[redacted]
UNCLASSIFIED

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, Massachusetts

R6629

Reference No. 51-84

Literature Survey of Oceanographic Information Concerning Boston Harbor

87

Prepared by D. F. Bumpus, W. S. Butcher, and W. D. Athearn

Contract N6onr-27712 (NR-084-008)
With Office of Naval Research

October 1951

APPROVED FOR DISTRIBUTION ____________
Director

UNCLASSIFIED
[redacted]

TABLE OF CONTENTS

	Page
LIST OF TABLES	iii
LIST OF FIGURES	iv
1. INTRODUCTION	1
2. GEOLOGY	
A. Bathymetry	2
B. Description of the formations	3
C. Areal geology	4
D. Structure	5
E. Bedrock topography	5
F. Seismicity	6
G. Magnetic and gravity anomalies	7
H. Surficial geology	7
I. Probings and borings	7
J. Rate of sedimentation	10
K. Dumping grounds	10
L. Cable areas	10
M. Location of wrecks	10
3. TIDAL INFORMATION	
A. Tides	16
B. Mean sea level	16
C. Tidal currents	16
a. Effect of tidal currents on drag of torpedo net sections	19
D. Flushing	19
4. WEATHER	
A. Climate	21
B. Open season for navigation	21
C. Prevailing winds	21
D. Storms	22
E. Sea and swell	23
F. Fog	26
G. Precipitation	27
H. Air temperature	28
I. Relative humidity	28
J. Summary	29

TABLE OF CONTENTS (cont'd.)

		Page
5.	SEA WATER	
A.	Temperature	31
B.	Density and salinity	31
C.	Refraction of sound	31
D.	Transparency	32
6.	BIOLOGICAL INFLUENCES	
A.	Borers	34
B.	Fouling	34
C.	Noise makers, ambient noise	36
7.	NEEDED INFORMATION	
A.	Bathymetry	40
B.	Surficial geology	40
C.	Magnetic anomaly	40
D.	Tidal currents	40
E.	Sea and swell	40
F.	Sonar conditions	40
G.	Ambient noise	41
H.	Transparency	41
8.	ACKNOWLEDGMENTS	42
9.	REFERENCES	43

LIST OF TABLES

			Page
Table	I	Lithology of formations	3
Table	II	List of earthquakes in southeastern New England up to 1941	8
Table	III	Wreck location list	10
Table	IV	Tidal data	17
Table	V	Tidal volumes in Boston Harbor	19
Table	VI	Direction of gales, 1870 to 1945	23
Table	VII	Average monthly distribution of sea direction and state	24
Table	VIII	Average monthly distribution of swell direction	25
Table	IX	Hours of operation of fog signal	26
Table	X	Precipitation in inches	27
Table	XI	Air temperature at Boston, Mass.	28
Table	XII	Relative humidity	28
Table	XIII	Climatic table	29
Table	XIV	Monthly mean sea water surface temperature	31
Table	XV	Monthly mean sea water surface density .	33
Table	XVI	Monthly mean sea water surface salinity .	33
Table	XVII	Summary of fouling activity in Boston Harbor	35

LIST OF FIGURES

Fig. 1 Location of area covered by recent bathymetric surveys.
Fig. 2 Bedrock geology, Boston Harbor and vicinity (from Emerson, 1917; Billings, 1927; LaFarge, 1932 and Billings et. al., 1939).
Fig. 3a Schematic cross section of Boston Basin from north to south (after Billings, 1927).
Fig. 3b Cross section from Savin Hill through Squantum to Quincy (Billings, 1927).
Fig. 4 Locations of epicenters and intensity of earthquakes recorded in southeastern New England up to 1941.
Fig. 5 Schematic gravity map (after Woollard).
Fig. 6 Surficial geology, Boston Harbor and vicinity (La Farge, 1932).
Fig. 7 Locations of selected probing and boring profiles.
Fig. 7A to 7T Probings and borings, sections A to T.
Fig. 8 Locations of dumping grounds.
Fig. 9 Locations of cable and pipe line areas.
Fig. 10 Locations of wrecks and offshore dumping grounds.
Fig. 11 Fluctuations in annual mean sea level.
Fig. 12 Fluctuations in monthly mean sea level.
Fig. 13 Maximum velocity of tidal currents.
Fig. 14 Strain on torpedo net, baulk, and barrel lines.
Fig. 15 Wind and swell diagram.
Fig. 16 Paths of tropical storms of hurricane intensity.
Fig. 17 Monthly mean sea water temperature and salinity.
Fig. 18 Annual progression of the difference between sound velocity at the surface and sound velocity at depth, just east of Boston Light Vessel.
Fig. 19 Visibility at the bottom.
Fig. 20 Pressure level spectra of ambient noise, Boston Navy Yard and off Nahant (after Knudsen et. al.).

1. INTRODUCTION

As a participant in the Inshore Survey Program under the aegis of the U. S. Navy Hydrographic Office, the Woods Hole Oceanographic Institution has undertaken a comprehensive oceanographic survey of Boston Harbor and approaches, the fundamental interest being that of harbor defense. This report contains the findings to date of a survey of the literature of all material which might be considered useful to that end. Although a considerable body of data appears to be available from numerous sources, unfortunately, there is not very much information available which is significantly useful to the problem. However, material is included herein so long as it, at least indirectly, contributes to the fundamental knowledge of the region. The marine area considered is that part of Massachusetts Bay west of 70°40'W. Longitude.

2. GEOLOGY

The geologic field work in the Boston area comprises chiefly the hydrographic surveys of the U. S. Coast and Geodetic Survey of 1940-45, supplemented by sparsely developed surveys made during 1854 and 1893, plus soundings from miscellaneous sources. Probings, jet probings, and test borings have been made in limited areas only in Boston Harbor. Hence, knowledge of the geology of the region is dependent chiefly upon previous geologic work on the land areas.

Boston Harbor and vicinity occupy a part of the Boston Basin and surrounding basement complex. Bedrock ages range from pre-Cambrian to Pennsylvanian or Permian. Pleistocene and recent deposits mantle much of the area. More complete details on the geology than are summarized below may be obtained from the references.

A. Bathymetry. The bottom in the Boston Harbor area is characterized by considerable relief. Isolated hills and depressions closely resemble the land topography. At least a part of the area is dominated by glacial topography for probings show glacial sediments in the Deer Island area (see Section G, Probings and Borings). In other parts of the area bedrock ledges have been found. Smooth sheets 6642, 6643, 6644, 6662, and 6663 (Coast and Geodetic Survey hydrographic surveys 1940-1945) have been carefully studied and the contours at one fathom intervals extended where they were incomplete. All charts have been reduced to the same scale, 1:20,000 (some were 1:10,000), are being redrawn as one chart, and will be submitted in an interim report. The area covered by the Coast and Geodetic Survey surveys (and those by the Army Engineers inshore of Deer Island) are indicated in Figure 1. This Institution will add information concerning the unsurveyed portion from fathometer soundings to be taken during the sediment survey, but a complete description must await further exploration by the Coast and Geodetic Survey.

The area of the outer islands apparently is dominated by rock ledges trending NE-SW. Northeast of The Graves the trend of the elevations changes to NW-SE, possibly indicating a change from bedrock to glacial sediments. Other rock ledges are present off Nahant and at Harding Ledge off Nantasket.

Glacial deposition has modified much of the area and probably has controlled the bathymetric characteristics of the bottom away from the rock ledges. Recent marine erosion and deposition has been responsible for eroding the elevations and for filling the depressions. Smooth slopes such as those off Revere and Nantasket may be a result of deposition.

B. Description of the formations. The lithology of the formations within the area is summarized briefly in Table I. All extrusive and intrusive rocks have been grouped for convenience into a basement complex. Rocks in this category range from pre-Cambrian to Pennsylvanian. Cambrian and Pennsylvanian or Permian sedimentary rocks also are found in the area.

Table I. Lithology of the formations

Age	Formation	Lithology
Permian or Pennsylvanian	Cambridge argillite	fine-grained dark blue-gray or brown-gray argillite. Partly well stratified, partly massive. Slaty cleavage poorly developed. Occasional sandy bed. Quartzite upper member.
	Squantum tillite	Breccia with striated and faceted pebbles. A few water laid drift layers.
	Roxbury cg.	Coarse conglomerate with indistinct bedding and generally well rounded boulders. A few volcanic flows. Red and purple sandy slate, sandstone, pebble conglomerate with cross-lamination
Cambrian	Milton quartzite	Coarse granular green quartzite
	Weymouth fm.	Siliceous slate, slaty quartzite and limestone
Pennsylvanian to pre-Cambrian	Basement complex	Paraschist, paragneiss, metavolcanics, quartzite, gabbro-diorite, granodiorite, quartz-diorite, volcanics, granite, diabase

C. Areal geology. Figure 2 summarizes the bedrock areal geology and is modified from maps by Emerson (1917), Billings (1929), and LaForge (1932). The areal distributions of the formations listed in Table I are discussed below.

Basement complex: The basement complex occurs along the southern border of the area and forms the land area north of a line from Cambridge to Nahant. The complex probably forms the floor beneath the submarine sediments both north of Nahant and south of Nantasket.

Weymouth formation: The Weymouth formation crops out in three small areas at Nahant. The outcrops are isolated erosion remnants and the formation probably is not extensive in the submarine section. Some of the basement near Nahant may be formed by this rock.

Milton quartzite: The Milton quartzite forms a narrow border to the basement complex in Milton. There is no indication that it is found in the submarine area.

Roxbury conglomerate: The Roxbury conglomerate occupies extensive areas south of Boston. Savin Hill, Squantum, Hingham, and Nantasket are underlain in part by the conglomerate. The basement below the submarine sediments off Savin Hill, Hingham, and Nantasket probably is formed by Roxbury conglomerate.

Squantum tillite: The Squantum tillite borders the Roxbury conglomerate in a narrow band south of Savin Hill, at Squantum, and in Quincy. Two small outcrops are present on Moon Head and Long Island. The Squantum tillite probably forms the harbor floor beneath the sediments in bands offshore from Savin Hill and Squantum Head. One band extends from Squantum Head through the eastern part of Moon Head to the southern tip of Long Island.

Cambridge argillite: The Cambridge argillite is the most extensive formation of the Boston Harbor area. It forms most of the shore line from Lynn Harbor to Nantasket with the exception of the areas of Roxbury conglomerate and Squantum tillite previously mentioned. All of the islands of Boston Harbor are underlain by Cambridge argillite except for the two small areas on Moon Head and Long Island. The basement beneath the harbor sediments is probably Cambridge argillite. The extent of the formation seaward from the outer islands is not known, but the structure of the area suggests that it may form a considerable portion of the area between the latitudes of Nahant and Nantasket.

D. Structure. Sedimentary Pennsylvanian or Permian rocks of the Boston Basin probably are separated from the basement complex by faults. Within the basin, faulting is important only south of Boston. Both longitudinal and transverse faults are present. Figure 3a is a cross section of the Boston Basin (modified from Billings, 1929) and Figure 3b is a cross section from Savin Hill through Squantum to Quincy (Billings, 1929). The extent and direction of the faults in the submarine section are unknown.

E. Bedrock topography. The bedrock surface in the vicinity of Boston appears to be extremely irregular. A few elongated deep areas may represent former stream valleys of Pleistocene or pre-Pleistocene age. Construction of a detailed bedrock contour map of the harbor area is not warranted because of the sparsity of data.

Most boring and coring data are on file at the office of the Boston Society of Civil Engineers. These data give a reasonably complete determination of bedrock depth for the Boston peninsula, but are less adequate elsewhere. Additional drilling and seismic data are available in publications of the Metropolitan District Commission, and of the Massachusetts Department of Public Works in cooperation with the United States Geological Survey. Under Boston Harbor, data on the depth of bedrock are practically nonexistent except for determinations for dredging in the main ship channel in the inner harbor. There are outcrops on the islands in the harbor and several ledges and shoals occur.

Known high points of bedrock generally underlie areas of glacial hills or drumlins such as Powder House Hill in northern Chelsea, Bunker Hill in the vicinity of the Charlestown Navy Yard, Telegraph Hill in South Boston, near Savin Hill in Dorchester, and a low hill west of Columbia Circle in northeastern Dorchester.

Known deep points in the bedrock generally lie below low areas in the surface topography. The more important deep areas are (1) a point at the Malden bridge between Sullivan Square and Everett; (2) a deep area extending from the Charlestown Navy Yard near Little Mystic Channel northeasterly across the northwestern part of East Boston to the Boston and Albany Railroad bridge across Chelsea Creek; (3) an area extending southeast from this same bridge to the southwest side of Deer Island; (4) deep areas at the west side of Fort Point Channel both north and south of South Station; (5) an area in the inner harbor between Boston and East Boston; (6) a point near the southern corner of the Public Garden; (7) a point just south of the Boston Fish Pier; and (8) a deep area under Old Harbor and Dorchester Bay extending northeastward from Columbia Circle and the Sewage Disposal Pumping Station at Calf Pasture to the pier off City Point.

Locations of the deep points in the bedrock suggest a valley from the Malden bridge southeast across Little Mystic Channel to the inner harbor where it joins a valley trending northerly from Fort Point Channel through the present inner harbor to the northwestern part of East Boston. From East Boston the latter valley extends northeasterly up Chelsea Creek. This valley may continue in the same direction toward Revere or it may turn southeastward at the Boston and Albany Railroad bridge to follow the deep area south of Orient Heights and Winthrop toward President Roads. The actual direction cannot be determined from available data.

Another valley appears to cross the Boston peninsula near the Public Garden in a southeasterly direction toward the Fort Point Channel. It may join the valley lying below the inner harbor between Charlestown and East Boston, or it may continue almost southerly from the Fort Point Channel to the north side of Columbia Circle. From Columbia Circle a valley trends northeasterly through Old Harbor, between Castle Island and Spectacle Island, toward President Roads.

The outlet of the pre-glacial valleys into the outer harbor cannot be determined from present information. The greatest known depth to bedrock, 224 feet below mean low water, occurs at the southwest side of the tombolo now occupying the former position of Shirley Gut between Point Shirley and Deer Island. The apparent convergence of the inner valleys toward this area and the depth to bedrock suggest an outlet valley beneath Shirley Gut, but further data on the bedrock depth in this area are needed to confirm this possibility. The valley beneath Old Harbor may have entered the outer harbor by the present deep channel between Deer Island Light and Long Island. Soundings show this channel to be 74 feet deep at mean low water, but there is no information on the depth of the bedrock below the bottom.

F. Seismicity. Earthquakes appear to have affected the Boston Harbor area infrequently and with mild intensity. No epicenters have been listed for the area within historical times. The glacial deposits do not appear to have been disturbed by earthquake activity, indicating that there has been no strong movement along the faults in the vicinity (cf. Fig. 2) since the Pleistocene. Figure 4 shows the location and intensity of earthquakes in southeastern New England prior to 1947. The locations are given to the nearest tenth of a degree. Some of the earthquakes are recorded as severe and all those recorded within a radius of thirty miles from Boston Harbor antedate modern seismological apparatus, and the intensities of those earthquakes may have been exaggerated. All of the more recent earthquakes, with the exception of a severe earthquake west of Portland, Maine (No. 22) have been moderate or mild.

Table II shows the locality and date of occurrence of the earthquakes plotted in Figure 4. More complete information regarding these earthquakes will be found in Coast & Geodetic Survey (1947) and supplementary data for the years 1938 to 1941 in Linehan and Leet (1942).

G. Magnetic and gravity anomalies. There have been few magnetic surveys carried out in New England, but several gravimeter traverses have been made since 1940. From the network of gravity observations Woollard (1948) has presented a generalized gravity map of the region, Figure 5, which shows a marked positive anomaly belt (greater than 20 milligals) running from Cape Ann across Cape Cod and Marthas Vineyard. Woollard has also determined from the limited information available that this same region appears to be subjected to high magnetic anomalies. He believes that a basic rock, gabbroic in character, may be present immediately beneath the coastal plain sediments in the area of the anomalies.

H. Surficial geology. Figure 6 presents the surficial geology of the area and is summarized from LaForge (1932). Glacial deposits mantle much of the bedrock and drumlins are prominent features. Recent alluvium and marine deposits also are extensive. The submarine topography suggests that glacial deposits form much of the submarine area along with bedrock outcrops. Farther offshore, marine sediments may mantle the glacial deposits.

I. Probings and borings. The principal data available concerning the distribution and thickness of the sediments in the Boston Harbor area are to be found on charts of probings, borings, and dredgings done for the U. S. Corps of Engineers between 1900 and 1951. From these data, bottom sediment profiles of various parts of the harbor have been constructed, Figures 7 to 7T, and the following discussion is based largely on these profiles. The profiles labeled A, B, C, etc., in Figure 7 are presented in Figures 7A, 7B, 7C, etc., respectively. A legend for all the profiles appears in Figure 7A.

Table II

List of Earthquakes in Southeastern New England
up to 1941

No.	Date		Locality
1.	1 or 2 June	1638	Plymouth, Mass.
2.	5 or 7 March	1642 or 1644	Plum Island, Mass.
3.	8 Nov.	1727	Plum Island, Mass.
4.	6 Dec.	1741	Norwood, Mass.
5.	18 Nov.	1755	Waltham, Mass.
6.	9 Nov.	1810	Exeter, N. H.
7.	5 Oct.	1817	Burlington, Mass.
8.	8 Aug.	1847	Southeastern, Mass. (42°N 71°W)
9.	8 Aug.	1849	Bridgewater, Mass.
10.	27 Nov.	1852	W. Newbury, Mass.
11.	10 Dec.	1854	Rye, N. H.
12.	18 Nov.	1872	Concord, N. H.
13.	21 Sept.	1876	E. Freetown, Mass.
14.	12 May	1880	Newburyport, Mass.
15.	19 Dec.	1882	Short Falls, N. H.
16.	21-22 Jan.	1903	Whitman, Mass.
17.	24 April	1903	Georgetown, Mass.
18.	30 Aug.	1905	Dedham, Mass.
19.	15 Oct.	1907	W. Newbury, Mass.
20.	7 Jan.	1925	Gloucester, Mass.
21.	24 April	1925	Wareham, Mass.
22.	9 Oct.	1925	Limington, Me.
23.	18 March	1926	Fitchburg, Mass.
24.	8 March	1927	Pittsfield, N. H.
25.	23 April	1935	Provincetown, Mass.
26.	23 June	1938	Chelmsford, Mass.
27.	1 Feb.	1939	Chelmsford, Mass.
28.	11 Oct.	1939	Londonderry, N. H.
29.	2 Jan.	1940	Littleton, Mass.
30.	28 Jan.	1940	Mattapoisett, Mass.

Glacial ground moraine deposits comprise the major part of the sediments in the area. Ground moraine is characteristically heterogeneous in composition and arrangement, and this condition is fully met in Boston Harbor. Deposits are found to be patchy, and adjacent deposits commonly vary greatly in texture and thickness.

More recent non-glacial deposits are largely lacking because no sizeable streams flow into the harbor. The Charles, and the Neponset Rivers both have dams near their mouths. The soft mud areas found in sheltered tidal inlets such as Town River, Quincy Bay, Chelsea Creek, and the part of the harbor between Logan Airport and Winthrop are probably the result of organic deposition with some marine deposition. Soft clay is also found mostly in the sheltered inner areas. Thicknesses of the mud and soft clay run from about 5 feet to an occasional thickness of 20 feet. The materials beneath these soft sediments, where they have been determined, vary from gravel to clay and are typical of ground moraine.

Outside of the soft areas mentioned, little generalization can be made regarding the type of sediments to be found on the bottom, except that they are heterogeneous. The profile between Fort Point Channel and Fort Independence reveals several sections of soft clay or mud 500 to 2000 feet in length, but these are separated by other deposits such as stiff clay, gravel and clay, or sand and clay. Adjacent borings frequently show no correlation between each other, either in sequential arrangement, or in thickness of the individual types. From Fort Independence through President Roads to Deer Island, the Boston blue clay is commonly encountered at depths of 30 to 40 feet below mean low water, and 3 to 38 feet below the bottom. The overlying sediments vary greatly in thickness and in composition within horizontal distances of only a few hundred feet. In North Channel deposits generally tend to be coarser than in the Inner Harbor.

Between the Brewster Islands and Calf Island and between Nash Rock Shoal and Point Allerton in the outer harbor, the sediments are also generally coarse, but again composition varies considerably over short distances. Sediments generally found are gravel, boulders, and sand and gravel. From Nantasket Gut toward Weymouth Fore River the sediments become finer and there is somewhat better correlation between borings.

In summary, the sediments underlying Boston Harbor are probably mostly glacial in origin. There has been little later sedimentation.

J. Rate of sedimentation. The rate of sedimentation in Boston Inner Harbor is very slow. There was little difference between two sounding surveys made by the Corps of Engineers between Charlestown and East Boston in 1934 and 1950. The accumulation amounted to 5,970 cubic yards equal to less than 0.1 foot accumulation in 16 years.

K. Dumping grounds. Locations of dumping grounds in Boston Harbor and approaches are shown in Figures 8 and 10. However, according to the U. S. Army Engineers, dumping occurs, or has occurred, indiscriminately east of a line between the Light Vessel and the D. G. Buoy.

A foul area, explosives, 2 miles in diameter is centered at 42°25.7'N, 70°35'W, in about 300 feet of water.

L. Cable areas. Figure 9 indicates the location of cable areas as shown on U. S. Coast & Geodetic Survey charts #240 and #246.

M. Wrecks. A list of the wrecks in the area, Table III, has been prepared from the Hydrographic Office Wreck Information List (1945) and its supplement dated 30 September 1946, Notice to Mariners from 30 September, 1946 through 30 August, 1951, and a list supplied by the Commander, FIRST Coast Guard District, 2 July 1951. The locations of same are indicated in Figure 10.

Table III

Wreck Location List

Wreck No.	Position	Information	Sunk
137	42-33-00N 70-15-00W	Natalie Hammond 110 Nt.	7/29/37
139	42-30-15N 70-39-20W	Moritz (Am) Freighter	7/2/30
142	42-30-00N 70-42-00W	James L. Mally 174 Nt.	B.W.*

* Date unspecified, but before World War II.

Table III (cont.)

Wreck No.	Position	Information	Sunk
143	42-26-24N 70-40-16W	Van (Am) Freighter	5/16/35
145	42-26-04N 70-37-33W	Gale (Am) Trawler	4/27/37
146	42-24-26N 70-39-00W	Massocoit (Am) Freighter	1/22/31
147	42-23-43N 70-51-46W	Romance (Am) Passenger	9/9/36
148	42-23-36N 70-39-18W	Mist (Am) Trawler	4/8/36
149	42-23-19N 70-35-33W	Ocean (Am) Trawler	4/26/38
150	42-23-00N 70-55-00W	Winifred Sheridan 934 Nt.	B.W.
151	42-22-26N 70-51-35W	Salisbury (Am)	B.W.
152	42-22-26N 70-43-23W	Eagle Boat No. 42	6/15/31
153	42-22-06N 70-43-06W	Coyote (Am) Freighter	1/11/32
154	42-22-05N 70-37-11W	King Philip (Am) Passenger (small)	4/7/35
155	42-20-56N 70-41-05W	Dredge No. 6 & Tug Bluejay	10/10/31
156	42-20-39N 70-40-43W	Roxana (Am) Yacht	9/10/35
157	42-20-24N 70-40-47W	C. H. Sprague (Am) Tug	10/5/31
163	41-55-00N 70-23-00W	Pioneer 233 Nt.	10/2/38

Table III (cont.)

Wreck No.	Position	Information	Sunk
164	41-55-00N 70-29-00W	Henry Endicott 1508 Nt,	B.W.
165	41-54-00N 70-22-00W	Surge 302 Nt.	B.W.
168	41-47-07N 70-29-05W	Exminster (Am) Freighter 3048 Nt. A sweep survey by the U.S. Engineers on July 3, 1946 showed a depth of 31 feet at M.L.W. over a wreck partially removed by blasting. The wreck in the listed position is located 890 yards 38°30' from Canal Breakwater Light.	4/20/42
548	42-30-00N 70-25-00W	Restless (Am) Fisherman	10/4/42
589	42-25-05N 70-51-25W	Herbert (Am) Steam Lighter	8/7/24
550	42-24-00N 70-50-00W	Leigh No. 3 (Am) Barge	11/11/19
551	42-23-30N 70-40-25W	Mary A. White (Am) Sloop	7/1/40
552	42-23-16N 70-51-49W	Wreck Salvage operations complete, approx. 60-ton mass of steel left in above position. Salvage Div. Navy Dept.	
553	42-22-45N 70-39-30W	Ethel N (Am) Schooner	12/31/30
554	42-22-45N 70-39-25W	Wave (Am) Trawler	9/21/36
555	42-22-24N 70-45-15W	James M. Hudson (Am) Barge	3/1/25

Table III (cont.)

Wreck No.	Position	Information	Sunk
556	42-22-00N 70-44-20W	W. A. Marshall (Am) Barge	1/8/22
557	42-21-45N 70-41-20W	NO. 9. (Am) Dredge	10/20/31
558	42-21-45N 70-40-25W	Joel Cook (Am) Lighter	8/18/38
559	42-21-45N 70-39-05W	Annie Conant (Am) Lighter	4/1/36
560	42-21-35N 70-39-35W	Wreck (Am) Lighter	5/26/32
561	42-21-25N 70-42-15W	Beatrice (Am) Tug	4/27/35
562	42-21-25N 70-42-00W	Reliance (Am) Lighter	8/3/33
564	42-21-10N 70-45-00W	McGowen (Am) Lighter	8/8/30
565	42-21-00N 70-42-50W	Evans (Am) Lighter	6/28/35
566	42-16-35N 70-36-26W	Southland (Am) Freighter	12/2/30
572	41-56-16N 70-29-33W	Mars (Am) Tug 278 Gt. in collision with the Bidwell (Am) Tanker	9/13/42
580	42-23-00N 70-50-50W	Wreck	B.W.
581	42-18-55N 70-51-36W	Wreck Located by a wire drag survey by U.S. Coast & Geodetic Survey in 1940. Cleared to a least depth of 22 feet.	B.W.

Table III (cont.)

Wreck No.	Position	Information	Sunk
582	42-09-18N 70-33-48W	Pinthis Freighter The wreck has a least depth of 58 feet over it at M.L.W.	6/10/30
583	42-03-00N 70-15-39W	Francis (Am) Trawler A wreck believed to be the trawler Francis has been located in 190 feet of water, about 2,200 yards 222° from Race Point Lighthouse.	B.W.
631	41-46-30N 70-27-45W	Wreck The wreck of the barge in the listed position is completely submerged. The light is not visible.	
650	42-28-45N 70-45-12W	L.&W.B.C. Co. 1 (Am) Barge	8/13/42
651	42-23-05N 70-45-05W	Cornelia (Am) Tug	7/8/33
652	42-24-30N 70-39-05W	Confidence (Am) Tug	11/5/40
653	42-21-50N 70-39-48W	Vesta (Am) Tug	4/26/38
654	42-21-50N 70-39-48W	William H. Yerkes Jr. (Am) Tug	4/26/38
655	42-21-50N 70-42-17W	Wreck The wreck of a mud scow lies sunk in the listed position.	10/25/28
656	42-21-06N 70-42-15W	Wreck The wreck of a concrete scow lies sunk in the listed position.	7/26/30
657	42-20-16N 70-41-00W	Sam Mengel (Am) Barge	10/16/35

Table III (cont.)

Wreck No.	Position	Information	Sunk
658	42-04-24N 70-19-50W	Georgina M (Am) Schooner	12/20/24
853	42-22-06N 70-54-53W	YMS - 14 (USS) The wreck of the YMS-14 has been removed to a least depth of 33 feet at M.L.W.; this depth is located 4,025 yards, 275° from the Graves Light.	1/11/45
874	42-19-52N 71-00-05W	Brina P. Pendleton (Am) Barge	
---	42-24.7N 70-34.8W	Augusta W. Snow	6/5/40
---	42-22.4N 70-38.9W	Joseph H. Ross Tug	5/4/44
---	42-02.2N 70-14.3W	Miladi Yacht	7/12/42
---	41-46.5N 70-30.0W	Arizona Sword (Am) Freighter. Decks awash near eastern end of Cape Cod Canal. Salvage operations have commenced.	(N.M. 20 - 5/19/51)
---	41-49.8N 70-03.0W	James Longstreet Bombing Target	(N.M. 40 - 10/1/49)
---	41-49-45N 70-02-55W	Southward	(N.M. 8 - 2/21/48)
---	42-01-52N 70-10-37W	Fishing vessel 60 feet deep	(N.M. 15 - 4/14/51)
---	42-35-59N 70-40-08W	Curlew	(N.M. 47 - 11/25/50)
---	42-02-25N 70-11-15W	Alberta	(N.M. 40 - 10/7/50)
---	42-16-05N 70-31-00W	Fishing vessel	(N.M. 26 - 6/25/49)
---	42-23-22.5N 70-55-08W	Barge Arco #8 45 feet of water over it.	(N.M. 24 - 6/16/51)

3. TIDAL INFORMATION

A. Tides. The tidal wave in Boston Harbor is a stationary wave. In general the times of tidal phases differ but slightly in different parts of the harbor. The tide is semidiurnal with little diurnal inequality. The mean range of tide is 8.9 feet at Boston Lighthouse and 9.6 feet in the upper harbor, in Chelsea River and in Fort Point Channel. The extreme range is about 4 feet greater (Board of Engineers for Rivers and Harbors, 1946). Table IV lists comparative tidal information with the time of tide referenced to Commonwealth Pier, Boston (Coast and Geodetic Survey, 1950a). The highest tide recorded at the Boston tide station occurred on 21 April 1940 with a height of 8.9 feet above mean sea level. The lowest tide recorded occurred on 25 January 1928 and again on 24 March 1940 with a height of 8.4 feet below mean sea level (Coast and Geodetic Survey 1951). On the occasion of the highest tide the wind blew steadily all day from the NE at greater than 30 mph, the maximum velocity observed at Boston being 43 mph. The lowest tides were associated with continuous westerly winds of greater than 20 mph velocity.

B. Mean sea level. Fluctuations in mean sea level are shown in Figures 11 and 12, prepared from the tabulation of tides, "Monthly Means of Sea Level for Boston", kindly supplied by Coast and Geodetic Survey. Zero staff reading is 21.45 feet below Bench Mark 7 at Commonwealth Pier #5. Figure 11 shows the fluctuation of the mean sea level for 1922 through 1950 together with the maximum and minimum monthly mean sea levels during that period. Sea level has been rising during this period, being 0.21 feet higher in 1950 than in 1922, or according to Marmer (1949) at 0.02 feet per year since 1930. Maximum variation in yearly mean sea level was 0.5 feet, being lowest in 1925 and highest in 1945. The large annual variations in sea level from year to year, Marmer (1949) reports, are due to wind and weather. The maximum variation between maximum and minimum monthly mean sea level, 0.8 feet, occurred in 1944. Mean sea level tends to be highest during the warm half of the year and lowest in January, the variation being approximately 0.2 feet.

C. Tidal currents.

"For some distance northwestward of Cape Cod the tidal currents have a slight set southward into Cape Cod Bay on the flood and eastward out of the bay on the ebb. Along the north shore of Massachusetts Bay the flood sets in a generally westerly or northwesterly direction

Table IV

Tidal Data

	Lat. N	Long. W	Time of Tide* h m	HWI h m	Mean Range of Tide	Spring Range of Tide
Boston (Commonwealth Pier)	42°21'	71°03'	-	11 16	9.5'	11.0'
Broad Sound						
Nahant	42 25	70 55	0 00	11 15	9.0	10.4
Lynn Harbor	42 27	70 58	+0 05	11 24	9.2	10.7
Boston Harbor						
Boston Light	42 20	70 53	0 00	11 18	8.9	10.3
Lovell Is., The Narrows	42 20	70 56	0 00	11 18	9.1	10.6
Deer Is. (South End)	42 21	70 58	-0 05	11 08	9.3	10.8
Bell Isle Inlet entrance	42 23	71 00	+0 15	11 34	9.5	11.0
Castle Island	42 20	71 01	0 00	11 14	9.4	10.9
Dover St. Bridge, Fort Point Channel	42 21	71 04	+0 05	11 20	9.6	11.0
Charlestown Br. Charles R.	42 22	71 04	0 00	11 18	9.5	11.0
Charles River Dam	42 22	71 04	0 05	11 21	9.5	11.0
Charlestown, Charles R. ent.	42 22	71 03	0 00	11 14	9.5	11.0
Chelsea St. Br. Chelsea R.	42 23	71 01	0 00	11 15	9.6	11.1
Mystic River						
Wellington Bridge	42 24	71 05	+0 10	11 25	9.6	11.1
Medford Bridge	42 25	71 07	+0 25	11 28	9.3	10.8
Boston Harbor						
Neponset, Neponset River	42 17	71 02	0 00	11 12	9.5	11.0
Moon Head	42 19	70 59	0 00	11 14	9.1	10.6
Rainsford I, Nantasket Roads	42 19	70 57	0 00	11 14	9.1	10.6
Hingham Bay						
Nut Island	42 17	70 57	+0 05	11 23	9.2	10.7
Sheep Island	42 17	70 55	+0 05	11 23	9.5	11.0
Weymouth Fore River Bridge	42 15	70 58	+0 05	11 23	9.5	11.0
Weymouth Back River Bridge	42 15	70 56	+0 05	11 22	9.5	11.0
Crow Point, Hingham Hbr. ent.	42 16	70 54	+0 05	11 21	9.5	11.0
Hingham	42 15	70 53	+0 05	11 23	9.5	11.0
Nantasket, Weir River	42 16	70 52	+0 05	11 21	9.4	10.9
Strawberry Hill	42 17	70 53	+0 05	11 21	9.5	11.0
Hull	42 18	70 55	+0 05	11 20	9.2	10.7
Outer Coast						
Cohasset Harbor (White Head)	42 15	70 47	0 00	11 19	8.8	10.2

* Referenced to Commonwealth Pier, Boston.

and the ebb in a southerly or southeasterly direction. The velocity of currents is influenced greatly by the force and direction of the wind. Off the entrance to Boston Harbor the flood sets westward and the ebb eastward, increasing slightly in velocity as the entrance is approached." (Board of Engineers for Rivers and Harbors, 1946).

The quantity of water entering and leaving Boston Harbor during mean tides is estimated to be 76,086 million gallons, or about 150,000 million gallons per day. Boston Harbor contains a number of relatively large islands, which in conjunction with the bottom topography and the dredging which has been done, tend to concentrate the flow of water and to make strong tidal currents in certain stretches of the harbor.

Coast and Geodetic Survey (1949b) shows the direction and velocity of the tidal currents in Boston Harbor at hourly intervals referenced to time of "slack; flood begins" and "slack; ebb begins" at Deer Island Light which are one-half hour after low and high water respectively at Commonwealth Pier. The times of current phases do not differ greatly in the different parts of the harbor. The slack before flood occurs near or soon after the time of low water and the strength of flood three to four hours later. The slack before ebb occurs near the time of high water and the strength of ebb three to four hours later. The velocity expressed in knots on the charts, represents the current at the time of spring tides; i.e., near the time of new or full moon when the currents are stronger than average. Factors for correcting the velocities shown on the charts are tabulated so that predictions for certain times may be made referring to the Current Tables (Coast and Geodetic Survey, 1950a).

The maximum velocities of the tidal currents at time of spring tides (strength of flood or ebb whichever is greater) at various places in Boston Harbor have been entered in Figure 13. These are the maximum velocities to be expected at the surface.

Current observations selected from those made by Woodworth in 1926 in Boston Harbor (Coast and Geodetic Survey 1928) yield average velocities at 0.5 and 0.8 of the depth relative to 0.2 of the depth as follows:

Depth	Flood Strength		Ebb Strength	
	Relative velocity	Range	Relative velocity	Range
0.5	97%	91-107%	92%	85-100%
0.8	88%	82-100%	82%	68-97%

Velocities one to two feet above the bottom may be 50 to 85% of the surface velocity. In general the average velocity varies logarithmically with the height above the sea floor (Kuenen, 1950, p. 252).

a. Effect of tidal currents on drag of torpedo net sections. Tests were made on a double line anti-torpedo net installation across the channel between Long Island and Deer Island, Boston Harbor, on 9 October, 31 October, and 1 November 1944. (Net. Nav. Dep. 1944). The strain on the baulk and barrel lines for various current velocities is indicated in Figure 14. At maximum velocity the catenary was approximately 45 feet for each of the four sections.

