INVESTIGATION OF BOTTOM SEDIMENT PROBING BY 12 KILOCYCLE SOUND PULSES REFLECTED FROM SHALLOW WATER BOTTOM SEDIMENT LAYERS

by

HAROLD PAYSON, JR.

SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE

DEGREE OF

MASTER OF SCIENCE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

January, 1963

Signature of Author...
Department of Geology and Geophysics, 14 January 1963

Certified by............ .....
Thesis Advisor

Accepted by.............. ....
Chairman, Department Committee
Graduate Students

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ABSTRACT

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A geological shetch of the Boston Basin is given to introduce the reader to the general features of the area, with emphasis on the Pleistocene and Recent Sedimentary deposits. Soft, black, carbonaceous mud over blue clay over glacial till is the combination most commonly found in the harbor and estuary regions. A descriptive section on the Sonar Sediment Probe is given next, followed by operations with the equipment in the Boston Harbor and Narragansett Bay areas. Low power, short pulse, 12 kc acoustic waves are reported to penetrate shallow water clayey sediments with considerable success. They fail to penetrate the soft, black mud but reflect from it in a remarkable manner. Bottom samples verify the type of bottom probed. A description of sample analysis is given at the end of the section. Finally, previous work in shallow water acoustic probing is discussed and conclusions drawn as to the efficacy of the work and its promise for the future. Continued development of the SSP and active field work in the local area is recommended.

Thesis Supervisor:

Title:

CONTENTS

	Abstract	i
	Acknowledgments	iv
I.	Introduction	1
II.	Post Glacial Sketch of the Boston Basin	4
III.	The Sonar Sediment Probe (SSP)	11
IV.	Operations	15
V.	Discussion	24
VI.	Conclusions	31
	Bibliography	65

LIST OF FIGURES

1.	Map of Boston Basin	32
2.	Idealized Section of Pleistocene Glacial Deposits in the Boston Area	33
3.	Key Map to Sections 1-4, Charles River Basin	34
4.	Sections 1-3, Charles River Basin	35
5.	Section 4, Charles River Basin	36
6.	Section in Dorchester Bay	37
7.	Section SW of Logan International Airport	38
8.	Section near Castle Island	39
9.	Calibration Line for Depth	40
10.	Multiple Bottom Echoes	40
11.	Shelly Area West of M.I.T. Faculty Club	41
12.	Shelly Area near Harvard Bridge	41
13.	Layering and Bubbles in Dorchester Bay	42

14. Layering Interrupted by Impenetrable Mud. 42

15. Good Bottom Layering in Main Channel. 43

16. Wreck in Dorchester Bay 43

17. Tunnels under Boston Harbor 44

18. Masking of Clay by Black Mud. 44

19. Rock Outcrop. 45

20. Sub-bottom Shelly Layer and Outcrop 46

21. Sub-bottom Rock Pinnacle. 45

22. Specific Gravity Test, Sample #1. 47

23. Specific Gravity Test, Sample #2. 48

24. Specific Gravity Test, Sample #3. 49

25. Hydrometer Analysis, Sample #1. 50

26. Hydrometer Analysis, Sample #2. 51

27. Hydrometer Analysis, Sample #3. 52

LIST OF PLATES

1. Track of KAY G in Boston Harbor 53

2. Track of PILOT I in Narragansett Bay. 54

3. Photographs of Sonar Sediment Probe 55

4. Photographs of Sonar Sediment Probe 56

5. Photographs of Sonar Sediment Probe 57

6. Photographs of Sonar Sediment Probe 58

ACKNOWLEDGMENTS

Indebtedness is gratefully acknowledged to: Professors R. R. Shrock and H. E. Edgerton for encouragement, inspiration and support; to Professor H. W.Fairbairn for help in proceeding safely through administrative channels; to Professors D. E. Carritt and E. Mencher for ideas and suggestions; to Lloyd Breslau for dynamic and expert instruction in electronic oceanography; to Martin Kline who knows so much about the SSP; to Donald Phipps and John Yearsley, tireless co-workers in sediment probing with special thanks to Don for the geological sections; to V. E. MacRoberts for skilled assistance in matters electronic; to A. E. Z. Wissa, Fred V. Lawrence and K. A. Healy for advice and help in the Soils Analysis Laboratory; to Miss P. G. Richmond, Miss D. C. Jope and Miss J. A. Mooney for providing the countless essential office services that are so much appreciated; to Mrs. D. Wade for deciphering my longhand and typing the manuscript; to W. C. Wood and G. M. Reed, Jr., for helping in things nautical; to the M.I.T. librarians and personnel of the Audio-Visual Aids Section for cheerful and skillful service; to the boat captains and crew members of KAY G and PILOT I for fine seamanship and good companionship; and finally to my patient and understanding wife.

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I. Introduction

Countless hours spent poring over charts while cruising the world oceans for thirty years have left me with an insatiable desire to know more about the nature of the ocean bottom. After nearly a century of fairly active oceanographic exploration there are still vast unmapped areas and no means in sight, yet, for greatly speeding up the mapping process. It is true that the sonic depth finder has given us a marvelous tool for measuring and recording depth, and the bathythermograph for temperature, but no suitable instrument has yet been devised for rapid and continuous recording of bottom types and bottom sediment layering.

The outstanding success of sonic depth finders has pioneered the way for the introduction of electronics into oceanography. The development and use of electronic instruments for exploration at sea hold great promise for the future. Some will supplant the old, painfully slow methods of the past, while others will supplement them or be completely new in concept and design. Fortunately, machines for handling the mass of raw data, which will be collected in ever increasing amounts, are already well along in the orderly development of computers, and young oceanographers are being trained in their programming and operation.

During the summer of 1962, I was fortunate in being able to make several cruises out of Woods Hole with Lloyd Breslav, who was collecting data for his thesis on bottom reflectivity. These cruises covered the shallow waters of Narragansett Bay, many miles over the continental shelf south of a line between Block Island and Martha's Vineyard, and the deep sea along the Richardson buoy line almost to Bermuda. The capability of Breslav's equipment to collect and record continuously for him the information he wanted was remarkable and greatly stimulated my imagination. When Professor Edgerton kindly offered the use of his newly developed Sonar Sediment Probe for conducting shallow water probing investigations, and Professor Shrock gave an encouraging approval to investigating the sediments of the Boston Basin, I was ready to go ahead with the investigations described hereafter.

The general plan of my thesis is to begin with a brief, geological sketch of the post glacial period of the Boston Basin. This will acquaint the reader with the various kinds of sediment deposited during the past 5,000 to 10,000 years and give him some idea of the thickness and nature of the different layers. It will also, hopefully, enable him to grasp the exciting potentialities in tracing the hidden sediment layering by means of continuous acoustic probing. Next will come a description of the probing equipment, itself, followed by an account of the investigations conducted during the month of November, 1962, by a three-man team of Payson, Phipps and Yearsley. This will include profiles run through the Charles River Basin, the inner and outer harbor area and Narragansett Bay. It will include also a short description of the laboratory method used to determine the specific gravity and grain count of three widely separated, key bottom samples. It will close with a discussion of the investigations and conclusions derived therefrom.

II. Post Glacial Sketch of the Boston Basin

According to W. O. Crosby[1] and others, the underlying bed rock of the Charles River Basin and Boston Harbor is largely of a slaty character and is, in general, so deeply buried beneath the glacial and later deposits as to be without appreciable direct influence in determining surface features and conditions. The character and structure of the bed rock have, however, under the processes of erosion, largely determined the contours and trends of the bed rock valley and thus, indirectly determined the massing of the glacial drift or boulder clay in which the relief features of this part of the valley are now mainly expressed. The prevailing strike of the slate varies from east-west near the Charles River to about northwest-southeast in the vicinity of the Mystic. Ridges or kames tend to form with the strike, with intervening valleys, which slope generally seaward. A fine example of a bed rock ridge is indicated by the drumlins of College and Winter Hills and the ledges on which they rest, the late Convent Hill, Bunker and Breed's Hills, Man-of-War Shoal (summit of a submerged drumlin), the low drumlin culminating in Maverick Square and the more prominent East Division drumlin, Bird Island flats (another submerged drumlin), Governor's Island drumlin and ledge, and the flats extending a mile beyond.

In order to gain some idea of the sedimentary deposits in the Boston Basin (see Figure 1) area, we may examine borings taken for some of the local bridges[1]. Thirty-nine borings on the lines of the Harvard Bridge to depths of -31.4 to -77.7 feet failed to reach bed rock and ended in blue clay. During the dredging directly east of the Harvard Bridge to fill in the shallows on the Cambridge side between the newly constructed wall along the river and the railroad tracks many shells were found. These occurred mostly in the sands and not in the superficial muds. The sands were some ten feet below mean low water. The most conspicuous species are an oyster (Ostrea virginica), short neck clam (Venus mercenaria), long neck clam (Mya arenaria), and a scallop (Pecten gibbus borealis). During colonial days (circa 1650) an extensive oyster bank here prevented large boats from going farther up the Charles.[3] Sixty-four borings for the West Boston Bridge, from -36.9 to -73.5 feet also failed to reach bed rock but did end in boulder clay, indicating that the bed rock is less deep than at the Harvard Bridge. The 70 borings for the Charlestown Bridge, on three different lines, gave depths from +4.3 feet to -58.3 feet. One reached ledge at -11 feet in Charlestown; two reached blue clay in Boston; the rest ended in boulder clay. Fifty-five borings were made for a drydock at the Charlestown Navy Yard, in an area 1300 by 700 feet, at depths of from -33 to -104.4 feet, and nine reached bed rock at from -39 to -98 feet. For typical geological sections, drawn from boring logs, see Figures 3-8.

It might be well to note here that the term boulder clay or hardpan denotes a heterogeneous mixture of clay with sand, gravel and large stones or boulders, and that it is the material of which drumlins are formed. It is also known by geologists as the till or ground moraine and is the unmodified (unmashed and unstratified) portion of the glacial drift or that part of the drift deposited on the final melting of the ice sheet without being exposed to the effective sorting or modifying action of water. It rests at most points directly upon the bed rock and is found chiefly on the higher parts of the bed rock surface, where it is very largely massed in the form of the above mentioned rounded hills or drumlins. In regards to the subterranean movement of water, the boulder clay, having been compacted by the tremendous and long continued pressure of the ice sheet, is comparable with the underlying bed rock. In many places the boulder clay is separated by a few feet of bluish (unoxidized) sand and gravel, often more or less clayey, from the blue clay, giving a gradation from the boulder clay into the blue clay. Another still more interesting feature is found in the interstratified beds of washed material, including gravel, sand and clay. Crosby[2] gives the following average percentages of the four distinct kinds of detritus composing the till:

Gravel	24.90
Sand	19.51
Rockflour	43.86
Clay	11.67
Misc.	0.06

It will be seen that the proportion of rockflour is surprisingly large while that of clay is surprisingly small. Evidently the main part of what appears to be clay is rockflour, or quartz and other minerals which have been ground to a minute fineness.

Under Boston Harbor and its tributary estuaries, blue clay is found above the boulder clay, or where the latter is missing, directly above the bed rock. This is a true glacial clay, a deposit of impalpable detritus from the waters of the glacial Lake Shawmut which was formed as the ice retreated from the harbor area, the land being then much more elevated than at present. The blue clay is tough and plastic and contains a large portion of finely ground sand or quartz flour. The absence of fossils and the fact that it is not being deposited in the harbor at the present time, except possibly in the eel grass flats, prove that it is not marine in origin. Recent discoveries however, of a few scattered marine fossils in certain parts of the clay beds leave the proof of non-marine origin still open to question. Occasional thin streaks and layers of the sand represent periods of greater motion in the depositing waters. Scattered rock fragments and boulders up to several feet in diameter were probably dropped by floe ice and icebergs.

The blue clay beds reach a maximum elevation of about 5 feet above high water and extend to about 200 feet below the same datum. Analyses of the clay show that it invariably contains a large proportion of quartz flour, a substance which adds greatly to its value for brickmaking. At its higher levels, and almost everywhere above the low water level, it has been superficially oxidized to a buff or yellow color. Both the oxidized and unoxidized clay are stiff, tough and impervious and are comparatively dry or free from any excess of water. Oxidation makes the clay harder and firmer and accounts for the boring records which indicate "hard clay" above, passing downward through "stiff clay" to "soft clay."

After the melting of the glacier and the hardening of the upper clay by gradation, the region was subjected to erosion by running water and during this period, or at least during the latter part of it, freshwater peat was broadly developed. In the majority of sections, this shows up directly above that glacial sediment; subsequent to the formation of the peat, the land sank and a large portion of the region was submerged beneath the ocean.[3] Boston Harbor as it is today came into existence when the land subsided to approximately its present level, and the inner harbor, at least, is confined almost wholly to the valleys which had previously been formed by fluvial erosion of the blue clay. As the land sank still lower carrying those deposits below the sea level, the sand and gravel gradually gave way to the silt, or the black, carbonaceous, sandy mud or muddy sand, which everywhere forms the immediate floor of the harbor.

In this description, the term "silt" is used for the recent deposits (including those now forming) which are of a fine or muddy character. It is a soft, black, carbonaceous, sandy mud, commonly containing shells or shell fragments, and normally covers the blue clay with a thickness of 2 to 5 feet. Where there are hollows in the clay, the silt may vary in thickness from 15 to 25 feet. It is an entirely loose and uncompacted deposit and is easily moved or drifted about by the action of currents. It is highly fossiliferous and contains many shells no longer living in Boston Harbor. Most of the shells are too heavy to be transported by the tidal currents and, where the silt is suffering erosion, are left behind, gradually forming a residual accumulation or layer, which then protects the silt against further erosion. The subsidence of the land, which made the accumulation of the silt possible, is apparently still in progress, and the silt is still accumulating. The best available evidence indicates deposition period of 5000 years, at a rate, varying according to locality, of from less than 1 foot to 5 feet in a thousand years.

For any given locality, the rate diminishes as the subsidence progresses and the depth of the water increases. The rate of deposition of the silt has, in the main, been exceeded by the rate of subsidence, for the natural channels have deepened rather than been filled and obliterated.

In subsequent pages we shall see that the blue clay and black silt discussed above play an important part in our investigations of sonar sediment probing.

Shimer[3] sums up the post glacial geological history of Boston in five stages:

1. Deposition in fresh water of mud and sand from the melting glacier.

2. Erosion by streams of some of this material after the disappearance of the glacier.

3. Growth of peat in swampy areas, probably at the same time as 2.

4. Partial submergence of the land beneath the ocean with the accumulation of mud and dead shells upon the peat beds. This record of submergence contains two distinct and intensely interesting elements. (a) In the earlier or lower beds the marine shells indicate a warm climate similar to that off the Virginia coast at present. (b) The upper beds, and continuing to the present, where still beneath the sea, contain a marine fauna indicative of a colder climate, that of today.

5. In certain areas, as Back Bay, the raising of the land again from its ocean bed by artificial filling.

One final significant item should be mentioned before concluding this brief geological sketch of the Boston Basin: the presence of man. That he existed here, at least some 2000 to 3000 years ago, is evidenced by the remnants of a fish weir found about 12 feet below the top of the silt in the subway excavation on Boylston Street, between Clarendon and Berkeley Streets. He is thought to have built this weir during a climatic period as warm as off the Virginia coast today, and upon a sinking coast. One is easily tempted at this point, to suppose that a branch of the Gulf Stream flowed much closer to Cape Cod then than it does now. Since the erection of the weir, the region has sunk 16 to 18 feet and undergone a cooling to its present climate.

The discovery of the weir naturally leads one to the conclusion that there may be more elsewhere, and perhaps other buried archaeological treasures not too far down in the silt and clay. If, indeed so, one must restrain one's excitement at the prospect of probing the shallow water sediments by means of acoustic waves.

III. The Sonar Sediment Probe (SSP)

The Sonar Sediment Probe, or Mud Penetrator, is a device especially designed to show objects submerged in the soft bottom sediments of rivers, harbors, bays and coast lines. It has evolved from the EG&G Sonar Pinger, which was originally developed for positioning deep sea cameras. The pinger emits a short, high power acoustic pulse capable of penetrating certain sediments and reflecting from objects or layers of different densities as a return signal. The pinger's short, high energy pulse, coupled with a high resolution recorder, give it a detection capability for locating a considerable variety of sediment layering and shallow buried objects. In order to increase the resolution, the pulse repetition rate has been raised from the 1 pps of the standard pinger to a range of from 5 to 30 pps.

The components of the SSP System (~~Figures~~ Plates 3-6) consist of:

1. A Sonar Trans-Driver, which is housed in a small metal cabinet, weighs 15 pounds and contains the pinger power supply, storage capacitors and discharge and triggering circuitry. It also contains a two-stage preamplifier for amplifying weak signals reflected from sub-bottom objects, with provision on the trans-driver panel for selecting the gain, (a) direct, (b) x 10, or (c) x 100. For additional gain of 10 or 100, an external amplifier may be used (Hewlett Packard type 466A).

2. A Marking Amplifier, housed in a cabinet similar to that of the sonar trans-driver, and designed to give the current and voltage output required to darken the Alden Alfax recording paper when a 1 volt or greater signal is impressed upon it. Fine adjustment of the

darkness of the recorded signal is effected by a continuously adjustable control located on the marking amplifier panel.

3. A High Resolution Recorder (Alden Recorder), which works on the principle of a negative helix electrode and a positive moving loop electrode. An Alden 5 inch Alfax recorder head is used. In the Alfax recording system, a chemically treated paper records by the deposition of ions (Fe) from the electrode whenever an electrical signal appears.

4. A Submersible Transducer (EDO Transducer Driver) which consists of an EG&G unit type 36236. The transducer is an ADP crystal array immersed in oil in an aluminum housing and weighs about 30 pounds. Together with an output transformer, it is mounted on a counter-balanced pipe framework designed for horizontal towing, through the water. A 150-foot, 3-conductor cable connects the transducer to the shipboard elements of the system and is strong enough to support it at whatever depth it is desired to work. The output frequency of the transducer is 12 KC with a pulse length of less than 0.5 msec. Its effective angle in air is about 15° and in water about 40°.

