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A Waterborne Seismic Reflection Survey of Three Tributaries in Boston Harbor, Massachusetts

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WES

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Preface

A waterborne seismic reflection investigation was conducted in three tributaries of Boston Harbor, Massachusetts, by personnel of the Geotechnical Laboratory (GL), U.S. Army Engineer Waterways Experiment Station (WES), during the period 10-14 November 1992. The investigation was performed under sponsorship of the U.S. Army Engineer Division, New England (CENED). The CENED Project Engineer was Mr. Bob Meader.

The overall test program was conducted under the general supervision of Drs. William F. Marcuson III, Director, GL, and Arley G. Franklin, Chief, Earthquake Engineering and Geosciences Division (EEGD). Mr. Keith J. Sjostrom was the Principal Investigator. This report was prepared by Messrs. Sjostrom and Rodney L. Leist under the supervision of Mr. Joseph R. Curro, Jr., Chief, Engineering Geophysics Branch, GL. Instrumentation support was provided by Mr. Tom S. Harmon, Jr., EEGD, GL. Data analysis assistance during this study was provided by Mr. Jeff S. Zawila, EEGD, GL, and by Mr. Richard G. McGee and Ms. Janie M. Vaughn, Hydraulic Structures Division, Hydraulics Laboratory, WES. Data collection and analysis assistance were also provided by Mr. Dave Caulfield of Caulfield Engineering. Computer graphics support was provided by Mr. Gary Hennington of Information Management Systems, Inc.

Acknowledgement is made to the personnel of the Engineering Design Section and Surveys Section, CENED, for their assistance during this study. The crew of the survey vessel 'Salem' is especially appreciated for its support in performing the field surveys. Subbottom sediment sampling and analysis was performed by the Materials Laboratory, CENED.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters

1 Introduction

Background

At the request of the U.S. Army Engineer Division, New England (CENED), the U.S. Army Engineer Waterways Experiment Station (WES) conducted a waterborne seismic reflection and side scan sonar survey of three tributaries to Boston Harbor, Massachusetts (see Figure 1). These geophysical studies were performed in the Mystic and Chelsea Rivers, Reserved Channel, and the Inner Confluence Area. The results of this study will be used in the development of plans and specifications for the proposed channel deepening and maintenance dredging of the project areas. These test results provide a description of the bottom and subbottom materials to be dredged in terms of density and soil classification which will assist in planning and monitoring the proposed channel deepening program.

Purpose and Scope

The objective of the seismic reflection study is to quantify, as a function of depth, the bottom and subbottom sediments in terms of density and soil type to elevation -42 ft Mean Low Water (MLW) in Mystic River, Inner Confluence Area, and Reserved Channel and to a minimum depth of -40 ft MLW in the Chelsea River. The results will supplement previously obtained soil borings by providing continuous profile line coverage of the entire length of each project area. This information will facilitate positioning of any additional soil borings that may be required, particularly in areas of suspected rock outcroppings. Specifically, the results from the processed seismic data will provide: (1) material density and soil classification information of sediments, (2) better descriptions of changes in actual subbottom conditions, (3) delineation of the geologic interface of the glacial till and/or rock, and (4) volumetric estimates on the quantities of material to be removed through dredging. Two high resolution subbottom profiling systems and a specially designed data acquisition and analysis software package were used to meet the primary objectives of the investigation. A dual frequency side scan sonar system was used to provide increased bottom coverage and detect any possible dredging or navigation hazards.

Overview of Site Geology

Preliminary geologic information provided by CENED prior to the geophysical survey indicated possible areas of rock outcrops in Mystic River, the Inner Confluence Area, and Reserved Channel. The bedrock has an irregular topography that is highly influenced by the preferential weathering and erosion of the rock material. Overlying the bedrock is a layer of glacial till comprised primarily of densely compacted sands, gravel, cobbles, and boulders. At a few locations in the project area, bottom samples have indicated glacial till present on the bottom surface. These interpreted areas will be noted later in the report. The next layer, a gray silty clay, typically called the Boston Blue Clay, ranges in thickness from zero to over 60 ft. The texture ranges from moist and very soft to stiff with water content values typically between 35 and 45 percent (Bowen et al. 1992). Throughout each project area and as noted in core samples taken in Boston Harbor, a thin veneer of saturated, black, organic sandy silty clay covers the channel bottom and ranges in thickness from a few inches to 5 ft. Water content values for this material typically range from 90 to 110 percent (Bowen et al. 1992).

2 Technical Approach

Seismic Reflection Principles

Acoustic subbottom reflection data are produced when a source of acoustic energy is deployed just below the water surface. When acoustic energy is generated from the deployed source and arrives at a boundary between two layers of differing material properties, part of the energy will be reflected back towards the surface and part transmitted downward. Portions of the transmitted energy will undergo absorption or attenuation in the material while the remainder propagates through to the next stratigraphic boundary. Ratios between transmitted and reflected energy, called reflection coefficients, are dependent on the density and velocity of the materials through which the energy is propagating. The acoustic reflection coefficient (R) is defined as:

$$R = \sqrt{\frac{E_R}{E_I}}$$

where E_R is the reflected energy and E_I the total energy incident to the stratigraphic boundary.

The reflection coefficient may also be expressed in terms of impedance using the following equation.

$$R = \frac{(Z_s - Z_w)}{(Z_s + Z_w)}$$

where the acoustic impedance of a sediment (Z_s) is defined as the product of the material density (ρ_s) and transmission velocity (C_s) and represents the influence of the material's characteristics on reflected and transmitted wave energy. Specifically

$Z_w = \rho_w \; C_w$ = water impedance
$Z_s = \rho_s \; C_s$ = sediment impedance

and

$\rho_w = 1.0\ g/cm^3$
$C_w = 1.5 \times 10^5\ cm/sec$

Substituting, the impedance of the subbottom sediments may be determined from measured ratios of the transmitted and reflected wave energy using the following relationship.

$$\sqrt{\frac{E_R}{E_I}} = \frac{(Z_s - Z_w)}{(Z_s + Z_w)}$$

The relationship between acoustic impedance and specific soil properties has been empirically based on an extensive data base of world averages of impedance versus sediment characteristics (Hamilton 1970, 1972; Hamilton and Bachman 1982). These relationships, however, are based primarily on surficial marine sediments. In order to extend the depth of investigation into multi-layer subbottom environments, Caulfield and Yim (1983) devised a geoacoustic model correlating Hamilton's work. The model is used to correct for absorption and transmission losses in the subbottom sediments as a function of frequency such that the reflection coefficients and impedance values may be calculated as if they were surficial sediments. The concept is extended to each subsequent layer until the signal-to-noise ratio is at a level where information cannot be extracted with accuracy. The model is then combined with classical multi-layer reflection analysis algorithms to yield acoustic impedance values equivalent to surficial sediments for subbottom layers. The calculated values are compared to the database developed by Hamilton to categorically classify each detected sediment regime.

Seismic Reflection Survey Approach

The energy sources used to acquire the acoustic subbottom reflection records are a 3.5 kiloHertz (kHz) high resolution 'pinger' system and an integrated, high definition, low frequency bubble pulse system. In general, higher operating frequencies permit greater resolution of the marine sediments but shallower depths of energy penetration depending on the characteristics of the subbottom material. The sources of acoustic energy are deployed just below the water surface and generate acoustic waves that propagate downward through the water column and sediments. As the transmitted energy propagates through sediment of varying densities and acoustic velocities, energy is reflected at geologic boundaries where there is a distinct contrast in the acoustic impedance between the layers. Reflected signals are detected, amplified, filtered, and recorded with a shallow seismic, digital data acquisition system. Acoustic data are acquired in near real-time to permit continual data quality control. Signals from both the bubble pulse and 'pinger' systems are also printed in the traditional 'shades-of-gray' analog format.

Because of the nonuniqueness of seismic reflection signatures, several combinations of geologic conditions could conceivably yield similar signal characteristics and computed impedance values. But in specific geologic regions such as Boston Harbor, differing sediment units have a characteristic range of impedance values. Therefore, using calibration procedures incorporating local core data, the reflection data are corrected for transmission and absorption losses and processed to yield acoustic impedance values at reflection horizons. Estimates of material density are derived from the computed impedance through geoacoustic modeling procedures developed by Caulfield (1983) and Hamilton (1980). The computed density results are correlated with ground truth information for verification. This specific technique is also described by McGee and Ballard (1992) and Ballard, McGee, and Whalin (1992). Through additional processing, the results are adjusted to the Mean Low Water (MLW) datum by removing tidal fluctuations and correlated with survey vessel positioning data.

The virtually continuous linear data coverage of the subbottom material are presented in amplitude cross-sections which illustrate the different reflection horizons in the subbottom. Incorporating the corrected depths, positioning information, and the computed sediment densities or material types, two-dimensional (2-D) profiles of the sediment distribution versus location are produced to assist the project engineer in assessing the subbottom characteristics throughout the project area. These plots also assist in placement of additional sample locations to directly investigate the sediment characteristics at the site.

Side Scan Sonar Operation

Side scan sonar is an acoustic imaging device used to provide wide-area, large-scale images of the bottom of a body of water. The system consists of an onboard recording system and control modules, an underwater sensor (typically referred to as a towfish), and a tow cable linking the two units. During survey operations, the side scan recorder continually charges capacitors in the towfish at set quantities determined as a function of the imaging range. The range may be adjusted between 25 and 600 meters. At discrete time intervals, the recorder transmits this stored power to the transducers in the towfish which in turn emit an acoustic pulse having a frequency of either 100 or 500 kHz. The acoustic signals propagate through the water over the set imaging range and reflect off differing interfaces along the bottom surface. The returning signals are received at the transducers, amplified using a time varied gain function, and recorded. The recorder performs further filtering, amplification, and digitizing functions before calculating the proper position of the signals on the final record. The recorder prints out and stores the resultant signature one scan at a time. The records produced provide a continuous image of the bottom surface along the survey line and, as a function of signal amplitude, denote bottom features and variations in site characteristics. Further information concerning the side scan sonar theory of operation may be found in the text 'Sound Underwater Images' (Fish and Carr 1990).

The printed amplitude signatures received from various bottom features can be qualitatively interpreted for the feature geometry, identification, and possible composition. The reflectivity potential of an underwater surface is a function of the side scan sonar's beam angle of incidence as it encounters that target. When the acoustic pulse is normal to a surface, more energy returns to the towfish than when a beam strikes at a differing angle. This angle of incidence along with the surface roughness are the primary reasons for dark and light areas on the sonar record. The various intensities of these shades assist in better record interpretation. Sandy or gravelly material typically produces a darker gray pattern on the side scan record whereby lighter shades may be indicative of more silty or clayey material. However, the beam angle, towfish path, survey vessel speed, signal gain, and other physical parameters may all affect the appearance and resolution of the side scan sonar record.

Geophysical Survey

A map showing the location of the geophysical survey lines along the Mystic River, Inner Confluence Area, Chelsea River, and Reserved Channel are presented in Figures 2 through 8, respectively. A total of 59 seismic reflection/side scan sonar surveys were performed in Boston Harbor. In terms of survey lines per project area, a total of 9, 16, 15, and 19 survey lines were conducted in Mystic River, the Inner Confluence Area, Chelsea River, and Reserved Channel, respectively. The survey layout of each area is described below.

Mystic River

Although improvement dredging is likely in select portions of Mystic River, the entire length of the project area between the Mystic River (Tobin) Bridge and Alford Street (Malden) Bridge was surveyed. Each of the seismic reflection surveys are conducted parallel with the channel centerline and denoted using the labels MP01 through MP09 as illustrated in Figure 2. Two profile lines, MP01 and MP02, are approximately 6,000 ft in length and surveys MP03, MP04, and MP07 through MP09 are approximately 4,500 ft in length. The survey lines are spaced 200 ft apart with the exception of the outermost surveys which had line spacings of 150 ft. Additionally, in an area where a rock outcrop is expected off the Exxon Pier, two additional profile lines, MP05 and MP06 of length of 2,500 ft, were conducted. The side scan sonar system was used along each survey line.

Inner confluence area

Maintenance dredging will likely be performed in the existing channel and along the northeast corner of the Inner Confluence Area. The Inner Confluence Area is located at the junction of the Mystic and Chelsea Rivers and the main ship channel. Because of suspected rock outcrops, eight profile lines were performed parallel with the centerline extending from the Inner Confluence Area into the Chelsea River (see Figure 3). The seismic reflection surveys are denoted using the labels IP06 through IP13. Five of the surveys are approximately 2,200 ft in length with the remaining three 1,500 ft in length. Each survey line was spaced 100 ft apart. Survey lines IP01 through IP05, each 2,000 ft in length and spaced 150 ft apart, were performed parallel with the centerline of the Mystic River approach (see Figure 4). Three additional survey lines, each approximately 1,500 ft in length, were performed along the northern and eastern edges of the Inner Confluence Area (Figure 4). The side scan sonar system was used along each survey line.

Chelsea River

Chelsea River is a narrow body of water extending northeastward from the Inner Confluence Area. Because of the narrowness of the channel between the McArdle and Chelsea Street Bridges, geophysical surveying was performed only along the edges of the existing channel. A total of four survey lines denoted as CP14N, CP14S, CP15N, and CP15S were conducted in this reach (see Figure 5). In the upstream reaches of Chelsea River, a total of thirteen profiles lines were surveyed (Figures 5 and 6). The survey lines are labelled CP01 through CP13. Directly upstream of the Chelsea Street Bridge, five profile lines, CP09 through CP13 were surveyed and spaced a distance of 150 ft apart. With the exception of survey CP13, each line is approximately 3,000 ft in length and positioned parallel with the southeastern channel outline. In the farthest upstream reach of Chelsea River, four survey lines (CP01, CP02, CP07, and CP08) each approximately 2,500 ft in length, were performed parallel to the Gulf Oil Dock (Figure 6). These lines were spaced 200 ft apart. Four additional surveys (CP03 through CP06) were performed in the adjacent turning basin with each line ranging in length from 1,000 to 1,500 ft in length and spaced 200 ft apart. The last profile, survey CP06, is situated in front of the Global-Gibbs and Northeast Oil docks. The side scan sonar system was used along each survey line.

Reserved channel

Improvement dredging is likely within the existing channel as well as two additional areas near the mouth of the tributary. Although current proposed plans call for maintenance dredging in the channel for a distance of only 4,000 ft, geophysical survey lines extended along the entire 4,500 ft length of Reserved Channel. Two lines each were positioned 100 and 250 ft either side of the centerline (see Figure 7). Due to positioning limitations, these four lines were divided into two parts each for a total of eight survey lines. These surveys are denoted RP15 through RP22. Four additional survey lines (RP10, RP11, RP12, and RP14) with spacing of 150 ft and length 1,600 ft were performed at the channel mouth parallel to the channel centerline beginning 400 ft to the north (Figure 7). Finally, seven profile lines parallel to the centerline of the 35 ft main ship channel were surveyed starting 200 ft downstream of Buoy #10 and extending 3,000 ft upchannel (see Figure 8). The spacing between these profiles is 150 ft. The survey lines are denoted as RP01 through RP09 with RP03 and RP06 not shown because of positioning problems during data acquisition. The side scan sonar system was used along each survey line.

Survey methodology

For the seismic reflection portion of the survey, the high-resolution 'pinger' system was mounted on the hull of the survey vessel and used as the primary investigative tool. The 'pinger' provides good resolution of the multi-layer geology in each project area to the required depth of investigation. The source/receiver separation was 20 ft and each set of transducers were situated approximately three feet below the water surface. The 'pinger' was operated at a tuned frequency of 3.5 Khz and a total trace length of 700 samples were selected during data collection. A digital acquisition sampling rate of 52 microseconds (ms) was used for seismic data collection whereby providing subsurface exploration to depths of approximately 90 ft below the water surface. The high definition bubble pulse system was towed behind the survey vessel during the investigation. The acoustic source was located 15 ft behind the vessel on the starboard side whereas the hydrophone array (receiver) was positioned approximately 40 ft behind the vessel on the port side. The bubble pulse was operated at a central frequency of 0.8 Khz. The digital acquisition sampling rate was 96 ms with a total trace length of 700 samples. The maximum depth of exploration using these parameters was approximately 150 ft.

The side scan sonar source/receiver was deployed off the front of the survey vessel and positioned at depths ranging from 5 to 10 ft below the water surface depending on the depth of water in the project area to be investigated. The unit was operated at a frequency of 100 kHz and an image range setting of 100 or 150 m depending on the width of the project area and degree of bottom resolution required. The high frequency acoustic signals were digitally recorded on magnetic tape and printed for near real-time visual display.

Navigational and positioning support was provided by CENED personnel. Positioning information for each survey line, collected using a Falcon IV Mini-Ranger system, was recorded during seismic data acquisition and correlated to the geophysical records with respect to time. The side scan sonar data are correlated to positioning fix points noted during the survey. CENED also provided precision bathymetric data referenced to Mean Low Water. Bottom depths for the subbottom profiles are adjusted to the CENED depth measurements since the data provides nearly a 10:1 improvement in resolution over any of the subbottom equipment.

3 Subbottom Sediment Sampling

During earlier phases of proposed maintenance dredging work, CENED has conducted exploratory boring programs in each of the project areas. An additional six cores were collected following the geophysical survey to more accurately calibrate the geoacoustic model and develop the necessary acoustic parameters to derive estimates of bottom and subbottom material density. The WES core locations in Mystic River and Chelsea River, illustrated in Figures 2 and 6, respectively, were positioned in areas of the project having differing seismic signatures as indicated on the seismic reflection field records. The WES cores are denoted as 'BOR#' where '#' indicates the core number. It should be noted that because of ship traffic, cores were unable to be obtained in the Inner Confluence Area or Reserved Channel.

Shallow penetration coring was performed by the CENED Materials Laboratory using a free-fall gravity corer. Sediment sample analysis was also performed by CENED and a short summary of the results are shown in Table 1. Laboratory analysis is designed to determine the parameters that most directly affect the propagation of an acoustic wave in submarine environments; i.e., density, porosity, mean grain size, and soil gradation. Sediment penetration was limited because of hard or cohesive materials encountered at each location. The length of the core samples (see Table 1) ranged from 1.6 to 2.0 ft. The results for cores BOR1 through BOR6 indicate that the material found at the bottom surface consisted of dark grey silt or clay with an oily or organic odor. At the bottom depth ranges, the material consisted primarily of light grey clay. Exceptions were noted at core BOR1 in Chelsea River where the material was mostly medium grey sand and at core BOR5 in Mystic River where the deeper sediment consisted mainly of gravel.

Fifteen cores completed during June 1993 and analyzed by CENED were also used during this investigation. The cores were positioned according to preliminary results derived from the seismic reflection investigation. These cores are denoted by the label 'FD-93-#' where '#' represents the alphabetic designation of each drill hole. The core locations with respect to the geophysical survey lines are shown in Figures 2 through 8. The holes were completed to an elevation range of -45 to -54 ft MLW with the lengths ranging between 6 and 17 ft. The average length is approximately 14 ft. Laboratory analysis information provided to WES for cores FD-93-A through

FD-93-N and FD-93-D2 were limited to representative soil classification at 2.0 ft intervals and Standard Penetration Test blow count values. Full documentation of both the WES and CENED cores is available from CENED.

4 Data Calibration and Ground Truth Correlation

Using calibration procedures for data with high signal to noise ratios, seismic reflection data can be processed to provide estimates of the density and soil type of bottom and subbottom sediments. Calibrations are performed by correlating acoustic impedance values calculated from the seismic reflection data at a sample location with the measured information (density, mean grain size, etc.) at that location. Experience to date has shown that calibrations made at a few locations within a geologic region provides the necessary shallow seismic parameters to accurately calibrate and describe the entire region (McGee 1991). Calibration of the acoustic reflection data for Boston Harbor are briefly described in this chapter.

Calibration locations may be thought of as acoustic cores taken at various locations within the project area. The calibration plots shown in Figures 9 through 44 illustrate the acoustically derived impedance and density values versus depth at a core location in which directly measured density values exist. At those location where no core information exists, the acoustic amplitude record illustrates representative seismic signatures of the bottom and subbottom geology or depicts changes in the bottom and subbottom geologic conditions. Using the calibration parameters for the project area, the acoustically derived impedance and density values are computed and displayed to assist in the geologic interpretation of the site.

Referring to Figure 9, a portion of the seismic reflection record taken at WES core location BOR2 is presented in the leftmost block entitled 'Acoustic Reflection Record'. The darker colors represent higher amplitude signals reflected and recorded from the varying geologic interfaces. The bottom surface is detected at an elevation -40 ft MLW and a second distinct interface, where a change in impedance exists, is measured at elevation -48 ft MLW. The depth to the top of the detected interface increases sharply at the left half of the record. Using surface and subbottom sediment calibration parameters, impedance values are computed for that portion of the seismic record and displayed in the block labelled 'Acoustic Impedance Record'. The impedance values are color-coded such that the darker colors are related to higher impedance values. Using the impedance versus sediment database developed by Hamilton (1970, 1972), the higher impedance values are related to more competent sediments having higher density values such as a sand or stiff clay.

In the block entitled 'Density', the solid line depicts the acoustically derived density values versus depth as related to the impedance versus density database. The black dots represent measured density values at specific depths for the core indicated in the title block. Visual sediment classification from the driller's log is outlined in the block titled 'Lithology'.

Bottom Sediment (Surface) Calibration

The first calibration procedure performed with the reflection data determines the total energy incident at the bottom surface. This process involves determining the most representative reflection coefficient for the first reflector (bottom surface) and the associated acoustic bottom loss for the given sediment. The surface calibration begins by determining the total energy produced by the acoustic energy source from the direct wave and the transmission losses associated with underwater acoustic wave propagation. These parameters are evaluated using the sonar equation. For an in depth discussion of the sonar equation, refer to Urick (1983). The computed source energy and transmission losses are in turn used to calculate the surface reflection coefficients. The reflection coefficients and bottom loss are then correlated with the measured sediment properties (density, mean grain size, water content, etc.) to calibrate the bottom surface materials.

Surface calibrations were conducted at WES core BOR2 in Chelsea River and cores BOR3, BOR4, BOR5, and BOR6 in Mystic River. Sediment analysis of each core is presented in Table 1. Surface sediment density values (in g/cm^3) of 1.58, 1.84, 1.74, 1.38, and 1.82 were measured using cores BOR2, BOR3, BOR4, BOR5, and BOR6, respectively. The acoustically derived density estimates, computed using the determined calibration parameters versus the measured characteristics of each core, are illustrated in Figures 9 through 13, respectively. Good correlation exists, with the possible exception of core BOR6, between the acoustically derived and measured density values for each of the shallow cores.

Subbottom Sediment Calibration

The second part of the calibration process adjusts the impedance function for effects of acoustic absorption in unique soil types as the acoustic wave is propagated down and reflected back through the subbottom sediments. Estimates of acoustic absorption, or the attenuation coefficient, are computed from reflection data only in areas where a multi-layered lithology exists. It should be noted that when only a surface reflection exists, the surface calibration is all that is necessary. The attenuation coefficients are initially correlated to empirical geoacoustic relationships developed to describe the characteristics of bottom and subbottom sediments (Hamilton 1980; Caulfield 1983). The density results are also compared to measured core information and any adjustments necessary are made in the acoustic analysis parameters in order to obtain the best correlation.

None of the WES cores extended deep enough into the subsurface to provide the distinct changes in lithology, such as the interface between the near-surface silty material and stiff clay, necessary to accurately calibrate the impedance function. Therefore, the subbottom calibration was accomplished at the following CENED core locations: (1) cores FD-93-K, FD-93-L, and FD-93-M in Mystic River, (2) cores FD-93-G and FD-93-H in the Inner Confluence Area, (3) core FD-93-N in Chelsea River, and (4) cores FD-93-C, FD-93-D2, and FD-93-E in Reserved Channel. WES core BOR5 is located near core FD-93-K in Mystic River. Figures 12 and 14 through 21 present the acoustically derived density estimates, using the developed calibration parameters, versus the laboratory determined sediment characteristics for the above CENED cores. Sediment analysis, using the Unified Classification System for soils, at each of the core locations are presented alongside the computed density values. It should be noted that none of the CENED cores provided to WES had any measured density values. Each density versus depth prediction illustrates increasing densities near the compacted clay or rock and gravel interfaces as one might expect.

Check Calibrations

To verify the assumption of regional calibrations, numerous check sites were evaluated in Boston Harbor. Acoustically derived estimates were compared with the remaining CENED cores and computed for select locations within each project area having multiple subbottom interfaces or characteristic seismic signatures using the final acoustic parameters established from the surface and subbottom calibrations. Check calibrations and/or verification locations, in addition to those thusfar presented in Figures 9 through 21, are illustrated in Figures 22 through 44 for locations in Mystic River, Inner Confluence Area, Chelsea River, and Reserved Channel. The title block of each figure points out the location of the check point. Where measured sediment density values or soil classification are available, the acoustically derived estimates demonstrate good correlation. Typically, the calculated densities deviate about the measured values by approximately $\pm$ 0.2 g/cm^3 or 10 percent.

5 Data Analysis and Results

Data Analysis

Continuous subbottom profiles of the acoustic reflection amplitudes obtained using the high resolution 'pinger' system for surveys performed in the Mystic River, Inner Confluence Area, Chelsea River, and Reserved Channel were delivered to the CENED Project Engineer in October 1993. The records are annotated with WES survey line and file number designations and CENED and WES core locations. Positioning and bottom depth information for each survey line and file number are presented in Appendices A, B, C, and D for the Mystic River, Inner Confluence Area, Chelsea River, and Reserved Channel, respectively. Correlating the information interpreted from the seismic amplitude records with existing core information, a general description of the subbottom sediments and material density distributions are provided for each area of the survey.

Limitations and boundary conditions

The seismic signatures reflected from various geologic interfaces are recorded and displayed to create seismic amplitude records. The seismic amplitude intensity, with the more competent reflectors correlating with the strongest signals, give indications of the depths to stratigraphic interfaces in the subsurface. However, it should be noted that interfaces between materials with similar densities and acoustic velocities, such as rock versus compacted sands, may not be detected because the difference between acoustic impedance values are not large enough. Two points must also be made concerning the capabilities of the geophysical instruments. First, the high-resolution 'pinger' system used sometimes has difficulty detecting surface sediments with densities less than 1.1 g/cm^3. Material below this density value is typically termed 'fluff' material. A 200 kHz fathometer commonly used in hydrographic surveying would be more readily able to detect this material but would provide little to no subbottom information. The 'bubble pulse' system has a much longer pulse length than the 'pinger' and, therefore, is also unable to readily detect fluff material; unless the thickness of the fluff zone is over 8 ft. Secondly, the resolution of geologic layers provided by the 'pinger' system is only on the order of two or three feet depending on the pulse length and sampling rate used during data acquisition. Sediment layer resolution obtained using the 'bubble pulse' is on the order of 7 to 8 ft.

Before discussing the density results from the four project areas of the Boston Harbor investigation, a few comments are needed regarding interpretation of acoustically derived estimates. These topics are addressed as follows.

Accuracy. The sediment predictions are an indirect determination based upon wave propagation principles and acoustic impedance versus density and soil type relationships and should not be considered an absolute measurement of density. Ground truth verification of the density estimates were limited to the upper two feet of sediment because of the shallow drop cores obtained following the survey. Directly measured density information were unavailable from the deeper CENED cores. However, computed density estimates should safely fall within 15 percent of insitu density values using the seismic analysis parameters. The variance in density values is primarily attributed to the shallowness of the directly measured density values and the lack of any deeper density information. At greater depths in the subbottom, the impedance function and absorption model used to estimate impedance and density predictions should compute values somewhat lower than insitu.

Impedance function. The impedance function used for this technique is based on empirical data collected from primarily deeper offshore environments in naturally occurring marine sediments (Caulfield 1983). Therefore, this algorithm may produce anomalous density values and estimates in the dynamic near-shore, harbor, and riverine environments. Compacted, cohesive clayey sediments or highly active organics could compute as something they are not; hence, one of the primary reasons for the regional calibration approach.

Correlation between acoustic profiles and core logs. The acoustically derived sediment profiles are cross-referenced to the core locations in each project area. Many of these cores are not located precisely on a survey line. Therefore, surface conditions may vary somewhat due to maintenance dredging, construction activities, or isolated surface anomalies which may produce apparent discrepancies between the reflection data and cores.

Correlation of density estimates to soil classification

The bottom and subbottom sediment analysis within the project area emphasizes density distribution with respect to lateral extent and depth. Sediment density ranges used for data presentation and discussion were provided by CENED personnel to more practically delineate the sediment distribution and better assess the difficulty of removing this material through dredging operations. The computed density values are related to a basic soil description, based on the database for natural, undisturbed marine sediments, as shown in Table 2. These relationships are valid for the sampled locations in the study area except for areas where anomalous sediment conditions are detected.

Data presentation

In general, the density ranges established delineate the predominantly clay, silt, and sand regions within the area surveyed. The distributions of computed sediment densities within each project area are presented in Plates 1 through 10 as 2-D profiles illustrating the primary subbottom interfaces and differing zones of sediment material along each survey line. The profiles are cross-sections of the project area along the survey lines and illustrate the depth to a particular interface (in feet MLW) and representative sediment density. The location of CENED and WES cores are also identified. The labelled black dots at the top of each profile denote the survey track line and direction. Each dot represents the beginning of every third seismic data file recorded in order to give an indication of the data coverage along each survey line and assist in correlating the raw data and interpreted results. The associated label represents the data file number. Appendices A through D note the location and bottom elevation in feet MLW for the appropriate data file number along each survey line in Mystic River, Inner Confluence Area, Chelsea River, and Reserved Channel, respectively. Each plate also illustrates a detailed site map of the area noting the direction and physical location of the survey lines. The survey line label arrow represents the direction with which each survey was performed. The large arrow labelled 'Cross-section Viewpoint' indicates the orientation of the survey line cross-sections on each diagram.

Results of the Seismic Reflection Survey

Mystic River

The Mystic River project area is located between the Mystic River (Tobin) Bridge and Alford Street (Malden) Bridge (see Figure 2). Nine seismic reflection surveys, lines MP01 through MP09, were performed in the channel and the 2-D cross-sections illustrating the interpreted sediment regimes and density distributions are shown in Plates 1 and 2. The interpretations for surveys MP02 through MP06 are presented on Plate 1 and surveys MP01 and MP07 through MP09 are shown on Plate 2. CENED and WES core locations and measured density information where available are also displayed. Sediment properties and the seismic data acquisition parameters allowed high quality data to be recorded for interpretation and density determination purposes to an elevation range of -50 to -75 ft MLW.

The near-surface sediments are primarily comprised of materials ranging in density from 1.4 to 1.7 g/cm^3; indicative of silty clay to sandy silts. Near surface information from WES cores collected along survey lines MP01 and MP02 correlate well with these results (see Figures 10 through 13). In the western part of Mystic River and along the project perimeter, higher density material is detected at the bottom surface and is found to have computed densities greater than 2.2 g/cm^3. This sediment type is indicative of compacted sands, stiff clays, or hardpan material which is supported by interpretation of the seismic records. This material is not rock or gravel. A portion of the seismic amplitude record along survey line MP05, files 000 through 030, is presented in Figure 45 and illustrates the transition zone from the much higher density material at the lefthand side of the figure to the less dense sediments at the right. Limited acoustic penetration in areas of this dense bottom material prevented subbottom analysis at deeper depths. It should also be noted that during subbottom sampling following the seismic survey, the upper sediment layer had a strong 'oily' odor indicative of the presence of a petroleum based residue on the bottom. It is technologically unclear at this time on what the effects of petroleum or other chemical residues have on the bottom and subbottom sediment characteristics or on the reflection coefficients determined at the bottom surface. This 'oily' smelling bottom sediment was also sampled in the upper turning basin of Chelsea River.