D. Flushing. The area of Boston Harbor, i.e. the area west of a line between Deer Island and Pemberton in the town of Hull and extending to the lowest bridge in each of the tributary rivers and estuaries is 43.3 square miles at high water and 39.5 square miles at low water (Commonwealth of Massachusetts 1951).

The tidal volumes in Boston Harbor are given in Table V.

Table V

Tidal Volumes in Boston Harbor

Area	Quantity of Water Entering and Leaving with Mean Tides x 10^6 cu. ft.	Quantity of Water Remaining at Mean Low Tide x 10^6 cu. ft.	Total Quantity of Water at Mean High Tide x 10^6 cu. ft.
Boston Inner Harbor	767	1990	2750
Dorchester Bay	1467	1080	2540
Winthrop Bay	1033	930	1960
Outer Harbor	2530	6260	8790
Quincy Bay	1400	1100	2500
Hingham Bay	2990	3150	6140
Total	10200	14500	24700

The drainage area, drained by the Charles, Mystic and Neponset, Chelsea, Monatiquot, Weymouth Fore, Weymouth Back and Weir Rivers and several smaller streams is 645 square miles. Ketchum (1951) in estimating the flushing rate of Boston Harbor has computed the mean river flow from the three gauged rivers to be:

Charles River	10.0	$\times 10^6$ cu. ft./tide
Mystic River	1.7	" " "
Neponset River	1.6	" " "
Total	13.3	" " "

A summary of tidal flushing data is as follows:

	Boston Harbor	Boston Inner Harbor
Tidal flow	11,000 $\times 10^6$ cu.ft./tide	767 $\times 10^6$ cu.ft./tide
Mean river flow	13.3 $\times 10^6$ " " "	11.7 $\times 10^6$ " " "
Ratio of volumes (tidal per river)	816	66
Flushing time	42	12 days

A further complication to the fresh water content of Boston Harbor is the amount of untrested sewage deposited in the harbor daily as follows (Commonwealth of Massachusetts 1951):

	$\times 10^6$ cu. ft. per day		$\times 10^6$ cu. ft. per day
at Deer Island	8.0 to 18.1	averaging	13.4
at Moon Island	5.4 to 14.7	"	9.9
at Nut Island	9.4 to 26.8	"	12.7
Total			36.0

This is nearly one and one-half times the mean river flow per day.

It can be calculated that the Deer Island sewage effluent will form about 0.4% of the intertidal volume entering the outer end of Boston Inner Harbor. Hence 10 million cubic feet of water in the Inner Harbor or about 0.36% of the high tide volume will be sewage effluent. This is in contrast to the average amount of river water accumulated in the Inner Harbor, which is 275 million cubic feet or about 10%.

4. WEATHER

A. Climate. Extracts from "Climate and Man" describe the New England climate as follows:

> "New England, lying in middle latitudes, comes within the influence of constant conflicts between cold, dry air masses flowing out of the great sub-polar region to the northwest and the warmer, moisture bearing, tropical marine air from the south. The tendency of most of the general cyclonic disturbances to skirt the polar front brings their paths of movement through this region and results in a more or less regular succession of biweekly storms of snow or rain, with intervening two-or three-day periods of fair weather, typically with warm southwest winds in summer and cold northwesterly winds in winter.
>
> "The most active precipitation-producing storms are those in which the moist southeast or east winds flow over the uplands and the air mass is forced aloft over cold resident air to condensation levels. In winter the great snow storms occur usually with northeasters; as a wedge of cold dry air displaces the moist air, they are followed by the prevailing northwesterly winds, accompanied by clearing sky and with temperature often falling below zero in the north. The easterly winds of spring and early summer, however, may be of shallow depth and limited trajectory, serving mainly to convert a hot day into one of refreshing coolness along the coast and often penetrating only a few miles inland. Land-sea breezes, induced by an unbalanced thermal gradient, may be strictly confined to the shore."

Further information on Boston weather is found in the Board of Engineers for Rivers and Harbors (1946) as follows:

B. Open season for navigation. The channels of this harbor are navigable throughout the year. Ice rarely forms in the main channels. Occasionally during severe winters the greater part of the harbor is frozen but tow boats and steamers keep the main channels open. The Charles, Mystic and Chelsea Rivers and the minor passages in the harbor are sometimes frozen during severe weather. When ice is prevalent the buoys may be displaced and carried away.

C. Prevailing winds. The prevailing winds are southwesterly during the summer and westerly during the winter. At all seasons the heaviest gales are generally from the northeast or eastward. A wind diagram compiled from observations of the U. S. Weather Bureau at Boston, Massachusetts, 1927 to 1937 is shown in Figure 15.

D. Storms. The paths of all hurricanes (defined as those with a central pressure of 29.0 inches or lower and winds near the center of more than 60 mph in some points in the path) which have struck within a 150 mile radius of Boston between the years 1874 and 1944 have been extracted from the book Hurricanes (Tannehill, 1943) and various other sources and plotted in Figure 16 (Beach Erosion Board, 1948). An examination of this figure shows that between 1874 and 1945, a period of 71 years, 34 tropical storms of hurricane intensity have passed within 150 miles of Boston; 5 occurred in June, 1 in July, 7 in August, 14 in September, and 7 in October.

> "The conditions under which a West Indian hurricane will strike our North Atlantic coast with full vigor are that (1) the general pressure gradient from East to West must be great throughout the troposphere; (2) the terrain in the front of the storm must be well bathed in moist tropical air; and (3) the storm remains over the open sea all the way from the West Indies to its northern landfall. Without the rapid progressive movement the storm would have a chance to lose much of its whirling velocity over the cooler waters north of the Gulf Stream. The presence of moist tropical air in the region helps to prevent a too rapid reduction in energy. Friction with land is a quick reducer of the velocity of the wind at the surface, causing a decrease in both the deflective effect of the earth's rotation and the centrifugal force of the whirling wind. This results in a considerable flow of air across the isobars into the low pressure center and, consequently, in a marked reduction of the pressure gradient which is immediately felt on all sides of the storm. In order to have one of these hurricanes strike the North American coast from the open sea it is, of course, first necessary that the general winds in the middle levels of the troposphere shall be directed essentially northward or perhaps northwestward, so as to give the storm a movement from the south or from the southeast." (Brooks 1939).

High storm tides as well as high seas and swells will be the disturbing effects of such tropical hurricanes crossing the coast from the sea.

A summary of the record of storms of gale force or greater compiled from records of the U. S. Weather Bureau at Boston covering the 75-year period, 1870-1945, inclusive, is given in the following table:

Table VI

Direction of Gales, 1870 to 1945 (inclusive)

Direction	No. of Gales	% of Total Gales
N	3	2
NE	80	50
E	4	6
SE	14	9
S	12	7
SW	15	8
W	13	8
NW	14	9
Total	160	100

E. Sea and swell. Sea and swell data for the immediate vicinity of Boston are lacking. The Hydrographic Office has averaged data for 5° squares in the North Atlantic (Hydrographic Office 1943 A and 1949). The "square" nearest Boston is bounded on the S by the 40° parallel, on the E by the 65° meridian and on the N and W by the coast line between Nova Scotia and Cape Cod. The average monthly distribution of sea direction and state as indicated for this area is given in Table VII. Sea directions are predominantly from the SW through W, NW and N to NE, corresponding to the prevailing wind system. Sea states are predominantly medium from November through April, and low the remainder of the year. It is obvious that in the offing of Boston Harbor lower sea states will prevail for SW, W, NW and N winds due to the limited fetch than for the area farther offshore encompassed by the 5° square. Calms for greater than 10% of the time occur from May through August.

The average monthly distribution of swell direction as given for this area in the above references is tabulated in Table VIII and the average for 10 years is shown in Figure 15. Swells in the offing of Boston Harbor are predominantly low with occasional medium and high swells from the NE and E in October, November, December and January.

Table VII

Average Monthly Distribution of Sea Direction and State

Month	% Direction from									State*, %		
	Calm	NE	E	SE	S	SW	W	NW	N	Low	Medium	High
Jan.	2	11				7	15	29	17	36	48	14
Feb.	3	9				9	16	30	18	27	53	17
Mar.	3	9			7	13	14	28	15	36	49	12
Apr.	6	12	8	8	8	15	16	19	8	40	45	9
May	11	12	7		9	19	19	9	8	57	26	2
June	15	9	8		11	26	10	8	9	49	37	3
July	14	10			13	29	14			61	24	1
Aug.	14	11	8		10	20	13	9	9	54	30	2
Sept.	9	13	9	8	10	16	13	10	11	50	35	5
Oct.	7	12	9	7	8	16	12	14	14	44	42	7
Nov.	2	11			10	13	16	24	12	36	48	14
Dec.	3	10				10	16	31	13	25	52	19

* Low refers to seas 0-3' in height.
Medium refers to seas 4-7' in height.
High refers to seas greater than 8' in height.

Table VIII

Average Monthly Distribution of Swell Direction

% Direction from

Month	NE	E	SE	S	SW	W	NW	N
Jan.	12	7	9	7	--	12	20	12
Feb.	11	--	--	--	9	16	19	13
Mar.	10	--	--	7	11	14	17	10
Apr.	13	12	7	--	14	11	10	--
May	9	8	--	8	16	11	7	--
Jun.	8	8	8	9	14	8	--	--
Jul.	7	--	7	15	24	8	--	--
Aug.	--	9	8	10	14	--	--	--
Sep.	12	9	7	9	12	--	--	7
Oct.	16	16	8	7	7	--	7	9
Nov.	10	9	7	9	10	12	17	9
Dec.	10	7	--	10	15	15	19	11

F. Fogs. Fogs are prevalent along the coast in summer. They are of frequent occurrence during June, July, and August. Winds from the E to SW bring in fog; westerly and northwesterly winds clear it away. The area of greatest fog frequency along the Atlantic Coast is directly SE of Newfoundland, where the Gulf Stream meets the cold Arctic currents. From this central area of greatest frequency the fog diminishes in all directions. During the winter this area is close to the Newfoundland shore, and the steamer routes to Europe are accordingly more northerly and shorter than during the summer when the area of greatest fog is farther S. The average number of days on which dense fog occurs at Boston is 14 per year, but its prevalence increases rapidly eastward over Massachusetts Bay. In the interior waters of the Inner Harbor it frequently dissipates toward noonday while remaining thick over the entrance and at sea.

Table IX shows the average number of hours per month that the fog signals were operated at stations in the vicinity of Boston, when visibility was reduced by fog or by snowstorms. The table was computed from Lighthouse Service records over a period of six years.

Table IX

	Hours of Operation of Fog Signal												
Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
Cape Ann	41	78	28	22	23	69	128	50	10	39	52	31	571
Boston L. S.	134	151	100	59	26	122	171	71	34	59	104	114	1145
The Graves	73	110	24	22	8	63	94	35	8	43	50	52	582
Boston L. H.	66	115	26	22	8	69	106	34	18	46	58	55	623
Plymouth (Gurnet)	15	64	1	8	5	63	126	44	-	18	51	28	423
Cape Cod Light	70	83	31	59	29	101	165	100	9	33	109	58	847

G. <u>Precipitation</u>. There is no rainy or dry season. The rain is distributed quite evenly throughout the year. The normal for each of the twelve months is over three and less than three and three-quarters inches. In summer much of the rain comes from convectional showers and thunderstorms--at other times from the cyclonic low pressure systems which pass each week with more or less regularity over the region, with an intermediate mid-period occurrence, thus producing precipitation roughly one day in three. The mean annual precipitation is 40.51 inches (80 year Weather Bureau Record). Precipitation as recorded in Tracy (1951) is given in Table X.

Table X

Precipitation in Inches

	Rain				Snow, Sleet and Hail		
	Mean Total	Max. Monthly	Min. Monthly	Max. in 24 hrs.	Mean Total	Max. Monthly	Max. in 24 hrs.
J	3.57	7.60	0.92	3.25	12.1	35.7	14.7
F	3.23	7.04	0.45	4.45	12.5	35.3	16.5
M	3.71	9.86	Trace	3.04	7.2	33.0	12.0
A	3.48	9.14	0.93	3.19	1.9	28.3	9.1
M	3.15	6.31	0.25	3.31	Trace	Trace	Trace
J	3.16	9.13	0.27	5.35	Trace	Trace	Trace
J	3.28	11.69	0.75	6.04	Trace	Trace	Trace
A	3.58	10.68	0.39	4.99	Trace	Trace	Trace
S	3.13	10.94	0.21	5.63	Trace	Trace	Trace
O	3.20	8.84	0.06	4.92	Trace	0.5	0.5
N	3.68	11.03	0.59	5.43	1.6	17.8	12.0
D	3.34	8.49	0.66	3.36	7.7	26.8	12.3
Year	40.51	11.69	Trace	6.04	43.0	35.7	16.5

Mean annual precipitation may vary from 60% of normal (1822) to 149% (1863). Within limits of about 10% more or less there is no apparent marked difference in the amount of precipitation throughout 102 years ending in 1935, but at any time we may expect above or below normal years for a year, 5, 10, 15, 20, or even 25 years (Safford, 1939).

H. Air Temperature. The mean annual air temperature is 51°F. (105 year Weather Bureau record). Maximum recorded temperature at Boston is 104°F. and the lowest -18°F. Monthly means and extremes for 79 years are listed in Table XI, from Tracy (1951).

Table XI

Air Temperature at Boston, Mass.

Month	Means: Daily Max.	Means: Daily Min.	Means: Monthly	Extremes: Record Highest	Extremes: Record Lowest
J	36.4	20.9	28.6	72	-13
F	36.5	20.8	28.6	68	-18
M	44.3	28.9	36.7	86	- 8
A	54.6	38.6	46.6	89	11
M	66.1	48.9	57.6	97	31
J	75.5	57.9	66.7	100	41
J	80.6	63.9	72.2	104	50
A	78.3	62.4	70.4	101	46
S	71.8	55.8	63.8	102	34
O	61.9	45.8	53.9	90	25
N	50.3	35.6	42.9	83	- 2
D	39.0	25.1	32.1	69	
Year	57.9	42.1	50.0	104	-18

I. Relative humidity. The average relative humidity is about 70% for morning and evening hours and a little under 60% for noonday. The maximum possible, 100%, is usually reached during rain or dense fog. It has been known to fall as low as 10%, approaching desert dryness, (Tracy, 1951). Table XII lists the Weather Bureau means for relative humidity at Boston.

Table XII

Relative Humidity

	J	F	M	A	M	J	J	A	S	O	N	D	Year
0130 EST	66	67	67	68	76	77	80	80	79	75	71	67	73
0730 EST	71	68	69	67	69	71	72	75	76	75	72	72	71
1330 EST	59	57	53	53	56	57	56	56	57	53	58	57	56
1930 EST	67	64	65	65	68	69	71	73	74	70	69	68	69

J. <u>Summary</u>. A tabular summary of other features of Boston Weather not already described above is given in Table XIII from Hydrographic Office (1943 B) and Tracy (1951).

Table XIII

Climatic Table

Wind	J	F	M	A	M	J	J	A	S	O	N	D	Year
Mean hourly speed (kts)	12.4	12.7	12.9	12.1	11.2	10.7	10.3	9.9	10.5	11.2	12.0	12.2	11.5
Prevailing direction	SW	WNW	WNW	SW	SW	SW	SW	SW	SW	SW	SW	WNW	SW
Fastest mile, speed (kts)	66	68	73	54	50	48	48	52	87	60	80	60	87
Fastest mile, direction	SW	W	E	W	W	W	N	NE	S	S	SE	NE	S
Gales, %	3	4	3	3	0	0	0	0	0	0	3	3	
% possible sunshine	47	56	58	57	59	62	64	63	61	58	48	48	57
Av. sky cover sunrise to sunset	5.9	5.5	5.6	5.8	5.8	5.6	5.6	5.3	5.1	5.3	6.0	5.9	5.6
Clear**	9	10	10	9	9	10	9	11	12	11	9	9	118
Partly cloudy**	8	8	9	10	12	9	13	11	9	10	9	9	117
Cloudy**	14	10	12	11	10	11	9	9	9	10	12	13	130
Precipitation .01" or more**	12	10	12	11	11	10	10	10	9	9	10	11	125
Snow, Sleet, Hail 1.0" or more**	6	6	4	1	0	0	0	0	0	0	1	5	23
Thunderstorms**	*	*	1	1	2	4	5	4	2	*	*	*	19
Heavy Fog**	1	1	1	1	1	1	2	1	2	2	1	1	15

** Mean number of days.

Table XIII (cont'd.)

Climatic Table

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Max. Temp. ≧ 90° **	0	0	0	0	*	2	4	2	1	0	0	0	9
≦ 32° **	10	9	3	0	0	0	0	0	0	0	1	7	30
Min. Temp. ≦ 32° **	26	24	19	4	*	0	0	0	0	1	9	22	105
≦ Zero **	1	1	*	0	0	0	0	0	0	0	*	1	3
Slight or no swell %	25	25	25	25	50	50	75	75	50	25	25	25	
Mean Pressure mbs (x 1/100)	18	17	15	15	15	15	15	16	18	18	18	18	

** Mean number of days.

5. SEA WATER

A. Temperature. Several series of sea water temperature measurements have been made near the surface in Boston Harbor or vicinity as tabulated in Table XIV and drawn in Figure 17. Seasonal thermoclines are present in Boston Harbor between April and November reaching their maximum in July.

Table XIV

Monthly Mean Sea Water Surface Temperature (°F)
Boston Vicinity

J	F	M	A	M	J	J	A	S	O	N	D
Boston Lightship (42°21.4'N 70°43.2'W) 13 year mean, 1927-1939											
38.8	36.2	36.2	39.6	46.6	55.7	60.5	62.0	60.3	53.9	49.3	42.7
Boston Harbor (42°21'N 71°03'W) 22 year mean, 1922-1943											
34.2	32.8	36.0	43.4	51.6	59.7	63.5	64.7	62.5	55.2	46.9	38.4
Boston Navy Yard 1 year mean, 1863											
--	32.2	32.9	42.6	52.7	57.4	64.8	64.8	61.5	56.5	45.9	34.3
Commonwealth Pier #5											
34.0	31.9	35.7	42.7	51.8	59.2	63.5	64.4	62.1	53.8	45.9	37.6
Lynn Gas & Electric Co., Lynn, Mass. 9 year mean, 1938-1946											
32.3	32.1	36.3	42.5	51.2	56.6	60.6	62.4	60.6	53.1	44.9	36.1

B. Density and Salinity. Three series of density measurements of sea water have been made near the surface in Boston Harbor as tabulated in Table XV. Density is expressed as density at 15°C and hence is readily converted to salinity Table XVI and Figure 17 by means of the table in the back of Coast and Geodetic Survey (1945).

C. Refraction of sound. No systematic study of the distribution of temperature and salinity with depth has been made in Boston Harbor although the approaches to the harbor were included in Bumpus (1948) and considerable data is available in our oceanographic file including measurements made by the Coast and Geodetic Survey in conjunction with tidal current measurements. The monthly progression of temperature, salinity, density and sound velocity are indicated in Bumpus' report. In the absence of carefully worked up velocity-depth studies in Boston Harbor, average velocity-depth information from just east of Boston Light Vessel might be indicative of the kind of velocity gradients to expect in Boston Harbor. Figure 18 indicates the seasonal change in the difference between the velocity at the surface and the velocity at 40 feet, 98 feet, and 164 feet. From this diagram it may be seen that there is essentially no velocity-depth gradient in January-March, but that commencing in April the velocity at the surface becomes greater than that at depth increasing to a maximum in July when the difference between the surface and 49, 98, and 164 feet is 74, 122, and 138 feet/sec., respectively, following which it diminishes to zero in November. These changes in velocity are due to the greater increase of the temperature of the water at the surface than at increasing depths. This will cause downward refraction of sound waves between April and November.

D. Transparency. Measurement of transparency in the surface water of Boston Harbor in May 1951 with secchi disks yielded values of 2 feet in the Inner Harbor to 5 feet west of Deer Island and nearly 20 feet at the Light Vessel. Black objects can be seen 1/2 to 1/3 as far. We have not attempted to investigate transmission at depth, but plan to do so as soon as equipment is available.

Mr. George C. Perry and Mr. Alfred C. John, divers, have been interrogated concerning their knowledge of the visibility at the bottom in various parts of the area. Visibility at the bottom as reported by these men is indicated in Figure 19. Our definition of visibility is the distance the diver can make out objects at the bottom with sunlight as the source of illumination. These divers do not use artificial light.

Table XV

Monthly Mean Sea Water Density ($\sigma_{15^\circ C}$) Boston Vicinity

	J	F	M	A	M	J	J	A	S	O	N	D	Extremes Max.	Extremes Min.
Boston Harbor (42°21'N 71°03'W) 23 year mean, 1922-1944	1.0217	1.0219	1.0203	1.0199	1.0208	1.0216	1.0222	1.0224	1.0223	1.0224	1.0223	1.0219	1.0257	1.0098
Boston Navy Yard 1 year mean, 1863	—	1.0203	1.0201	1.0173	1.0186	1.0224	1.0215	1.0205	1.0206	1.0205	1.0194	1.0188	1.0251	1.0123
Commonwealth Pier #5 6 year mean, 1921-1926	1.0221	1.0221	1.0208	1.0203	1.0205	1.0218	1.0216	1.0224	1.0224	1.0229	1.0227	1.0221	1.0239	1.0124

Table XVI

Monthly Mean Sea Water Salinity (°/oo) Boston Vicinity as computed from $\sigma_{15^\circ C}$

	J	F	M	A	M	J	J	A	S	O	N	D	Extremes Max.	Extremes Min.
Boston Harbor (42°21'N 71°03'W) 23 year mean, 1922-1944	29.4	29.7	27.6	27.1	28.2	29.3	30.0	30.3	30.2	30.3	30.2	29.7	34.6	13.9
Boston Navy Yard 1 year mean, 1863	—	27.6	27.3	23.7	25.4	30.3	29.1	27.7	27.8	27.7	26.4	25.6	33.8	17.1
Commonwealth Pier #5 6 year mean, 1921-1926	29.9	29.9	28.2	27.6	27.8	29.5	29.3	30.3	30.3	31.0	30.7	29.9	32.3	17.3

6. BIOLOGICAL INFLUENCES

Information concerning the prevalence of marine borers and fouling organisms in Boston Harbor is available in the seven annual reports of the Bethlehem Steel Co., who have made careful studies, in cooperation with the W. F. Clapp Laboratories at four shipbuilding facilities in Boston Harbor as well as at New York, Baltimore, San Francisco, and San Pedro (Bethlehem Steel Co., 1945, 1946, 1947, 1948, 1949, 1950, 1951).

A. Borers. Only one Teredo has been reported from the Boston area, namely, at the Quincy Yard in the course of the Bethlehem Steel Co. surveys, although its presence has been recorded by the W. F. Clapp Laboratories in 1935, 1939, and 1940.

Limnoria has proven a serious threat to wooden structures at the Quincy, Atlantic, and Simpson Yards but not at the Hingham Yards. They have reached the intensity of 100 per square inch in one month in test panels at Quincy; 50 per square inch at Atlantic and Simpson Yards.

Chelura has also been found present but proves of little destructive consequence compared to Limnoria.

In comparison New York, Baltimore, and Beaumont suffer little destruction from marine borers whereas San Francisco suffers severe attacks from Limnoria and three species of Teredo.

Creosoting of pilings has proved to be a definite inhibitor of boring activity.

Without doubt more complete and comprehensive information concerning marine borers in Boston and other harbors of the world can be obtained from the W. F. Clapp Laboratories, if desired.

B. Fouling. The fouling of underwater structures in Boston Harbor varies from year to year for undetermined reasons. The chief fouling agents are hydroids (tubularia), barnacles (Balanus improvisus, B. eberneus, B. balanoides; occasionally B. crenatus), bivalves (Mytilus and occasionally Cupidula and Anomia) and tunicates (Molgula and Botryllus). Occasionally tubeworms, filamentous bryozoa (Bugula) and encrusting bryozoa (Electra) appear. The bivalves tend to choke sea water lines and in general require annual removal. Table XVII summarizes the fouling activity at the several installations in Boston Harbor.

Table XVII

Summary of Fouling Activity in Boston Harbor

Yard	General	Hydroids	Barnacles	Bivalves	Tunicates
Simpson	mod-heavy	trace-heavy	mod-heavy	light-heavy	occ-mod
Atlantic	light-mod	" "	light-"	none-mod	" "
Quincy	mod-heavy	" "	" "	" "	" "
Hingham	" "	" "	mod- "	few-light	--

The breeding periods of the various groups appears to be as follows:

Hydroids - summer to fall but has occurred during all months
Barnacles - late spring to fall
Bivalves - summer to early fall
Tunicates - mid-summer to fall

Fouling on the Boston anti-torpedo net has been reported by Hutchins and Deevey (1945) as follows:

"1. Observations. The section inspected was about quarter of the distance from the Long Island end. The exposure was 5 months, 28 February to 25 July, 1944.

"Net fabric. Fouling on the grommets was very light occurring only in scattered patches, and for practical purposes was insignificant. It consisted of small tufts of a hydroid, Tubularia crocea. Most of these were less than two inches high, although a few were as much as four inches. This type of growth is frequently known as 'moss'. Embedded among the hydroids were large numbers of young mussels, Mytilus edulis, less than one-quarter inch long.

"Auxiliary gear. The headline was heavily fouled by kelp up to three feet long. Only one or two scattered strands of kelp were found on the net grommets. The headline immediately under the small, barrel-type buoys was free of kelp also, but this was not true of the cylindrical Mark buoys with two points of attachment to the headline. Under the Mark buoys, however, there was less kelp than occurred between buoys. The buoys were fouled with green algae ('grass') near the water line, and with kelp, barnacles, and Tubularia on their deeper parts. The Tubularia was particularly dense on the underside of the Mark buoys.

"2. Reported conditions. Fouling in 1943 was much more severe than in 1944. Photographs taken during cleaning operations in August 1943 show a very heavy, dense Tubularia fouling uniformly distributed over the grommets, which were about half occluded. The thickness appears to have been about 4 inches. Cleaning was imperative under these conditions. The kelp fouling on the headline and buoys did not occur in 1943. The balks, on the other hand, carried a thick population of mussels. At the time the photographs were taken, the gear had been exposed about six months. The contrast between the hydroid fouling on the net and the mussel fouling on the balks was very marked.

"Fouling is reported to increase in quantity from the Deer Island end toward the Long Island end of the net. Local personnel attribute this difference to the sewage discharging from Deer Island.

"An anti-submarine net at Hingham Bay is reported to be subject to much the same type of fouling as found on the anti-torpedo net inspected. On the basis of descriptions and tentative identification by maintenance men, the chief form is again the hydroid Tubularia. Fouling on the anti-submarine net, however, does not seem to have presented a serious problem in the last two years."

Hydroids such as Tubularia, exhibit cyclic periods of growth and degeneration. Following the mature stage, the upper parts degenerate and decay, leaving only the basal parts of the stems and stolons. Some of these remain alive, and may regenerate new growth, as in a subsequent year; even those basal parts which are dead are fairly persistent. In temperate zones, the stages of the cycle are broadly correlated with the seasons. It appears from observations in Boston that the maximum development of the growth occurs in August. It has been reported that fouling on the Hingham Bay net actually reduced in quantity during the fall, hence necessitating little maintenance of the net.

C. Noise makers, ambient noise. A discussion of possible sources of noise of biological origin in the Gulf of Maine (Bumpus 1948) is repeated here for information.

"No fish, shrimp or other biological noises which increase the background noise have been reported in the literature. However, Fish (1948) suggests three groups of noise making creatures which may be possible noise-makers in the Gulf of Maine or its environs:

1. Fish known to be noise makers but not common to the region.

2. Fish common to this and adjacent regions which have been reported to make noise in other regions.

3. Marine mammals - whales, porpoises, and seals.

"The fishes of noisiest reputation are tropical or temperate forms and do not occur in abundance northward in the western Atlantic. However, of those which stray into the Gulf of Maine, the toadfish, Opsanus tau, the weakfish Cynoscion regalis, the kingfish, Menticirrhus saxatilis, and the black drum, Pogonias cromis, are the noisiest. The toadfish, the noisiest of all, which, according to Knudsen et al (1944), makes intermittent 'boops' of about 1/2 second duration similar to a boat whistle, might be encountered in the summer time in shallow water on muddy or sandy bottom. The others make 'croaker' noises which are described as bursts of drumming in rapid succession, individual drum beats or isolated groans, according to the species.

"Of the fishes common to the region four families have been reported to make sonic noises. These are members of the cod, sculpin, scorpion fish, and gurnard families. It is improbable that sound produced by the fourteen species of the cod family is of great intensity but the vast numbers and large size of some members of the group make them suspect until suitable experiments have been performed. The sculpins, of which there are at least eight species in the region, grunt and gurgle when disturbed. These are the Arctic sculpin which is fairly common in depths over 40 fathoms; the deep sea sculpin, below 100 fathoms; little or grubby sculpin, common inshore; short horn and long horn sculpins, both very common alongshore; the mailed sculpin and stag horn which are of more northern range so occur rarely in the Gulf; and the sea raven. The scorpion fish, which include the common rosefish, make long drawn-out gutteral 'snoring' sounds. The common sea robin and the red-winged sea robin, representatives of the gurnard family, are rare north of Cape Cod. Their sound 'resembles somewhat that produced by the croaker, but is more rasping' (Knudsen et al). Because of their tendency to congregate in large schools they can 'give rise to noise level comparable to that of a ship' according to preliminary observations by the Naval Ordnance Laboratory.

"The noises of marine mammals are not quite as well known as those of the fishes although their noises are more disconcerting. The only underwater noises of biological origin consistently noted in Submarine Patrol Reports in the Pacific during World War II are those attributed to whales and porpoises. These soundswere described as 'noises so rhymthic that they counted the "rpm", sounds like squealing, clucking, and short and long scale "pings"'. Porpoises which are capable of producing high noise levels and which are more apt to be encountered than any of the other beasts will suddenly arrive on the scene and depart just as quickly. Their noise is reported by one observer to consist of a series of barks followed by a gobble similar to that produced by a turkey cock, but varies considerably from moment to moment. Another observer reports these sounds as high pitched squeals often accompanied by swishing noises. Several species of whales are endemic to the Gulf of Maine, the commonest being the blackfish with grampus, killerwhales and finback whales less so. Because the blackfish tend to swim in large schools, whatever sound making propensities they have must be greatly amplified. Harbor seals have been known to occur in considerable numbers about the mouth of the Ipswich River, about the islands in Boston Harbor, and the eastern shore of Cape Cod. Further north they become more common especially along the Maine coast.

"The frequencies of the known noises of the above-mentioned creatures, both fish and mammals, range from about 100 cycles to 10 kilocycles."

The Massachusetts Institute of Technology-Bureau of Ships Research Group made measurements of ambient noise off Nahant in water 80 feet deep and in Boston Harbor at the Navy Yard in 1941. The measurements were made with an HK hydrophone through a 20 cycle band pass filter. The pressure level spectra measured at these locations is shown in Figure 20. Knudsen et al (1944) summarize the findings as follows:

"Each spectrum is based on one set of measurements. Considerable variation with time is to be expected. In view of the small amount of data a single straight line has been drawn as approximately representative of the Nahant ...spectra. With respect to the spectrum measured at the

Boston Navy Yard...the data...is of interest principally because its represents a rather extreme case. Nearly all of the sound energy...has its origin in the mechanical operations...at the yard... The curve has been selected from a large amount of data in order to represent something like an average result. Actually there are 15 db fluctuations in the over-all sound level about the value quoted and large variations as well in the frequency distribution."

7. NEEDED INFORMATION

A. Bathymetry. Careful sounding surveys are required outside of the area covered by the Coast and Geodetic Survey's surveys of 1940-45, out to the 25-fathom line, see Figure 1. This Institution will undertake the task of developing profiles of bathymetry along proposed swept channels, but it must be left to the Coast and Geodetic Survey to satisfactorily develop the bathymetry of the unsurveyed region.

B. Surficial geology. Much more information is required to adequately describe bottom sediments in the offing of Boston Harbor, the location of boulders and bedrock as well as the sand, mud, and kelp areas in order to best employ various types of underwater detection equipment. This includes the determination of how foul the dumping grounds are. This Institution is undertaking such a survey.

C. Magnetic anomaly. In the absence of magnetic observations over the marine area, a study of the magnetic field in the region would aid in a better understanding of the geology of the area. It would further point up locations of high anomalies which might tend to give spurious results when MAD searches are made.

D. Tidal currents. Further information is needed on the velocity and direction of tidal currents in the offing of Boston Harbor. However, data on velocity and direction of tidal currents at the bottom, over the whole area of consideration, are more urgently needed. This Institution will endeavor to develop methods for studying the bottom currents. It is hoped the Coast and Geodetic Survey will develop the current pattern offshore.

E. Sea and swell. Accurate knowledge of sea and swell conditions in relation of wind force and direction in the Boston Harbor approaches is woefully inadequate. We plan to set up a wave measuring station at Nahant. The analysis of the recorded information will be carried out through cooperation with New York University. Aerial photographs will be required to aid in the study of refraction.

F. Sonar conditions. Effective ranges of various types of underwater acoustic detection devices are not known. Undoubtedly the results of the current temperature and salinity survey will aid in predicting seasonal variations in sound conditions.

G. Ambient noise. Knowledge of ambient noise will probably be better understood when pilot underwater acoustic devices are set in place in various places by the Harbor Defense Unit. The Harbor Defense Officer should make a careful record of ambient noise due to various wind, sea, and current conditions as well as those of biological origin.

H. Transparency. We have at the moment only a little information on the transparency of the waters in the area. This Institution will undertake a survey of the transparency near the bottom as soon as suitable equipment is developed and provided.

8. ACKNOWLEDGMENTS

The writers wish to acknowledge the assistance of the many organizations and individuals contributing information so willingly upon request; namely, U. S. Army Engineers, N. E. District; Headquarters, FIRST Coast Guard District; U. S. Coast and Geodetic Survey; Boston Society of Civil Engineers; Port of Boston Authority; Boston Edison Company; Director, Seismological Laboratory, Weston College; Boston Office, U. S. Geological Survey; Boston Office, U. S. Weather Bureau; Metropolitan District Commission; Massachusetts Department of Public Works; Mr. George C. Perry and Mr. Alfred C. John.

9. REFERENCES

Beach Erosion Board, War Department
1948 Beach erosion report on cooperative study of Winthrop Beach, Mass. 80th Cong. 2nd Sess. H.R. Doc. #764.

Bethlehem Steel Company
1945 Marine borers and fouling organisms and their prevalence in the vicinity of Bethlehem Shipyards properties.
1st Annual Report; Development and Research Report #22
1946 2nd " " " " " " #39
1947 3rd " " " " " " #53
1948 4th " " " " " " #60
1949 5th " " " " " " #64
1950 6th " " " " " " #69
1951 7th " " " " " " #72
Shipbuilding Div., Central Tech. Dept., Quincy, Mass. (Mimeo).

Billings, M. P.
1929 Structural geology of the eastern part of the Boston Basin. Am. Journ. Sci. 5th Ser. 18 pp 97-137

Billings, M. P., F. B. Loomis, Jr., and G. W. Stewart
1939 Carboniferous topography in the vicinity of Boston, Mass. Bull. Geol. Soc. Am. 50 (12) Pt. I, pp 1867-1884.

Board of Engineers for Rivers and Harbors
1946 The Port of Boston, Massachusetts. War Dept., Corps of Eng. U.S. Army and U.S. Maritime Comm. Port Series #3. Revised.

Brooks, C. F.
1939 Hurricanes in New England. Geogr. Rev. 29:119-127.