Description and diagrams of the various circuits of the system are available at EG&G but are not reproduced here as they are not considered within the scope of this paper. A word of caution is in order, however, concerning the transducer circuit. Excitation for the crystals comes from an EG&G type TR-55, matching transformer, which has a secondary inductance that tunes to 12 KC with the electrical capacitance of the crystals. The primary of this transformer has about 15 turns. Current pulses from a capacitor (0.25, 0.50, 1.0, 1.0 mfd) charged to about 900 volts are switched by an FX-6A trigger tube at a rate determined by the angular position of the recorder helix.

Operation of the SSP system requires a 15 volt, 60 cycle power source. This is usually supplied by a 500 watt, portable, gasoline driven motor-generator set. Normal operating current is 2 amperes, starting current several times greater. Voltage should be held between 110 and 125 volts at a frequency of 60 cycles within a 5 cycle range. It is safe practice to ground the equipment through its power supply cable to the source of power switch, which in turn should be grounded to the boat.

To start the recorder, just check to see that the Alfax paper is damp and then turn on the power switch on the front panel. As the blade electrode may cut the soft Alfax paper, it is well to lift the electrode by the thumb out of contact with the paper until helix operating speed has been obtained and the paper is moving. Paper speed is varied by the speed control knob on the front panel of the recorder. When the toggle switch on the Trans-Driver is placed in the ON position, the transducer should emit pings at a rate in accordance with the helix speed.

If the recorder has been idle for some time, dried salts from previous operations may encrust the helix and prevent the signal current from properly marking the paper. To avoid this it is advisable to dab the helix gently with a wet cloth, being careful not to dislodge the wire from the spring holders.

Depth calibration of the helix sweep is accomplished either by measuring the speed of the helix drum or by hanging a reflector at a known depth below the transducer. A 4-inch lead hemisphere suspended on a marked line gave excellent results. Three helix speeds are available, each requiring a separate calibration. The speed is selected by placing the drive belt on one of the three pulley combinations on the right side of the recorder.

Approximate Speeds and Ranges

Helix Speed	RPM	RPS	Inches per sec.	Range (ft. in air)	Range (ft. in water)	Range (meters in water)
Slow	540	9	45	61	278	85
Med.	850	14.1	67.2	38.8	176	53.7
Fast	1755	29.2	146	18.8	85.5	26

IV. Operations

After testing the Sonar Sediment Probe equipment in the laboratory and again on the M.I.T. Sailing Pavilion float, it was embarked in one of the small motor launches for a first exploratory run on 2 November 1962. Calibration for depth was readily obtained by lowering a 4-inch lead hemisphere a measured length below the transducer and noting the signal received on the recorder. In Figure 9, the line indicates a depth of 10 feet below the transducer, whose distance beneath the surface must, of course, be taken into account.

Runs up and down the Charles River Basin provided a chance to adjust the equipment, to make the first recordings and to take four bottom samples. It was decided to mark the recording paper with the dial settings in the order in which the dials appear on the equipment, i.e., from left to right:

Signal Level   Paper Speed   Amplifier Gain   Ping Power   Ping Length.

These runs did not show much, if any, penetration beneath the bottom surface layer but did show remarkable variations in the number of bottom echoes received. As might be expected, shallow water gave more repeated bottom echo traces than deeper water, except where shelly bottom replaced the usual soft, fine black mud. In these places the traces of bottom echoes were repeated only three or four times instead of fifteen or twenty. Figure 10 shows a repetition of about 20 bottom echoes recorded near the Harvard Bridge over the black mud in contrast to very few echoes received over the shelly bottom. Evidently the acoustic waves are dispersed by the angular disposition of the broken shell fragments. The type of bottom was identified by taking samples with a Phleger Corer, a bomb shaped device easily handled from a small boat. Figure 11 shows traces similar to those of Figure 10 but recorded in an area opposite the M.I.T. Faculty Club. Bottom sampling proved the bottoms to be similar to those of the first case.

The second outing on the Charles Basin, 6 November, was made under freezing conditions, with light, intermittent snow falling. Nevertheless, the equipment worked perfectly and made good recordings. As before, multiple bottom echoes predominated and little penetration was perceptible. It had already become apparent, however, that the two types of bottom so far encountered in the basin, black mud and shells, could readily be mapped by running appropriate profiles with the SSP. Although the cold was beginning to numb, the operating personnel, the shelly bottom area in the vicinity of the Harvard Bridge was quickly traversed in directions parallel and perpendicular to the bridge. The boat speed was about 3 knots. The data obtained showed the area of the shells to be between the sixth and eighth spans of the bridge from the south end, and from about 75 yards east of it to about 50 yards west (see Plate 1). This rough reflectivity mapping experiment is cited merely as an instance of what can sometimes be done, unexpectedly, with equipment designed primarily to do something else. The black, impenetrable mud encountered is the same as that described by Crosby and mentioned heretofore in the geology section.

The next three cruises were made in the KAY G, a converted former Navy 40-foot motor launch. Best operating speeds were between 3 and 4 knots, although fairly good results could be had, up to 5.5 knots. The transducer was hung over the side, nearly amidship, about 5 feet down, or a foot below the keel. As the boat was kept at the Savin Hill Yacht Club, on Dorchester Bay, advantage was taken of the opportunity to examine the bay bottom on the runs to and from the harbor main ship channel. On 7 November a profile was run along the coring line shown in Figure 6, but little penetration was obtained to compare with the geologic section. It was hardly to be expected because, as may be seen from Figure 6, the top sedimentary layer is mud, the same stuff that Crosby said covered most of the harbor bottom, and which we first met in the Charles River Basin. Some successful penetration is displayed in Figure 13, however, together with the signal given by bubbles escaping from a leaky sewer pipe. Figure 14 is a good example of layering, interrupted by a covering of the black mud. Still better layering is shown in Figure 15. This is in the main ship channel near nun buoy #8, off Dorchester Bay. The sediment here is light blue clay, with the mud dredged away and probably kept clear by the scouring action of the tidal currents. A charted wreck in Dorchester Bay is located in Figure 16 and the tops of two tunnels under Boston Harbor are gracefully curved in Figure 17.

On 9 November a run was made out of Dorchester Bay, across the main channel to the cove southeast of Logan Airport and thence past Deer Island Light to the outer harbor. In running northward from the main channel near Flasher #2, it was noted that the excellent penetration obtained across the main channel was abruptly terminated in the shallower water of the cove (see Figure 18). Samples again showed blue clay where penetration occurred and black mud where none occurred. But this time, one core sample exhibited only 3 or 4 inches of black mud over the clay at a point where there was still no penetration. This discovery would seem to indicate a strong blanketing effect on the part of only a few inches of black mud against the low power, low frequency waves of the SSP. It is hoped to discover the reason for this by further investigation and laboratory experiment. In order to get a trace of a known rock outcrop, a run was made across a charted outcrop southeast of Deer Island and the signal recorded in Figure 19. The wavy outline of the rock was caused by the rough water tossing the boat up and down.

Previous investigations by Professor Edgerton in Mediterranean harbors at night had uncovered considerable bottom activity beginning after sunset and often resulting in a seeming mass rise from the bottom of unknown organisms. To find out if there was any such activity in Boston Harbor in November, a run was made to Deer Island and back on the night of the 14th. Good bottom profiles were made but no sign of night life, other than an occasional fish, was to be seen. The night was bitterly cold, however, and no doubt unconducive to evening activity. A summer look might be more rewarding. Cold weather drives most bottom dwelling creatures deep into the mud for the winter.

For the last run of the fall series, operations were shifted to Narragansett Bay and conducted on 16 November on board the PILOT I, a boat from Somerset, Massachusetts. It was hoped that a lost torpedo or two might be located along the Navy torpedo range north of Gould Island, and to this end, two Navy petty officers were taken on board from the Torpedo Station. A choppy sea, however, whipped up by a strong nor'wester that morning, made the search almost hopeless from the beginning, and after an hour it was given up. The high resolution of the SSP translated the surface wave motion to the bottom, making identification of small objects thereon or in, virtually impossible. There is, nonetheless, great promise in this equipment for locating objects on and under the bottom.

Two very interesting profiles were obtained later in the day. The first, in Figure 20, is a sub-bottom layer, east of Conanicut Island, which, after running submerged for some distance, finally broke through the sediment long enough to be identified as a shelly layer. Outcrops like this might be deceptive to a geologist mapping the bottom by means of bottom sampling alone. In most cases, they would not even be found by him, and in no case, unless he took relatively deep corings, could he know of the existence of the submerged shelly layer. The second profile, Figure 21, is that of a rock pinnacle beneath the bottom sediment, southeast of Hope Island. It is more than likely that this is an "undiscovered" peak and quite likely that it will not be discovered again until another pinger-penetrator uncovers it.

Three key bottom samples were examined in the Soil Mechanics Laboratory for specific gravity and grain analysis. One was from the black mud in the Charles River Basin, one from the blue clay in the main ship cannel and one from the sediment east of Conanicut Island in Narragansett Bay, through which the shelly layer was detected. The specific gravity of the first sample is calculated to be 2.6384; of the second sample, 2.7841; and of the third, 2.5854 (see Figures 22-24). The grain size distribution of the three samples is illustrated in Figures 25-27.

Determination of specific gravity and grain size distribution was made according to the procedures described in SOIL TESTING FOR ENGINEERS, by T. W. Lambe. In the specific gravity test, about 50 g. (in dry weight) of the sample is worked into a smooth paste by mixing it with de-aerated water. The paste is poured into a calibrated pycnometer and the entrapped air removed by boiling for ten minutes in a partial vacuum. The bottle is then allowed to cool and enough water is added to bring the bottom of the meniscus to the calibration mark. The outside of the bottle and the inside of the neck above the meniscus are dried and the bottle, with water and sediment in it, weighed to 0.01 g. The contents of the bottle are checked for uniform temperature and the temperature recorded. The entire mixture is then poured into a large evaporating dish of known weight and dried in an oven. After cooling, the dish and sediment are weighed. This weight, less the known weight of the dish, gives the weight of the sediment grains, which is used in the equation for determining the specific gravity.

Determination of grain size distribution was made by hydrometer analysis. In this method, the procedure is as follows:

1. Mix approximately 50 g. (in dry weight) of moist sample with de-aerated water to form a thin smooth paste.

2. Add a deflocculating agent (e.g. sodium tetraphosphate) to the paste and wash the mixture into the cup of a mixing machine by using a syringe.

3. Mix the suspension in the mixer until the sample is broken down into its individual particles (about 10 minutes).

4. Fill a graduated jar with de-aerated water in which to store the hydrometer.

5. After mixing, was the sample into a graduated cylinder and add enough de-aerated water to bring the level to the 1000 cc mark.

6. Mix the sediment and water in the graduate by placing the palm of the hand over the open end and turning the graduate upside down and back. Be sure no sediment is stuck to the base of the graduate.

7. After shaking it for about 30 seconds replace the graduate on the table, insert the hydrometer in the suspension and start a timer.

8. Take hydrometer readings at total elapsed times of 0.25, 0.5, 1.0 and 2.0 minutes (or any other convenient intervals) without removing the hydrometer. The suspension should be remixed, and this set of four readings repeated until a consistent pair of sets have been obtained.

9. After the 2-minute reading, remove the hydrometer, remix and restart the test at the 2-minute mark. For this reading and all the following ones, insert the hydrometer just before reading. Before each insertion of the hydrometer, dry the stem.

10. Take hydrometer readings at total elapsed time intervals of 2, 5, 10, 20 minutes, etc., approximately doubling the previous time interval. The hydrometer should be removed from the suspension and

stored in the graduate of de-aerated water after each reading. Take frequent temperatures of the suspension.

11. Attempt to minimize temperature variations by working in a constant temperature room.

12. Keep the top of the jar containing the soil suspension covered to retard evaporation and to prevent the collection of dust from the air.

13. Obtain the height of meniscus rise of the de-aerated water on the stem of the hydrometer. This meniscus correction is used in the calculations.

14. Continue taking observations until the hydrometer reads approximately one, i.e., ground 1.001, or until readings have been obtained at elapsed times large enough to give the sediment particle diameter desired.

15. After the final reading, pour the suspension into large evaporating dishes; take special care to avoid losing any sediment.

16. Evaporate the suspension to dryness in the oven, cool the dishes in a dessicator and weigh to 0.1 g.

17. The weight of the dishes subtracted from that determined in step 16 gives the weight of the dry soil used.

The above procedure depends on STOKES' equation for the terminal velocity of a falling sphere. A number of assumptions in the equation are not completely fulfilled, among them:

1. No interference of particles by other particles or by the walls of the container.

2. Spherical particles.

3. Known specific gravity of the particles.

Detailed explanation of each one of these is unnecessary here. The net result gives a fairly useful classification.

Calculations are made, using STOKES' equation and are illustrated in Figures 25-27.

V. Discussion

A. S. Laughton, in a study of variations of velocity with changes of compaction pressure in ocean sediments, reminds us that the mechanism of elastic wave propagation in granular media has been the subject of many recent papers (Urick 1947, Gassman 1951, Morse 1952, Ament 1953) and that these have shown how only with very simple models can expressions for the velocity and attenuation be formulated explicitly in terms of the composition of the media. Using a more empirical approach, he obtained some interesting results. His data suggests, for instance, that in uncompacted material, the more calcareous the sediment, the higher the velocity. This is, however, probably a secondary effect to the basic relation between grain size and velocity. No shear waves could be measured in the uncompacted material.

Expressing anisotrophy as the ratio of the P (compression) wave velocity in a transverse direction to that in a longitudinal direction, measurements showed that in some cases the velocity along the axis of the compacted sample differed from that perpendicular to it by as much as 30 percent. Furthermore, Laughton finds a notable increase in anisotrophy with increasing clay content. In compacted clays and similar laminated sediments, anisotrophy occurs under natural conditions as a result of uniaxial compaction, an effect often observed in sedimentary rocks and schists, where the velocity parallel to the bedding is always greater than that perpendicular to it.

The velocity of compressional waves increases with pressure in the range of ocean sediments studied by Laughton according to the relation:

$$Vp = 1.5 + 0.04p^{\frac{1}{2}} \qquad \begin{array}{l}(Vp \text{ in km/sec.})\\(p \text{ in kg/sq. cm.})\end{array}$$

up to velocities of 3.0 km/sec. To account for velocity changes, the sediment particles may be supposed to form a structure which in part supports the stresses during the transmission of an elastic wave and which plays an increasingly important part as the compaction becomes more advanced. The effect of hydrostatic pressure applied to the interstitial water is negligible. When a pressure of 400 kg/cm^2 was applied, in no case did the velocity change by more than 3 percent. At 5 kg/cm^2 the velocity increase was the same for clay as for sea water. The increase becomes less, however, with reduction of the water content in the clay. Seismic experiments give an increase of velocity from between 1.5 and 1.8 km/sec at the surface of the sediment to over 2 km/sec at a thickness of a kilometre.

Zietz and Pakiser take note of work somewhat similar to that under discussion. Modified sonar transducers are siad to have been successfully used in water covered areas to determine water depths, layers within the bottom sediments and depth to bed rock. Whereas velocity discontinuities at depths of several hundred or more feet have long been successfully mapped by means of conventional seismic reflection methods, the possibility of detecting shallow horizontal beds by placing a sonar transducer on the ground (or bottom) is particularly attractive. Reflections from closely spaced horizons have been recorded by increasing the filtered frequency range of the amplifiers to an upper limit of 300 to 500 cycles per second. Evison has successfully recorded still shallower reflections by using an electromechanical vibrator that generates a square-enveloped pulse of sine waves at frequencies of 100 to 800 cycles per second and pulse widths of from 5 to 100 milliseconds.

Several years ago, using a crystal sonar transducer manufactured by the Telephonics Corporation, the U. S. Geological Survey conducted sonic tests in Portage County, Ohio. The signal output is a square-enveloped pulse ranging in length from 1 to 9 msec. and containing waves of frequencies 6, 11.5, or 16 kc. The transducer delivers a maximum of 2500 watts of acoustic power in water. Because it was designed for maximum energy transfer into water, an acoustic mismatch occurs when it is placed directly over the ground and it is necessary to devise a suitable coupling. Of four devices tried, the best proved to be a water-filled, galvanized steel cylindrical tank about three feet high and three feet in diameter surrounded by a thin plastic membrane that also formed the bottom of the tank. A thin film of grease was placed between the plastic and the ground for more efficient coupling. The transducer was immersed in the water.

In the Ohio test, apparent reflections coming from velocity discontinuities a few feet below the surface of the ground to depths as great as 100 feet or more were recorded. Although sound absorption in earth increases with frequency, maximum energy penetration of the unconsolidated glacial till and coarse glacial outwash occurred with a transmitter frequency of 11.5 kc, rather than with 6 kc. The transducer was designed, however, for maximum power output at 11.5 kc. The sonar records were similar to those obtained with the transducer immersed completely in a large body of water. Most of them displayed many multiple reflections, as did our own SSP in the Charles River Basin. At a number of locations, a prominent reflection repeating as many as 17 times (compare with 20 in the Charles River Basin) with an interval of 5 to 6 msec. was noted. As it was known, from seismic refraction data at two of these locations, that the two-way delay time in the weathered layer,above the shallow water table was almost identically the same (5 to 6 msec.), it was assumed that the multiple reflection represented repeated travel of the acoustic pulse between the surface of the ground and the shallow water table.