In areas of deeper acoustic penetration, material densities ranged from 1.6 to 2.2 g/cm^3 and, relating available core information, these sediments are indicative of stiff, cohesive clay, namely the Boston Blue Clay, till material, or rock and gravel. In areas located near CENED cores, the density results in comparison with the physical subbottom samples correlate well. Representative seismic signatures in areas of deeper penetration are presented in Figures 45 through 47. In Figure 46, layering in the subbottom is particularly distinct; especially within the clay material. The deepest interface, detected in the lower right-hand corner of the figure, is that of a rock and gravel zone. Along survey line MP08 (Figure 47), near-surface anomalous zones having high sediment density values and reflection coefficients limit acoustic penetration into the subbottom but deeper clay layers are still visible along the seismic line.

Analysis of the seismic data collected in Mystic River indicate two areas of rock, gravel, or till outcrops on the channel bottom. These interpreted areas are located on the site map in Figure 48. The first outcrop area is located near the Exxon Dock. Seismic amplitude data collected along survey line MP02, files 050 through 080, are presented in Figure 49 and best characterize this outcrop. Depth to rock in this zone ranges from 2 to 5 ft. This was verified by WES Core BOR5, taken during the field survey, in which approximately two feet of clay with sand were collected over rock and gravel. The second area is located near the Mystic River Bridge and extends from the Mystic River into the Inner Confluence Area. Seismic data collected along survey line MP01, files 050 through 080, are presented in Figure 50 and illustrate the detected interface of the rock, gravel, or till material. The average depth to rock is approximately three feet. Limited acoustic penetration in the western portion of Mystic River may mask any additional outcrop areas.

Inner confluence area

The Inner Confluence Area is located at the entrance of both the Mystic and Chelsea River channels (see Figures 3 and 4). Sixteen seismic reflection surveys, lines IP01 through IP16, were performed in the project area and the

2-D profiles illustrating the different geologic interfaces and density distributions are shown in Plates 3 and 4. The results from seismic surveys IP01 through IP05 and IP14 through IP16 are displayed on Plate 3 whereas surveys IP06 through IP13 are presented on Plate 4. CENED core locations are also displayed. High quality seismic data was recorded for interpretation to an elevation range of -50 to -75 ft MLW.

The acoustically derived results indicate that the upper layer of material, having thicknesses between 1 and 5 ft, ranges in density from 1.4 to 1.8 g/cm^3. Material classification determined from the computed densities is clayey silt to silty sand which is consistent with drill hole information. Higher computed sediment densities at the bottom surface are located sporadically throughout the area and along the project area perimeter; particularly alongside of the primary approaches to Mystic or Chelsea River. One such pocket of more dense sediment is detected along survey line IP07 as shown at left hand side of Figure 51. The material is interpreted as being primarily sand.

Underlying the near-surface material, the sediments transition into a stiff, cohesive clay, likely the Boston Blue Clay, or rock, gravel, and till zones having acoustically computed density ranges of 1.6 to 2.3 g/cm^3. Sediment information received from the CENED drill holes indicated predominantly lean clay with sand overlying a layer of rock fragments, gravel, cobbles, or till. Referring to Figures 51 through 54 which illustrate seismic data collected along survey lines IP07, IP02, IP03, and IP06, respectively, numerous layers and interfaces are detected in the subbottom. The bottom-most interface is that of the rock and gravel or till layer. The remaining interfaces are within the Boston Blue Clay. The thickness of the clay material is highly variable.

Using seismic data collected in the Inner Confluence Area, two rock, gravel, or till outcrop areas near the channel bottom were detected. These areas are located on the site map in Figure 55. The first area is an extension of the outcrop detected in the Mystic River near the Mystic River Bridge. Data collected in this area are representative of this rock and gravel outcrop and correlates well with the Mystic River survey data. The depth to rock is approximately three feet. The second, much larger area is located in the central portion of the confluence area. Seismic data presented in Figures 52, 53, and 54 illustrates the rock and gravel interface as it approaches the channel bottom in this area as detected along survey lines IP02, IP03, and IP06, respectively. The depths to rock and gravel are more variable in this zone and range from 3 to 7 ft. The portion of the seismic record for survey IP03 (Figure 53) illustrates particularly well the undulating surface of the interpreted rock and gravel interface at depth. The acoustically determined densities for this material range from 1.9 to 2.3 g/cm^3.

Prior to the seismic reflection study, CENED personnel indicated that there was a near-surface rock or gravel zone along the eastern edge of the confluence area; an area proposed to be widened. Because of shallow water, limited seismic surveying was performed. One survey, line IP15, was conducted in this area along the eastern boundary of the current channel. The seismic data, see Figure 56, was inconclusive on whether or not an outcrop exists in this area. CENED core information near this line indicated sand with some gravel which correlates well with the acoustic results for survey IP15. However, further subbottom information should be obtained via drilling or some other technique to investigate the possibility of a rock outcrop in this region.

Chelsea River

The Chelsea River project area extends towards the north and east of the Inner Confluence Area as shown in Figures 5 and 6. Fifteen seismic reflection surveys, lines CP01 through CP15, were conducted along the length of the area and the acoustically derived results are presented in 2-D profiles which illustrate the interpreted sediment interfaces and density distributions. The results from seismic surveys CP01 through CP08 are displayed on Plate 5, survey lines CP09 through CP13 on Plate 6, and surveys CP14 and CP15 on Plate 7. The existing CENED and WES core locations and appropriate density information where available are also displayed. Sediment properties and the data acquisition parameters allowed high quality seismic data to be recorded for interpretation and density determination purposes to an elevation range of -50 to -75 ft MLW.

Two surveys, lines CP14 and CP15, were conducted between the McArdle and Chelsea Street Bridges. Results from the seismic data analysis of these survey lines, see Plate 7, indicate that the density of the near-surface material is within the range of 1.8 to 2.2 g/cm^3. No drill hole information is available in this area to determine the soil classification. A typical example of the seismic signatures recorded in this area are presented in Figure 57. The record was collected along survey CP15N just upstream of the McArdle Bridge. Because of the competent nature of the surface reflector, limited acoustic penetration was obtained and, therefore, prevented detailed acoustic analysis below depths of -50 ft MLW. No distinct geologic interfaces at depth were detected along this length. Also shown in Figure 57 are two small trenches which may indicate the location of pipelines or utilities traversing the channel area. Unfortunately, positioning problems during the survey prevent accurate location of the features. The depth to the possible utilities could not be determined because of the small target size.

Upstream of the Chelsea Street Bridge, the near-surface sediments have highly variable density values ranging from 1.5 to 2.3 g/cm^3. The less dense material are indicative of loosely compacted sandy, silty clay or clays with higher water content. The soil classification and acoustically derived density values compare well with the driller's logs and measured densities for WES cores BOR1 and BOR2 and CENED core FD-93-N (see Figures 9, 18, and 30). In many areas of Chelsea River, surface materials having densities greater than 2.0 g/cm^3 limit acoustic penetration into the subbottom and therefore possibly mask the detection of any subbottom interfaces. These areas are likely comprised of sandy material but petoleum residue detected in cores BOR1 and BOR2 may also affect the bottom sediment characterisics as well as limiting acoustic penetration. In areas having lower density surface material, deeper acoustic penetration was obtained thereby allowing detection of deeper subbottom interfaces. Portions of seismic amplitude records recorded along survey lines CP07 and CP09 are presented in Figures 58 and 59, respectively. Along survey CP07 (see Figure 58), a window of less dense material is interpreted amongst a competent bottom surface to allow detection of a few subbottom interfaces. These few interfaces occur within the stiff, cohesive clay material which has computed densities ranging from 1.8 to 2.1 g/cm^3. The deepest interface may indicate a rock, gravel, or till layer approaching the channel bottom. The rock/gravel interface, however, is greater than 10 ft below the bottom. Referring to Figure 59, intermittent zones of competent material partially mask the deeper subbottom interfaces within the clay material. The computed densities of the deeper sediments range from 1.9 to 2.1 g/cm^3 along this profile (see also Plate 6).

Analysis of the seismic data collected in the Chelsea River indicate two small areas of either a rock, gravel, or till outcrop near the channel bottom. The first area is located in the upper reach of the Chelsea River near the Global-Gibbs and Northeast Oil petroleum transfer facility. Data from survey line CP03, presented in Figure 60, illustrates the interpreted outcrop interface. CENED core FD-93-N was drilled at this location following the geophysical survey. The second zone is detected along the southern edge of the ship channel at the Chelsea Street Bridge (see Plate 6). The depth to the rock or gravel interface is approximately 3 to 5 ft below the channel bottom. Both of these rock or gravel outcrop areas are located just outside of the current dredging scope. It should also be noted that in large areas of Chelsea River, limited acoustic penetration was obtained and, therefore, other outcrop areas may exist along the river but were unable to be detected with this technique.

Reserved channel

The seismic reflection investigation in and around Reserved Channel was divided into two areas as shown in Figures 7 and 8. A total of nine surveys, RP01 through RP09, were performed northeast of the entrance to Reserved Channel with each survey line parallel to the centerline of the 35 ft Main Ship Channel. The 2-D profiles illustrating the sediment density distributions and geologic interfaces for these surveys are presented in Plate 8. Survey lines RP03 and RP09 are not used in the subbottom interpretation. Thirteen seismic survey lines were conducted within Reserved Channel and just north of the channel mouth (see Figure 7). Acoustically derived results are presented in 2-D cross-sections which illustrate sediment density distributions and geologic interfaces along these survey lines. The results for surveys RP10 through RP18, excluding survey RP13, are displayed on Plate 9 and for surveys RP19 through RP22 on Plate 10. Recent CENED core locations are also displayed. High quality seismic data was recorded for interpretation purposes to an elevation range of -45 to -75 ft MLW.

Outside of reserved channel. In the area surveyed northeast of the entrance to Reserved Channel, in the 35 ft Main Ship Channel, the near-surface sediments varied in density with computed values ranging from 1.4 to

2.2 g/cm^3. The lower density material, less than 1.8 g/cm^3, are indicative of loosely compacted sands, silts, and/or clays as identified from three CENED cores retrieved in this area. Deeper sediments are comprised almost exclusively of gray clay, according to the core logs, with traces of silt material. Computed densities for this material range primarily from 1.5 to 1.7 g/cm^3. Numerous interfaces are also found within the clay material as shown in Figures 61 through 63. The deepest interfaces detected in Figures 62 and 63 are due to an interpreted rock or gravel layer which will be discussed later. It is noted that deeper acoustic penetration was obtained primarily in areas where the bottom surface sediments have lower density values.

Locations where higher computed density values are determined along the bottom surface may be correlated to materials such as sands on the channel bottom. It is unknown whether or not chemical residues are present on the bottom surface. These more dense sediments limit the acoustic penetration of the signal and partially or fully mask any of the subbottom reflectors. An example of this effect is shown along the leftmost and rightmost sides of Figure 61 where seismic data was collected along survey line RP07. The bottom material along survey lines RP08 and RP06, conducted outside of the 35 ft Main Ship Channel, consists primarily of sandy sediments with computed densities typically greater than 2.0 g/cm^3.

In areas of deeper acoustic penetration, the rock, gravel, and/or till interface is detected. One possible outcrop area is identified along the centerline of the Main Ship Channel, see Figure 64, and is likely within 5 ft of the current channel bottom. A portion of the seismic amplitude record illustrating this feature is presented in Figure 62 with the interpreted rock and gravel outcrop and interface shown on the left side of the record. This data was collected along survey line RP07. CENED core FD-93-D is located in this vicinity but did not encounter the seismic feature (see Figures 40 and 62). Other rock, gravel, or till pinnacles or ridges are also detected using this technique but are located more than 10 ft below the channel bottom. Figure 63 illustrates the seismic signature of one such pinnacle detected along survey line RP05.

Within reserved channel. The near-surface sediments nearest the mouth of the channel and within the current channel limits are primarily comprised of materials ranging in density from 1.4 to 1.7 g/cm^3, indicative of silty clay to sandy silts. Acoustically derived bottom sediment densities greater than 1.8 g/cm^3 are computed along the remaining length of the channel. This sediment type may be indicative of compacted sands, stiff clays, or hardpan material. It is unkown whether of not chemical residues are present on the bottom surface. Interpretation of the seismic records, however, concludes that this material is not rock or gravel. A portion of the seismic amplitude record along survey line RP18, files 010 through 030, is presented in Figure 65 and illustrates the transition zone from the lower density surface material on the left to the much higher density bottom sediments on the right. Limited acoustic penetration in areas of this dense bottom material prevented subbottom analysis at deeper depths and masked any geologic interfaces. Intermittent windows through the more dense material, however, permit investigation deeper into the subbottom. An example of one such area is shown in Figure 66 along survey line RP20.

In areas of deeper acoustic penetration, the subbottom material densities typically range between 1.6 and 2.0 g/cm^3. These sediments are typically stiff, cohesive clay, indicative of the Boston Blue Clay, possible till material, or rock and gravel. Representative seismic signatures in an area of deeper acoustic penetration is presented in the left half of Figure 65. The layering in the subbottom is particularly distinct; especially within the clay material. The deepest interface detected may be a possible rock and gravel zone.

North of Reserved Channel, five seismic surveys were performed in an area proposed to be deepened (see Figure 7). The acoustically derived density values for the near-surface sediments ranged from 1.4 to 1.8 g/cm^3 in areas nearest the main ship channel to greater than 1.8 g/cm^3 near the existing dock facilities. The less dense material, according to CENED core information, consists primarily of unconsolidated clayey and silty sand whereas the more dense material is mostly sand mixed with some gravel. The more dense material limits acoustic penetration into the subbottom and thereby masking any geologic interfaces. An example of this effect is evident in a portion of the seismic record along survey RP12 (see Figure 67). In areas of deeper acoustic penetration, the subbottom material has a density range of 1.6 to 1.9 g/cm^3. Referring to CENED core information, this material correlates to stiff, gray clay with trace silt.

Analysis of the seismic data collected within Reserved Channel indicate a rock, gravel, or till outcrop in the area north of the channel mouth proposed to be deepened. The outline of this area is located on the site map shown in Figure 68. Seismic amplitude data collected along survey line RP15, files 010 through 033, are presented in Figure 69 and best characterize this layer. Because of limited acoustic penetration due to the competent near-surface material, the rock/gravel interface is poorly defined in most of the area and cannot be resolved along some survey lines. In the few areas in which the interface can be mapped, the depth to rock ranges from 10 to 15 ft below the bottom surface. This range correlates well with CENED core information taken in this particular area. Limited acoustic penetration in the western extent of Reserved Channel may also mask any additional outcrop areas. Therefore, it should be noted that other rock areas may exist in the channel but were not able to be detected with this technique.

Results of the Side Scan Sonar Survey

The side scan sonar was used in conjunction with the seismic equipment to provide an image of the channel bottom in each of the four project areas. Side scan sonar information was collected along each survey line. The unit was operated at a frequency of 100 kHz with a range setting of either 100 or 150 meters. Each record was analyzed and interpreted to investigate the following: general channel bottom features, gross soil classification, utility crossings, obstructions to navigation, possible dredging hazards, and other anomalous features. As directed by CENED, special attention is given to areas along wharfs and bulkheads in each area. It should be remembered that the side scan provides minimal, if any, subbottom information.

Mystic River

The side scan sonar investigation in Mystic River was directed along the seismic reflection survey lines shown in Figure 70. Interpreted side scan sonar anomalies are also presented in Figure 70. In the western part of the area from the Boston Edison wharf to Distrigas, the bottom signatures produce a relatively smooth texture indicative of silt or clay bottom material. An area of scattered debris is detected along the north bank near coordinate position 717855, 505900. This location, see Figure 70, is adjacent to a scrap metal yard and dock and the signatures received are likely reflected off pieces of metal that have fallen into the water. A portion of the side scan record taken in this area is presented in Figure 71. Numerous drag marks are also detected along the channel bottom.

In the central and eastern portions of Mystic River, recorded side scan data create an image of the bottom surface that is much more irregular in texture. The rougher texture is likely indicative of coarser sediment on the channel bottom. This texture may be due to more frequent ship traffic in these locations which prevent settling of fines on the bottom. The rock, gravel, or till outcrops off the Exxon Dock and near the Mystic River Bridge are unable to be detected or resolved on the records. Shallow rows and troughs are also present along this section of the channel bottom. A small circular anomaly is detected near coordinate 720720, 505270 (see Figure 70).

There are no utility or pipeline crossings apparent on the side scan records collected in Mystic River. There are also no bottom obstructions detected that may cause a hazard to navigation. The only detected dredging hazards are likely the scrap metal debris discussed earlier and located in western Mystic River. The sonar images recorded may indicate a small boat on the bottom surface near coordinate 721095, 505405 (see Figure 70) and approximately 25 m offshore. This location, however, is outside the current dredging scope. Analysis of the sonar records near the wharfs and bulkheads along the Massport Terminal on the south shore of Mystic River indicate a change of slope along the base of the bulkhead which likely indicates a buildup of sediment material.

Inner confluence area

The side scan sonar investigation was conducted simultaneously with the seismic reflection study and follows the surveys lines presented in Figure 72. Interpreted side scan sonar anomalies are also noted on this figure. The image of the channel bottom appears relatively free of finer sediments as denoted by the rough and irregular texture. The lack of fines are likely due to frequent ship traffic which prevent the settling of silty or clayey material in the central portion of the project area and along the primary approaches to Mystic and Chelsea River. The bottom of the ship channel contains scattered objects, likely rocks, of all shapes and sizes. Most of the anomalies are relatively flat on the bottom surface although several cast a distinct acoustic shadow indicating some relief above the bottom (see Figure 73). These features may be due to the rock, gravel, or till outcrop near the channel bottom at this location. The channel bottom texture becomes smoother around the perimeter of the project area which may indicate a higher percentage of clays and silts on the bottom surface.

No utility crossings or apparent obstructions to navigation are apparent on the side scan records. A circular shaped anomaly is detected along survey line IP16. Analysis of the side scan information near existing docks and bulkheads reveal few anomalous conditions. Some debris is detected approximately 25 m off the end of a dock near the start of survey line IP07 (see Figure 72).

Chelsea River

The side scan sonar investigation in Chelsea River was performed concurrently with the seismic reflection study along the survey lines shown in Figure 74. Anomalous areas detected with this technique are also shown in the figure. Between the McArdle and Chelsea Street Bridges, the texture of the channel bottom is primarily rough and irregular with intermittent regions having smoother texture. The irregular texture is indicative of sand or gravel on the bottom surface. Some the features have various degrees of relief which may indicate rocks, cobbles, or other objects on the bottom. The areas of smoother texture likely consist of finer sediments which have settled on the bottom surface.

No utility crossings or pipelines are readily apparent on the side scan records; even in the area of McArdle Bridge where two trenches were noted during the seismic reflection survey. An extensive area of debris was detected along the channel bottom just downstream of the Chelsea Street Bridge (see Figure 74). The objects are of varying sizes and lengths which protrude slightly up off the bottom surface. A portion of the side scan sonar record presented in Figure 75, taken along survey line CP14N, illustrates these bottom features. A rectangular shaped object was detected approximately 12 m south of survey line CP14S near coordinate 728140, 504830. An additional three rectangular objects, thought to be submerged vehicles, are located off the end of a pier located near the beginning of survey line CP14S (see Figure 76). The majority of the bulkheads, wharves, and docking facilities have few if any anomalous conditions associated with them. However, according to the side scan records, the bulkheads situated along the northern bank just downstream of the Chelsea Street Bridge have failed and soil, rocks, and other debris have fallen into the channel area (see the side scan record in Figure 75). This may pose a possible hazard to navigation along this part of the channel.

Upstream of the Chelsea Street Bridge, the channel bottom has a much smoother texture indicating that larger quantities of fine sediment are present on the bottom surface. Coarser sediments are detected intermittently along the channel perimeter. A large area having irregular texture is noted along the southern boundary of the upper turning basin in the vicinity of a possible rock and gravel outcrop area (see Figure 74). Interpretation of the sonar signatures indicate coarse material and possibly rock fragments on the channel bottom and side slope. A few of the objects have some relief above the bottom surface. Drag lines are also detected along the channel bottom.

No utility crossings, pipelines, or navigation hazards are detected in the upper reaches of Chelsea River. Located just upstream of the Chelsea Street Bridge (see Figure 74), an anomalous area indicative of a debris pile was detected on the channel bottom. A rectangular bottom anomaly is located along survey line CP02 near coordinate 730500, 507835. Acoustic anomalies are also detected in the vicinity of the Global-Gibbs and Northeast Oil petroleum transfer facilities. Few anomalous conditions were detected along any of the other bulkheads or docking facilities in this area.

Reserved channel

The side scan sonar survey was performed simultaneously with the seismic reflection investigation in Reserved Channel and the area directly opposite the channel entrance. Seven surveys were performed in the area opposite of the entrance to Reserved Channel and conducted parallel to the centerline of the 35 ft Main Ship Channel. A total of 12 surveys were performed within Reserved Channel and in the area north of the channel entrance. The survey lines and interpreted anomalies are shown in Figure 77.

In the area across the main ship channel from the Reserved Channel entrance, the texture of the bottom surface image becomes more irregular near the southeastern end of the survey area. This signature may indicate a higher proportion of coarser sediments and/or rocks on the bottom surface. Some of the detected objects have some relief above the bottom surface. The bottom material in the northwest section of the area is interpreted as having more clay or silt material at the surface. Near the beginning of survey line RP05, a large anomalous area indicative of a debris pile is detected and interpreted as likely being comprised of rocks, gravel, or other coarse material. A portion of the side scan sonar record illustrating this feature is shown in Figure 78. At the location of a suspected rock or gravel outcrop, as detected with seismic reflection data (see Figure 64), the sonar images show few anomalous signatures that may indicate the presence of rock, gravel, or cobbles on the channel bottom.

No definite hazards to vessel navigation were determined from the results of the survey performed in this area. Bottom images did detect numerous signatures interpreted as lobster traps or other man-made debris. Two long, linear anomalies were detected in the southeastern part of the area surveyed (see Figure 77) and are illustrated in Figure 78. These distinct linear features may be trenches for utility crossings or drag marks on the channel bottom.

Within the current boundaries of Reserved Channel, the bottom image has a smooth to moderately irregular texture indicative of predominantly finer sediments with traces of coarse material, probably sand, on the bottom surface. This correlates well with the results from the seismic reflection survey. Two separate piles of sediment material are detected in the berthing area at and beyond the western end of the Castle Island (Massport) Terminal bulkhead. These features are illustrated in the side scan record shown in Figure 79. The mounds do not have much relief and do not pose a hazard to ship traffic. A few drag marks and trenches are detected along the channel bottom but it cannot be determined if these features represent utility crossings. Numerous sonar signatures interpreted as lobster traps are noted along the length of the channel with the heaviest concentration nearest the main ship channel. The bulkheads on either side of the channel appear structurally sound from information displayed on the side scan records but small intermittent anomalies appear along their edges. These anomalous images may likely be man-made debris that has fallen in the water.

North of the entrance to Reserved Channel, the texture of the bottom image is more irregular than that detected within the channel which likely indicates coarser material present on the channel bottom. These results correlate well with the interpretation from the seismic reflection survey in this area. Numerous scattered targets are detected which appear to be man-made debris, buoy anchors, or lobster traps. Some of these targets may also represent rocks or cobbles. No utility crossings were detected in this area.

Volumetric Estimates

One of the objectives of the seismic reflection investigation is to not only characterize the subbottom sediments but also quantify the sediment types. Seismic signatures reflected from various geologic interfaces are recorded and displayed to create seismic amplitude cross-sections. The seismic amplitude intensity, with the more competent reflectors correlating with the strongest signals, give indications of the depths to differing stratigraphic interfaces in the subsurface. Using the three material categories of interest: (1) rock, gravel, and till, (2) stiff, cohesive clay and sandy material, and (3) loosely compacted sediments (muck), thicknesses were determined from the amplitude cross-sections. Investigation of the seismic data have indicated that the density and acoustic impedance contrasts between the sandy material and stiff, cohesive clay, namely the Boston Blue Clay, are small and distinguishing between the two geologic units is difficult. Therefore, estimates reflect the combined volume of sandy material and clay to be removed through dredging. The survey results for each of the bottom and subbottom material categories are discussed below.

Loosely compacted sediment (muck)

During analysis of the seismic data collected in the four project areas, thicknesses of loosely compacted sediments were measured along each profile line and correlated to the surface areas of the proposed dredging efforts. The volume estimates for this material classification in each area of investigation are shown in column 1 of Table 3. The best volume estimate of the loosely compacted sediment (muck) for the dredging effort in Boston Harbor is 578,700 yd^3.

Stiff, cohesive clay/sandy material

The thicknesses of this interpreted material above set dredging limits are measured along each profile line and correlated to the surface areas within each project area. The generalized category of stiff, cohesive clay/sandy material encompasses the Boston Blue Clay, areas of hardpan clay, sands, and compacted or bonded sandy silt material. The volume estimates for this material classification for each area of investigation are shown in column 2 of Table 3. The best volume estimate for the dredging effort in Boston Harbor is 1,297,500 yd^3 with nearly 41 percent of the quantity retrieved from Mystic River. Separate estimates for the sandy sediments and clay material were unable to be made because of the sediments similar density and acoustic impedance values.

Rock, gravel, and till material

Volume estimates of the rock, gravel, and till material were made through analysis of the seismic data collected in the four project areas. Areas of possible rock outcrops were determined from the seismic amplitude cross-sections and outlined in a letter report provided to Mr. Yuri Yatsevitch, CENED-ED-GG, on 2 February 1993. The estimated thicknesses of rock and gravel material were measured along each seismic profile line and correlated to the surface areas of the interpreted outcrop areas within the proposed dredging effort. The volume estimates for this material classification for each area of investigation are shown in column 3 of Table 3. The best volume estimate of rock and gravel material for the dredging effort in Boston Harbor is 79,600 yd^3. It should be noted that possible rock outcrops were detected in the Chelsea River but are located outside of the current dredging scope. In Reserved Channel, the competent near-surface sandy material limited acoustic penetration of the seismic signal into the subbottom and thereby lessened the identification and detection of rock or gravel interfaces in and around the channel mouth. Further analysis of these areas using CENED drill hole information assisted WES investigators in determining volumetric estimates of this material.

The proposed dredging effort also includes widening of the Inner Confluence Area along the eastern side. Limited seismic surveying was performed in this area because of shallow water depths. Using the seismic data obtained and information provided by CENED, the sediment material is comprised of muck, sandy silt, clay, and possible rock outcrops. A gross estimate of sediment volume to be removed through dredging is approximately 229,400 yd^3.

Total volume of dredged material

The volumes of rock and sediment material to be removed from each project area during the proposed harbor deepening is outlined in column 4 of Table 3. The total volume of rock and sediment material to be removed from Boston Harbor through dredging is estimated at approximately 1,955,800 yd^3. Adding the material volume estimate from the proposed widening of the Inner Confluence Area, the total volume is approximately 2,185,200 yd^3.

6 Project Summary

A high-resolution, seismic reflection survey was performed in three tributaries of Boston Harbor, MA to quantify the densities and soil types of the near-surface and subbottom marine sediments. The project areas investigated include the Mystic River, Inner Confluence Area, Chelsea River, and Reserved Channel. Analysis of the seismic data yielded computed sediment densities which may vary by ± 0.20 g/cm^3 from insitu values.

Near-surface material densities are highly variable across the entire project scope with values ranging from 1.4 to 2.2 g/cm^3. Surface material having computed densities between 1.4 and 1.8 g/cm^3 are indicative of sediments ranging from silty clays to silty sands. The higher density sediments are likely rock, gravel, or till material, sandy material, stiff, cohesive clays typically called the Boston Blue Clay, or hardpan material. Areas of higher density sediments could readily be detected on the seismic records because of limited penetration of the acoustic signal in these areas. Density and soil classification of the bottom sediments, as determined from the seismic data, correlated well with existing CENED and WES drill hole information.

Below the depths set by the proposed dredging work, the subbottom material becomes primarily a stiff, lean clay or rock, gravel, and till. These materials are detected in many of the deeper core logs. This material has acoustically derived densities ranging from 1.6 to 2.2 g/cm^3.

The results of the seismic reflection survey did detect and delineate three regions of rock, gravel, or till outcrops near the channel bottom in the Mystic River and Inner Confluence Area. The undulating interface generally forms pinnacles or ridges and at the areas noted, approaches to within 3 to 5 ft of the channel bottom. The estimated volume of this competent material to be removed through dredging is approximately 46,100 yd^3. Two outcrop areas were also detected along the Chelsea River; one near the Chelsea Street Bridge and another southwest of the Global-Gibbs and Northeast Oil petroleum transfer docks. These outcrop areas are, however, outside the current dredging scope. One rock or gravel outcrop was detected across from Reserved Channel in the 35 ft Main Ship Channel. The depth to this zone is approximately three feet. Three other rock or gravel pinnacles were also identified but are located at least 10 ft below the channel bottom. North of the mouth to Reserved Channel, limited acoustic penetration prevented delineation of a suspected rock, gravel, or till outcrop area. Further analysis during CENED drilling and probing efforts provided additional subbottom information at this location. Seismic data collected in the Chelsea River, Reserved Channel, and western Mystic River had limited depth penetration and, therefore, few geologic interfaces could be detected and interpreted. Therefore, it should be noted that other rock, gravel, or till outcrops may exist in these areas but are not able to be detected with this technique.

After analysis of the seismic reflection data, the survey results were able to delineate the acoustic signatures of the differing sediment regimes outlined within the report. Volume estimates of the loosely compacted bottom material (muck), stiff, cohesive clay/sandy material, and rock, gravel, and till are computed from the interpreted sediment thicknesses. The total volume of rock and sediment material to be removed from the three tributaries of Boston Harbor is estimated at approximately 1,955,800 yd^3. Of this total, a quantity of 1,297,500 yd^3 or 66 percent of this material is categorized as stiff, cohesive clay and/or sandy material. An additional 229,400 yd^3 of material are estimated to be removed during the proposed channel widening along the eastern side of the Inner Confluence Area. The volumetric results provided in this report are best estimates and should be used judiciously in the development of any finalized dredging specifications.

The side scan sonar was operated concurrently during the seismic reflection survey and provide an acoustic image of the channel bottom in each project area. The results provided qualitative assessments of the bottom sediment characteristics and identified any anomalous conditions that may pose a hazard to navigation or the proposed dredging effort. One area of concern is located along the northern retaining wall in Chelsea River just downstream of the Chelsea Street Bridge. The wall has collapsed and sediment material or other debris have fallen into the channel. The presence of any utility or pipeline crossings are noted in each area investigated.

Analysis of the seismic information provides a continuous description of the bottom and subbottom sediments in terms of density and material type. The sediment characteristics and profiles highlight changes in the actual subbottom conditions and delineates the extent and depth of various geologic features. With additional information provided from a side scan sonar, an acoustic image of each channel bottom qualitatively characterized the bottom sediments and delineated any navigation or dredging hazards. This information will be especially helpful in coordinating and completing a sediment coring program or proposed maintenance or new work dredging.