Bumpus, D. F.
1948 Material for a Subsurface Pilot of the Gulf of Maine. WHOI Tech. Rept. #C-1 on the Hydrography of the Western Atlantic. (Mimeo.).

Coast and Geodetic Survey
1928 (Schureman, P.) Tides and Currents in Boston Harbor, U. S. Dept. of Comm. C.&G.S. Spec. Pub. #142.

1941 United States Coast Pilot - Atlantic Coast, Sect. A. St. Croix River to Cape Cod. Fourth Ed., U. S. Dept. of Comm. C.&G.S. #640, with supplement of 1949.

Coast and Geodetic Survey (cont'd.)
1942 (Haight, F. J.) Coastal Currents along the Atlantic Coast of the United States. U. S. Dept. of Comm., C.&G.S. Spec. Pub. #230.

1945 Density of Sea Water at Coast and Geodetic Survey Tide Stations, Atlantic and Gulf Coasts. DW-1. Revised.

1947 (Heck, H. H.) Earthquake history of the United States, C.&G.S. Serial No. 609. Revised (1947) edition.

1949 Tidal Current Charts, Boston Harbor. U. S. Dept. of Comm. C.&G.S. Serial #504.

1950a Current Tables, Atlantic Coast North America for the Year 1951. U. S. Dept. of Comm. C.&G.S. Serial #738. (published annually).

1950b Tide Tables, East Coast North and South America (including Greenland) for the Year 1951. U. S. Dept. of Comm. C.&G.S. Serial #731 (published annually).

1951 Personal communication dated 20 August 1951.

-- Chart 1207-A Massachusetts Bay (Bottom Sediment and Wreck Chart) (out of print).

-- Chart 1106-BS Bay of Fundy to Cape Cod (Bottom Sediment Chart).

Commonwealth of Massachusetts
1936 Report of the Special Commission on the Investigation of Discharge of Sewage into Boston Harbor and its Tributaries. House Doc. #1600.

Commonwealth of Massachusetts, Metropolitan District Commission
1951 Engineering Report on a Proposed Plan of Sewerage and Sewage Disposal for the Boston Metropolitan Area. Charles A. Maguire and Associates, Engineers.

Crosby, I. B.
1934 Evidence from drumlins concerning the glacial history of Boston Basin. Bull. Geol. Soc. Am. 45 (1) pp 135-158.

Emerson, B. K.
1917 Geology of Massachusetts and Rhode Island. Bull. U. S. Geol. Survey #597.

Fish, M. P.
1948 Private communications dated 12 and 15 December 1948.

Hutchins, L. W. and E. S. Deevey, Jr.
1945 The fouling of underwater defensive nets. Marine Fouling and its Prevention. WHOI Interim Report #11 (Mimeographed).

Hydrographic Office
1943a Sea and Swell Charts, North Atlantic Ocean. H. O. Misc. No. 10,712-A. (Restricted).

1943b Strategic Aerological Surveys, Part I Atlantic Area. H. O. No. 222.

1945 Wreck Information List. Corrected to 10 March 1945 (declassified).

1946 Corrections and additions as of 30 September 1946 to H. O. Wreck Information List of 10 March 1945.

1949 Frequency of Sea by five degree squares in the North Atlantic. H. O. Study 108.

Ketchum, B. H.
1951 The dispersion and fate of pollution discharged into tidal waters and viability of enteric bacteria in the sea. WHOI Ref. No. 51-11 (mimeographed).

Knudsen, V. O., R. S. Alford and J. W. Emling
1944 Survey of underwater sound. Report #103. Ambient Noise. N.D.R.C. Sect. 6.1 - N.D.R.C.-1848. (declassified).

Kuenen, Ph. H.
1950 Marine Geology. John Wiley & Sons, Inc., New York.

La Forge, L.
1932 Geology of the Boston Area, Massachusetts. Bull. U. S. Geol. Survey #839.

Linehan, D. and L. D. Leet
1942 Earthquakes of the Northeastern United States and Eastern Canada 1938, 1939, 1940. Bull. Seis. Soc. of Am. 32 (1) pp 11-17.

Marmer, H. A.
1949 Sea Level Changes along the coasts of the United States in recent years. Trans. Am. Geophys. Union. 30 (2) pp 201-204.

Net. Nav. Dep., Melville, R. I.
1944 Rest. ltr. NT4-21/N20-12 dated 17 November 1944.

Safford, A. T.
1939 Rainfall and runoff of New England. Jour. of Bost. Soc. Civil Eng. 26 (2) p 1.

Tannehill, I. R.
1943 Hurricanes. Their Nature and History. Princeton Univ. Press.

Tracy, W. H.
1951 Local Climatological Summary with comparative data, 1950, Boston, Massachusetts. U. S. Dept. of Comm., Weather Bureau.

U. S. Dept. of Agriculture
1941 Climate and Man. Year Book of Agriculture. House Doc. #27, 77th Congress 1st Session.

Woollard, G. P.
1948 Gravity and Magnetic Investigations in New England. Trans. Am. Geophys. Union, 29 (3) pp 306-317.

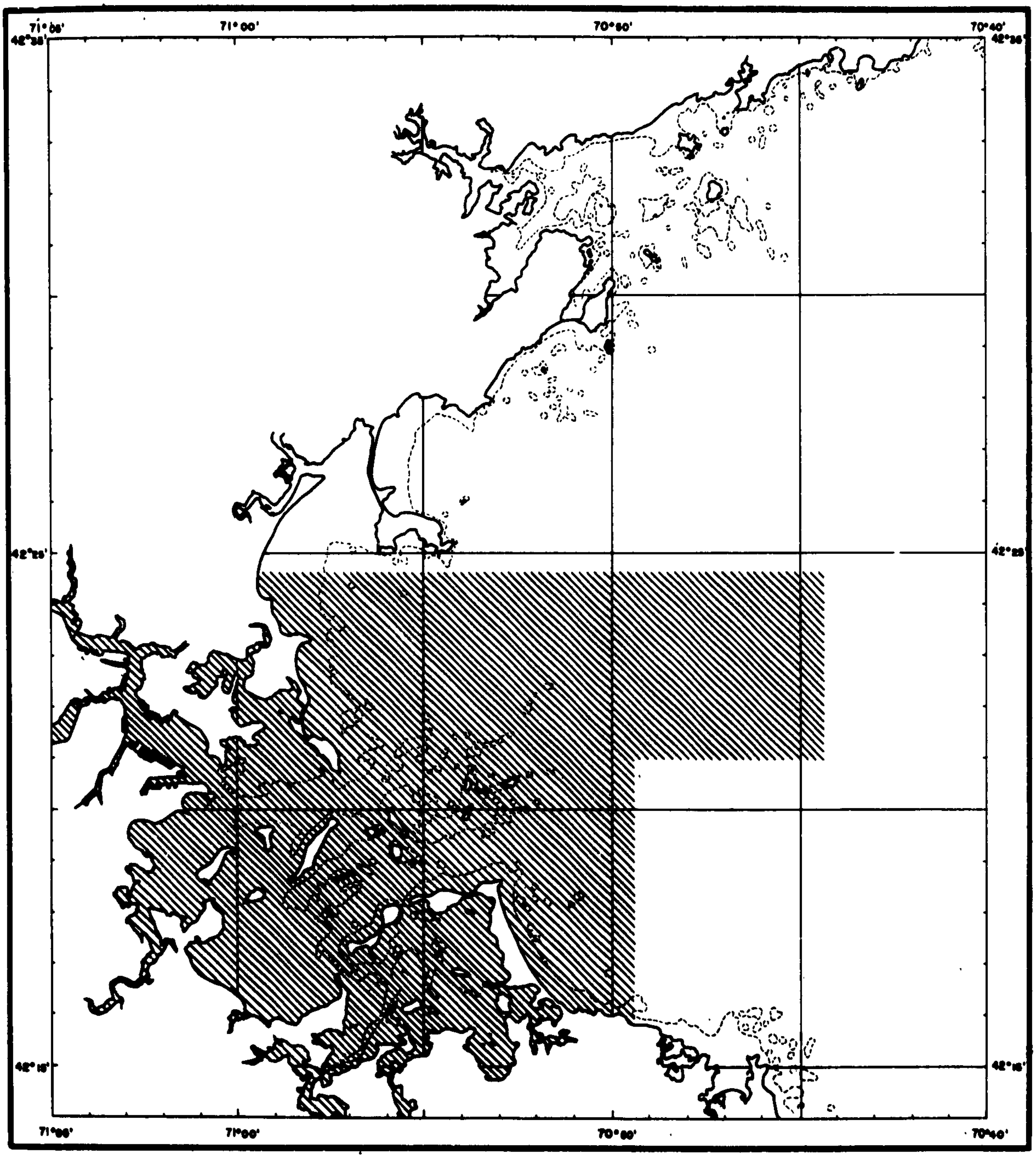


Fig. 1 Location of area covered by recent bathymetric surveys.

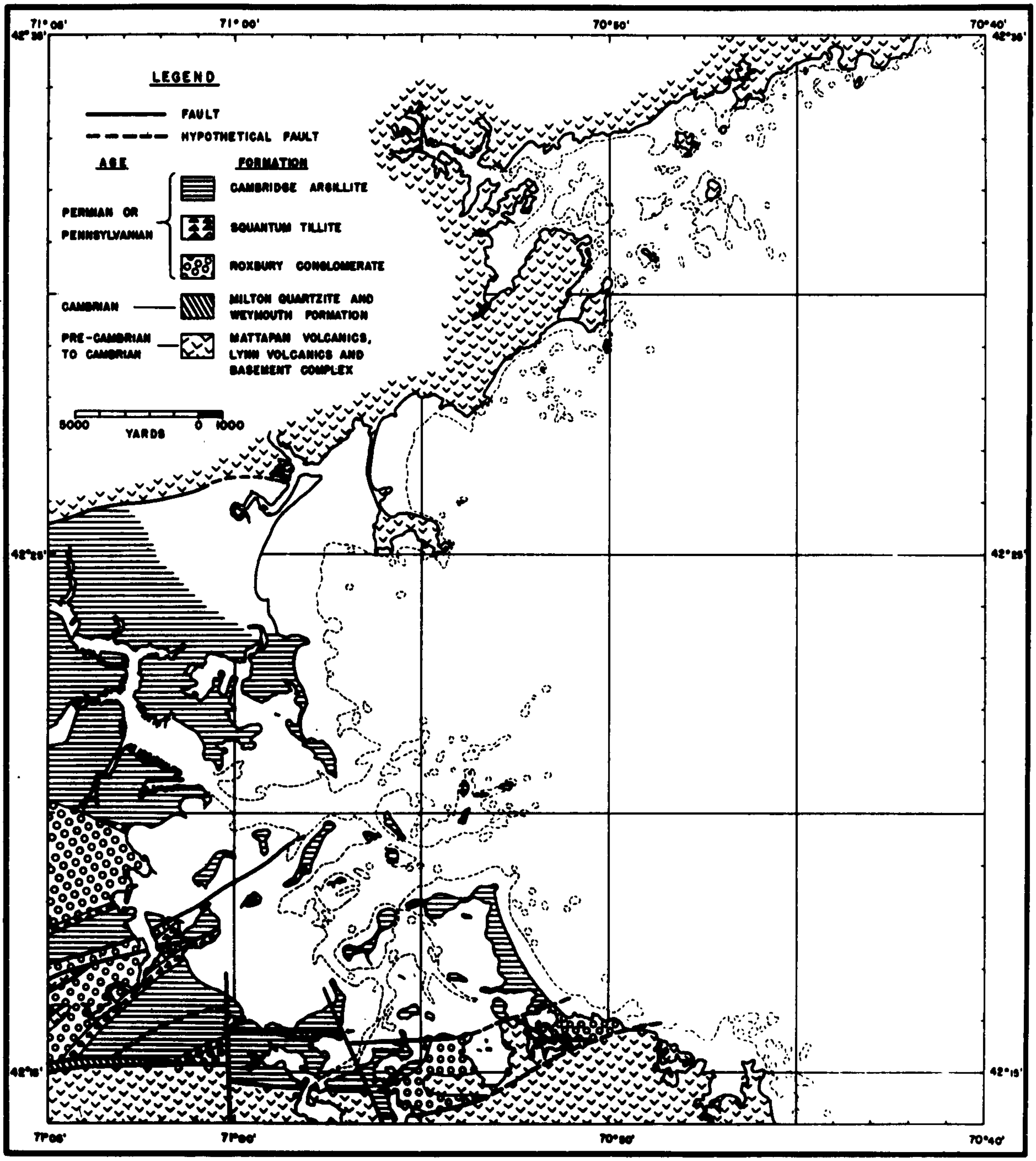


Fig. 2 Bedrock geology, Boston Harbor and vicinity (from Emerson, 1917; Billings, 1927; LaFarge, 1932 and Billings et al, 1939).

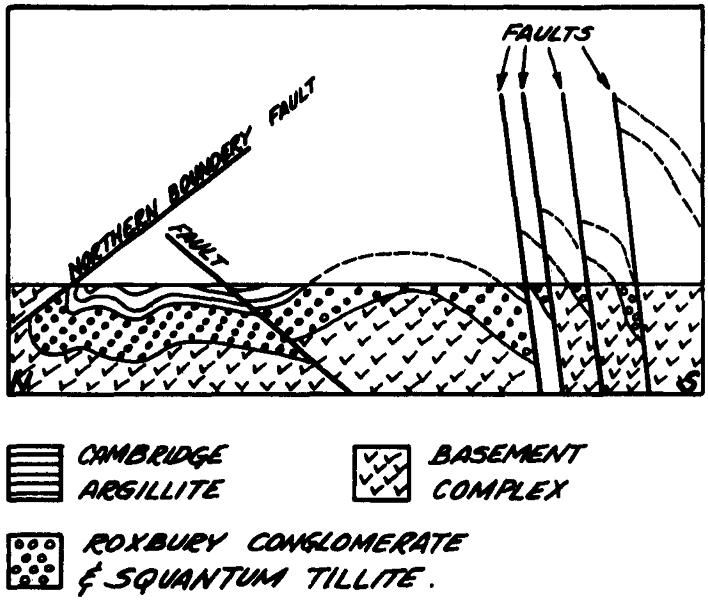


Fig. 3a Schematic cross section of Boston Basin from north to south (after Billings, 1927).

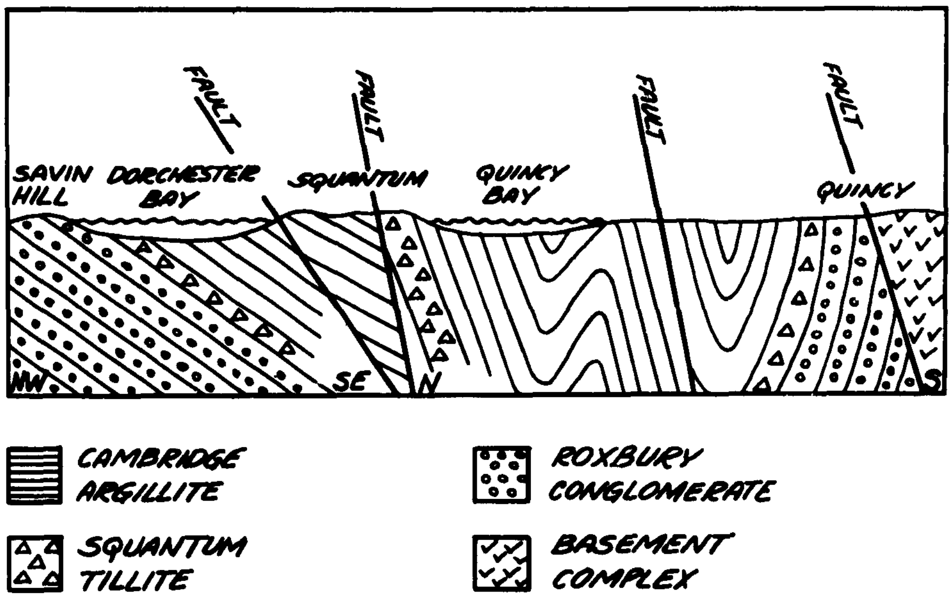


Fig. 3b Cross section from Savin Hill through Squantum to Quincy (Billings, 1927).

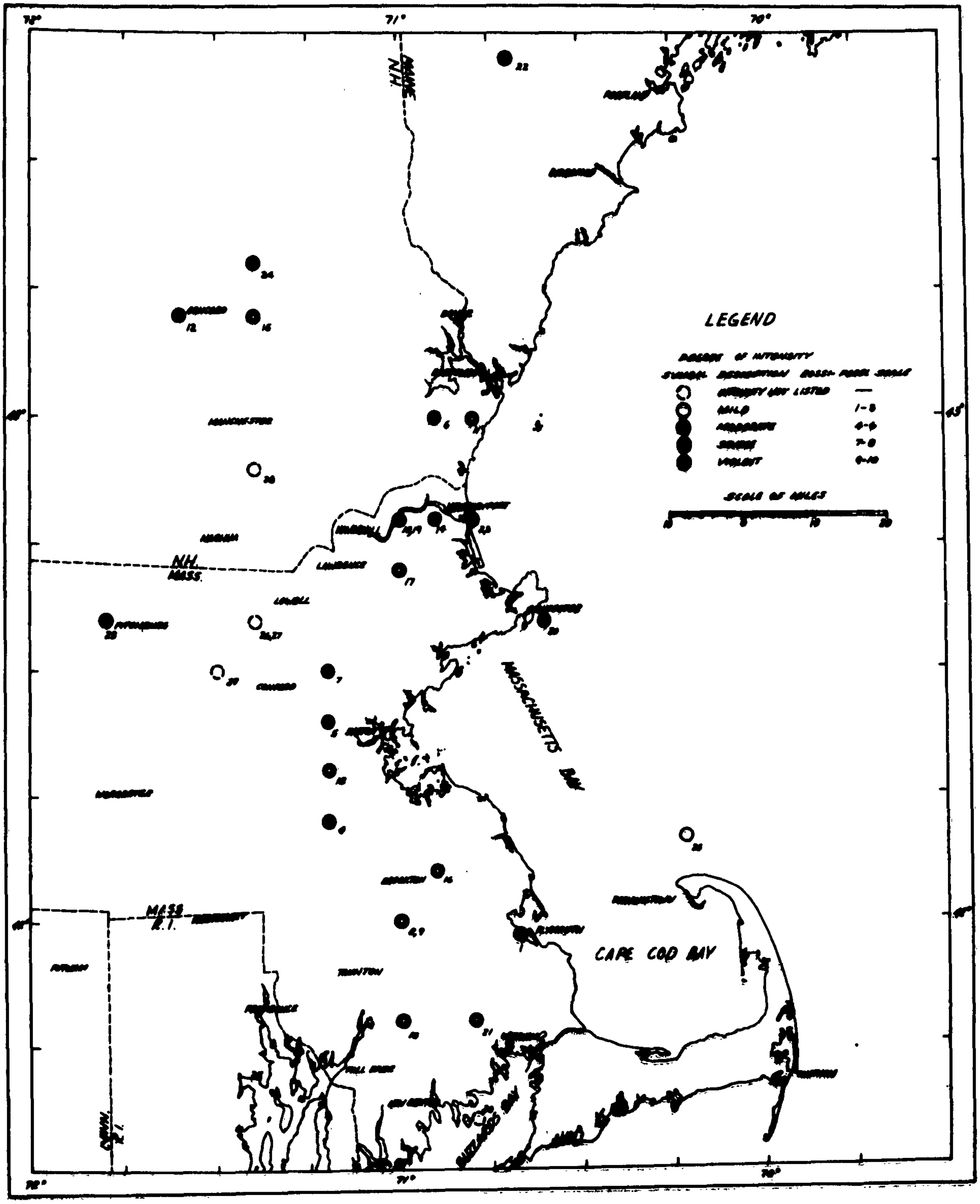


Fig. 4 Locations of epicenters and intensity of earthquakes recorded in southeastern New England up to 1941.

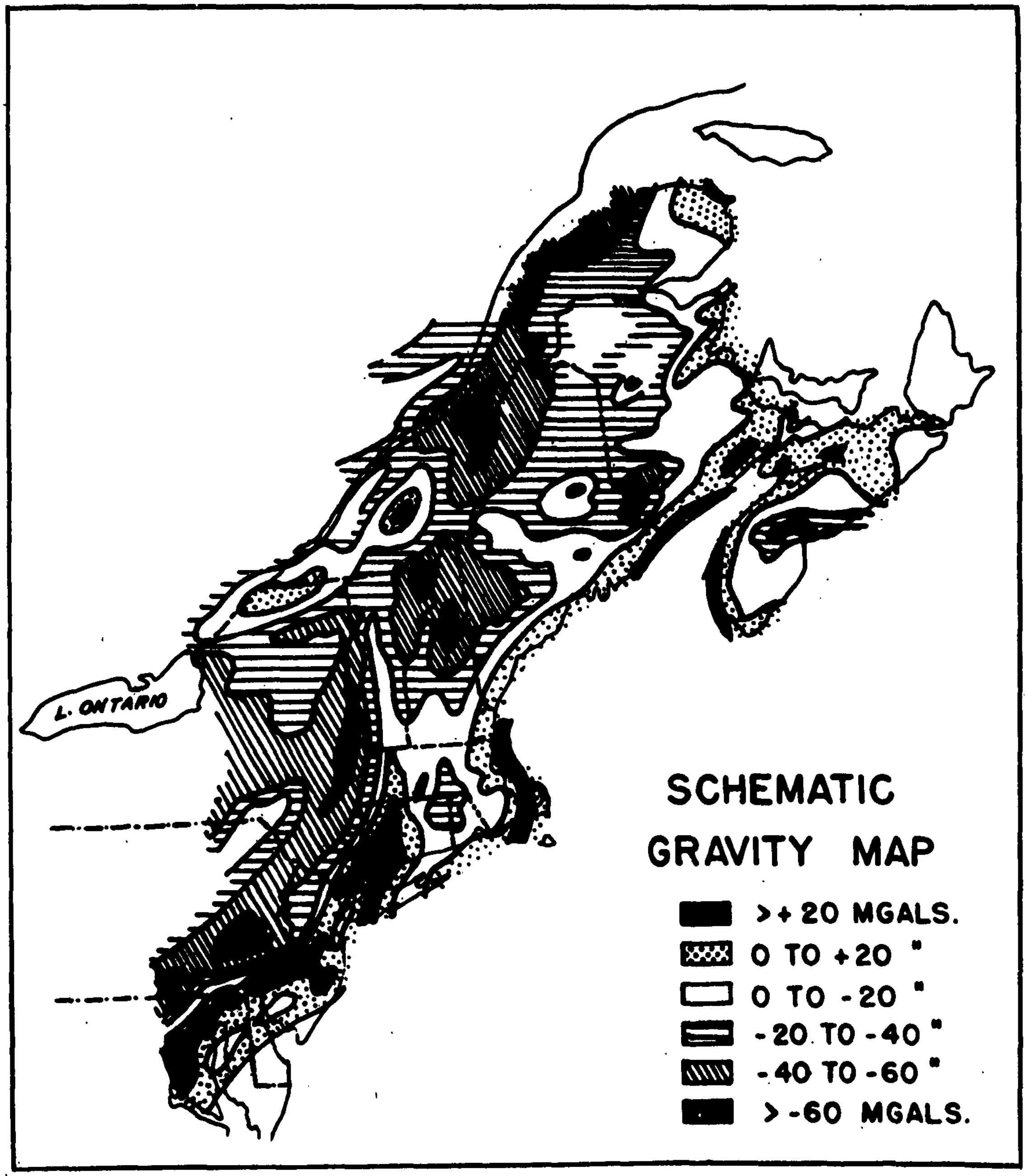


Fig. 5 Schematic gravity map (after Woollard).

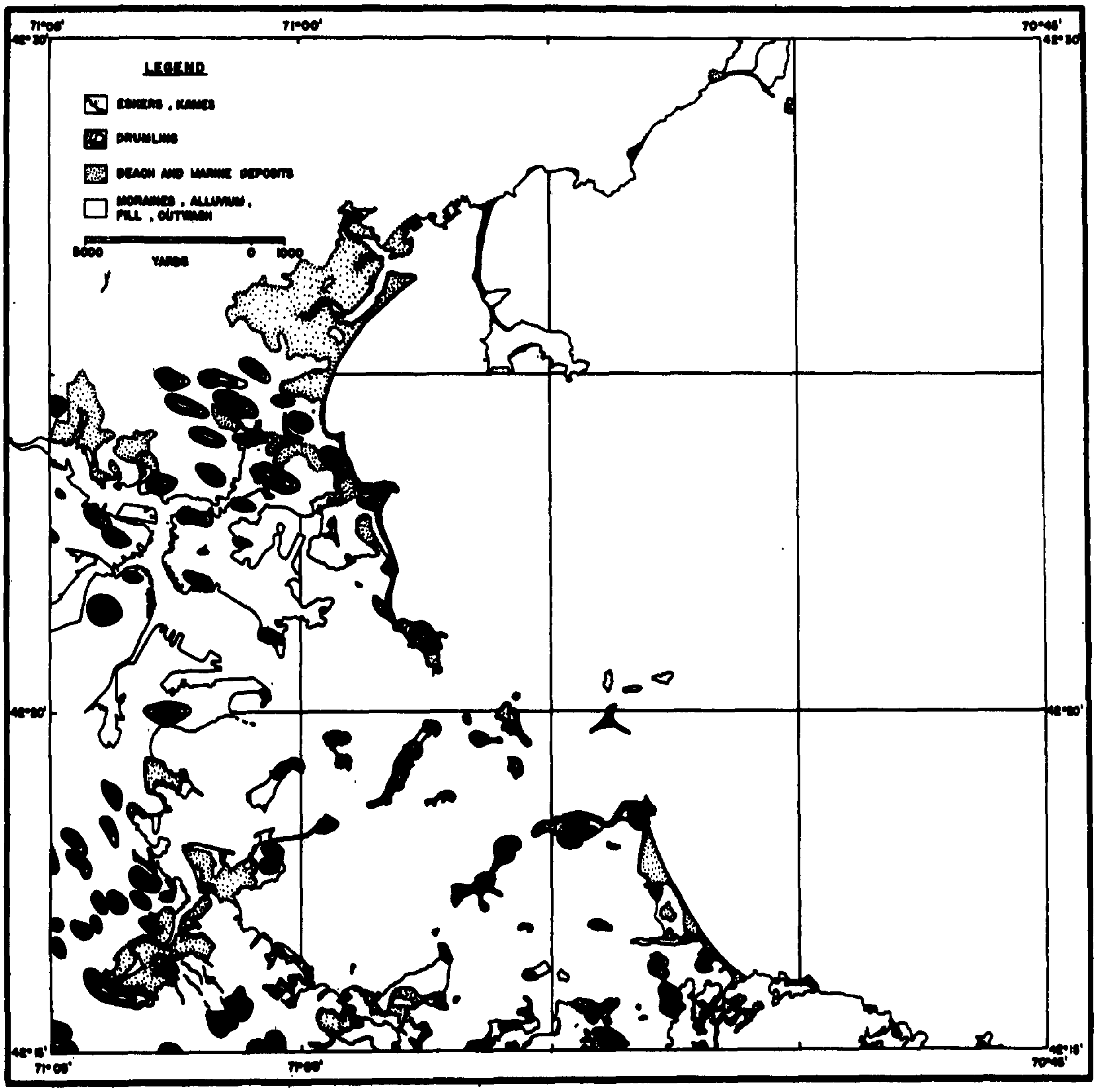


Fig. 6 Surficial geology, Boston Harbor and vicinity (LaFarge, 1932).

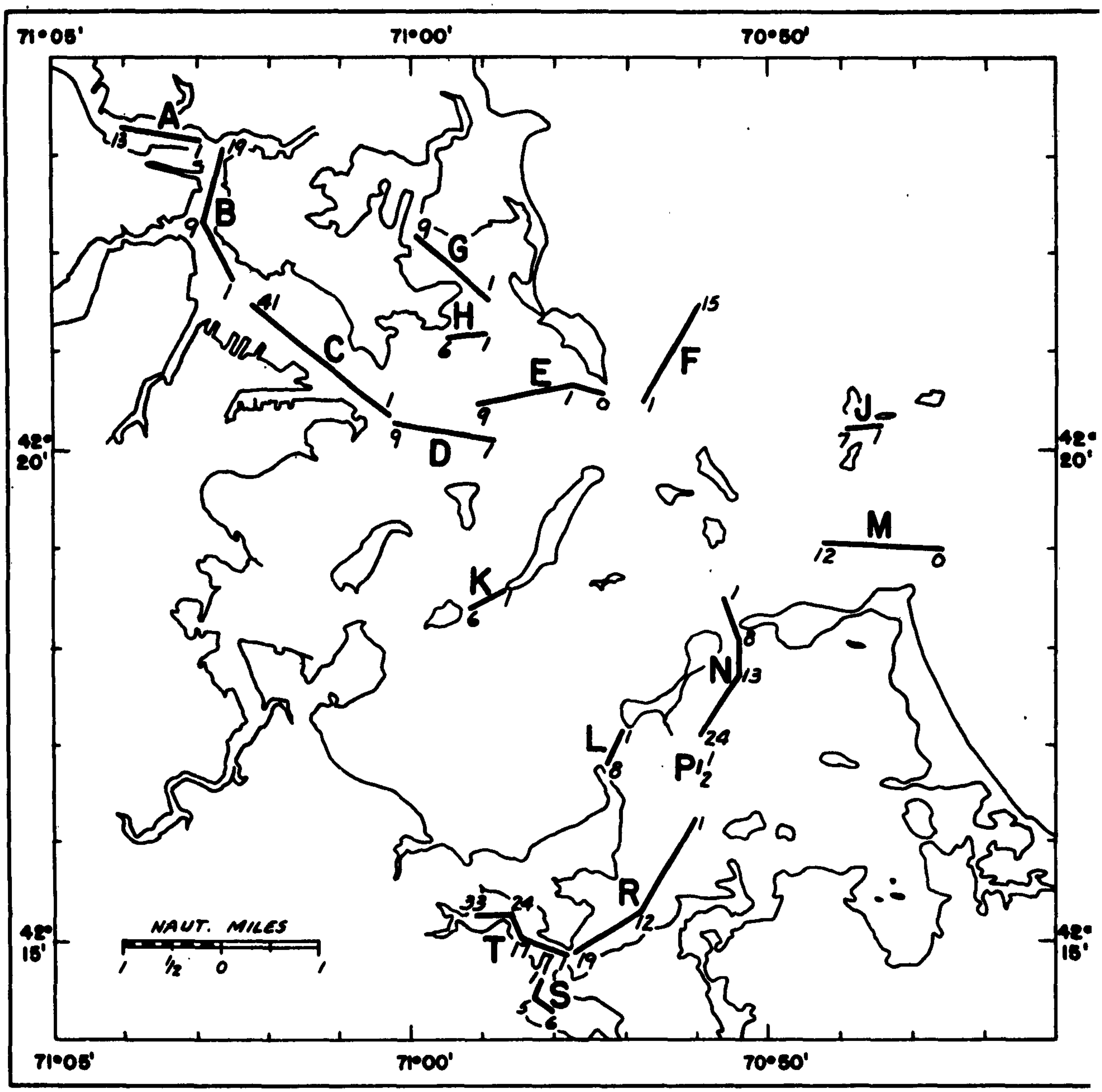


Fig. 7 Locations of selected probing and boring profiles.

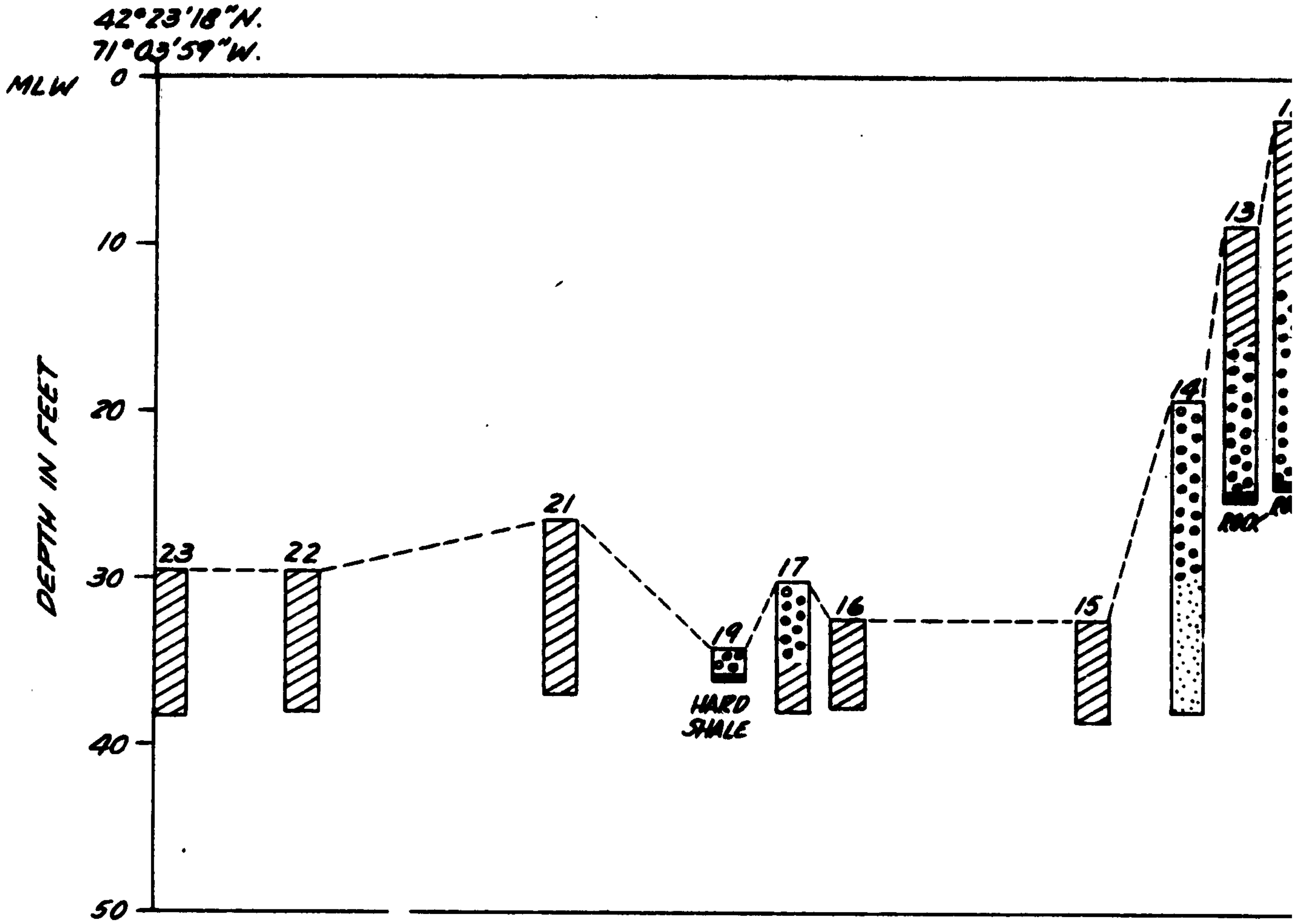
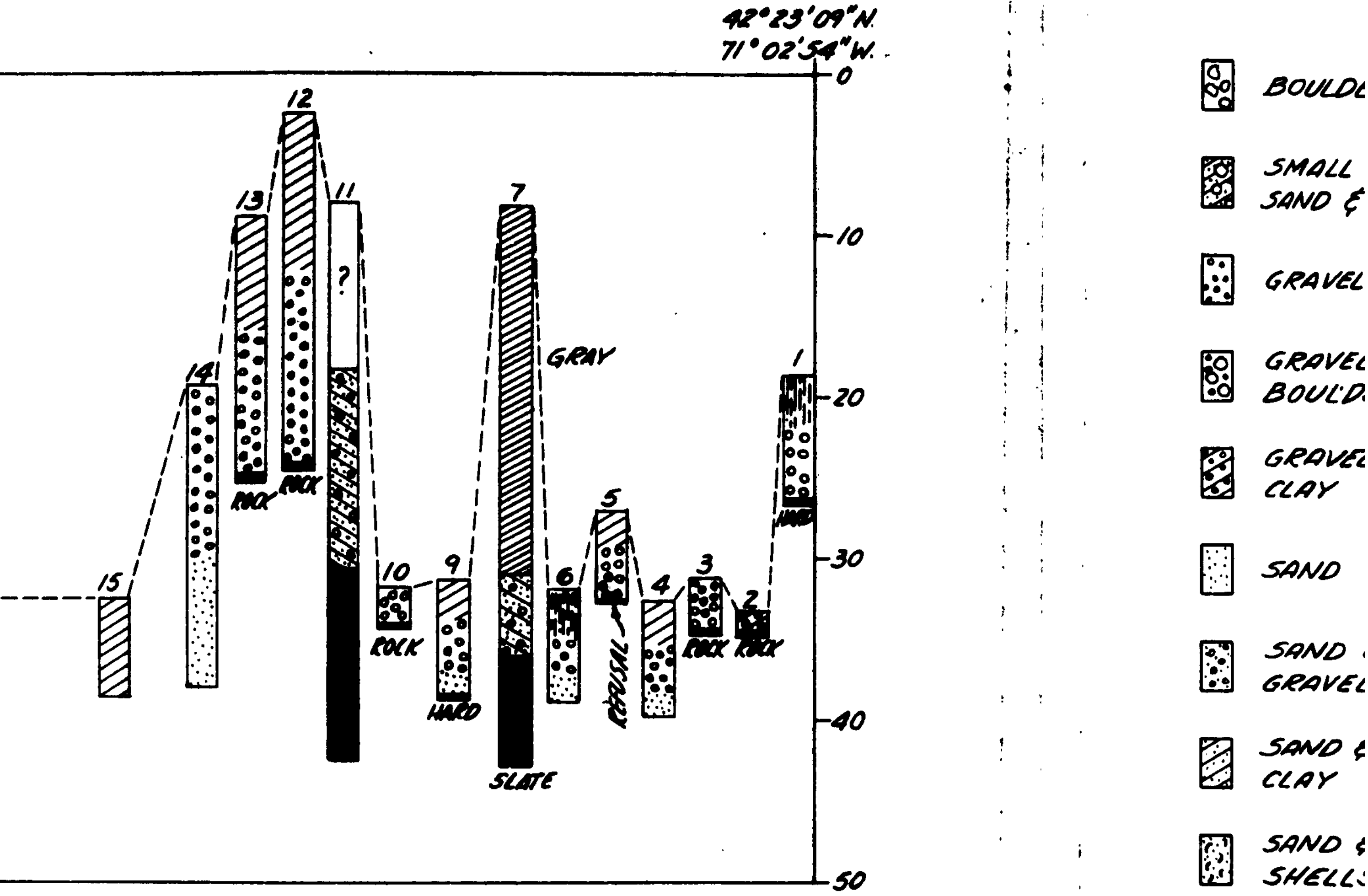


FIG. 7A

PROFILE ALONG THE NO. SIDE OF MYSTIC R. BETWEEN MALDEN BRIDGE A

DATA FROM: MYSTIC RIVER, MASSACHUSETTS, CORPS. OF ENGINEERS, FILE

DEPTHS OF THE BOUNDERIES BETWEEN SEDIMENT TYPES UN



7A

EN MALDEN BRIDGE AND CHELSEA NORTH BRIDGE.