W. O. Smith obtained some excellent results in locating shallow bed rock with low frequency sound. At Lake Mead, where the sediments are mostly clay of high water content, penetration to a depth of 140 feet was reached by low power (about 20 watts) sound at 14.2 kc. Sound of 50 and 80 kc would not penetrate. At Passamaquoddy Bay excellent delineation of bed rock at 250 feet was obtained with 6 kc and about 700 watts of output power. This was much better than 11 kc at higher power. Long power pulses were used of from 14 to 25 msec. Still deeper penetration was accomplished in Huntington Bay, Long Island, with a frequency of 6 kc, a variable pulse length of from 1 to 9 msec. and an output of acoustic power of about 2500 watts. With the transducer in ordinary operating positions penetration reached 400 feet, which increased to 750 feet when the transducer was placed directly on the bottom.

The velocity of sound where penetration occurred in the Lake Mead sediments was determined to be approximately 5000 ft/sec, about the same as in water. The answer to the question as to why there is a difference in acoustic penetration is not simple and seems to depend upon both the nature of the sediments and the sound characteristics. Our investigations show a definite relation between penetration and the clay content of the sediment, the penetration being deeper in sediments containing a higher percentage of clay. Our experience has been similar to that at Lake Mead in obtaining no penetration through sand, and very little through the black, silty, carbonaceous mud. We have also had similar experiences with multiple echoes, which arise in sediments as well as in water. Smith cites as illustration a simple case where a water surface, a water bottom and an underlying bed rock exist. Considering the overburden homogeneous, the simplest case is that of reflection of a part of the first bedrock echo at the water surface and its return to the water bottom, where it is reflected to form a second bedrock echo. Another case is that arising from return from the water surface of a part of the energy of the first bedrock echo back through the water bottom and its second reflection at the top of the bedrock, back through the water bottom to the transducer. Very unusual conditions can arise from internal reflections within complex sediments.

J. E. Nafe and C. L. Drake have found in a study of the dependence of the velocity of compressional waves in marine sediments upon the thickness of overburden, that the velocity-depth relationship in shallow water sediments is distinctly different from that in deep water sediments. The difference between the two cases is illustrated by the straight lines that best represent their data:

$$V = 1.70\ Z + 1.70 \qquad \text{shallow water}$$

$$V = 0.43\ Z + 1.83 \qquad \text{deep water}$$

where V is in km/sec and Z is in kilometres. Shallow and deep water are defined arbitrarily to be under 100 fathoms and other 1500 fathoms, respectively. It is seen that the velocity in shallow water sediments rises much more rapidly with depth than in deep water and this is supposed to be the consequence of different degrees of lithification.

The major factor controlling velocity variations in sediments is generally thought to be porosity. At the same depth of overburden porosity is much greater in deep water sediments than in shallow. The velocities of elastic waves in porous media are related to the properties of the medium in a complex manner. Not only are waves of dilation and rotation possible but there may be two dilational waves of different velocities dependent upon properties of the fluid, the lattice and the coupling. A velocity equation that appears to be quite satisfactory is:

$$V^2 = {}_1Vw^2 \left(1 + \frac{p_1}{p} \phi_2\right) + \frac{p_2}{p} \phi_2^n V_2^{\,2}$$

where ϕ_1 = porosity

$\phi_2 = (1 - \phi_1)$

p = density = $p_1 \phi_1 + p_2 \phi_2$

The exponent n is determined by comparison with experiment and observation and for a value of 4 or 5 gives a fairly good representation of the facts both at high and low porosity. The subscripts 1 and 2 refer to fluid and suspended particles, respectively.

and Vw is given by the equation,

$$\frac{(1 + q)}{pV^2} = \frac{\phi_1}{p_2V_1{}^2} + \frac{\phi_2(1 + q_2)}{p_2V_2{}^2}$$

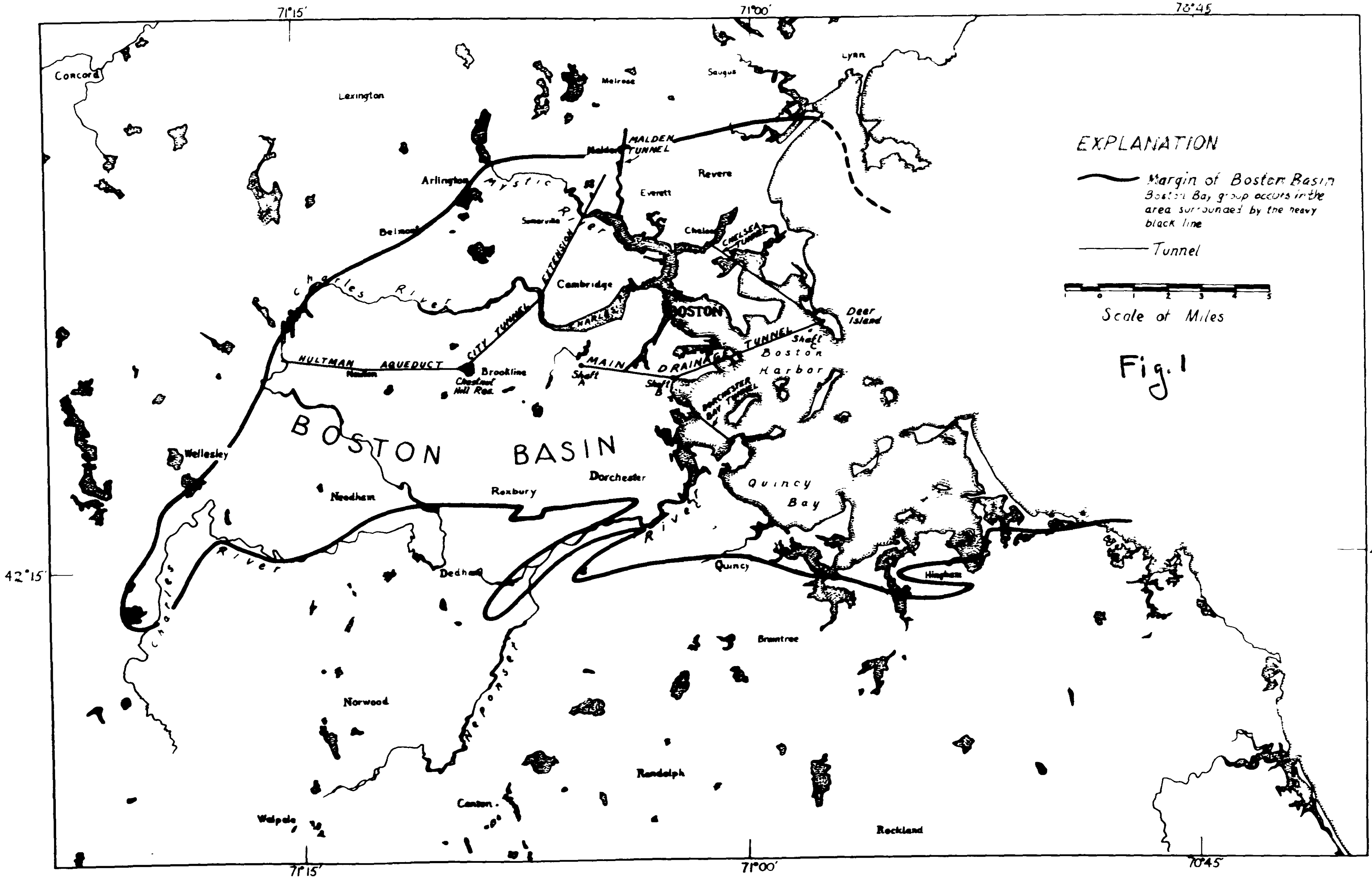
with $q = q_2 = 0$.

Porosity appears to be a highly significant factor in compressional wave velocities, and it is certainly a measure of the relative importance of the lattice of connected particles in determining stiffness and of the kind and number of particle contacts. From laboratory experiments on bottom corings with an acoustic probe, L. R. Sykes concludes that velocity in water saturated bottom sediments is largely a function of water content or porosity, and that lithological changes involving differences in porosity have a much greater influence on velocity than depth.

Although no part of the foregoing discussion seems to give us a direct explanation of our inability to penetrate the soft, black, basin mud with the low power, low frequency acoustic waves of the sonar sediment probe, it does suggest that the answer probably lies within the complex physical relationships between sediment composition, porosity, water and gas content, density, lithology, depth and velocity gradient. Further investigation, involving various combinations of power output, frequency, pulse length and transducer positioning, together with acoustical experiments on sediment samples in the laboratory should enable us to penetrate the darkness.

VI. Conclusions

Low power, 12 kc., short pulse acoustic waves penetrate shallow water clayey sediments very effectively. Depth of penetration appears to be a function of clay content; the more clay the better penetration. The particular characteristic of clay which makes it so readily penetrable by these waves, in contrast to the impenetrability of the black mud, is not yet understood. Various combinations of power, transducer positioning, pulse length and frequency ought to be tried, and the sediments examined in the laboratory in order that more may be learned about their chemical and physical qualities. In its present state of development, the Sonar Sediment Probe can already be useful in a variety of ways. Its excellent resolution makes it very helpful in locating objects on the bottom, rock outcrops, wrecks, etc. Its ability to penetrate clayey sediments enables it to see continuously things heretofore unseen in the sub-bottom deposits. If more can be learned about the nature of the sediments, suitable modifications can undoubtedly be incorporated in the sonar equipment to broaden its penetrative capability. The Boston Basin offers a splendid testing ground for developmental work which should be pushed with renewed vigor. The mapping of the basin sediments would be a signal accomplishment in itself, while the possibilities opened up by still better acoustic devices for shallow water exploration and mapping would be exciting indeed.



71°15′
71°00′
70°45′
42°15′
Concord
Lexington
Melrose
Saugus
Lynn
Arlington
Mystic River
Malden
MALDEN TUNNEL
Revere
Everett
Somerville
Belmont
Chelsea
CHELSEA TUNNEL
Cambridge
Charles River
CITY TUNNEL EXTENSION
BOSTON
Deer Island
HULTMAN AQUEDUCT
Newton
Brookline
Chestnut Hill Res.
MAIN DRAINAGE TUNNEL
Shaft A
Shaft B
Shaft C
Boston Harbor
DORCHESTER BAY TUNNEL
BOSTON BASIN
Wellesley
Needham
Roxbury
Dorchester
Quincy Bay
Neponset River
Dedham
Quincy
Hingham
Braintree
Norwood
Randolph
Canton
Walpole
Rockland
EXPLANATION
Margin of Boston Basin
Boston Bay group occurs in the area surrounded by the heavy black line
Tunnel
0 1 2 3 4 5
Scale of Miles

Fig. 1

IDEALIZED SECTION OF PLEISTOCENE GLACIAL DEPOSITS

IN THE BOSTON AREA.

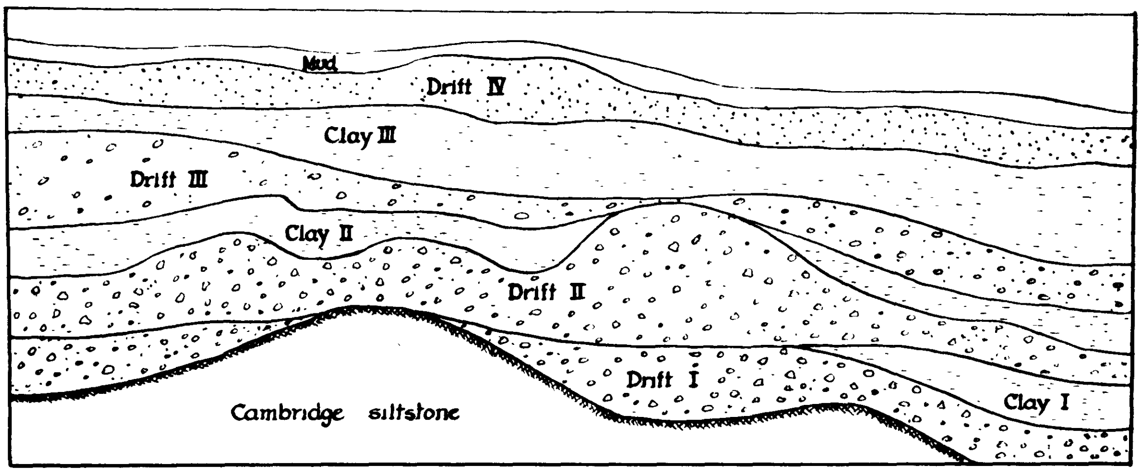


Fig. 2

KEY MAP TO SECTIONS 1, 2, 3 & 4.

CHARLES RIVER BASIN.

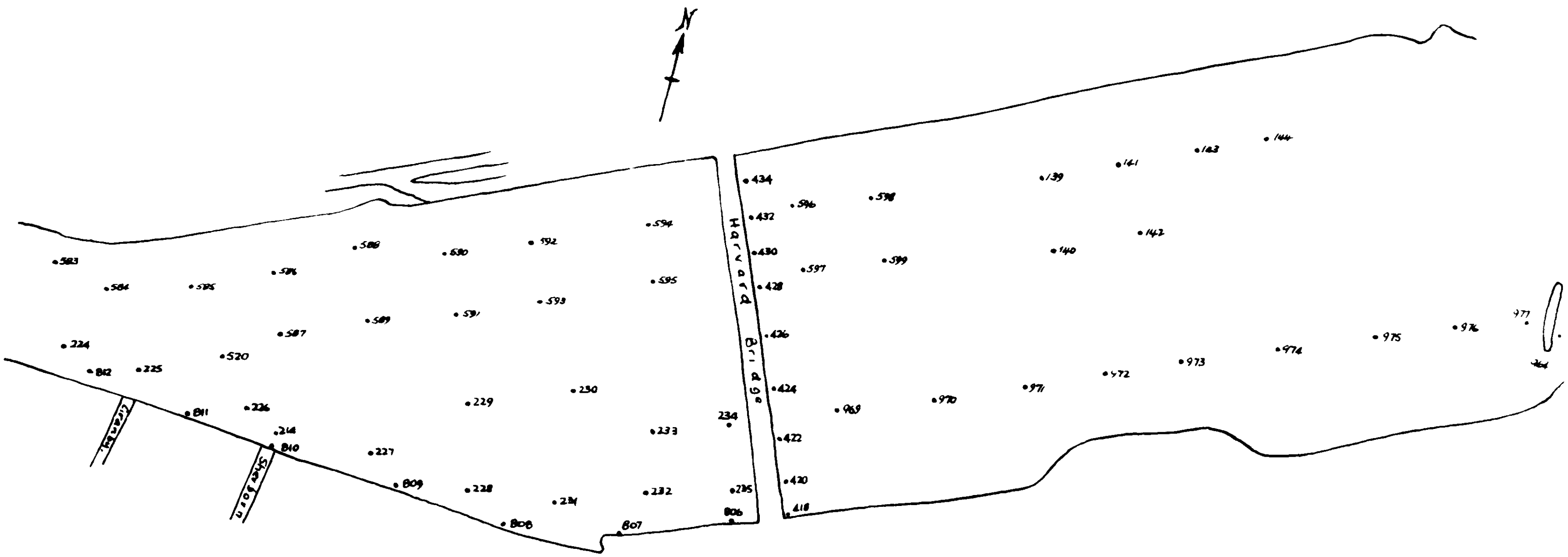
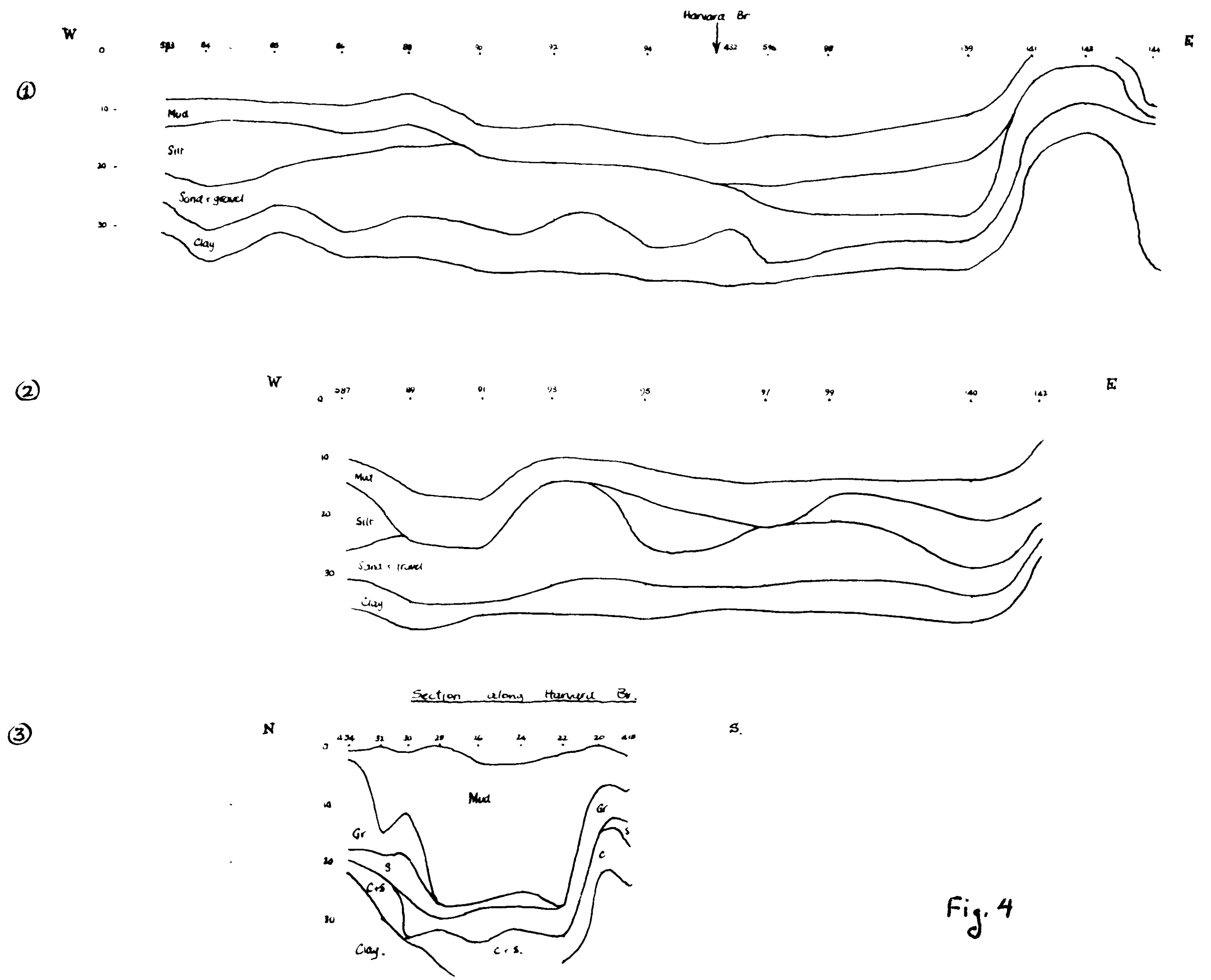


