

The complex of marine passages which form Narragansett Bay appears to cover three main buried bedrock valleys. The locations of the thalwegs are given in figure 3. These are all extensions of known valleys that are present beneath the land areas mainly north of the bay. The westernmost of the main valleys is that of the Blackstone River. It has been traced along a course through Providence and Cranston to Greenwich Bay. The next valley to the east is herein called the Providence bedrock valley. This valley is mainly beneath the bay, and is apparently the extension of a buried channel beneath the Seekonk River estuary and Abbotts Run. The easternmost valley is called the Taunton-Sakonnet bedrock valley. It is a continuation of the Taunton River bedrock valley which extends southward from near Taunton, Mass. Details of geography and topography in these areas are shown on the U.S. Geological Survey 7½-minute topographic quadrangle maps listed in table 3, and also on the following maps, which are not listed: Pawtucket, Tiverton, and Sakonnet Point, Rhode Island or Rhode Island-Massachusetts.

The courses of the bedrock valleys beneath the land areas and for part of the Bay area are based upon information obtained from the files of the Ground Water Branch of the U.S. Geological Survey in Providence. This information was collected and interpreted in the course of cooperative ground-water investigations with the State of Rhode Island and Providence Plantations. Published information is given in maps and cross sections for reports on the geology and ground-water conditions in several Rhode Island quadrangles (Allen, 1956; Allen and Gorman, 1959; Bierschenk, 1954 and 1959; Hahn, 1959; Johnson and Marks, 1959; and Quinn and others, 1948). The courses of the valleys beneath the bay are based in part on bridge borings and geophysical surveys in the bay area outside the regions of current ground-water investigations.

Narragansett Bay occupies a large part of the Narragansett Basin, a structural depression composed of sedimentary and metasedimentary rocks mainly of Pennsylvanian age (fig. 1). (See also Quinn and Oliver, 1962, p. 62 and 66.) These rocks form a downfolded and downfaulted synclinorium within metamorphic and igneous rocks, most of which are of pre-Pennsylvanian age. In general, the basin sediments are considerably less resistant to erosion than the surrounding rocks. However, the metamorphic grade of the

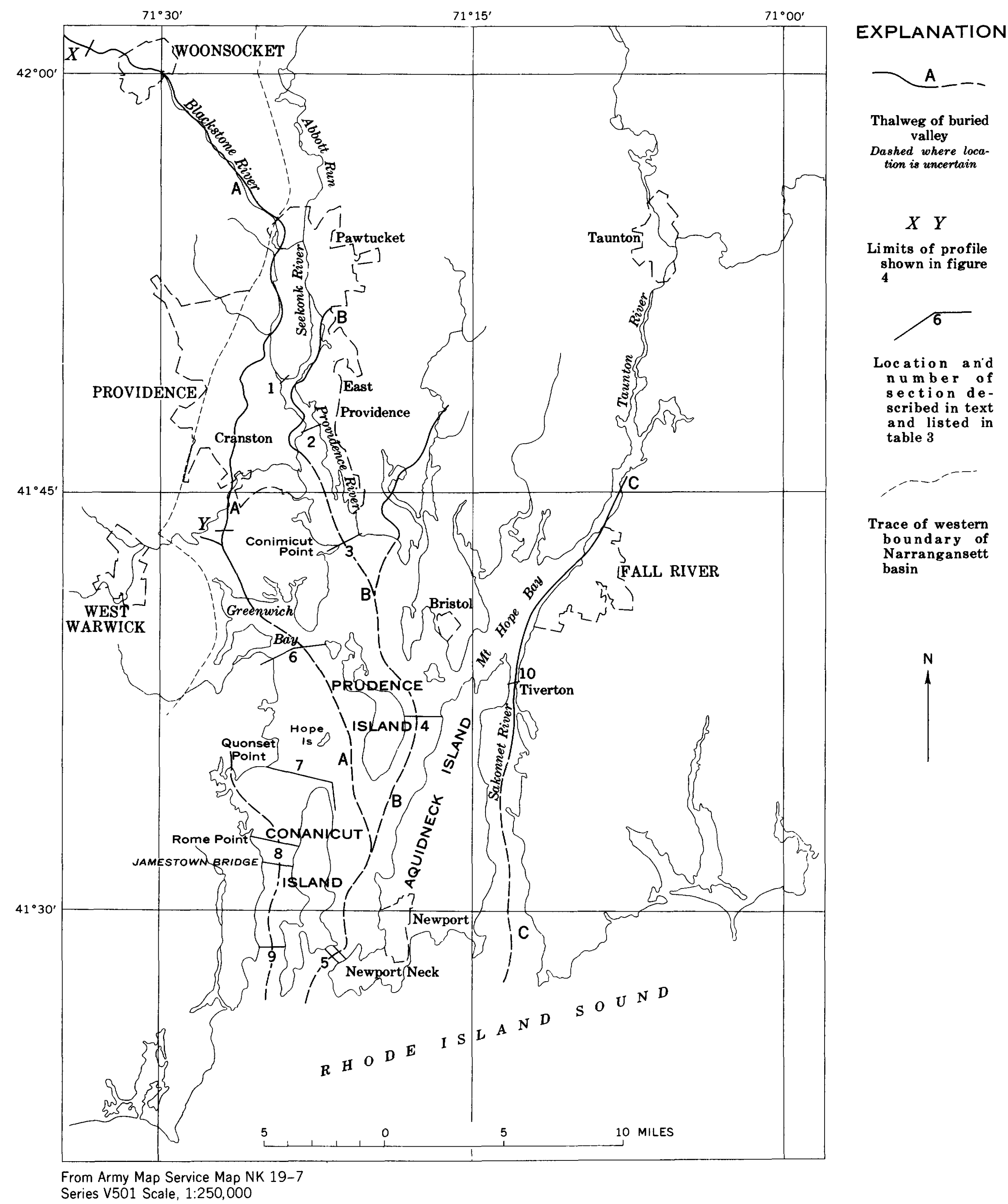


Figure 3.—Sketch map of Narragansett Bay showing locations of bedrock valleys and sites of sections or where other data were obtained. Bedrock valleys are designated as follows: *A*, Blackstone; *B*, Providence; *C*, Taunton-Sakonnet.

Pennsylvanian rocks increases to the south, and the rocks seem to become somewhat more resistant. From relatively unmetamorphosed less resistant shales in the northern part of the basin, the rocks gradually change southward to muscovite schist at the mouth of the bay (Quinn, 1953, p. 268).

The structural trend of the bordering pre-Pennsylvanian rocks is roughly northwest and southeast (Quinn, 1953, p. 266), but the trend of the basin rocks in the vicinity of Narragansett Bay is virtually north and south. The various passages of the bay are alined about north and south or slightly northeast and southwest, and the trends of the several bedrock valleys generally coincide with these directions. Thus, they appear to be generally controlled by the rock structure. Where detailed data are available, the courses are revealed to be somewhat sinuous, as in the vicinity of Providence and Pawtucket.

Figure 3 shows, in addition to the courses of the buried bedrock valleys, 10 localities for which data on the depth of the bedrock were obtained from bridge borings and seismic or seismic reflection surveys. The information is summarized in table 3. The data are referred to in the ensuing discussion of specifically identified valleys.

DEPTHS OF BEDROCK THALWEGS

BLACKSTONE BEDROCK VALLEY

Approximate elevations of the thalweg of the Blackstone bedrock valley are known from several cross sections and scattered well data. Beneath the land area, the Blackstone valley has two different reaches. The upper reach is above New Pond, north of Pawtucket, where the bedrock valley approximately coincides with the course of the present river. Well records in this reach indicate that the thalweg lies generally at or above sea level. The lower reach extends from New Pond southward through Providence to the head of Greenwich Bay. In this reach the bedrock valley departs from the course of the present Blackstone River and lies beneath the concealing outwash west of Narragansett Bay. Eight of the deepest wells drilled in Pawtucket, Providence, Cranston, and Warwick give

TABLE 3.—*Summary of data on bedrock valleys at 10 sites in Narragansett Bay, R.I.*

Locality No. on fig. 3	Bedrock valley	Location	Topographic quadrangle	Source of information	Lowest bedrock elevation	Estimated lowest elevation of estuarine deposits	Remarks
					Figures are in feet below mean sea level		
1	Not named	At Fox Point in Providence.	Providence	Five test borings	Deepest boring ended in till at −130.	−45	U.S. Army Corps of Engineers (1957, pl. E–1).
2	do	At Fields Point in Providence.	do	do	Deepest boring ended in till at −123.	−55	U.S. Army Corps of Engineers (1957, pl. E–2).
3	Providence	Conimicut Point to Nayatt Point.	Bristol	Eight test borings	Deepest boring ended in till at −158.	−85	U.S. Army Corps of Engineers (1957, pl. E–3).
4	do	Prudence Island to Aquidneck Island.	Prudence Island	Four test borings	Deepest boring ended in gray sandy silt at −158.	−110	U.S. Army Corps of Engineers (1957, pl. E–4, sec. *C–C*). So-called "Middle Bay Site."
5	do	Conanicut Island to Newport Neck.	Newport	Seismic survey	Lowest computed elevation: −320; actual lowest elevation possibly −350.		U.S. Army Corps of Engineers (1957, pl. E–5). Seismic reflection survey by Woods Hole Oceanographic Institution suggests bedrock as deep as −350 feet msl.[1]
6	Blackstone	Pojac Point to Patience Island.	East Greenwich and Bristol.	Five test borings	At one boring, bedrock entered at −115; one well ended in gray silt at −118; actual lowest elevation is deeper.	−40	U.S. Army Corps of Engineers (1957, pl. E–4, sec. *A–A*). So-called "Middle Bay Site."
7		Quonset Point to north end Conanicut Island.	Wickford and Prudence Island.	Seismic reflection survey and 3 test borings.	One boring entered probable bedrock at −130 feet msl. Lowest elevation probably somewhat deeper.		Seimic reflection surveys by Woods Hole Oceanographic Institution. Test holes contracted by U.S. Navy. Data from First Naval District, Public Works Office.
8		Rome Point to Conanicut Island.	Wickford	Seismic survey	Actual lowest elevation probably somewhat deeper than lowest computed elevation of −157.		
		Plum Beach to Conanicut Island.	do	12 test borings	Deepest boring penetrated bedrock at −125.	−80	Borings made for Jamestown Bridge.
9		The Bonnet to Conanicut Island.	Narragansett Pier.	Seismic survey	Lowest computed elevation −280.		U.S. Army Corps of Engineers (1957, pl. E–6, seismic sec. 3). Seismic reflection survey by Woods Hole Oceanographic Institution suggests bedrock at about −360 feet msl.
10	Taunton-Sakonnet	Sakonnet River Bridge at Tiverton, R.I.	Fall River, Mass.-R.I.	16 test borings	Deepest boring penetrated bedrock at −370; lowest elevation estimated at −400.	−80	Borings by American Drilling Co. for C.A. Maguire Associates. Section given in fig. 5.

[1] See footnote on p. M18.

bedrock elevations within the bedrock valley ranging from −164 to −200 msl.

From the head of Greenwich Bay southward beneath Narragansett Bay, the bedrock valley swings eastward, passes through the section at locality 6 (fig. 3) where we know only that the bedrock is deeper than −115 feet msl, and then follows one of two possible courses to the south. The first guess would be that the Blackstone bedrock valley passes west of Hope Island and west of Conanicut Island. The maximum depths to bedrock in the section off Quonset Point (loc. 7, fig. 3) are not known, and the valley might go through it, though incomplete data suggest that bedrock there is not much more than −150 feet msl. The bedrock also appears to be too shallow farther south along the west side of Conanicut Island (loc. 8, fig. 3 and table 3). From a seismic survey made about a mile north of the Jamestown Bridge, an elevation for bedrock of −157 feet msl was computed (Johnson and Marks, 1959). The deepest boring for the Jamestown Bridge (fig. 3, table 3) reached bedrock at an elevation of about −125 feet msl. If these figures are close to the maximum thalweg depths for the passage west of Conanicut Island, the bedrock is not deep enough to be in the Blackstone bedrock valley, unless elevations deeper than −150 feet msl are due to overdeepening by glacial scour. Therefore, the valley probably lies east of Conanicut Island and presumably is tributary to the Providence bedrock valley which it joins somewhere south of Prudence Island. This course is shown on figure 3.

Figure 4 shows an approximate profile of the thalweg of the Blackstone bedrock valley from Woonsocket to the city of Warwick, R.I. Woonsocket is north of the area shown on figure 3, but the city of Warwick borders Greenwich Bay. The zero point of the profile is about 3 miles north of Greenwich Bay. (See Allen, 1956, section *A–A′* of pl. 1.)

Upstream from about mile 13, most of the plotted points are for individual wells. Below Ashton, one point represents two wells close together that penetrated bedrock at about the same depth. In Woonsocket, a large number of wells and test holes have been drilled in several clusters along the river; near the northwestern edge of the city several seismic measurements have been made. For each cluster of wells, the lowest elevation of bedrock is plotted and the seismic shot point is shown. None of these points can be assumed to be exactly the lowest point of the thalweg for the locality. However, the valley in this reach is rather narrow, and the points cannot be too far from the deepest places. Also, longitudinally the points fall reasonable well along an even slope as indicated by the smooth thalweg curve drawn slightly below the points. The thalweg, however, is probably more irregular than the curve.

Downstream from about mile 13, the thalweg of the bedrock valley is drawn to follow the trough delineated by the bedrock contours shown in the Providence quadrangle (Bierschenk, 1959, pl. 1) and East Greenwich (Allen, 1956, pl. 1) quadrangle reports on ground water. The points shown on the profile are for wells situated in the deepest parts of the bedrock valley, where there is perhaps less control than for the reach farther upstream, but the deepest wells show bedrock at elevations ranging from about −150 to about −200 feet msl, and several at about −190 feet msl. Longitudinally these elevations also appear to be fairly uniform. The thalweg is indicated as being at about −200 feet msl and is probably somewhat more irregular than shown.

The data suggest reaches at two general elevations: one upstream rising from about sea level to 70 feet above, and the other downstream at about −200 feet msl and rising slightly upstream. The change between these two reaches is fairly abrupt and takes place about at the boundary of the Narragansett Basin.

Downstream, beneath Narragansett Bay, some bedrock elevations are deeper than −350 feet msl. The reach at −200 msl is so nearly level that one would expect somewhere beneath the bay a rather abrupt change to the deeper elevations, but available data are insufficient to show it.

PROVIDENCE BEDROCK VALLEY

Providence bedrock valley is the name used in this report to designate the middle one of the three major bedrock valleys in the Narragansett Bay area (fig. 3). It lies beneath the south end of the Seekonk River and beneath the Providence River. The valley passes east of Prudence Island and between Conanicut and Aquidneck Islands; it reaches into Rhode Island Sound at Newport Neck.