OF ENGINEERS, FILE NBR. 346 DR 50, 1946

SEDIMENT TYPES UNDETERMINED EXCEPT IN BORINGS 7 & 11

LEGEND

BOULDERS	HARDPAN	SOFT CLAY & MUD
SMALL BOULDERS, SAND & CLAY	HARDPAN & BOULDERS	MUD
GRAVEL	MEDIUM CLAY OR CLAY	MUD & SAND
GRAVEL & BOULDERS	STIFF CLAY	SOFT SILT
GRAVEL & CLAY	STIFF, SANDY CLAY	SILT & SAND
SAND	MEDIUM STIFF CLAY	SILT, SAND, & GRAVEL
SAND & GRAVEL	STIFF CLAY & GRAVEL	SILT & GRAVEL
SAND & CLAY	CLAY & SHELLS	PEAT
SAND & SHELLS	SOFT CLAY	SEDIMENT TYPE UNDETERMINED

HORIZONTAL SCALE 1" = 500 FEET
VERTICAL SCALE 1" = 10 FEET
VERTICAL EXAGGERATION 50 TIMES

3

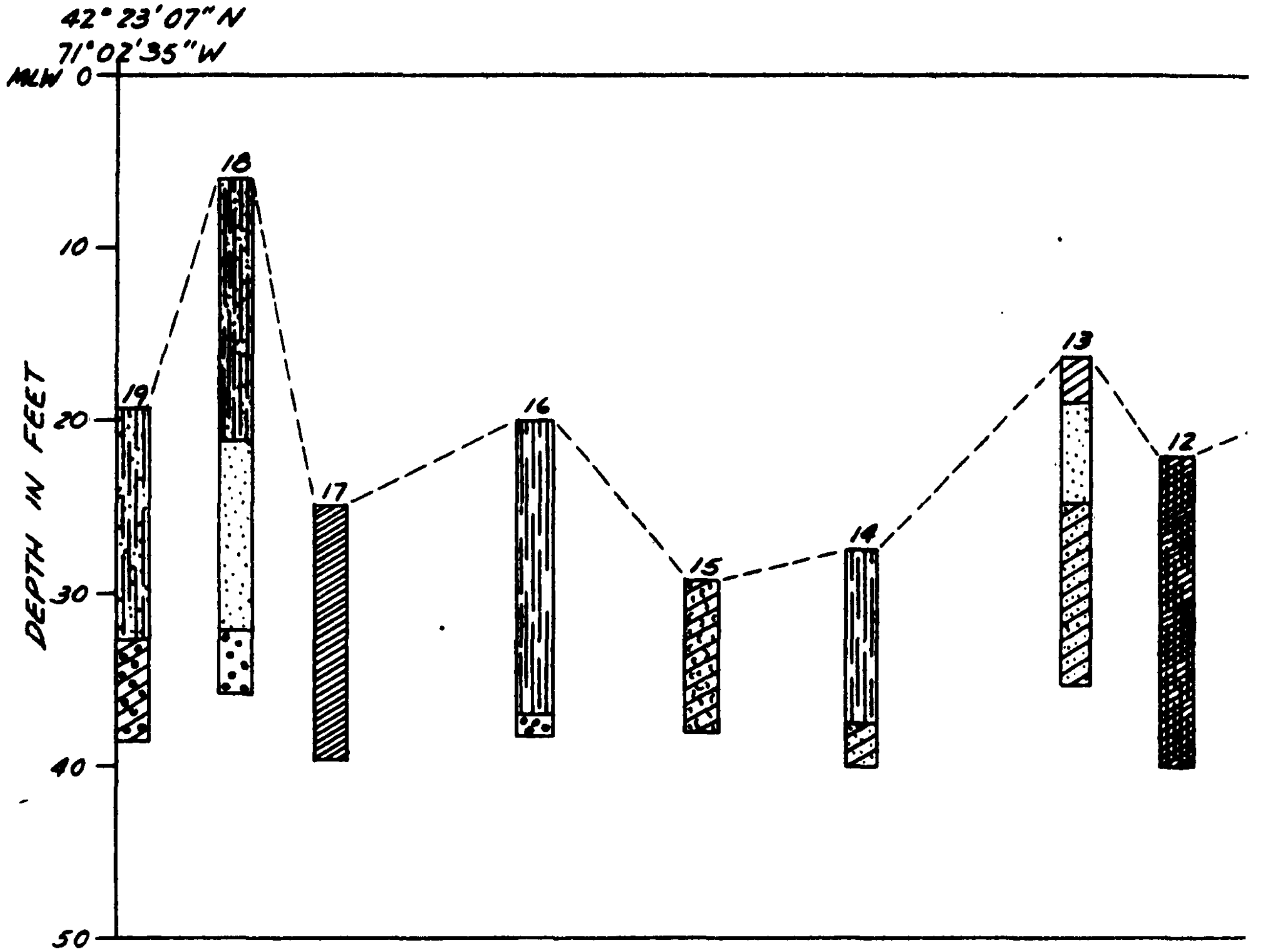
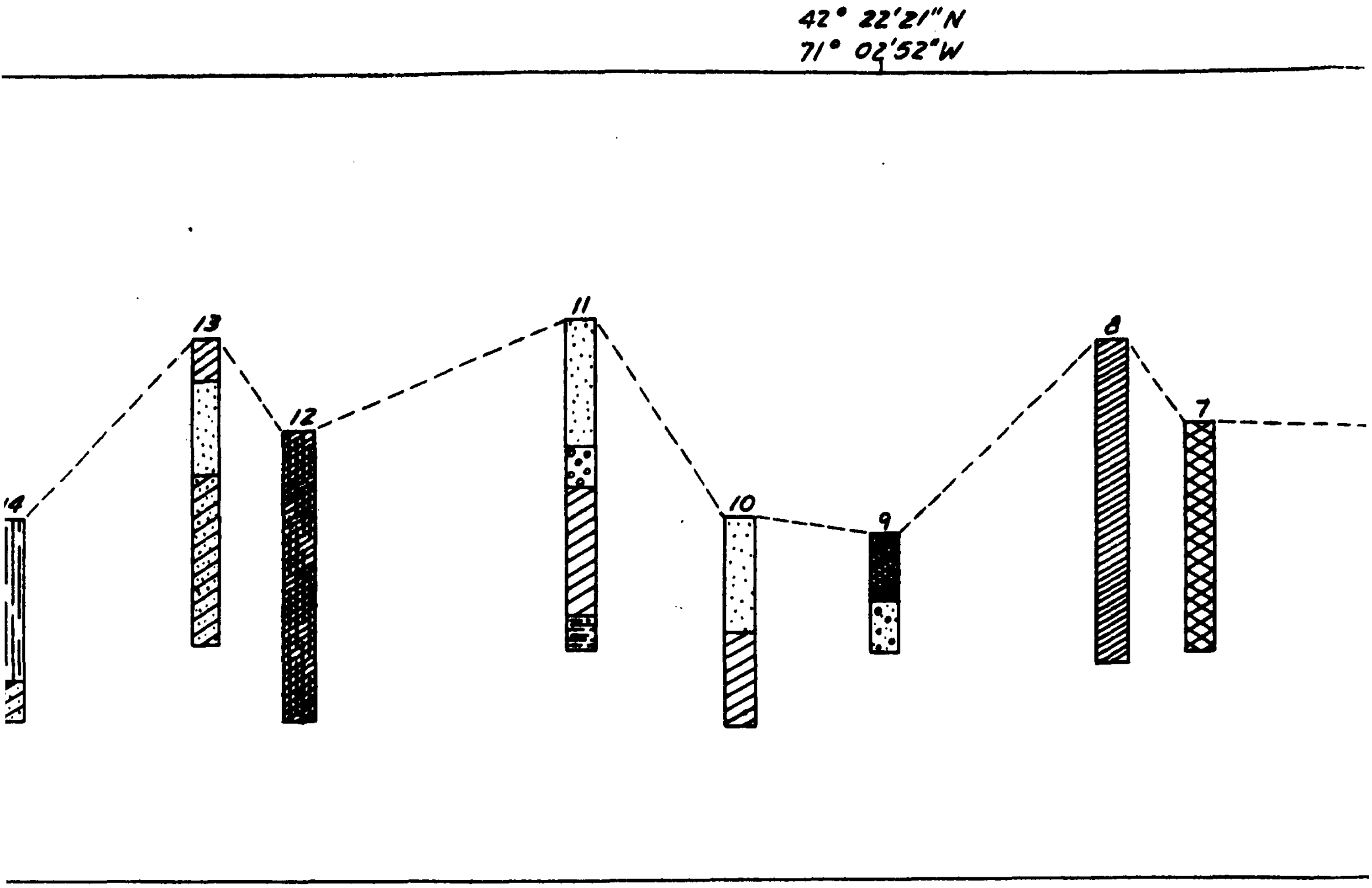


FIG. 7 B

PROFILE OF BOSTON INNER HARBOR BETWEEN CHELSEA AND FC

DATA FROM: BOSTON HARBOR, MASS. 35 FT. CHANNEL, CORPS. OF E

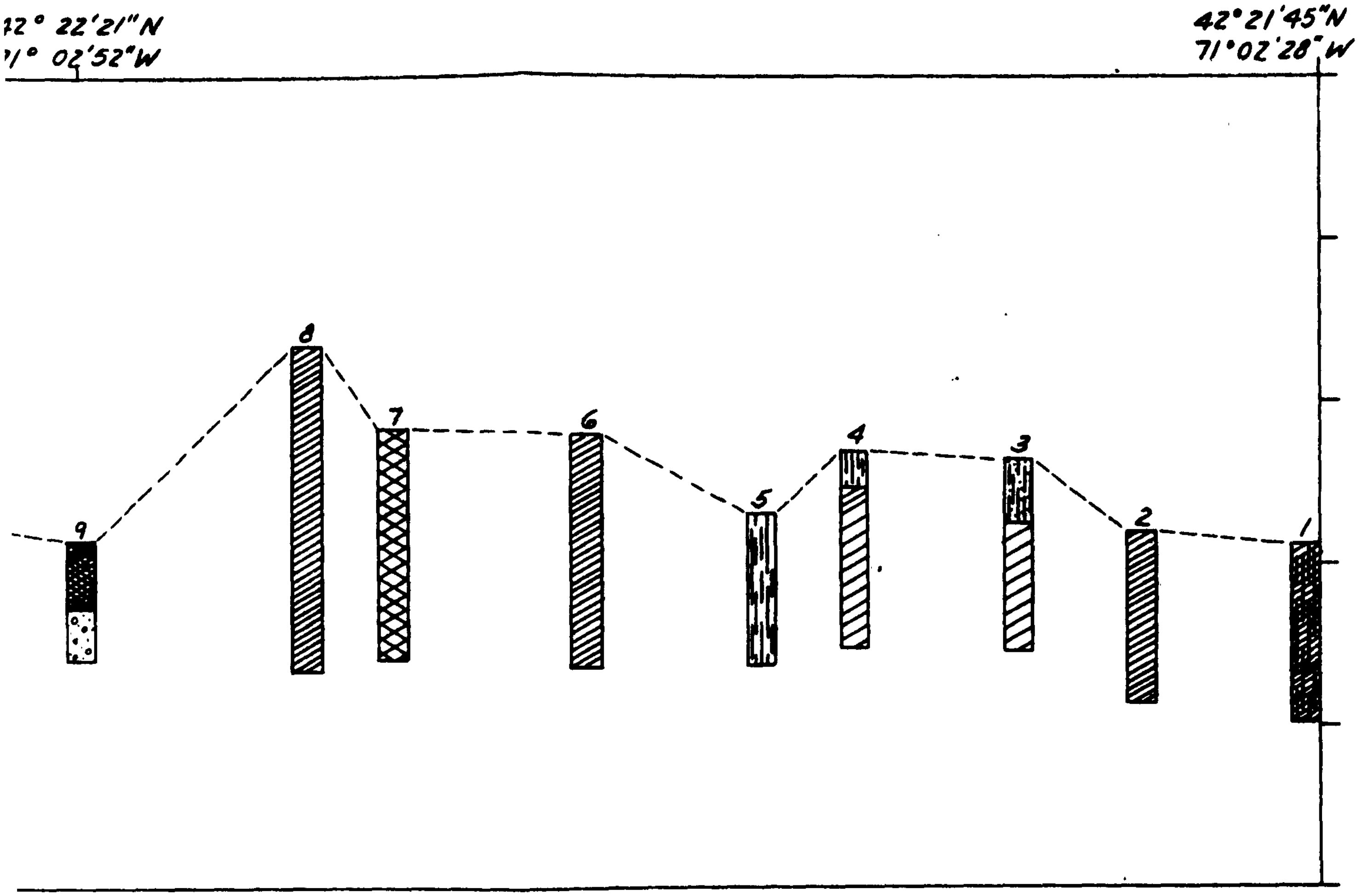


. 7 B

EEN CHELSEA AND FORT POINT CHANNEL

CHANNEL, CORPS. OF ENGINEERS NBR. 74, 1907

2



3

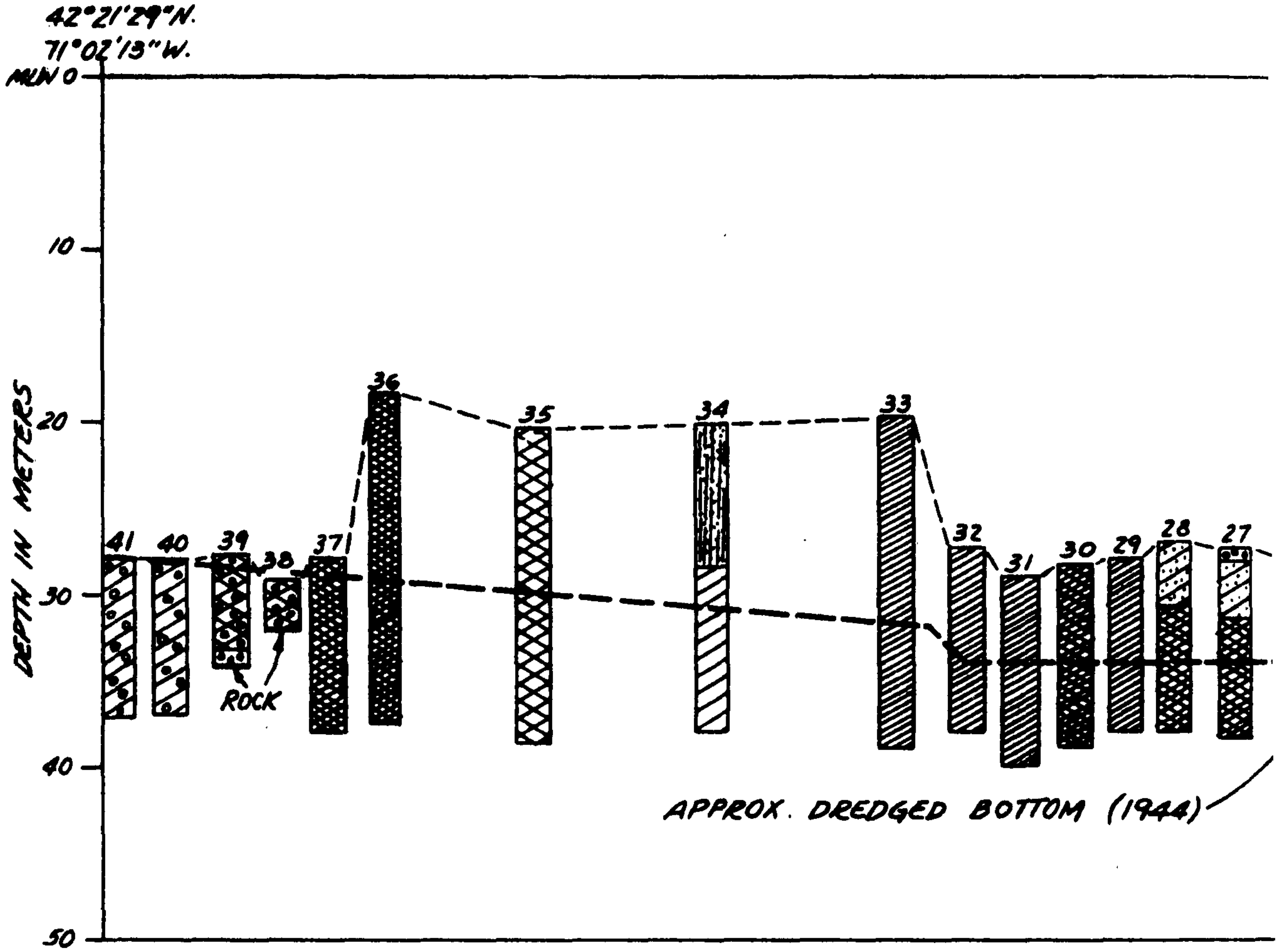
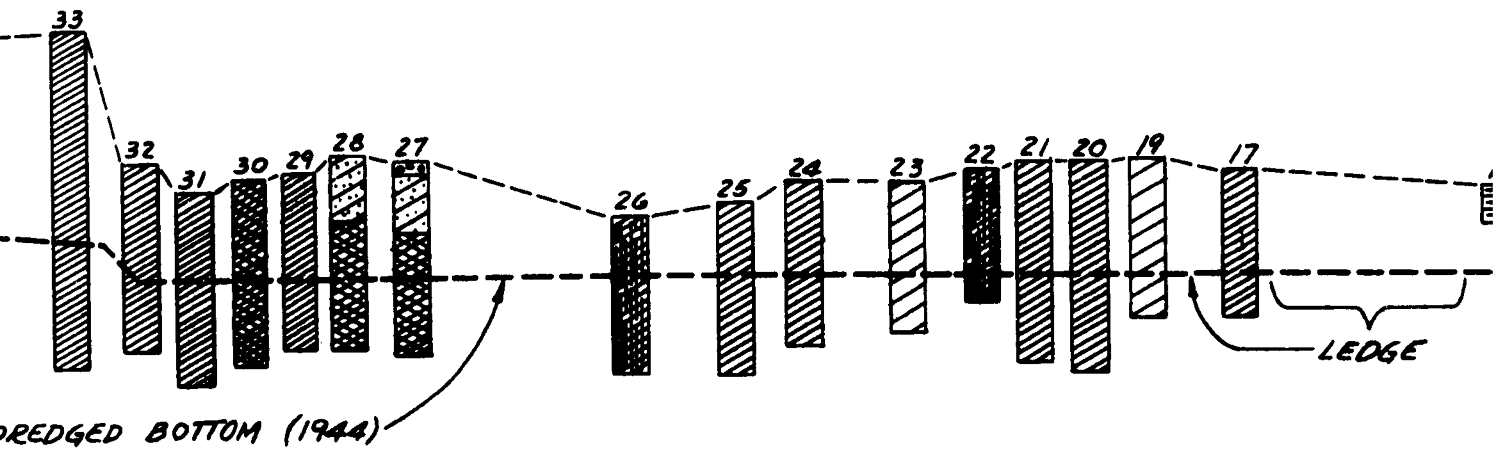


FIG. 7C

PROFILE ALONG NORTH SIDE OF SHIP CHANNEL BETWEEN FORT POINT C

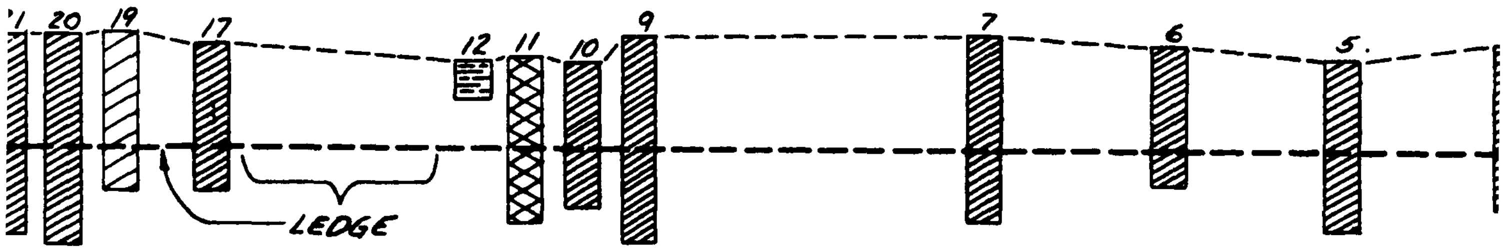
DATA FROM: BOSTON HARBOR, MASS. 35 FT. CHANNEL, CORPS OF ENGIN



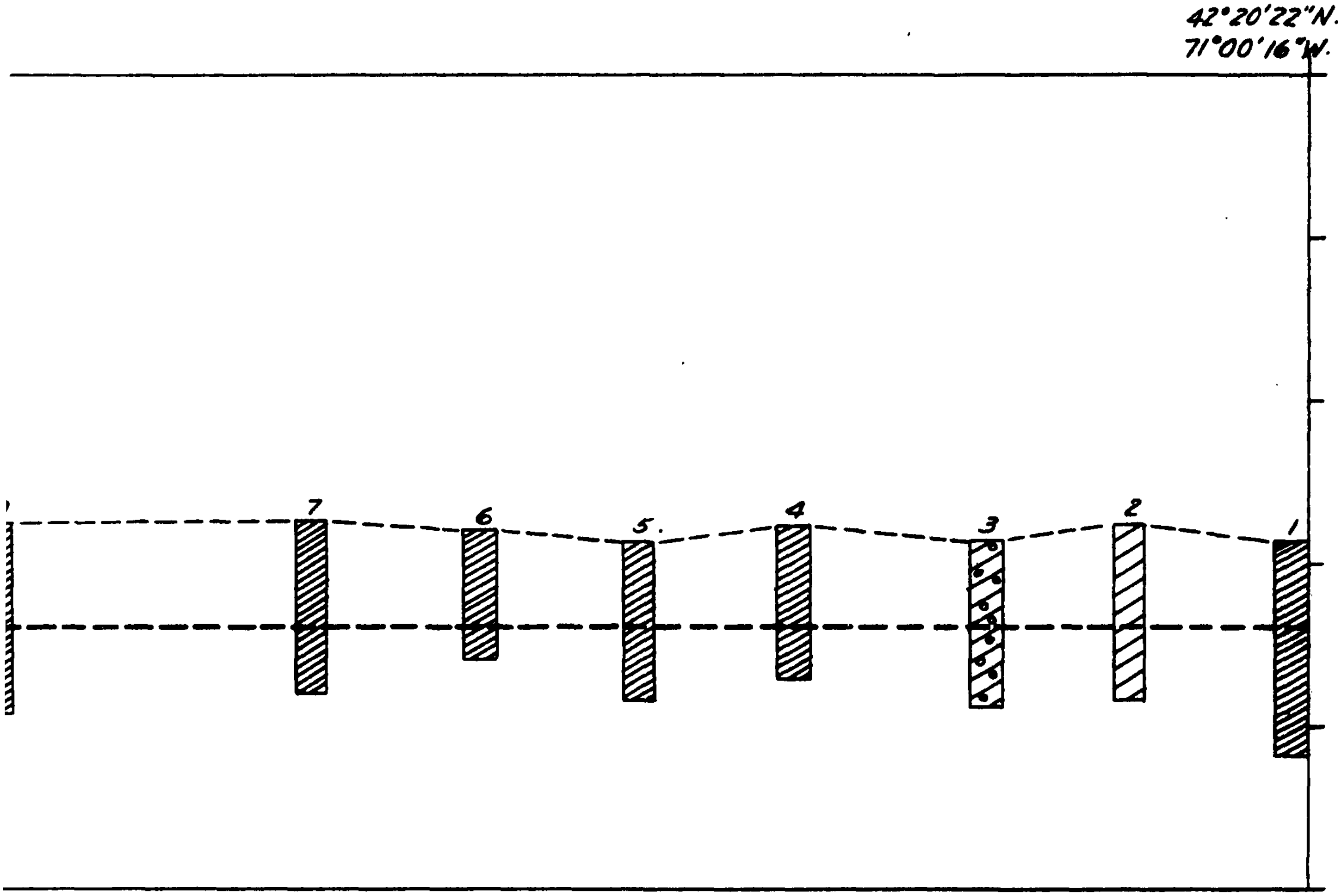
IG. 7C

L BETWEEN FORT POINT CHANNEL AND FORT INDEPENDENCE

T CHANNEL, CORPS OF ENGINEERS NBR 74, 1907



3


42°20'22"N.
71°00'16"W.
7
6
5
4
3
2
1

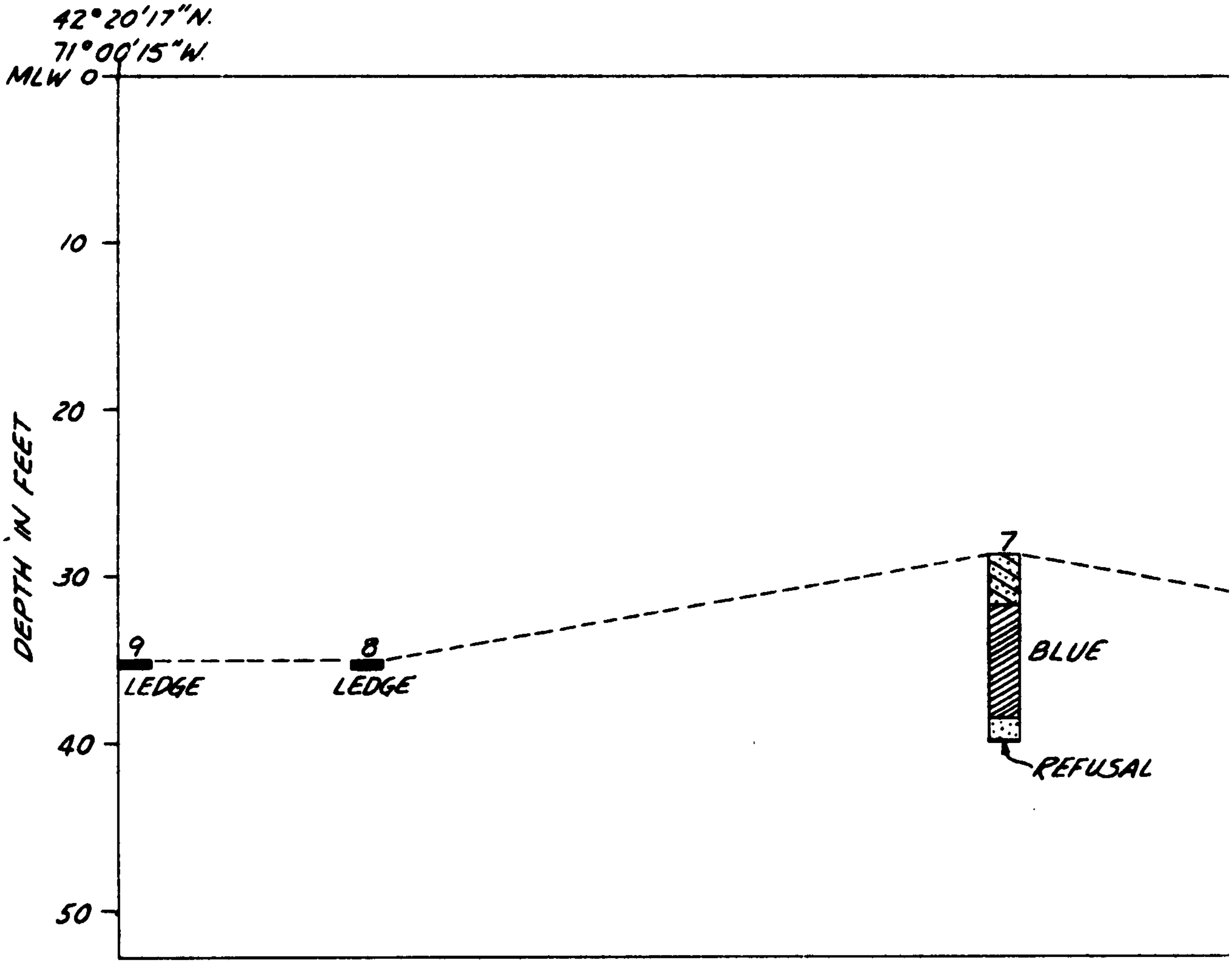


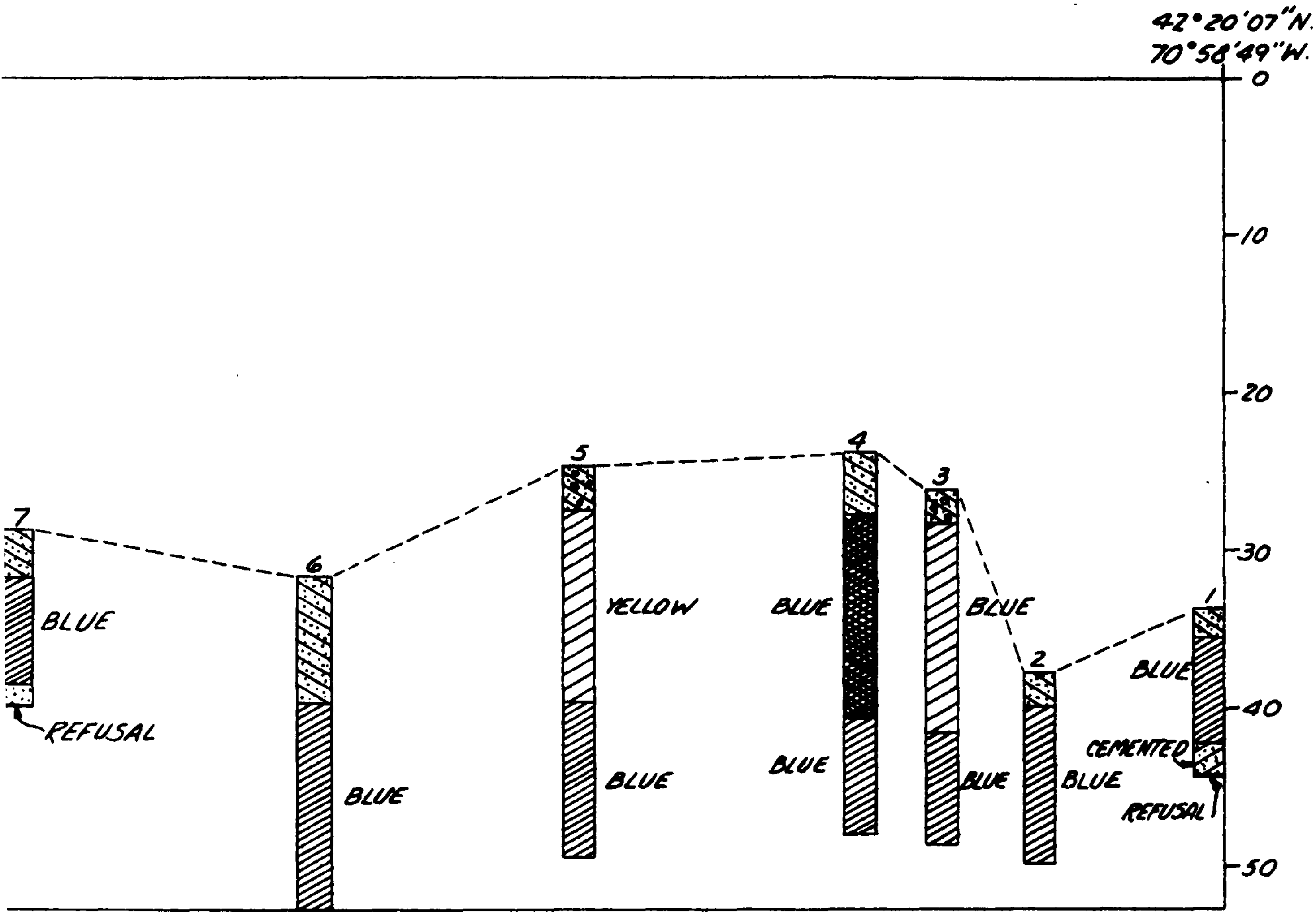
FIG. 7D

PROFILE ALONG NO. SIDE OF MAIN SHIP CHANNEL BETWEEN FORT INDEP

DATA FROM: BOSTON HARBOR, MASS. CORPS. OF ENGINEERS FILE

BOSTON HARBOR, MASS. 35 FT. CHANNEL CORPS OF

1



)

EN FORT INDEPENDENCE AND PRESIDENT ROADS

INEERS FILE NBR. 1677 DR 1 1946 (BORINGS)