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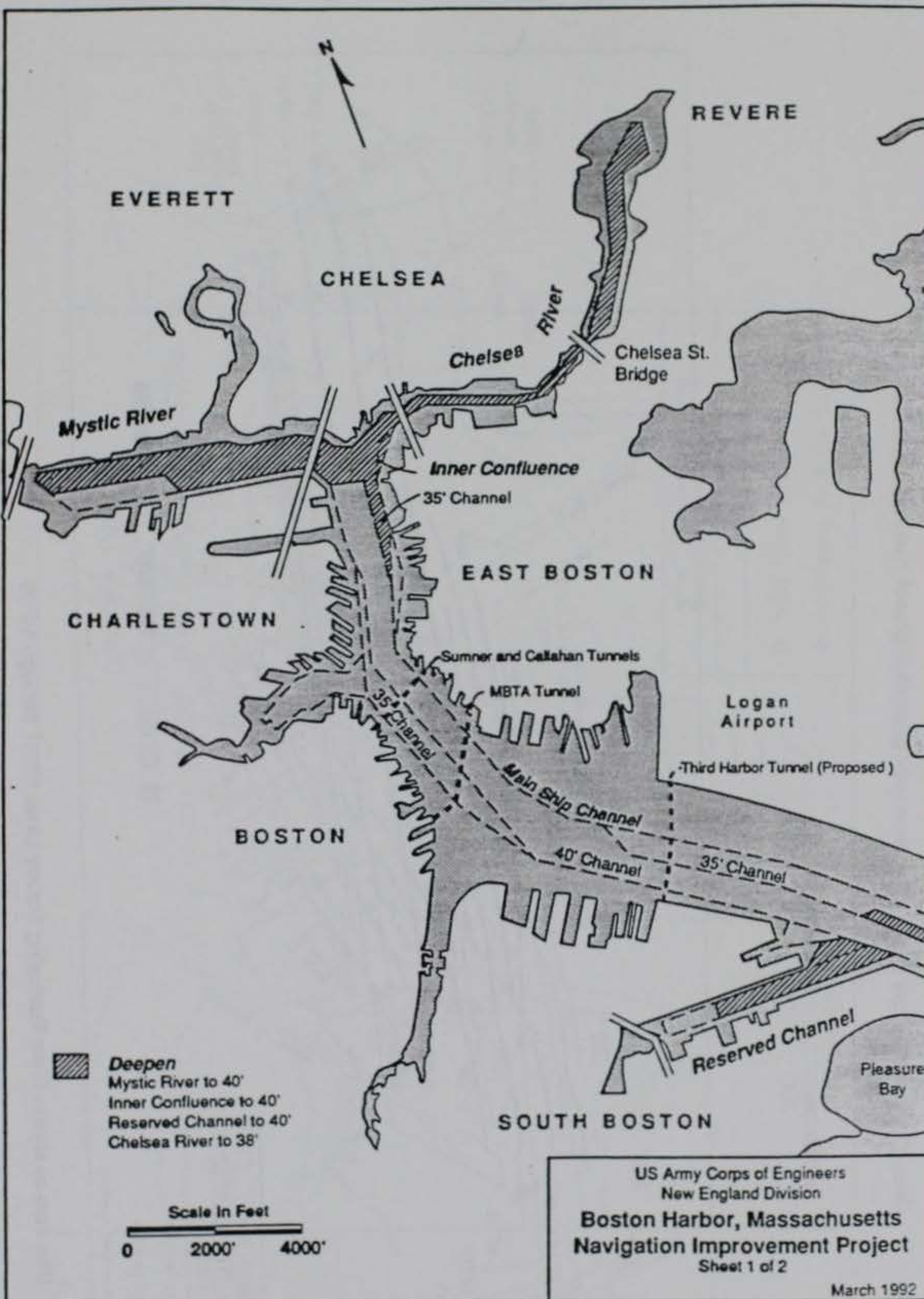


Figure 1. Site map illustrating the three tributaries (four project areas) surveyed in Boston Harbor, MA

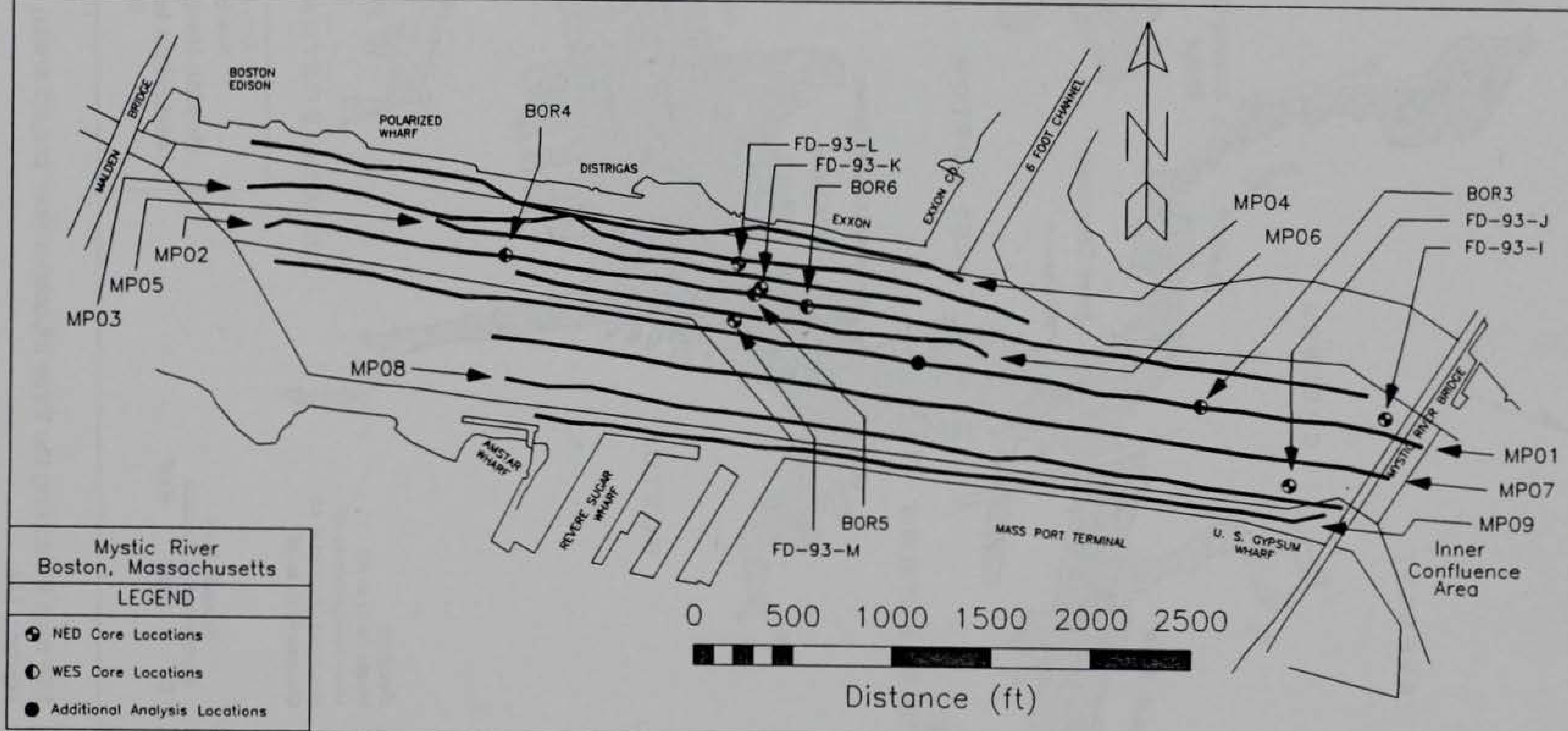


Figure 2. Site map of Mystic River illustrating Survey Lines MP01 through MP09

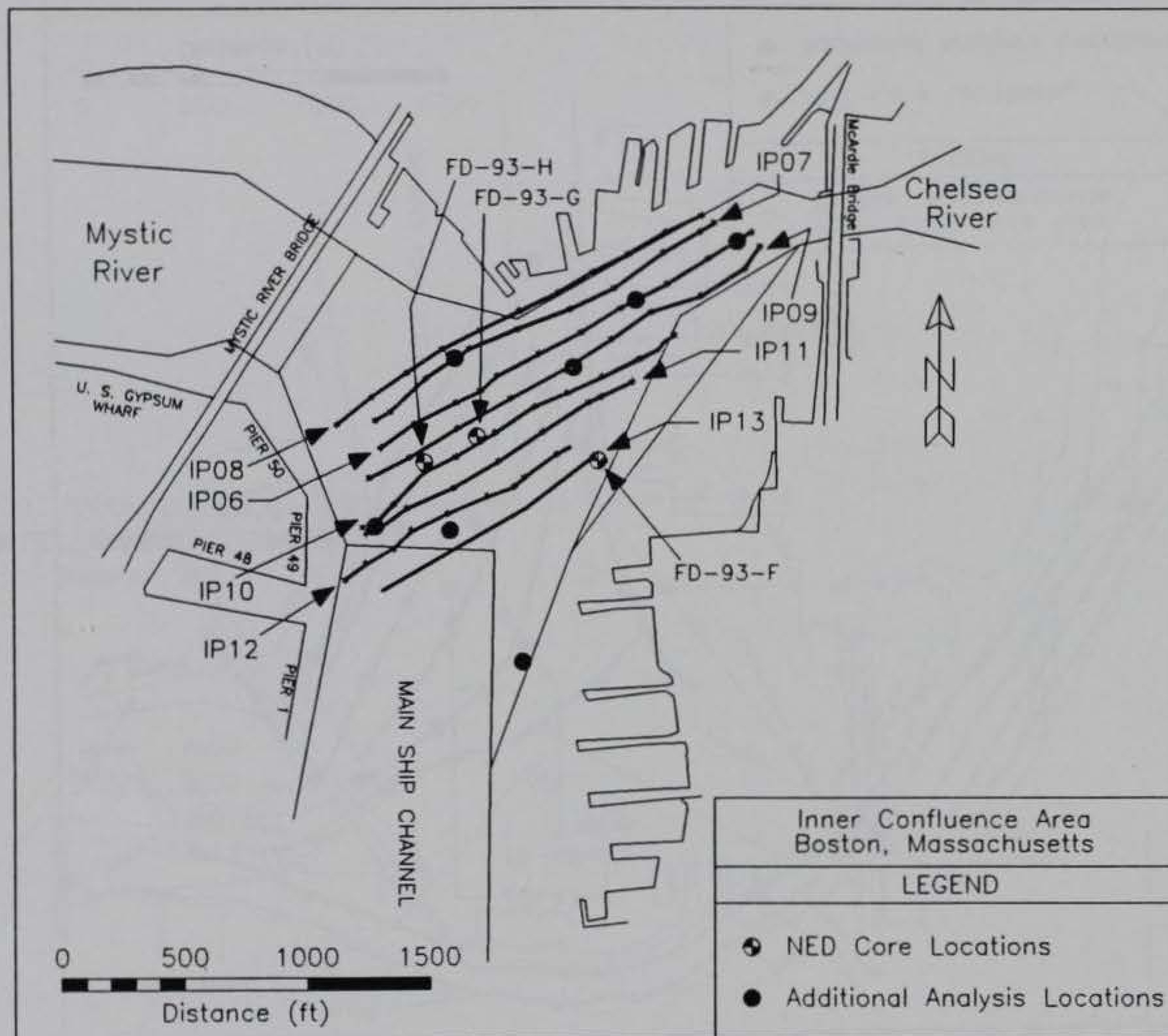


Figure 3. Site map of the Inner Confluence Area illustrating Survey Lines IP06 through IP13

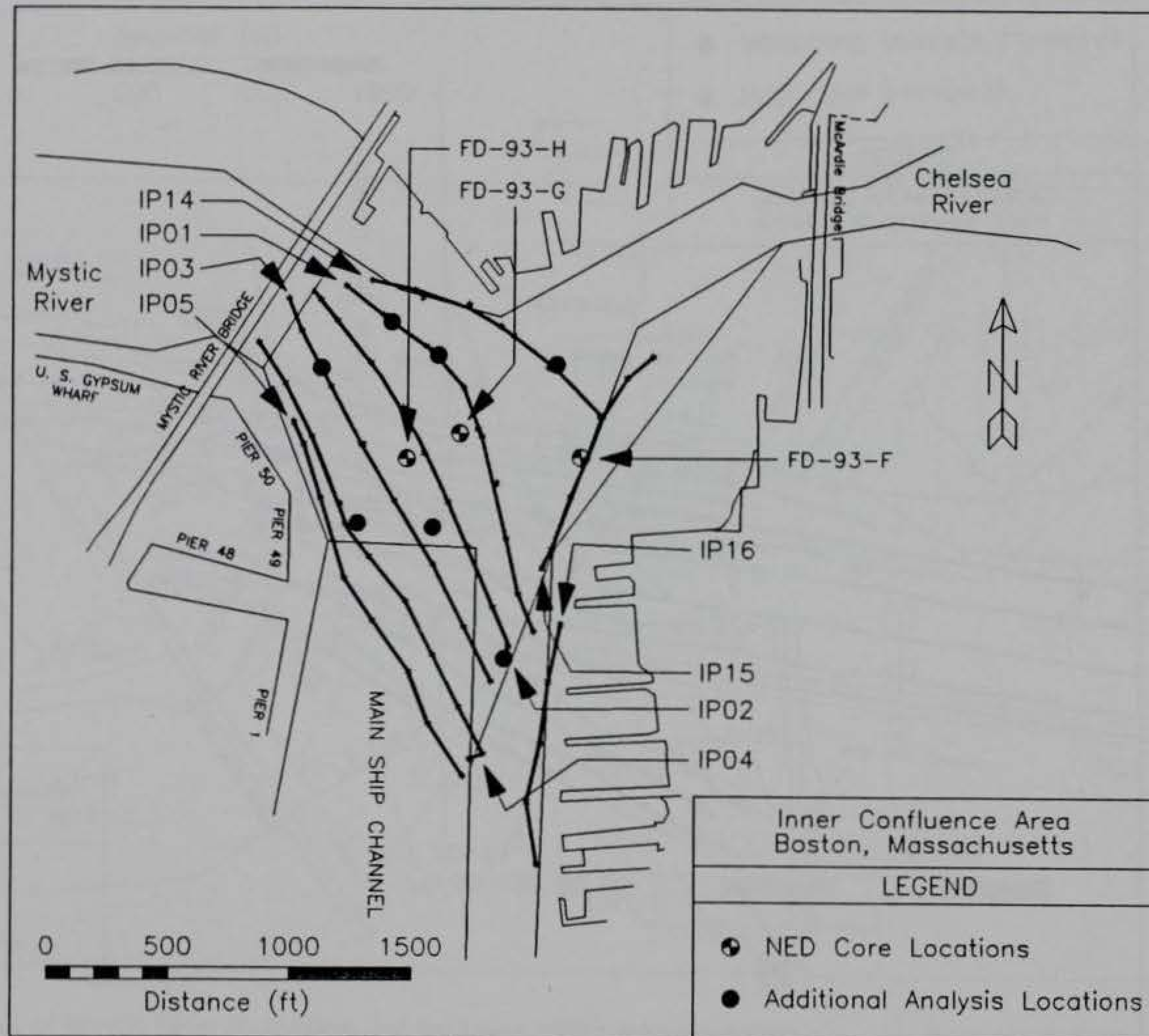


Figure 4. Site map of the Inner Confluence Area showing Survey Lines IP01 through IP05 and IP14 through IP16