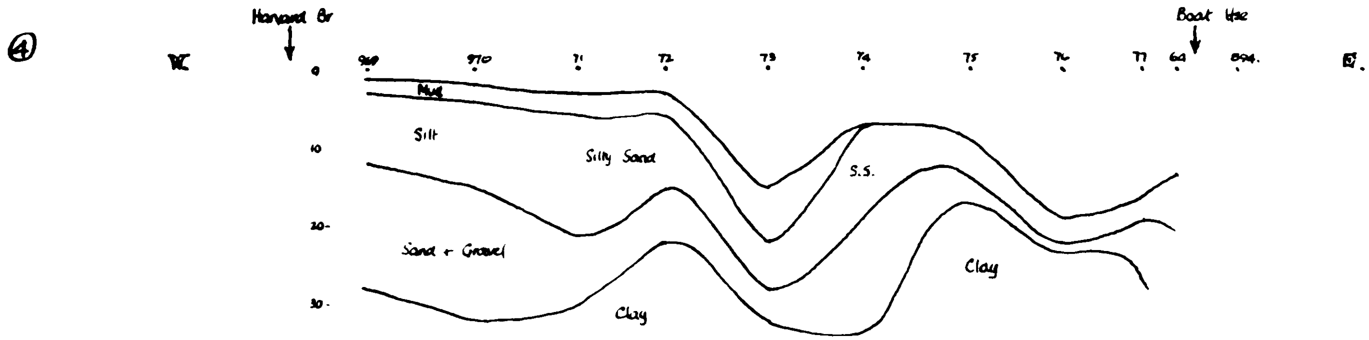
Fig. 3



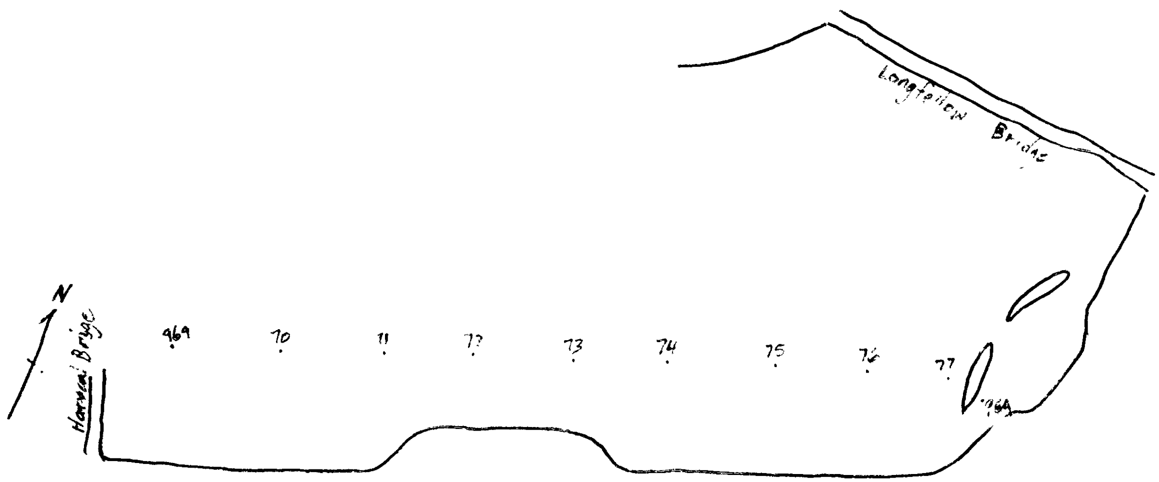
①
W
E
Harvard Br
Mud
Silt
Sand + gravel
Clay
②
W
E
Mud
Silt
Sand + gravel
Clay
Section along Harvard Br.
③
N
S.
Mud
Gr
S
C+S
Clay.
C + S.
C

Fig. 4

④

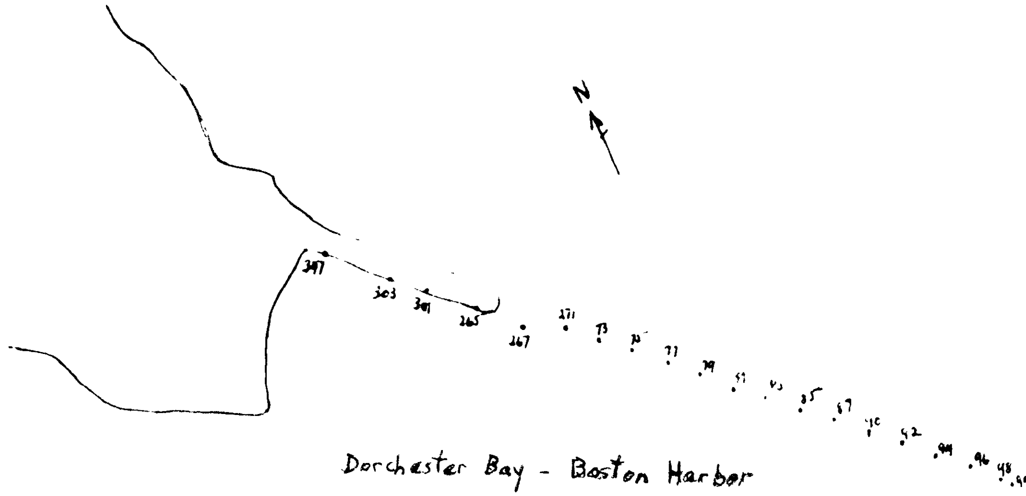


Harvard Br
Boat Hse
W
969
970
71
72
73
74
75
76
77
64
894.
E.
0
10
20
30
Mud
Silt
Silty Sand
S.S.
Sand + Gravel
Clay
Clay



Longfellow Bridge
N
Harvard Bridge
969
70
71
72
73
74
75
76
77
964

Fig. 5



Dorchester Bay - Boston Harbor

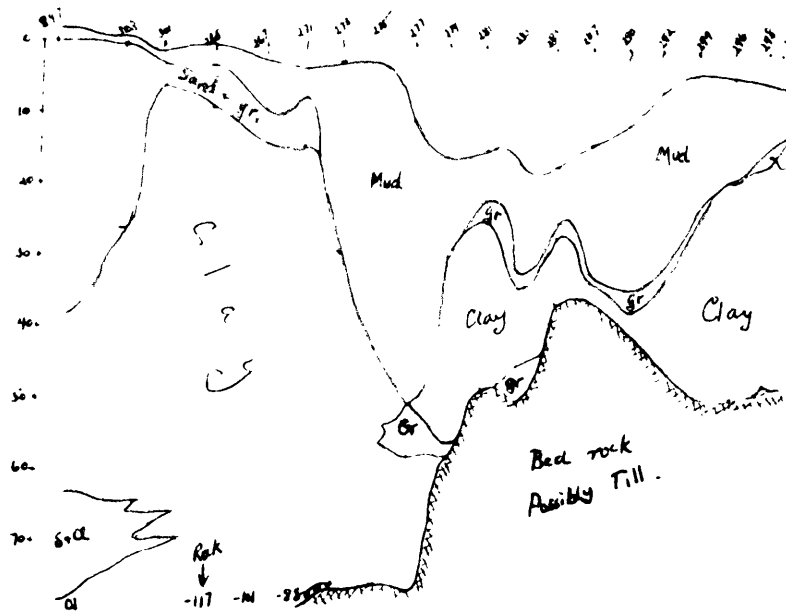
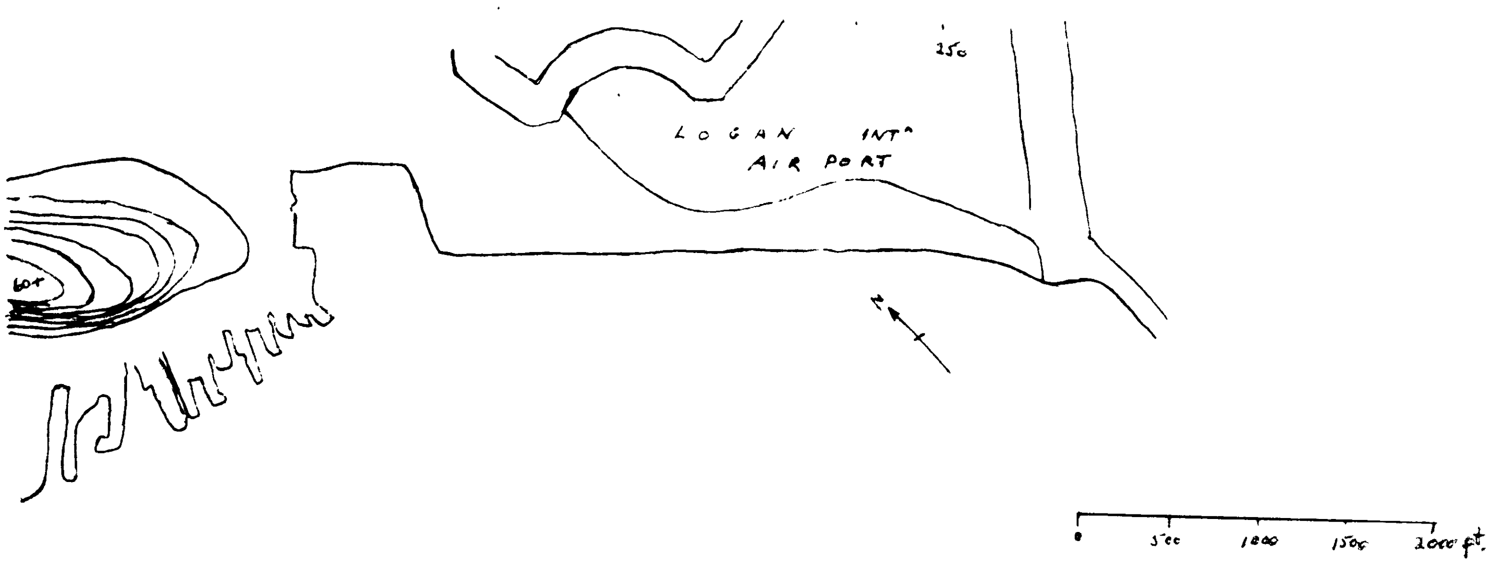
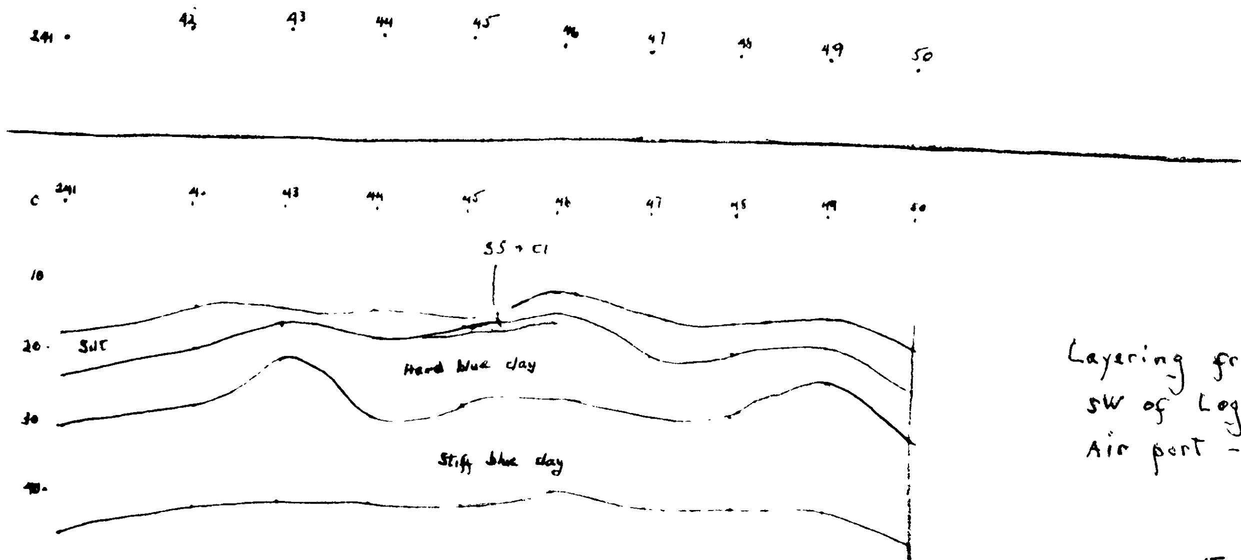


Fig. 6





Layering from core logs
SW of Logan International
Air port - Boston Harbor

Fig. 7

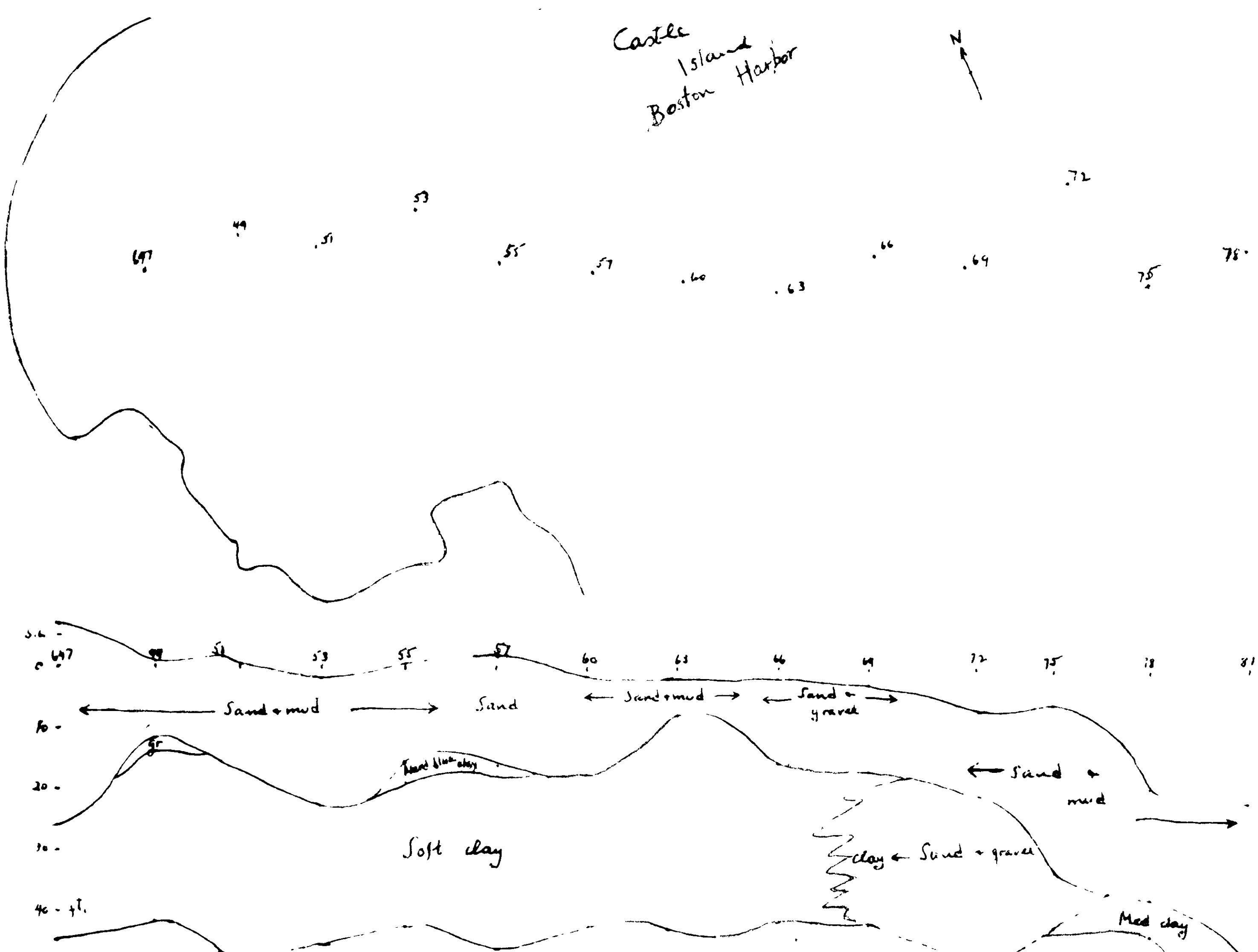
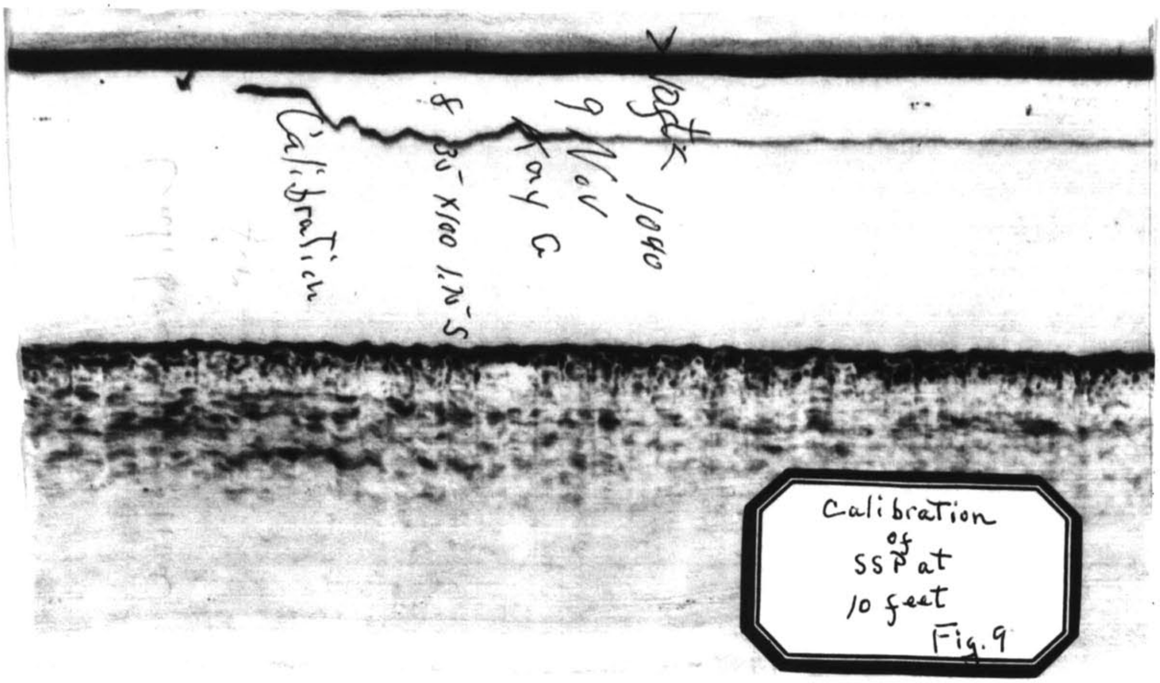
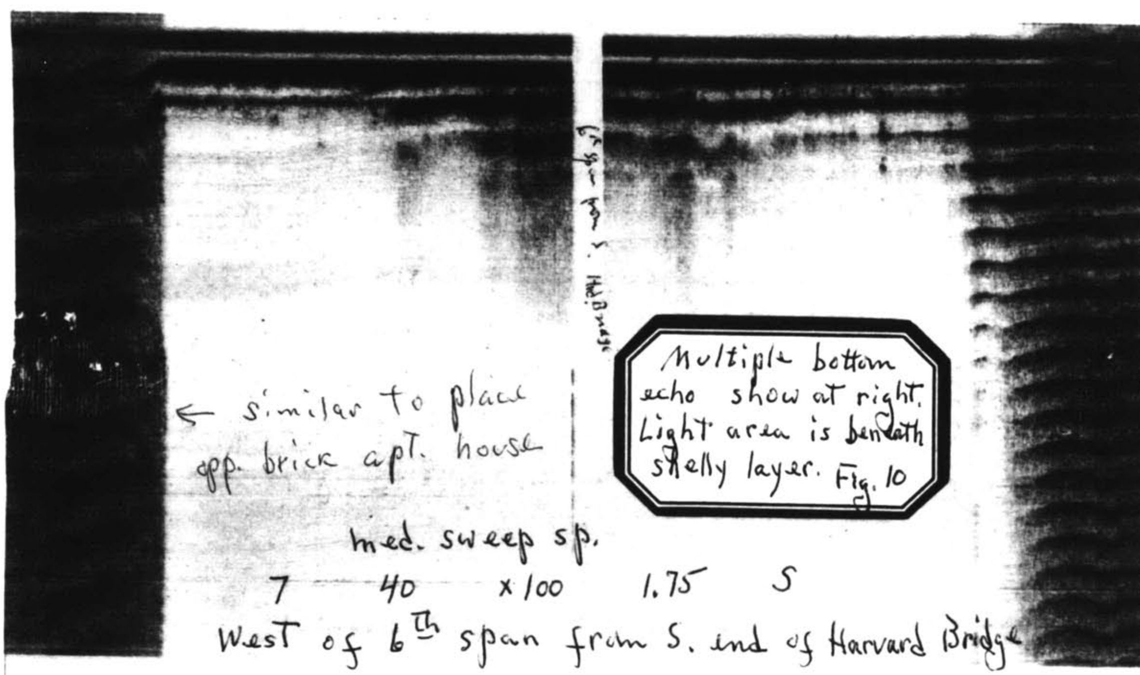