The presence of a buried valley in Providence and East Providence was first reported by Roberts and Brashears (1945, p. 9). The valley's location, approximately beneath the Seekonk and Providence Rivers, is taken in part from that report and in part from later reports by Bierschenk (1959) and by Allen and Gorman (1959). The thalweg of this valley does not appear to pass through either the Fox Point or the Fields Point sections of the U.S. Army Corps of Engineers (1957) across the present Providence River (loc. 1 and 2, fig. 3). A more likely course was indicated by Bierschenk (1959, pl. 1). Roberts and Brashears (1945, p. 9) suggested that the valley may be 200 feet deep in this area. One well put down about a mile south-southeast of the confluence of the Providence and Seekonk Rivers penetrated bedrock at −190 feet msl. Thus in this reach

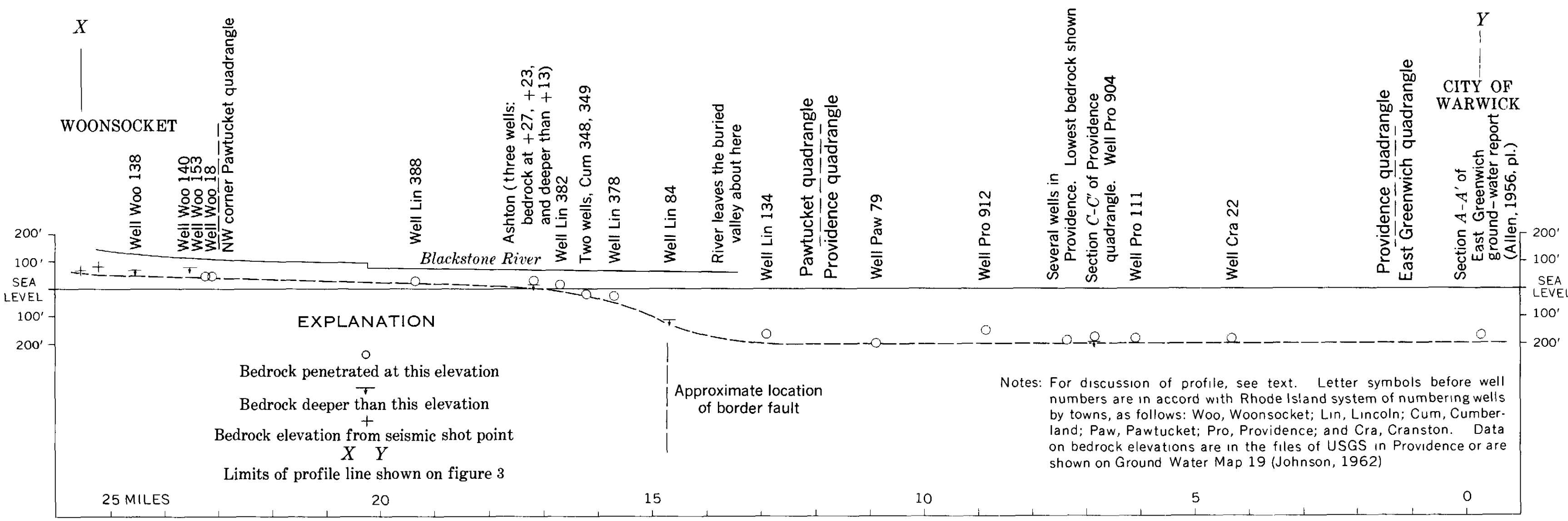


Figure 4.—Profile of thalweg of Blackstone bedrock valley between Woonsocket and the city of Warwick, R.I.

the depth is comparable to that of the Blackstone bedrock valley in about the same latitude.

South of locality 2, the suggested course of the Providence bedrock valley beneath Narragansett Bay is as shown in figure 3. Borings put down at, and northeast of, Conimicut Point (loc. 3, fig. 3, table 3) are probably in this valley, where the greatest depth was reached by one boring which ended in till at about −158 feet msl. Still farther south, at locality 4 (fig. 3 and table 3) one of four borings was drilled to −158 feet msl but did not reach bedrock. Lastly, at locality 5 near Newport Neck (fig. 3 and table 3) seismic data indicate an elevation of bedrock of at least −320 feet msl, and seismic reflection surveys [3] made by Woods Hole Oceanographic Institution suggest that it may be as deep as −350 feet msl.

A buried valley mapped by Bierschenk (1954, pl. 1) and by Allen and Gorman (1959, pl. 1) southeast of East Providence reaches elevations deeper than −100 feet msl, and is probably a tributary to the Providence bedrock valley. The tributary appears to join the Providence valley south of Conimicut Point.

TAUNTON-SAKONNET BEDROCK VALLEY

On the east side of Narragansett Bay is another bedrock valley that extends south-southwestward beneath the Taunton River estuary. The valley begins far upstream in Massachusetts, but how far is not now known. It apparently passes beneath the northwestern edge of the city of Fall River, Mass., and enters Mount Hope Bay (fig. 3). From the configuration of this bay the valley appears to continue southwestward toward Prudence Island, but borings for the Mount Hope Bay bridge near Bristol (Bierschenk, 1954, fig. 2) show that the lowest elevation of bedrock at the bridge is probably not much below −80 feet msl, whereas bedrock lies much deeper directly to the south beneath the bridge at Tiverton. Therefore, below Fall River this valley probably swings southward and continues beneath the Sakonnet River estuary and thence to Rhode Island Sound. The writers propose to call this bedrock valley the "Taunton-Sakonnet bedrock valley." Between Fall River and Tiverton, this valley is cut in sedimentary rocks of Pennsylvanian age and is generally about 0.3 to 0.4 mile northwest of the nonconformable contact of the basal Pennsylvanian metasediments on pre-Pennsylvanian igneous rocks as determined by Foerste (1899, pl. 31).

There is not much information about the depth of this valley. Test borings made in Fall River, Mass., show that the thalweg there lies at least −157 feet msl (Allen and Ryan, 1960). Figure 5 shows the configuration of bedrock in the Taunton-Sakonnet bedrock valley as determined from logs of borings made for the Rhode Island State Route 138 bridge over the Sakonnet River between Portsmouth and Tiverton, R.I. (loc. 10, fig. 3). The bridge boring records are dated 1953 and 1954.

In this section, the Sakonnet River estuary is fairly well centered over the axis of the bedrock valley. The deepest boring, boring D, entered bedrock at −370 feet msl, and—as shown on the section—the bedrock here may be as deep as −400 feet msl. Bedrock is exposed near both ends of the bridge. The bedrock cores obtained from borings A, C, D, F, G, and H were examined by A. W. Quinn of Brown University. The rock in all these borings was found to be black shale and some sandstone of Pennsylvanian age. Bedrock penetrated by borings 1–1 and 1–1A was described in the original plans as "limestone rock." This "limestone" may actually be the cataclastic granite gneiss that crops out west of the bridge.

UNCONSOLIDATED DEPOSITS

The unconsolidated deposits in the bedrock valleys of the Narragansett Basin area contain the same three units as do the valleys of coastal Connecticut—till, outwash, and estuarine deposits. Here, however, the outwash is predominantly fine grained, and much of it could be classed as lacustrine or glaciolacustrine deposits. There may also be a body of till younger than the basal till.

Within the land area, the deposits in the Blackstone buried valley are the best known. Most of them apparently represent the outwash unit, which exhibits a general decrease in grain size downstream. Above Providence, the material is mainly gravel or gravel and sand. In the vicinity of Providence, fine to coarse sand predominates, whereas near Greenwich Bay fine sand predominates. Available logs record little material to suggest the presence of till, although till discontinuously blankets the bedrock underlying the land surface outside all the valleys. Near Nayatt Point, some clay is known from well records or from exposures that were seen by workers in the area. (See Bierschenk, 1954, p. 27.)

Schafer (1961), Smith, and others mapped outwash deposits in areas west of Narragansett Bay and suggested that at least the top layers were laid down by melt-water streams flowing from a lobe of ice in the Narragansett Basin and occupying successive retreatal positions. Thus the deposits probably actually comprise several subunits of successively younger age.

[3] These surveys were made by a seismic profiler—an instrument that uses low-frequency sound energy which is reflected and recorded from horizons in sediments below water somewhat as ocean depths are determined with an echo sounder. The depth figures are preliminary because they are based on uncorrected values for the velocity of sound in the water and sediments. If the true velocity of sound transmission in the sediments is greater than that in water (W. O. Smith, 1958, p. 76 and 86), the true depths to bedrock may be appreciably deeper than indicated by the depth figures.

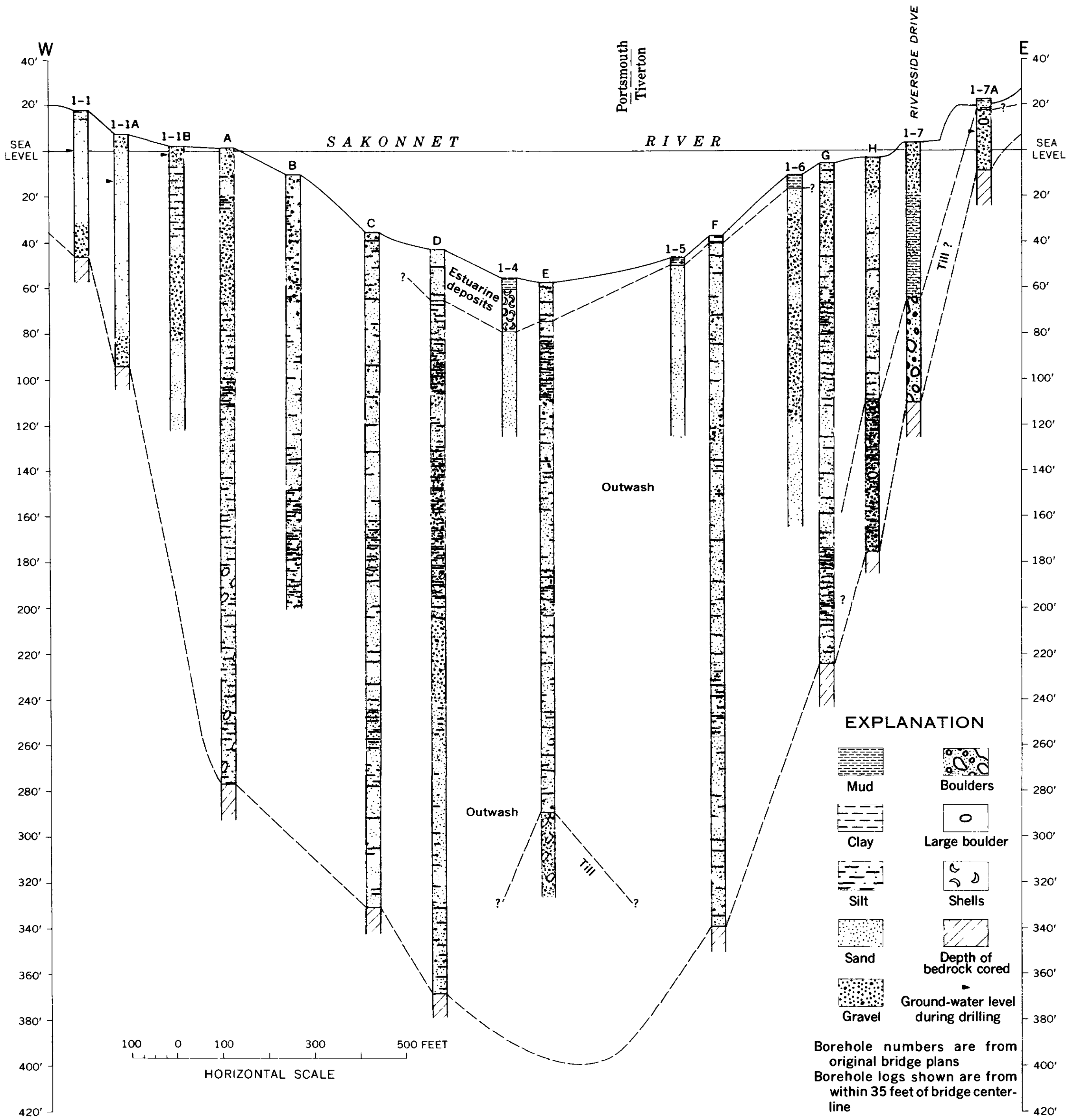


FIGURE 5.—Section of Taunton-Sakonnet bedrock valley at Tiverton, R.I.

Beneath Narragansett Bay the deposits are not well known, as available data are scanty in comparison with the size of the area. They may be extensions of the deposits beneath the land areas. For example, laminated clay and silt with scattered sandy layers penetrated by borings at locality 3 (U.S. Army Corps of Engineers, 1951, pl. E–3) apparently extend westward beneath Conimicut Point and may grade into the deposits beneath outwash plains mapped by Smith (1955). The laminated clay may also extend eastward and correspond with the thin clay beneath the Nayatt kame delta (Bierschenk, 1954, pl. 3). On the other hand, the deposits may constitute, at least in part, a younger body separated from the others by uncomformities, depending on the exact manner of withdrawal of the ice. For example, Schafer (written communication, 1961) suggested that the outwash deposits west of the bay terminate in ice-contact slopes along or near the present shore. If so, the bay must have been occupied by ice, and the deposits in the bay were laid down after the ice had melted away. The deposits must lie unconformably, then, against the outwash that occurs beneath the land. The outwash beneath the bay proper is therefore here treated as a separate unit although it may not be.

For the deposits beneath the bay, the following generalized description is based mainly on records of borings made by the U.S. Army Corps of Engineers (1957). The deposits have three recognizable units: till, predominantly fine-grained outwash, and estuarine deposits. The fine-grained outwash may comprise more than one stratigraphic unit, and an intermediate body of till may occur at one locality.

Borings at many of the localities shown on figure 3 terminated in material of pebbly or bouldery sand and clay whose compactness and poor sorting indicate that it is till. At some places bedrock was entered beneath this deposit, but at others it was not fully penetrated.

Above this till is a considerable thickness of varied but mainly fine-grained material. It consists mostly of clay, silt, and fine sand. Beds of gravel and sand are present locally, as indicated by the boring records, but they are usually described as silty or clayey and do not seem to occur in a particular depth range. As gravel seems to be more abundant in the marginal parts of the bay, it may merely be the interfingering edge of the coarse-grained facies upstream.

At the Portsmouth-Tiverton Bridge (fig. 5) the entire thickness of deposits seems to be made up of varying amounts of silt, sand, and gravel, which contain some boulders in certain beds. There is practically no clay; hence, the deposits at this locality are generally coarser grained than the deposits beneath other parts of the bay. Much of the material is indicated in the original boring records as compact or cemented, which suggest that some of the material might be till. However, test pile penetration tests studied by Mr. F. C. Pierce (oral communication, 1958) of Charles A. Maguire and Associates indicated that the material was not cemented or unusually compacted. As to thickness, one boring, D (fig. 5), penetrated 326 feet of deposits, which except for the upper 20 feet, is probably all outwash.

In contrast to the relatively coarse-grained material at the Tiverton Bridge, the deposits in much of the rest of Narragansett Bay are predominantly fine grained. Sections at localities 1, 2, 3, 4, and 6 and the Navy borings at locality 7 show a considerable thickness of material described as gray clay, silty clay, or silt and clay. There are also beds of silt and sand, or sandy silt, and silty gravel and sand generally either above or below the clay. The clayey material is ordinarily in recognizable beds a small fraction of an inch thick. The gray silt midway in the section at the Tiverton Bridge (fig. 5) may be the same body. Farther south, at localities 3 and 6, the material is predominantly clay and silt in thin laminae.

This predominantly fine-grained unit is classed as outwash because it rests on till, is probably derived from melt-water streams, and contains no organic remains. In a classification that has more subdivisions, it might properly be called lacustrine or glaciolacustrine. It may grade continuously upward into the supposedly fresh water clays noted in the Barrington area (Bierschenk, 1954, p. 24 ff. and Smith, 1955b) and earlier reported by other geologists (Woodworth, 1896, p. 162, and Hyyppä, 1955, p. 210). It was presumably deposited in ponded water, but whether this water was dammed in some way by ice to form a lake (Schafer, written communication, 1961) or was in a marine embayment like the present Narragansett Bay, an interpretation favored by the writers, is not known.

In the section of the Providence valley between Prudence Island and the northern part of Aquidneck Island (loc. 4, fig. 3 and table 3), a 10-foot interval in one boring showed "gray, silty, sandy gravel (Till-like)" and "gray, clayey sand (Till-like)" overlying a cored boulder. This till-like material rests on at least 40 feet of "gray, clay." This is the only evidence of till stratigraphically higher than the basal till known in the deposits of Narragansett Bay.

Elsewhere, the deposits above the clay and silt are the estuarine deposits.