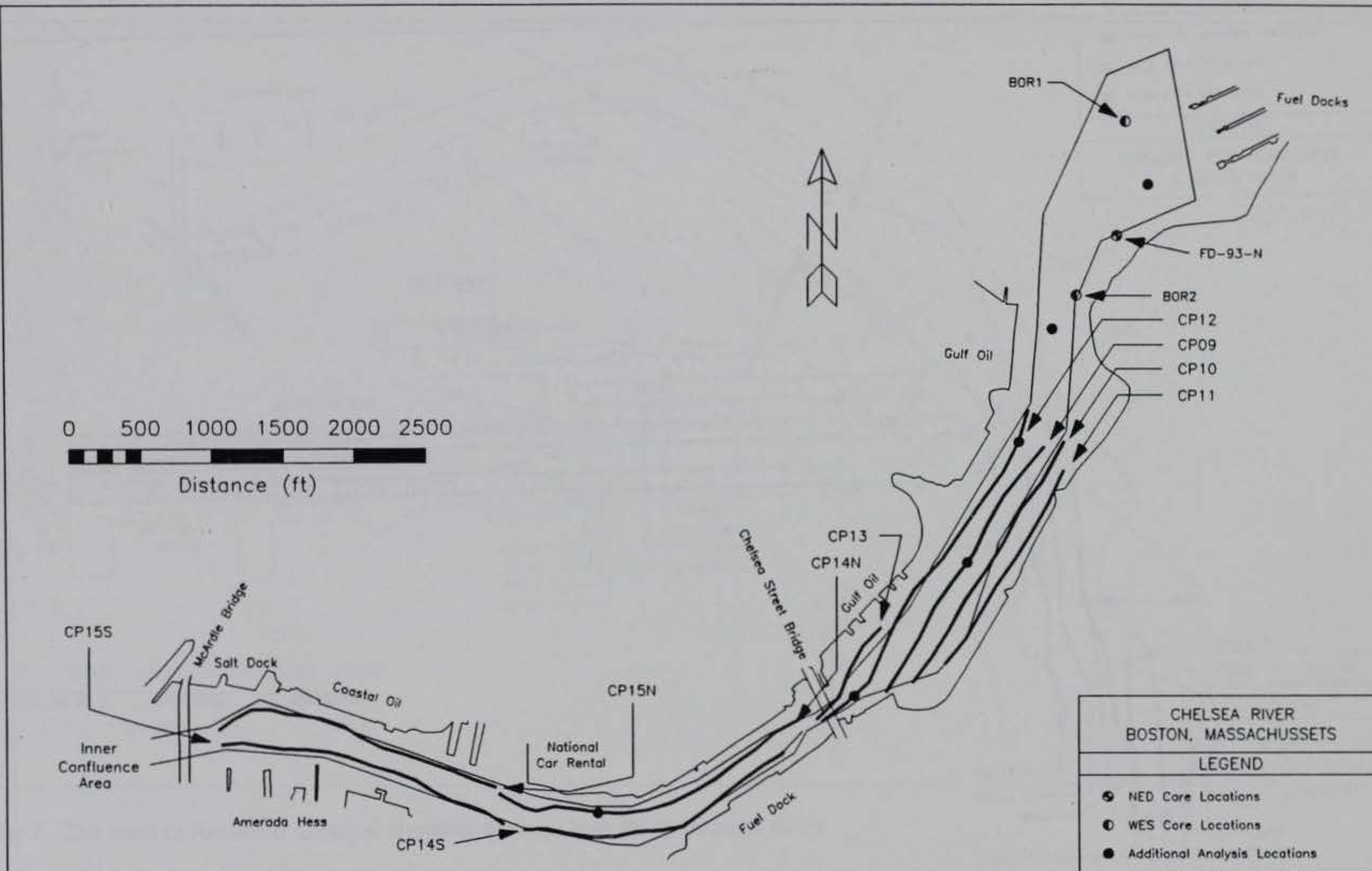


Figure 5. Site map of Chelsea River illustrating Survey Lines CP09 through CP15

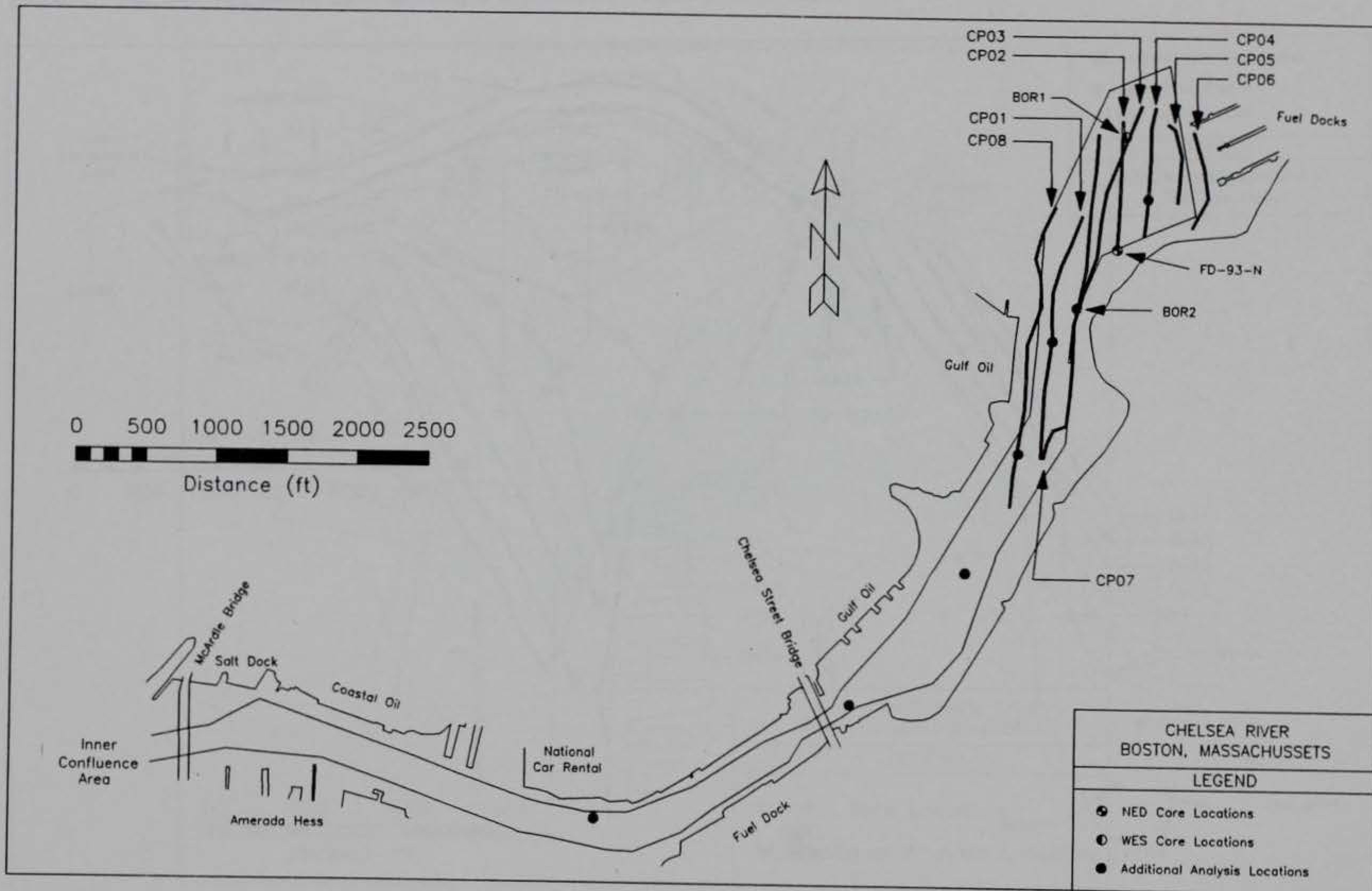


Figure 6. Site map of Chelsea River showing Survey Lines CP01 through CP08

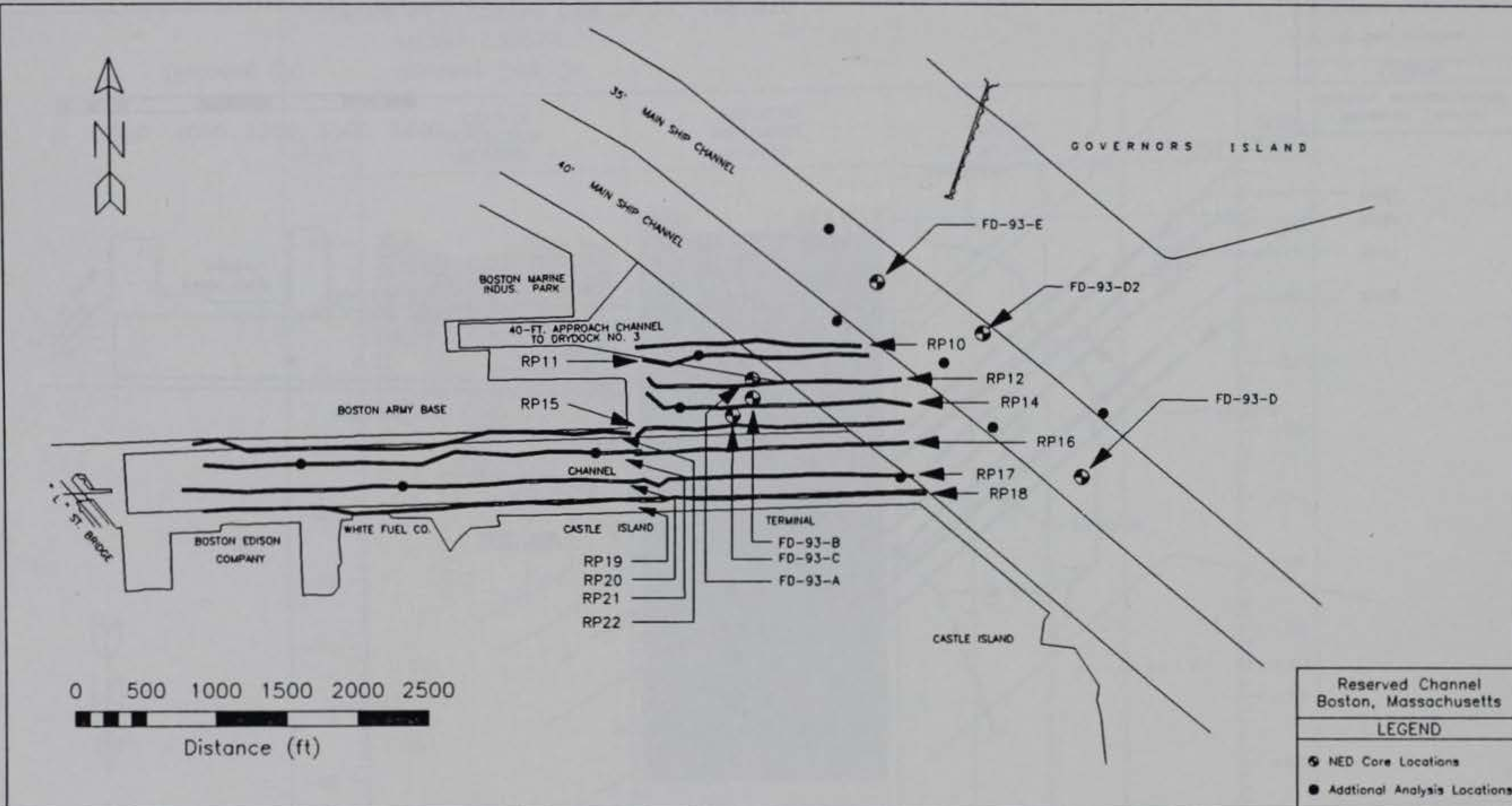


Figure 7. Site map of Reserved Channel showing Survey Lines RP10 through RP22

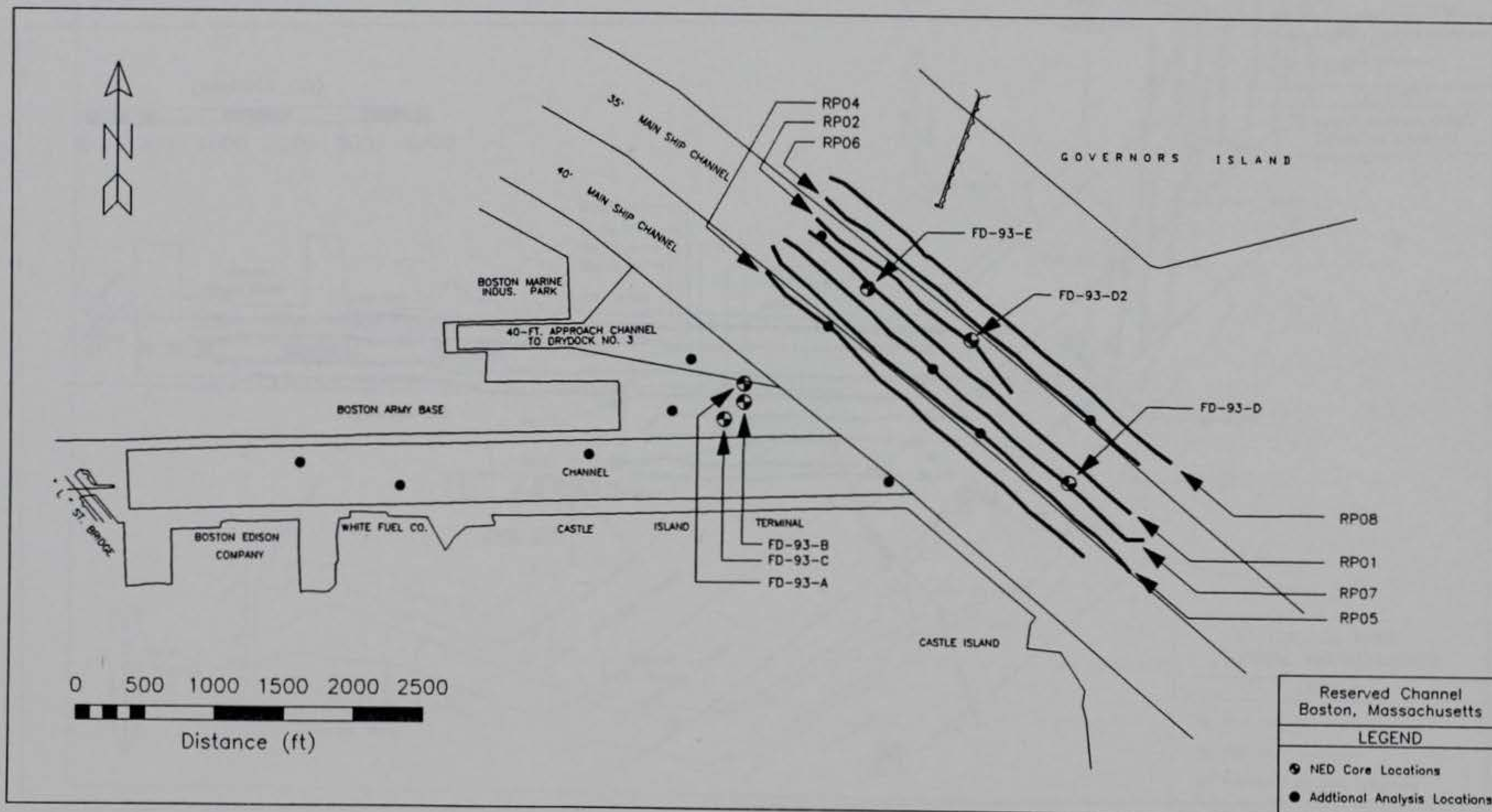


Figure 8. Site map of Reserved Channel showing Survey Lines RP01 through RP09

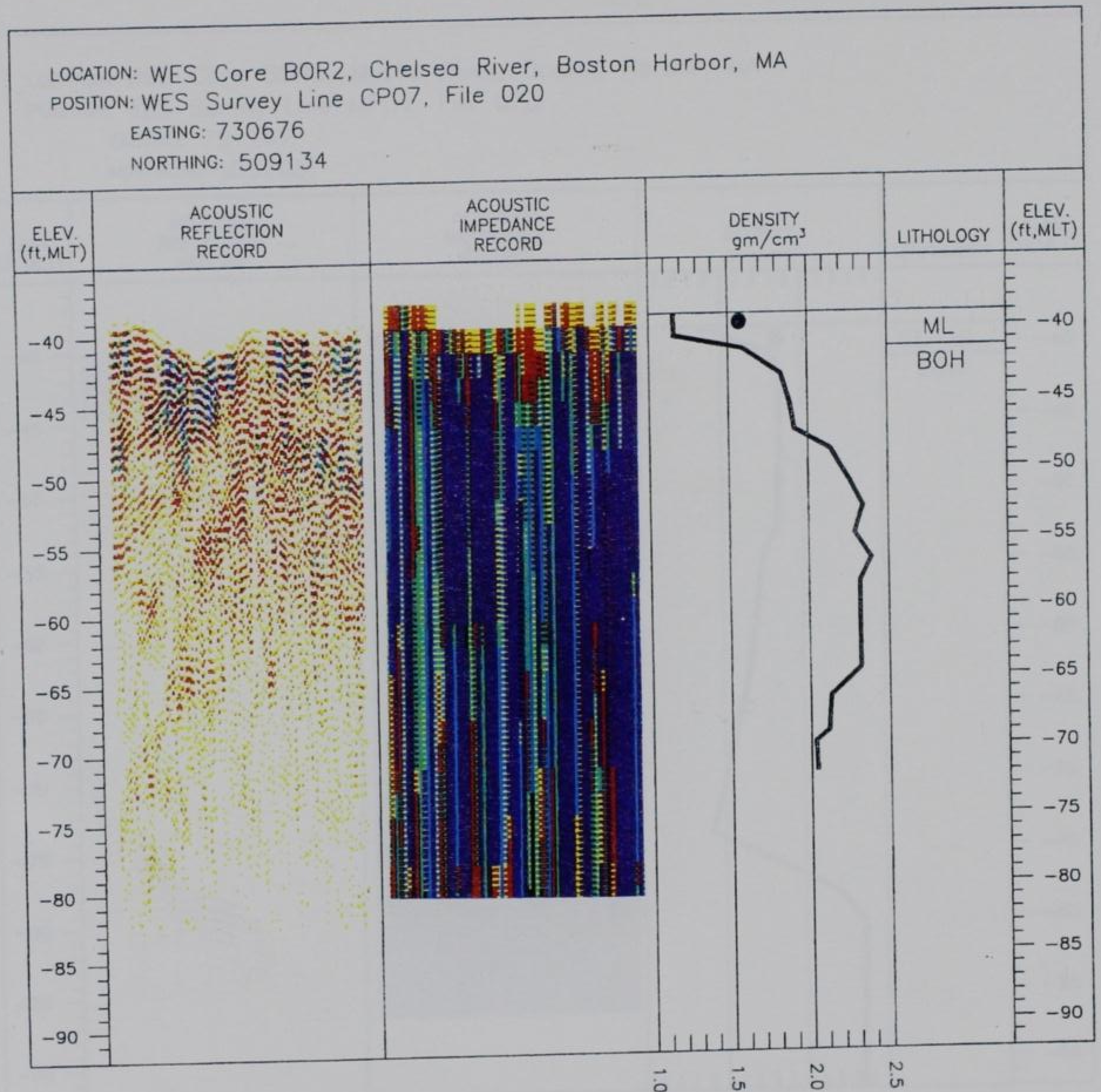


Figure 9. Bottom surface calibration at WES Core BOR2, Chelsea River

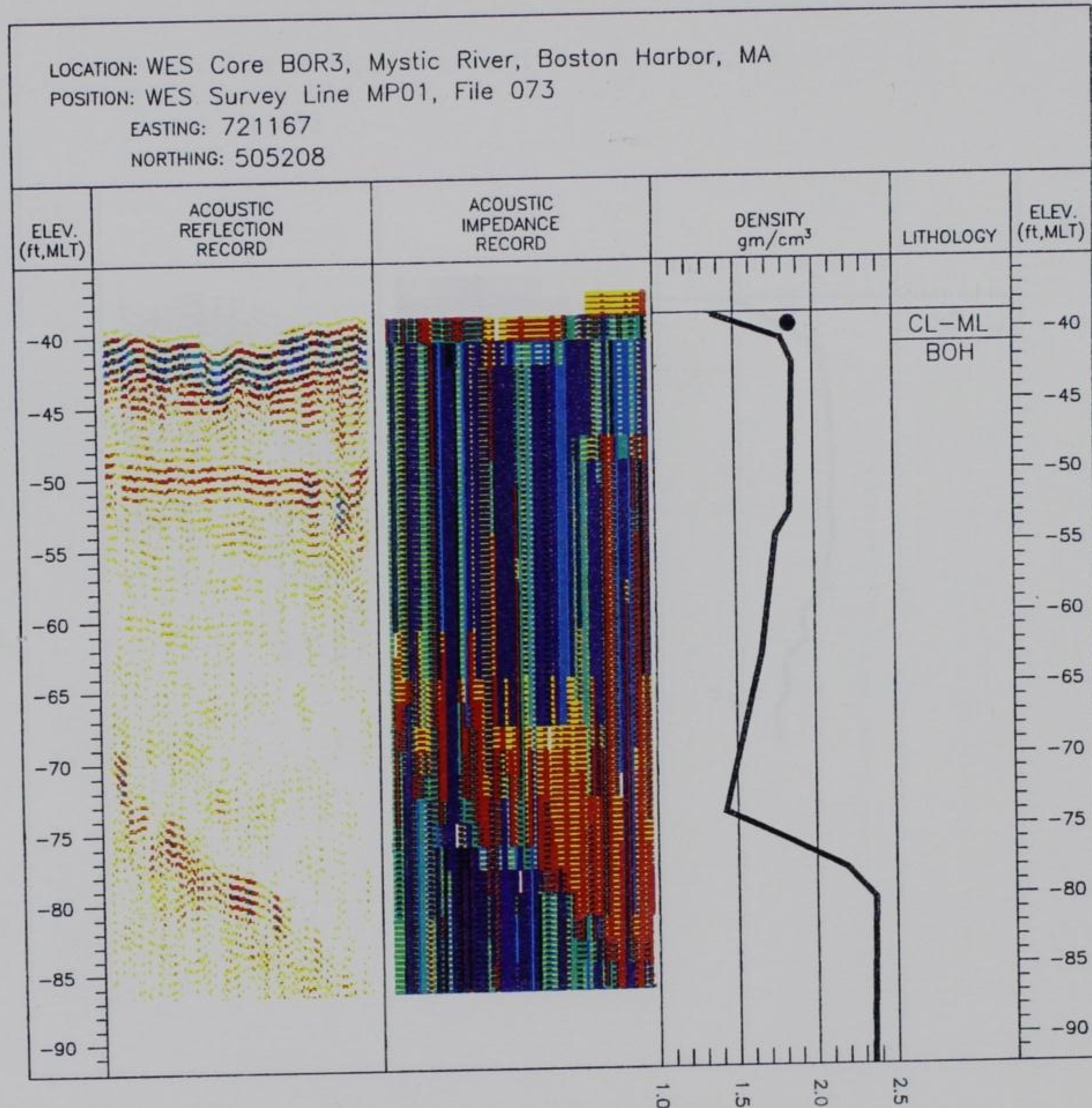


Figure 10. Bottom surface calibration at WES Core BOR3, Mystic River

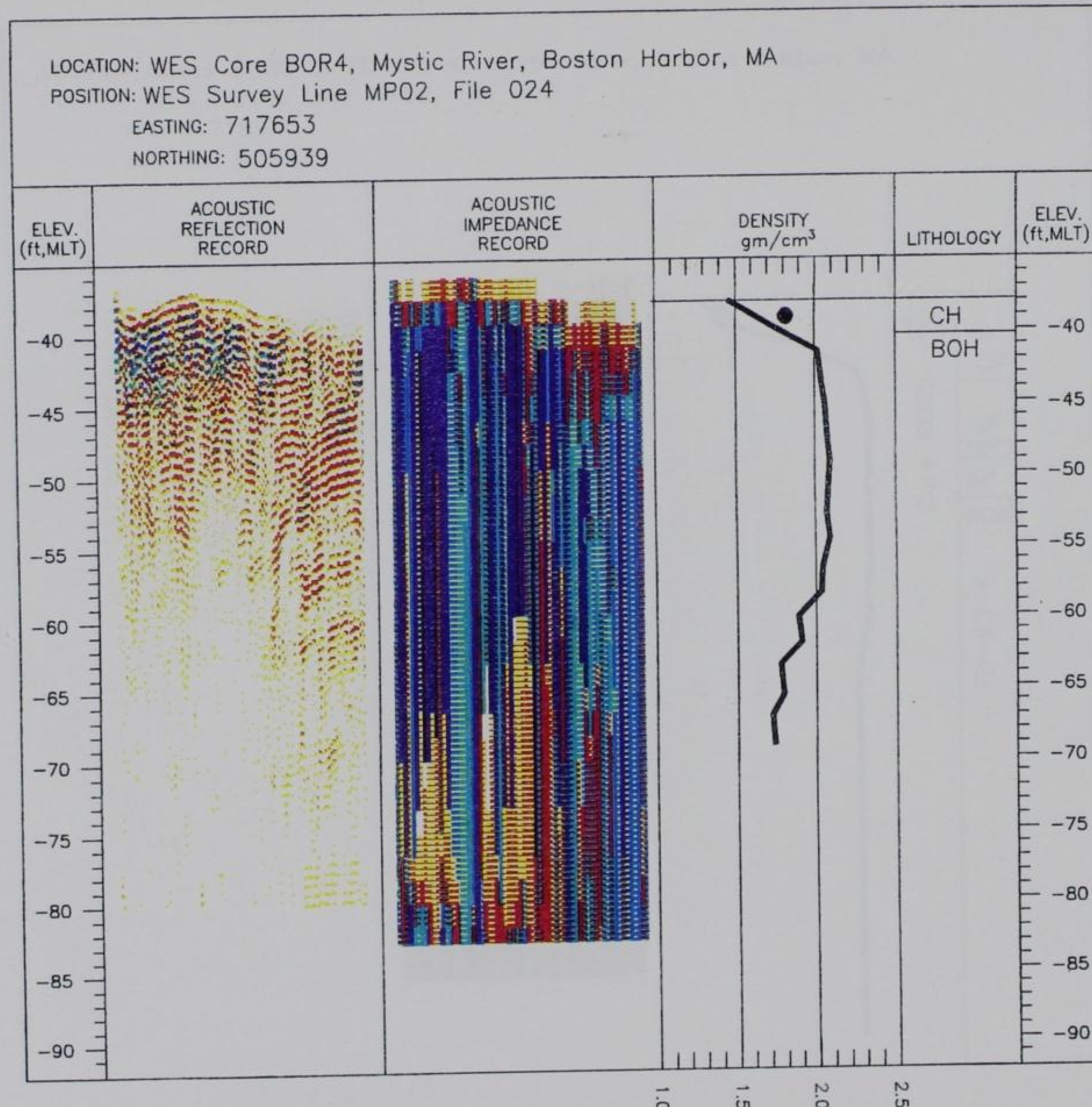


Figure 11. Bottom surface calibration at WES Core BOR4, Mystic River

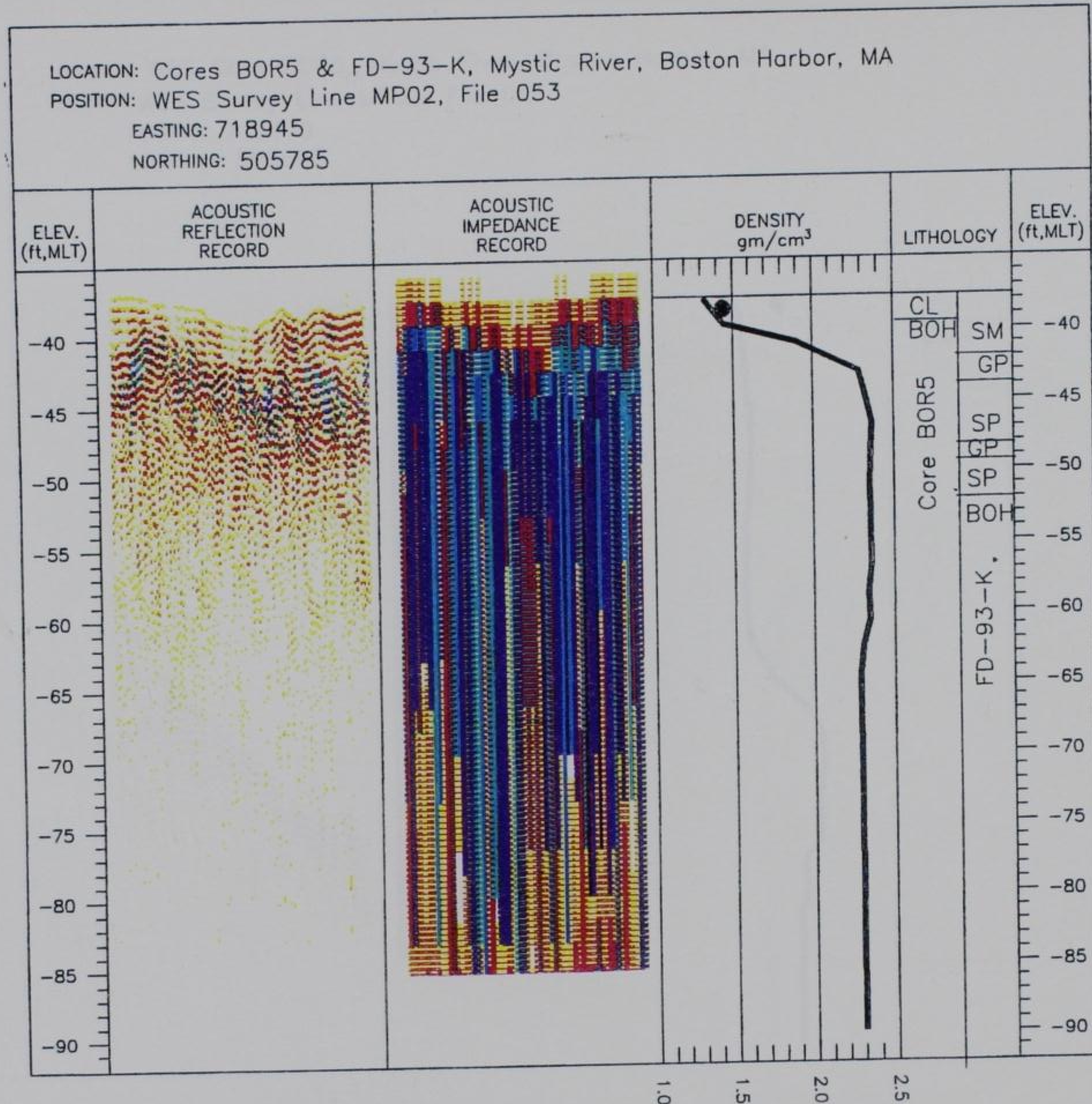


Figure 12. Bottom surface calibration at WES Core BOR5 and CENED Core FD-93-K, Mystic River