EL CORPS OF ENGINEERS 1907

2

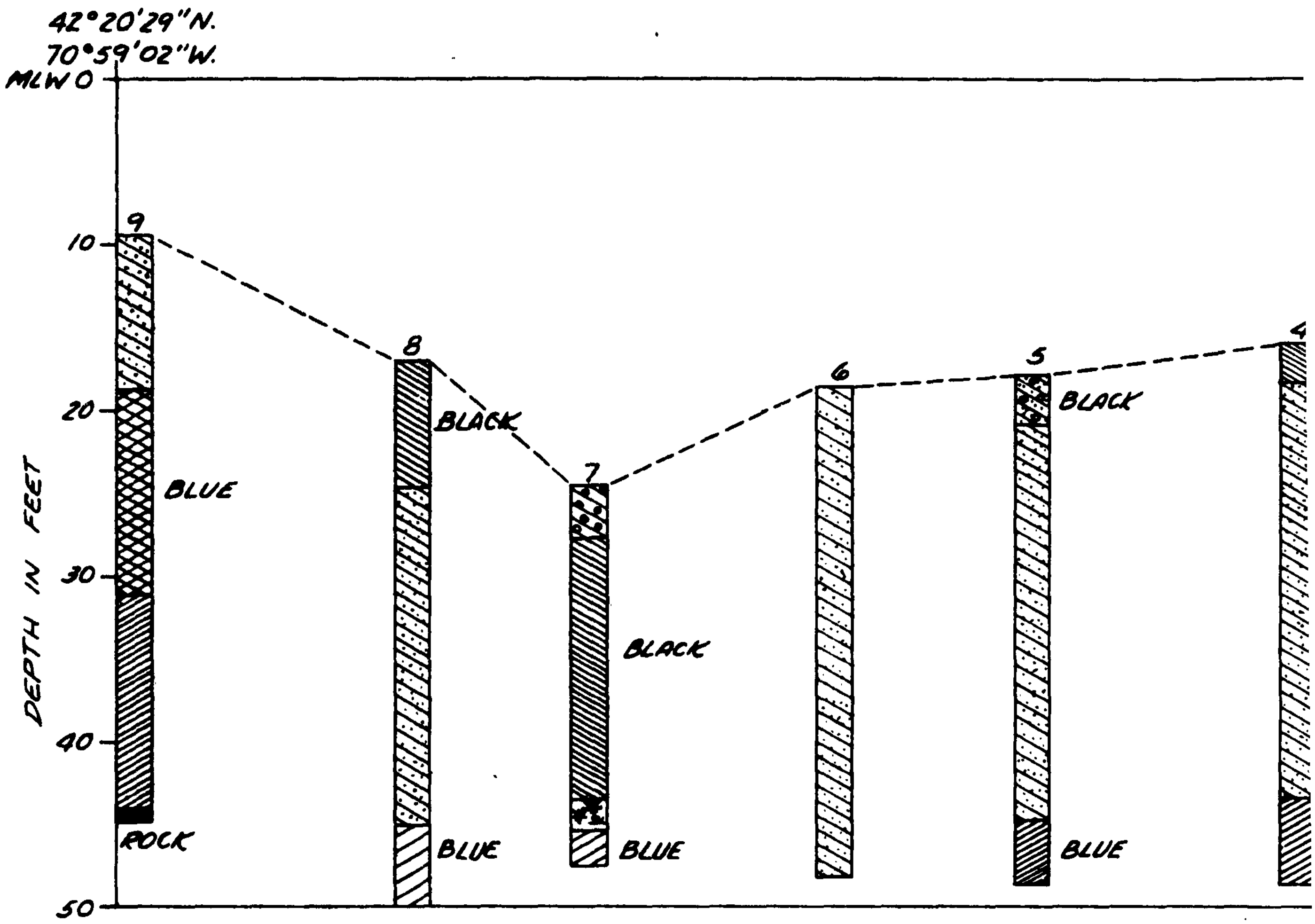


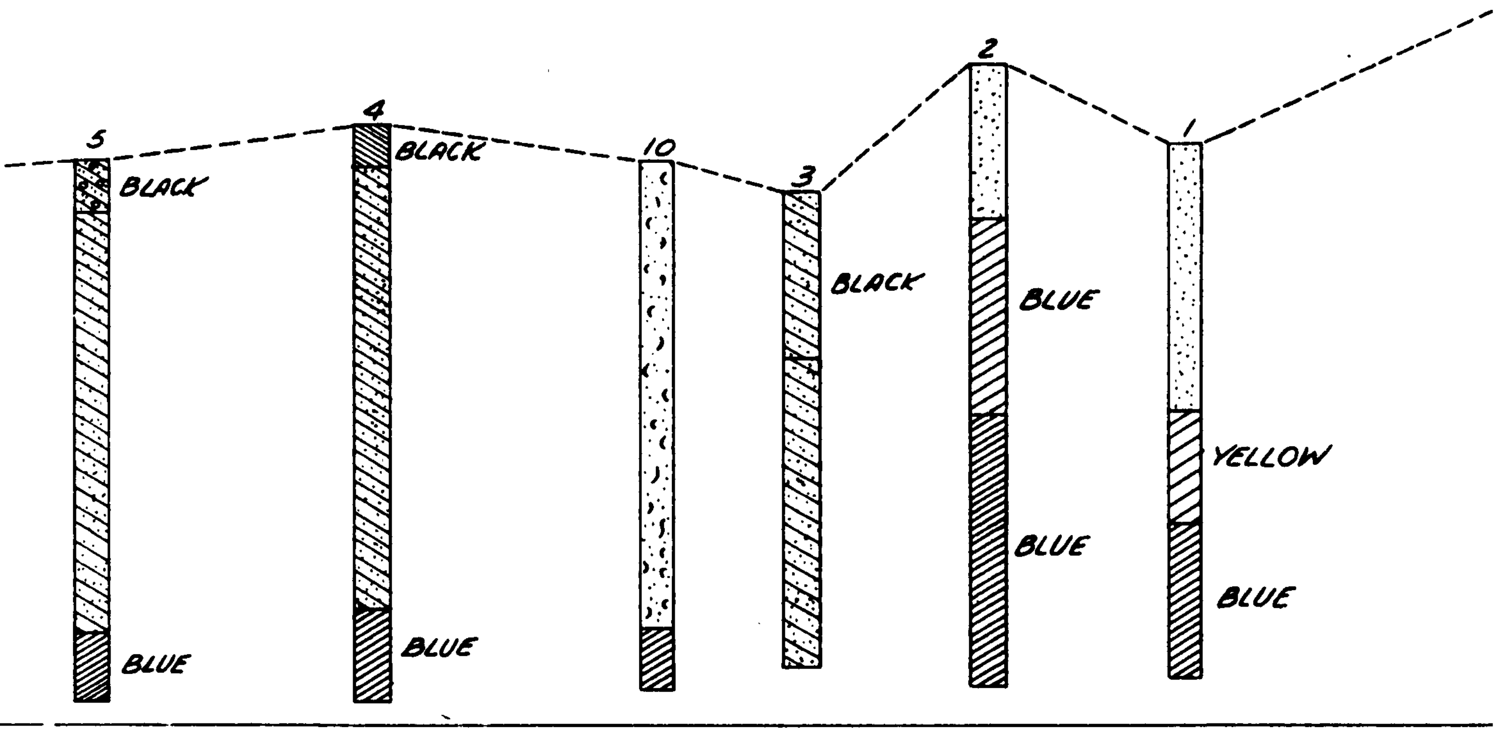
FIG. 7E

PROFILE NORTH OF PRESIDENT ROADS, BETWEEN THE GENERAL ANCHOR

DATA FROM : BOSTON HARBOR, MASS. PROBINGS, CORPS OF ENGINEER

BOSTON HARBOR, MASS. CORPS OF ENGINEERS FILE NBR.

42°20'40"N.
70°57'43"W.



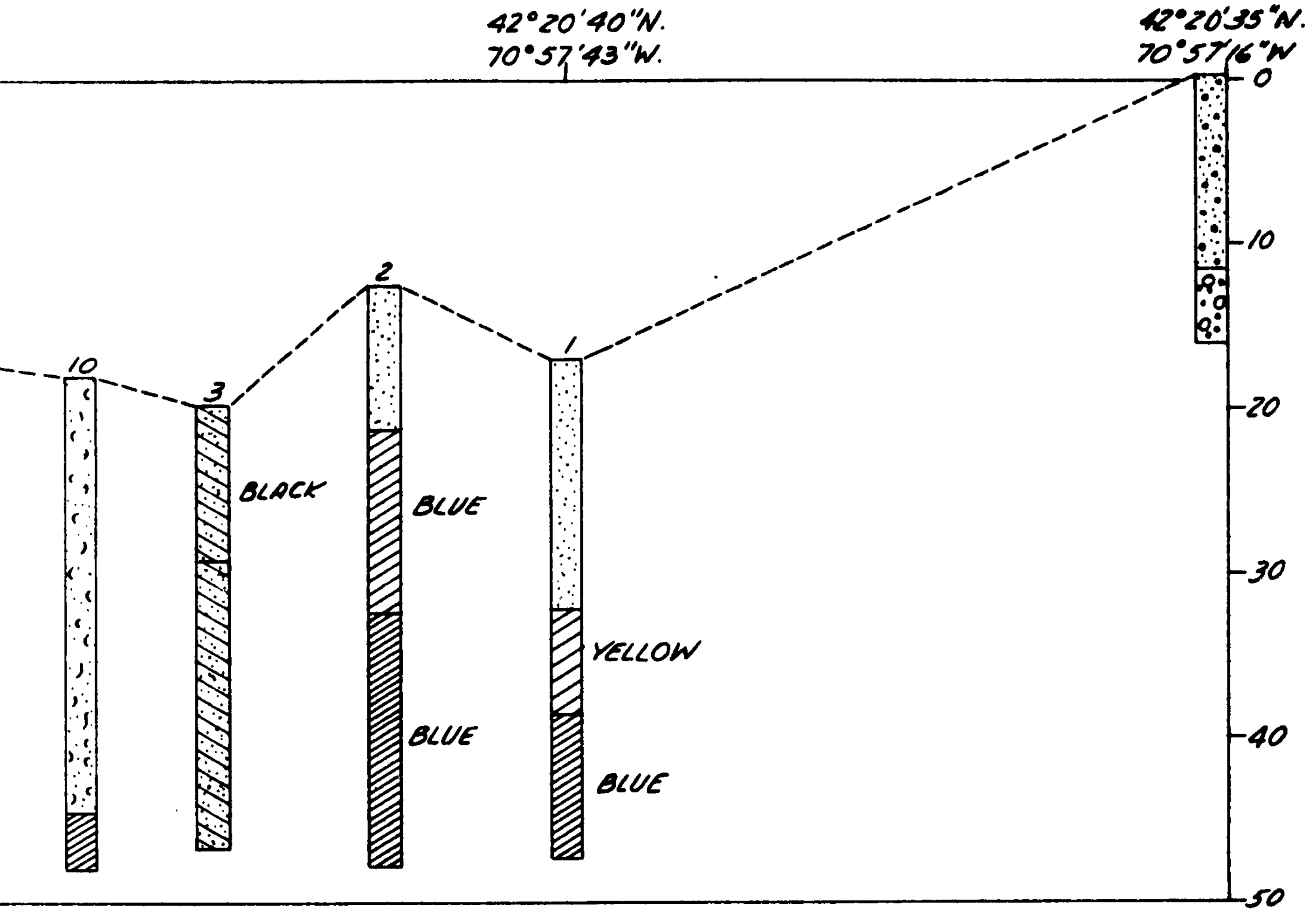
E

THE GENERAL ANCHORAGE AND DEER ISLAND FLATS.

, CORPS OF ENGINEERS FILE NBR. 1458 DR 2 1940 (MOST EASTERLY PROBING I

ENGINEERS FILE NBR. 1677 DR 1 1946 (BORINGS 1 TO 10)

2



DEER ISLAND FLATS.

NBR. 1458 DR 2 1940 (MOST EASTERLY PROBING IN SECTION)

1 1946 (BORINGS 1 TO 10)

3

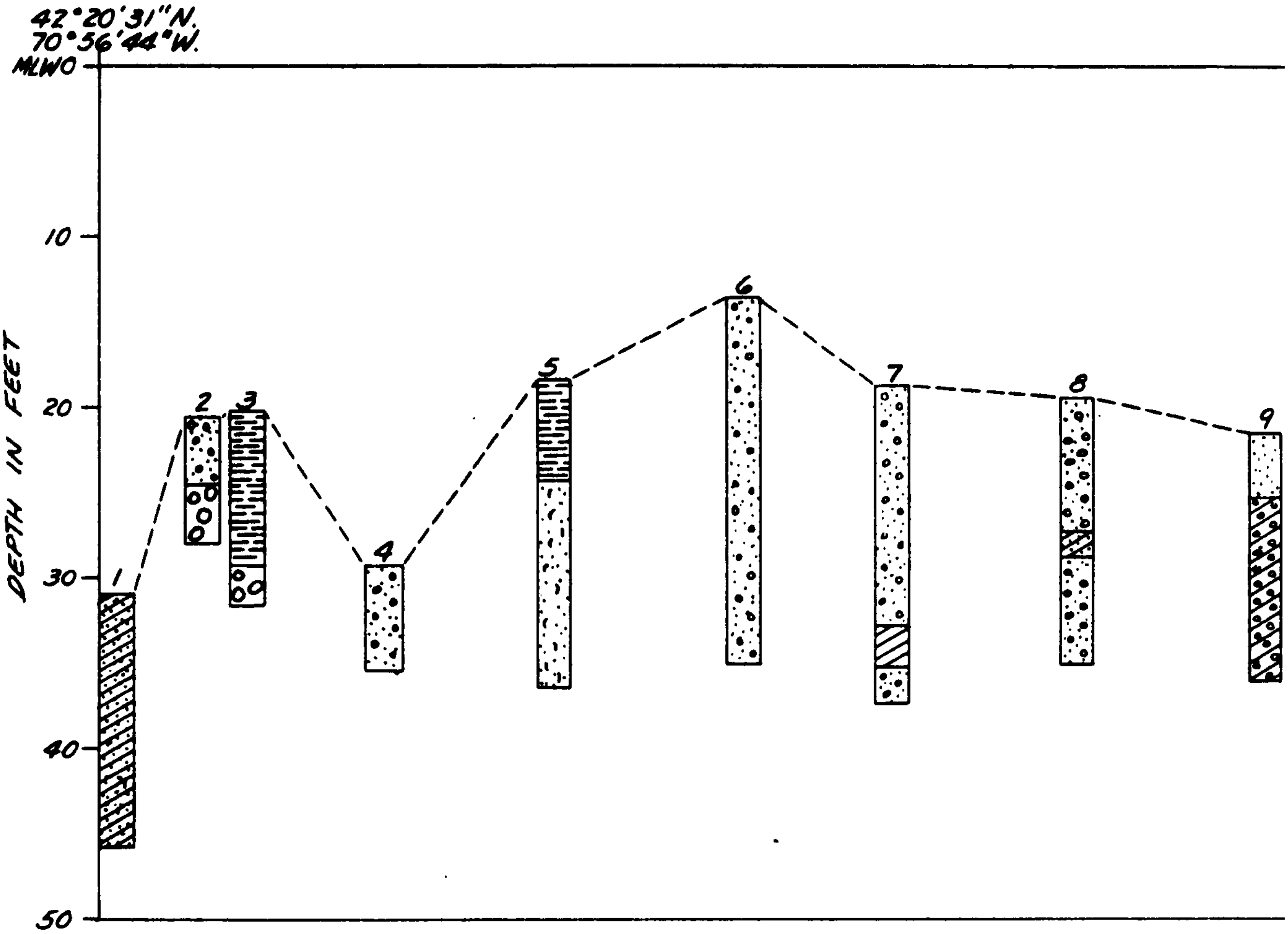
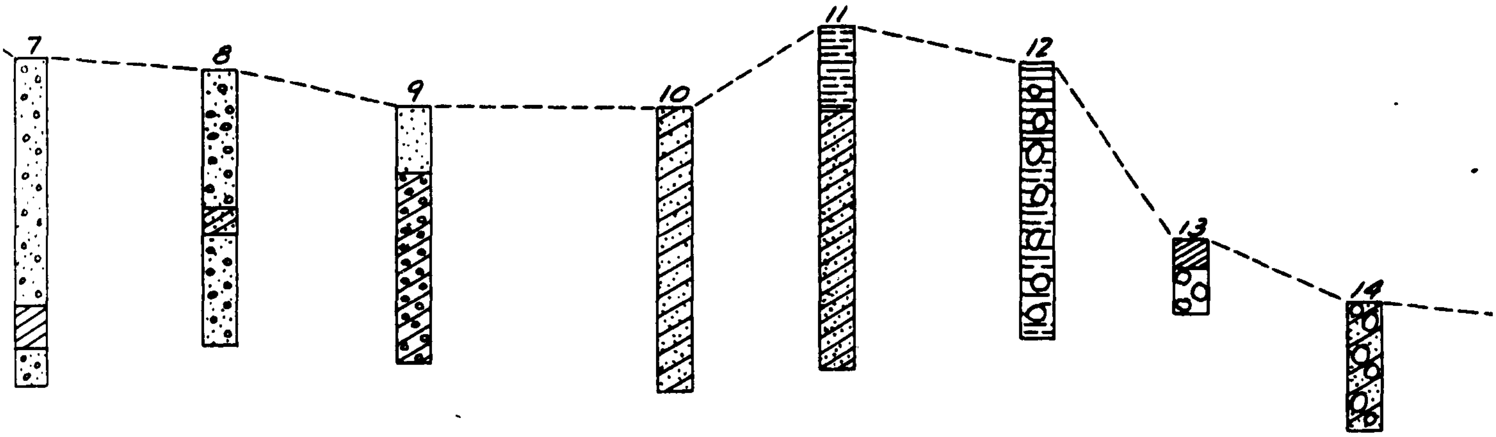


FIG. 7 F

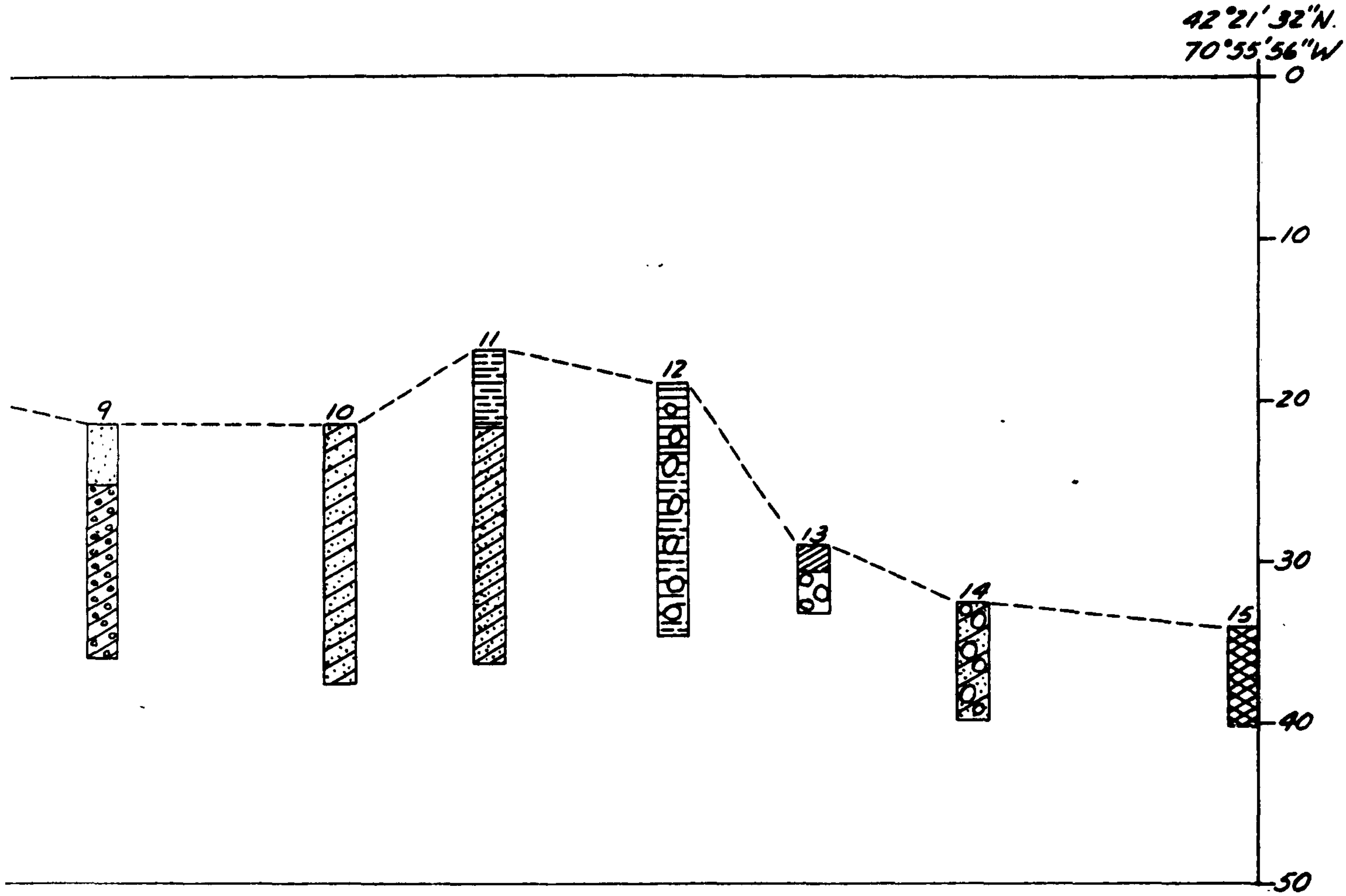
PROFILE ALONG WEST SIDE OF NORTH CHANNEL, EAST OF DEER
DATA FROM: BOSTON HARBOR, MASS. 35 FT. CHANNEL CHART NBR



NNEL, EAST OF DEER ISLAND

FT. CHANNEL CHART NBR. 75 U.S ENGINEER OFFICE, BOSTON, MASS. 1907

(3)



DEER ISLAND

ɿRT NBR. 75 U.S ENGINEER OFFICE, BOSTON, MASS. 1907

3

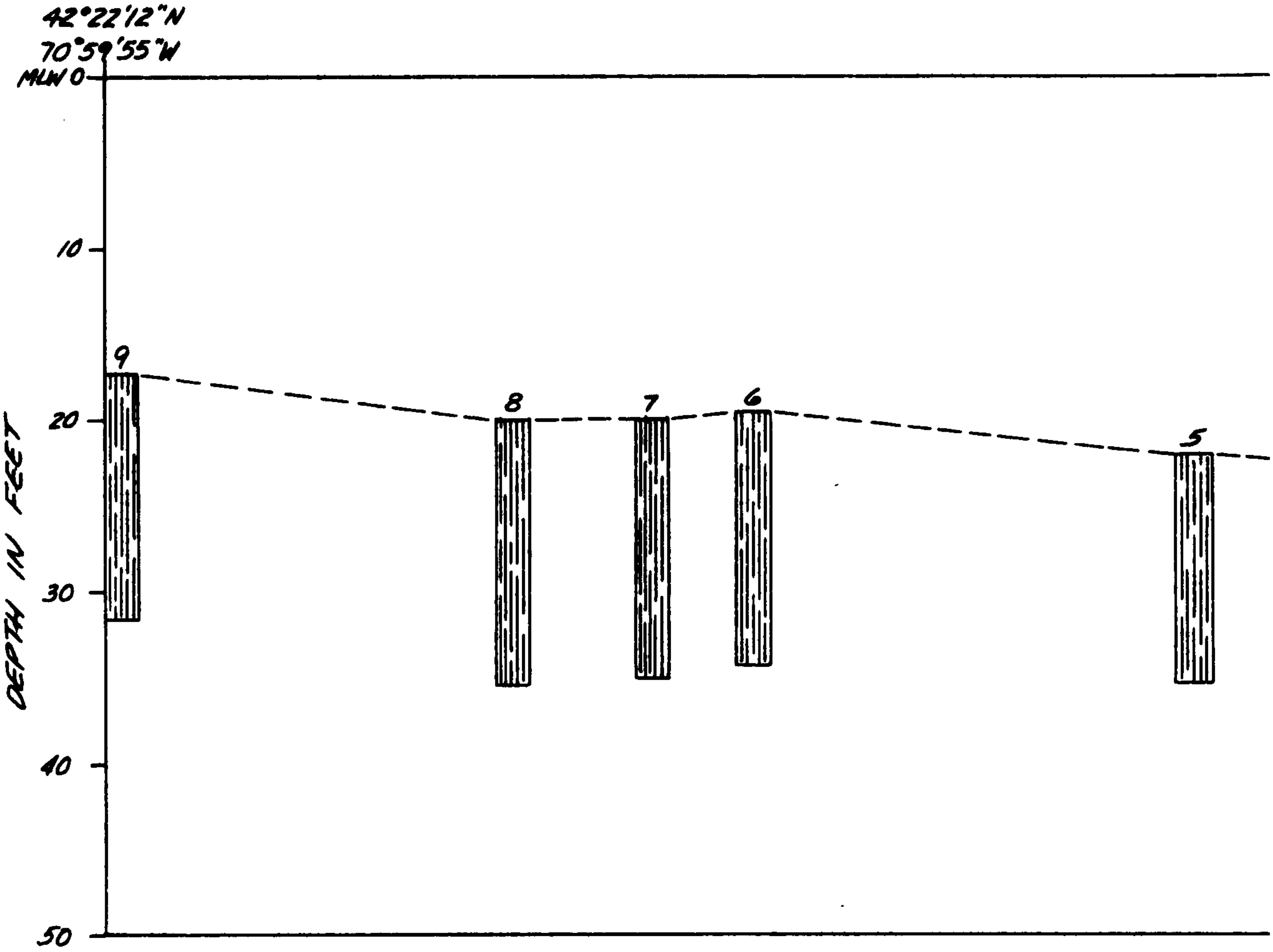
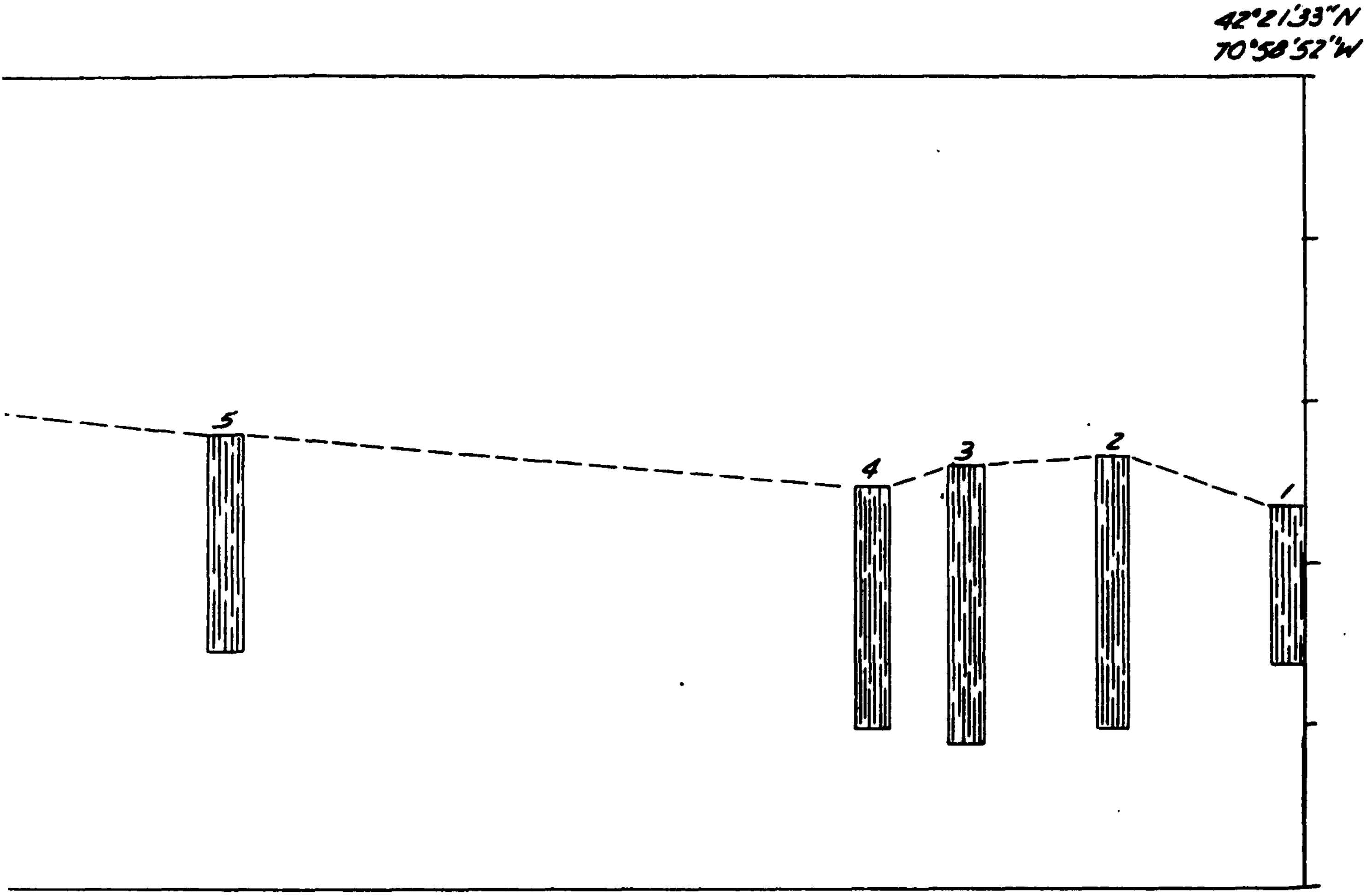


FIG. 7G

PROFILE NORTHEAST OF LOGAN AIRPORT FROM CHELSEA POINT T

DATA FROM: BOSTON HARBOR, MASS. INSIDE DISPOSAL AREA, CORP



. 7G

CHELSEA POINT TO POINT SHIRLEY

OSAL AREA, CORPS OF ENGINEERS FILE NBR. 1688 DRS, 1951

2

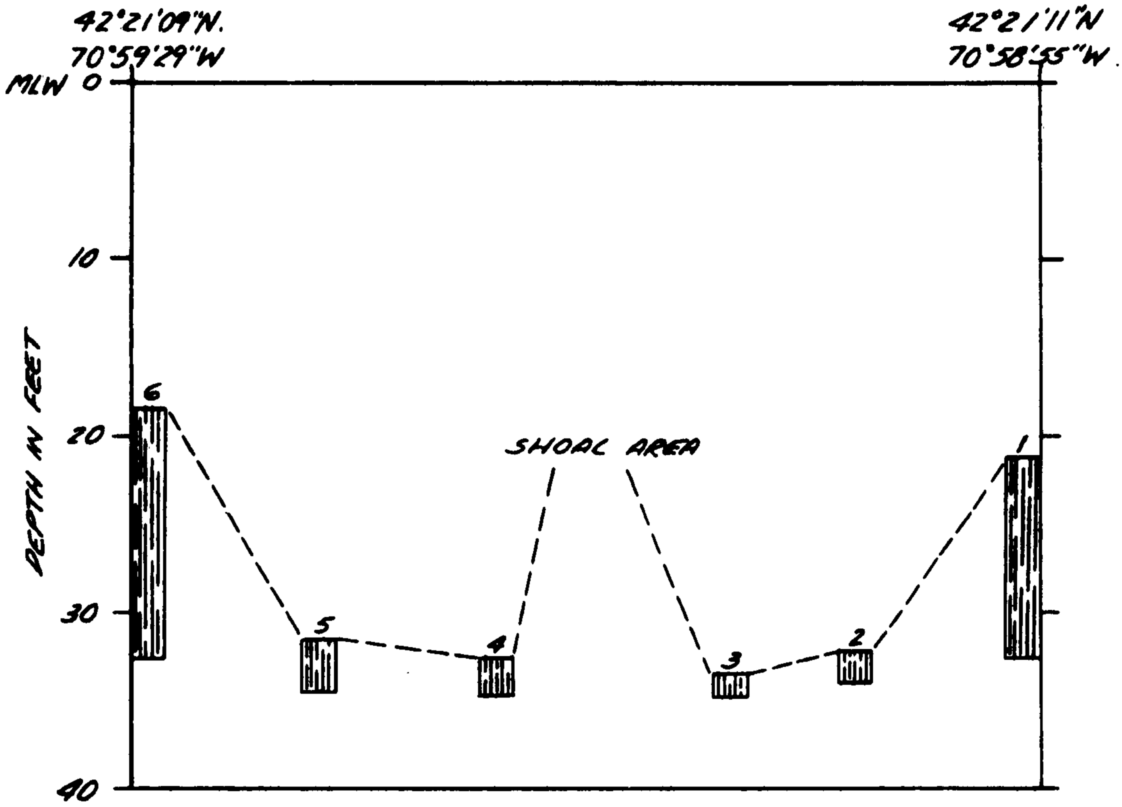


FIG. 7H

PROFILE EAST-WEST BETWEEN LOGAN AIRPORT AND DEER ISLAND FLATS.

DATA FROM: BOSTON HARBOR, MASS. EXAMINATION OF DISPOSAL AREAS, CORPS. OF ENGINEERS, FILE NBR. 1687 DRS, 1951

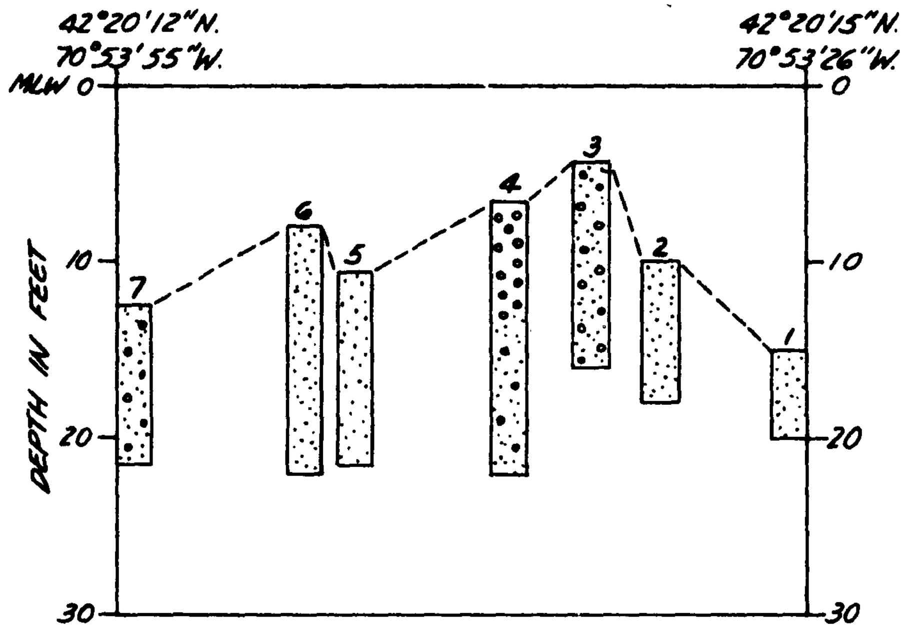


FIG. 7 J

PROFILE ALONG SHOAL AREA BETWEEN CALF, MIDDLE BREWSTER & GREAT BREWSTER ISLANDS.