This uppermost unit in every section studied consists of material that is described as "loose." It contains plant remains and locally shell fragments, and rests on a channel-shaped surface apparently eroded in the underlying sand and gravel. The material varies in thickness within each section and also from one section to another. The unit is 25 to 50 feet thick and except for perhaps the uppermost few feet, at most places it consists of estuarine material deposited during a late Pleistocene or Recent relative rise of sea level.

The approximate elevations of the lowest points on the pre-estuarine surface from section to section are summarized in table 3. They range from −45 feet msl at Providence to −110 feet msl near the middle of the bay. At locality 5, the water alone is about 160 feet deep (see U.S. Coast and Geodetic Survey chart 236), which is about 30 feet deeper than the base of the estuarine deposits in the Thames. (See p. M13.) However, there are no data on the subbottom sediments, and this depth may be due in large part to scour by tidal currents.

SUMMARY OF FEATURES OF NARRAGANSETT BAY AREA VALLEYS

In the Narragansett Bay area, the lowest elevations of the bedrock valleys range from about sea level near Woonsocket to more than 350 feet below sea level beneath the eastern and southern parts of Narragansett Bay. The lowest elevation observed is about −370 feet msl. The best information on longitudinal profiles is for the Blackstone bedrock valley whose thalweg seems to have a nearly level reach at about −200 ft msl and a shallower reach in the part outside the Narragansett Basin. The upstream reach rises from about sea level to about 70 feet above in Woonsocket. Depths are greater downstream beneath the bay, but data are not at hand to indicate how nor where the elevation changes from −200 msl to the lower elevations farther south.

The deposits are mainly stratified clay, silt, sand, and gravel, which are herein classed as outwash. Beneath the stratified drift, till rests directly on the bedrock. Upstream from Providence, the outwash is mostly gravel, but downstream, except for the upper few feet, it is generally finer grained and composed of layers of sand, fine sand, and silt. The sand was deposited in or beneath outwash plains described in the maps of the quadrangles surrounding Narragansett Bay. (See for example, J. H. Smith, 1955a and 1955b.)

Beneath Narragansett Bay proper, inadequate data suggest that the sequence consists of (1) till resting on the bedrock, (2) a thick body of varied material, mainly fine grained, consisting predominantly of clays, silts, and fine sands, (3) possibly a body of till known at only one locality, and (4) estuarine deposits that rest on the fine-grained unit with erosional unconformity.

The surface at the base of the estuarine deposits is probably an erosion surface. The elevations of the lowest points of these channels, −40 to −110 feet msl (table 3), suggest a gentle seaward gradient and are in the same depth range as the corresponding points in the coastal valleys of Connecticut. They are considered also to result from subaerial erosion by a stream system that formed on the underlying deposits above water level. Schafer (written communication, 1961) suggested that the fine-grained outwash of Narragansett Bay was deposited in an ice-dammed lake. The postulated erosion then would have occurred after the dam disappeared and when sea level was lower than at present. It is also possible that the exposure occurred because of a decline of sea level. (See p. M39.)

BURIED VALLEYS OF THE BOSTON AREA

GENERAL FEATURES

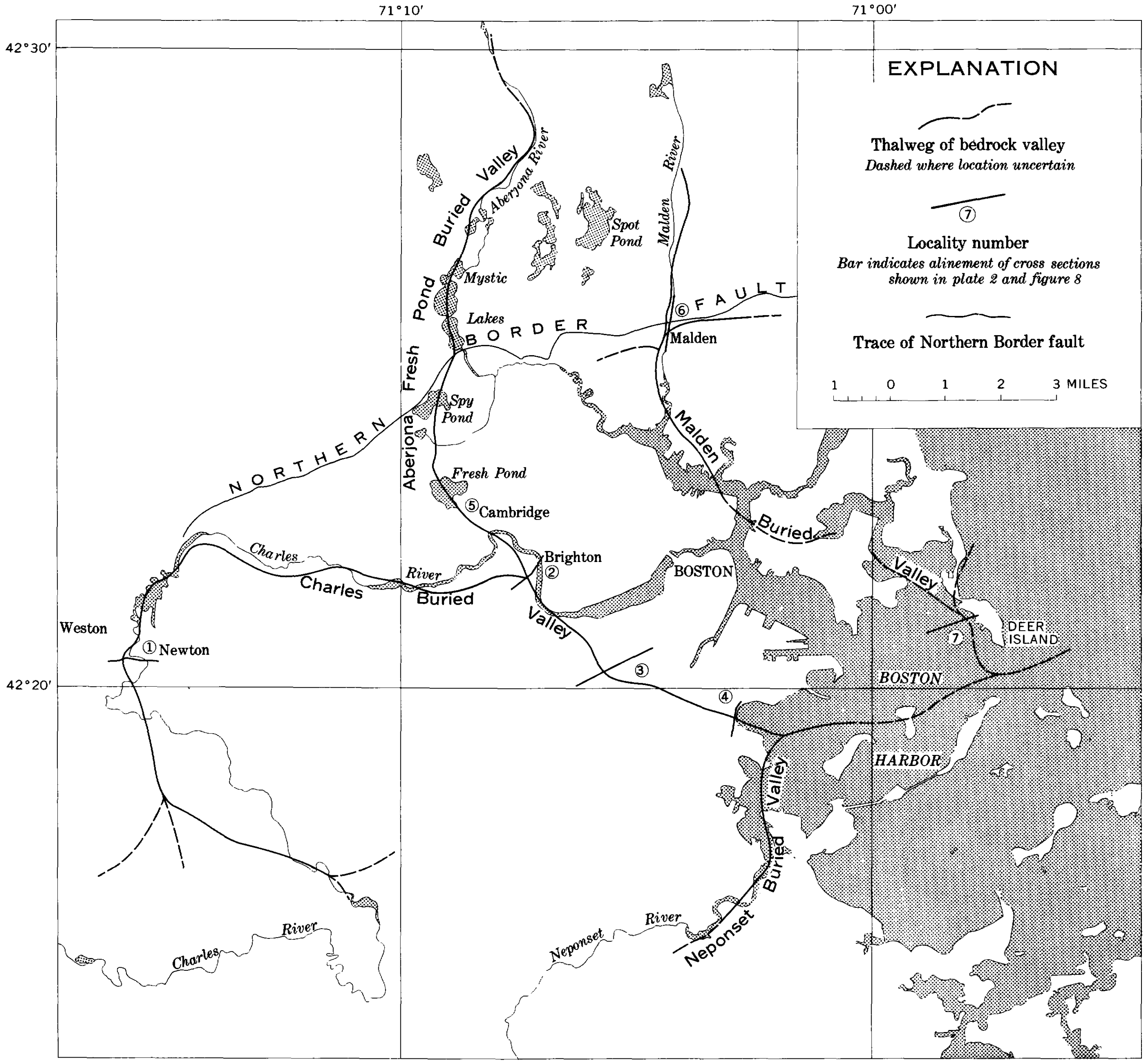
The Boston area, for purposes of this report, is an area of about 400 square miles bordering Boston Harbor on the north and west. It is occupied by parts of the present-day Charles, Mystic, Malden, and Neponset Rivers. In comparison with such rivers as the Connecticut or the Kennebec, these are insignificant streams; however, the bedrock valleys associated with them reach considerable depth. The bedrock valleys have been studied by geologists of three generations, and considerable data are available.

The most comprehensive and the most recent works on the geology of the Boston area are those of Billings (1929) and La Forge (1932). As described in these reports, the Boston Basin is a structural depression, like the Narragansett Basin, and is underlain by complexly folded and faulted sedimentary and volcanic rocks which Billings (1929, p. 106) considered to be of Pennsylvanian (?) and Permian age. These rocks are separated by fault contacts from older igneous and metamorphic rocks that range in age from Precambrian to Devonian (?). In general, the younger rocks are less resistant to erosion than the older ones and, having been more extensively and deeply dissected, form a topographic as well as a structural depression. A major fault marks the north boundary of the basin. This fault was named the Northern Border Fault by Billings (1929, p. 107, fig. 2), and was further described by La Forge (1932, p. 63). The parts of the valleys that are north of the fault are appreciably shallower than the parts to the south. Also, at places the valleys or their tributaries seem to have been localized along the fault zone itself.

The unconsolidated sediments that rest on the bedrock are virtually all glacial deposits or marine and fluviatile deposits formed in association with glaciation. La Forge (1932, pl. 2, p. 79–86) mapped the glacial deposits of the Boston area in moderate detail, and Judson (1949) made a rather thorough study of the subsurface deposits as revealed by borings and foundation excavations for certain large buildings in Boston.

For most areas discussed in this paper, the term "bedrock valley" is preferably used. In the Boston Basin area, however, the valleys are so extensively filled, or buried, that most of them have no surface expression. They are often referred to in the older literature as "buried," and the one beneath Fresh Pond has the word "buried" in its name. Therefore, the bedrock valleys of the Boston area are generally referred to in this part of the text as "buried valleys." (See p. M4.)

Figure 6 shows the approximate outline of the buried valley system that probably underlies the Boston area



Base by Commonwealth of Massachusetts, 1957

Location of buried valleys by C. W. Spencer, modified from Crosby, 1937, and Halberg and Pree, 1950

FIGURE 6.—Sketch map of Boston area, Massachusetts, showing locations of buried bedrock valleys and of geologic sections.

and the locations of the sections given in plate 2 and figure 8. In subsequent paragraphs, localities referred to by number are shown on figure 6. Most of the buried valleys lie approximately as shown by I. B. Crosby (1937) although the courses are slightly different, as indicated by work done by Halberg and Pree (1950, fig. 3) and by data collected in the course of the present study. The thalweg of the Aberjona-Fresh Pond buried valley is from Chute (1959, pl. 14) but is modified slightly in part on the basis of test-well data furnished by H. N. Halberg (oral communication, 1959). Table 4 lists the localities for which sections are drawn and the source of the data for each.

The names of most of the buried valleys used in this paper are the names of the present streams. Some explanation however, is desirable. W. O. Crosby (1899, p. 302) postulated that the ancestral Merrimack River (fig. 1) followed a valley southeastward from New Hampshire to a position beneath the present Aberjona and Mystic Rivers (fig. 6) and thence to Boston Harbor. I. B. Crosby (1937) at first adopted this postulate but later evidently modified the view, as he wrote (1939, p.

TABLE 4.—*Summary of information on crossings of buried valleys in the Boston Basin area, Massachusetts*

Buried valley	Locality No. on fig. 6	Purpose for which borings were made	Agency for which borings were made	Date of plans
Charles	4	Main drainage sewer tunnel at Columbus Park, Boston.	Metropolitan District Commission.	1954
Do	3	Proposed water supply tunnel loop (south line), in Boston.	do	1937
Do	2	City water tunnel extension between Boston and Cambridge.	do	1953
Do	1	Pressure aqueduct between Weston and Newton (sections 6 and 7).	Metropolitan District Water Supply Commission.	1939, 1947
Aberjona-Fresh Pond.	5	Proposed loop water tunnel in Cambridge.	do	
Malden	7	Main drainage sewer tunnel in Boston.	Metropolitan District Commission.	1953
Do	6	Spot Pond Brook Flood Control Project in Malden.	do	1956

374), "The valley coming from the north is in line with the projection of the buried valley of the Merrimack, and these valleys will be described as the pre-glacial Merrimack-Mystic Valley, although it is not yet proved that these were one continuous valley." La Forge (1932, p. 79) stated that there is no evidence that the Merrimack extended as far south as the Aberjona River, a view supported by more recent seismic surveys (Lee and others, 1940) and investigations of ground-water conditions near Lowell, Mass. (J. A. Baker, oral communication). Thus the name "Merrimack" should not be used. Halberg and Pree (1950, p. 209–210) showed that the main stem of the buried valley beneath the Aberjona River continues southward, passing beneath the Mystic Lakes, and instead of following the present Mystic River continues more nearly southward beneath Spy Pond and Fresh Pond. Thus, although I. B. Crosby used the name "Merrimack-Mystic," the use of "Mystic" is also incorrect. Halberg and Pree (1950, p. 209) used the term "buried Aberjona valley" informally, and also (1950, p. 211) the name "Aberjona-Fresh Pond buried valley." Subsequently, Chute (1959, p. 189) formally applied the named "Fresh Pond buried valley." Fresh Pond lies above the extreme southern part of the buried valley, and use of this name ignores the greater, or northern, part of it beneath the Aberjona Valley. Accordingly, in this report the writers use the name, "Aberjona-Fresh Pond buried valley" as it is more descriptive and has some precedence in former usage.

For the most part, the Charles buried valley follows the course of the Charles River except in Boston proper where it lies several miles to the south. This valley, because of its possible upstream continuation in an ancestral Sudbury River (I. B. Crosby, 1937) is considered to be the major buried valley of the Boston area.

Halberg and Pree (1950, p. 208–211) also briefly described the other valleys beneath the Malden and Neponset Rivers. Only the one beneath the Malden, herein called the "Malden buried valley," is further described in this report.

DEPTH OF BEDROCK THALWEGS

CHARLES BURIED VALLEY

The sections in plate 2 show a progressive downstream deepening of the bedrock thalweg of the Charles buried valley. At locality 1 (pl. 2*A*) the thalweg is probably at about −100 feet msl. It is not located within close limits, but is thought to be just west of boring 6–2, which entered bedrock at about −82 feet msl.

About 4 miles down the buried valley from this section a test boring put down by the Metropolitan District Water Supply Commission near the south side of the present Charles River penetrated bedrock at about 97 feet below sea level.

Still farther downstream, about at the confluence of the Charles and Aberjona-Fresh Pond buried valleys (pl. 2*B*), the lowest observed position of bedrock is at about −145 feet msl at boring 160–16. The depth of the thalweg itself is estimated indirectly as follows: Assuming a smooth curve between the Fresh Pond area of the Aberjona-Fresh Pond buried valley (p. M24) where the lowest elevation is about −170 feet msl, and the Columbus Park section (loc. 4 and pl. 2*D*), where the lowest elevation is about −240 feet msl, the lowest elevation at locality 2 (pl. 2*B*) would be about −210 feet msl.

The sections, plate 2*C* and 2*D*, show the bedrock surface well controlled, and the positions of the thalweg to be at about −244 and −243 feet msl, respectively. At the section shown in plate 2*C*, most of the borings penetrate rock recognized as typical of the Boston Basin formations, but two borings (30–A and 31) penetrated several hundred feet of material reported as gray-white shale and some sandstone, which is unusual. Pearsall (1937, p. 178) suggested that this gray-white shale may be sediment of Cretaceous or Tertiary age filling a "preglacial gorge." In any case, it seems to be part of the preglacial bedrock.

ABERJONA-FRESH POND BURIED VALLEY

There are considerable scattered data on the bedrock depth in this valley, but the best section lies about east-west just north of Fresh Pond in Cambridge. (See loc. 5, fig. 6.) This section, not reproduced here, was published by Halberg and Roberts (1949, fig. 2). It shows the lowest elevation of the thalweg to be about

−165 feet msl. One boring, about 0.9 mile north of Fresh Pond and on a proposed Loop Water Tunnel of the Metropolitan District Water Supply Commission, penetrated bedrock at about −170 feet msl. The low point at this section may be as low as −180 feet msl. Several borings also suggest the presence of buried bench, or terrace, remnants at an elevation of about −80 feet msl. (See Chute, 1959, p. 189.) Interpretive sections prepared by Chute (1959, pl. 16) show the lowest elevation of bedrock near Fresh Pond to be about −170 msl. A well and a test boring 5 to 7 miles upstream from Fresh Pond entered the bedrock at −145 and −137 feet msl, respectively. A seismic profile made on the east side of Spy Pond (about 1 mile north of Fresh Pond in Cambridge) gave a lowest bedrock elevation of −270 feet msl (Chute, 1959, fig. 33, and p. 193).