Castle
Island
Boston Harbor
N
53
49
51
55
57
60
63
66
69
72
75
78
81
Sand + mud
Sand
Sand + mud
Sand + gravel
Sand + mud
Soft clay
clay
Sand + gravel
Med clay
10
20
30
40 - ft.

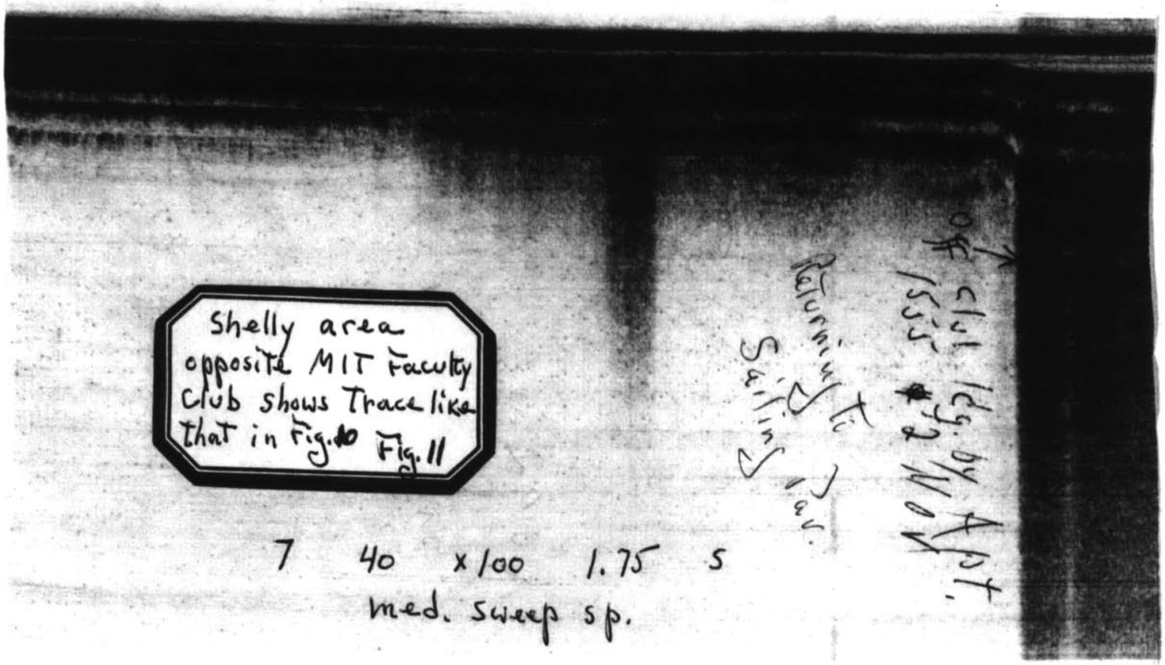
Fig. 8



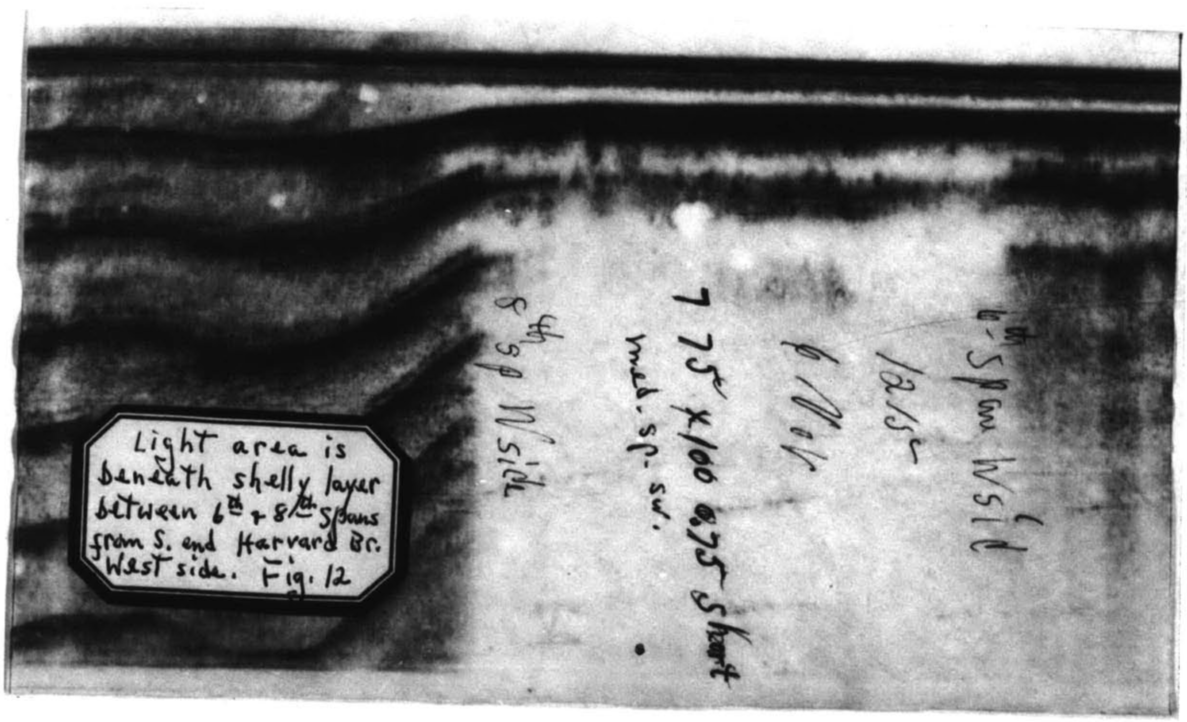
Calibration of SSP at 10 feet Fig. 9



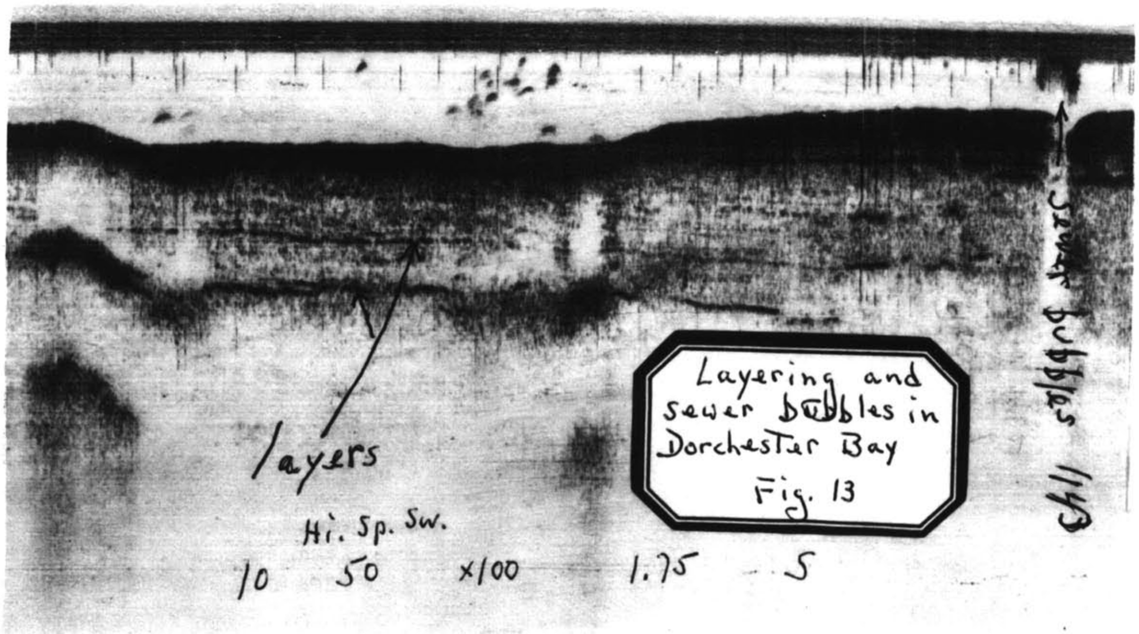
Multiple bottom echo show at right. Light area is beneath shelly layer. Fig. 10



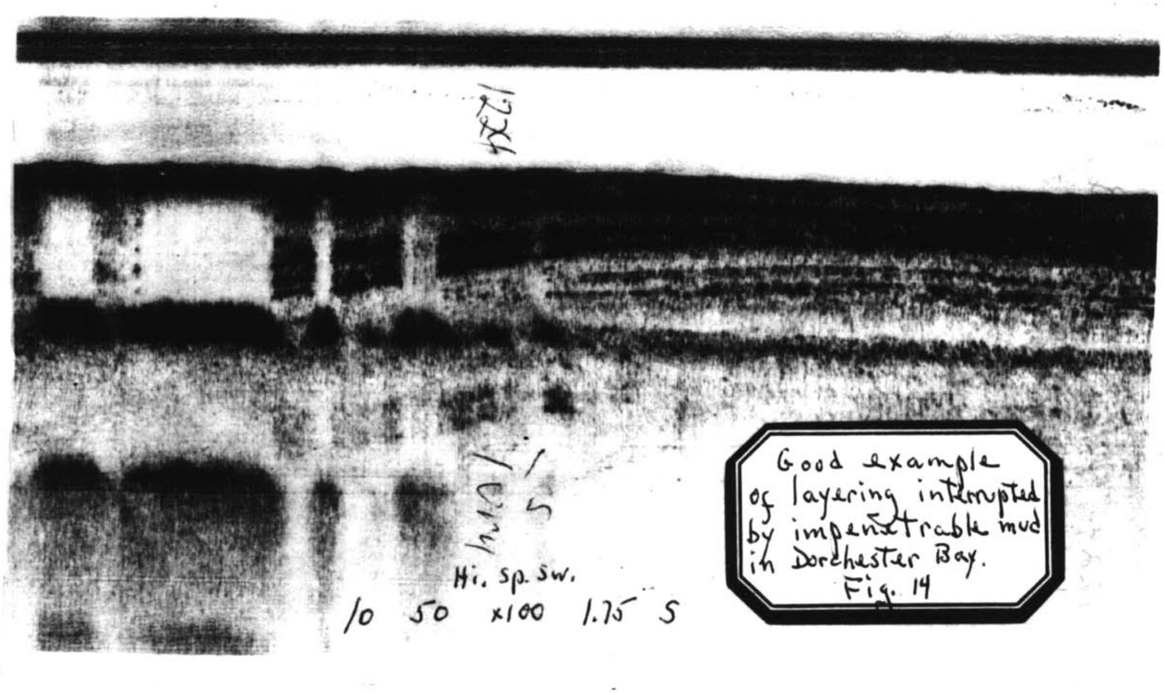
Shelly area opposite MIT Faculty Club shows Trace like that in Fig. 10 Fig. 11



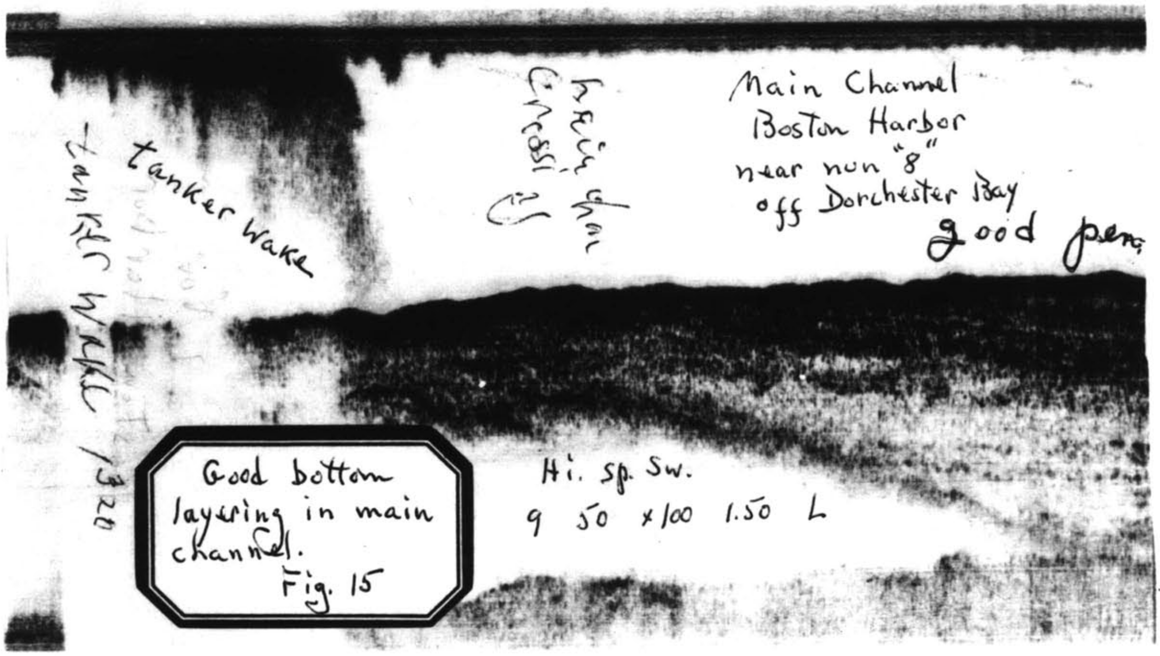
Light area is beneath shelly layer between 6th + 8th spans from S. end Harvard Br. West side. Fig. 12