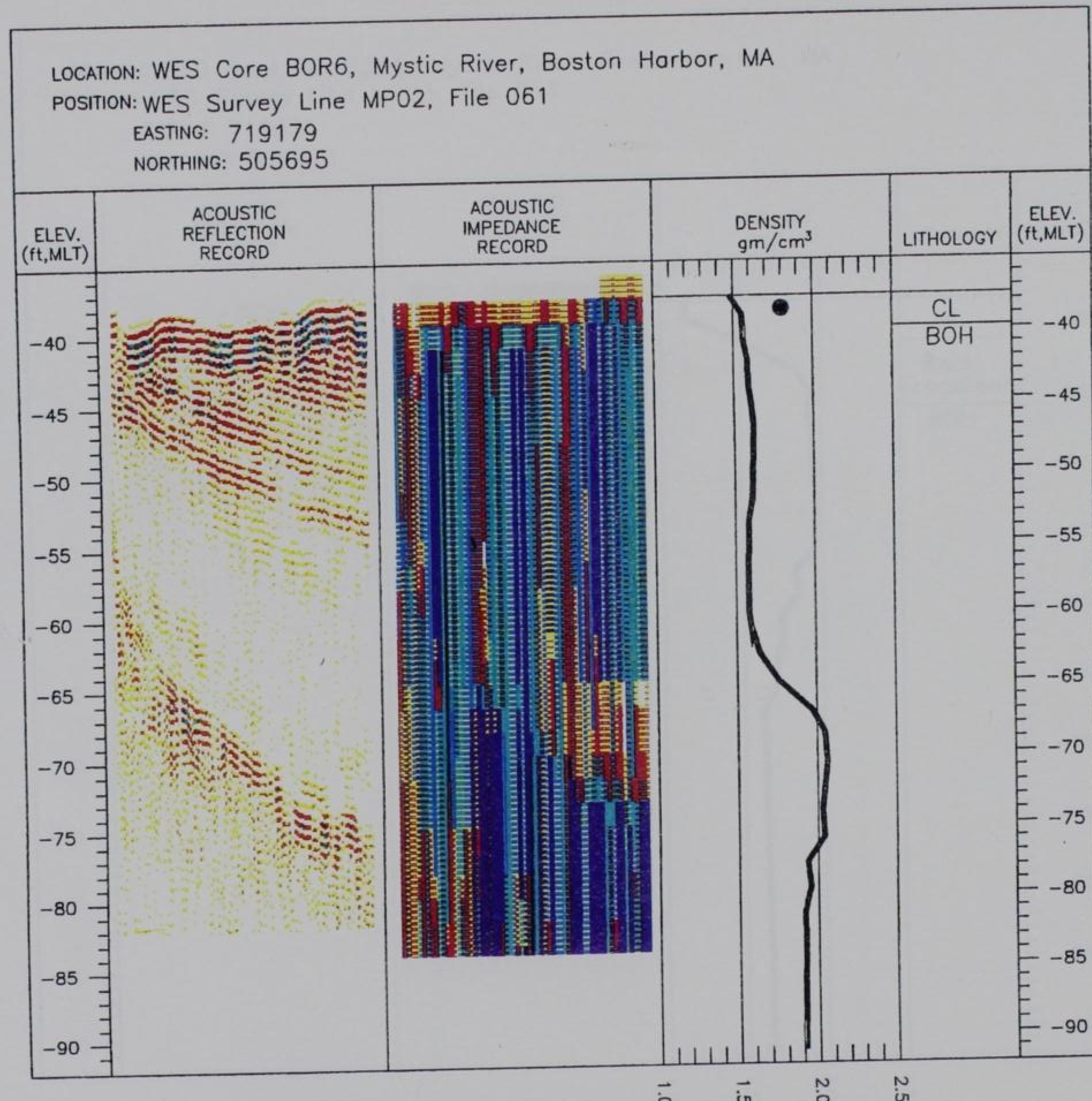


Figure 13. Bottom surface calibration at WES Core BOR6, Mystic River

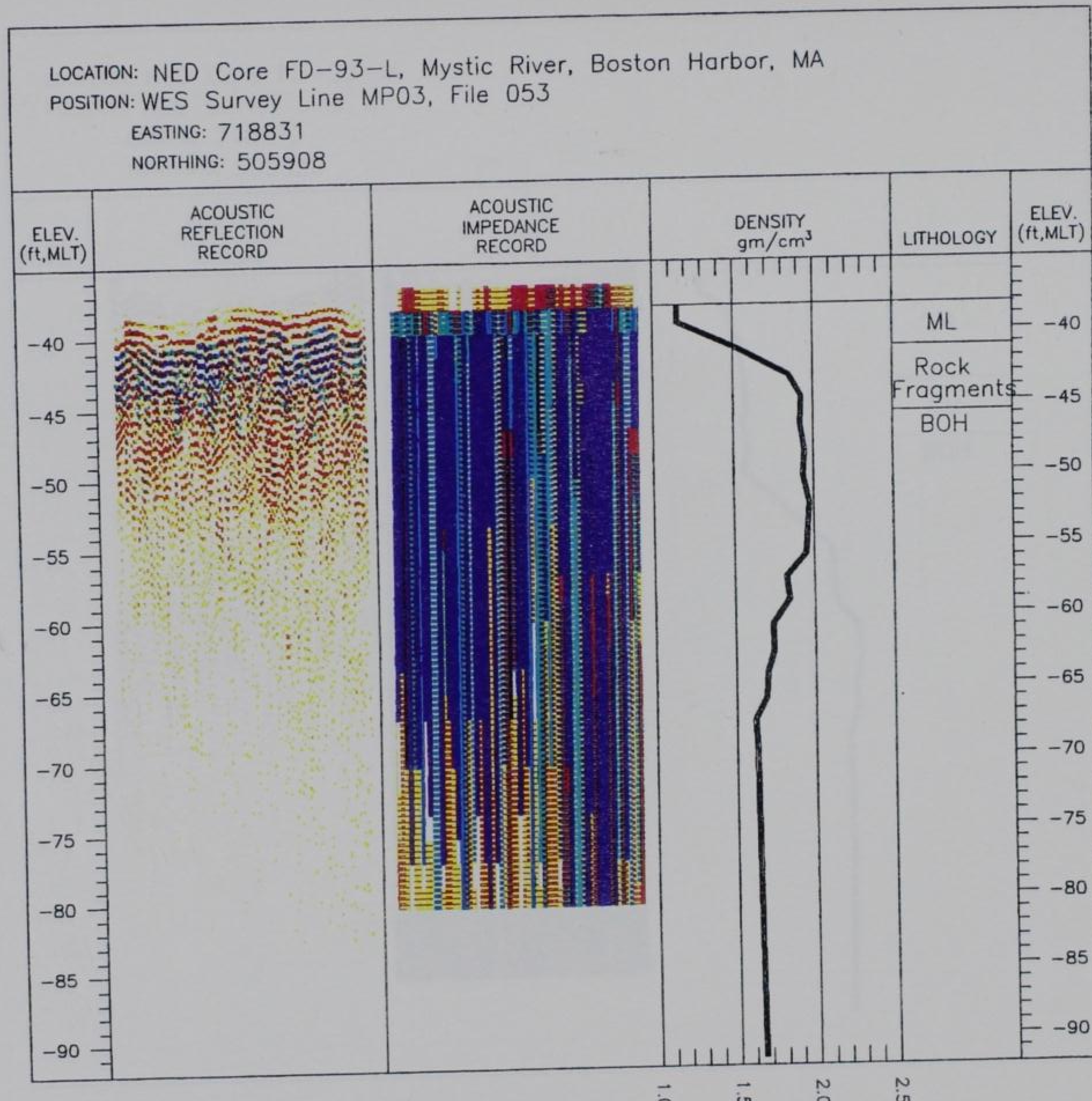


Figure 14. Subbottom sediment calibration at Core FD-93-L, Mystic River

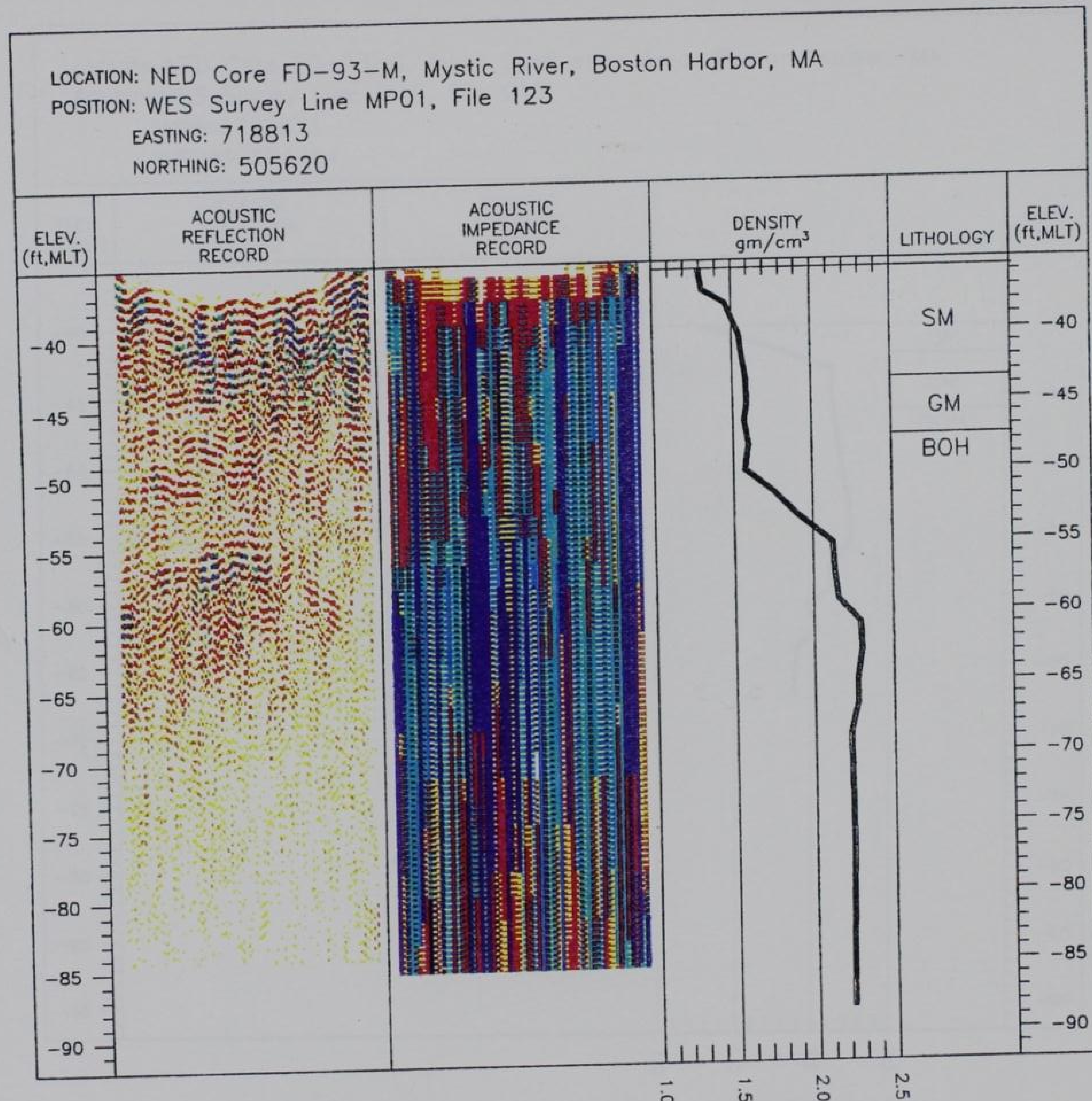


Figure 15. Subbottom sediment calibration at Core FD-93-M, Mystic River

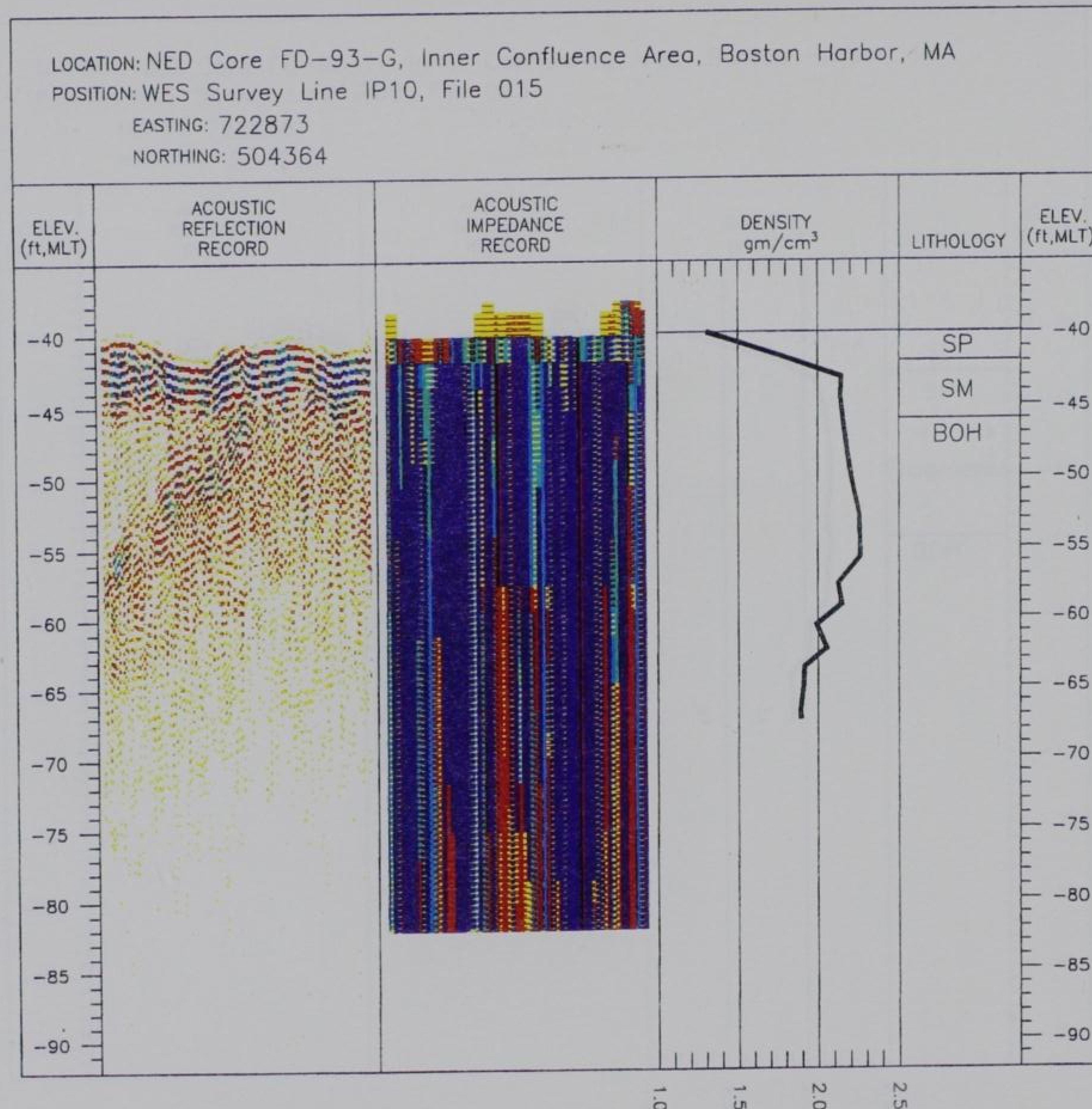


Figure 16. Subbottom sediment calibration at Core FD-93-G, Inner Confluence Area

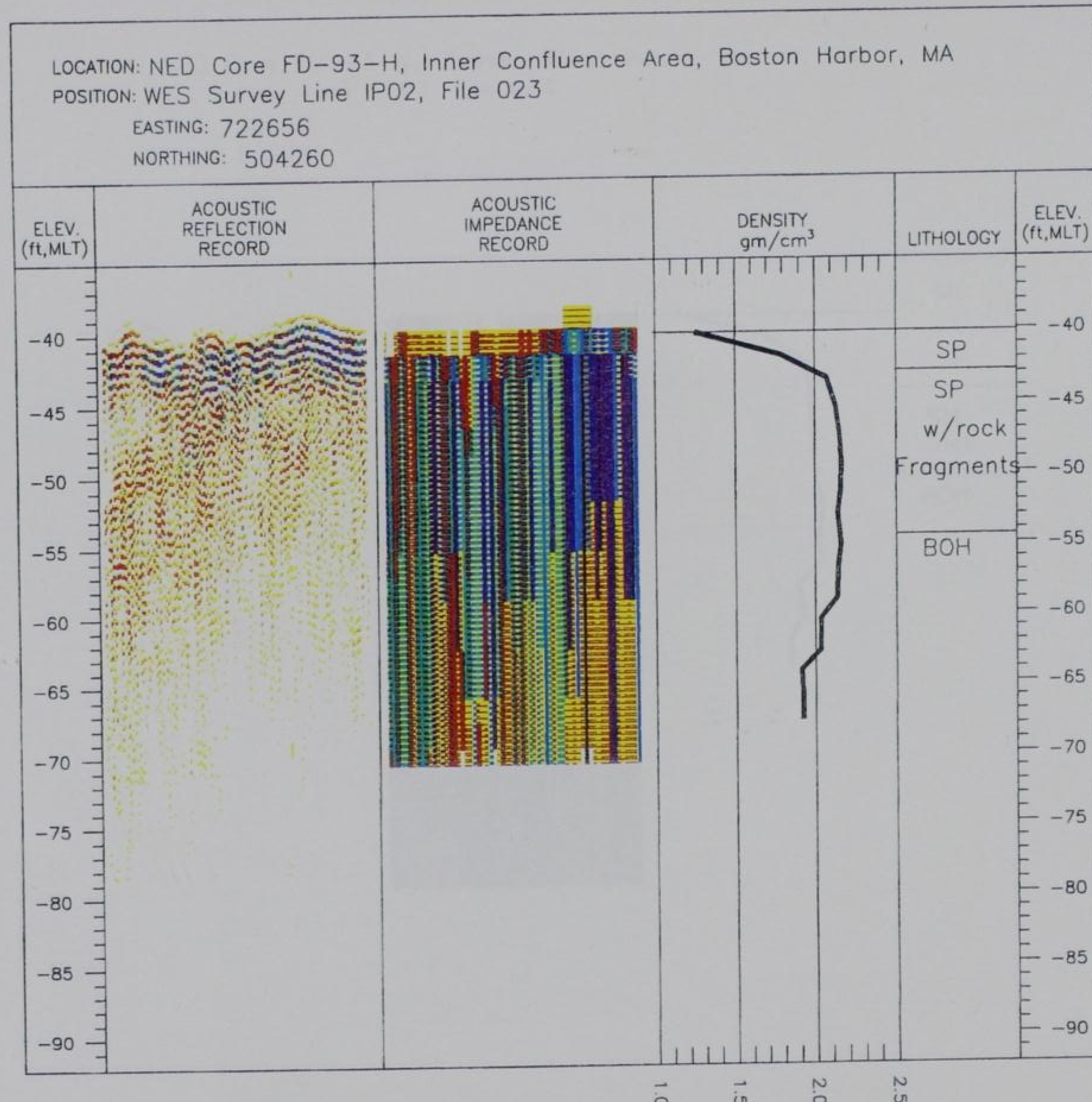


Figure 17. Subbottom sediment calibration at Core FD-93-H, Inner Confluence Area

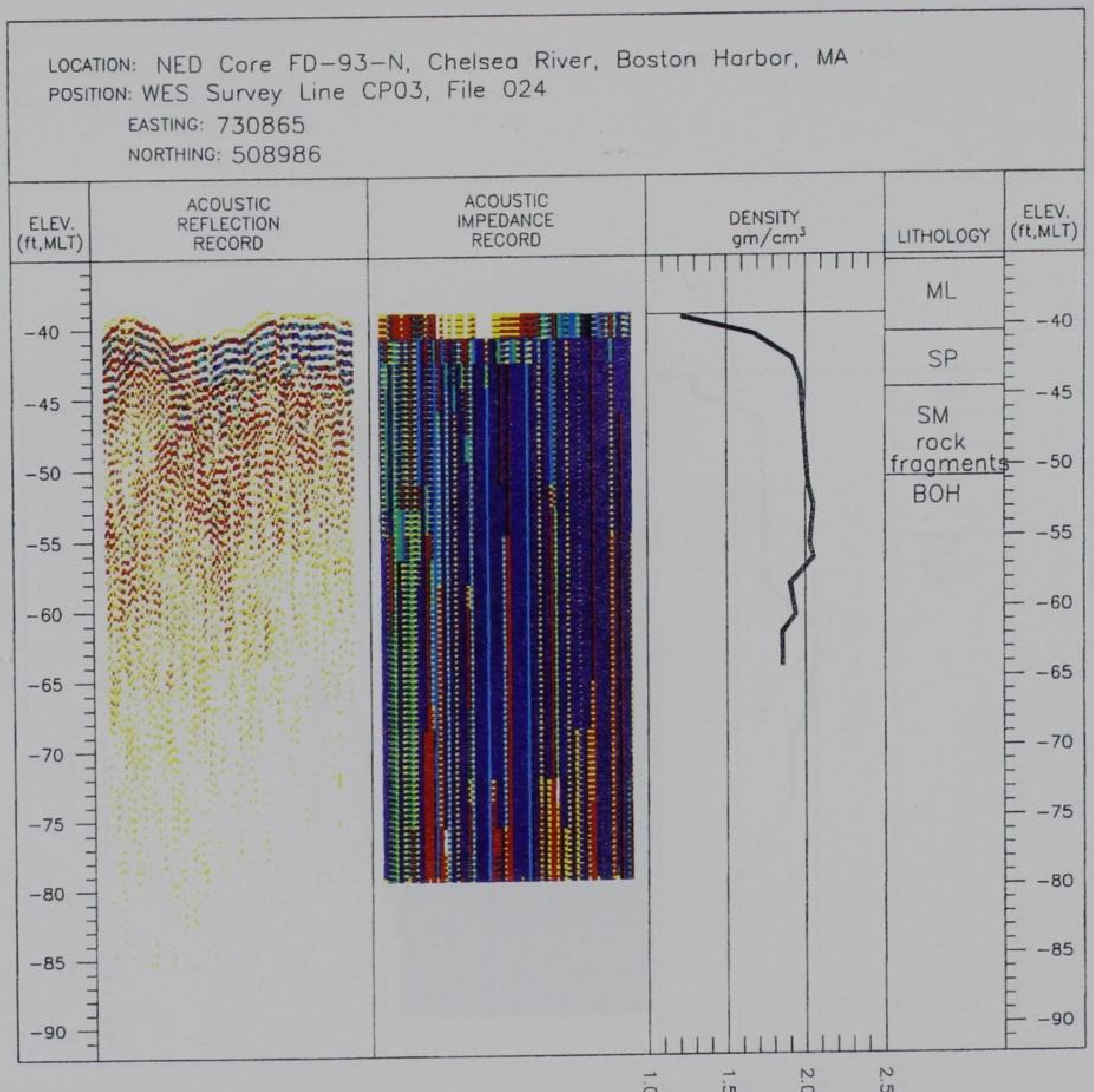


Figure 18. Subbottom sediment calibration at Core FD-93-N, Chelsea River

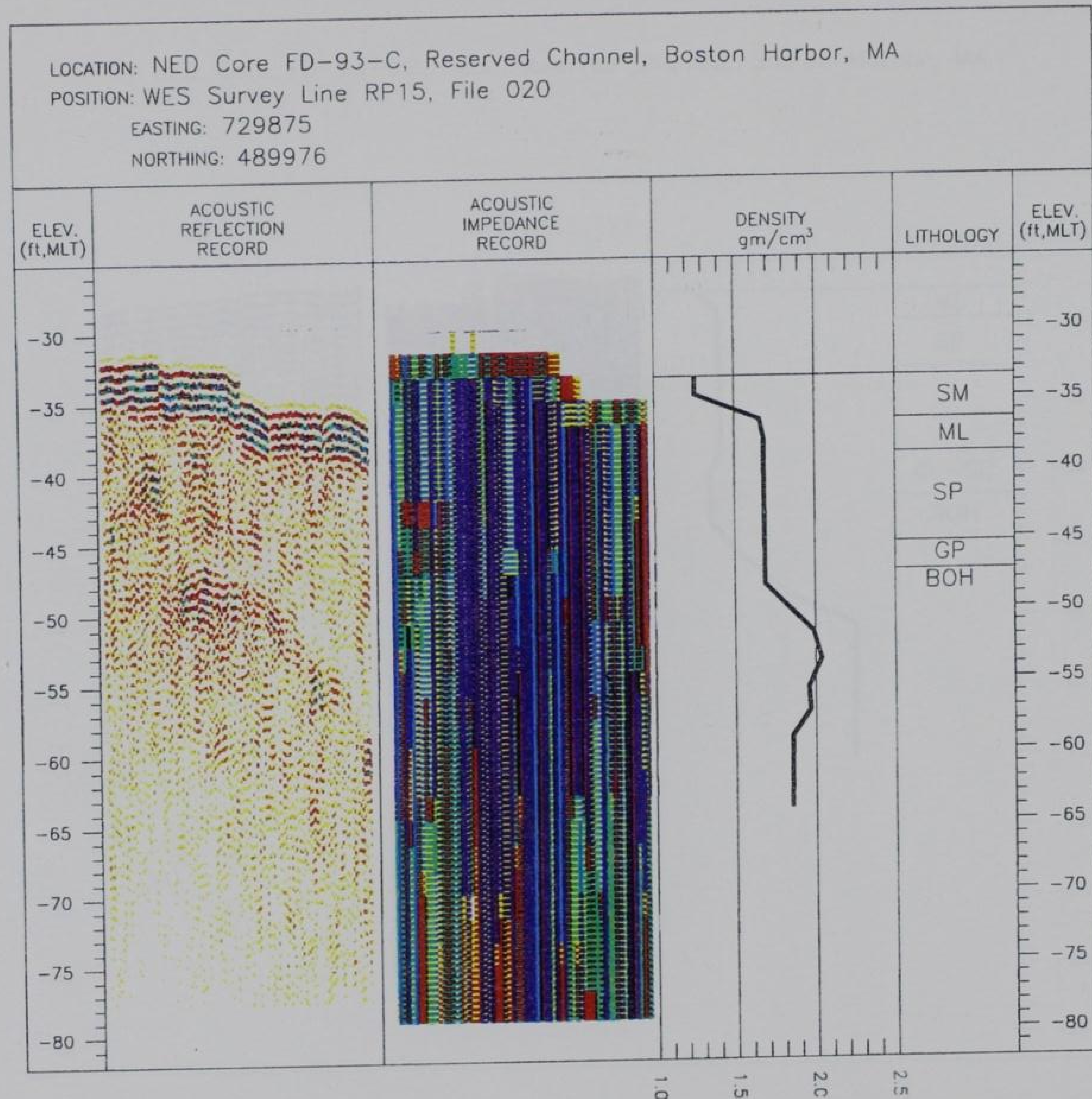


Figure 19. Subbottom sediment calibration at Core FD-93-C, Reserved Channel

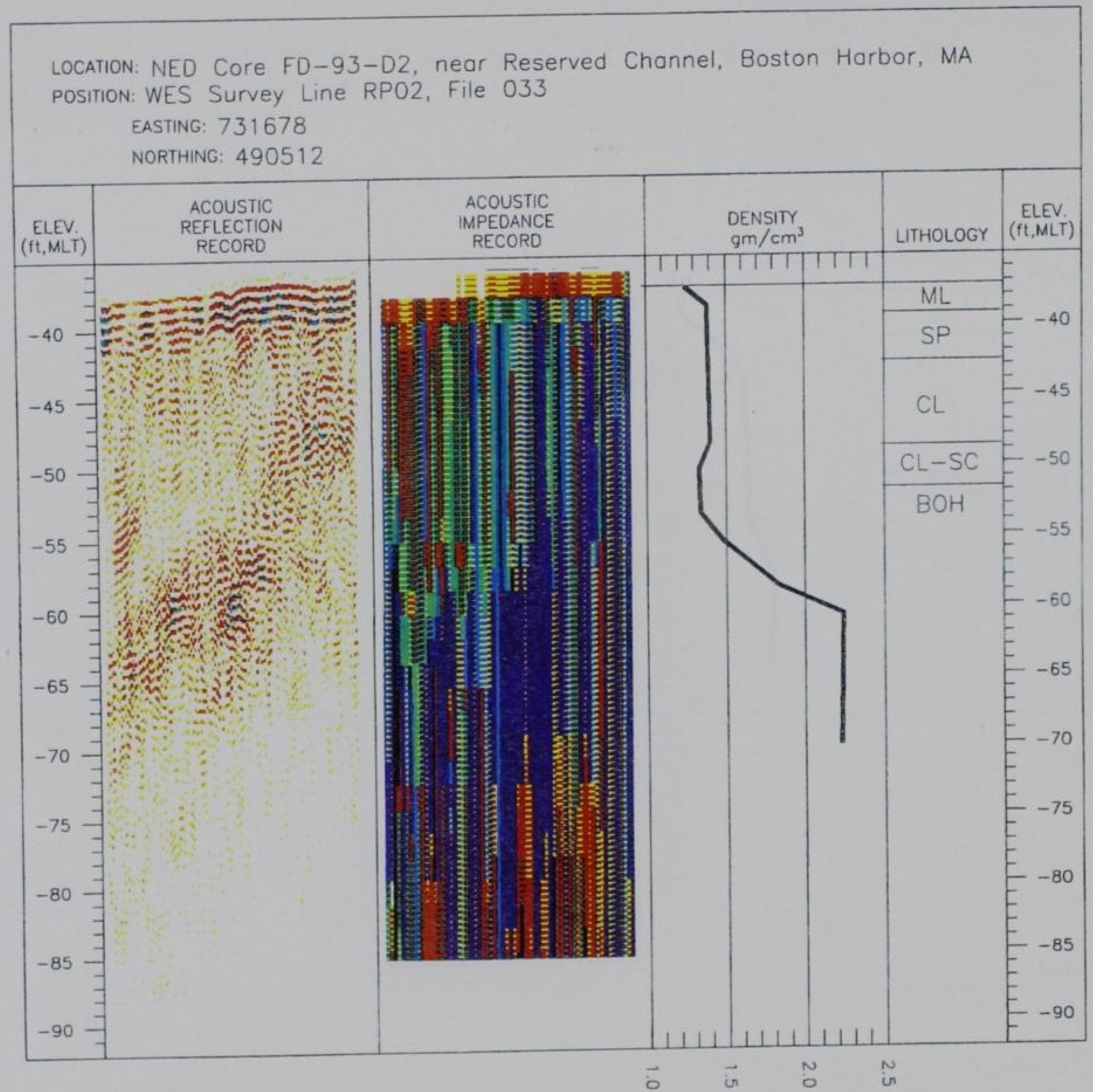


Figure 20. Subbottom sediment calibration at Core FD-93-D2, Reserved Channel

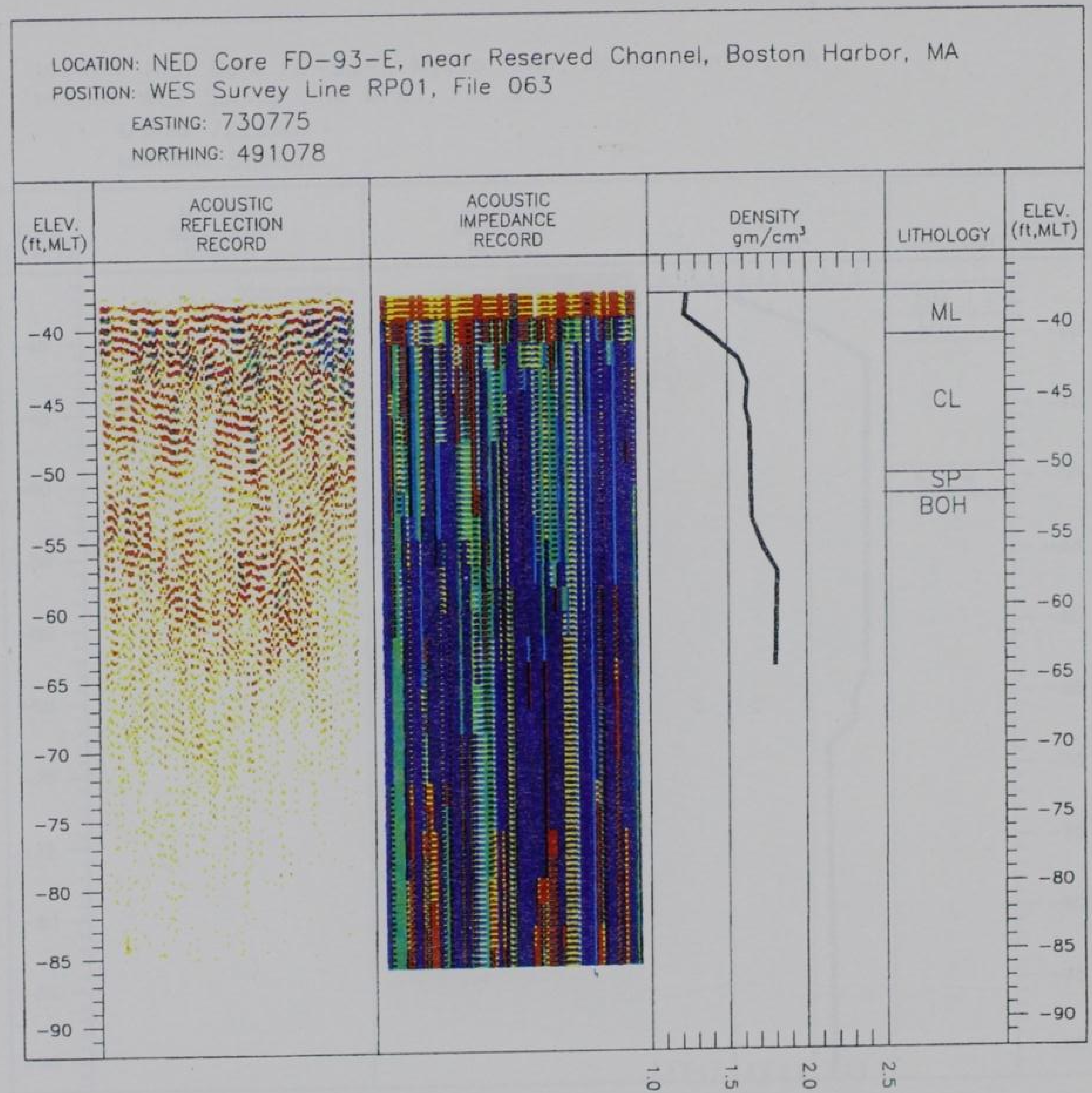


Figure 21. Subbottom sediment calibration at Core FD-93-E, Reserved Channel

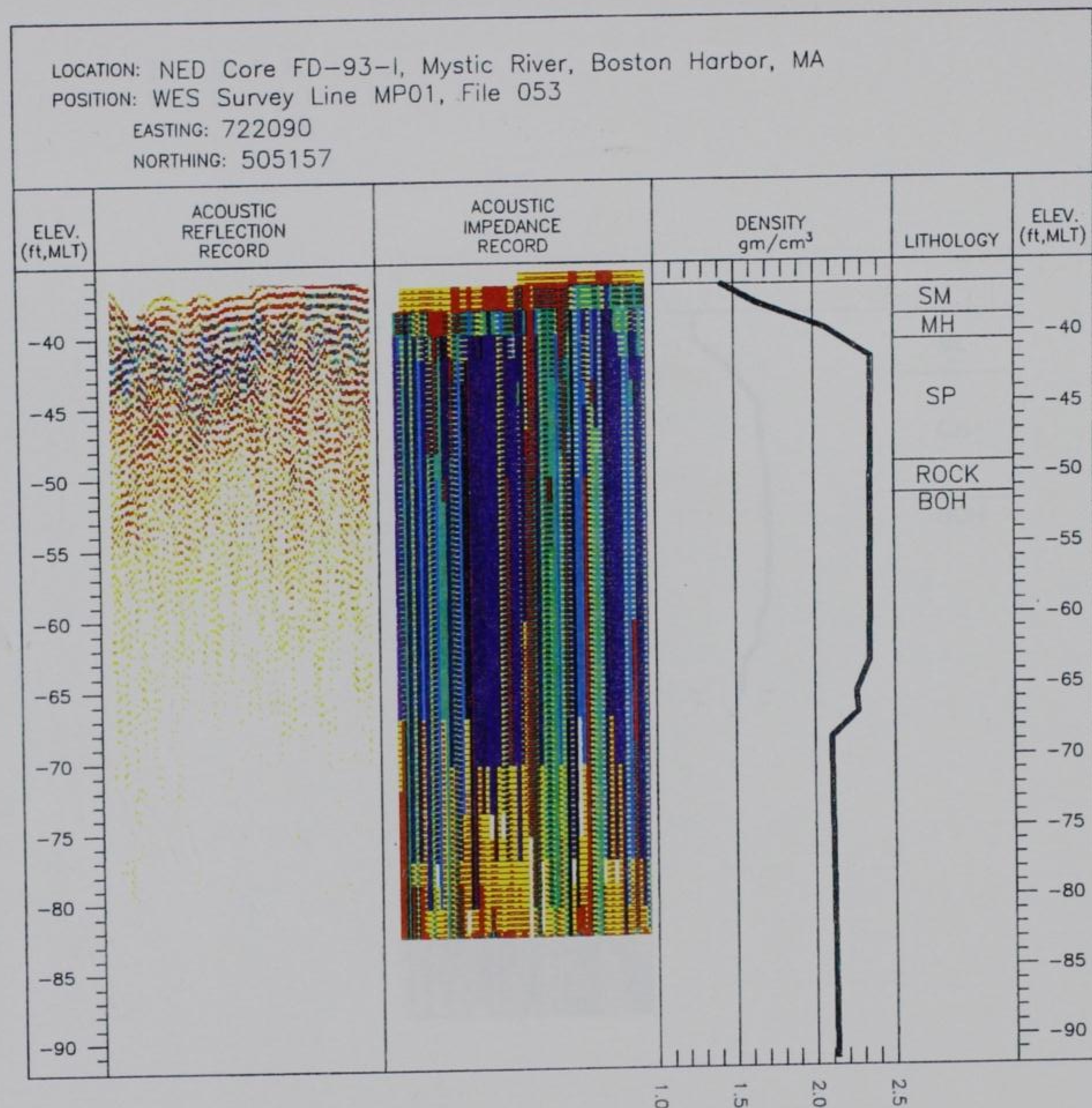


Figure 22. Check calibration at Core FD-93-I, Mystic River

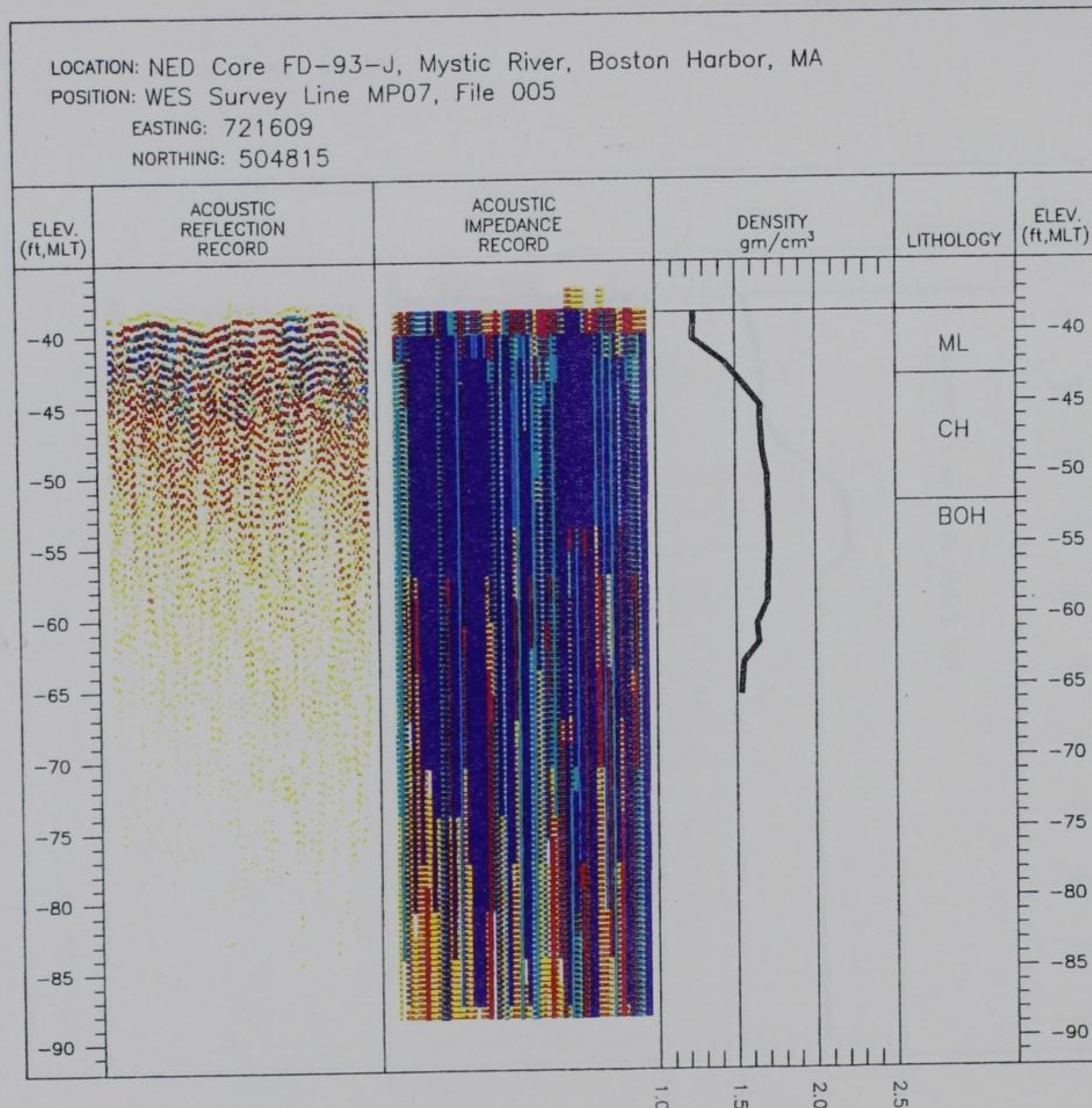


Figure 23. Check calibration at Core FD-93-J, Mystic River

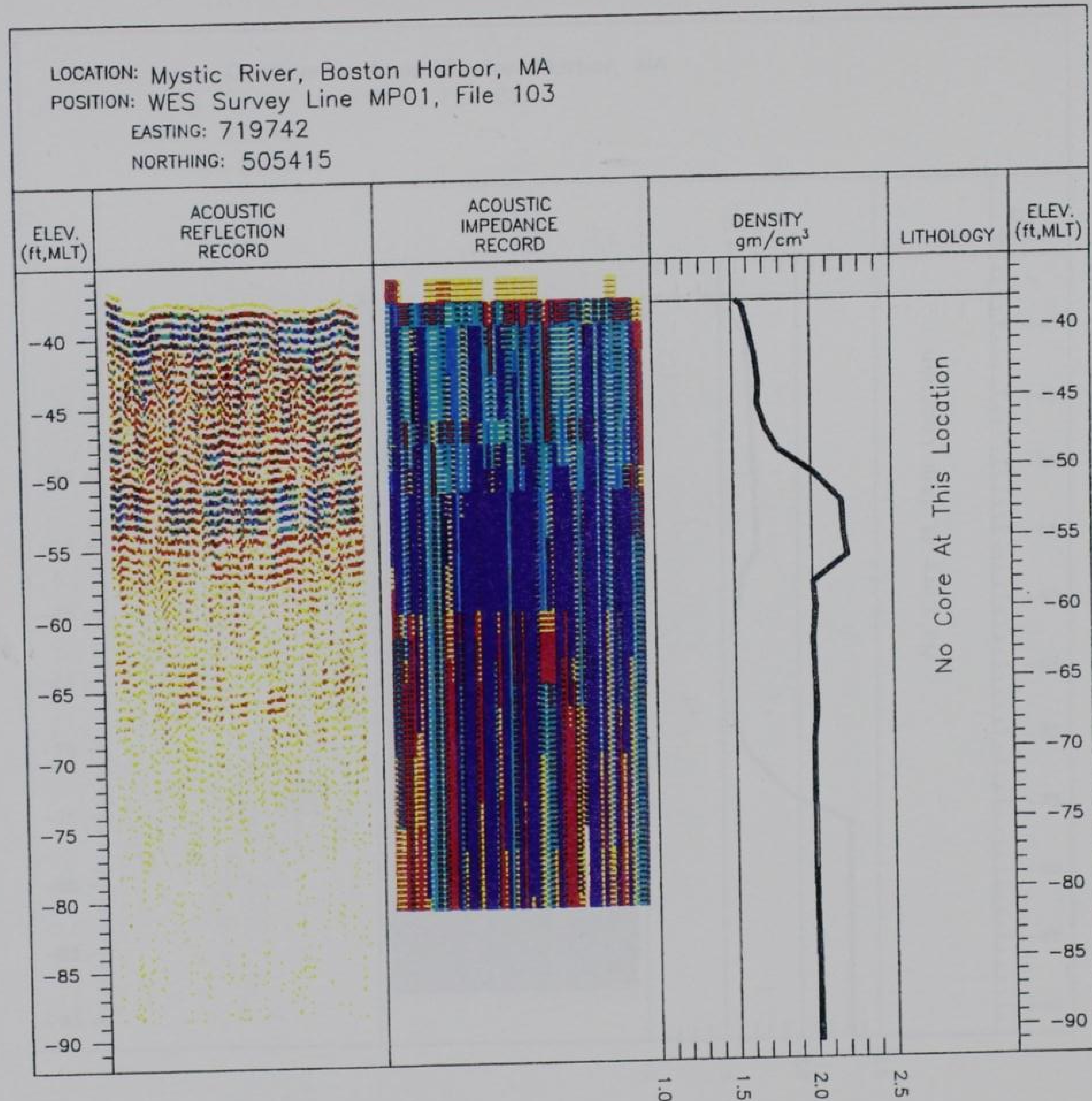


Figure 24. Check calibration, Mystic River

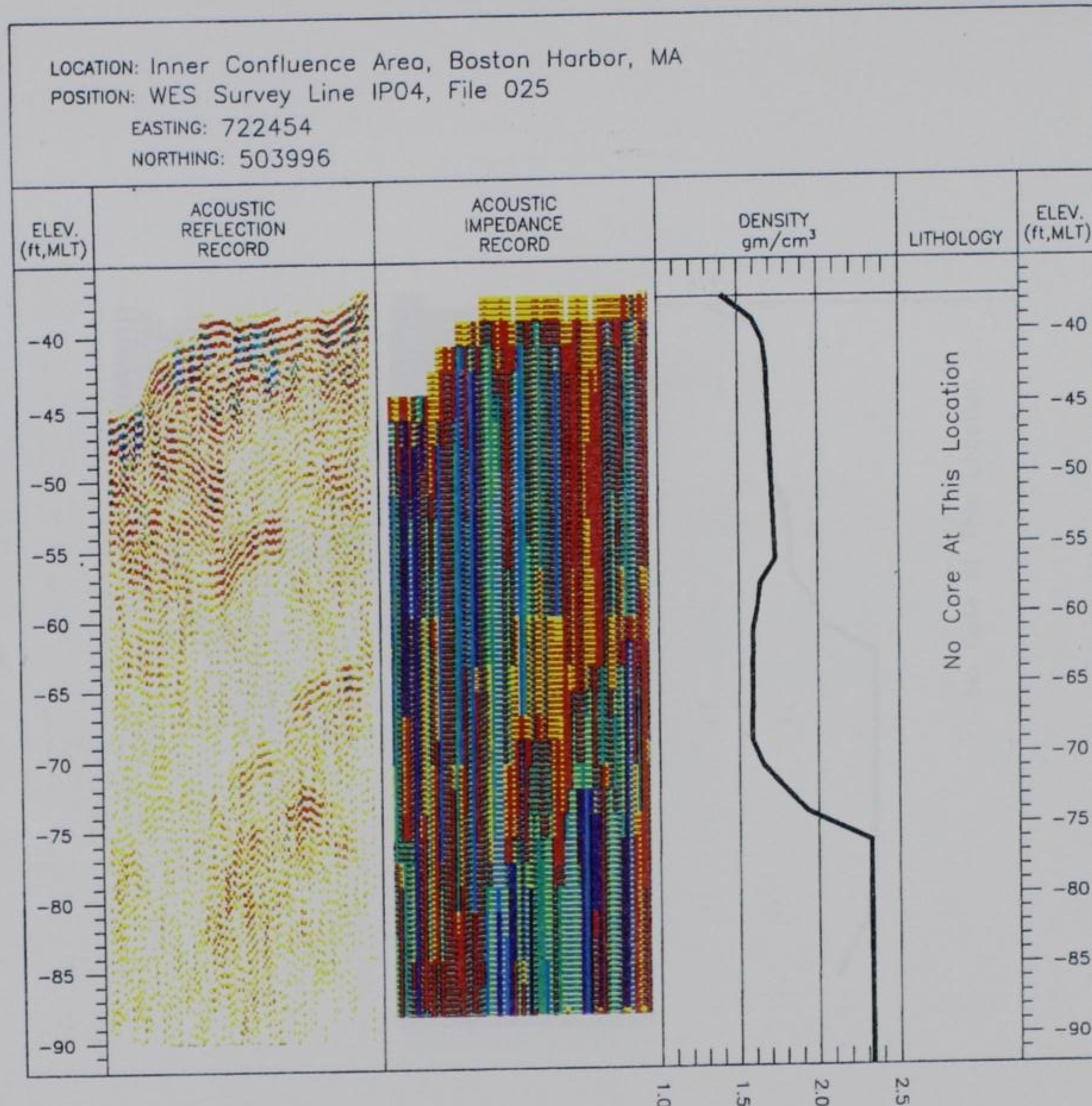
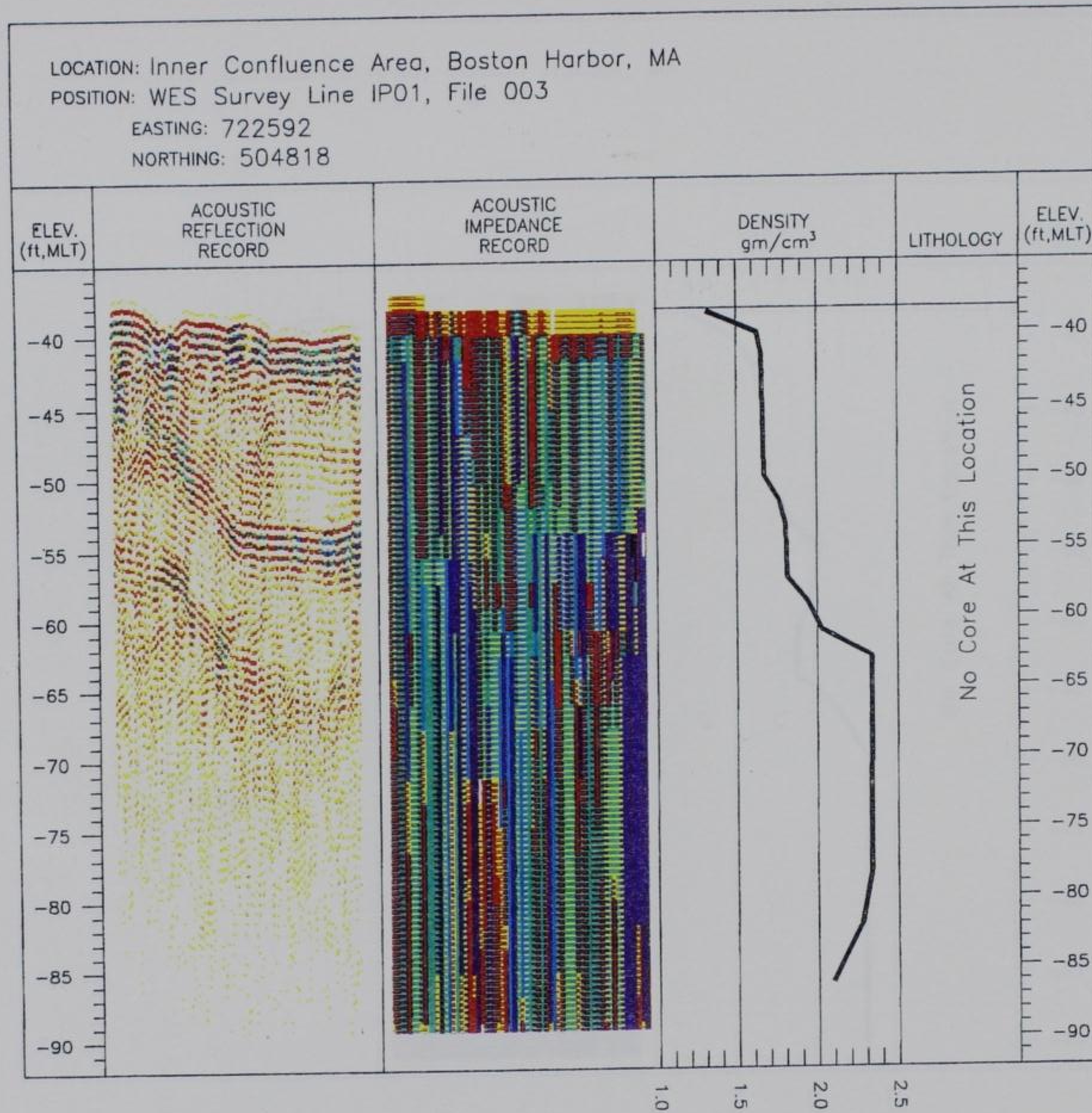