Figure 7 shows an approximate profile for the thalweg of the Aberjona-Fresh Pond and lower part of the Charles buried valleys. The profile is based on data presented in plate 2, table 6, and in the text. Assuming that the thalweg is likely to be at least a few feet lower than the observed elevations (more for a single well) no matter how well controlled the sections seem to be, the thalweg line is drawn slightly below the plotted points. Note that the Spy Pond seismic profile point seems to be excessively deep. If the seismic data permitted an accurate interpretation, this depth probably indicates local overdeepening by glacial erosion—perhaps plucking or scour along the Northern Border fault.

This profile indicates reaches of the thalweg at two elevations, one at somewhat above −200 feet msl and rising upstream, and the other beneath the lowland part of the basin and nearly level at an elevation of about −250 feet msl.

MALDEN BURIED VALLEY

The Malden buried valley extends southward through Melrose and Malden and then swings southeastward to join the Charles buried valley apparently at the north edge of Boston Harbor. (See fig. 6.) Two sections are shown across this valley: one at locality 7 beneath Boston Harbor (pl. 2*E*), and one in the upstream part at locality 6 (fig. 8).

The borings shown in figure 8 are along a line that is almost parallel to the Malden valley axis at a place where the valley crosses the Northern Border fault of the Boston Basin. On the basis of bedrock exposures, the borings in the northern half of this section are apparently along the flank of the buried valley and thus probably did not penetrate the bedrock at its maximum depths.

From water-well data in the files of the U.S. Geological Survey in Boston, the Malden bedrock valley in the upland north of the section may be as deep as about 40 feet below sea level. Here the valley is apparently cut in pre-Pennsylvanian igneous and metamorphic rocks, which are generally relatively resistant to stream erosion. Near boring SPT 6–B (fig. 8) the slope of the longitudinal profile begins to steepen and drops from an estimated level of about −60 feet msl (this place is west of the line of section) to about −195 feet msl beneath the Malden River. This drop, which amounts to 130 feet in a little more than 1,300 feet, occurs about at the north border of the Boston Basin where the thalweg crosses from the resistant upland rocks to the less resistant Cambridge Slate.

The zone of the Northern Border fault doubtless passes through the section at about this place. The apparently crushed nature of the bedrock cored in boring SPT–3, which is described as "soft and broken," "broken bad," "bad and soft," and "soft broken and clay seam," suggests that at least one fracture intersects this boring. The lowest elevation of the bedrock surface along the line of section was −193 feet msl at boring SPT–4. The bedrock penetrated by this boring is described as "shale argillite." The elevation is also about the lowest point of the thalweg, which may have been overdeepened somewhat by glacial erosion along the Northern Border fault zone. Other subsurface data in this vicinity suggest that bedrock valleys tributary to the Malden, whose approximate positions are shown in figure 6, may extend some distance along the fault zone here.

The second cross section of the Malden buried valley is near Deer Island in Boston Harbor (loc. 7, fig. 6). Plate 2*E* shows the configuration of bedrock at this place. The bedrock valley thalweg here is probably at least 230 feet below sea level and may be deeper. The deepest bedrock reported on the boring logs was at −212 feet msl at boring 195–H3A. A fault zone was penetrated near the bottom of the boring. Bedrock was described on all of the boring logs as argillite, presumably the Cambridge Slate.

UNCONSOLIDATED DEPOSITS

The unconsolidated deposits within the buried valley system of the Boston Basin are complex locally, but—as revealed by the sections examined in this study—seem generally to conform to the sequence observed by Judson (1949). They are separated into five major units: (1) till at the base, probably the Boston Till of Judson (1949, p. 12), (2) a thick body of marine clay and silt, the Boston Clay of Judson (1949, p. 16), (3) outwash, which interfingers with the clay around the margins of the Basin, (4) a unit of sand and gravel that overlies the marine clay and silt at most places, probably the Lexington outwash of Judson (1949, p. 23)

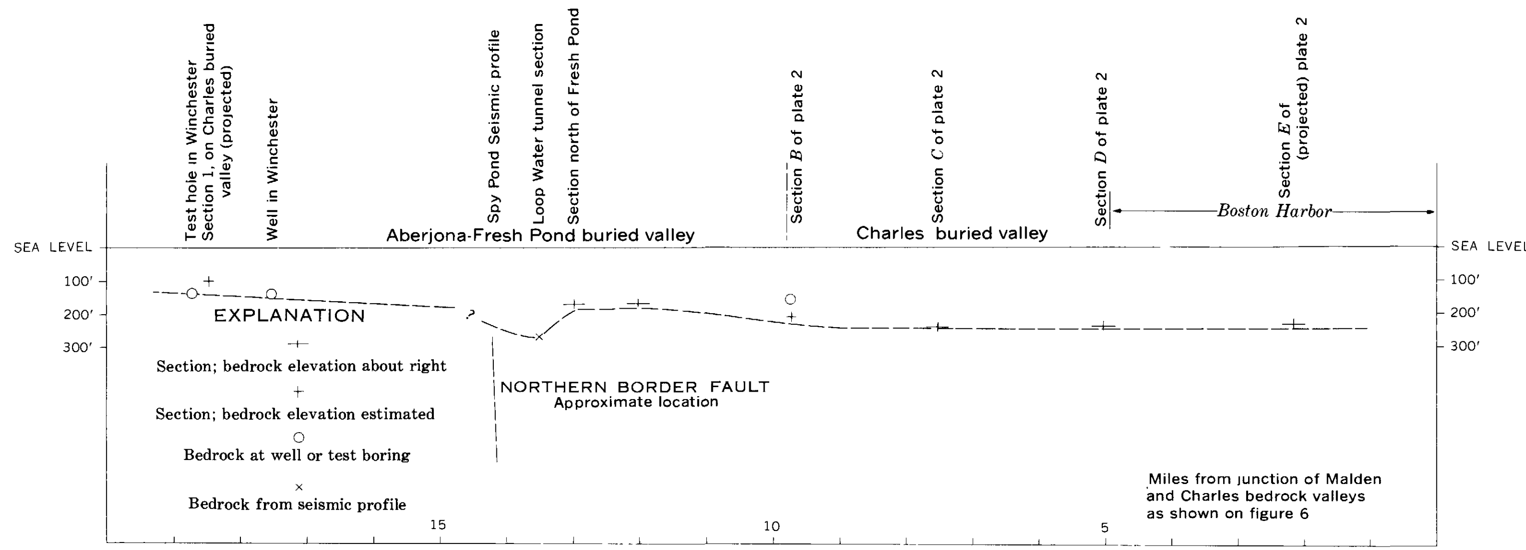


FIGURE 7.—Profile of thalweg of Aberjona-Fresh Pond and lower Charles buried valleys.

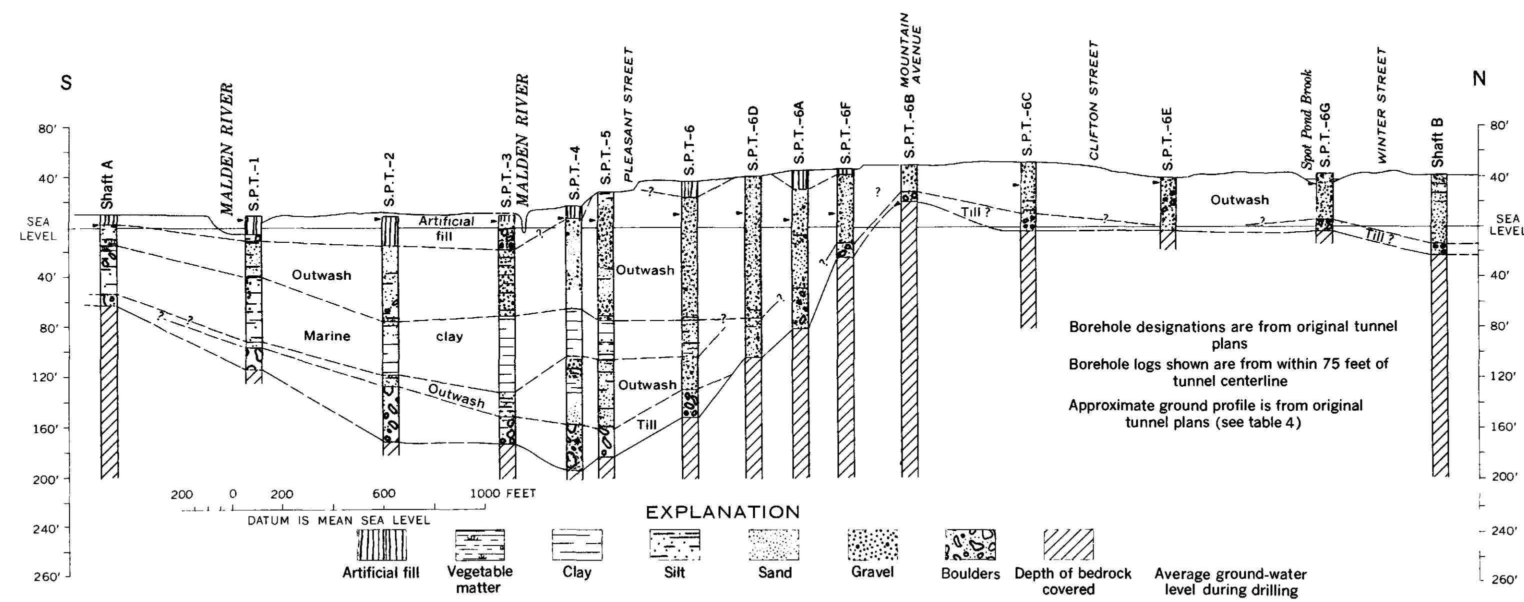


FIGURE 8.—Section of Malden buried valley at Malden, Mass. For location of section see locality 6, figure 6.

and at least partly correlative with unit (3) above, and (5) a unit composed of several deposits not fully differentiated, including silt and clay, peat, and other plant remains. This last unit is herein called estuarine deposits. It includes the lower peat, the marine silt, and the upper peat of Judson (1949, p. 27–32).

Judson (1949, p. 10) recognized the presence of a till older than the Boston Till; and recently Kaye (1961, p. 73–76) described a complex sequence of glacial deposits exposed in the excavation for the Boston Common garage, in which he recognizes four drift layers separated by three marine clays. Of these, the lower three drift layers underlie Clay III (Kaye, 1961, p. B–75), which is probably the Boston Clay of Judson. Kaye (p. B–75) considered that the deposits below this clay are early Wisconsin and older, and that Clay III is of middle Wisconsin, or Tazewell, age. This age estimate is based on indirect evidence, and may not be final. However, not only may there be middle and lower Pleistocene glacial deposits locally in the Boston area, but the Boston Clay itself is possibly older than most of the deposits considered in this report.

Nevertheless, the identity and age of the last period of lower sea level is significant. Both Judson (1949, p. 20, 27) and Kaye (1961, p. B–75) recognized that the sea level was relatively low following the deposition of both the Boston Clay and the Lexington outwash, although whether or not there were two separate episodes of lower sea level is not known. In any event, there was a period during which the level of the sea rose following deposition of the Lexington outwash and during which the sequence of peat, marine silt, and peat of Judson was laid down. This period corresponds to the episode of estuarine deposition described in this report.

The several sections shown in plate 2, especially those across the Charles Buried valley, show the general sequence fairly well (secs. 7 *B*, *C*, *D*, at locs. 2, 3, and 4, respectively). Till occurs generally at the base and is overlain by the marine clay. There may be more than one unit of clay deposits, but the available data do not show it. In none of these sections does the clay extend above sea level.

At the site shown in plate 2*C* the clay body contains a lens or lenses of fine sand shown by symbol for outwash. This sand constitutes the only apparent break in the uniformity of the clay body, except at the margins of the Boston Basin, and thus probably is a slightly coarser grained facies resulting from local depositional conditions.

In the section at locality 7 (pl. 2*E*) across the Malden buried valley, the deposits are undescribed except at boring 194–1C on Deer Island. This boring penetrated sand and gravel at the top, and then entered compact poorly sorted clay, sand, and gravel considered to be till. The deposits in this section probably consist mostly of the marine clay known to occur elsewhere in the area.

Around the margins of the basin, the deposits are different. For example, at locality 1 (fig. 6 and pl. 2*A*) they consist almost entirely of sand and gravel, and constitute a body of outwash. This outwash rests on a discontinuous layer of heterogeneous material above the bedrock, evidently till. A body of clay and silt penetrated by borings 6–1 and 6–2 at the base of the outwash may be a tongue extending westward from the main body of marine clay or may represent lacustrine deposits in an arm of glacial Lake Sudbury as postulated by I. B. Crosby (1939, p. 381).

In the upstream part of the Malden buried valley (fig. 8), the deposits are mostly sand and gravel, as in the upstream section of the Charles (pl. 2*A*). There seems to be till at the bottom, overlain by predominantly sandy material, some of which contains gravel and some of which contains silt and clay. Possibly the gravel penetrated by borings SPT–6 and SPT–6D (fig. 8) is outwash, but the silt and clay penetrated by borings SPT–2 to 5 may be a basal coarse-grained facies of the marine clay unit. In about the middle of the section (vertically) and penetrated by borings SPT–1 to SPT–5 is a body of stiff gray clay, containing interbedded silt and silty clay and some pebbles. This body of clay is probably a tongue of the Boston clay. The top of this body is irregular and may have been eroded before deposition of the succeeding material.

The deposits above the clay are mainly sand and gravel and, for the most part, are probably outwash. However, some of the boulders and gravel that contain clay, such as those penetrated by borings SPT–2, 3, 4, and 5 above the clay unit, may be till. For example, at boring SPT–3, material above the clay is described as "sand, clay, and rock particles, very compact."

In the central part of the basin, where the estuarine deposits occur, the deposits above the marine clay are varied, and different units cannot be clearly distinguished from one another. The greatest diversity seems to be at locality 2 (pl. 2*B*), where a body of sand and gravel rests on the clay and is in turn overlain by a body containing silt, peat, and other plant remains. The sand and gravel probably represents the Lexington outwash of Judson, and the unit containing organic remains probably represents the post-Lexington unit of marine and marsh deposition. In the north end of the section and along the Charles River is a body of estuarine deposits which probably lie unconformably on the sand and gravel. These estuarine deposits may be correlative with the peat and plant remains in the central part of the section.

Estuarine deposits, resting unconformably on the marine clay, are also shown in plate 2*D*. On the original record, these deposits are shown simply as "silt" and it is not known whether they represent the outwash that lies above the clay, or the marine silt of Judson (1949, p. 29), but are probably the latter. These deposits are shown here as estuarine deposits because of the lithologic description as "silt." They may represent the outwash because they appear to be overlain by sand and gravel (boring 34) and because some sand and gravel were penetrated in the upper part by shaft B.

Judson (1949, fig. 1 and p. 21) presented data on the erosion of the Boston Clay and suggested that the streams that dissected the Boston Clay before the deposition of Lexington outwash were graded to a base level 90 to 100 feet below present sea level. This depth range may be correct, but whether it is for a pre-Lexington or a pre-estuarine erosion surface is not known. More dependable information is probably afforded by the depth of the lower peat, the lowermost part of which is herein called the estuarine deposits.

Barghoorn (1949, p. 73), referring to this lower peat, stated that it is clearly a fresh-water accumulation, and "probably the basin in which it formed was periodically affected by brackish invasions from the Charles River estuary." Thus the lower peat was probably approximately at the sea level of the time. Barghoorn's inference was based upon examination at the Boylston Street fishweir site, where the base of the peat is nearly 30 feet below sea level (Judson, 1949, p. 31). Boston City base is −5.75 feet msl at the Boston Navy Yard. Judson (1949, p. 27) reported that buried peat, presumably the same as that at the Fishweir site, occurs elsewhere in the Boston area as low as about −50 feet msl (45 ft below Boston base). Therefore, sea level during pre-estuarine time was probably at least 50 feet lower, with respect to the land, than it is at present. This elevation is given on plate 5 as the low point of the pre-estuarine surface, though farther seaward it may have been lower.