DATA FROM : SURVEY BETWEEN CALF, MIDDLE BREWSTER & GREAT BREWSTER ISLANDS, CORPS OF ENGINEERS, FILE NBR.1581 DRS, 1943

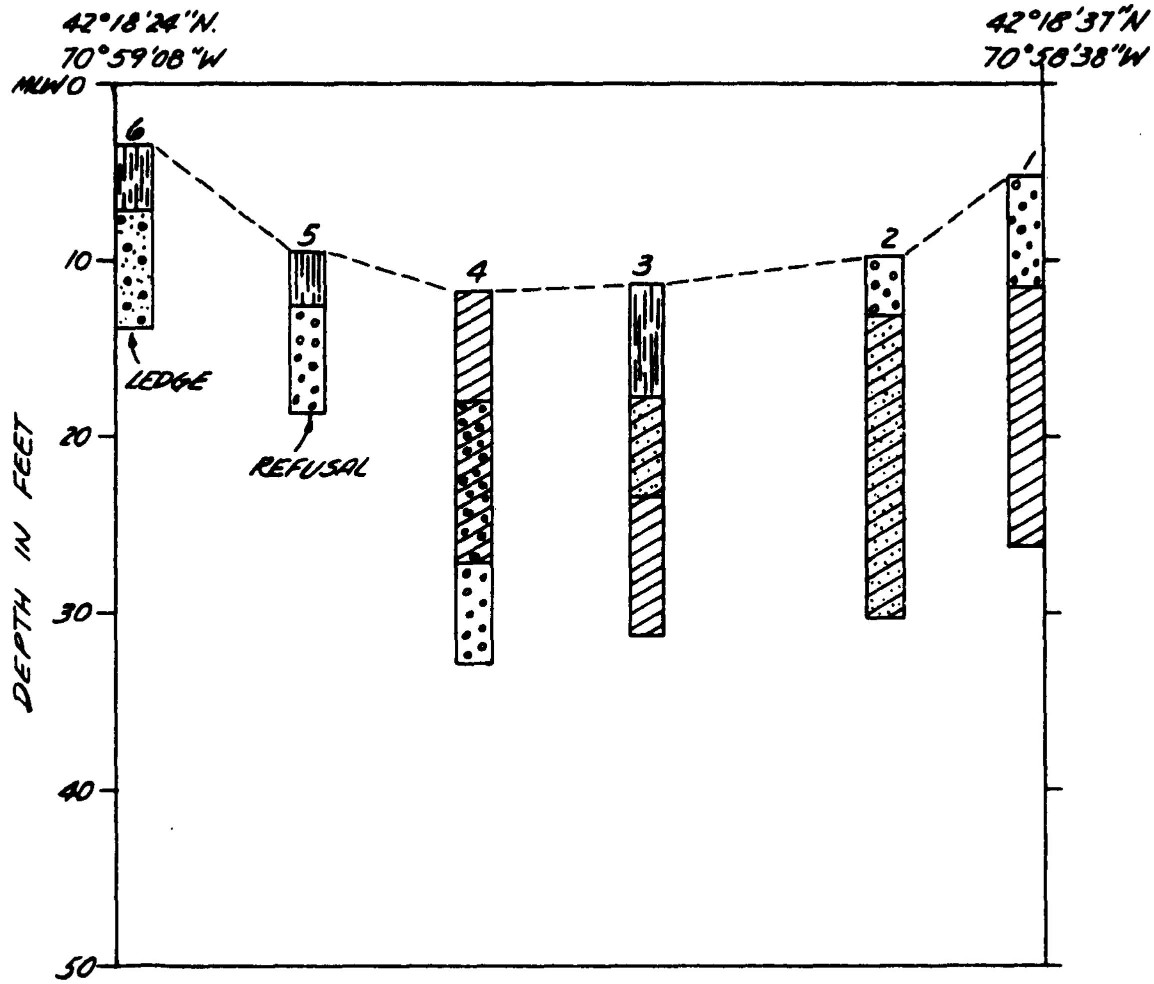


FIG. 7 K

PROFILE THROUGH THE PASS BETWEEN MOON HEAD & LONG ISLAND

DATA FROM : BOSTON HARBOR, MASS., PROBINGS, CORPS OF ENGINEERS, FILE NBR. 1458 DR 2, 1940

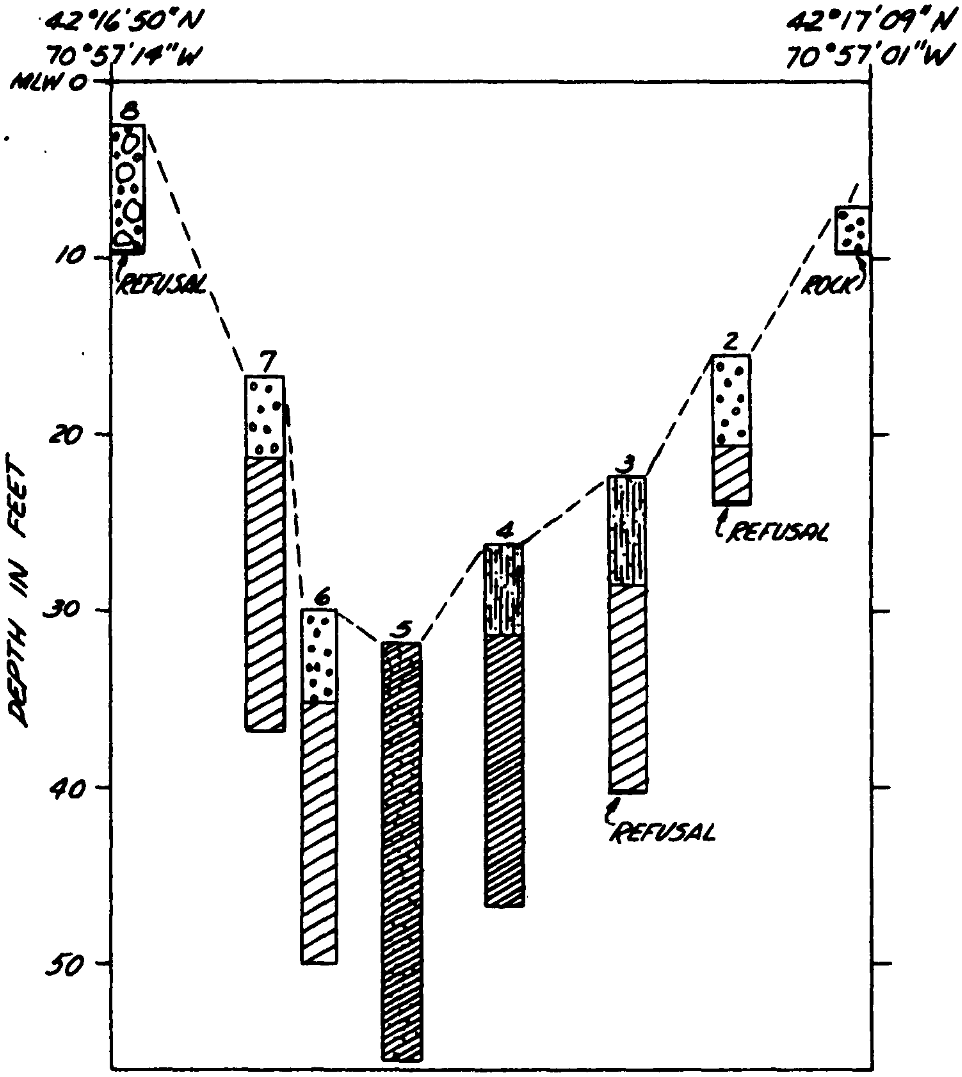


FIG. 7L

PROFILE THROUGH WEST GUT BETWEEN PEDDOCKS I. AND NUT I.

DATA FROM: BOSTON HARBOR MASS., PROBINGS, CORPS. OF ENGINEERS FILE NBR. 1458 DR 2, 1940

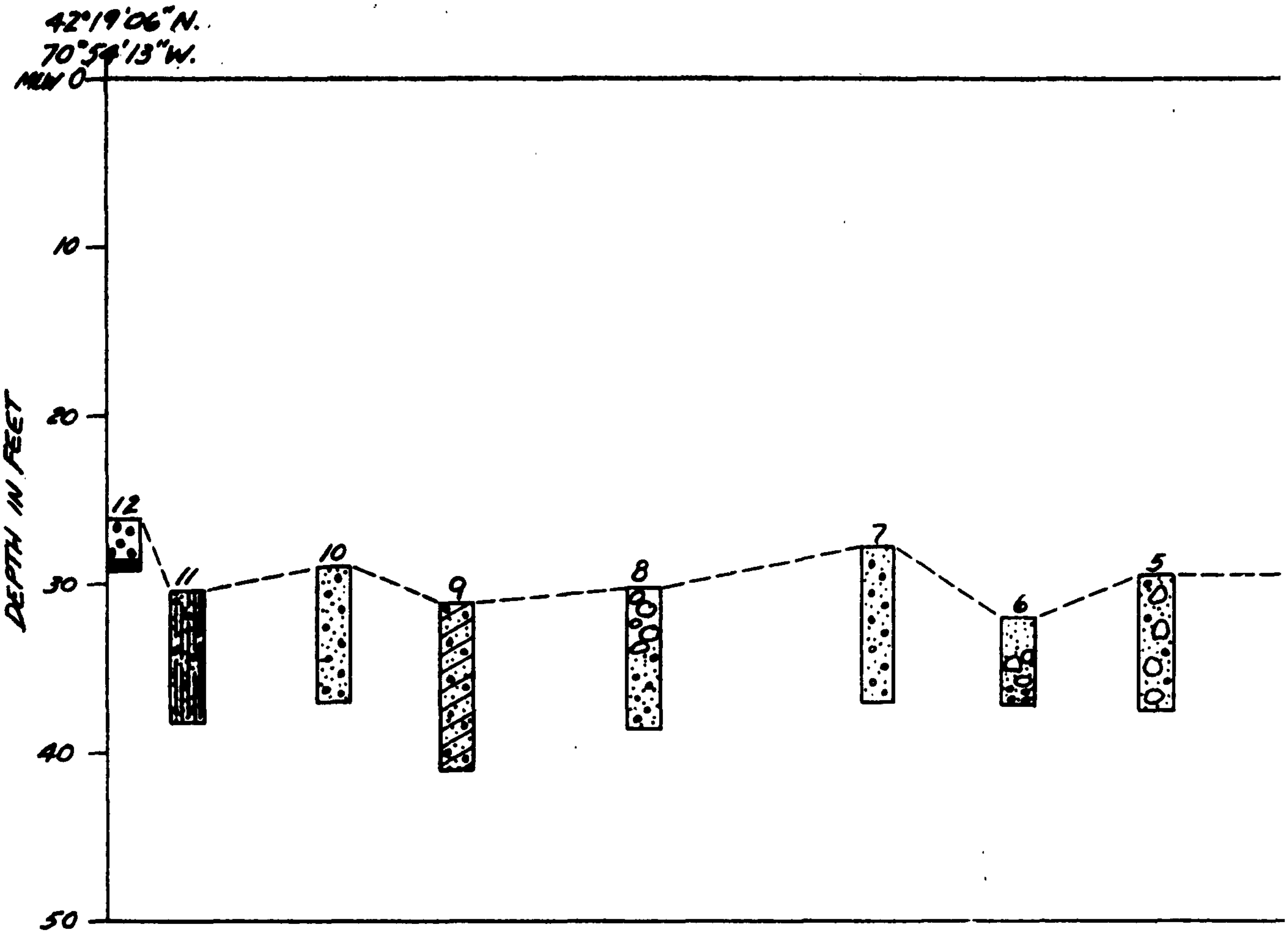
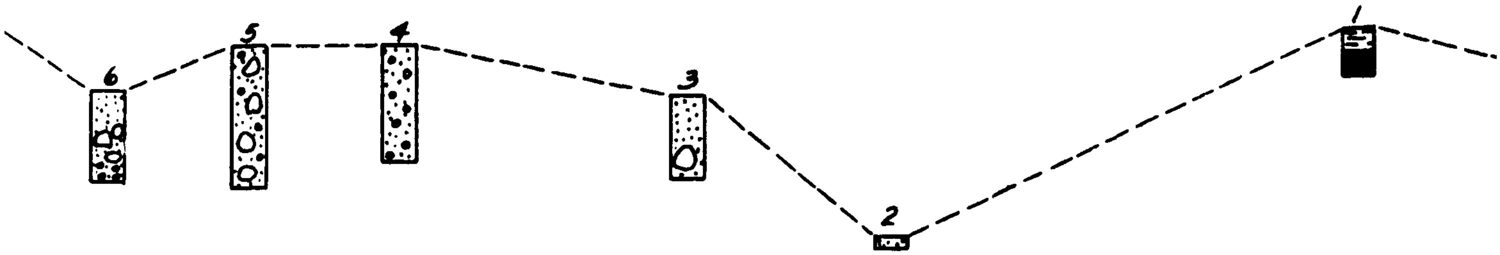


FIG. 7 M

PROFILE NORTH OF POINT ALLERTON FROM NANTASKET ROADS TOWA
DATA FROM : WEYMOUTH FORE RIVER, MASS. DETAIL PLAN, CORPS O
BOUNDARIES BETWEEN SEDIMENT TYPES NOT DETERMINED



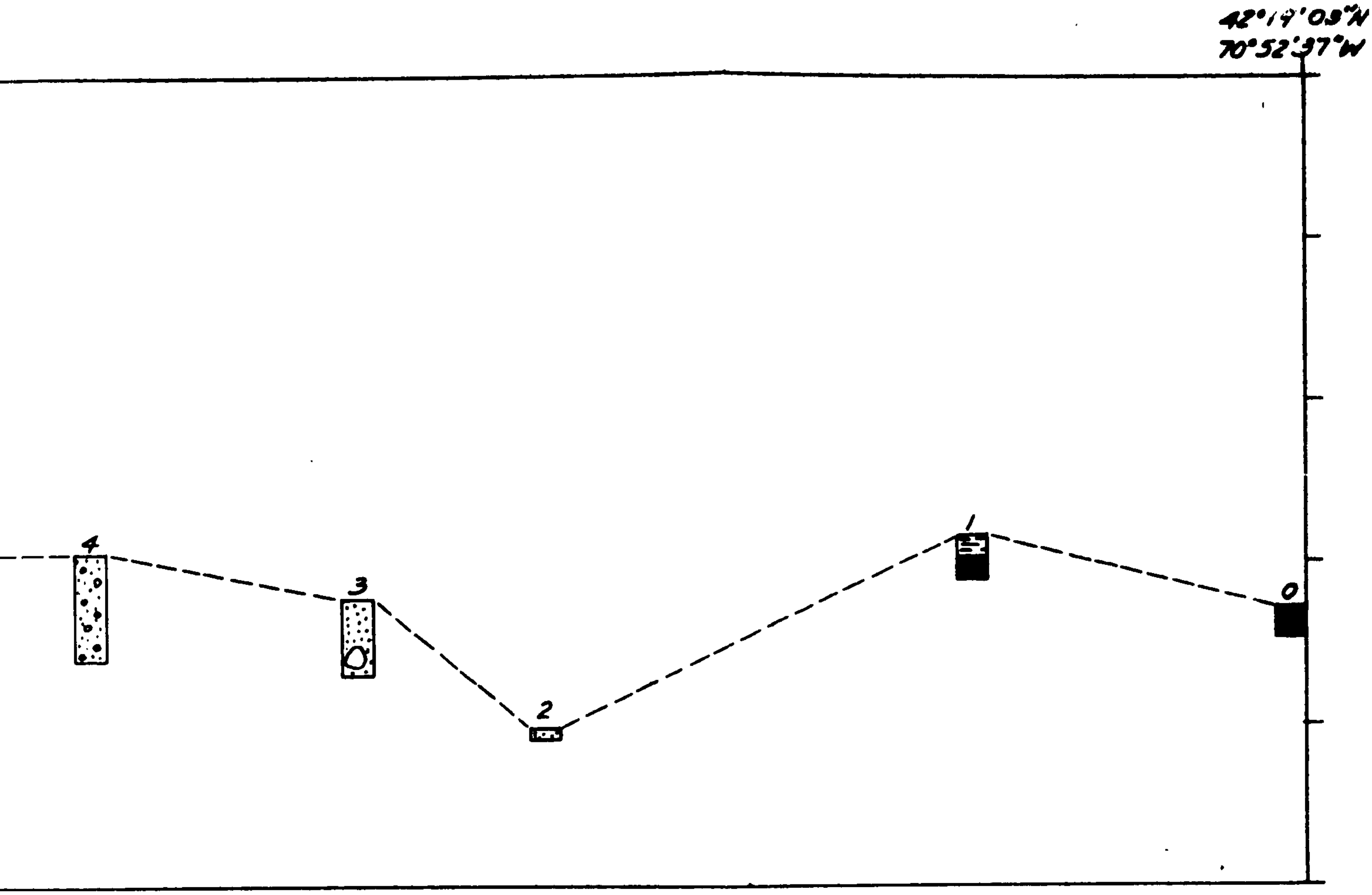
A

'NTASKET ROADS TOWARD ULTONIA LEDGE

'ETAIL PLAN, CORPS OF ENGINEERS, FILE NBR. 314 DR 23, 1949

ERMINED

2



TOWARD ULTONIA LEDGE

PS. OF ENGINEERS, FILE NBR. 314 DR 23, 1949

3

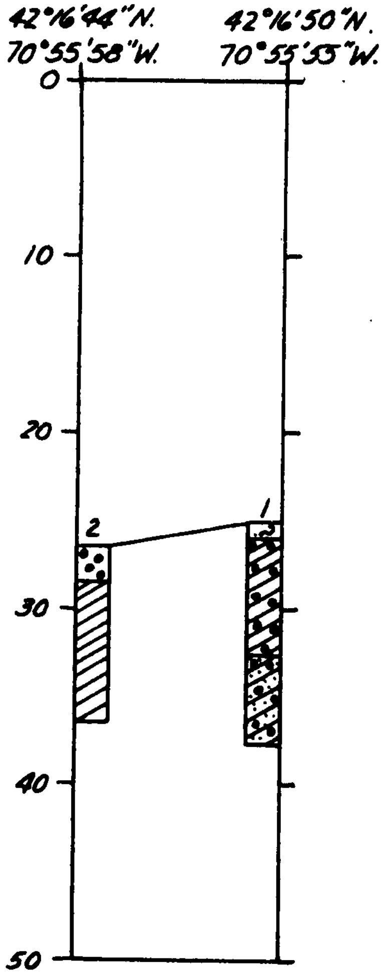


FIG. 7P

PROFILE OF WEYMOUTH FORE RIVER CHANNEL BETWEEN PIG ROCK AND SHEEP ISLAND

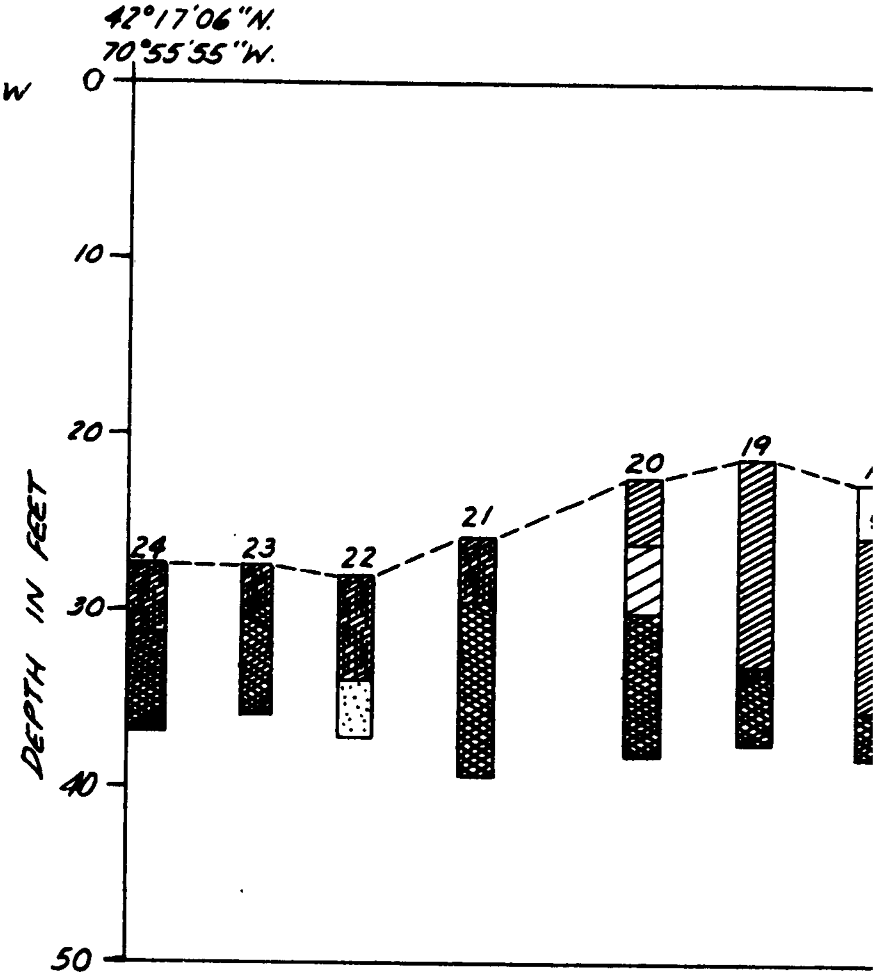


FIG. 7

PROFILE THROUGH NANTASKET GUT BETWEEN
DEPTHS OF BOUNDARIES BETWEEN DIFFERE

DATA FROM :- WEYMOUTH FORE RIVER, MASS. DETAIL PLAN, CORPS. OF ENGINEER

1

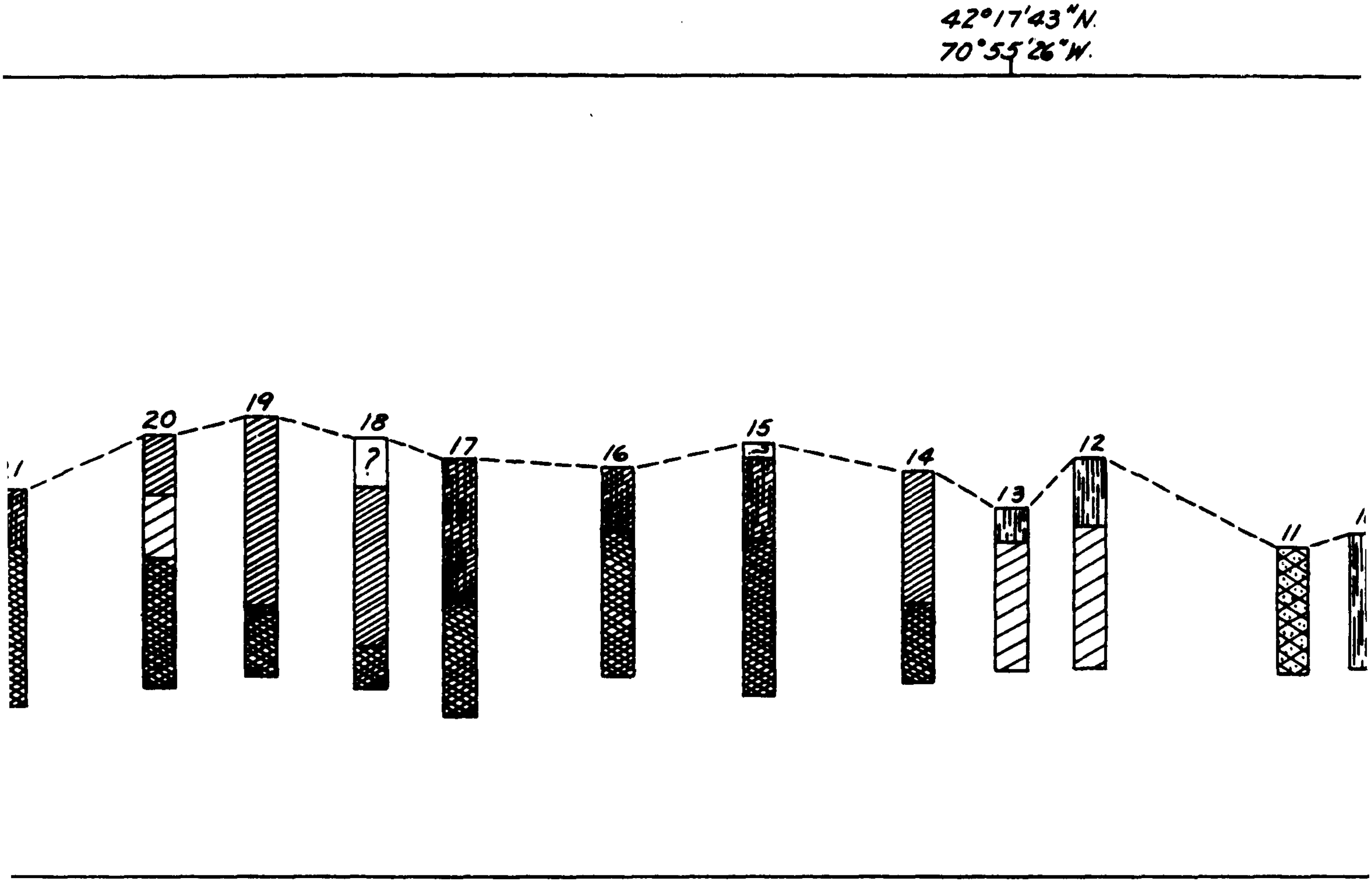


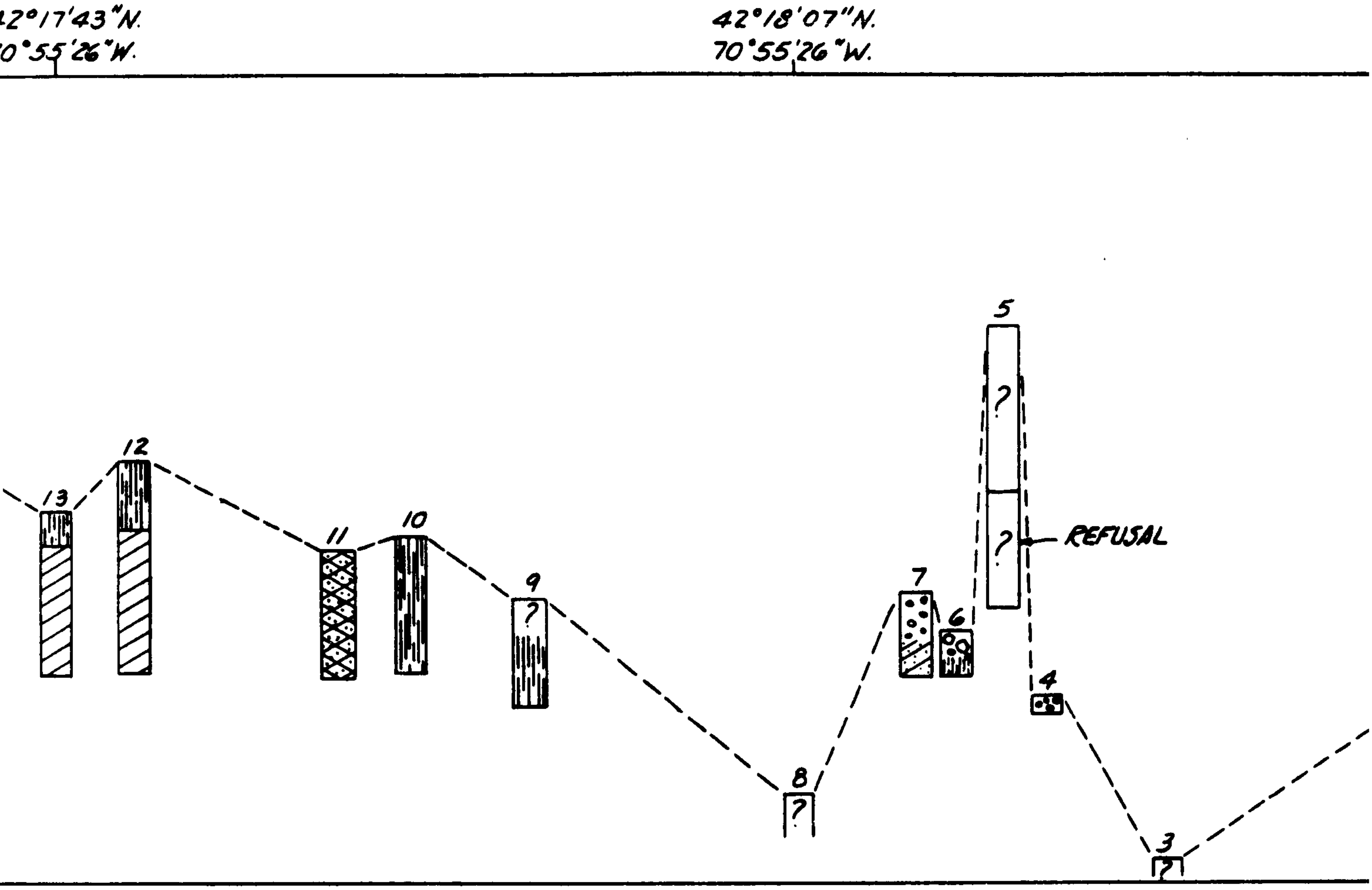
FIG. 7 N

VTASKET GUT BETWEEN HINGHAM BAY & NANTASKET ROADS

'IES BETWEEN DIFFERENT SEDIMENT TYPES NOT DETERMINED IN PROBINGS 1 TO 11

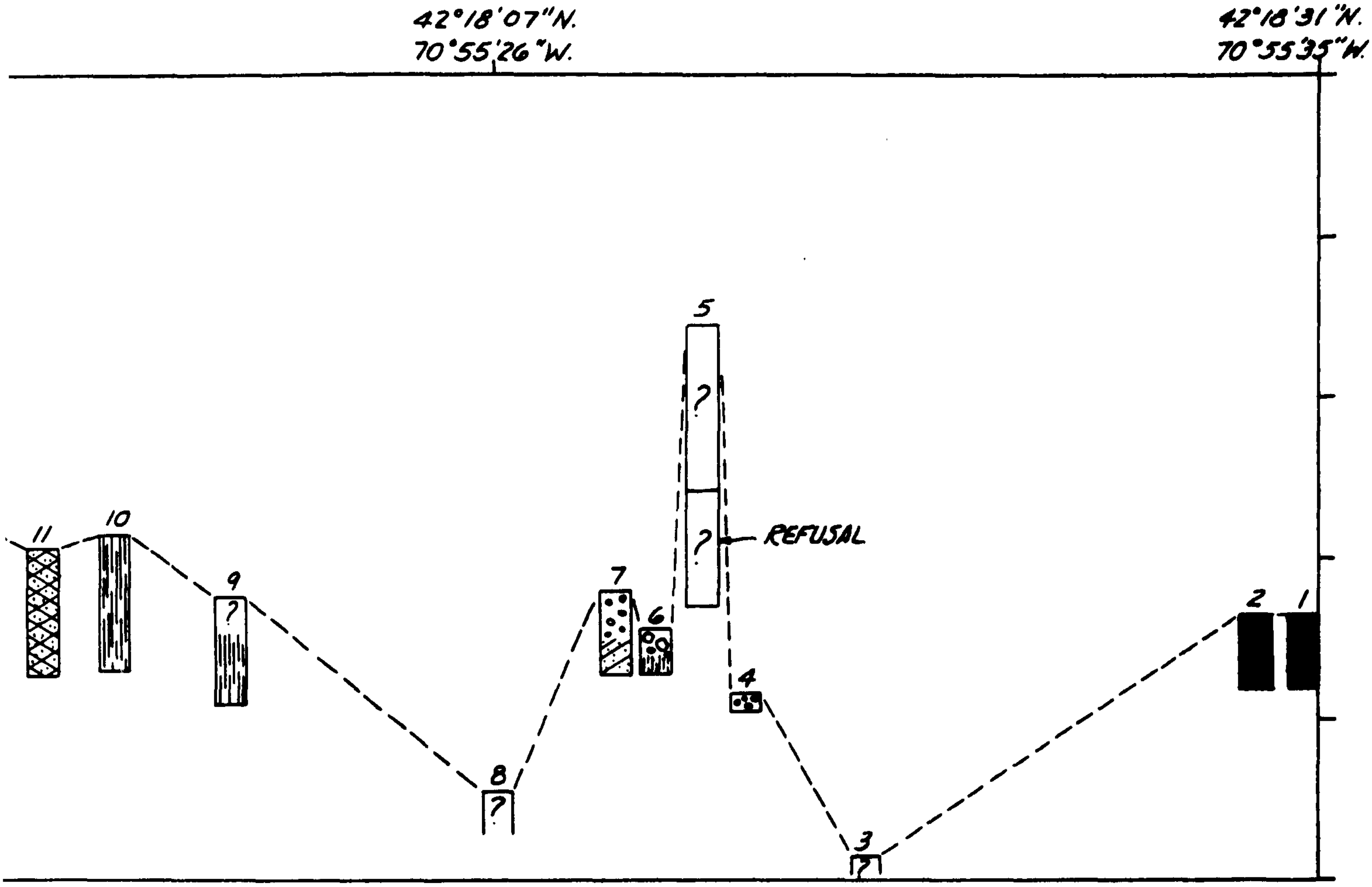
'LAN, CORPS. OF ENGINEERS, FILE NBR. 314 DR 23, 1949

2



IN PROBINGS 1 TO 11

3


42°18'07"N.
70°55'26"W.
42°18'31"N.
70°55'35"W.
11
10
9
8
7
6
5
4
3
2
1
REFUSAL

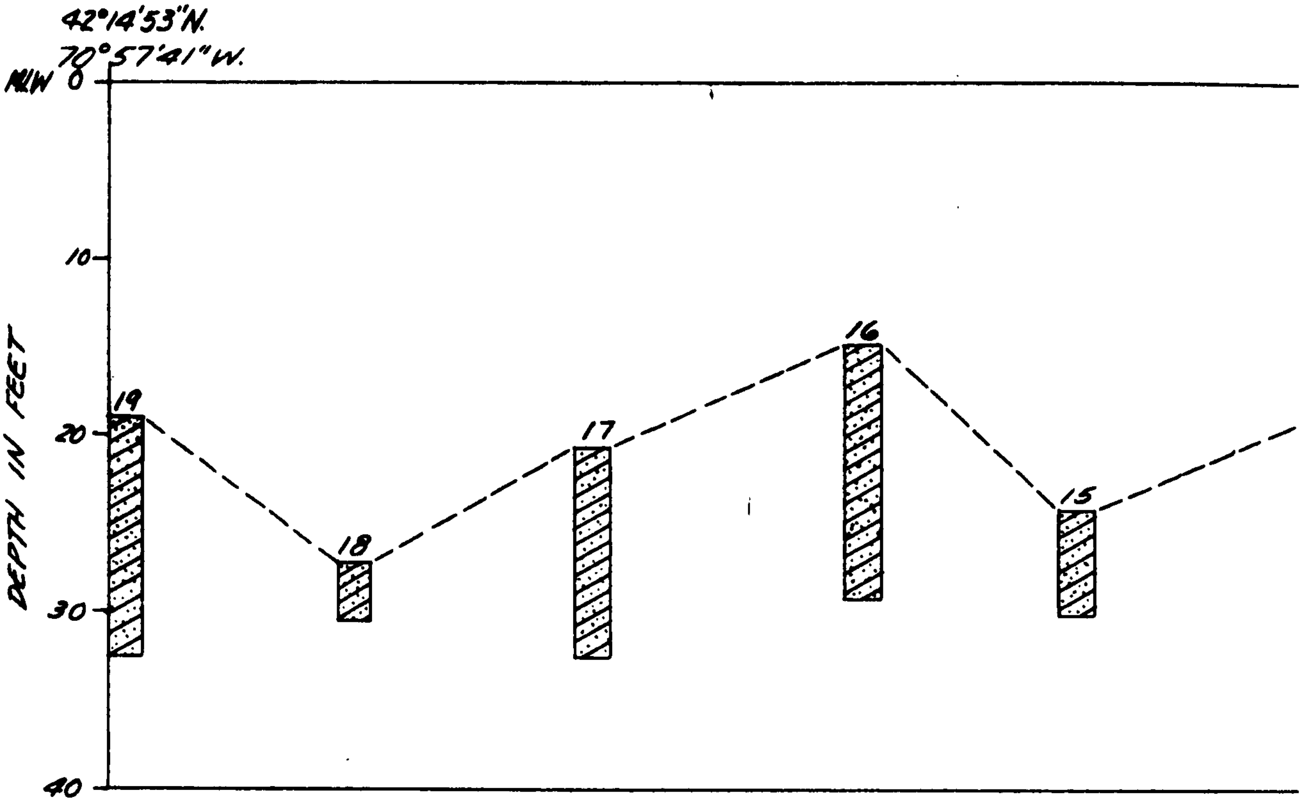
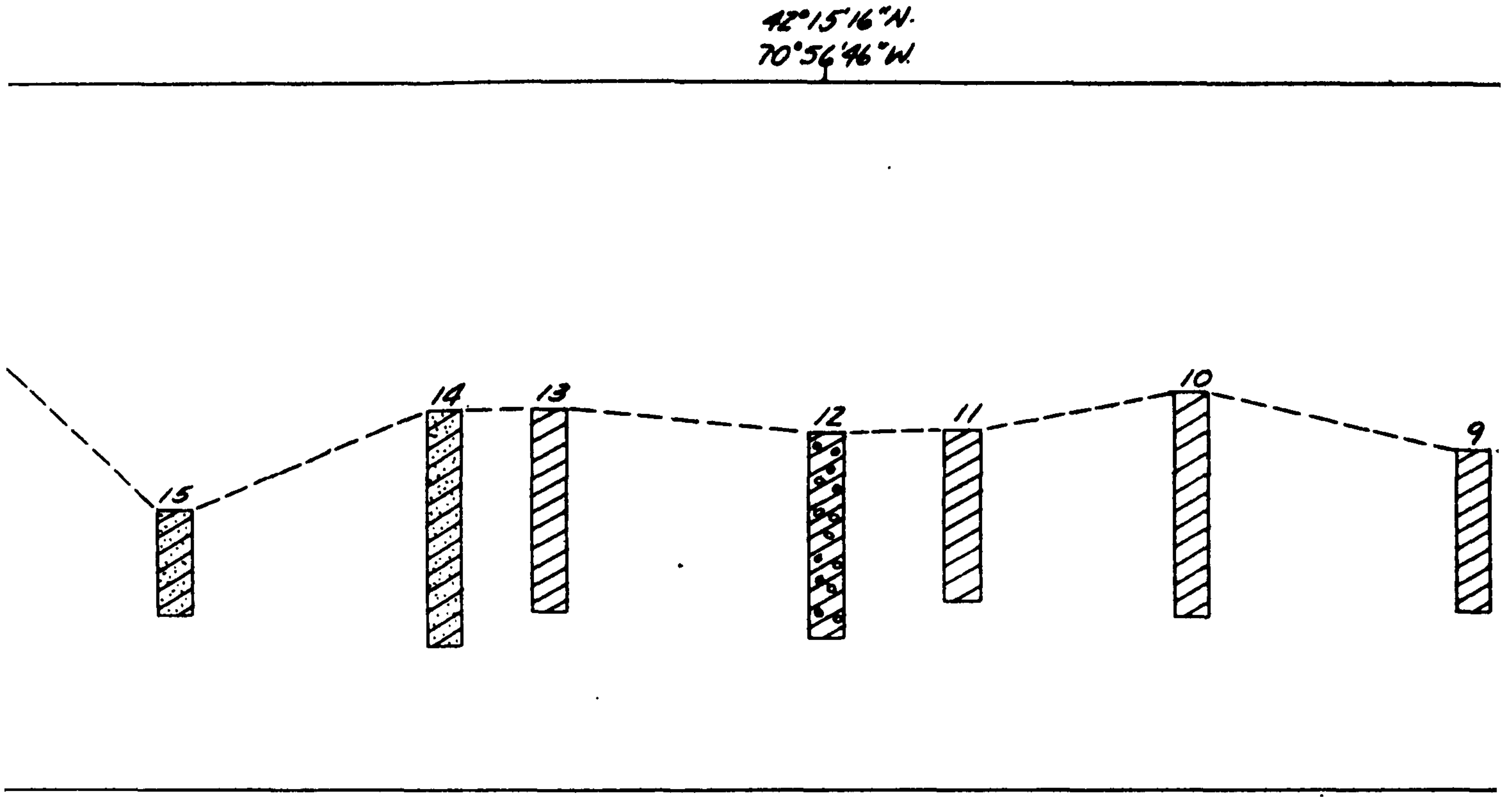