Figure 25. Check calibration, Inner Confluence Area



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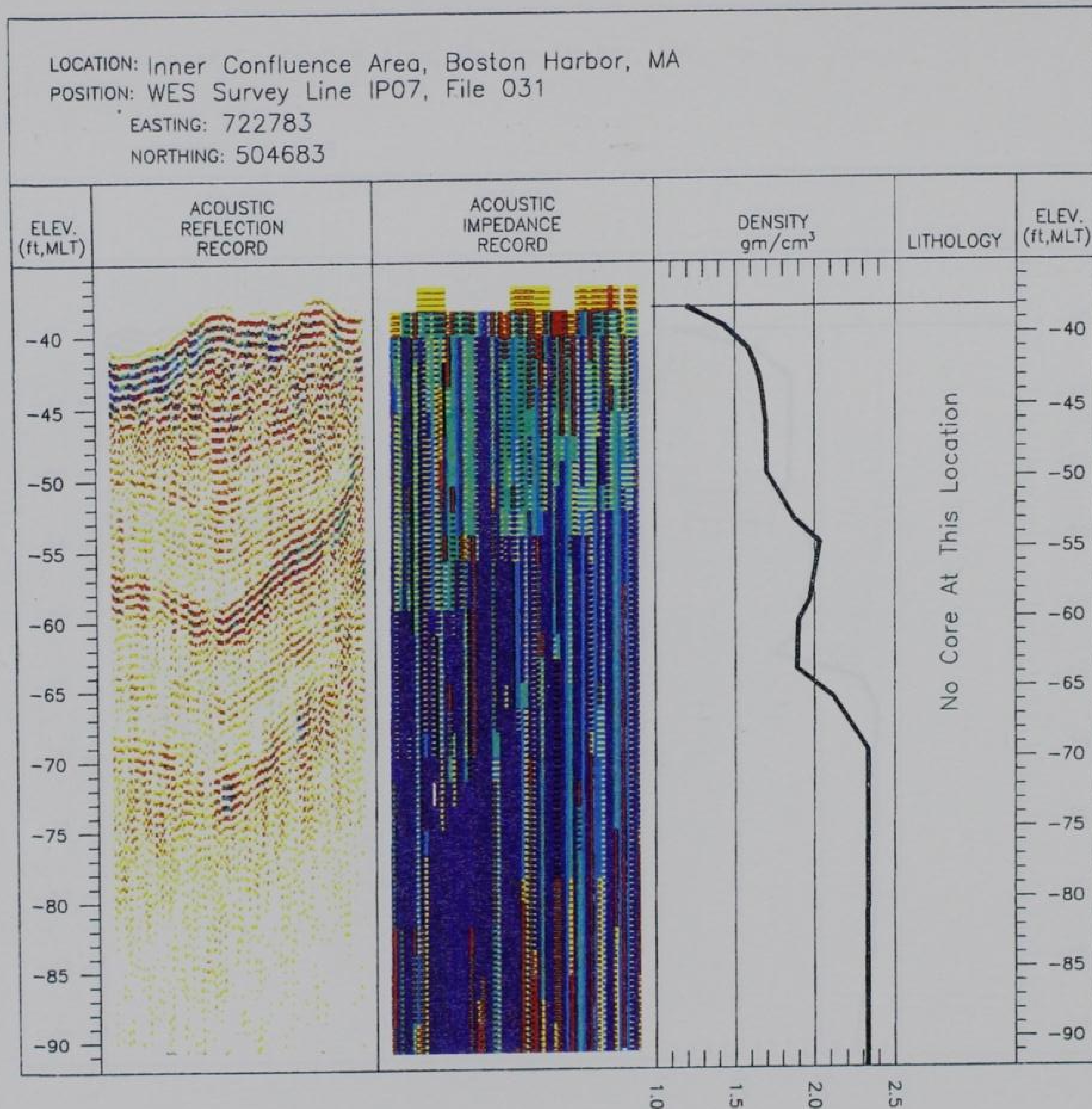

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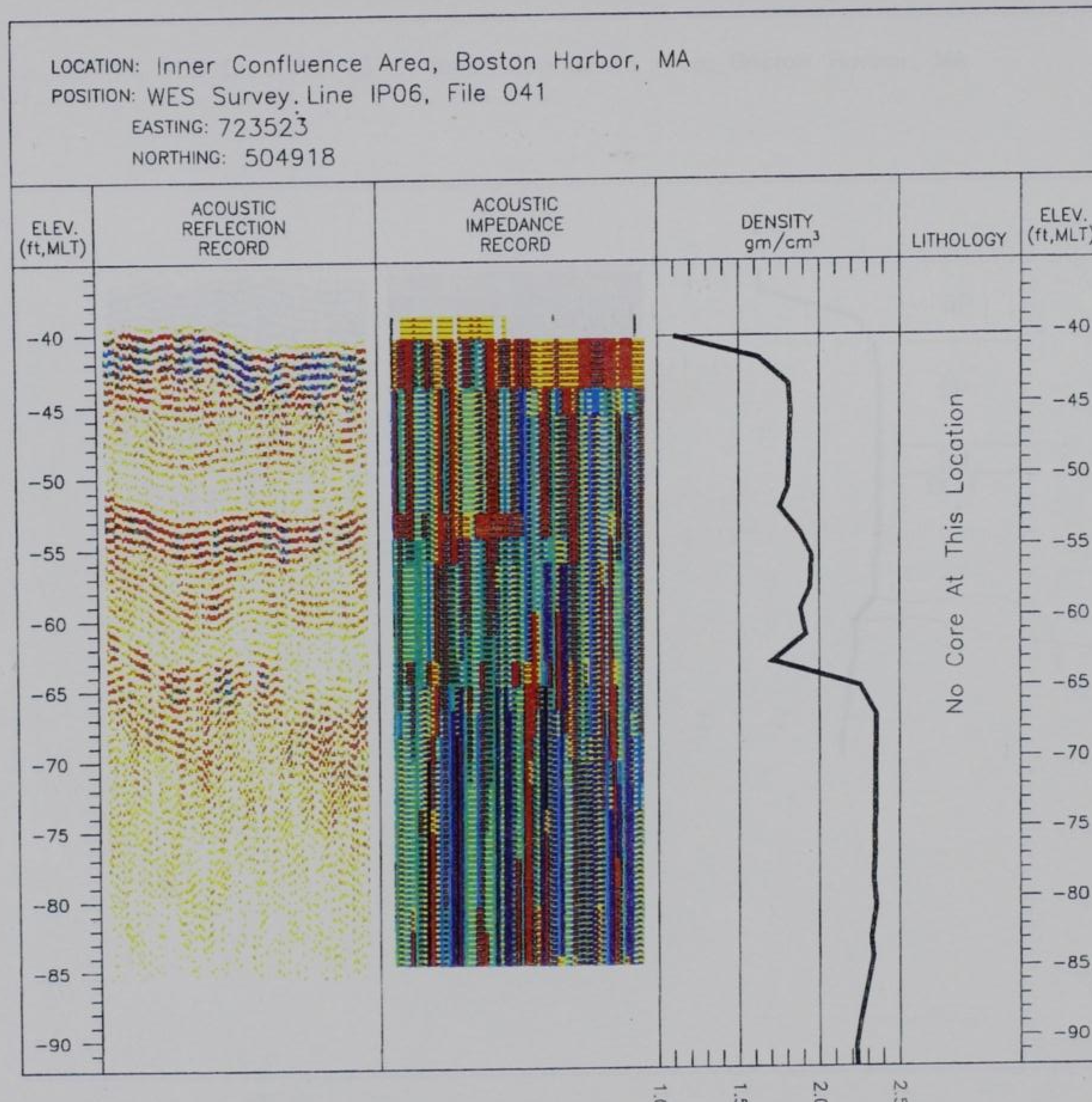

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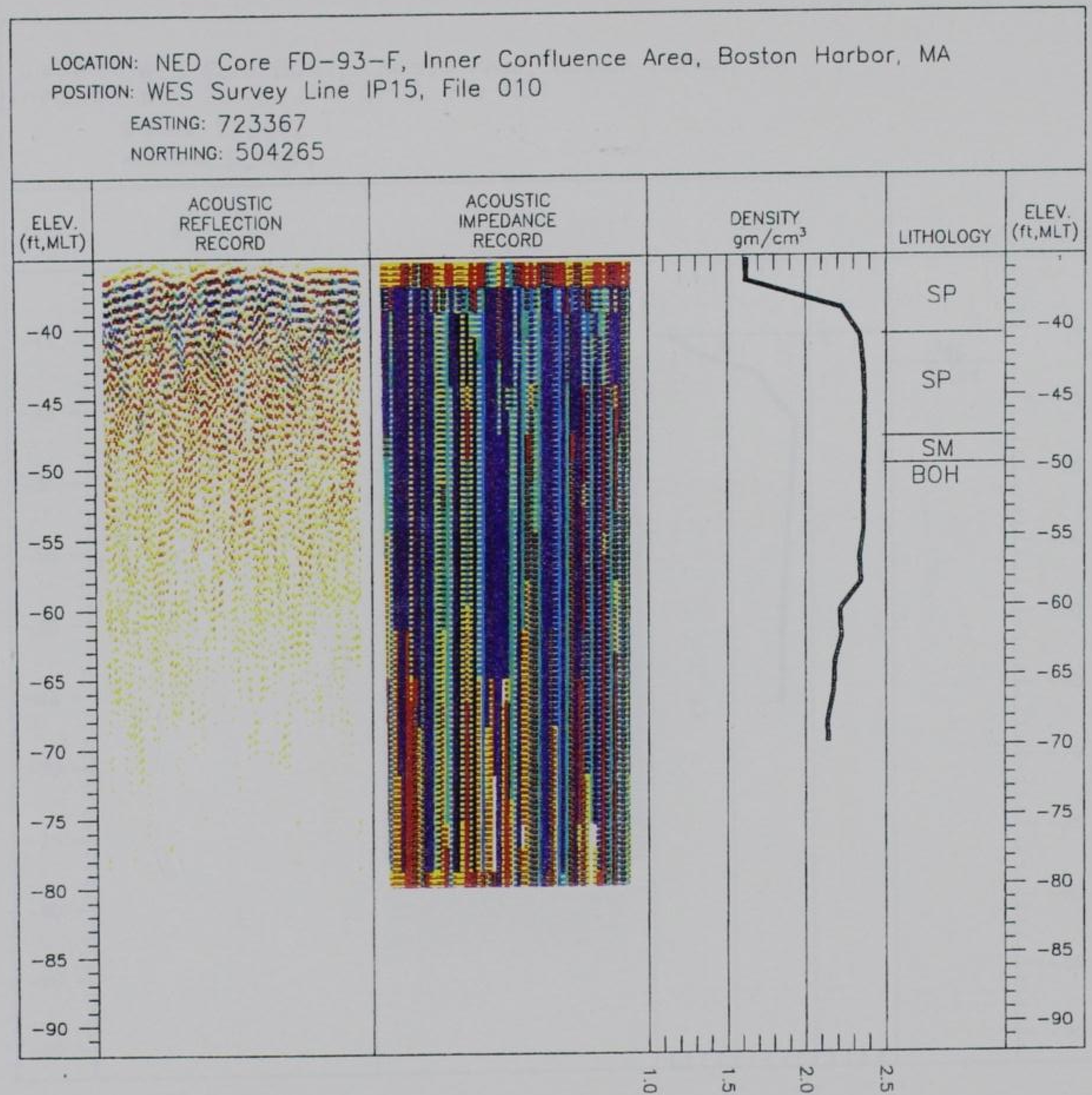


Figure 29. Check calibration at Core FD-93-F, Inner Confluence Area

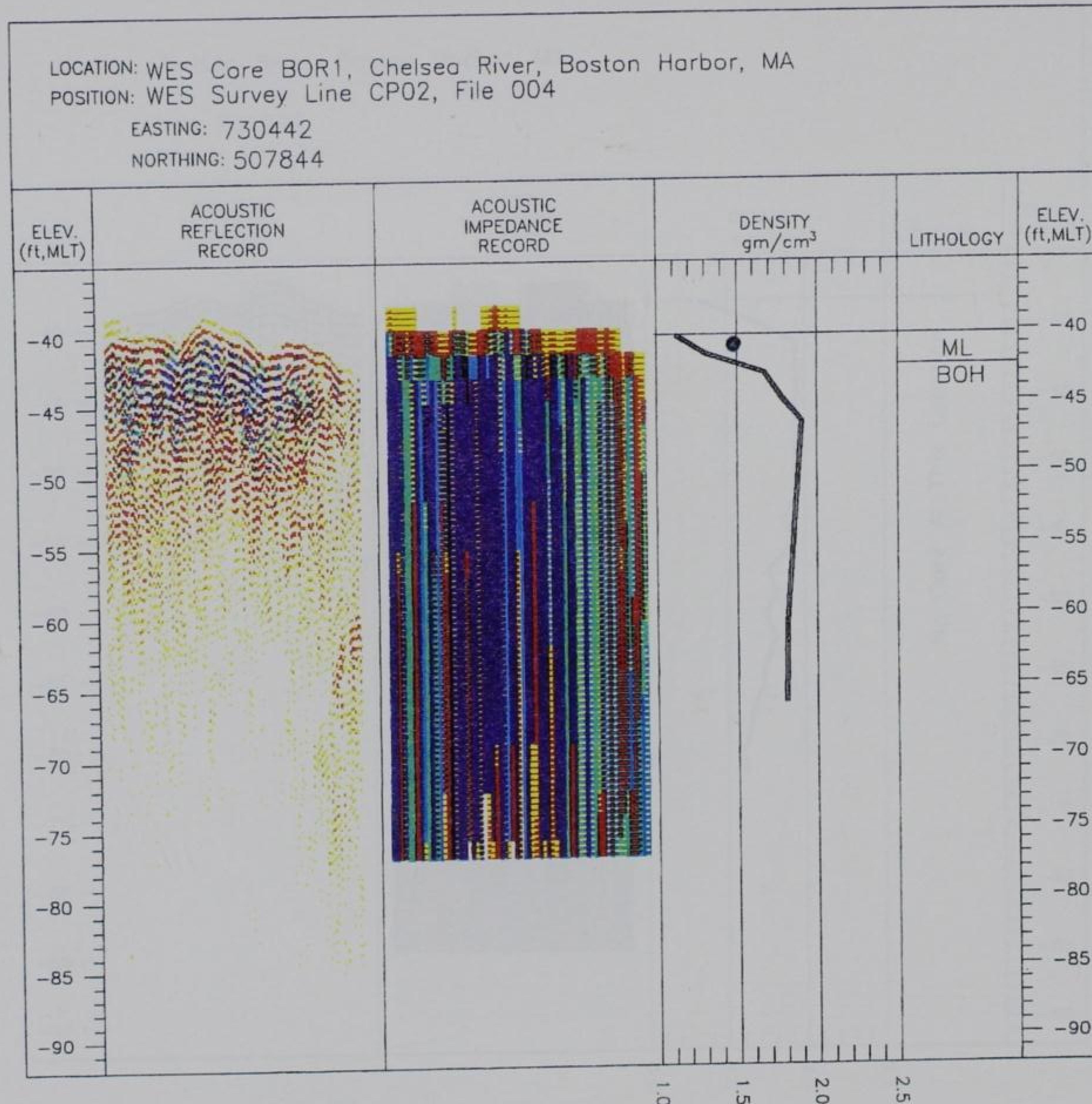
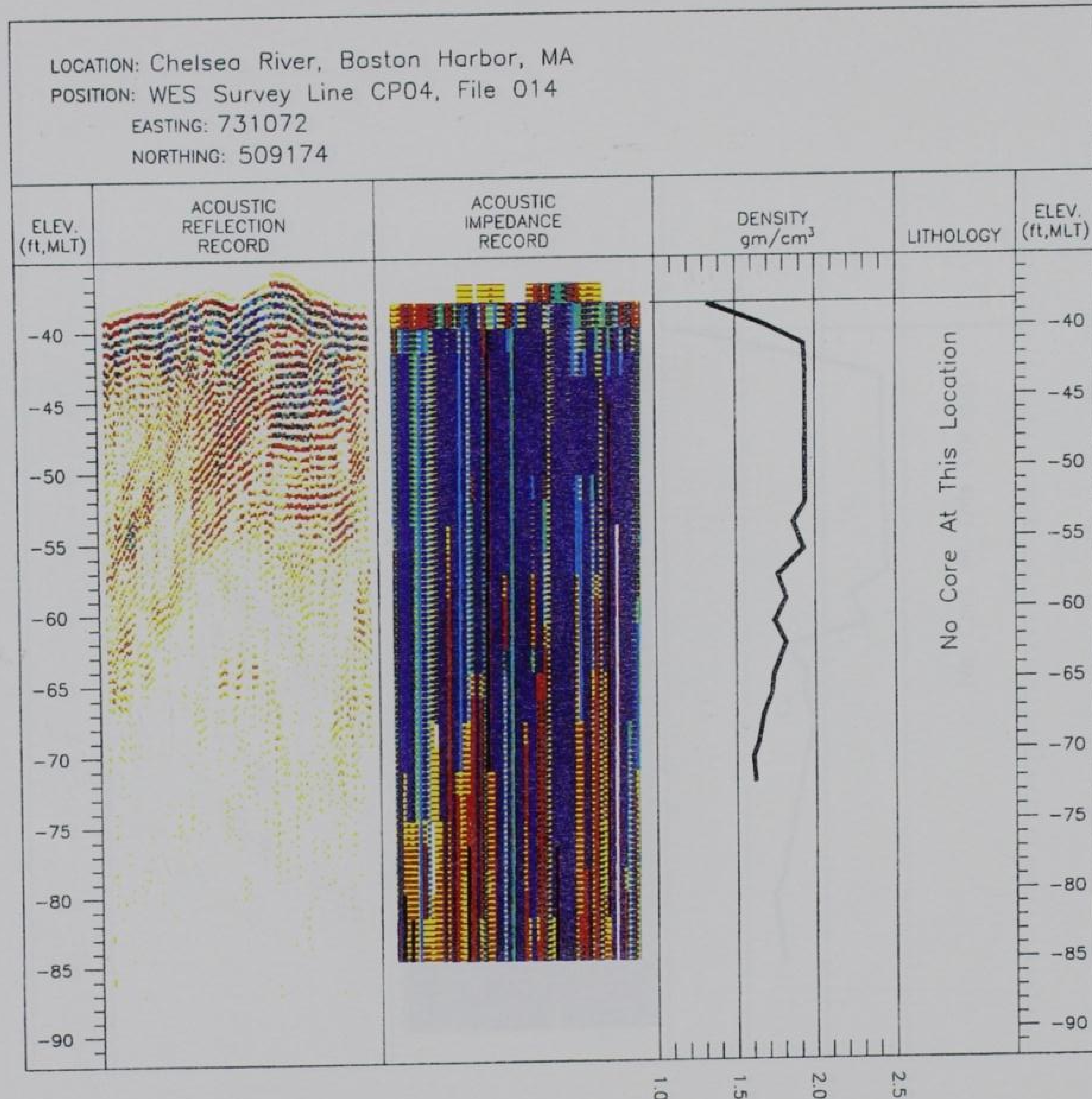


Figure 30. Check calibration at Core BOR1, Chelsea River



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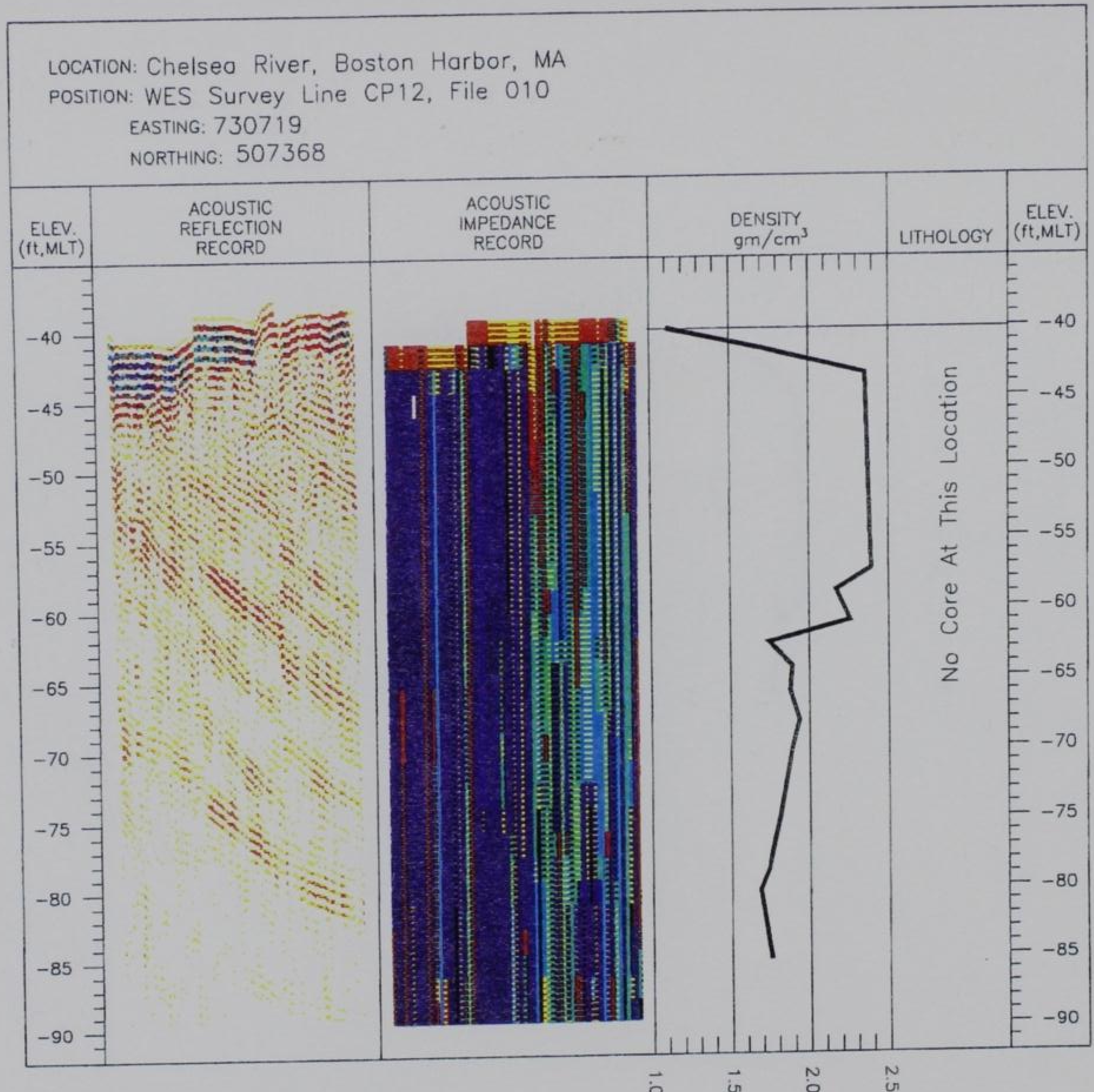

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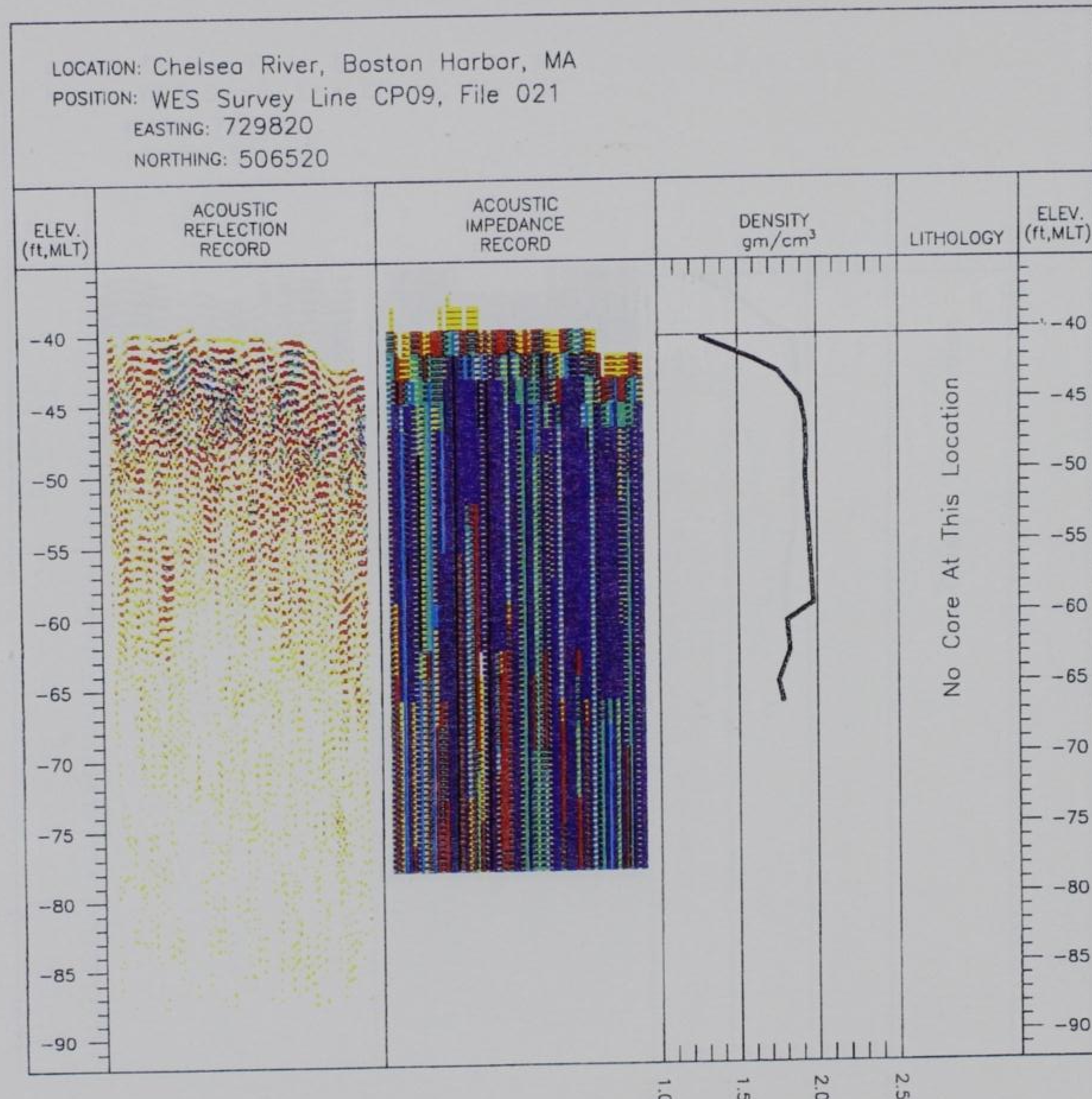