SUMMARY OF FEATURES OF THE BOSTON BASIN AREA BURIED VALLEYS

The lower reaches of the thalwegs of the bedrock valleys of the Boston Basin area lie between −230 and −245 feet msl. The elevations at about −243 feet msl on the Charles Buried valley in Boston (pl. 2*C*), at about −244 feet msl on the Charles at Columbus Park (pl. 2*D*), and at −230 feet msl at the lower end of the Malden buried valley indicate a very low grade which may represent a local base level somewhat below −240 msl, at say −250 feet msl. Such a level, however, may represent adjustment to varying rock resistance and not necessarily indicate any position of sea level.

The data do not indicate any systematic elevations for the upper reaches of these thalwegs. The thalweg of the Malden buried valley rises abruptly upstream to an estimated elevation of about −60 feet msl north of the Northern Border fault. The upper part of the Aberjona-Fresh Pond buried valley is lower, about −145 feet msl in Winchester (p. M24), perhaps because it was the valley of a larger stream. The intermediate levels between −165 and −180 msl feet near Fresh Pond and Spy Pond probably represent a rapids between the deep reach to the south and a shallower reach north of the Northern Border fault. The terrace remnants mentioned by Chute (1959, p. 189) at about −80 feet msl may also represent a shallower base level. (See also p. M24 this report.) Perhaps the bench on the Charles buried valley in Newton, at about −80 feet msl (pl. 2*A*), represents the same level.

The unconsolidated deposits in these valleys indicate a complex sequence of events culminating in a relative rise of sea level accompanied by deposition of estuarine and marsh deposits, some in fresh and some in salt water. The elevation of the preceding position of sea level may have been 90 to 100 feet below present level, but this estimate is perhaps confused with an earlier episode of lower sea level. In other words, there must have been a decline of sea level at some time after the deposition of the last marine clay, but whether or not there was an actual decline following the deposition of the Lexington outwash is not known. A lower peat deposit at the base of the estuarine deposits reaches a depth of about −50 feet msl in the Boston area, and that elevation is plotted in plate 5.

BEDROCK VALLEYS NEAR PORTSMOUTH, N.H.

A rather intricate system of drowned river mouths in the vicinity of Portsmouth, N.H., marks the bedrock valleys of the Piscataqua River and its tributaries. (See Dover and York quadrangles, New Hampshire-Maine, scale 1:62,500; and the more up-to-date Portsmouth and Kittery, N.H.-Maine 7½-minute quadrangles, scale 1:24,000.) Data on the crossings of the Piscataqua River at Portsmouth, if available, were not obtained. However, borings for modern bridges between islands southeast of Portsmouth, give refusal depths, probably near bedrock, of about −55 feet msl.

About 5½ miles northwest of Portsmouth the Scammel Bridge for U.S. Route 4 crosses the Bellamy River between Cedar Point and Dover Point in the City of Dover, N.H. At this place the Bellamy River is a sizable tidal estuary which joins the Piscataqua about 4 miles above Portsmouth. In 1933, seven wash borings were made at this crossing for the New Hampshire Toll Bridge Commission. The borings penetrated unconsolidated deposits until they struck either bedrock or a boulder too large to be broken or driven aside. The deepest point of refusal is near the middle of the crossing at an elevation of −91.5 feet msl. This elevation is probably close to the bedrock surface and the thalweg of the valley is plotted as −95 feet msl in plate 4. This locality is a few miles inland, and the bedrock thalweg may deepen downstream. The water depth alone in the Piscataqua at Portsmouth is as much as −70 feet msl.

From the description of the deposits given on the records, the borings penetrated four depositional units, from the top: (1) silt, fine sand, and shells, (2) a thick and fairly uniform body of very soft blue clay and sand, (3) a body of variable thickness of sharp gray sand, which is "hard" in some borings and "loose" in others, and (4) hard gray gravel and sand, with some clay reported at one or two of the borings. Refusal points are in or at the base of this gravelly unit. Unit 2 is the marine clay and silt which is exposed in the vicinity and which is similar to the marine clay in the Portland area to the north (p. M34).

The uppermost unit, No. 1, is evidently the estuarine deposits found in other areas. The lowest observed point at the base of these deposits is −36.5 feet msl. This elevation is considered to be approximately the lowest point, and is shown as −36 feet msl on plate 5.

BEDROCK VALLEYS OF THE MAINE COAST

GENERAL FEATURES

The Maine coast is highly indented, marked at most places by many islands and long narrow estuaries. The coast reflects the structural alinements of the bedrock, which consists chiefly of folded and more or less metamorphosed sediments and intrusives of Paleozoic age. The full explanation for the detailed indentation of the Maine coast is doubtless complex, involving the nature of the bedrock, amount of marine submergence, amount of crustal recovery from ice load, crustal deformation if any, and previous erosional history. Most of the rivers enter the sea through estuaries that extend many miles inland and mainly are extensions of buried bedrock valleys.

The Maine coast valleys discussed are those of the Presumpscot River, the Kennebec, and Sheepscot, the Penobscot, and the St. Croix including its continuation through Passamaquoddy Bay (fig. 1). Representative sections are given in plate 3. Table 5 gives nontechnical information about the sites and sources of data on borings.

TABLE 5.—*Summary of information on crossings of bedrock valleys along the Maine coast*

Bedrock valley	Locality No. on fig. 1	Purpose of borings	Agency for which borings were made	Date of plans	Topographic quadrangle maps on which the sites and vicinities are shown
Presumpscot	8	Veterans Memorial Bridge (U.S. Route 1) over Fore River between Portland and South Portland.	Maine State Highway Commission.	1952	Portland West.
Do	7	Maine Turnpike in Portland	Maine Turnpike Authority	1953	Do.
Kennebec	10	U.S. Route 1 bridge between Bath and Woolwich.	(1)	1926	Bath.
Do	9–A	Highway bridge between Richmond and Dresden.	Directors of the Maine Kennebec Bridge.[1]	1930	Gardiner.
Do	9	Augusta Memorial Bridge, U.S. Route 202, in Augusta.	Maine State Highway Commission.	1945, 1949	Augusta.
Sheepscot	11	U.S. Route 1 bridge between Wiscasset and Davis Island in Edgecomb.	do	1931	Wiscasset and Boothbay.
Penobscot	13	U.S. Route 1 between Prospect and Verona.	(1)	1930	Bucksport.
	12	Highway bridge between Bangor and Brewer.	Maine State Highway Commission.	1953	Bangor.
Passamaquoddy Bay	14	Proposed tidal dam across Head Harbor Passage between Deer and Campobello Islands, New Brunswick, Canada.	Sonar investigation for U.S. Army Corps of Engineers.	1952	(2).
Do	15	Proposed tidal dam between Estes Head in Eastport and Treat Island, in Lubec.	U.S. Army Corps of Engineers.	1936	Eastport.[2]

[1] Data obtained from Maine State Highway Commission.
[2] U.S. Coast & Geodetic Survey chart 801.

DEPTH OF BEDROCK THALWEGS

The crossings of the buried bedrock valleys of the Maine coast are all either about at the heads of the estuaries of the rivers, or several miles upstream where the valleys are narrow. Some information has been obtained about the Passamaquoddy Bay part of the St. Croix bedrock valley by sonar exploration. Each of these valleys is different, or there is some special problem involved; hence, the respective bedrock depths are discussed separately in the following paragraphs:

PRESUMPSCOT BURIED VALLEY

The present-day Presumpscot River is the largest of several streams that cross the lowland around the city of Portland, Maine. Except for the prominent hill on which much of the city is built, the area has moderate relief. Low hills, underlain mainly by bedrock, rise short distances above a blanket of glacial deposits. The bedrock consists of more or less strongly metamorphosed sedimentary rocks whose foliation has steep dips and a northeasterly strike.

The Presumpscot River originates at Sebago Lake (fig. 1) and flows directly southeastward for about 12 miles as if to enter the sea at the south side of Portland. Instead, it turns abruptly northeastward for about 4 miles, and then turns east-southeastward again to enter Casco Bay north of Portland. Hitchcock (1874) suggested that the Presumpscot River fomerly continued southeastward all the way to the sea. If so, this course is now completely buried. The bedrock profiles at localities 7 and 8 (pls. 3 *A* and *B*), however, appear to show a valley along this trend. The small Stroudwater River now lies approximately along this course, which is considered to be that of an ancestral Presumpscot River.

Plate 3*A* shows the subsurface geology at the Maine Turnpike crossing over the Stroudwater River (loc. 7, fig. 1). Most of the borings shown in this section penetrated the unconsolidated deposits only until they encountered some obstruction; that is, the point of refusal. The obstruction may have been a boulder, very compact till, or bedrock. For lack of other subsurface data, the assumed bedrock surface is shown at about the point of refusal of the borings.

The depth to bedrock at this section is not everywhere well established. Boring 23–05, the deepest, extended to about −56 feet msl, and ended in "gray wet compact silty fine sand, some gravel." The lowest elevation of the bedrock surface here is not known but is probably at least −60 feet msl and could be substantially deeper. For example, a 2-foot-thick boulder at −18.3 to −20.3 feet msl was penetrated by boring 23–05. Had this obstruction not been penetrated, the depth would have been reported as refusal and the elevation would have agreed with the positive bedrock depth at boring 23–14 and the point of refusal at boring 23–67A. Hence, at least locally, bedrock may be appreciably deeper that the assumed bedrock surface shown.

Plate 3*B* shows a section across the Fore River estuary at the southwestern tip of Portland. All borings were stopped at refusal; probably most holes ended within a few feet of bedrock. Based on the refusal depths, the bedrock surface has a minimum observed elevation of about −115 feet msl. Some older borings (p. M35) approximately along the same line reached refusal: one at −129.8 feet msl and another at 128.4 feet msl.

KENNEBEC BEDROCK VALLEY

The Kennebec is one of the largest rivers in Maine. It rises at Moosehead Lake and follows an irregular, but generally southerly, course through Augusta, and thence to the sea at Merrymeeting Bay. From Augusta south, the bedrock channel is several tens of feet below river level. The alinement of the bedrock ridges, islands, and promontories south of the 44th parallel suggests that the buried course of the Kennebec would continue about southwestward to the northeastern part of Casco Bay. However, the data on the rather fully concealed bedrock are insufficient either to determine or to disprove the presence of a buried bedrock valley in that area. On the other hand, the course of the pre-Wisconsin Kennebec may have been about the same as that of the present river.

The only section surely on the ancestral Kennebec is at Augusta (loc. 9, fig. 1), about 24 miles upstream from the middle of Merrymeeting Bay. At four borings (Nos. 5, 14, 16, and 27) the bedrock was cored, and its elevation accurately determined. The lowest point on the bedrock reported in the logs was at boring 27 which penetrated "granite ledge" at about −76 feet msl. The thalweg of the bedrock valley here may be −80 feet below msl. Boring 26 (not shown), about 50 feet south of boring 27, entered bedrock at about −65 feet msl, which is the basis for drawing the bedrock shelf shown on the cross section just southwest of boring 27.

At Bath, Maine, about 35 miles downstream from Augusta, the U.S. Route 1 toll bridge crosses the estuary part of the Kennebec River (loc. 10, fig. 1). The records do not indicate whether or not bedrock was actually cored, but they do report "hardpan" at the bottom, suggesting that a more positive identification of the base of the deposits was made than simple "refusal." If so, the bedrock depth figures are reasonably accurate. The lowest bedrock elevation is at boring 30, 138.4 feet below "mean water level," probably close to the lowest bedrock elevation in the section. The figure used is −140 feet msl.

SHEEPSCOT RIVER AT WISCASSET

A few miles east of the mouth of the Kennebec is the estuary of the Sheepscot River. A set of records from wash borings for the bridge at locality 11 (fig. 1) are illustrated in plate 3*E*. Records of two borings are also available for the subsidiary bridge from Davis Island eastward to the mainland. At the main bridge, locality 11, the minimum elevation of the bedrock, based on refusal depths in fairly closely spaced borings, is about −150 feet msl. The minimum elevation plotted is −160 feet msl.

PENOBSCOT RIVER BEDROCK VALLEY

Within the coastal region under consideration in this report, the Penobscot River extends northward as a narrow estuary from Penobscot Bay about to Bangor. The head of Penobscot Bay (taken as the southern tip of Vinalhaven Island) is about 34 miles from the sea, and Bangor is about 20 miles farther. The depth to bedrock beneath Penobscot Bay is not known, and appreciable data for along the river itself are available at only two places. One location is where the U.S. Route 1 bridge crosses between Prospect and Verona, about 4 miles upstream from the head of the Bay (loc. 13, fig. 1) and the other is at Bangor (loc. 12, fig. 1).

There is some question as to whether or not either locality 12 or 13 is actually on the course of the ancestral Penobscot. Bastin in Barrows and Babb, 1912, p. 12) suggested that the bedrock valley of the Penobscot near Bangor passes some 4 to 5 miles west of the Bangor business center. J. M. Trefethen (oral communication) and students are now working to delineate the former course of the Penobscot in the vicinity of Bangor. Farther south, about 5 miles upstream from locality 13 (fig. 1), the South Branch Marsh River joins the Penobscot after flowing directly northward for several miles in a broad marsh-floored steep-walled valley. Trefethen made a rod sounding in this valley about a mile from the Penobscot estuary to −190 feet msl without reaching refusal, and suggested (oral communication, 1958) that the South Branch Marsh River valley may mark a former course of the Penobscot.

The suggestion that the course passes west of Bangor may be valid, but a possible outlet for a deep buried valley beneath the South Branch Marsh River other than along the present Penobscot is not readily apparent from field examination in the area. Nevertheless, the sections at localities 12 and 13 are either on some preglacial or early glacial course of the Penobscot or on tributaries thereto.

The section at Bangor shows cored bedrock at a minimum elevation of about −43 feet msl, overlain by stratified sand and gravel. The information on the Prospect-Verona bridge site is sketchy. The deepest and lowest of four borings below sea level penetrated 96 feet of clay containing gravel and boulders to an elevation of −124 feet msl. Bedrock was not reached. If the 190-foot minimum elevation reported by Trefethen a few miles to the north is in a tributary to the main Penobscot buried valley, and is not due to glacial overdeepening, the elevation of the bedrock surface at locality 13 could be at least −200 feet msl.

The depth is considerably greater farther southeast beneath Penobscot Bay. In fact, the water alone is deeper than 400 feet in the area just south of the narrow part of the passage between the west side of Vinalhaven Island and the mainland (U.S. Coast and Geodetic Survey, chart 1203). This depth is comparable to the depths in the outer parts of Passamaquoddy Bay to the north.

ST. CROIX BEDROCK VALLEY (PASSAMAQUODDY BAY)

The St. Croix River heads in Canada, and the lower 95 miles of its course forms the boundary between Maine in the United States and New Brunswick in Canada. It enters an arm of Passamaquoddy Bay a few miles downstream from Calais, Maine, and thence exists as a narrow channel trending south-southeast in an almost straight line for about 19 miles. This course lies beneath Western Passage, the channel that forms the southern outlet of Passamaquoddy Bay. (See fig. 9.) Nearly east of Eastport, the channel turns abruptly northeastward and passes in a broadly curving course through Head Harbor Passage around the north end of Campobello Island, New Brunswick, to the Bay of Fundy. At Eastport, the St. Croix bedrock valley is joined by a tributary channel from Cobscook Bay to the south and west, probably a continuation of the Pennamaquan River valley that enters Pennamaquan Bay.