FIG. 7 R

PROFILE ALONG NORTHWEST SIDE OF FORE RIVER CHANNEL, G
DATA FROM: FORE RIVER, MASS. DETAIL PLAN, CORPS. OF ENGINEERS

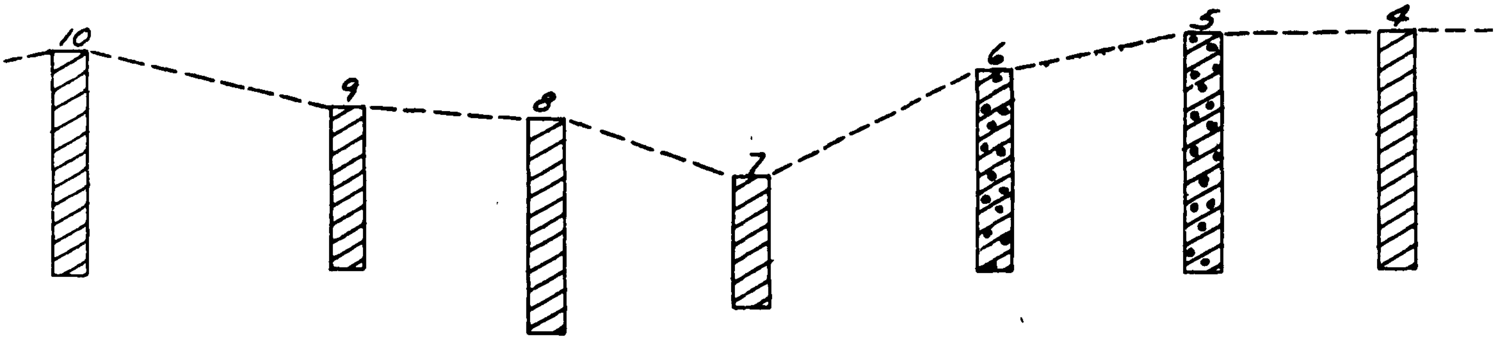


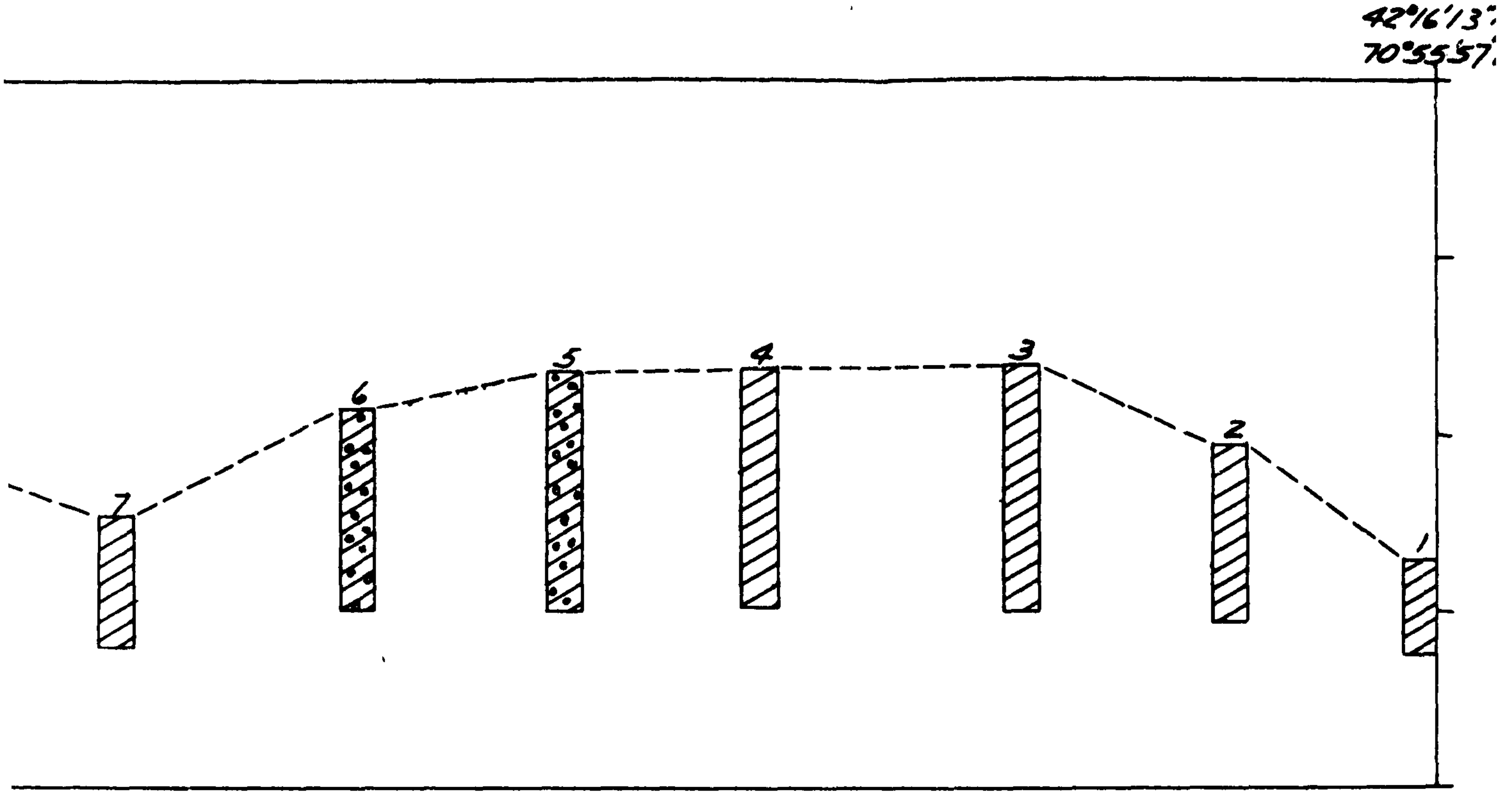
R

RIVER CHANNEL, GERMANTOWN POINT TO GRAPE ISLAND.

, CORPS. OF ENGINEERS FILE NBR 314 DR.23 1949

2


10
9
8
7
6
5
4



4

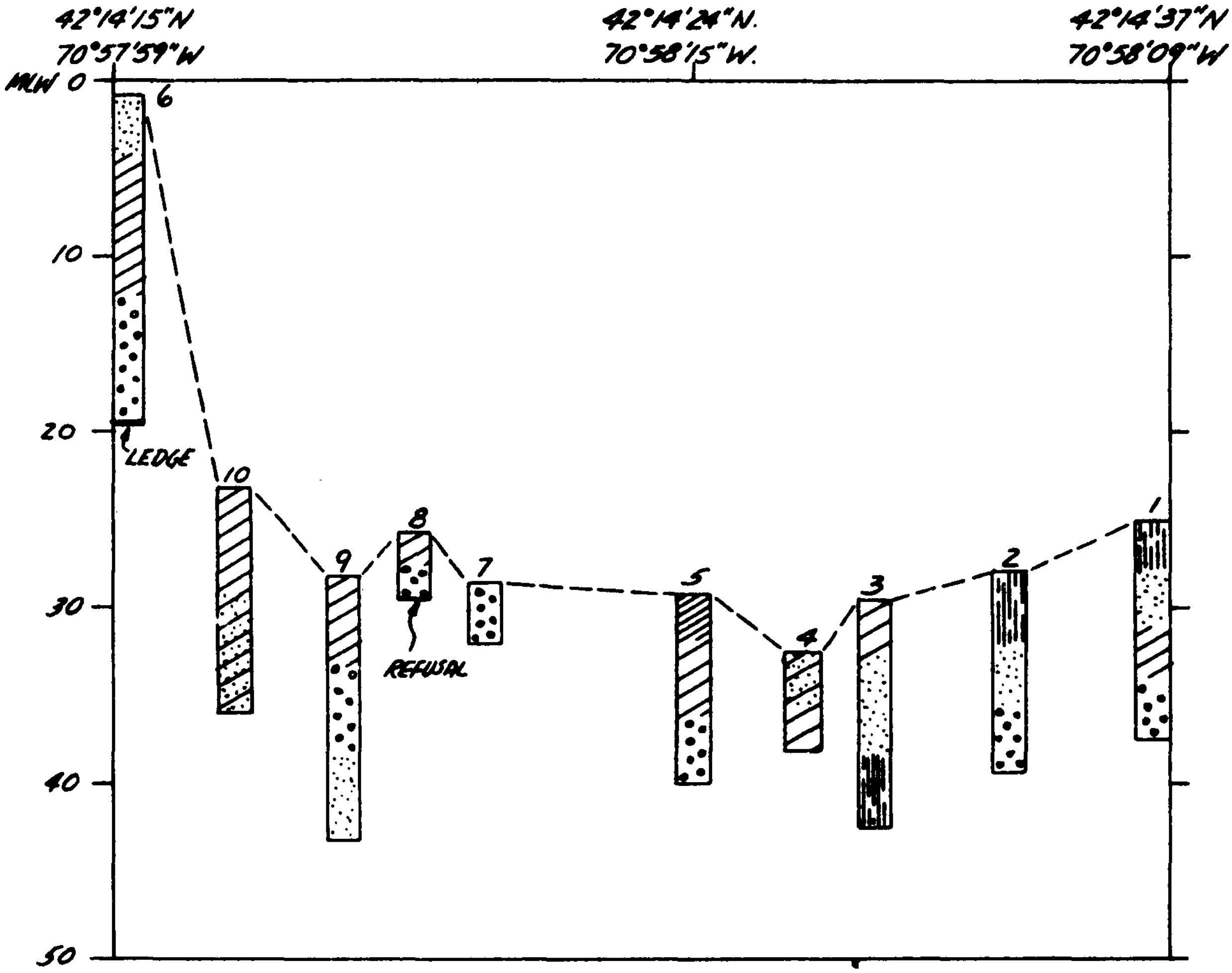


FIG. 7S

PROFILE OF WEYMOUTH FORE RIVER BETWEEN FORE RIVER BRIDGE AND THE HEAD OF THE NAVIGABLE PART OF FORE RIVER

DATA FROM: WEYMOUTH FORE RIVER, MASS., DETAIL PLAN, CORPS OF ENGINEERS FILE NBR. 314 OR 23, 1949

DEPTHS OF BOUNDARIES BETWEEN SEDIMENT TYPES NOT DETERMINED

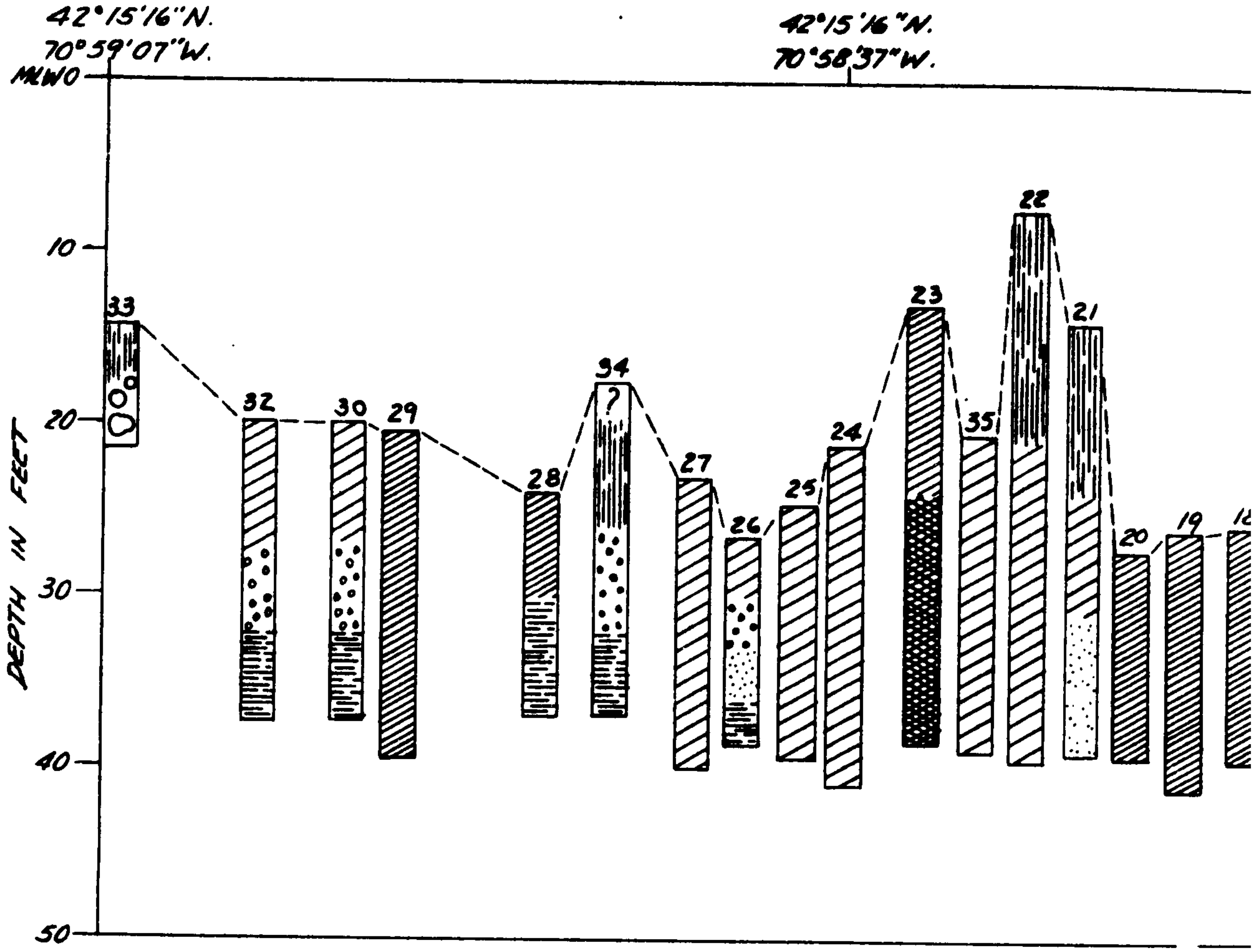


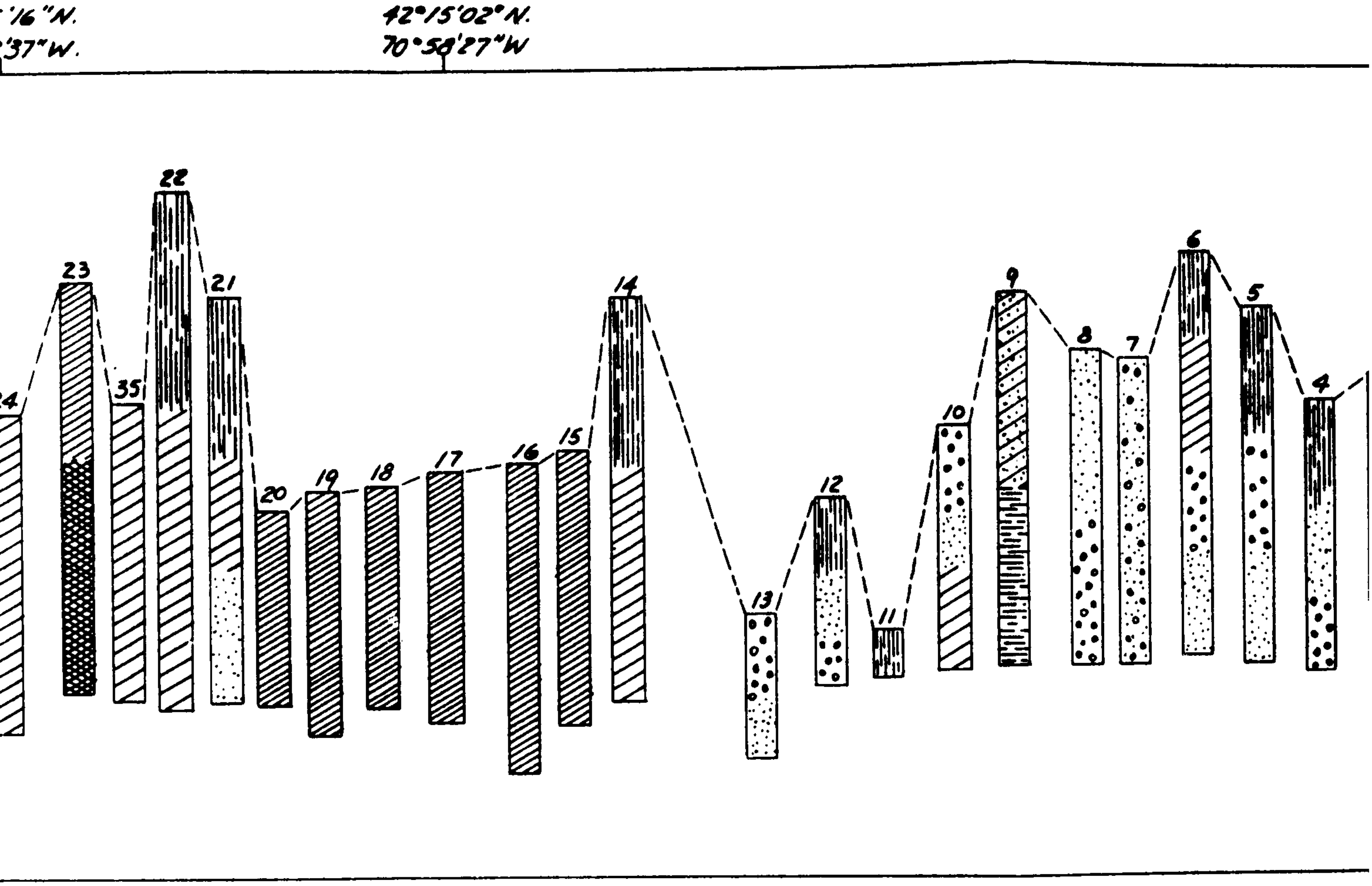
FIG. 7T

PROFILE OF QUINCY TOWN RIVER CHANNEL FROM BROAD MEADOWS TO

DATA FROM : TOWN RIVER QUINCY, MASS. CORPS. OF ENGINEERS FILE NBR.

DEPTH OF BOUNDARIES BETWEEN SEDIMENT TYPES NOT DETERMINED

R



7T

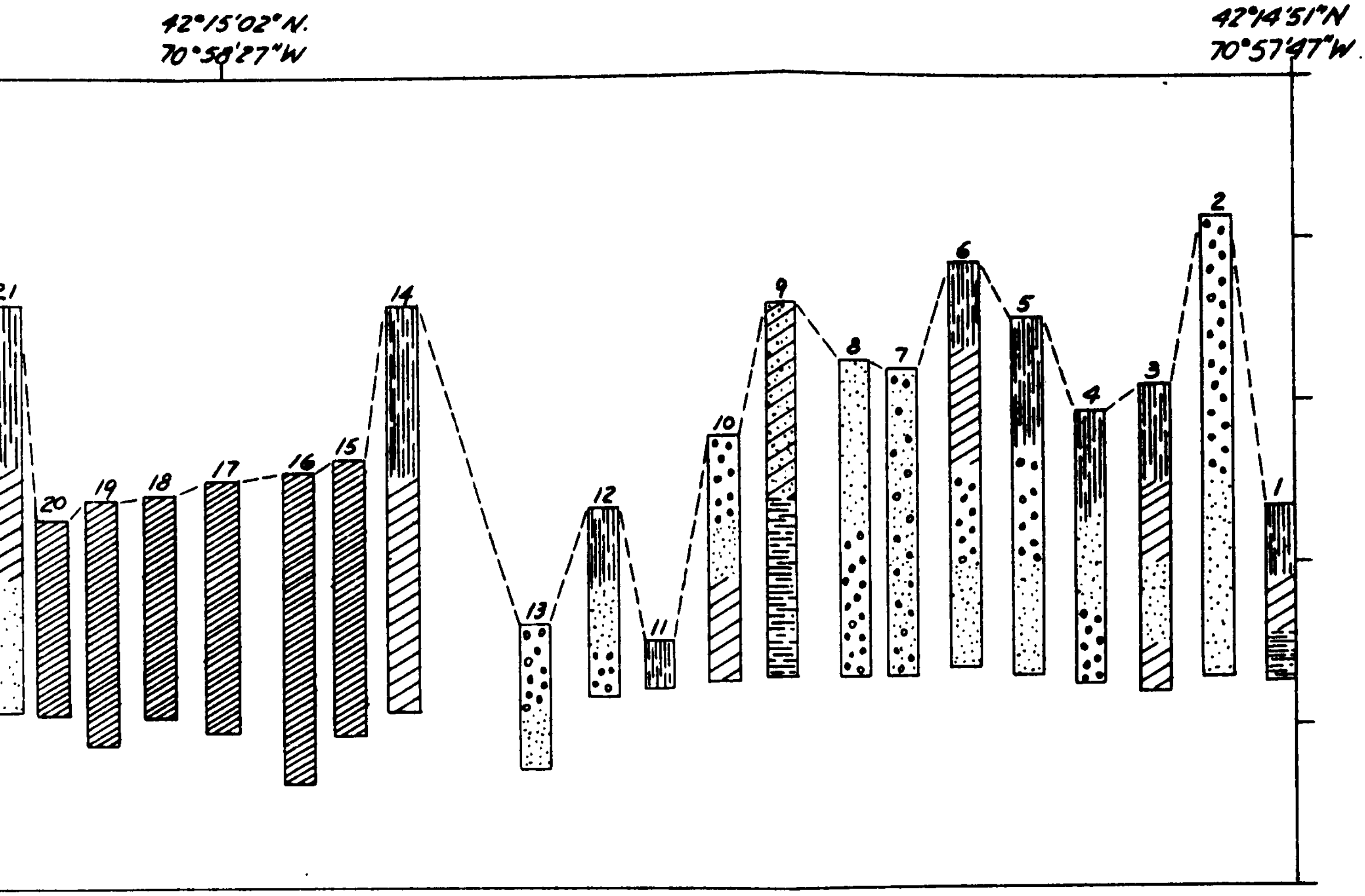
ROM BROAD MEADOWS TO GERMANTOWN POINT

. OF ENGINEERS FILE NBR. 188 DR 18, 1950

YPES NOT DETERMINED

2

R-



EADOWS TO GERMANTOWN POINT

S FILE NBR. 188 DR 18, 1950

TERMINED

3

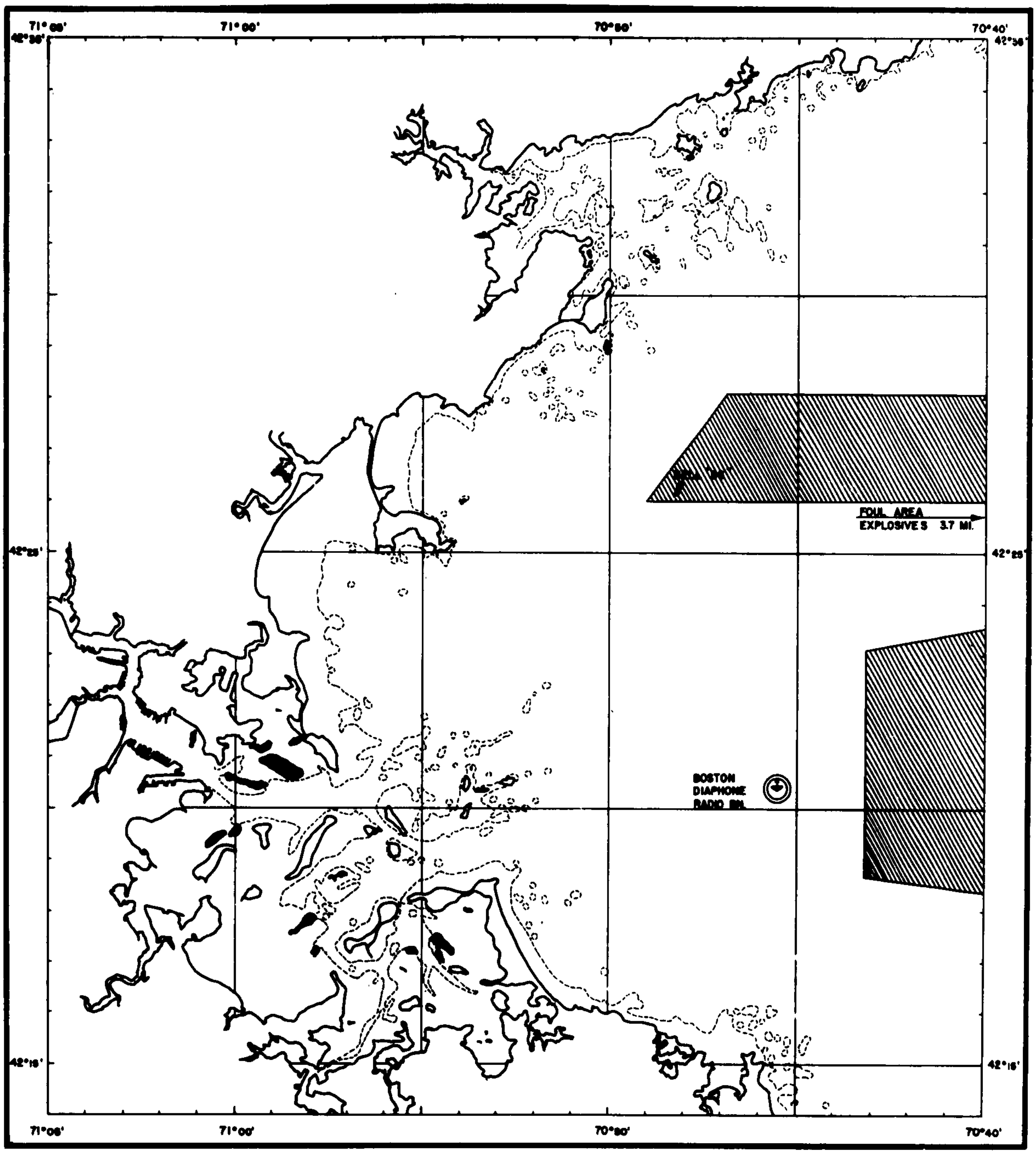


Fig. 8 Locations of dumping grounds.

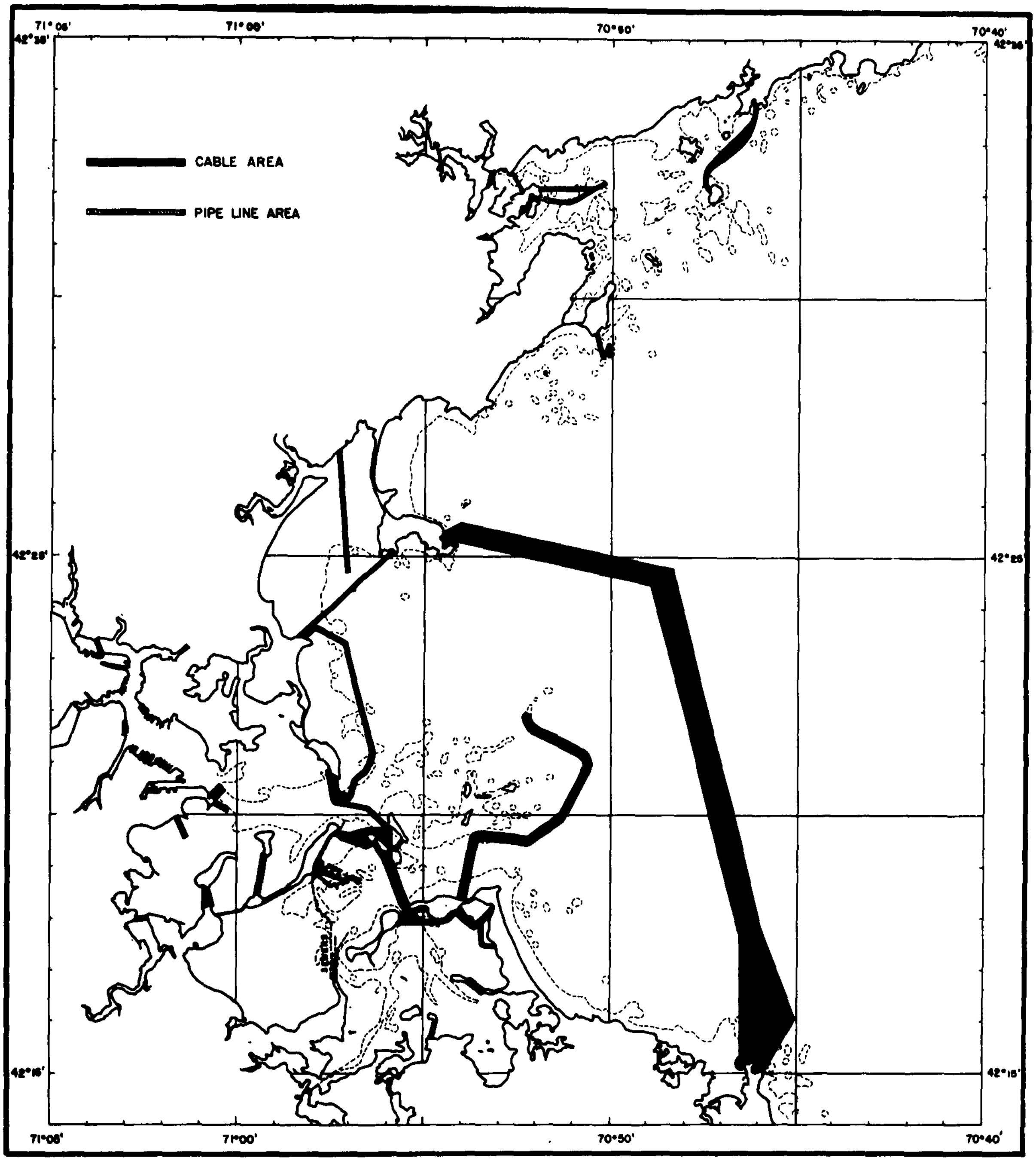


Fig. 9 Locations of cable and pipe line areas.

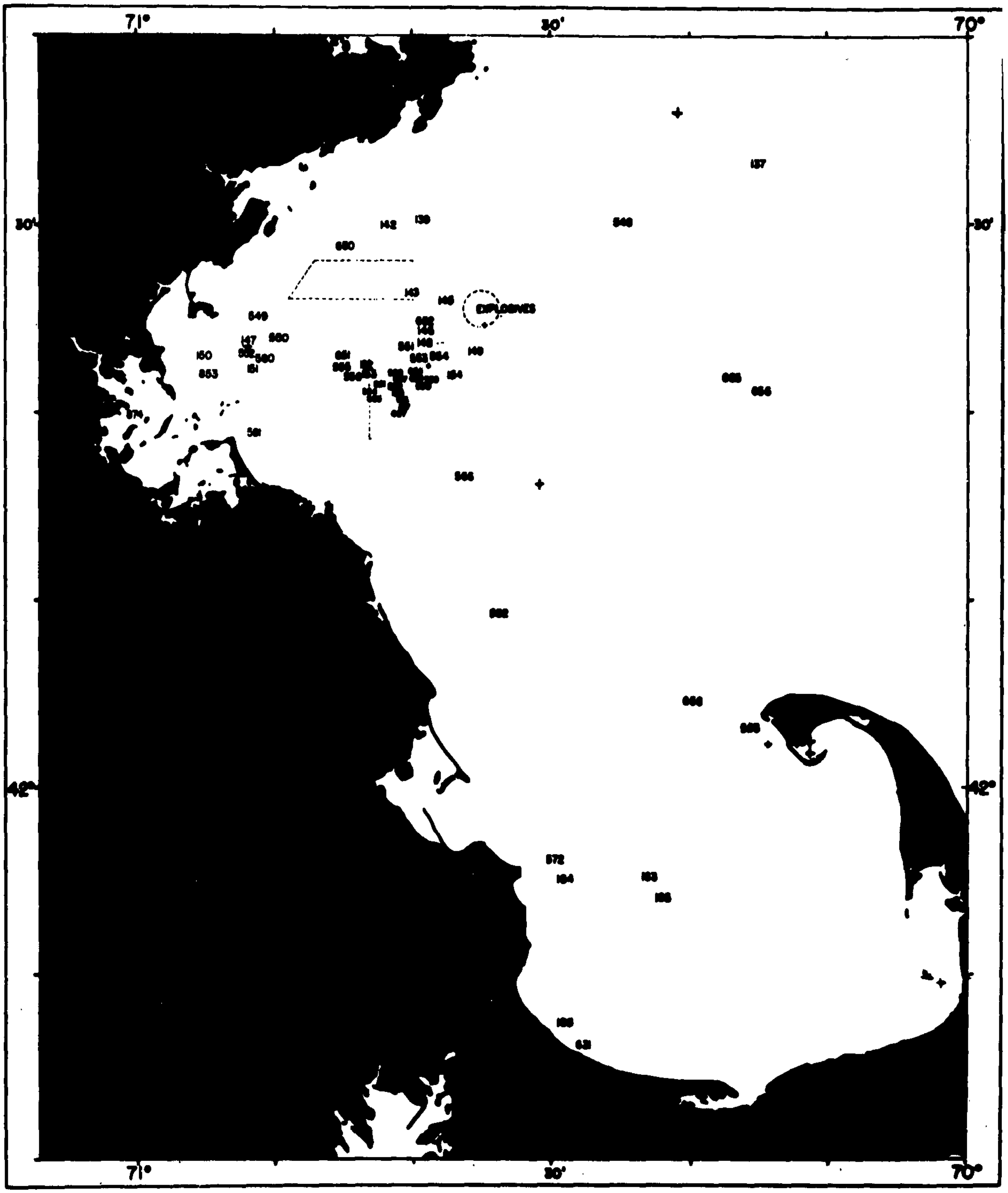


Fig. 10 Locations of wrecks and offshore dumping grounds.