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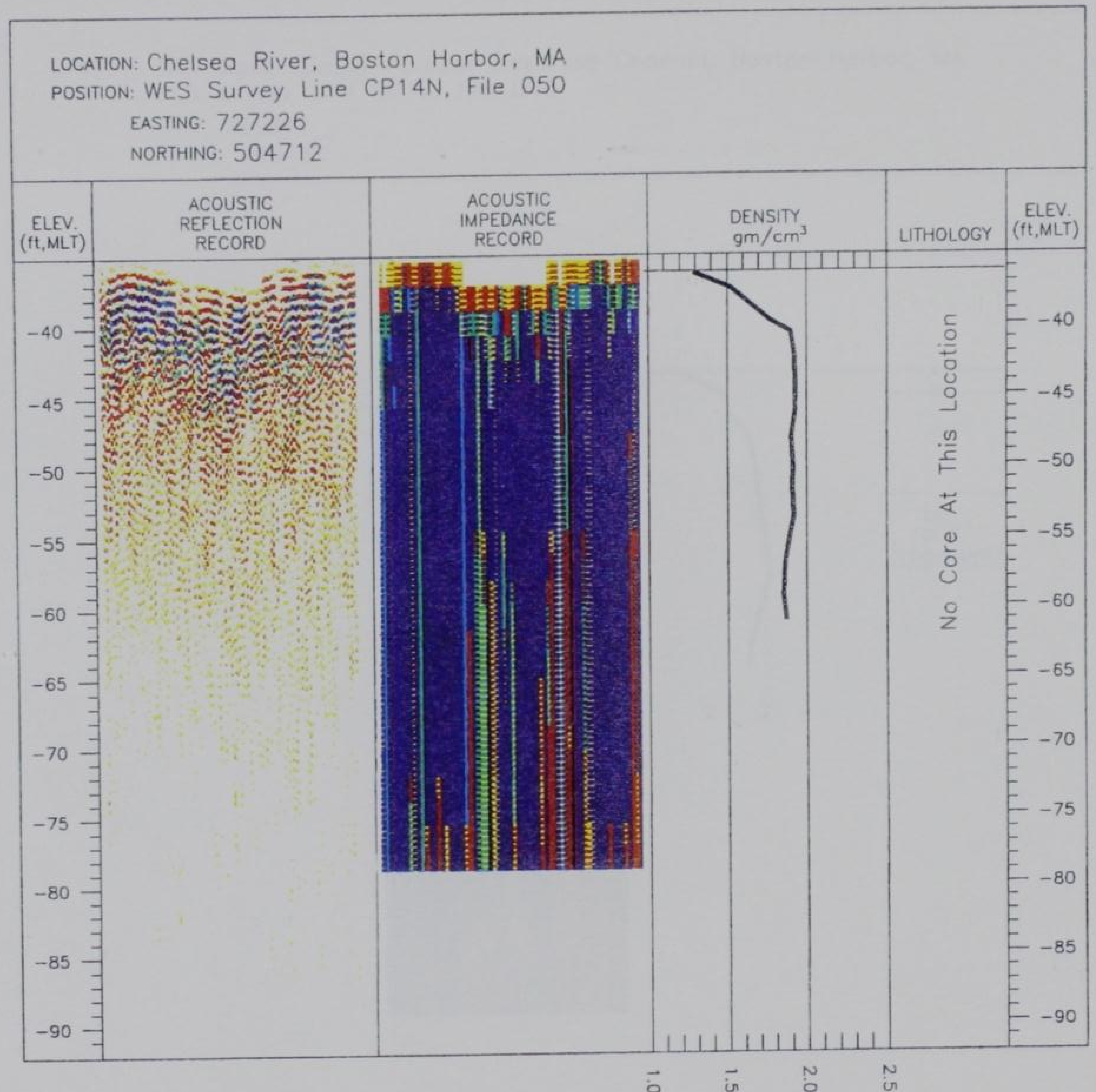


Figure 34. Check calibration, Chelsea River

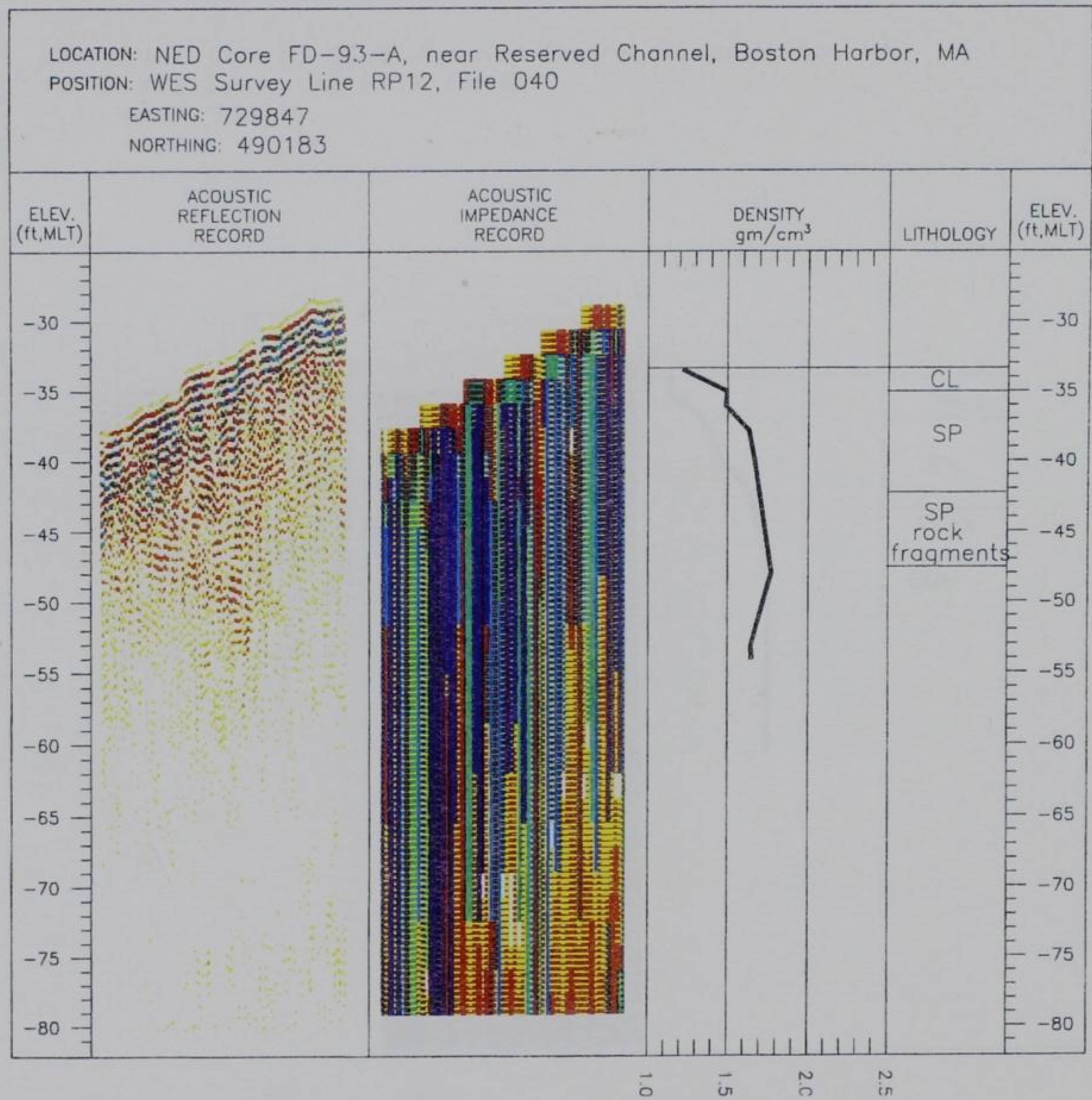


Figure 35. Check calibration at Core FD-93-A, Reserved Channel

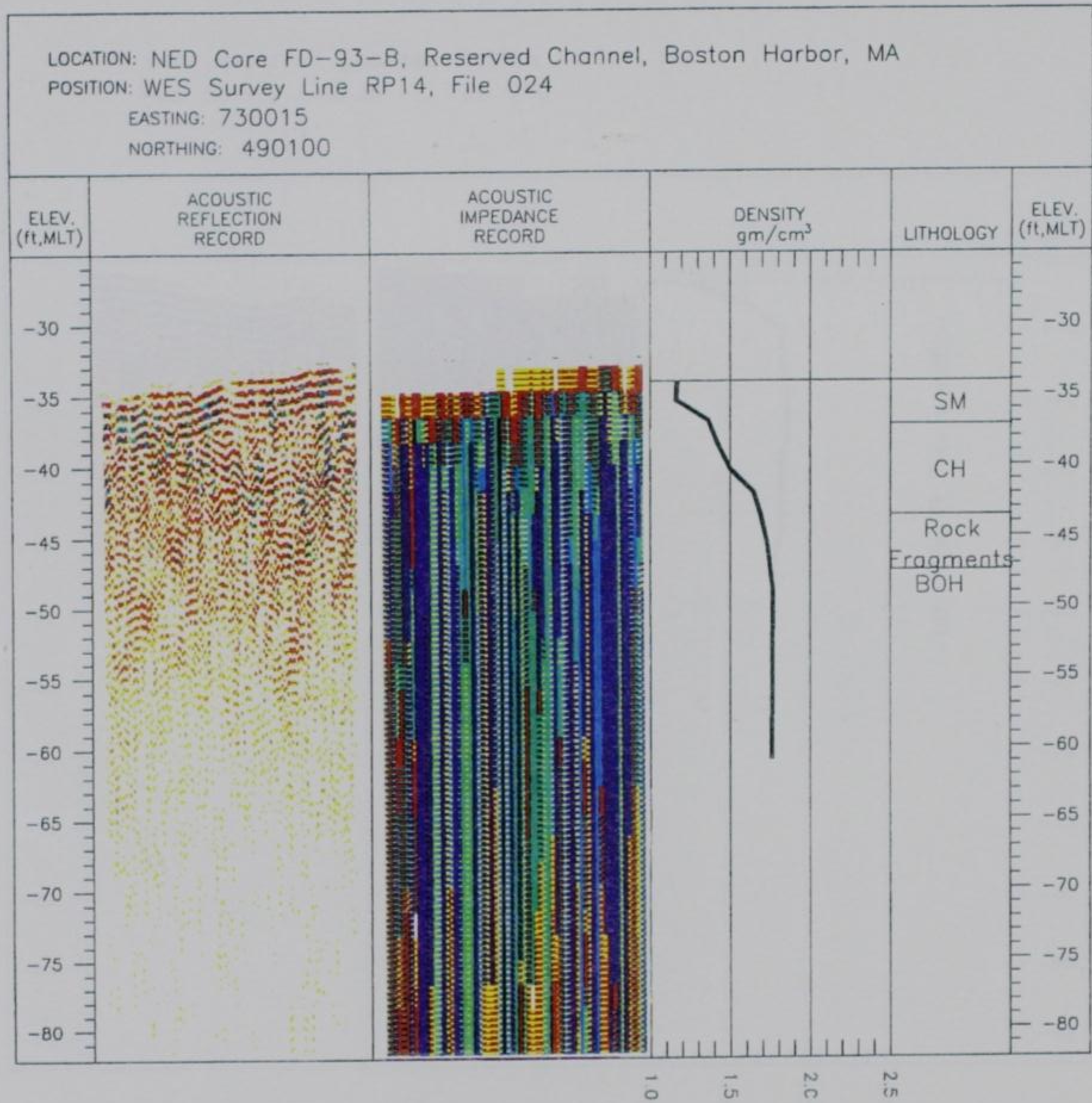
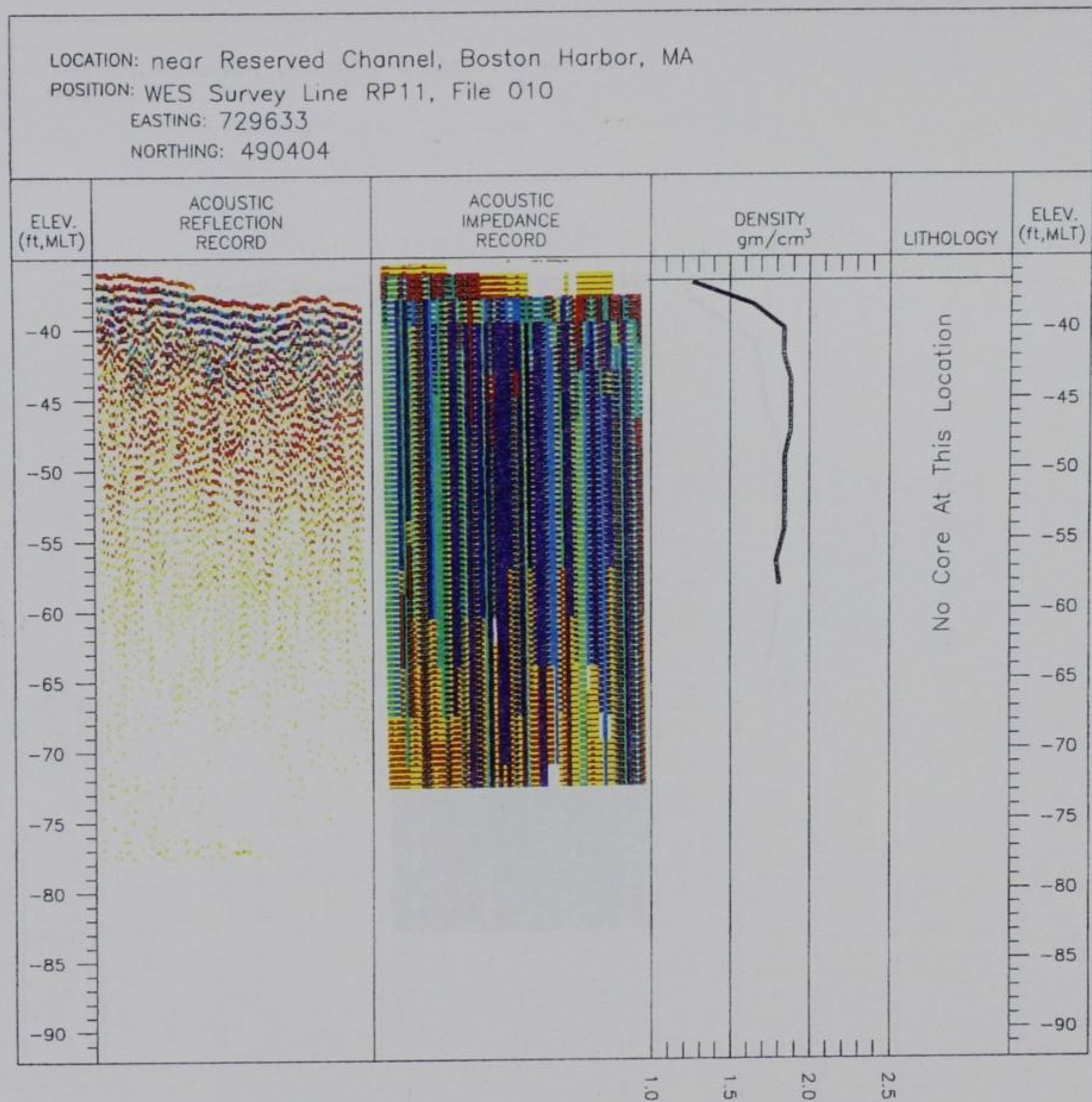


Figure 36. Check calibration at Core FD-93-B, Reserved Channel



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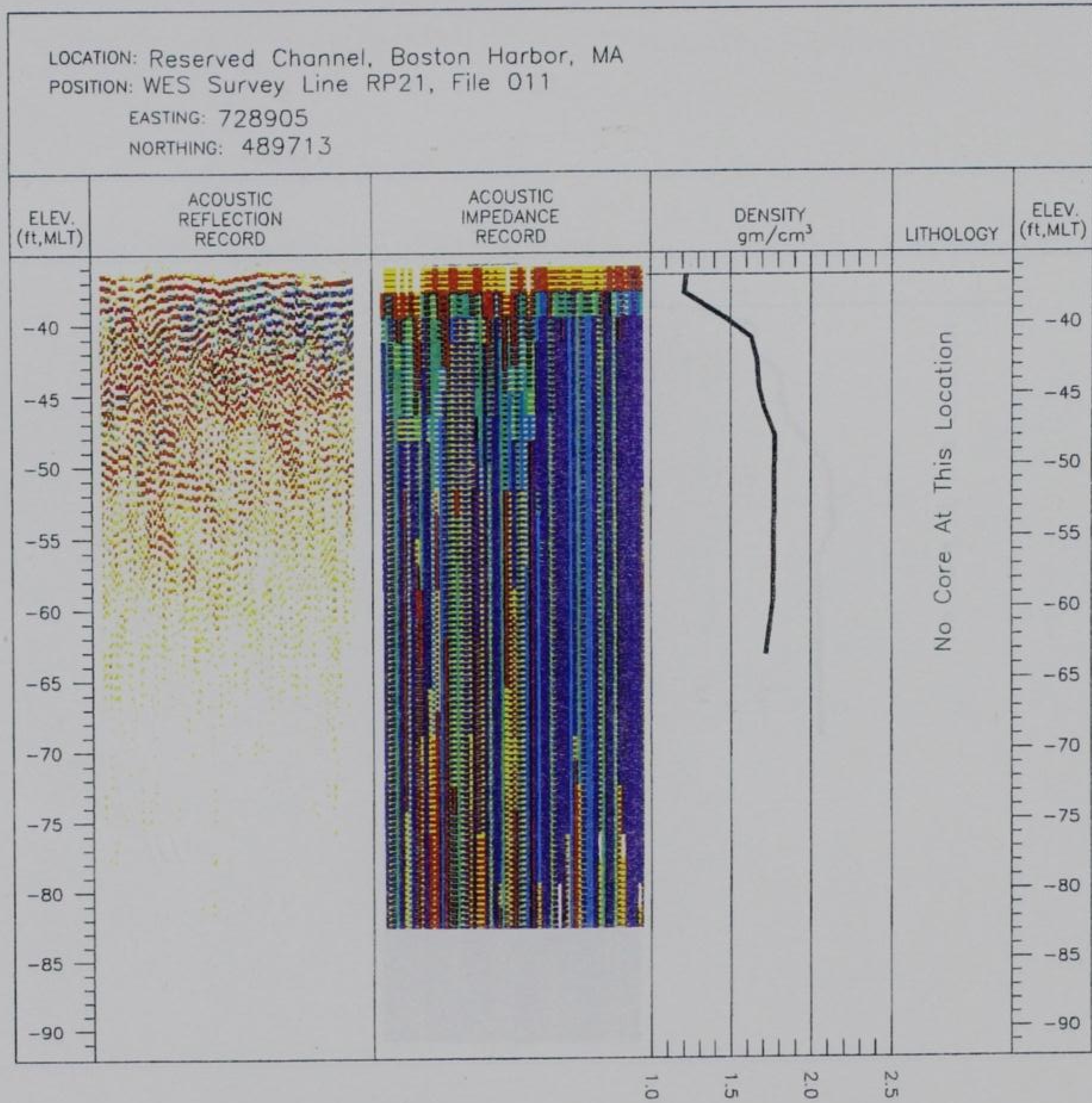

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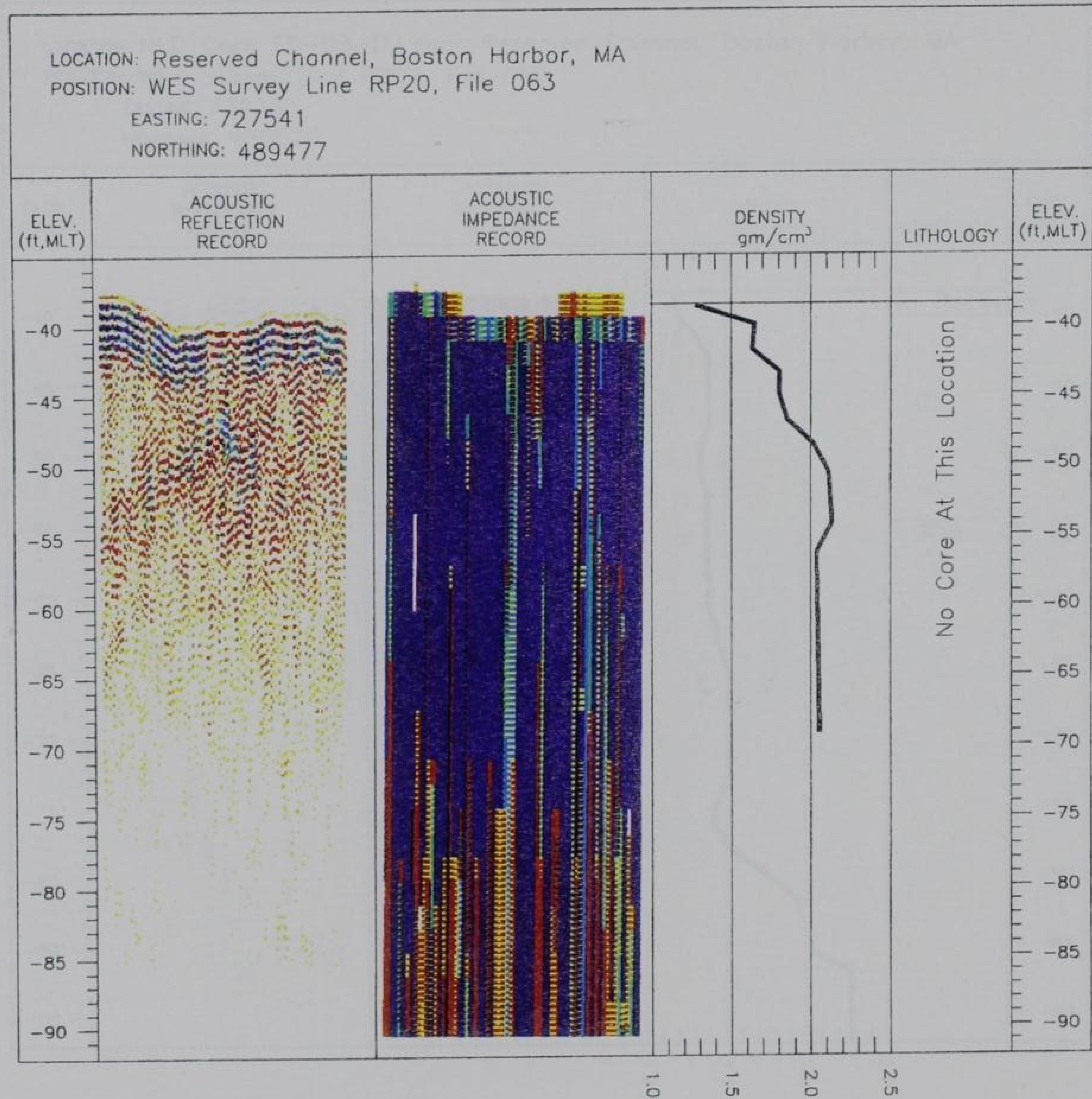

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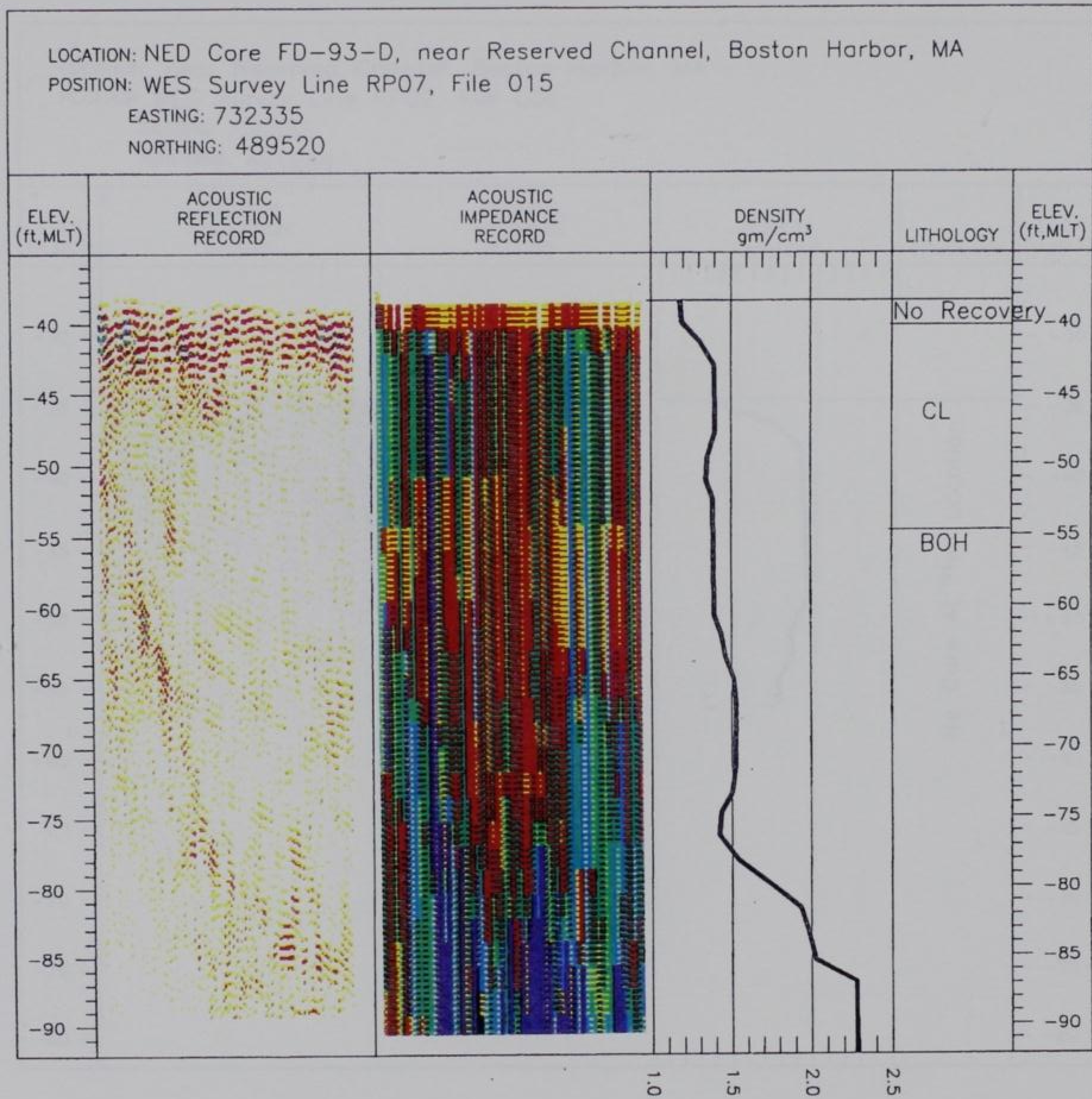


Figure 40. Check calibration at Core FD-93-D, Reserved Channel

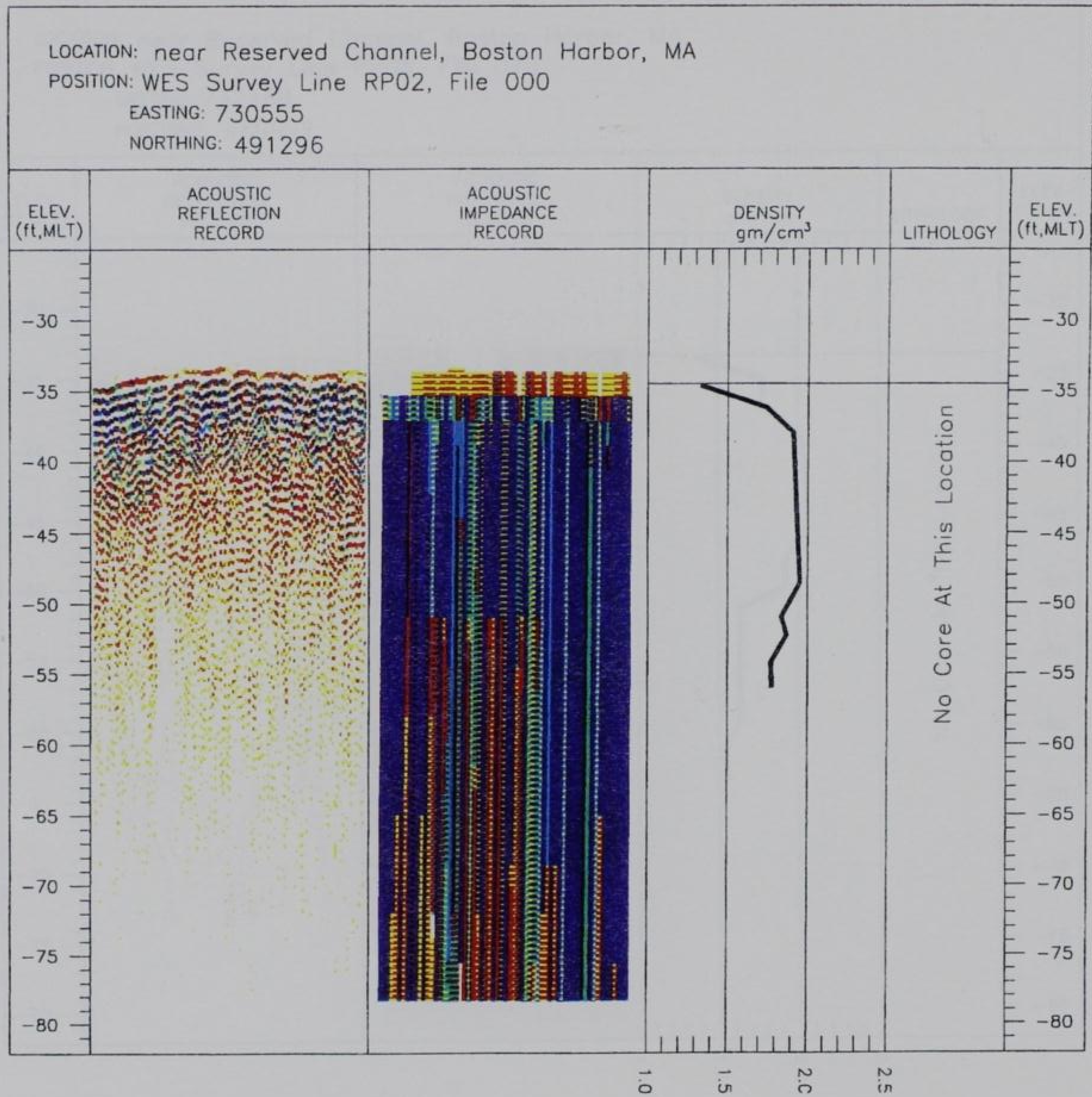
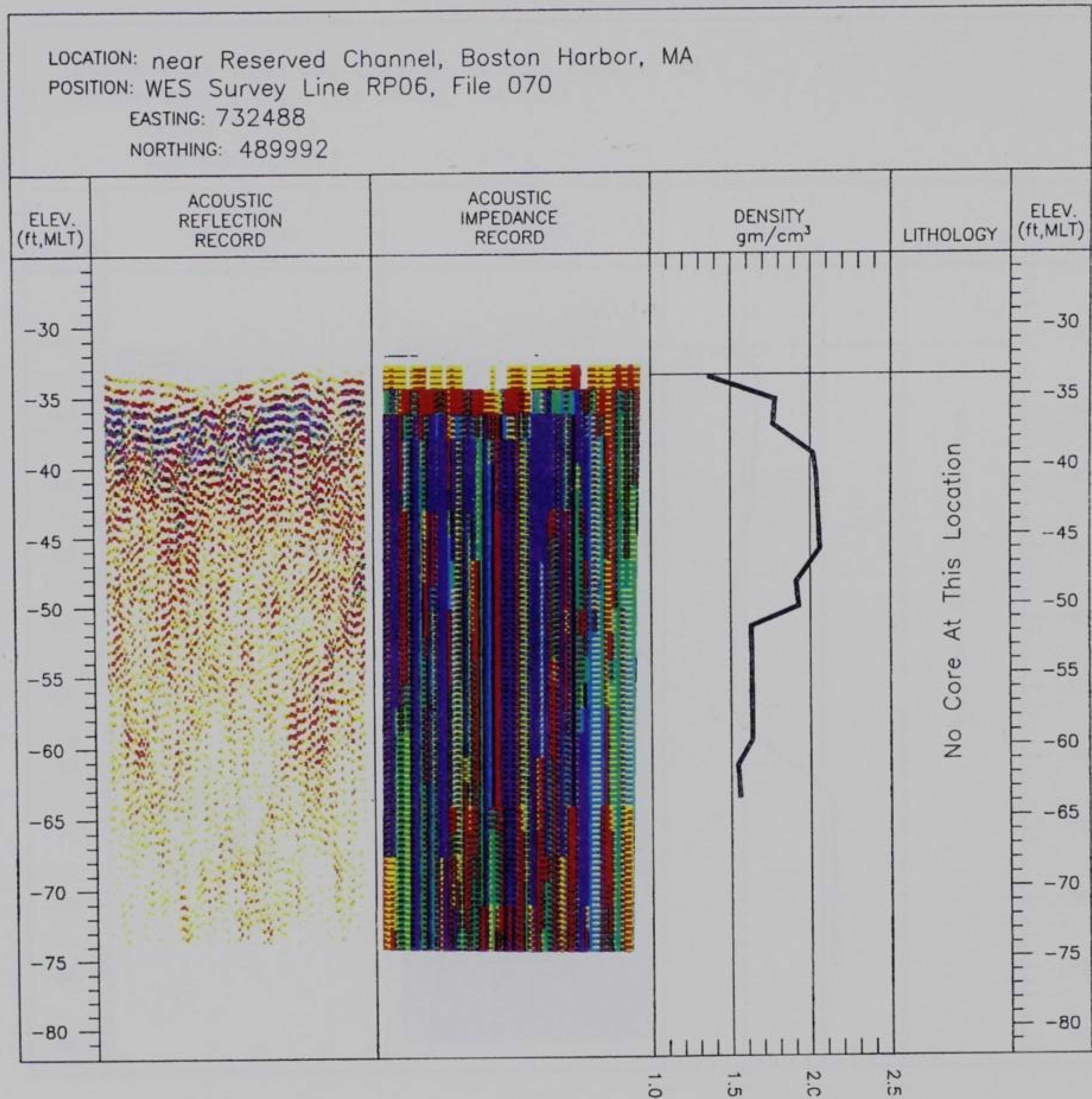