The bedrock geology of the Passamaquoddy Bay area has been described by Bastin and Williams (1914), Perry and Alcock (1945), and Alcock (1946). The rocks consist of some more or less metamorphosed, and some unmetamorphosed, sedimentary rocks of Paleozoic age associated with igneous rocks, mainly extrusive. There are two major fault zones. One of these, inferred, lies beneath the Western Passage and strikes northwest parallel to the alinement of the passage. The other, likewise inferred, is a northerly extension of one of the faults mapped by Bastin and Williams (1914) between Lubec Neck and Seward Neck. This fault probably continues northward east of Eastport and beneath Head Harbor Passage west of Campobello Island.

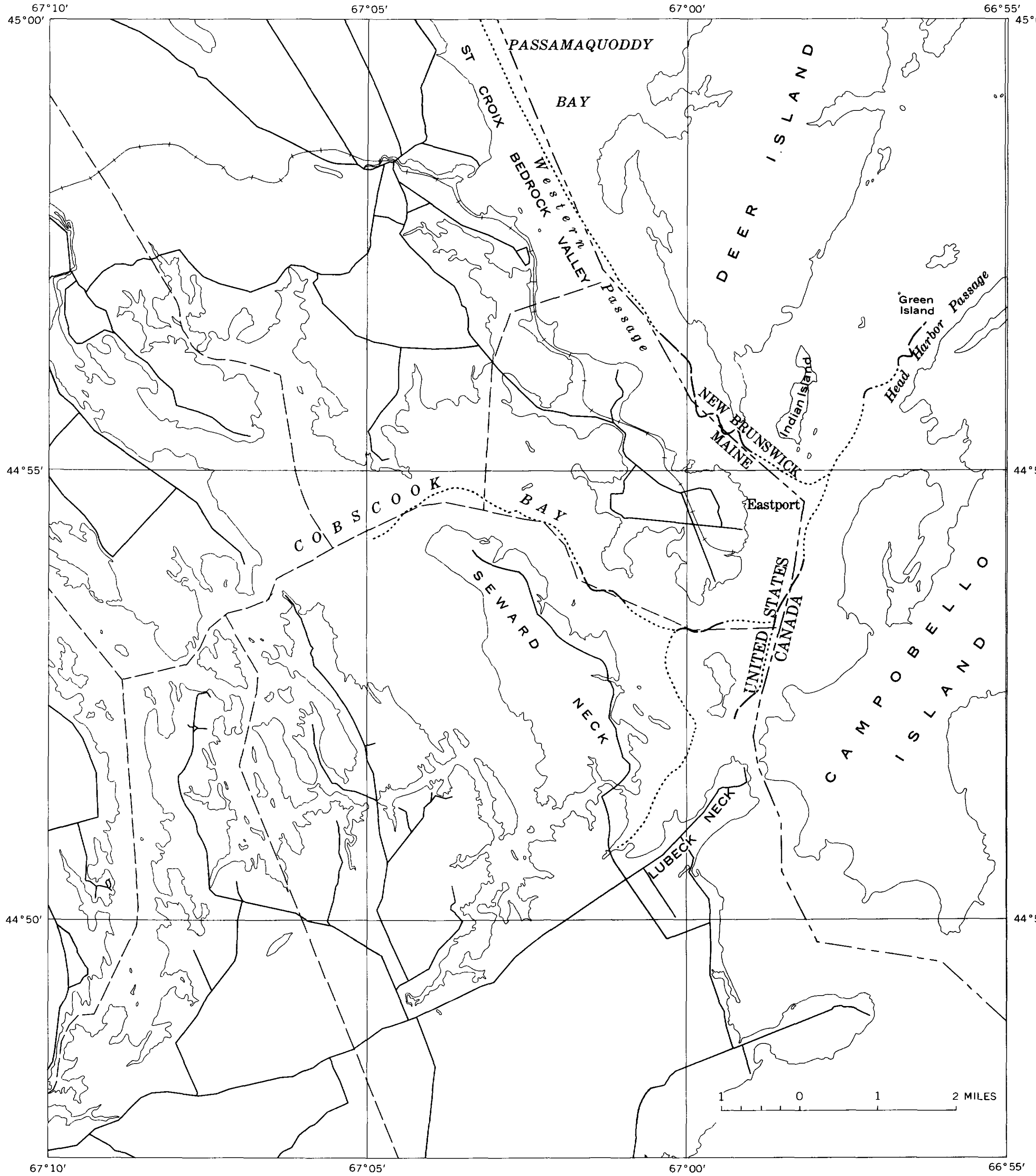


FIGURE 9.—Sketch map of the vicinity of Eastport, Maine, showing thalwegs of St. Croix bedrock valley and tributaries in the southern Passamaquoddy Bay area. Segments shown by dashed lines are taken from 1951 sonar survey (Smith, Upson, and others, 1952); those shown by dotted lines are estimated.

Probably other faults in the region have trends that diverge from those described. The alinement of the sea passages herein discussed appears to be broadly controlled by these fault zones, along which erosion took place more readily than in the adjacent blocks.

Deeply buried bedrock valleys along the lower part of the St. Croix River and the Cobscook Bay tributaries are revealed by subsurface investigations made by the U.S. Army Corps of Engineers since 1930 in connection with plans for the International Passamaquoddy Tidal Survey aided by sonar studies carried out by the U.S. Geological Survey in 1951. The results of the earlier work are in reports by the corps, and the results of the later work are in a preliminary report by Smith, Upson, and others (1952) and a paper by Upson (1954). The results of more recent work, done in 1958 by the corps aided by Fairchild Aerial Surveys sonoprobe, are summarized in a report by the International Passamaquoddy Engineering Board (October 1959). The most complete information pertinent to the present discussion on the configuration of the bedrock and the nature of the sediments is in the report by Smith, Upson, and others (1952).

Largely on the basis of sonar surveys the bedrock channel beneath the Western Passage lies slightly below −400 feet msl. A little more than 4 miles downstream, about opposite Green Island in Head Harbor Passage, the bedrock thalweg also lies a little below −400 feet msl. A figure of −420 feet msl, considered to be approximately correct, is used. These depths are approximate because the velocity of sound transmission used was not specifically determined for the area. Also, it was difficult at places to recognize the bedrock reflection in the recorder trace. The results of the 1958 investigations are not closely comparable with the 1951 results but are not inconsistent with the depths herein mentioned. The Western Passage reach is alined, in general, with the direction of glacial ice movement, whereas the Head Harbor Passage reach lies athwart the direction of ice movement. It would be expected that, of the two, the former would be deepened more by glacial erosion. The fact that the depths at these places are about the same suggests that glacial erosion was not the principal agent in forming the valleys, although there may have been some scour or plucking in either or both reaches.

Bedrock depths beneath other channels in the area agree with the concept of a major bedrock valley for an ancestral St. Croix River, which was perhaps graded to some level lower than 400 feet below present sea level. This depth is appreciably greater than that known or inferred for any other bedrock valley on the New England coast except for Penobscot Bay (p. M31) and part of the Taunton-Sakonnet valley in Naragansett Bay (p. M18).

UNCONSOLIDATED DEPOSITS

The unconsolidated deposits in the bedrock valleys of the Maine coast comprise altogether five units, of which only three or four occur in any one valley. In general the units are: (1) till at the base, (2) local bodies of ice-contact deposits classed as outwash, (3) marine clay and silt, (4) late glacial outwash or fluviatile deposits, and (5) estuarine deposits.

TILL

Till, designated as unit 1 in the sections shown in plate 3, occurs discontinuously on the bedrock surface in all the valleys. It is recognized in the boring records as poorly sorted material composed mainly of gravel plus varying amounts of clay, silt, and sand. It is compact, or hard, is sometimes described as "hardpan," and causes a markedly higher blow count than any of the overlying deposits. At most places it is 10 to 20 feet thick, but at others (pl. 3*A*) it may be 40 feet or more.

Till is not recognized everywhere, as the sections (pl. 3) show; it might be present as a thin layer of pebbles or be only a few feet thick, as in some exposures, but was not noted during drilling or boring. Some of the material, generally in the upper few feet, is less compact and comprises gravel and sand. This material may actually be thin outwash but is not differentiated in the sections.

OUTWASH

There are no extensive outwash deposits above the till such as there are in the valleys of Connecticut. In the valleys of coastal Maine, outwash, designated as unit 2 in plate 3, mainly occurs as local bodies of fine to coarse sand with some gravel or boulders. The material contains little clay or silt and is not hard, although at places it is described as "compact." Because it contains no appreciable clay or silt and because it occurs locally along the valley sides, it is probably an ice-contact deposit and is herein classed as outwash. Examples of this outwash are at the south sides of the Presumpscot buried valley (pl. 3*A*) and of the Kennebec valley at Augusta (pl. 3*C*).

MARINE CLAY AND SILT

The predominant deposit in the Maine coastal valleys is marine clay and silt (unit 3 shown in pl. 3). (See Goldthwait 1951; Katz, 1913.) This deposit is usually gray, but locally blue, mostly compact clay and silt. At places it contains some sand. Locally, it contains shell fragments, but ordinarily no other organic matter. At most places it is tough or compact, but at some places it is soft and in some borings is reported as stratified. Locally, it contains scattered pebbles. The unit is as much as 120 feet thick (pl. 3*E*). Perhaps the best subsurface characterization of this deposit is found in the boring records for the Presumpscot buried valley (pl. 3*A*, *B*), where the material is variously described as "gray silty clay," "clay and silt," "silt and traces of clay," or "gray silty clay and traces of sand."

These deposits are entirely below sea level at some of the sections, but in the vicinity of Portland (pl. 3*A*, *B*) and Augusta (pl. 3*C*) they extend above sea level where their observed characteristics are the same as those herein described from boring records. In the vicinity of Portland, the deposits are continuous with the Presumpscot Formation of Bloom (1959).

In the Sheepscot valley (pl. 3*E*), the marine deposits form a thick unit that, in all but six of the boring records, is designated "blue clay." In one it is designated "soft blue clay," and in five the material is not named, but the symbol used on the drawing is the same as where blue clay is named. This material reaches a maximum thickness of more than 120 feet in the deepest part of the bedrock valley. It is doubtless the marine formation of clay and silt that occurs along the entire coast and that is exposed farther inland.

The records of the borings across the Sheepscot do not indicate whether or not this clay comprises more than one stratigraphic unit. Two units of clay, however, are indicated by records of two borings and a "soils profile" drawn by the State Highway Commission for the subsidiary bridge between Davis Island and the mainland to the east. The lower clay is gray silty clay described as having "medium consistency." The upper, which appears to occupy a channel eroded in the gray silty clay, consists of "soft sensitive clayey silt with a few sea shells." The channel, if present, extends down to about −95 feet msl. However, the lowest elevation of probable estuarine deposits is about −30 feet msl. (See p. M35).

Whether these are two divisions of the marine clay or whether the younger unit here represents the estuarine deposits that are present in other valleys farther south is not known. The upper material has sea shells, but apparently no plant remains, and the authors consider it to be older than the estuarine deposits in the buried valleys of the Presumpscot and Kennebec Rivers.

The deposits in the Penobscot are not well known. The section at Bangor shows mostly stratified sand and gravel that is actually younger than the marine clay. At the Prospect-Verona Bridge (loc. 13, fig. 1) the available boring records report primarily clay with varying amounts of gravel. The data are not adequate to define the stratigraphy, but the deposits appear to consist mainly of clay and silt.

In the St. Croix buried valley system, the marine clay and silt occur for the most part in the broad shallow bays west of Eastport and Lubec (fig. 9) (Upson, 1954). They are similar to the Presumpscot Formation of Bloom, but they may not be the same formation. Within Passamaquoddy Bay proper, the marine clay and silt deposits are widespread. Whether or not they are covered with an appreciable thickness of estuarine deposits is not known.

The deposits have been examined in detail south of Eastport, Maine, beneath the sea passages north of Treat Island and south of Dudley Island (fig. 9). Detailed descriptions of samples taken during test drilling in these channels were made by geologists of the U.S. Army Corps of Engineers. The material penetrated was marine clay and silt. The descriptions suggest a possible differentiation between an upper "soft clay" and a lower "stiff clay." The "soft clay" contains shells and some silt and sand; the lower stiff clay is, in general, described as banded. Thus a significant difference is suggested. However, in a few holes "soft clay" occurs below "stiff clay," and in one or two holes banding is noted in the lower part of the "soft clay." Locally, the "stiff clay" also appears to grade upward into the "soft," and the two are not separated by any clear-cut unconformity. Therefore, the upper clay is considered part of the glacial marine sequence, and not of the nonglacial estuarine deposits like the soft shell-bearing estuarine deposits of the Connecticut coastal valleys, Narragansett Bay, and the harbors of Portland and Boston. However, if the marine clay and silt unit does comprise two subdivisions, the distinction may be related to different relative positions of land and sea. During decline from its highest position (Upson, 1954, p. 293), the postglacial sea near Eastport apparently stood against the land for an appreciable length of time at a level now about 90 feet above sea level. Possibly the lower beds of the marine clay unit were deposited when the sea was higher, and the upper beds were deposited while and after the sea was at a level that was 90 feet higher than it is at present.

In summary, the deposits herein designated marine clay and silt rest on the till and at places directly on the bedrock where the till is missing. Locally, they overlap bodies of outwash. They occur along the coast from Portsmouth, N.H., to Eastport, Maine, and beyond, and they extend inland up the major stream valleys as much as 75 miles from the coast. They appear to be equivalents throughout, but it is not certain that they are entirely.

The surface of the marine clay and silt was eroded in the Presumpscot valley near Portland and in the lower part of the Kennebec at Bath, but farther east evidence of erosion is slight. It may have been channeled slightly in the Sheepscot River at Wiscasset but apparently was not channeled in the vicinity of Eastport, Maine.

Above the marine clay and silt is a fourth unit, consisting of estuarine deposits, that occurs everywhere except in the northeastern part of the coast. As exemplified by the top unit beneath the Fore River (pl. 3*B*), the deposits are soft, loose material, in which the bore casing settled under its own weight. They are described as soft silt, or river mud. At some borings (for example, D–20) traces of shells are recorded, and in some borings plant organic material was penetrated.

According to the borings used for the section shown in plate 3*B*, the base of the estuarine deposits extends to about −40 feet msl. However, older borings (p. M30) made along the same line by the Edw. F. Hughes Co. of Boston in the period August 1946 to November 1947 show material that appears to be the underlying marine clay and silt but that contains organic material down to an elevation, at two borings, of nearly −90 feet msl. Except for some pieces of decayed wood in the interval −41.5 to −50.5 feet msl at one boring, the organic matter is undescribed and presumably consists of pieces or seams of carbon or perhaps finely disseminated carbon. The strata that contain this organic material are separated from overlying shell-bearing clearly estuarine material that reaches about −40 feet msl by beds of clay, silt, and sand without organic material.

Woody organic material apparently is not characteristic of the Presumpscot Formation of Bloom, whose rather full description (1959, p. 55–61) mentions only shells or shell fragments at a few places. Either the organic material reported in the older borings is a misidentification of some other dark material, or organic material was not recognized in the later borings. If the organic material is present, the sediments probably represent a post-Presumpscot estuarine deposit; and thus there may have been two periods of post-Presumpscot down cutting and filling in this area, the older one reaching a depth of about 90 feet below sea level. The evidence at present is considered inconclusive.

At Bath, Maine (pl. 3*D*), the unit consists of sand, and sand and gravel. Rotten wood is reported at boring 16 and "sound spruce drift" at boring 11, but otherwise no plant remains or shells are indicated. This unit may be the equivalent of estuarine deposits in other areas, although the reported coarse grain size suggests that the material is composed of outwash.

In the Sheepscot valley, the deposits consist of material described as "mud" or "soft mud." At most borings this material is reported to be 4 feet thick; at one it is reportedly 16 feet thick. This is probably present-day bottom mud. However, it rests on an irregular surface that may have been formed by subaerial erosion, and thus may be partly estuarine material and correlative with estuarine deposits in the Maine valleys farther south. The base of the deposits extends to about −30 feet msl.