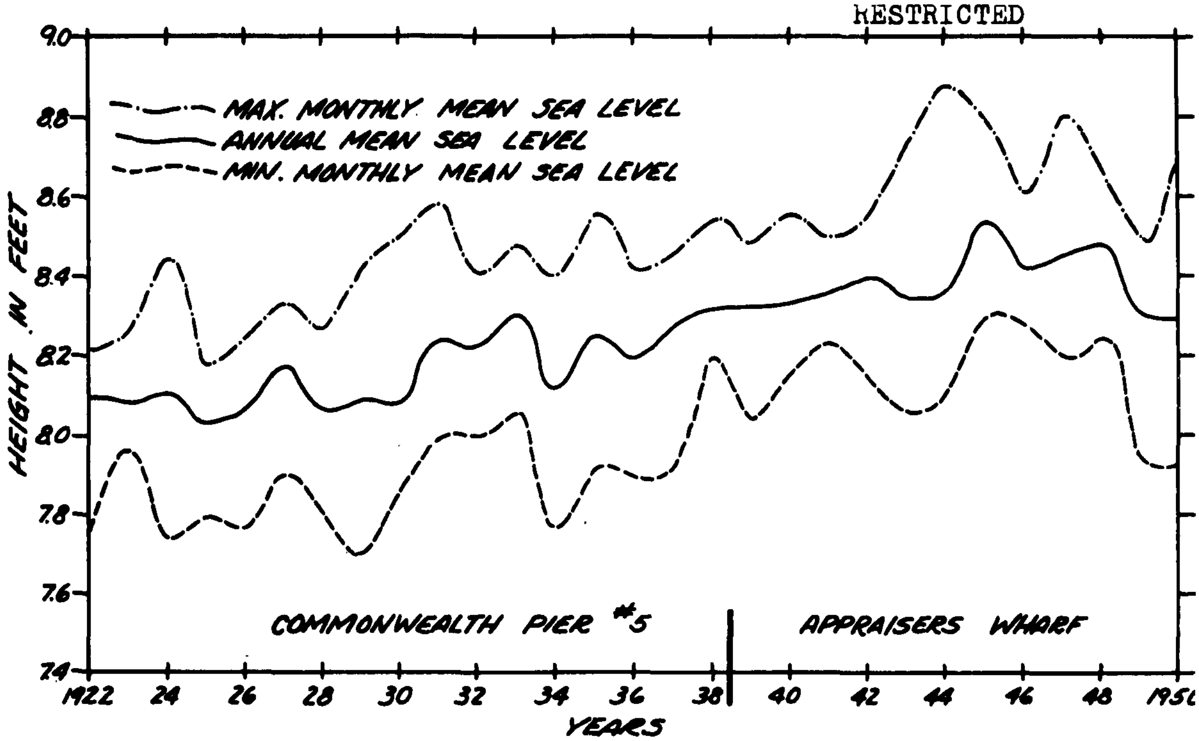


Fig. 11 Fluctuations in annual mean sea level.

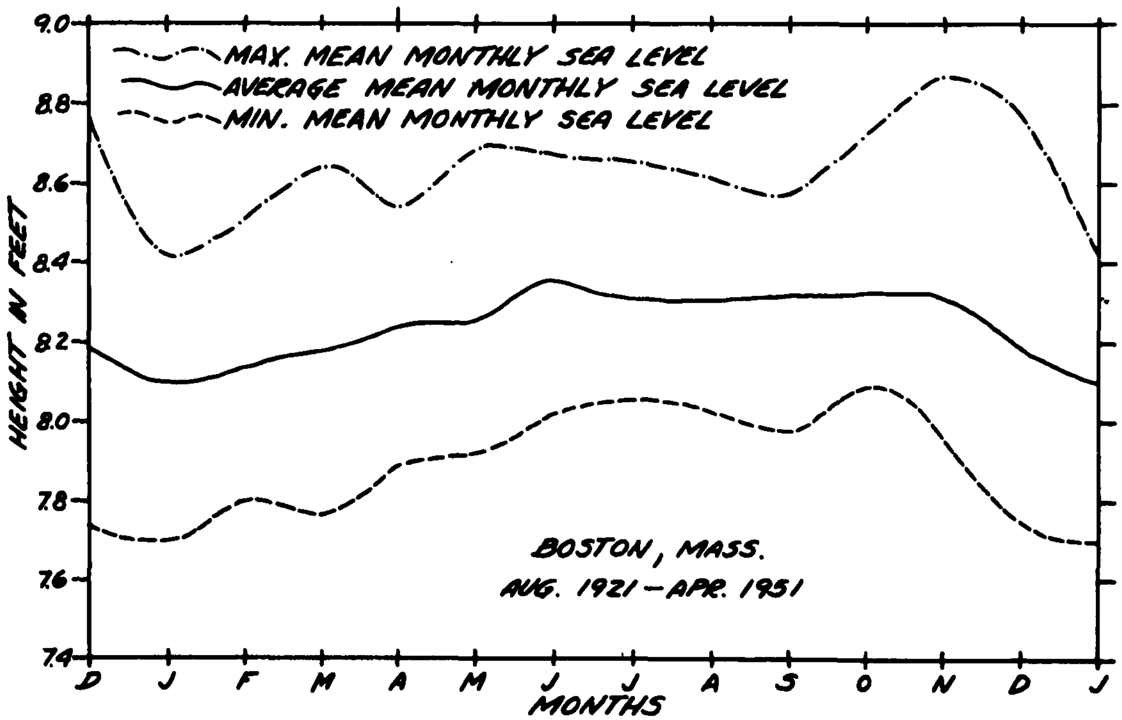


Fig. 12 Fluctuations in monthly mean sea level.

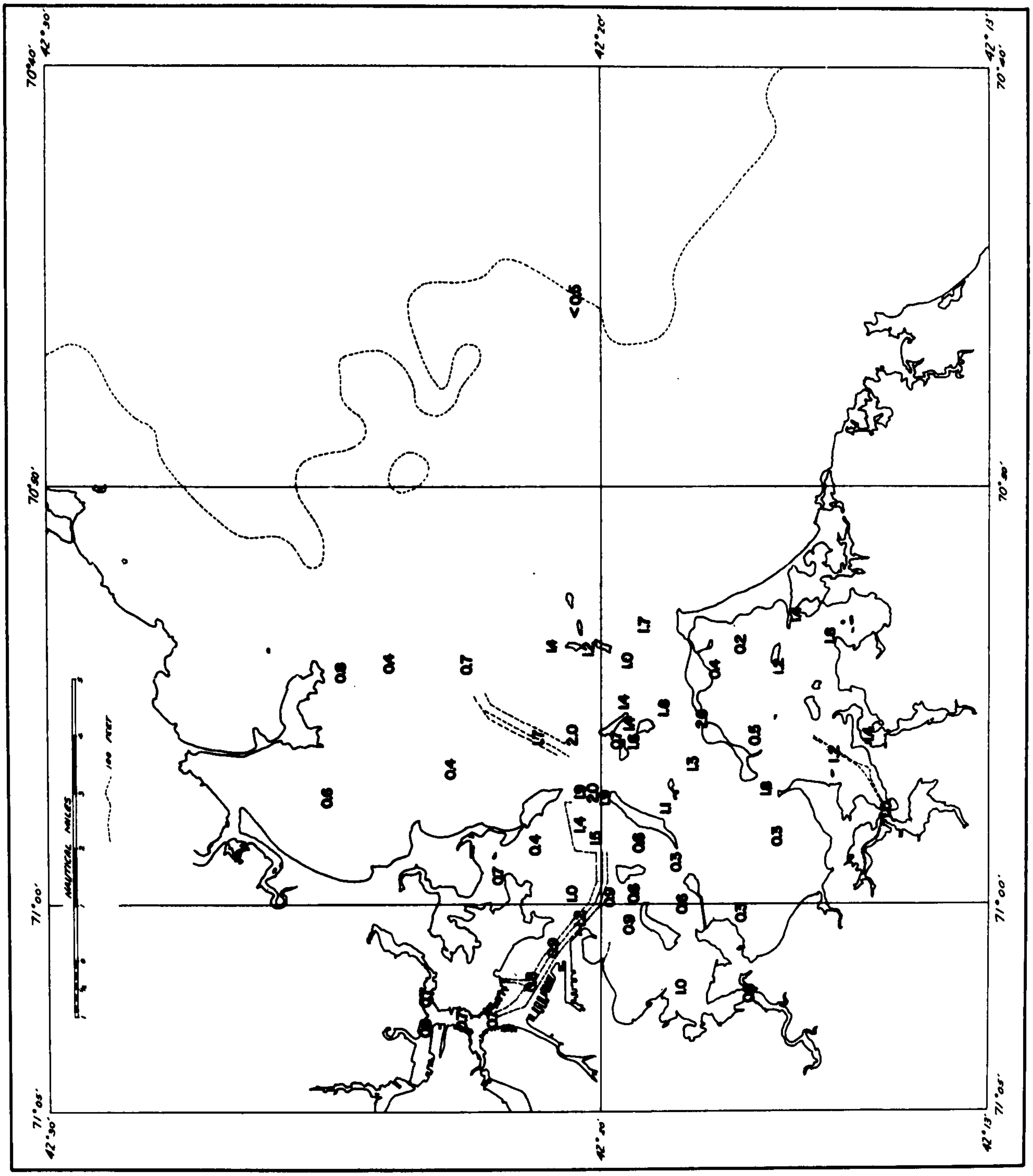


Fig. 13 Maximum velocity of tidal currents.

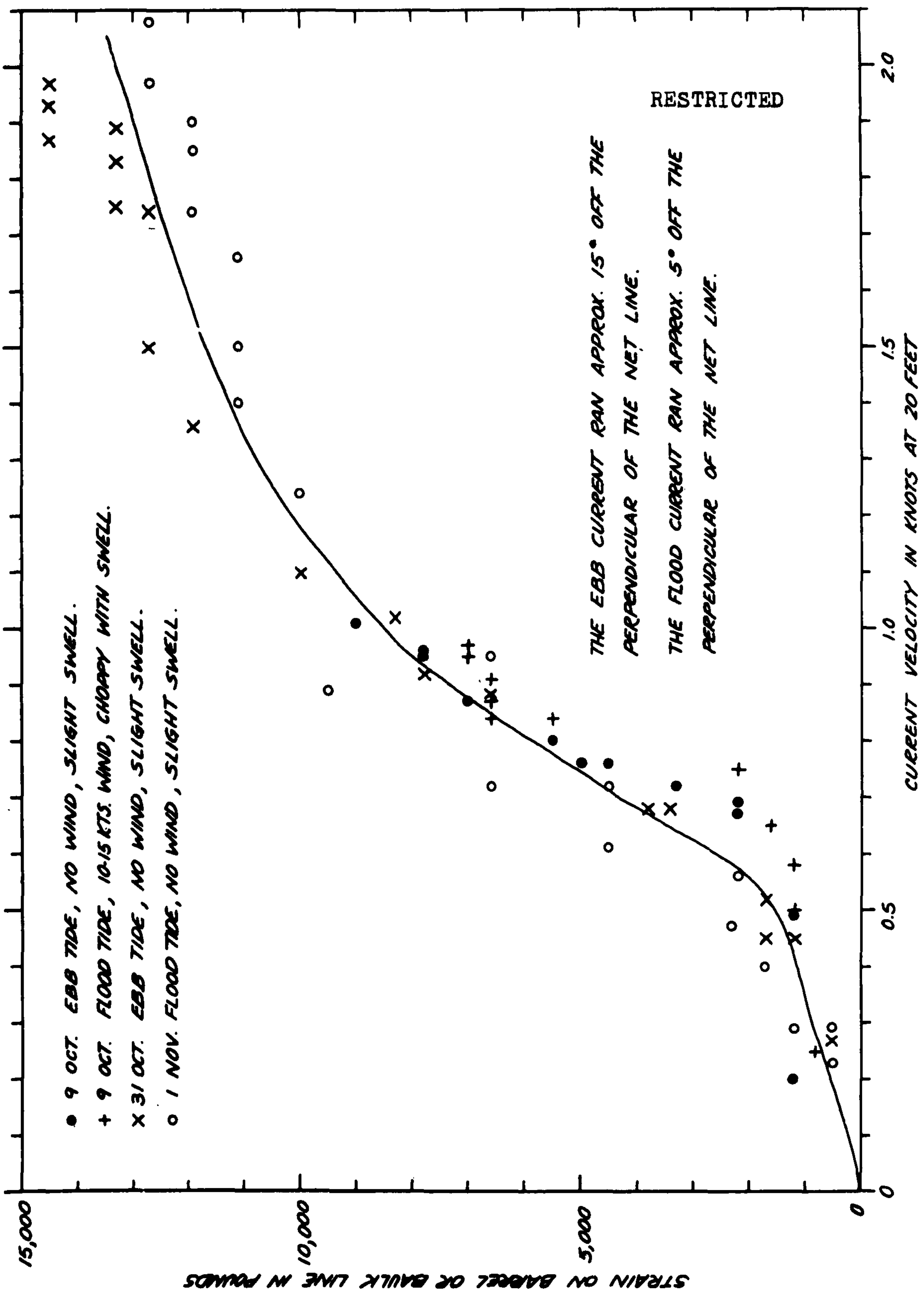


Fig. 14 Strain on torpedo net, baulk, and barrel lines.

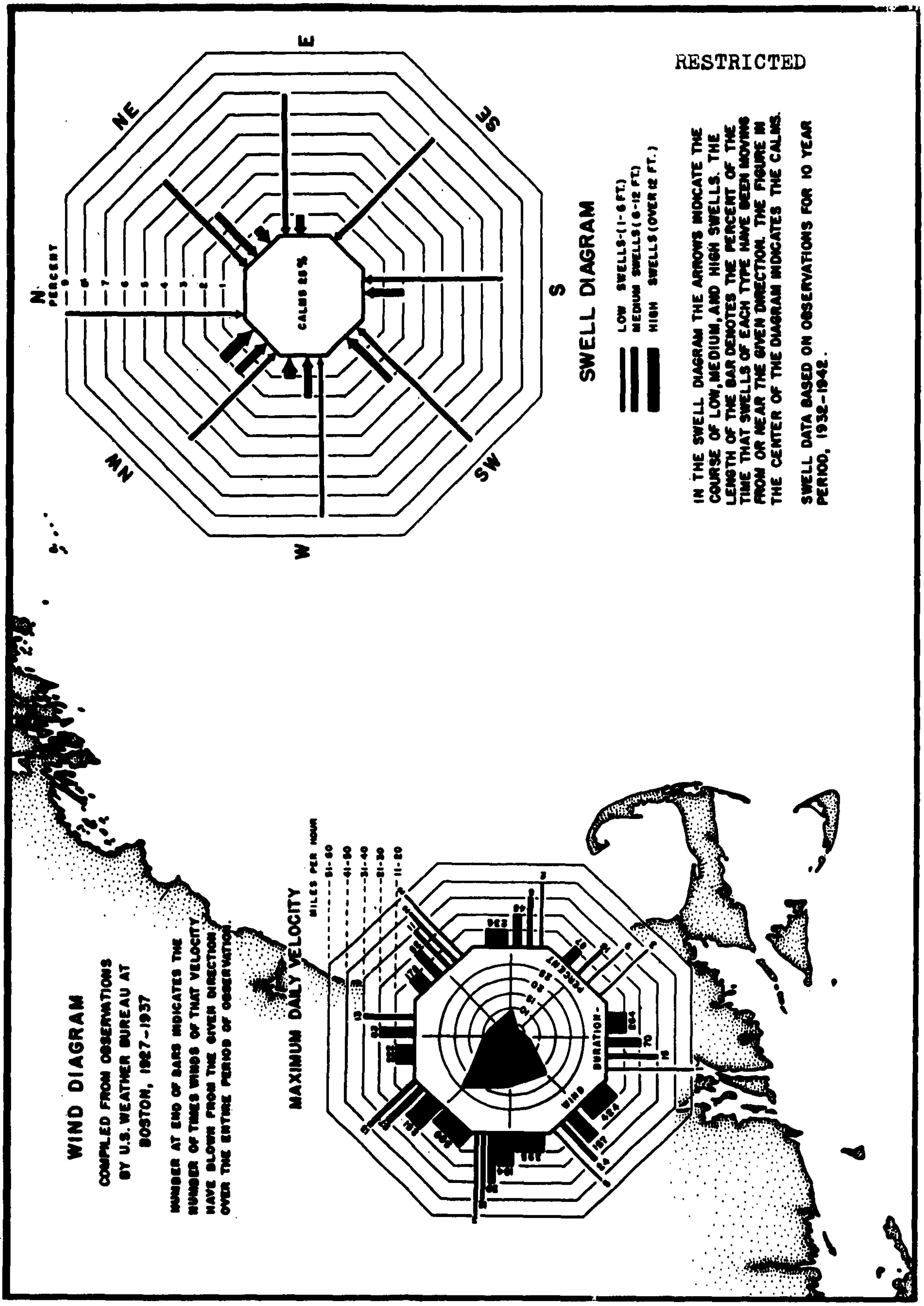


Fig. 15 Wind and swell diagram.

RESTRICTED

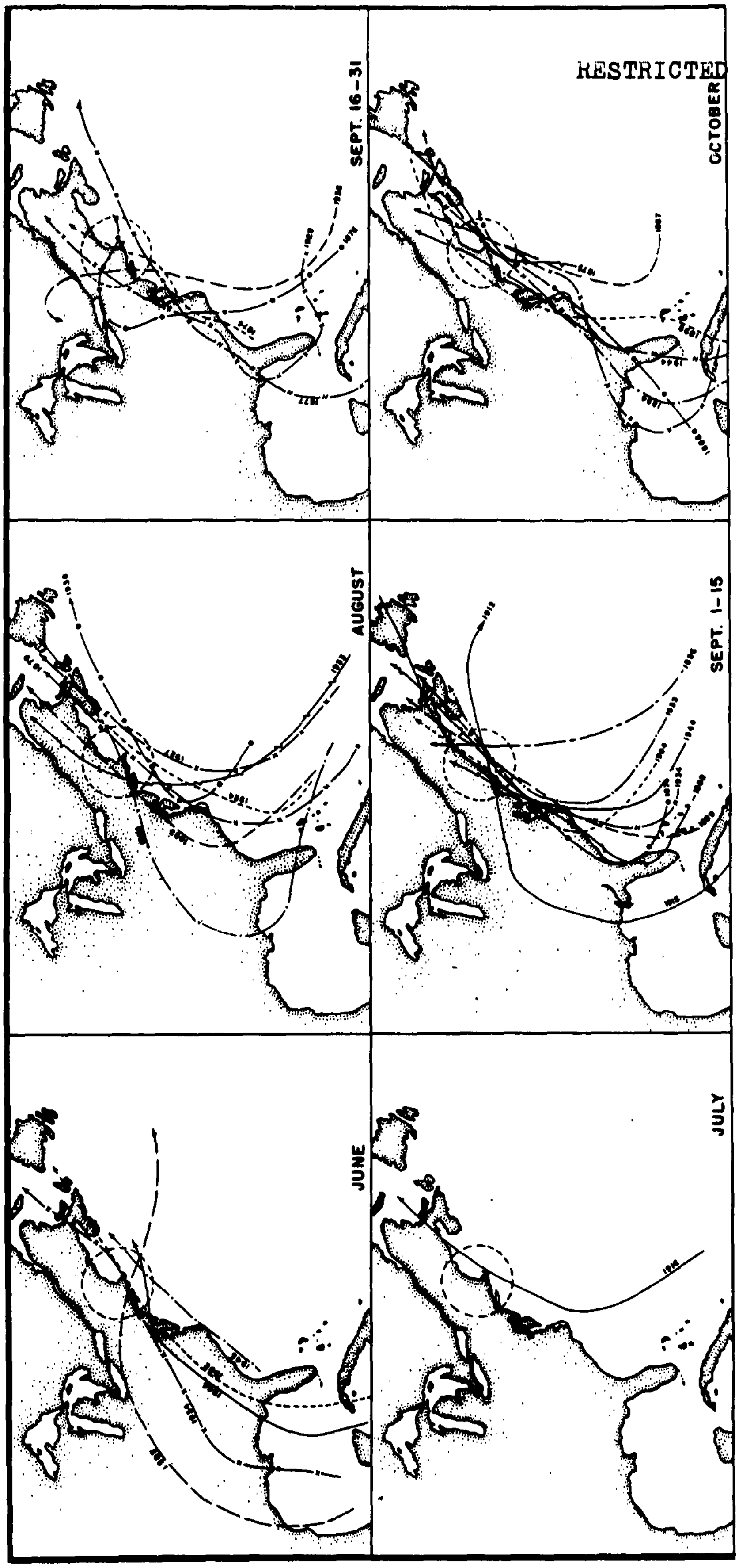


Fig. 16 Paths of tropical storms of hurricane intensity.

RESTRICTED

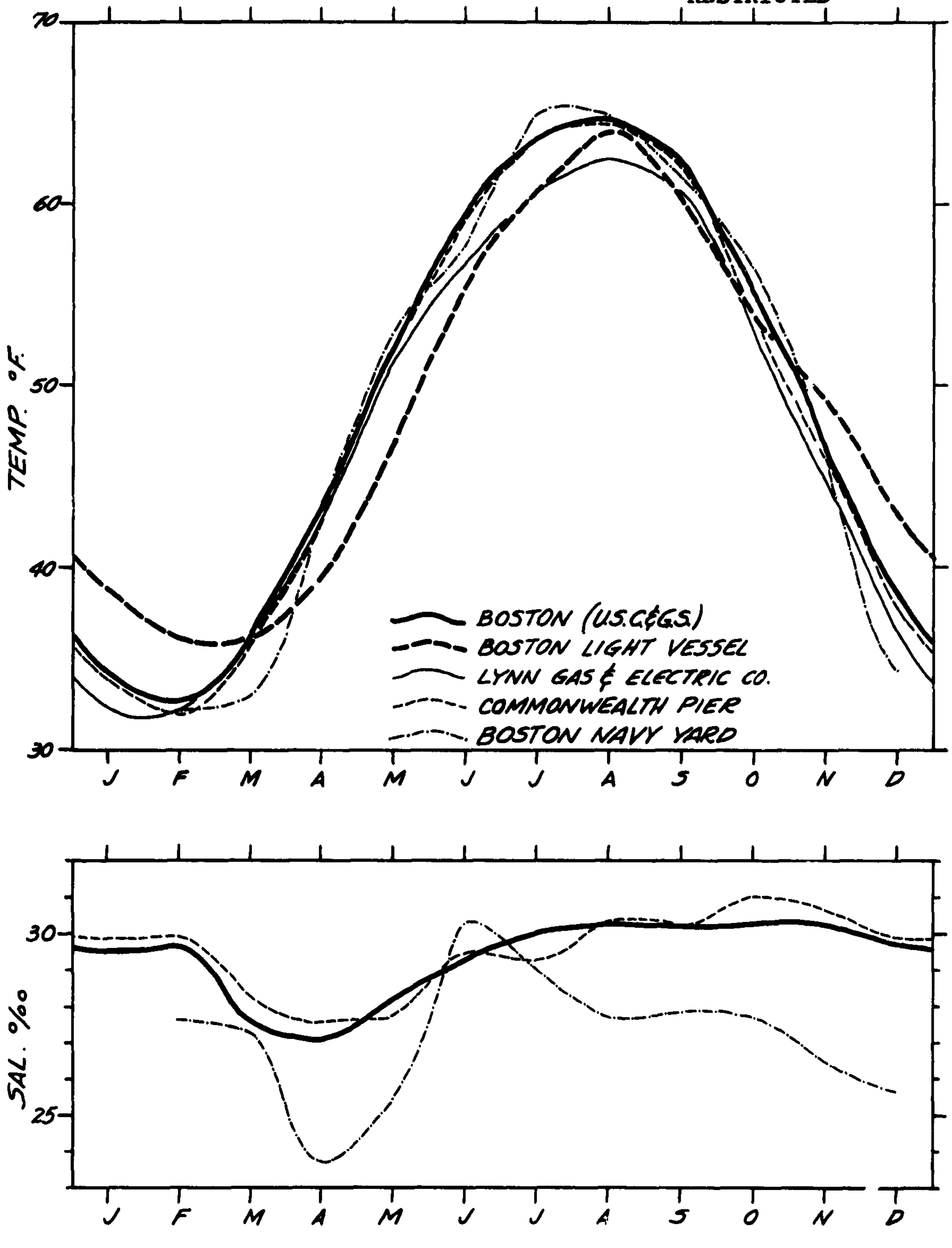


Fig. 17 Monthly mean sea water temperature and salinity.

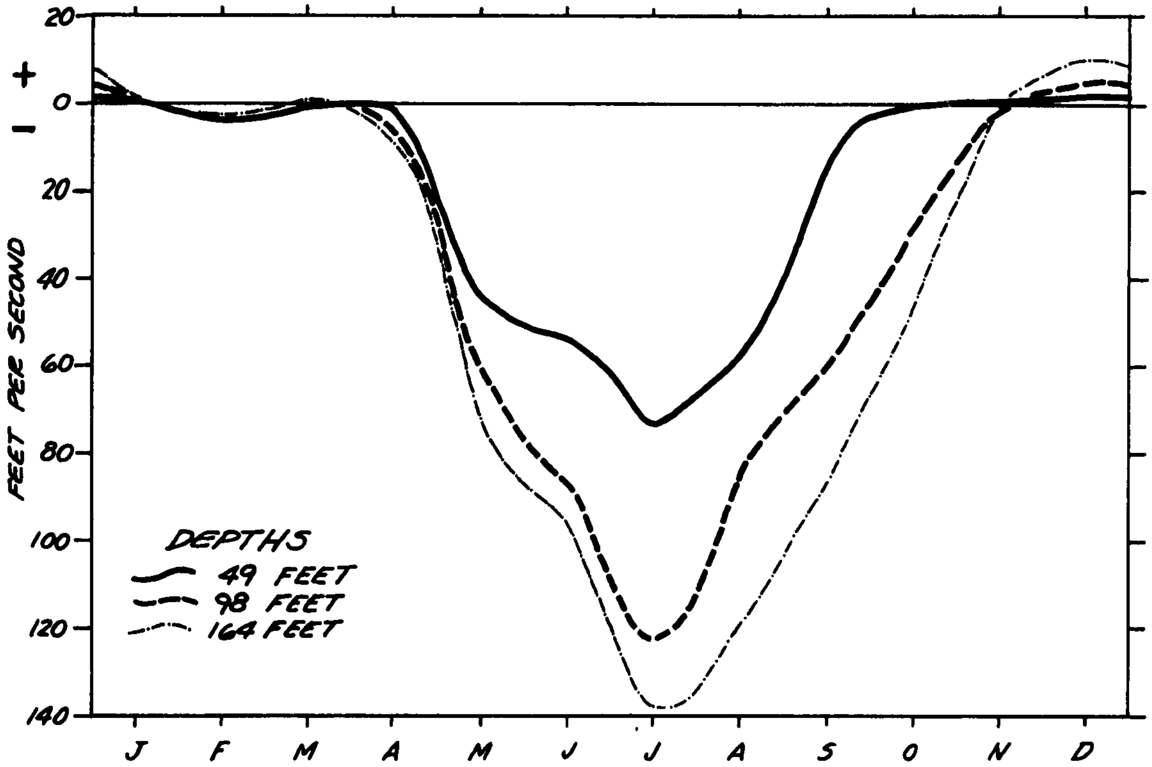


Fig. 18 Annual progression of the difference between sound velocity at the surface and sound velocity at depth, just east of Boston Light Vessel.

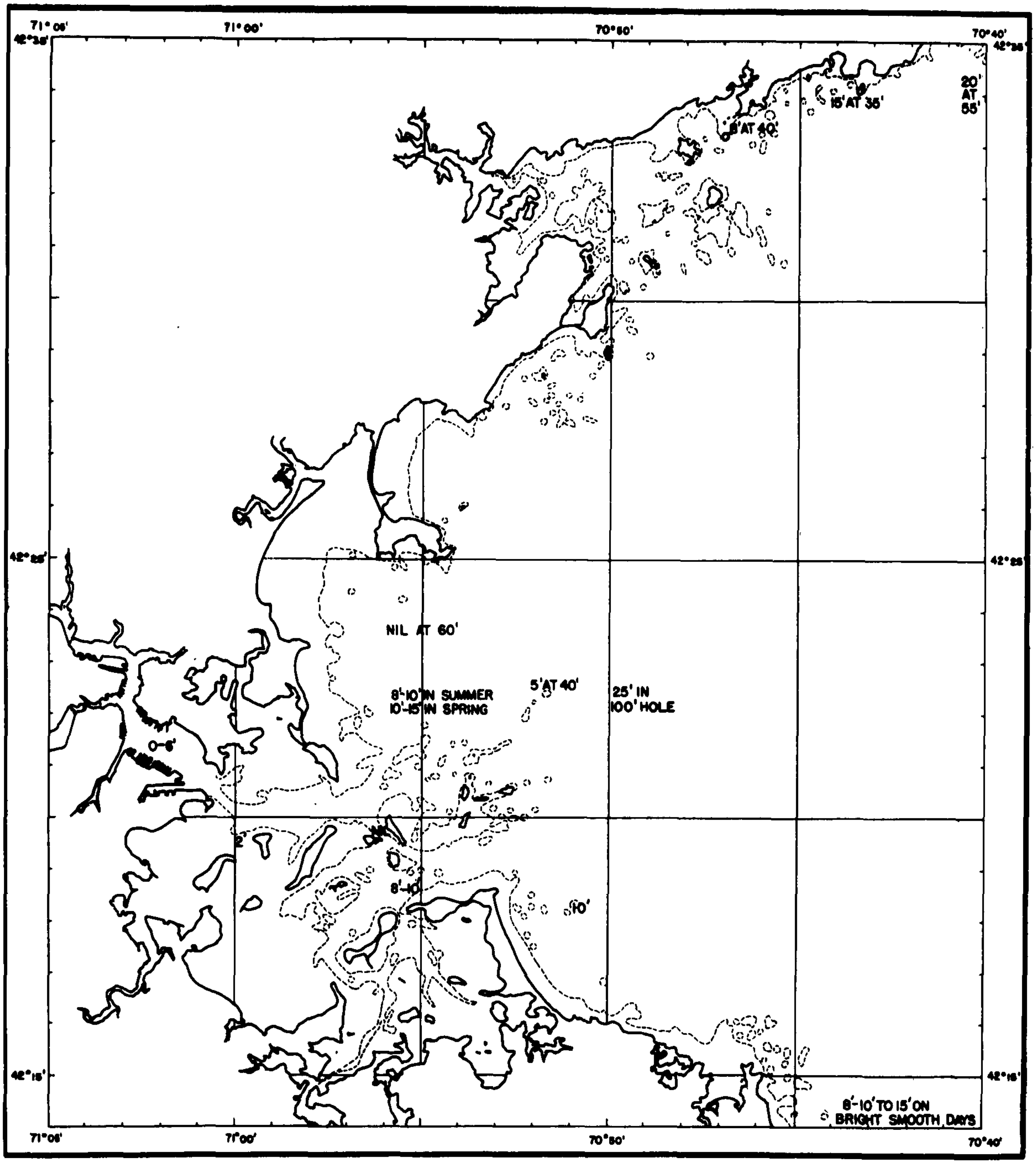


Fig. 19 Visibility at the bottom.

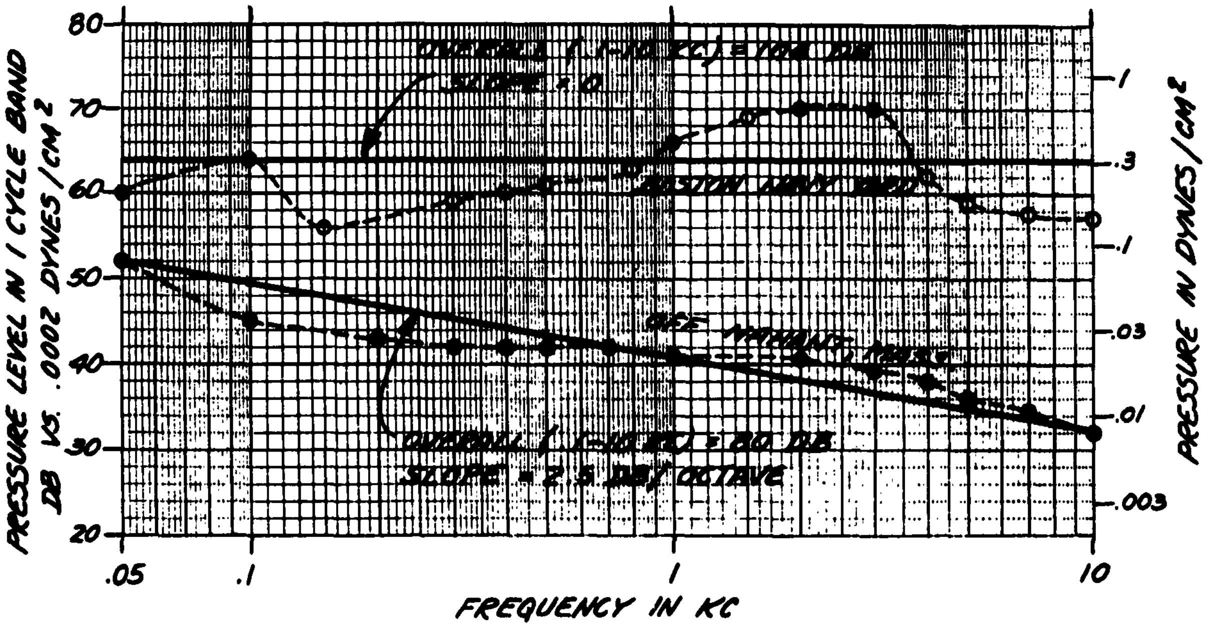


Fig. 20 Pressure level spectra of ambient noise, Boston Navy Yard and off Nahant (after Knudsen et al).

DISTRIBUTION LIST

U.S. Navy Hydrographic Office
Washington 25, D. C.
Attn: Hydrographer 1 copy
Librarian 1 copy
Division of Oceanography 8 copies

Chief of Naval Research
Department of the Navy
Washington 25, D. C.
Attn: Code 407 1 copy
Code 416 1 copy
Code 463 1 copy

Commanding Officer
Branch Office of Naval Research
150 Causeway Street
Boston, Massachusetts 2 copies

District Engineer
U. S. Corps of Engineers
P. O. Box 2316
Boston, Massachusetts 2 copies

Director
U.S. Coast and Geodetic Survey
Washington 25, D. C. 1 copy

Commanding Officer
U.S. Coast and Geodetic Survey
Custom House
Boston, Massachusetts 1 copy

Director,
Narragansett Marine Laboratory
Kingston, Rhode Island 2 copies

Director,
Chesapeake Bay Institute
Box 26A
R.F.D. #2
Annapolis, Maryland 2 copies

Director,
Department of Oceanography
Cornell University
Ithaca, New York 2 copies

Rutgers University
New Brunswick, New Jersey
Attn: Dr. H.H. Haskin 2 copies

University of Delaware
Newark, Delaware
Attn: Dr. E. Cronin 2 copies

Harbor Defense Officer
FIRST Naval District
495 Summer Street
Boston 10, Massachusetts 2 copies

Officer-in-Charge
Harbor Defense Unit
U. S. Naval Base
Boston, Massachusetts 2 copies