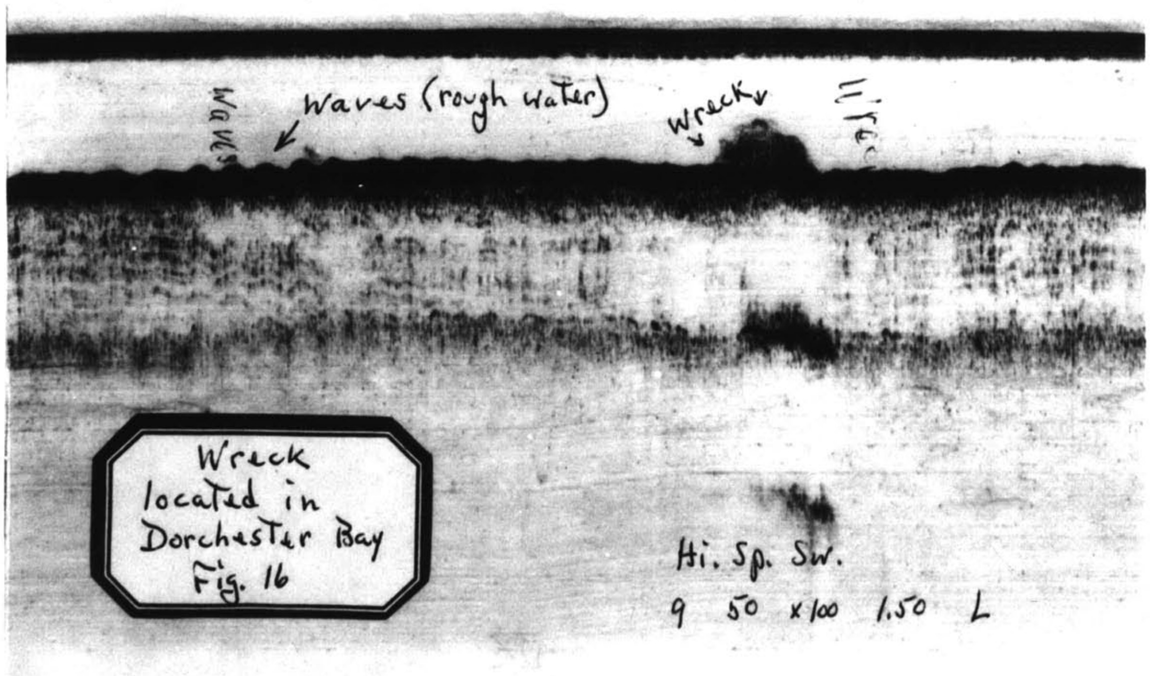
Layering and sewer bubbles in Dorchester Bay
Fig. 13



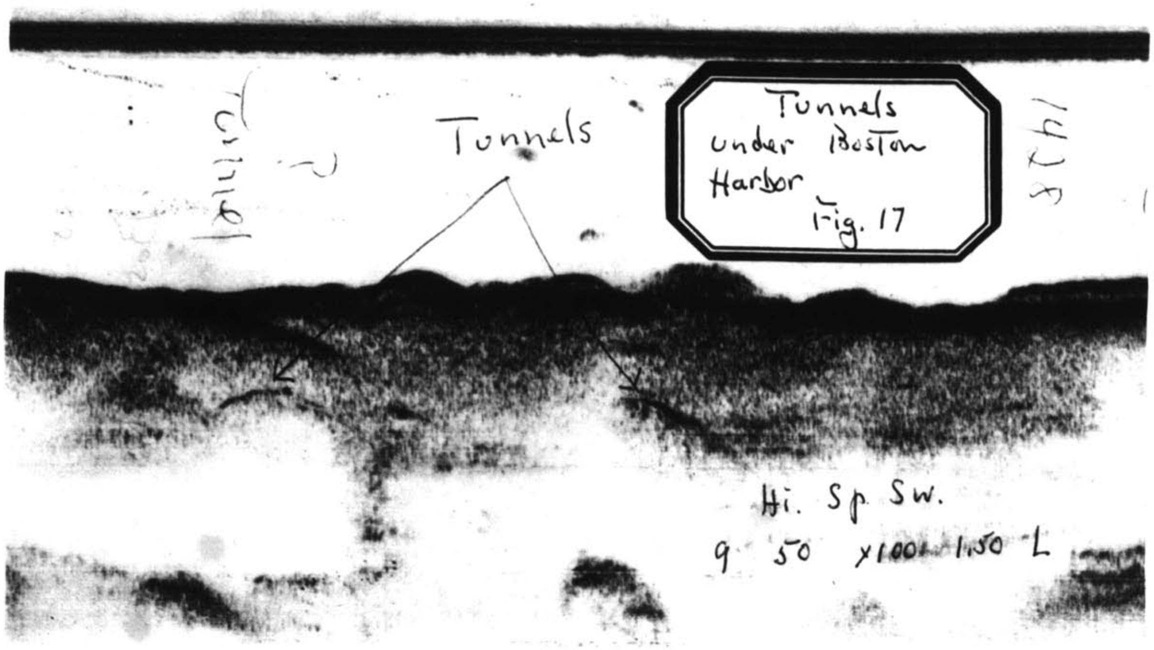
Good example of layering interrupted by impenetrable mud in Dorchester Bay.
Fig. 14

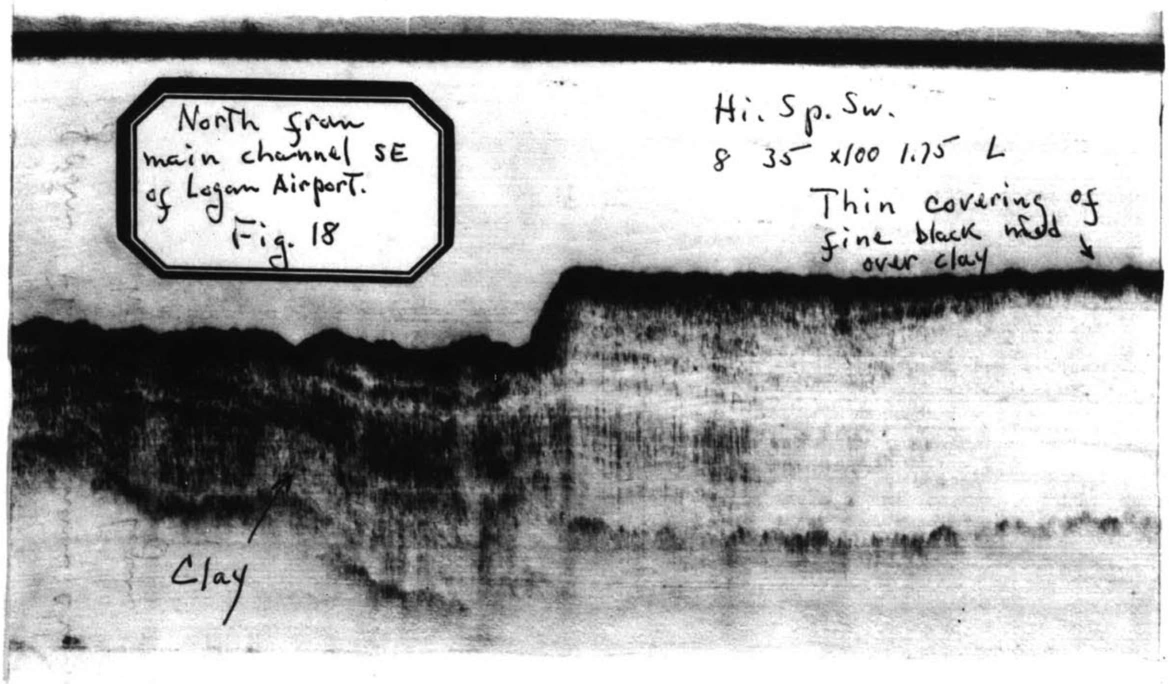


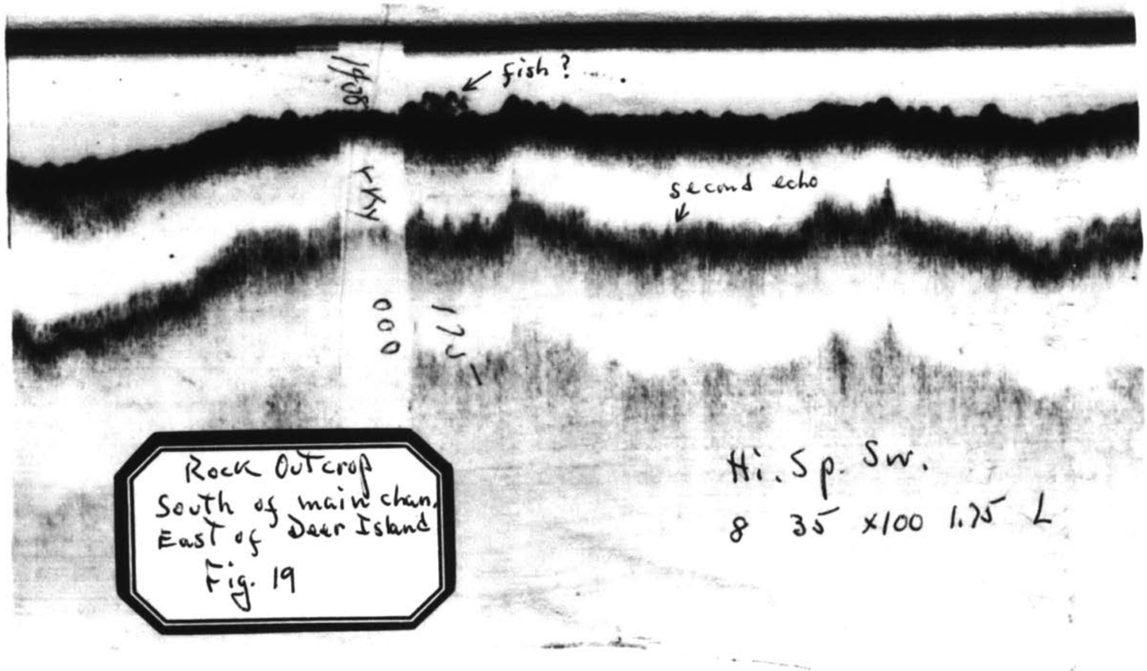
Good bottom layering in main channel.
Fig. 15



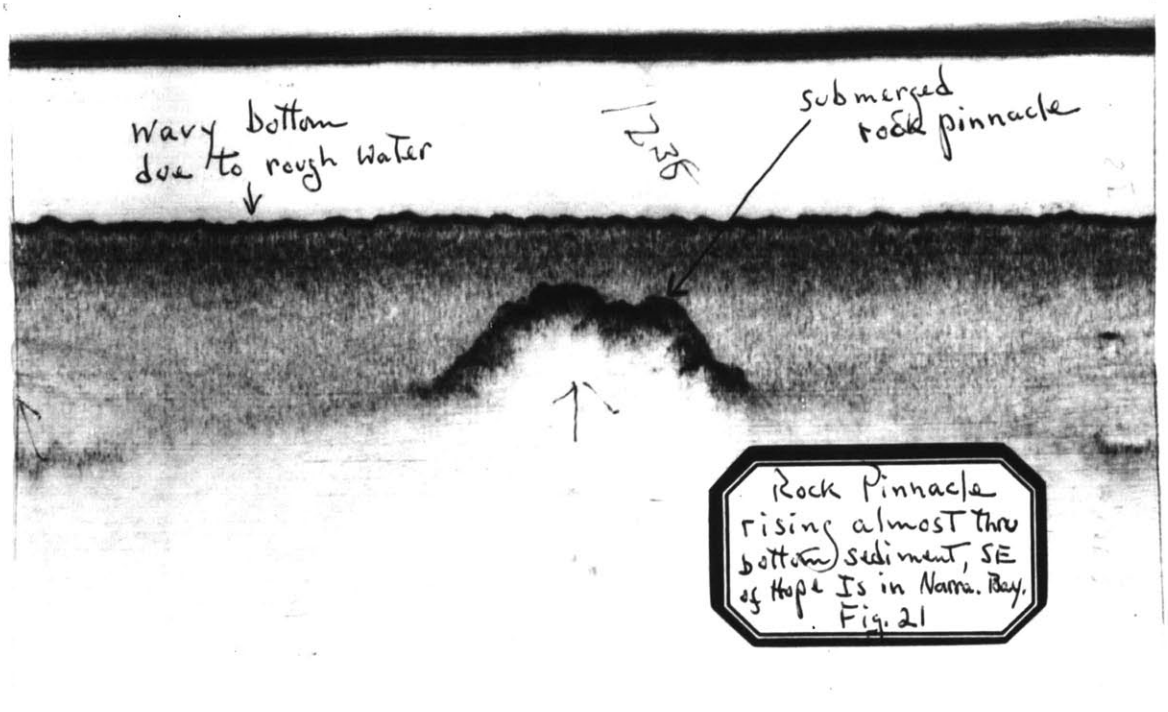
Wreck located in Dorchester Bay
Fig. 16


Tunnels
Tunnels under Boston Harbor Fig. 17
Hi. Sp. Sw.
9 50 x100 1.50 L

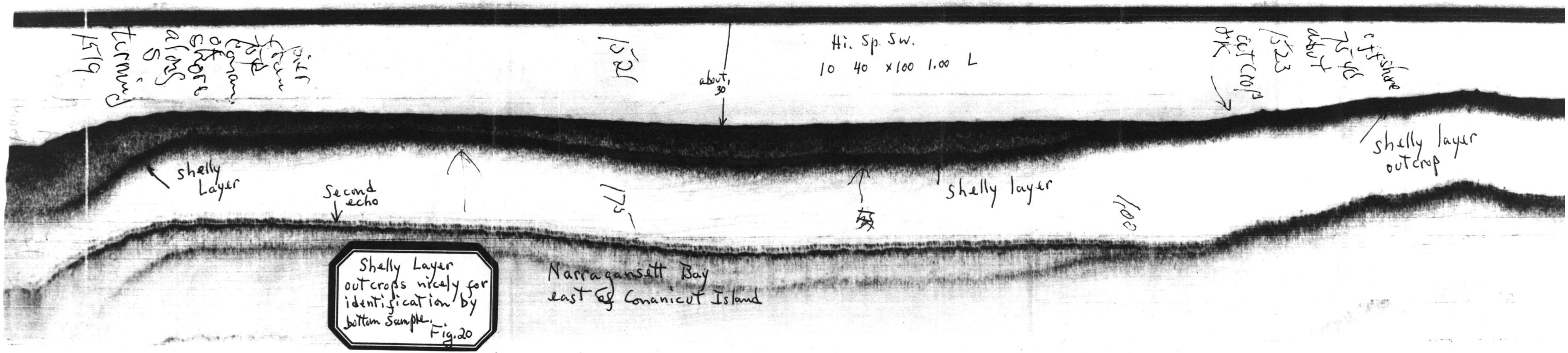

North from main channel SE of Logan Airport. Fig. 18
Hi. Sp. Sw.
8 35 x100 1.75 L
Thin covering of fine black mud over clay
Clay



Rock Outcrop South of main chan, East of Deer Island Fig. 19



Rock Pinnacle rising almost thru bottom sediment, SE of Hope Is in Narra. Bay. Fig. 21



Shelly Layer outcrops nicely for identification by bottom sample. Fig. 20

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SOIL MECHANICS LABORATORY

SPECIFIC GRAVITY TEST

SOIL SAMPLE #1

VISUAL CLASSIFICATION AND DESCRIPTION Fine black mud carbonaceous

LOCATION opp. steps, across river fr. Sail. Pav.

BORING NO. 1 SAMPLE DEPTH 10 ft.

SAMPLE NO. 1

TEST NO. 1

DATE 11 December 1962

TESTED BY Payson - Phipps - Yearley

DETERMINATION NO.	1	2	3	4
BOTTLE NO.	1			
WT. BOTTLE + WATER + SOIL, W_1, IN g	700.93			
TEMPERATURE, T, IN °C	25.45			
WT. BOTTLE + WATER, W_2, IN g	643.44			
EVAPORATING DISH NO.	N-7			
WT. DISH + DRY SOIL IN g	605.83			
WT. DISH IN g	513.42			
WT. SOIL, W_s, IN g	92.41			
SPECIFIC GRAVITY OF WATER AT T, G_T	0.99695			
SPECIFIC GRAVITY OF SOIL, G_s	2.6384			

REMARKS The Recorder showed remarkable reflectivity from this black sediment, but little penetration into it.

$$G_s = \frac{G_T W_s}{W_2 - W_1 + W_s} ; \quad G_s \; 2.6384$$

Fig. 22

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SOIL MECHANICS LABORATORY

SPECIFIC GRAVITY TEST

SOIL SAMPLE #2

VISUAL CLASSIFICATION Blue Clay
AND DESCRIPTION light blue green
LOCATION bet. #7+8, Main Chan., Boston Hbr.
BORING NO. 1 SAMPLE DEPTH 35 ft.
SAMPLE NO. 1

TEST NO. 1
DATE 14 December 1962
TESTED BY Payson-Phipps-Yearsley

DETERMINATION NO.	1	2	3	4
BOTTLE NO.	4			
WT. BOTTLE + WATER + SOIL, W_1, IN g	678.21			
TEMPERATURE, T, IN °C	28.90			
WT. BOTTLE + WATER, W_2, IN g	641.64			
EVAPORATING DISH NO.	A-1			
WT. DISH + DRY SOIL IN g	495.75			
WT. DISH IN g	438.81			
WT. SOIL, W_s, IN g	56.94			
SPECIFIC GRAVITY OF WATER AT T, G_T	0.9960			
SPECIFIC GRAVITY OF SOIL, G_s	2.7841			

REMARKS This clay is readily penetrated by the low power, 12 Kc, acoustic waves. A few inches of black mud overlying it, however, completely masks it.

$$G_s = \frac{G_T W_s}{W_s - W_1 + W_2}$$; G_s 2.7841

Fig. 23

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SOIL MECHANICS LABORATORY

SPECIFIC GRAVITY TEST

SOIL SAMPLE # 3

VISUAL CLASSIFICATION Clayey silt
AND DESCRIPTION dark fine silt
LOCATION E. of Conanicut Is., Narra. Bay
BORING NO. 1 SAMPLE DEPTH 25 ft.
SAMPLE NO. 1