Upstream, these deposits apparently merge with more sandy material, at least in some stream valleys. For example, along the Kennebec at Augusta (pl. 3*C*) the uppermost unit lies beneath the river, and also extends about 15 feet above river level on the east side to form a low terrace. Beneath the river this unit is sand and gravel generally less than 5 feet thick. Beneath the terrace it reaches a thickness of about 20 feet and consists mostly of sand and silt. Locally, its surface is covered by artificial fill. The original log of boring 3 (pl. 3*C*) reported "boulders or logs embedded in sand" near the bottom of the unit at −3.99 to −0.99 feet msl. The overlying material is decribed as "medium brown sand, soft silt and very fine sand, sawdust and rotten wood." From inspection of the site, the authors believe that at least the upper part of boring 3 penetrated artificial fill. This material appeared to have been excavated from the silty sand and sandy silt deposits exposed nearby. The writers also believe that this unit, except for the artificial fill, is late fluviatile alluvium. At least the part beneath the river currently must be subject to cutting and filling with variations in riverflow. The unit is clearly not estuarine but may be the time equivalent of estuarine deposits farther downstream. The lower part of the deposits beneath the terrace may be a fine-grained late outwash.

There appear to be no estuarine deposits in the valleys of Passamaquoddy Bay, at least south of Eastport, except perhaps for a few feet of present-day bay mud.

In the Presumpscot valley and in the Kennebec at Bath, estuarine deposits rest on a surface which, because it is irregular and has a channellike shape and because it is on marine deposits, is probably an erosion surface formed subaerially by streams. The low point, or thalweg, of this pre-estuarine unconformity lies at about −40 feet msl (possibly −90 ft msl) at the Fore River bridge at Portland, and apparently about −94 feet beneath the Kennebec at Bath. This thalweg may have been as low as −95 feet msl beneath the Sheepscot River at Wiscasset (p. M34), but probably not deeper than −30 feet msl.

Suggested channeling within the deposits to depths of about 90 to 95 feet is considered to mark variations within the marine clay and silt, although it may indicate a pre-estuarine unconformity extending to such depths.

SUMMARY OF FEATURES OF MAINE COASTAL BEDROCK VALLEYS

The bedrock thalwegs of most of the Maine coastal valleys range from about 95 (the Piscataqua at Portsmouth, N.H., or Kittery, Maine) to about 160 feet beneath the Sheepscot River at Wiscasset. The submerged thalweg of the St. Croix in Passamaquoddy Bay reaches a level of about −420 feet msl.

The deposits in these valleys consist for the most part of glacial-marginal marine clay and silt separated from the bedrock by a thin discontinuous layer of till. The marine clay and silt reaches a maximum thickness of more than 100 feet. In the valleys of southern Maine the marine clay and silt are overlain unconformably by estuarine deposits that occur above erosional channels. The lowest places on these channels reach at least −40 feet msl and possibly −90 to −95 feet msl. This unconformity either is not present or is not recognizable with existing data in the Penobscot valley, and the clays in the vicinity of Eastport do not seem to have been channeled at all.

CONCLUSIONS

The conclusions are divided into two main categories, corresponding to the main topics discussed in the report: (1) depths and origin of the bedrock thalwegs, and (2) inferences drawn from the stratigraphy of the glacial deposits in the valleys, especially the unconformity at the base of the estuarine deposits.

DEPTHS AND ORIGIN OF THE BEDROCK THALWEGS

One of the objectives of the current study was to obtain an idea of the time of origin of the bedrock valleys and to ascertain their relationship, if any, to lowered sea level accompanying glacial stages or substages of the Pleistocene Epoch. Table 6 shows the inferred depths of the thalwegs below sea level at the localities examined. The significant depths are plotted for the entire coast on plate 4. Examination of the map shows that there is no obvious pattern for the thalweg depths along most of the coast. However, one or two general features are revealed. The depths on the Thames River in Connecticut (elev −190) on the Blackstone buried valley in the Narragansett Basin (elev −200) and the valleys in the Boston area (elev −250) are all within the same general range which may indicate that they represent a single general level of erosion. However, the rough correspondence of depths may be simply fortuitious.

At two places the thalweg elevations are substantially lower. One is Narragansett Bay where some elevations are around −350 feet msl level and the other in Passamaquoddy Bay where elevations are a little lower than −400 feet msl. A recent report by Woods Hole Oceanographic Institution (Hersey and others, 1961) indicates that bedrock thalweg elevations in the southern part of Narragansett Bay may be more than −400 feet msl. The bedrock in the outer part of Penobscot Bay is also more than −400 feet msl. These elevations are within a limited range, and an erosional level at −350 to −400 feet msl may be indicated. However, only in the Passamaquoddy Bay area is there indication that such a level is at all extensive longitudinally. Also, there is not enough information to show whether or not such elevations are a consistent feature of the whole coast. Most of the thalweg depths along the Maine coast are appreciably shallower.

Even if the elevations at about −200 to −250 feet msl and at about −350 to −400 feet msl should represent segments of erosional levels, such levels may reflect merely local base levels due to varying rock resistance. The depth of drowning of the bedrock topography, and variations in the depth are then largely an expression of the relative amounts of local erosion that preceded the drowning, and they are not controlled by a coastwide base level such as sea level would be. Also, the amount of glacial erosion—by scour, plucking, or by subglacial streams—is not known. Although possible, it seems unlikely to the writers that the thalweg depths below sea level are wholly, or even in major part, the result of deepening by glacial erosion. More detailed studies of the longitudinal bedrock profiles might reveal critical evidence.

Because of the lack of a consistent depth pattern, and because some of the isolated depths may be the result of appreciable glacial erosion, it seems that with present knowledge, the thalweg depths probably do not represent positions of lower sea level accompanying glacial stages, and hence do not indicate the magnitude of eustatic lowering.

Furthermore, the bedrock valleys, in general, have a veneer of Wisconsin till that extends down the valley sides and at many places appears on the valley bottoms. Unless, of course, the ice itself is the main agent of erosion, this relationship suggests that the valleys were already in existence before at least the Wisconsin ice reached the present coastal region.

If these thalwegs, below sea level, are not related to eustatically lowered stages of sea level, the question arises as to why they are below sea level at all. The reason must be either that the crust is still recovering from Wisconsin glacial loading or that the crust itself has been warped downward during Pleistocene and Recent time. Consideration of this problem is outside the scope of this report.

TABLE 6.—*Inferred elevations of thalwegs of New England coastal bedrock valleys*

[Elevation: >, below indicated elevation]

Bedrock or buried valley	Locality		Data		Minimum elevation of bedrock from well, test boring, or seismic data	Inferred elevation of thalweg of bedrock valley	Inferred minimum elevation of unconformity at base of estuarine deposits	Approximate distance upstream from coast (miles)	Relative competency of bedrock: resistant (R); nonresistant (N)
	No.	Shown on—	Type	Reference	Feet above (+) or below (−) mean sea level				
Coastal valleys of Connecticut									
Housatonic	2	Figure 1	Cross section	Plate 1*B*	−115	−115	−65	3.3	R
Do	1	do	do	Plate 1*A*	−92	−92	−43	6.6	R
Quinnipiac	3	do	do	Plate 1*C*	−171	>−280	−40	4.0	N
Connecticut	4	do	do	Plate 1*D*	−132		−92	3.5	R
Do			Water well at Maromas, in Middletown, Conn.		>−155			22.9	R
Do	6	do	Cross section	Figure 2	−118	−120	−66	29.3	N
Thames	5	do	do	Plate 1*E*	−174	−190	−130	3.7	R
Narragansett Bay area									
Blackstone	6	Figure 3		See table 3	>−115		−40	15.0	N
Do			Water wells in Warwick, Providence, and Pawtucket, R.I.[1]		−165–−200	−200		16.4–32.5	N
Do			Test boring for bridge at Ashton, in Cumberland, R.I.[2]	See figure 4	+23	>+13		38.4	R
Providence	5	Figure 3		See table 3	>−320	[3] −350		1.8	N
Do	4	do		do	>−158		−110	12.3	N
Do	3	do		do	>−158		−85	18.8	N
Taunton-Sakonnet.	10	do		do	−370	−400	−80	12.0	N
Boston Basin area									
Charles	4	Figure 6	Cross section	Plate 2*D*	−243	−250	−35	1.6	N
Do	3	do	do	Plate 2*C*	−244	−250		4.2	N
Do	2	do	do	Plate 2*B*	−145	−210	−28	6.4	N
Do			Test boring in Newton, Mass.		−97			11.2	N
Do	1	Figure 6	Cross section	Plate 2*A*	−82	−100		15.1	N
Aberjona-Fresh Pond	5	do		See p. M24 in text	−170	−180		8.9	N
Do			Water well in Winchester, Mass.		−145	−150		14.1	R
Do			Test well in Winchester, Mass.		−137	−140		15.3	R
Do			Washington Street over Aberjona River in Woburn, Mass.		>−70			16.2	R
Malden	7	Figure 6	Cross section	Plate 2*E*	−212	−230		.7	N
Do			Mystic River Bridge Boston.		[4] −120			5.7	N
Do			Revere Beach Parkway over Malden River between Medford and Everett, Mass.		[4] −155			7.7	N
Malden	6	Figure 6	Cross section	Figure 8	−193	−195		9.3	N
Do			Water well in Melrose, Mass.		[4] −43			10.5	R
Do			do		40			11.3	R

See footnotes at end of table.

TABLE 6.—*Inferred elevations of thalwegs of New England coastal bedrock valleys*—Continued

[Elevation: >, below indicated elevation]

Bedrock or buried valley	Locality: No.	Locality: Shown on—	Data: Type	Data: Reference	Minimum elevation of bedrock from well, test boring, or seismic data	Inferred elevation of thalweg of bedrock valley	Inferred minimum elevation of unconformity at base of estuarine deposits	Approximate distance upstream from coast (miles)	Relative competency of bedrock: resistant (R); nonresistant (N)
					Feet above (+) or below (−) mean sea level				
Vicinity of Portsmouth, N.H.									
Bellamy River	6A	Figure 1	Wash boring near Scammel Bridge for U.S. Route 4.	See p. M28 in text.	−91.5	−95	−36	10.5	?
Maine coast									
Presumpscot	8	Figure 1	Cross section	Plate 3*B*	−115	−130	−40	3.1	?
Do	7	do	do	Plate 3*A*	>−56		−38	5.9	?
Kennebec	10	do	do	Plate 3*D*	−138	−140	[5] −94	13.0	
Do	9-A	do		Table 5	−70	−90		26.9	R
Do	9	do	Cross section	Plate 3*C*	−76	−80	−10	43.4	R
Sheepscot	11	do	do	Plate 3*E*	[4] −150	−160	−30	16.0	
Penobscot	13	do	Route 1 Bridge between Prospect and Verona, Maine.		>−124	>−124		38.5	R
Do				See page M31 in text.	>−190			45.2	R
Do	12	Figure 1		See table 5	−43	−45		59.1	R
St. Croix (Passamaquoddy Bay.	14	do		do		Approx −420			?

[1] See A. W. Quinn and others (1948); W. H. Bierschenk (1954, 1959).
[2] See A. W. Quinn and others (1948).
[3] From seismic reflection survey by Woods Hole Oceanographic Institution. Depths are preliminary because based on uncorrected velocity values.
[4] Figure is refusal depth; at most borings probably close to bedrock.
[5] At base of outwash or fluviatile deposits; may not be pre-estuarine unconformity.

STRATIGRAPHY OF THE DEPOSITIONAL FILL

The glacial deposits in the several valleys discussed in this report are highly varied and were deposited under different conditions in the different valleys. They are broadly correlative in the sense that they are all pleistocene, but they are not closely correlative. For example, certain deposits in the lower part of the section in the Boston Commons garage excavation were considered by Kaye (1961, p. B–75) to be early Wisconsin or older. The outwash in the Connecticut valleys, though probably Cary, may be somewhat different in age from the ice-marginal clays along the Maine coast. And those clays themselves may be progressively younger northward, or those in eastern Maine may be younger than the others. A generalized comparison, not a correlation chart, is given in table 7. However, all the valleys except those in eastern Maine have an uppermost unit of estuarine deposits, and related peat, swamp, and marsh deposits, which rest unconformably on the underlying glacial deposits.

TABLE 7.—*Generalized comparison of late Pleistocene and Recent deposits in bedrock valleys*

Connecticut	Narragansett	Boston Basin area (after Judson, 1949 and Kaye, 1961)	Maine coastal valleys: Southern (Bloom, 1959)	Maine coastal valleys: Eastern (Upson, 1954)
Estuarine deposits	Estuarine deposits	Peat and marsh deposits Marine silt Peat	Estuarine deposits	
Unconformity	Unconformity	Lower sea level	Unconformity	
Outwash	Outwash (Including marine(?) clay and silt) Thin outwash	Lexington Till and outwash } Drift IV of Kaye Erosion and lower sea level Boston Clay (marine) (Clay III of Kaye)	Presumpscot formation (Marine)	Ice-marginal marine clay and silt
Ground moraine	Ground moraine	Boston Till (Also older clays and drifts of Kaye)	Ground moraine	Ground moraine

In all the sections from southern Maine to Connecticut, the surface at the base of the estuarine deposits is curving, somewhat irregular, and convex downward.

The low point on this surface at each of the localities studied is probably the thalweg of a pre-estuarine valley and is plotted on plate 5.

The possibility that the pre-estuarine surface in the Connecticut valleys is not a surface of fluvial subaerial erosion has been previously mentioned (p. M13). It is also conceivable that the corresponding surface in Narragansett Bay is not of subaerial origin. However, the elevations in Narragansett Bay, as has been pointed out (p. M21), suggest a gentle seaward slope and in the same sense correspond to elevations in the valleys of the Connecticut coast. Thus, these elevations seem to fit a possible drainage system that could have extended seaward off the eastern end of Long Island. The lowest point of this system would be at least −130 feet msl and perhaps somewhat lower.

The elevations at Boston Harbor and farther north do not fit so obviously. They are north of Cape Cod, and hence were probably on a different drainage system, or systems, than those south of Cape Cod. However, they are all less than −94 feet msl and thus are of the same order of magnitude. Especially in southern Maine, where the channels occur on the marine clay and silt, which must have been deposited beneath the sea, the channels are not likely to be ice-block depressions, and exposure must have occurred after a decline of sea level with respect to the land.

As stated previously (p. M35), evidence for an erosional interval seems to be lacking in the Passamaquoddy Bay area, and in general the unconformities may become increasingly shallow northward. If so, this gradation may signify that at the time of sea-level decline some northward-increasing crustal recovery was still to take place. The thalwegs of valleys formed at the time would have been initially shallower with respect to the lower sea level, and now, with full crustal recovery, would stand higher to the north. In extreme eastern Maine, the land may have been so deeply submerged that an eustatic decline of sea level was not enough to expose the land, thus accounting for the apparent absence of erosion there. It is possible, however, that the whole coast was exposed to subaerial erosion at the same time.

It is certainly reasonable to suppose that the estuarine deposits, representing evidently the last depositional episode in the coastal valleys, are approximately of the same age everywhere and were formed during a single rise of sea level along the whole coast. The underlying surface, on the other hand, may not be the same age everywhere, and may not have been formed in the same way everywhere. However, except possibly for the Boston area, it does seem to have been formed everywhere on glacial deposits of Cary age. In the Connecticut valleys the outwash is considered to be of Cary age (Flint, 1953, p. 899); the Lexington outwash in the Boston area is said by Kaye (1961, p. B-75) to be of Cary age; and MacClintock (1954, fig. 2, and p. 382) suggested that the uppermost drift in Maine is of Cary age. Therefore, if the pre-estuarine surface does represent a general episode of erosion, this episode evidently is post-Cary in age and could correspond to lowered sea level accompanying the ice advance next younger than Cary, which would be of Mankato or of Valders age. (See Flint, 1957, p. 346–347; and Leighton, p. 547–550.)

Regardless of the detailed manner and exact time of formation of the pre-estuarine surfaces, the deposition of the estuarine deposits resulted from the rise in sea level which accompanied the waning and retreat of the ice in Recent and late Pleistocene time. Sea level was at least 130 feet lower than the present (as at the Thames River). According to radiocarbon dating, the retreat of the Valders ice began about 8,500 B.C. 10,500 B.P., Flint, 1957, table 20–B, p. 347). If the low point coincided with the beginning of Valders retreat, sea level rose at least 130 feet in 10,500 years, or at least 0.012 foot per year.

Organic material near the base of the estuarine deposits in the Quinnipiac valley at New Haven (see pl. 1*C*) at a depth of −30 to −31.5 feet msl has a carbon-14 age of 5,900 years ±200 B.P. (Upson and others, 1964.) (Sample W–945.) This date indicates a much slower average rate of rise in the last 5,900 years.

The estuarine deposits discussed in this paper presumably have correlatives in the estuaries elsewhere along the Atlantic coast. Identification of the correlatives south of the glaciated area, and especially the underlying erosion surfaces, might lead to more precise estimates of the rate of late or postglacial sea-level rise. Thus far, the estuarine deposits in the New England valleys would seem to be correlative of either unit C or D as defined by Hack (1957, p. 821, and figs. 4 and 5) in the Susquehanna valley system.

REFERENCES CITED

Alcock, F. J., 1946, Geologic map of Campobello sheet, New Brunswick: Canada Geol. Survey Map 964A.

Allen, W. B., 1956, Ground-water resources of the East Greenwich quadrangle, Rhode Island: Rhode Island Devel. Council, Geol. Bull. 8, 56 p.

Allen, W. B., and Gorman, L. A., Ground-water map of the East Providence quadrangle, Massachusetts-Rhode Island: Rhode Island Water Resources Coordinating Board, Ground Water Map 4.

Allen, W. B., and Ryan, D. J., 1960, Ground-water map of the Fall River quadrangle, Massachusetts-Rhode Island: Rhode Island Water Resources Coordinating Board, Ground Water Map 7.

Barghoorn, E. S., 1949, Paleobotanical studies of the Fishweir and associated deposits, *in* Barghoorn, E. S., and others, The Boylston Street Fishweir II: Andover, Mass., Robert S. Peabody Foundation, v. 4, p. 49–83.

Bastin, E. S., 1912, *in* Barrows, H. K., and Babb, C. C., Water resources of the Penobscot River Basin: U.S. Geol. Survey Water-Supply Paper 279, p. 11–12.

Bastin, E. S., and Williams, H. S., 1914, Description of the Eastport quadrangle [Maine]: U.S. Geol, Survey Geol. Atlas, Folio 192.

Bierschenk, W. H., 1954, Ground-water resources of the Bristol quadrangle, Rhode Island-Massachusetts: Rhode Island Devel. Council, Geol. Bull. 7, 98 p.

——— 1959, Ground-water resources of the Providence quadrangle, Rhode Island: Rhode Island Water Resources Coordinating Board, Geol. Bull. 10, 104 p.

Billings, M. P., 1929, Structural geology of the eastern part of the Boston Basin: Am. Jour. Sci., v. 18, no. 104, p. 97–137.

Bissell, M. H., 1925, Pre-glacial course of the Connecticut River near Middletown, Conn., and its significance: Am. Jour. Sci., ser. 5, v. 9, no. 51, p. 233–240.

Bloom, A. L., 1959, Late Pleistocene changes of sea level in southwestern Maine: Office of Naval Research duplicated rept., 143 p.

Brown, J. S., 1925, A study of coastal ground water, with special reference to Connecticut: U.S. Geol. Survey Water-Supply Paper 537, 101 p.

——— 1928, Ground water in the New Haven area, Connecticut: U.S. Geol. Survey Water-Supply Paper 540, 206 p.

Chute, N. E., 1959, Glacial geology of the Mystic Lakes-Fresh Pond area, Massachusetts: U.S. Geol. Survey Bull. 1061–F, 216 p.

Clapp, F. G., 1901, The geological history of the Charles River in Massachusetts: New England Water Works Assoc. Jour., v. 53, no. 3, p. 372–383.

Crosby, I. B., 1922, Former courses of the Androscoggin River: Jour. Geology, v. 30, no. 3, p. 232–247, 5 figs.

——— 1937, Ground-water conditions of parts of Middlesex, Worcester, and Norfolk Counties in the buried valleys of the preglacial Merrimack, Sudbury and Charles Rivers: Massachusetts Dept. Pub. Health Ann. Rept. year ending Nov. 30, 1937, Commonwealth of Massachusetts Pub. Doc. 34, p. 219–224.

——— 1939, Ground water in the pre-glacial buried valleys of Massachusetts: New England Water Works Assoc. Jour., v. 53, no. 3, p. 372–383.

Crosby, W. O., 1899, Geological history of the Nashua Valley during the Tertiary and Quaternary periods: Technology Quart., v. 12, p. 288–324.

——— 1903, A study of the geology of the Charles River estuary and the formation of Boston Harbor: Boston Rept. of the Comm. on the Charles River Dam, p. 345–369.

Cushman, R. V., 1960, Ground water in north-central Connecticut: Econ. Geology, v. 55, p. 101–114.

Denny, C. S., 1956, Wisconsin drifts in the Elmira region, New York, and their possible equivalents in New England: Am. Jour. Sci., v. 254, p. 82–95.

Ewing, John, and others, 1960, Sub-bottom reflection measurements on the continental shelf, Bermuda Banks, West Indies Arc, and in the West Atlantic Basins: Jour. Geophys. Research, v. 65, no. 9, p. 2849–2859.

Ewing, M. E., and others, 1960, Revised estimate of Pleistocene ice volume and sea level lowering [abs.]: Geol. Soc. America Bull., v. 71, no. 12, p. 1860.

Fairbridge, R. W., 1958, Dating the latest movements of the Quaternary sea level: New York Acad. Sci. Trans., ser. 2, v. 20, no. 6, p. 471–482.

Flint, R. F., 1930, The glacial geology of Connecticut: Connecticut Geol. Nat. History Survey Bull. 47, 294 p.

——— 1933, Late Pleistocene sequence in the Connecticut Valley: Geol. Soc. America Bull., v. 44, p. 965–988.

——— 1953, Probable Wisconsin substages and late-Wisconsin events in northeastern United States and southeastern Canada: Geol. Soc. America Bull., v. 64, p. 897–920.

——— 1956, New radiocarbon dates and late-Pleistocene stratigraphy: Am. Jour. Sci., v. 254, p. 265–287.

——— 1957, Glacial and Pleistocene Geology: New York, John Wiley & Sons, Inc., 553 p.

Foerste, A. F., 1899, Geology of the Carboniferous strata of the southwestern portion of the Narragansett Basin, with an account of the Cambrian deposits, *in* Shaler, N. S., and others, Geology of the Narragansett Basin: U.S. Geol. Survey Mon. 33, p. 223–395.

Goldsmith, Richard, 1960, Surficial geology of the Uncasville quadrangle, Conn.: U.S. Geol. Survey Geol. Quad. Map GQ–138.

——— 1962, Surficial geology of the New London quad., Conn.-N.Y.; U.S. Geol. Survey Geol. Quad. Map GQ–176.

Goldthwait, Lawrence, 1951, Marine clay of the Portland-Sebago, Maine, region: Marine State Geologist Rept., 1949–50, p. 24–34.

Hack, J. T., 1957, Submerged river system of Chesapeake Bay: Geol. Soc. America Bull., v. 68, p. 817–830.

Hahn, Glenn W., 1959, Ground-water map of the Narragansett Pier quadrangle, Rhode Island: Rhode Island Water Resources Coordinating Board, Ground Water Map 5.

Halberg, H. N., and Pree, H. L., 1950, Ground-water resources of the Greater Boston area, Massachusetts: Boston Soc. Civil Engineers Jour., v. 37, no. 2, p. 204–230.

Halberg, H. N., and Roberts, C. M., 1949, Recovery of ground-water supplies by pumping from water-table ponds: Am. Geophys. Union Trans., v. 30, p. 285.

Hersey, J. B., Nalwalk, A. H., and Fink, D. R., 1961, Seismic reflection study of the geologic structure underlying southern Narragansett Bay, R.I.: Woods Hole Oceanographic Inst., duplicated rept., no. 61–19, 24 p. 16 figs., 21 pls.

Hitchcock, C. H., 1874, The geology of Portland: Am. Assoc. Advancement Sci. Proc., pt. 2, p. 163–175.

Hyyppä, Esa, 1955, On the Pleistocene geology of southeastern New England: Geologinen Tutkimuslaitos, Comm. Geol. Finland Bull. 167, 225 p.

International Passamaquoddy Engineering Board, 1959, Investigation of the International Passamaquoddy Tidal Power Project, Report of the International Joint Commission: Washington, D.C. and Ottawa, Ontario, app. 1, 11 p., and app. 2, 58 p.

Jahns, R. H., 1947, Geologic features of the Connecticut Valley, Massachusetts, as related to recent floods: U.S. Geol. Survey Water-Supply Paper 996, 158 p.

Johnson, D. W., 1931, Stream sculpture on the Atlantic slope: New York, Columbia Univ. Press, 142 p.

Johnson, K. E., and Marks, L. Y., 1959, Ground-water map of the Wickford quadrangle, Rhode Island: Rhode Island Water Resources Coordinating Board, Ground Water Map 1.

Johnson, K. E., 1962, Ground water map of the Rhode Island parts of the Attleboro, Blackstone, Franklin, Oxford, and Uxbridge quadrangles: Rhode Island Water Resources Coordinating Board, Ground Water Map 19.

Judson, Sheldon, 1949, The Pleistocene stratigraphy of Boston, Massachusetts, and its relation to the Boylston Street fishweir, *in* Barghoorn, E. S., and others, The Boylston Street Fishweir II: Andover, Mass., Robert S. Peabody Foundation, v. 4., p. 7–48, and fig. 1.

Katz, F. J., 1913, Clay in the Portland region, Maine: U.S. Geol. Survey Bull. 530, p. 202–206.

Kaye, C. A., 1961, Pleistocene stratigraphy of Boston, Massachusetts, *in* Geological Survey Research 1961: U.S. Geol. Survey Prof. Paper 424–B, p. B–73—B–76.

Krynine, P. D., 1950, Petrology, stratigraphy and origin of the Triassic sedimentary rocks of Connecticut: Connecticut Geol. Nat. History Survey Bull. 73, 247 p.

La Forge, Laurence, 1932, Geology of the Boston area, Massachusetts: U.S. Geol. Survey Bull. 839, 105 p.

Lee, F. W., and others, 1940, The seismic method for determining depths to bedrock as applied in the Lowell quadrangle, Massachusetts: Massachusetts Dept. Pub. Works-U.S. Geol. Survey Coop. Geol. Proj. Spec. Paper 3, 46 p.

Leighton, M. M., 1960, The classification of the Wisconsin glacial stage of north-central United States: Jour. Geology, v. 68, no. 5, p. 529–552.

MacClintock, Paul, and Richards, H. G., 1936, Correlation of late Pleistocene marine and glacial deposits of New Jersey and New York: Geol. Soc. America Bull., v. 47, p. 289–338, 2 pls., 5 figs.

MacClintock, Paul, 1954, Leaching of Wisconsin glacial gravels in eastern North America: Geol. Soc. America Bull., v. 65, p. 369–384.

Oliver, J. E., and Drake, C. L., 1951, Geophysical investigations in the emerged and submerged Atlantic coastal plain, pt. 6, The Long Island area: Geol. Soc. America Bull., v. 62, p. 1287–1296.

Pearsall, C. S., 1937, Report on the geological features along the Pressure Tunnel *in* Special Report of the Metropolitan District Water Supply Commission and Department of Public Health relative to improvements in distribution and to adequate prevention of pollution of sources of water supply of the Metropolitan Water District: Commonwealth of Massachusetts, House Doc. no. 262, app. D, p. 174–183.

Perkins, E. H., 1927, The evolution of the drainage of the Waterville region (Maine): Am. Jour. Sci., ser. 5, v. 14, p. 352–364.

Perry, S. C., and Alcock, F. J., 1945, Geologic map of St. George sheet, Charlotte County, New Brunswick: Canada Geol. Survey, prelim. map 45–1.

Quinn, A. W., 1953, Bedrock geology of Rhode Island: New York Acad. Sci. Trans., ser. 2, v. 15, p. 264–269.

Quinn, A. W., and Oliver, W. A., 1962, Pennsylvanian Rocks of New England *in* Pennsylvanian System in the United States: Tulsa, Okla., Am. Assoc. Petroleum Geologists, p. 60–73.

Quinn, A. W., and others, 1948, The geology and ground-water resources of the Pawtucket quadrangle, Rhode Island: Rhode Island Port and Indus. Devel. Comm., Geol. Bull. 3, Ground Water Map.

Roberts, C. M., and Brashears, M. L., Jr., 1945, Progress report on the ground-water resources of Providence, R.I.: Rhode Island Port and Indus. Devel. Comm., Bull. 1, 35 p.

Rodgers, John, and others, 1956, Preliminary geologic map of Connecticut: Connecticut Geol. Nat. History Survey Bull. 84.

Schafer, J. P., 1961, Surficial geology of the Wickford quadrangle, Rhode Island: U.S. Geol. Survey Geol. Quad. Map GQ–136.

Sharp, H. S., 1929, The physical history of the Connecticut shore line: Conn. Geol. Nat. History Survey Bull. 46, 97 p., 29 figs., 8 pls.

Smith, J. H., 1955a, Surficial geology of the East Greenwich quadrangle, Rhode Island: U.S. Geol. Survey Geol. Quad. Map GQ–62.

——— 1955b, Surficial geology of the Bristol quadrangle and vicinity, Rhode Island-Massachusetts: U.S. Geol. Survey Geol. Quad. Map GQ–70.

Smith, J. H., 1956, Surficial geology of the Providence quadrangle, Rhode Island: U.S. Geol. Survey Geol. Quad. Map GQ–84.

Smith, W. O., 1958, Recent underwater surveys using low-frequency sound to locate shallow bedrock: Geol. Soc. America Bull., v. 69, no. 1, p. 69–98.

Smith, W. O., Upson, J. E., and others, 1952, Preliminary report on the Passamaquoddy bedrock survey—July–August 1951: U.S. Geol. Survey open-file rept., 49 p., 23 figs., 10 pls.

Swarzenski, W. V., 1963, Hydrogeology of northwestern Nassau and northeastern Queens Counties, Long Island, New York: U.S. Geol. Survey Water-Supply paper 1657. (In press).

Tuttle, C. R., Koteff, Carl, and Hartshorn, J. H., 1960, Seismic investigations in the Connecticut River Valley, southern Massachusetts: Geol. Soc. America Bull., v. 71, no. 12, pt. 2, p. 1994.

U.S. Army Corps of Engineers, 1957, Hurricane Survey, Interim report, Narragansett Bay area, Rhode Island, Massachusetts: Boston Mass., unpublished report, 74 p. plus appendices.

Upson, J. E., 1949, Late Pleistocene and Recent changes of sea level along the coast of Santa Barbara County, California: Am. Jour. Sci., v. 247, p. 94–115.

——— 1954, Terrestrial and submarine unconsolidated deposits in the vicinity of Eastport, Maine: New York Acad. Sci. Trans., v. 16, no. 6, p. 288–295.

Upson, J. E., Leopold, E. B., and Rubin, Meyer, 1964, Postglacial change of sea level in New Haven Harbor, Connecticut: Am. Jour. Sci., v. 262, p. 121–132.

Woodworth, J. B., 1896, The retreat of the ice sheet in the Narragansett Bay region: Am. Geologist, v. 18, p. 150-168, 391–392.

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