TEST NO. 1
DATE 14 December 1962
TESTED BY Payson-Phipps-Yearsley

DETERMINATION NO.	1	2	3	4
BOTTLE NO.	1			
WT. BOTTLE + WATER + SOIL, W_1, IN g	694.17			
TEMPERATURE, T, IN °C	26.4			
WT. BOTTLE + WATER, W_2, IN g	643.35			
EVAPORATING DISH NO.	A-1			
WT. DISH + DRY SOIL IN g	521.50			
WT. DISH IN g	438.79			
WT. SOIL, W_s, IN g	82.71			
SPECIFIC GRAVITY OF WATER AT T, G_T	0.9967			
SPECIFIC GRAVITY OF SOIL, G_s	2.5854			

REMARKS Good penetration was made through this sediment to a clearly recorded shelly layer 5-10 ft. under. The shelly layer was identified at an out cropping farther along the bottom.

$$G_s = \frac{G_T W_s}{W_s - W_1 + W_2}$$; G_s 2.5854

Fig. 24

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SOIL MECHANICS LABORATORY

HYDROMETER ANALYSIS

SOIL SAMPLE # 1 (#5 - 6 Nov.)
Fine black carbonaceous mud

LOCATION opp. steps across river fr. sail. pav.
BORING NO. 1 SAMPLE DEPTH 10 ft.
SAMPLE NO. 1
SPECIFIC GRAVITY, G, 2.6384

SOIL SAMPLE WEIGHT
CONTAINER NO. A-1
WT. CONTAINER + DRY SOIL IN g 496.53
WT. CONTAINER IN g 438.79
WT. DRY SOIL, W_s, IN g 57.74

TEST NO. 1
DATE 19/20 Dec. 1962
TESTED BY Pay-Phi-Yea

HYDROMETER NO. 6067
MENISCUS CORRECTION +0.0005

$N\,\% = \frac{G}{G-1}\frac{V}{W_s}\gamma_c(r-r_w)\times 100 =$ ____ $(R-R_w)$; $N' = \%$ FINER NO. 200 × N = ____ N (FOR COMBINED ANALYSIS ONLY)

$D = \sqrt{\frac{18\mu}{\gamma_s-\gamma_w}}\sqrt{\frac{z_r}{t}}$; D IN mm = ____ $\sqrt{\frac{z_r \text{ IN cm}}{t \text{ IN min.}}}$

DATE	TIME	ELAPSED TIME IN min.	R = 1000(r-1)	R_w = 1000(r_w-1)	TEMPERATURE IN °C	R-R_w	N IN %	z_r IN cm	$\sqrt{z_r \text{ IN cm} / t \text{ IN min}}$	D IN mm.	N'
19 Dec.	1404	15 s	30	-1	20.0	31.5	86.3	14.30		0.105	
		30 s	28	-1	20.0	29.5	82.2	14.62		0.074	
	1405	1 m	25	-1	20.0	26.5	73.8	15.40		0.054	
	1407	3 m	19	-1	20.0	20.5	57.1	17.95		0.033	
	1409	5 m	17	-1	20.0	18.5	51.5	18.38		0.026	
	1414	10 m	13.5	-1	20.0	15.0	41.8	19.20		0.0185	
	1424	20 m	10	-1	20.0	11.5	32.0	19.94		0.0134	
	1444	40 m	7	-1	20.0	8.5	23.7	20.60		0.0095	
	1524	80 m	5.2	-1	20.0	6.7	18.6	21.00		0.0069	
	1712	3h 08m	3.9	-1	19.9	5.4	15.0	21.30		0.00455	
	2304	9h 00m	2.2	-1	18.9	3.7	10.6	21.70		0.00275	
20 Dec.	1050	20h 46m	0.8	-1	20.0	2.3	6.4	22.00		0.00178	
	1404	24 00	0.2	-1	20.5	1.7	4.7	22.10		0.00167	

REMARKS D from Casagrande Nomogram

Fig. 25

GRAIN SIZE DISTRIBUTION

of Sample no. 1

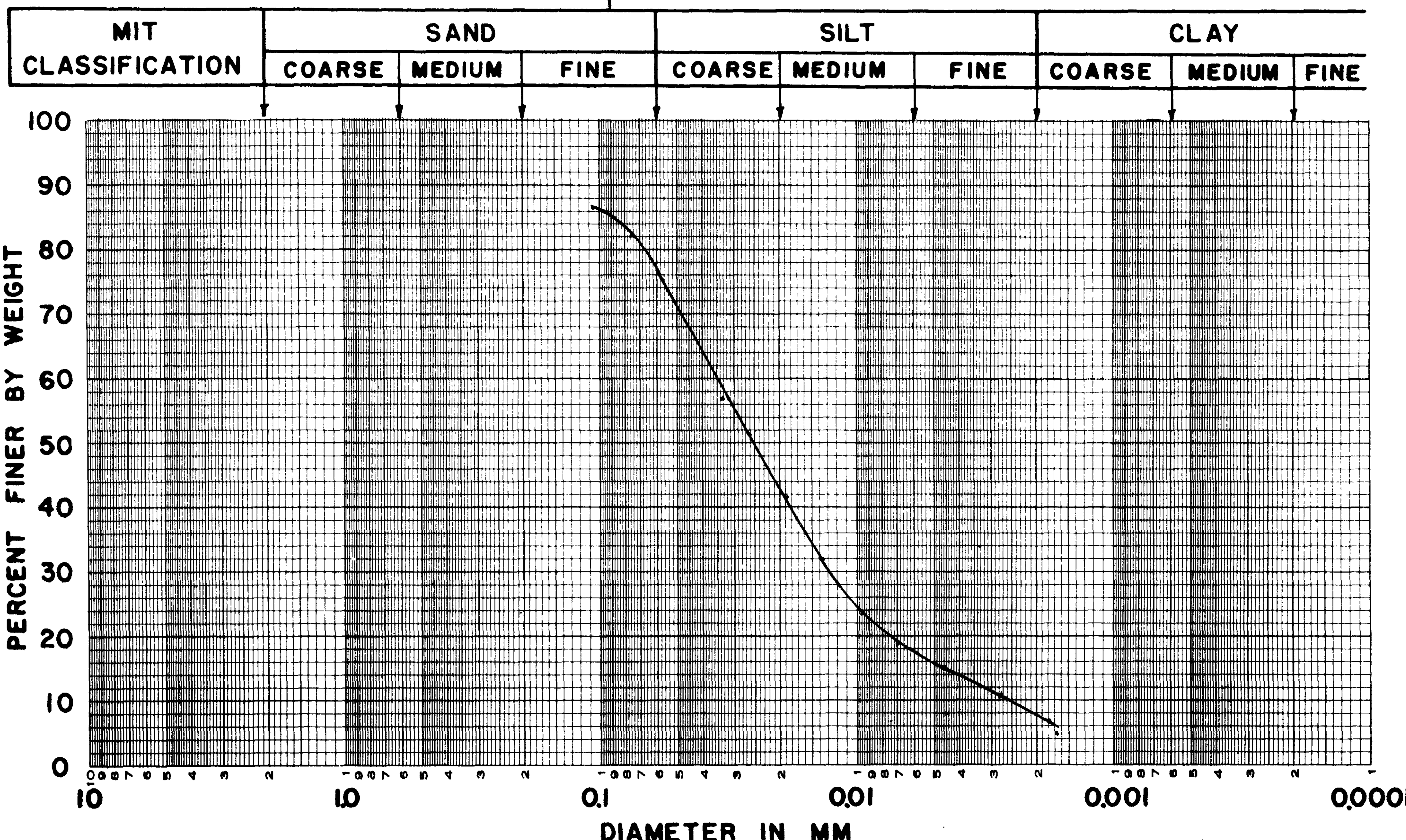


Fig. 25a

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SOIL MECHANICS LABORATORY

HYDROMETER ANALYSIS

SOIL SAMPLE #2 (#8 - 9 Nov.)
light blue green clay

LOCATION Det. #708, Main Chan., Boston Hbr.

BORING NO. 1 SAMPLE DEPTH 35 ft.

SAMPLE NO. 1

SPECIFIC GRAVITY, G, 2.7841

SOIL SAMPLE WEIGHT

CONTAINER NO. 3A2 + A1

WT. CONTAINER + DRY SOIL IN g 937.06

WT. CONTAINER IN g 877.04

WT. DRY SOIL, W_s, IN g 60.02

TEST NO. 1

DATE 14-17 Dec. 1962

TESTED BY Pay-Phi-Yea

HYDROMETER NO. 6067

MENISCUS CORRECTION +0.0005

$N\% = \frac{G}{G-1}\frac{V}{W_s}\gamma_c(r-r_w)\times 100 =$ ____ $(R-R_w)$; $N' = \%$ FINER NO. 200 × N = ____ N (FOR COMBINED ANALYSIS ONLY)

$D = \sqrt{\frac{18\mu}{\gamma_s-\gamma_w}}\sqrt{\frac{z_r}{t}}$; D IN mm = ____ $\sqrt{\frac{z_r \text{ IN cm}}{t \text{ IN min.}}}$

DATE	TIME	ELAPSED TIME IN min.	R = 1000(r-1)	R_w = 1000(r_w-1)	TEMPERATURE IN °C	$R-R_w$	N IN %	z_r IN cm	$\sqrt{\frac{z_r \text{ IN cm}}{t \text{ IN min}}}$	D IN mm.	N′
14 Dec	1423	15 s	35.2	-2	23.5	37.7	98.0	13.20		0.091	
		30 s	35.0	-2	23.5	37.5	97.4	13.27		0.065	
	1424	1 m	34.7	-2	23.5	37.2	96.7	13.30		0.045	
	1425	2 m	34.2	-2	23.5	36.7	95.3	13.37		0.033	
	1427	4 m	34.0	-2	23.5	36.5	94.8	14.63		0.0235	
	1433	10 m	33.8	-2	23.5	36.3	94.3	14.70		0.0152	
	1446	23 m	32.1	-2	23.5	34.6	90.0	15.05		0.0100	
	1503	40 m	30.3	-2	23.5	32.8	85.2	15.48		0.0078	
	1543	80 m	29.0	-2	23.5	31.5	81.8	15.79		0.00555	
	1703	2h 40m	28.0	-2	23.4	30.5	79.3	16.00		0.00390	
	2000	5h 37m	27.2	-2	23.4	29.7	77.1	16.20		0.00270	
15 Dec	0022	9h 59m	23.7	-2	23.4	26.2	68.0	16.96		0.00212	
	1130	21h 07m	6.6	-2	23.4	9.1	23.6	20.72		0.00157	
16 Dec	1315	46h 52m	3.2	-2	23.7	5.7	14.8	21.48		0.00111	
17 Dec	1345	71h 22m	2.5	-2	23.7	5.0	13.0	21.63		0.00089	

REMARKS D from Casagrande Nomogram

Fig. 26

GRAIN SIZE DISTRIBUTION

of Sample no. 2

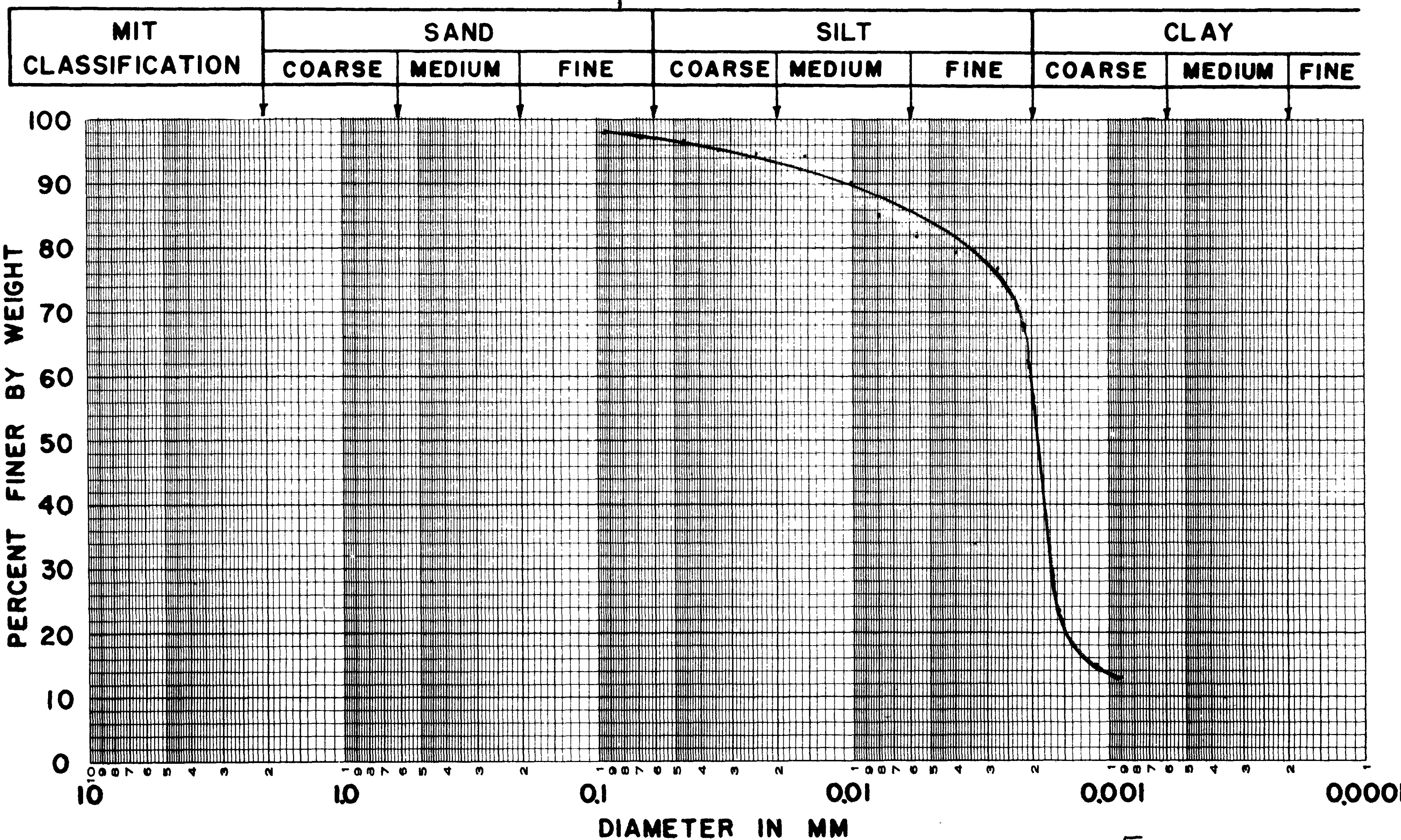


Fig. 26a

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SOIL MECHANICS LABORATORY

HYDROMETER ANALYSIS

SOIL SAMPLE #3 (#6 – 16 Nov) dark fine silt
LOCATION E. of Conanicut Is., Narra. Bay
BORING NO. 1 SAMPLE DEPTH 25 ft.
SAMPLE NO. 1
SPECIFIC GRAVITY, G, 2.5854

SOIL SAMPLE WEIGHT
CONTAINER NO. 3A2
WT. CONTAINER + DRY SOIL IN g 502.32
WT. CONTAINER IN g 438.25
WT. DRY SOIL, W_s, IN g 64.07

TEST NO. 1
DATE 19-20 Dec. 1962
TESTED BY Pay-Phi-Yea
HYDROMETER NO. 6067
MENISCUS CORRECTION +0.0005

$$N\% = \frac{G}{G-1}\frac{V}{W_s}\gamma_c(r-r_w)\times 100 = \_\_\_\_(R-R_w)\ ;\quad N' = \%\text{ FINER NO. 200} \times N = \_\_\_\_ N \text{ (FOR COMBINED ANALYSIS ONLY)}$$

$$D = \sqrt{\frac{18\mu}{\gamma_s-\gamma_w}}\sqrt{\frac{z_r}{t}}\ ;\quad D \text{ IN mm} = \_\_\_\_ \sqrt{\frac{z_r \text{ IN cm}}{t \text{ IN min.}}}$$

DATE	TIME	ELAPSED TIME IN min.	R = 1000(r−1)	R_w = 1000(r_w−1)	TEMPERATURE IN °C	R−R_w	N IN %	z_r IN cm	$\sqrt{\frac{z_r \text{ IN cm}}{t \text{ IN min}}}$	D IN mm.	N′
19 Dec	1356	15 s	25	−1	20.2	26.5	67.2	15.48		0.170	
		30 s	21	−1	20.2	22.5	57.1	16.32		0.078	
	1357	1 m	14.5	−1	20.2	16.0	40.6	17.76		0.057	
	1358	2 m	11	−1	20.2	12.5	31.7	18.58		0.042	
	1401	5 m	8.5	−1	20.2	10.0	25.4 ~~20.28~~	20.28		0.0275	
	1411	15 m	7.5	−1	20.2	9.0	22.8	20.50		0.0159	
	1423	27 m	4	−1	20.2	5.5	13.95	21.28		0.0121	
	1441	45 m	3	−1	20.2	4.5	11.41	21.57		0.0094	
	1521	1 h 25 m	2.5	−1	20.2	4.0	10.16	21.63		0.0068	
	1710	3 h 14 m	1.8	−1	19.9	3.3	8.37	21.78		0.0042	
	2300	9 h 04 m	1.1	−1	18.9	2.6	6.60	21.97		0.00285	
20 Dec	1045	20 h 49 m	1.0	−1	20.0	1.5	3.83	22.16		0.00180	
	1400	24 h 04 m	0.9995	−1	20.4	1.0	2.54	22.30		0.00170	

Note: 11.42 gm of sand, or 17.8% of sample, did not pass through no. 50 sieve (297 microns opening). Another 15% must have been smaller than this but larger than 0.17 mm. Except for the sand, this is similar in grain size to sample #2.

REMARKS D from Casagrande Nomogram

Fig. 27

GRAIN SIZE DISTRIBUTION

of Sample no. 3

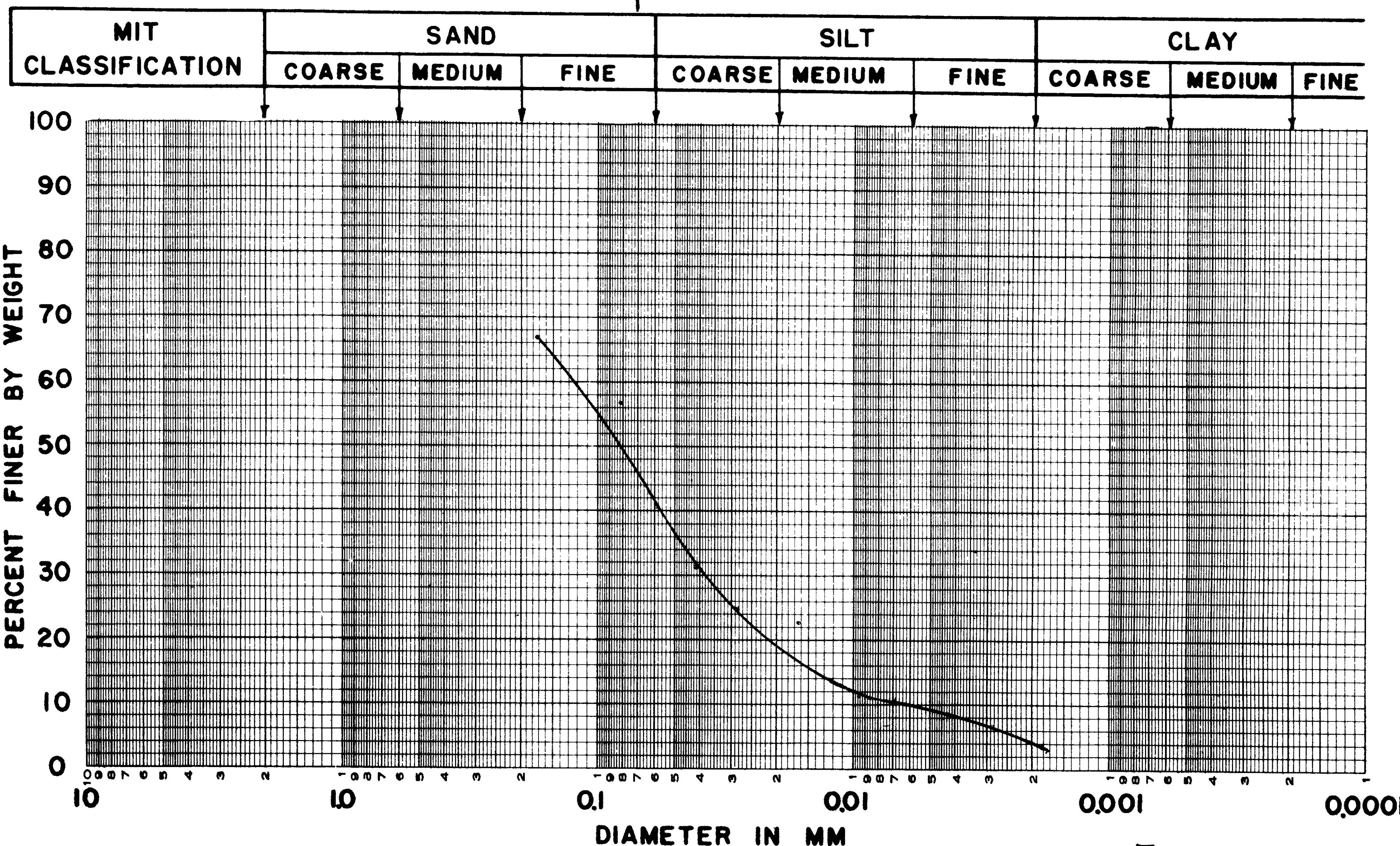
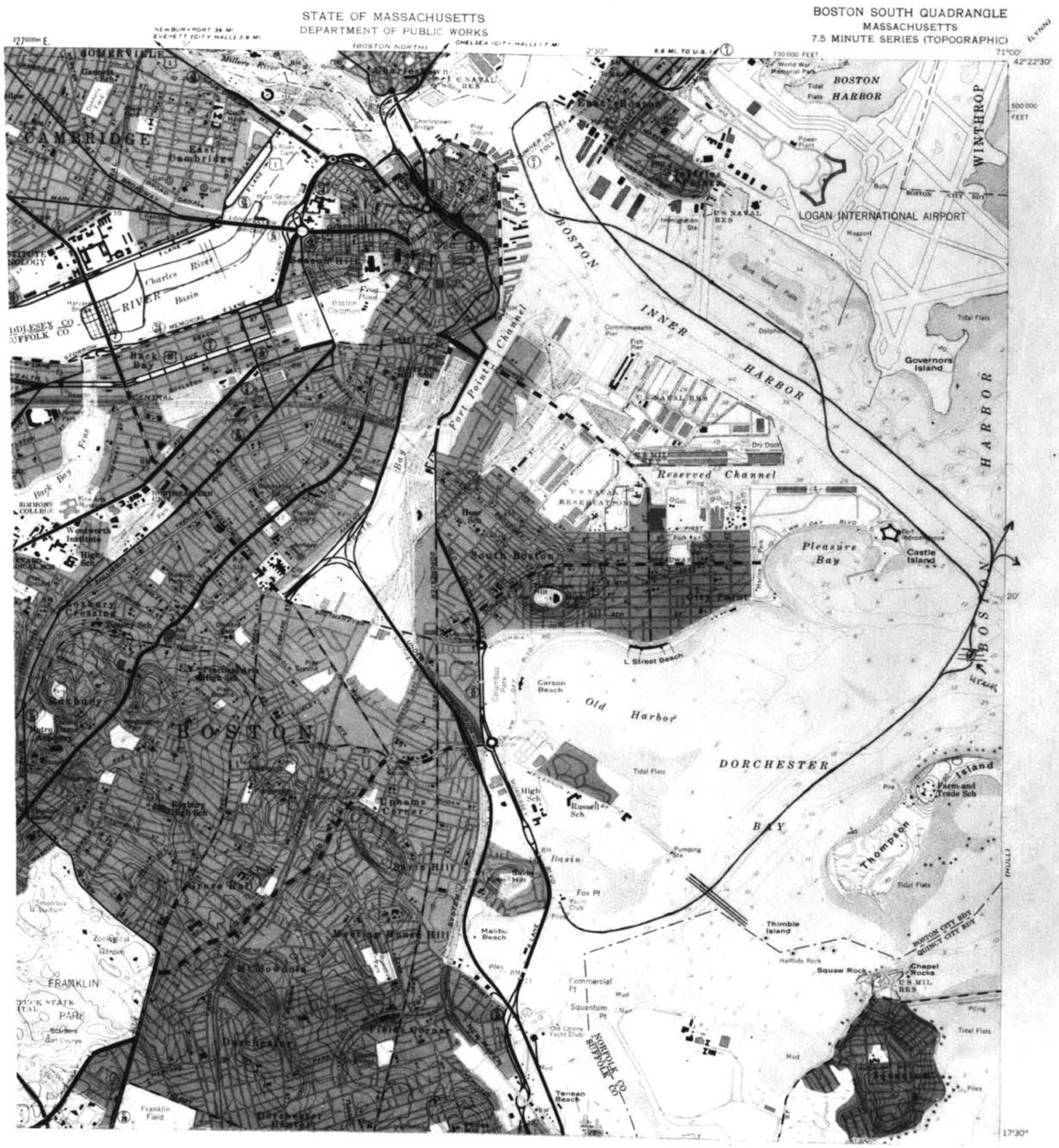
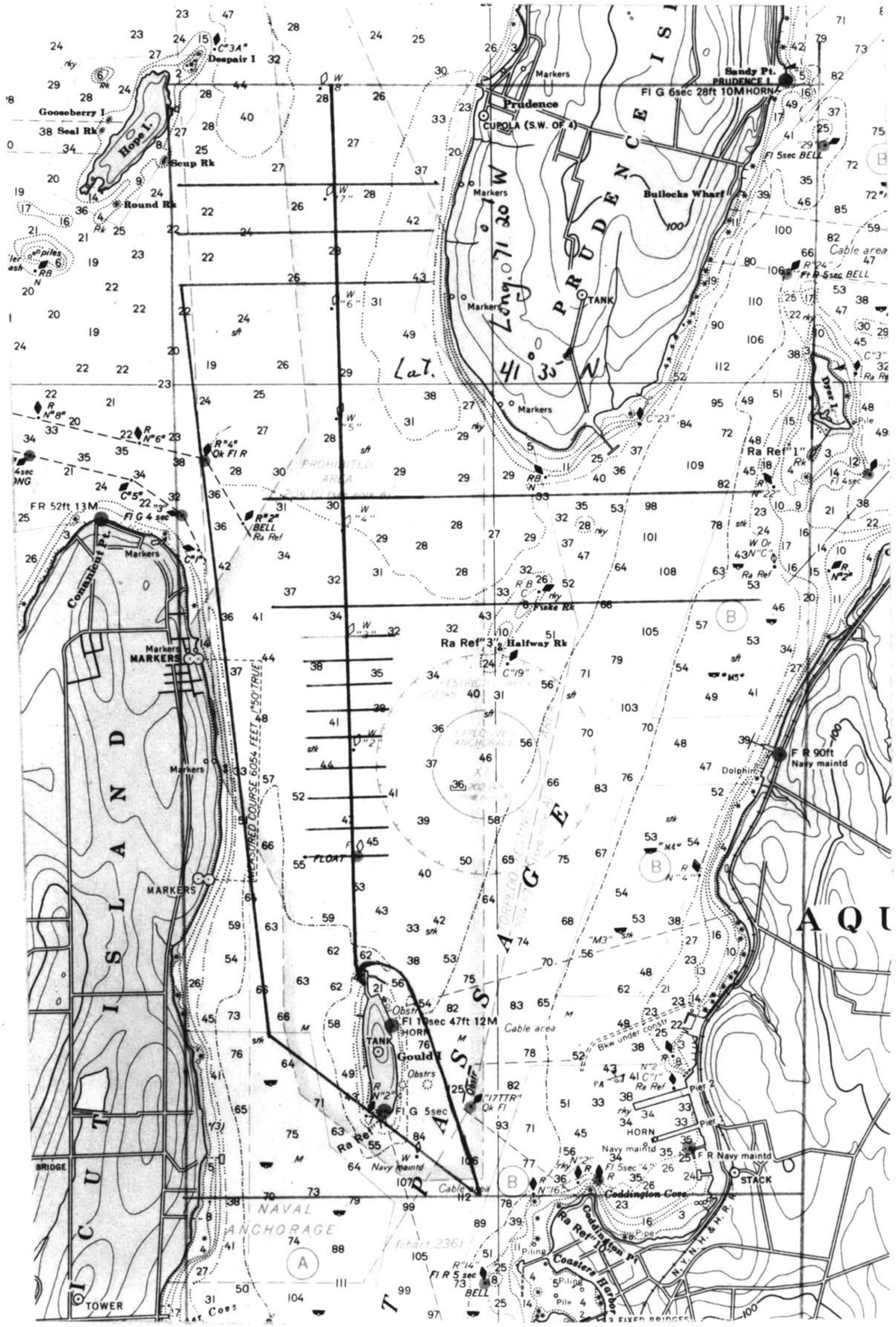


Fig. 27 a

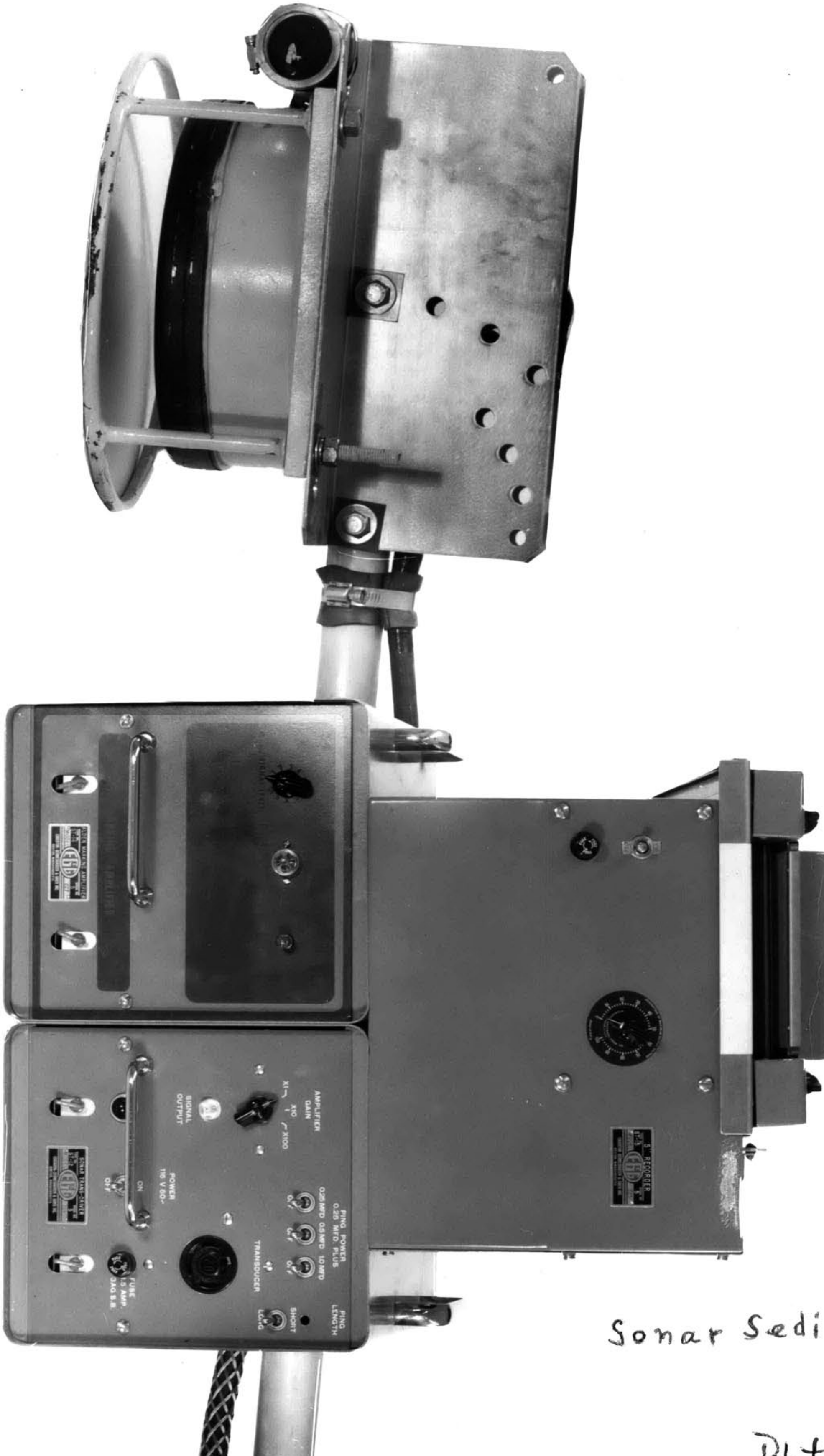


Track of KAY G

Plate 1

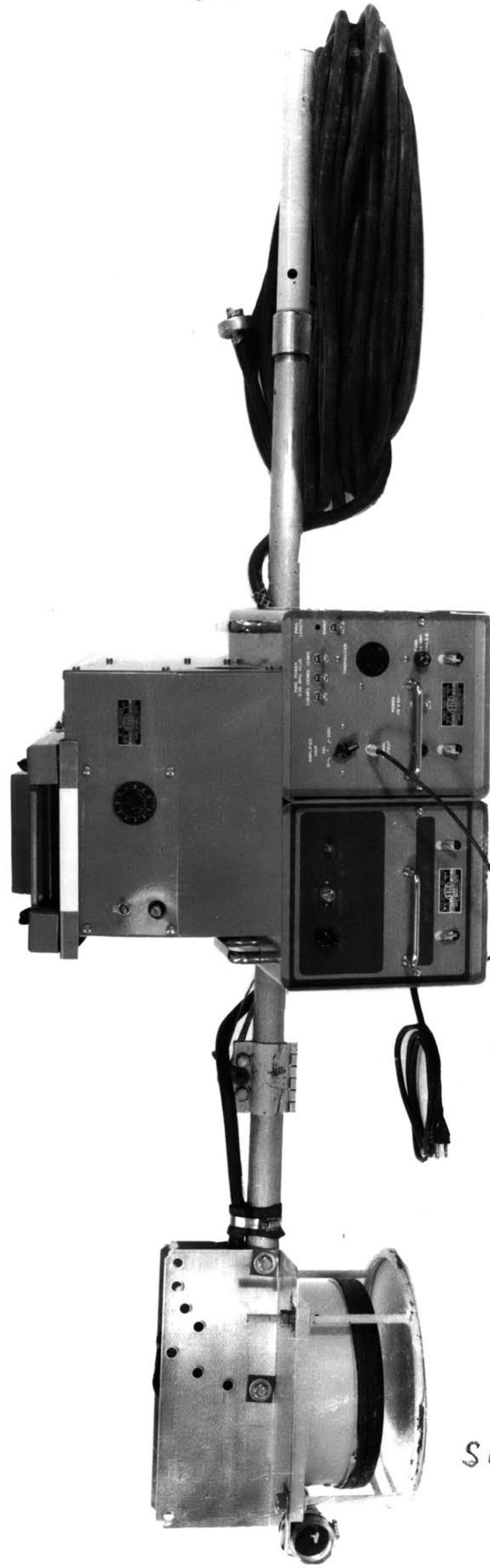


Track of PILOT I Plate 2



Sonar Sediment Probe

Plate 3



Sonar Sediment Probe

Plate 4

Sonar Sediment Probe

Plate 5

Transducer
of
Sonar Sediment Probe

Plate 6

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