Figure 41. Check calibration, Reserved Channel



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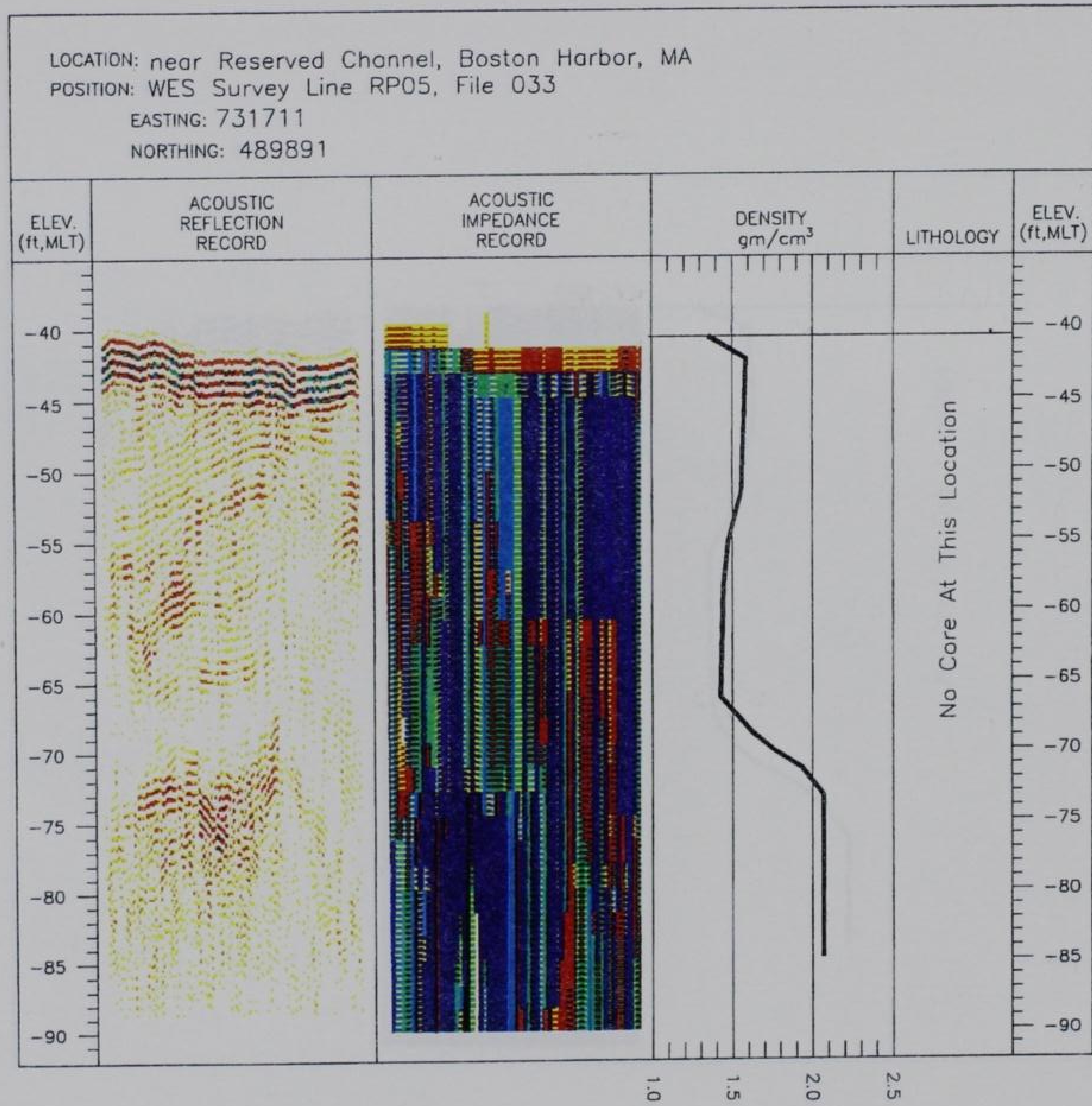

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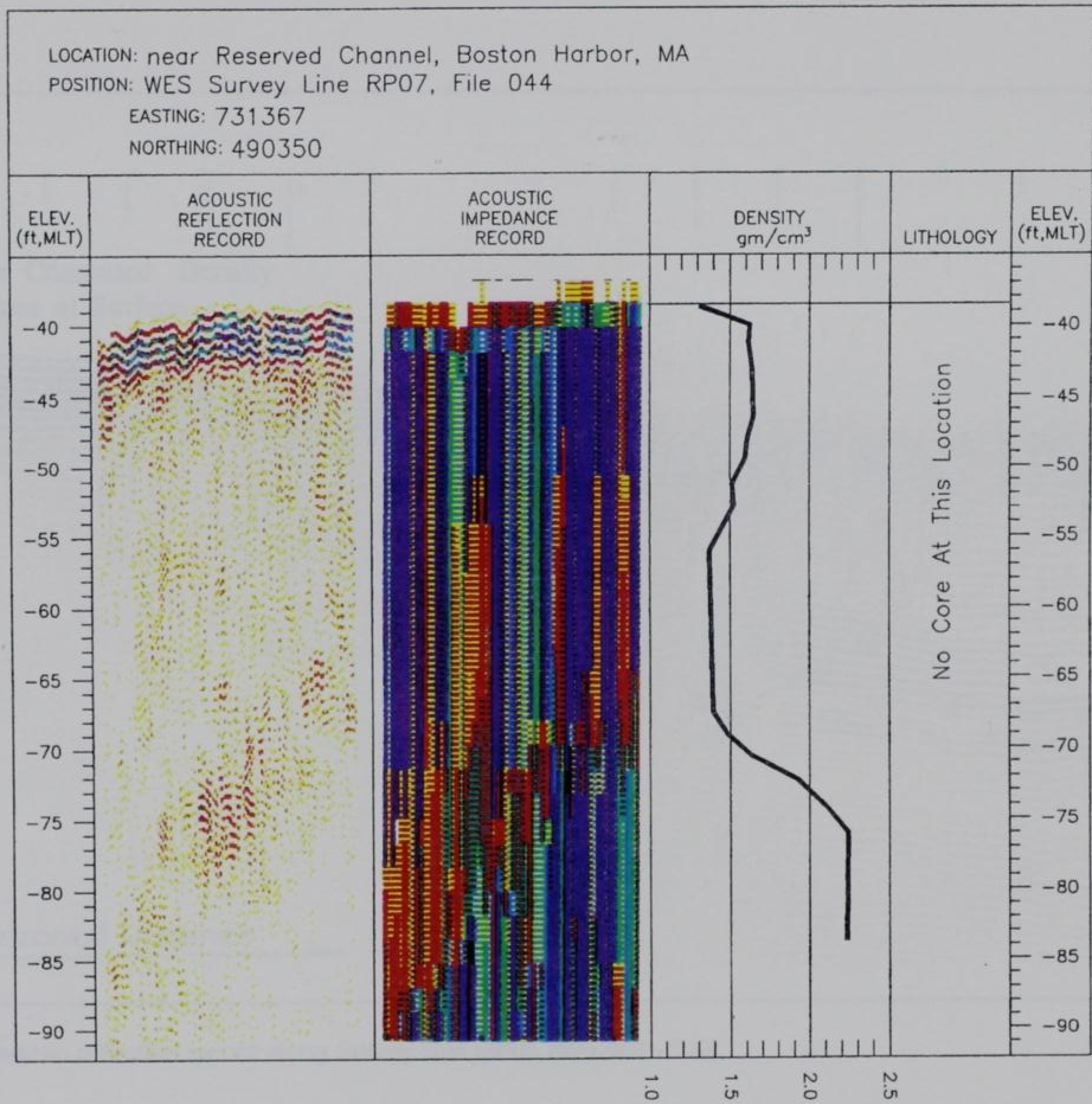

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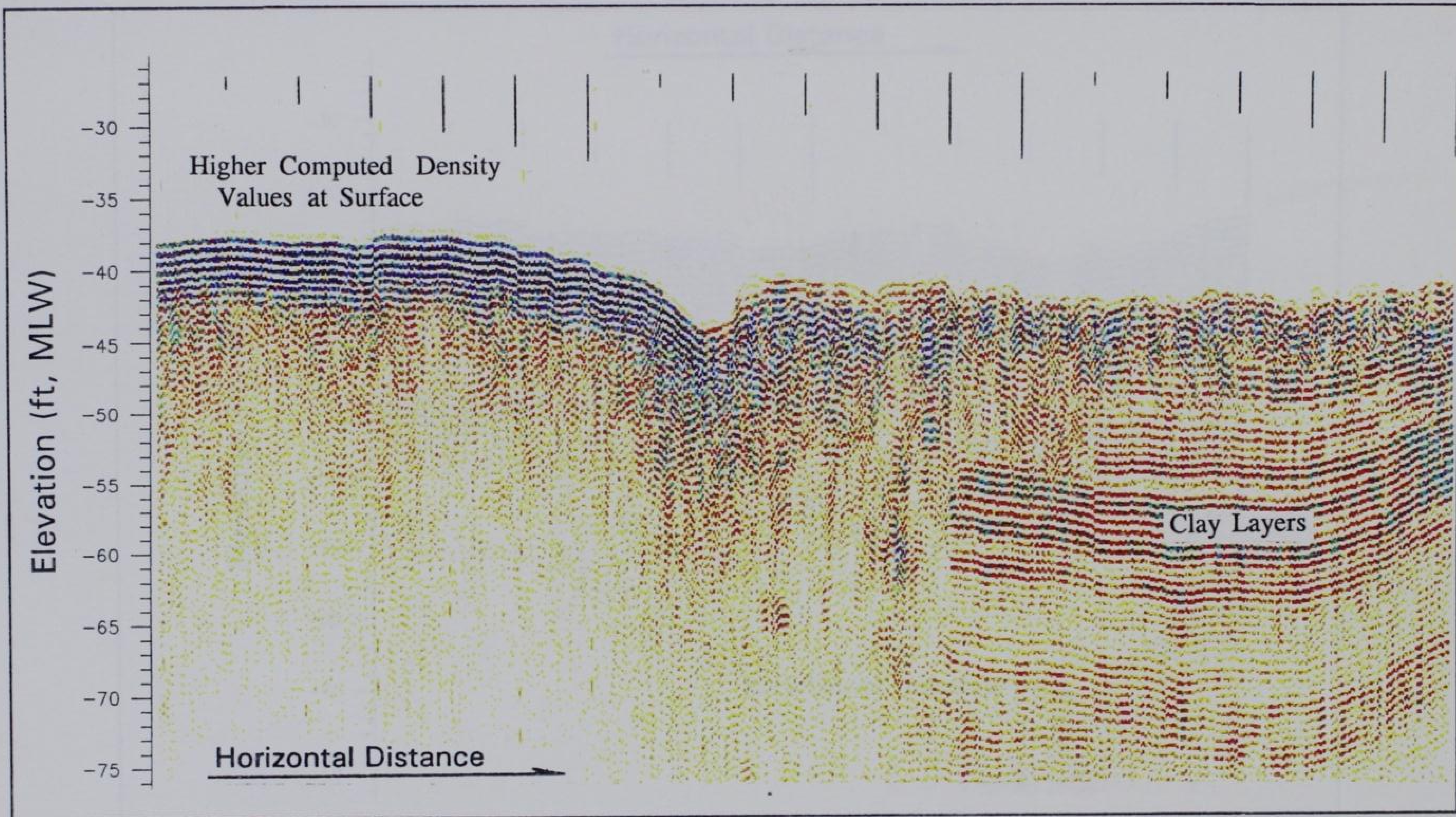

Figure 45. Subbottom seismic reflection record along Survey Line MP05 (files 000 - 030), Mystic River

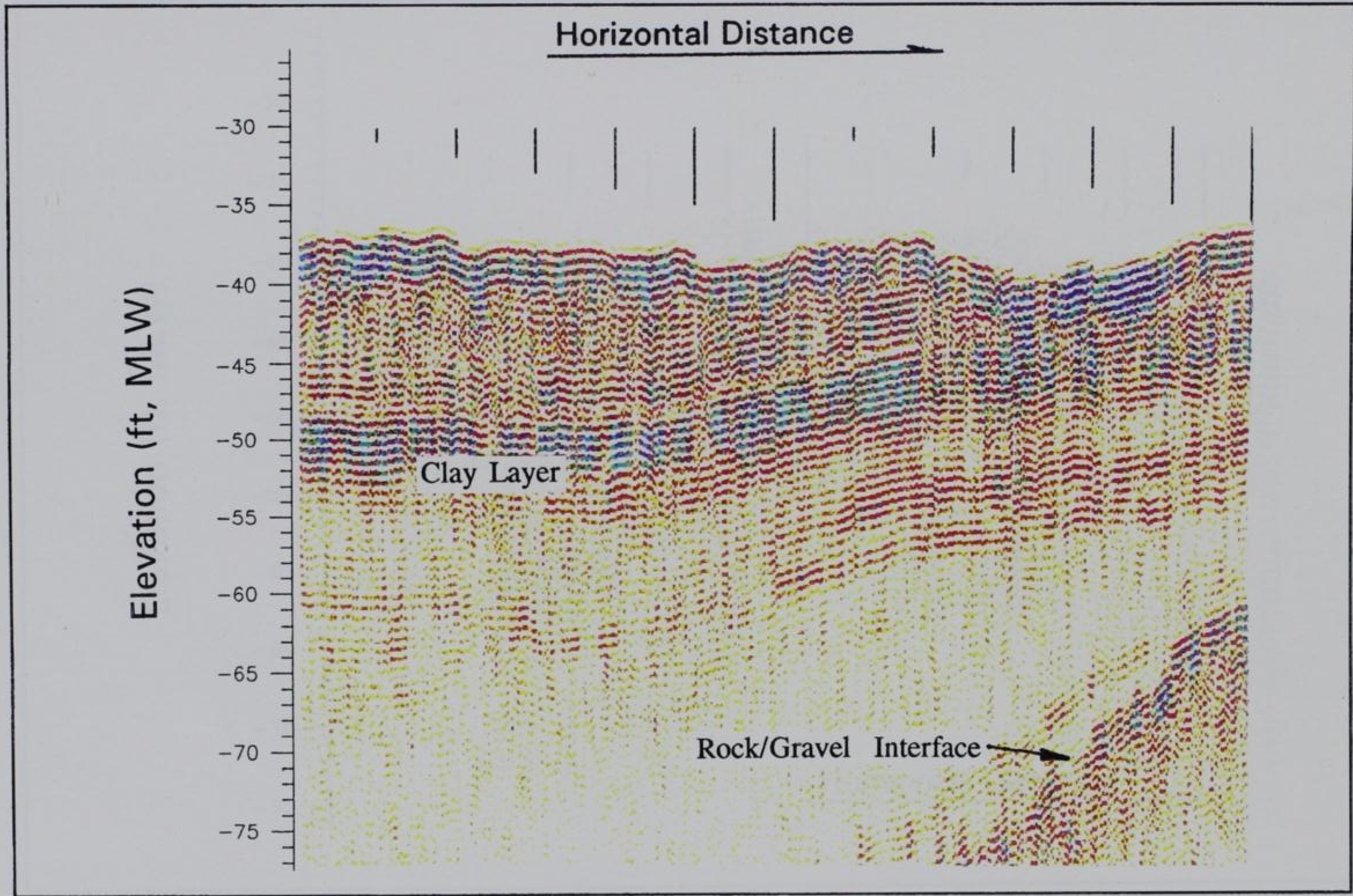

Figure 46. Subbottom seismic reflection record along Survey Line MP01 (files 100 - 120), Mystic River

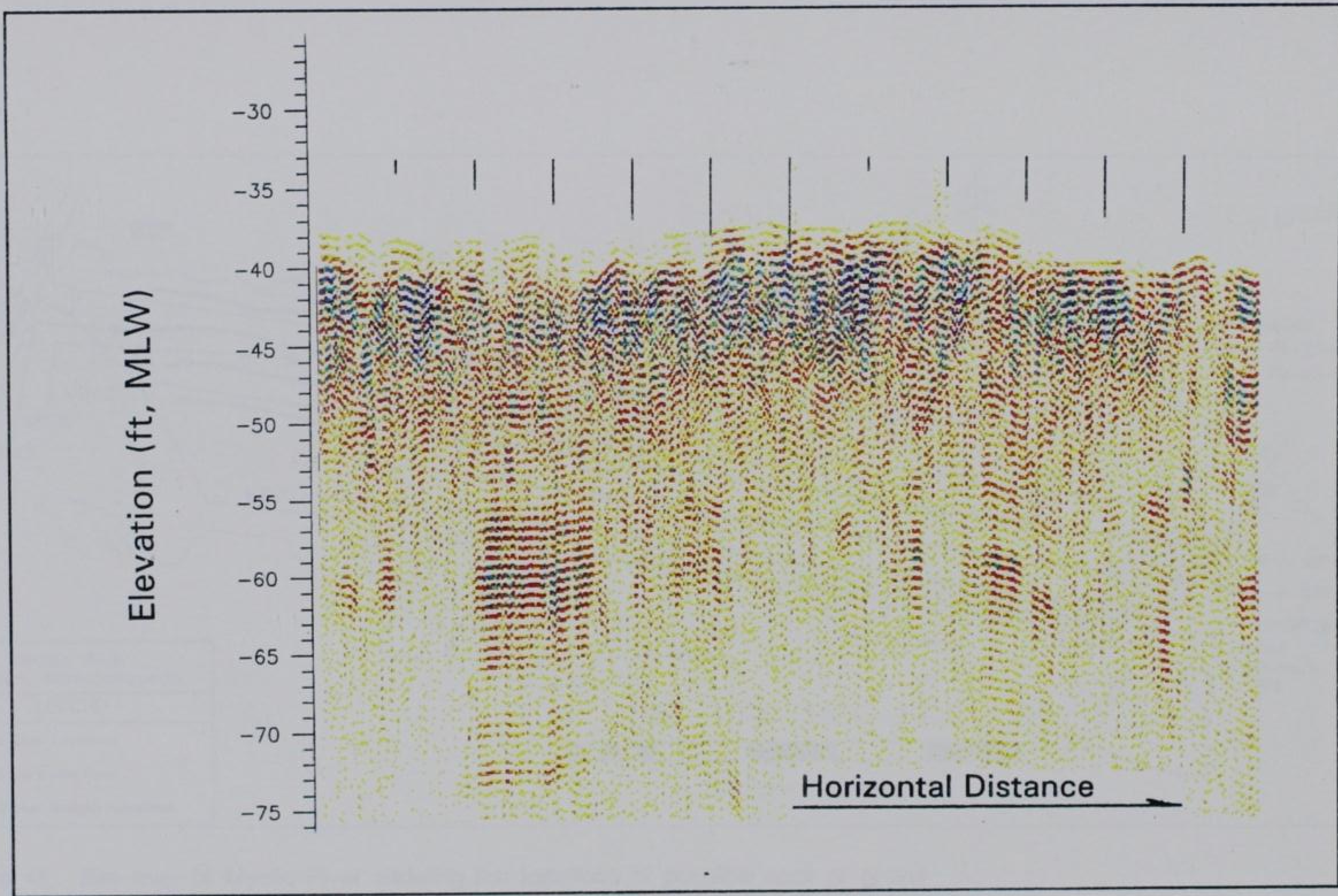

Figure 47. Subbottom seismic reflection record along Survey Line MP08 (files 040 - 060), Mystic River

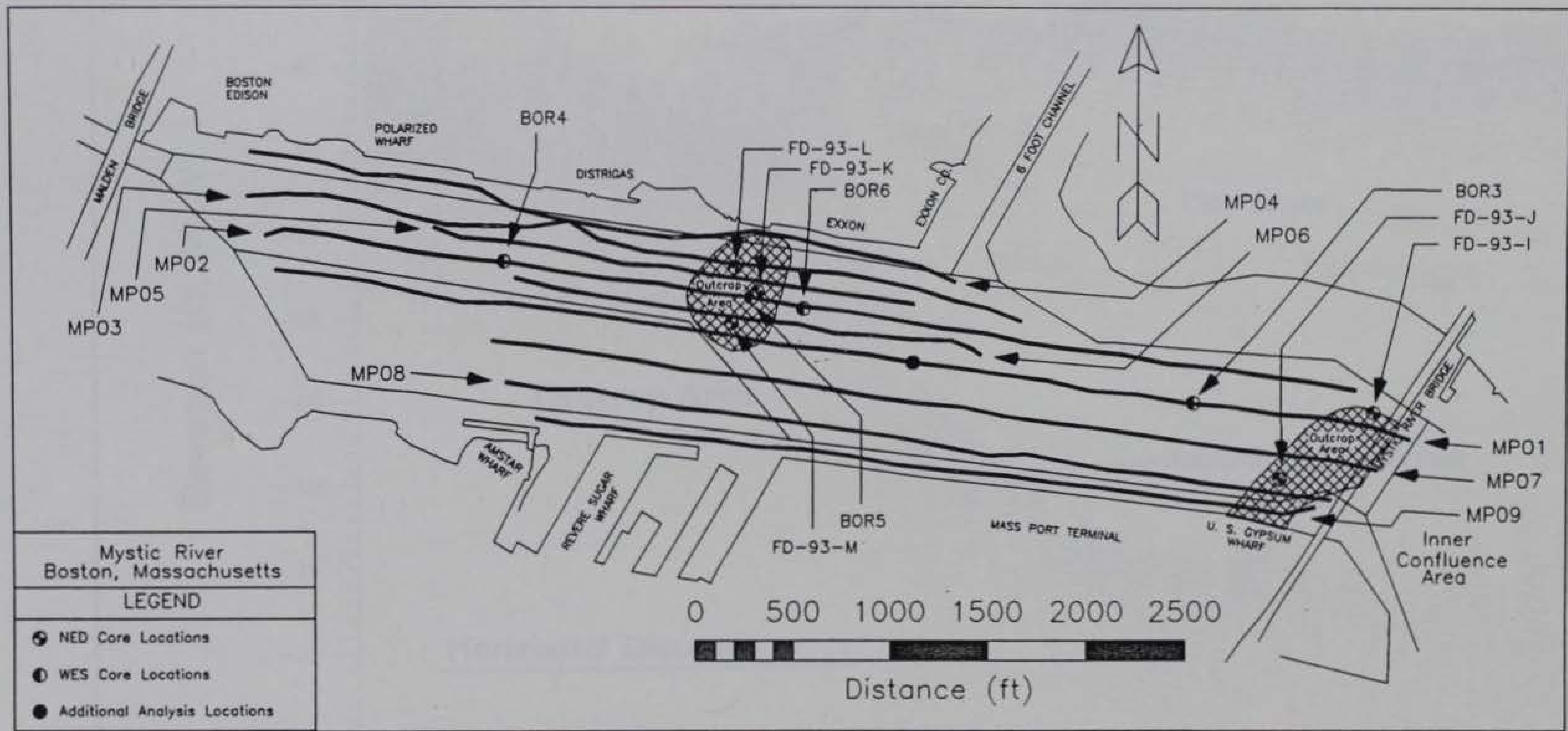

Figure 48. Site map of Mystic River showing the locations of possible rock or gravel outcrop areas. Seismic survey lines and core locations are also shown

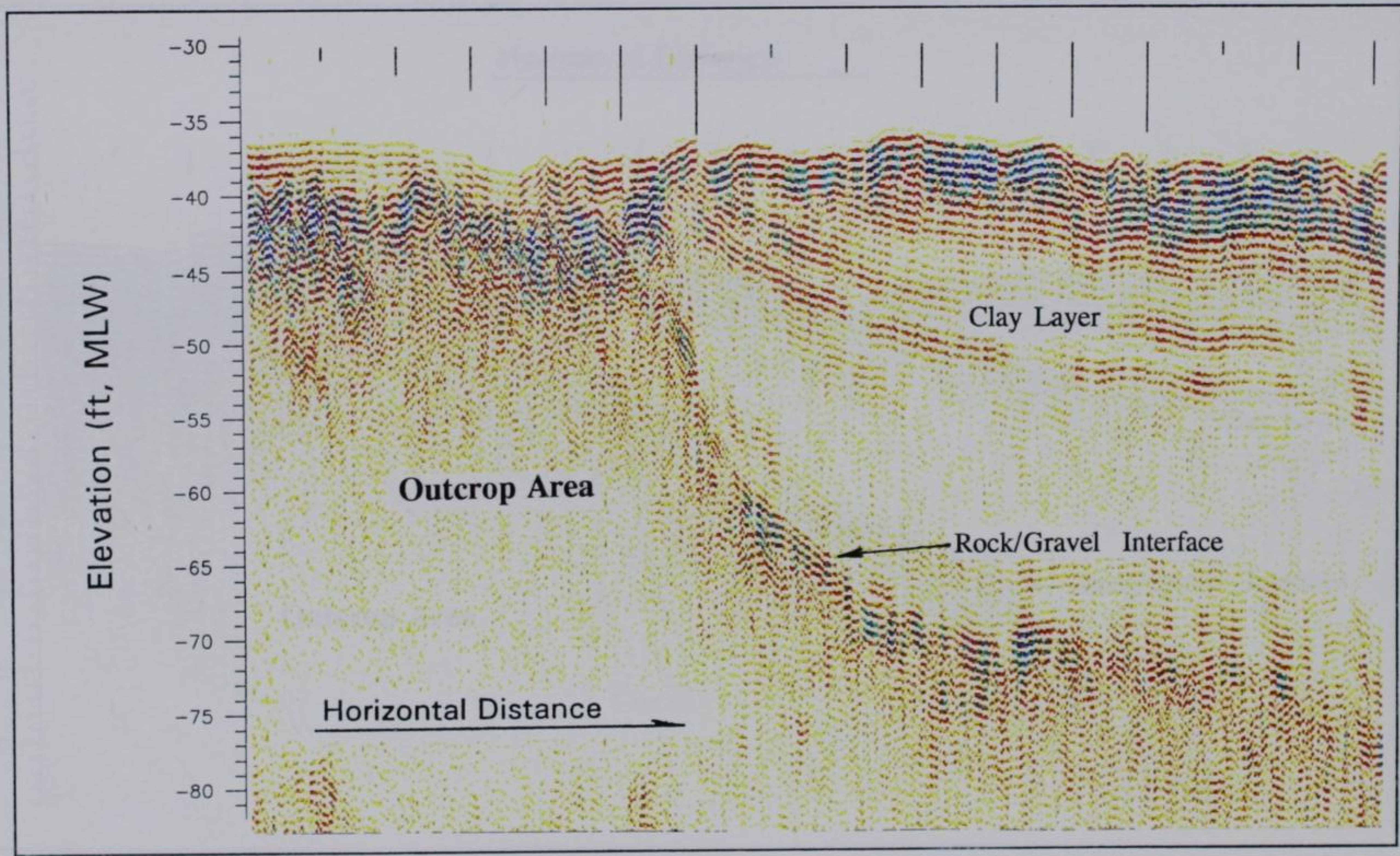

Figure 49. Subbottom seismic reflection record detecting a rock or gravel outcrop along Survey Line MP02 (files 050 - 073), Mystic River

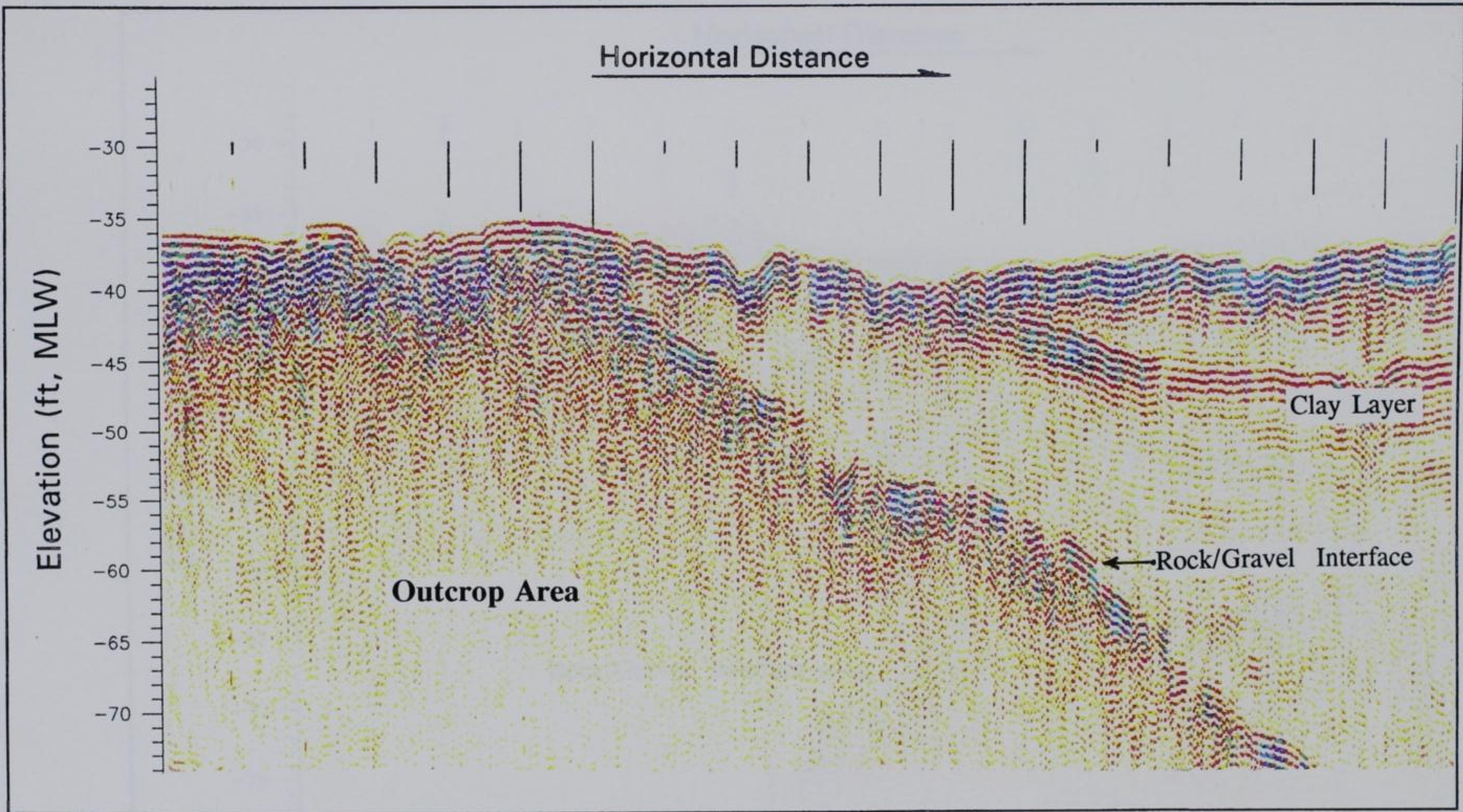

Figure 50. Subbottom seismic reflection record detecting a rock or gravel outcrop along Survey Line MP01 (files 050 - 080), Mystic River

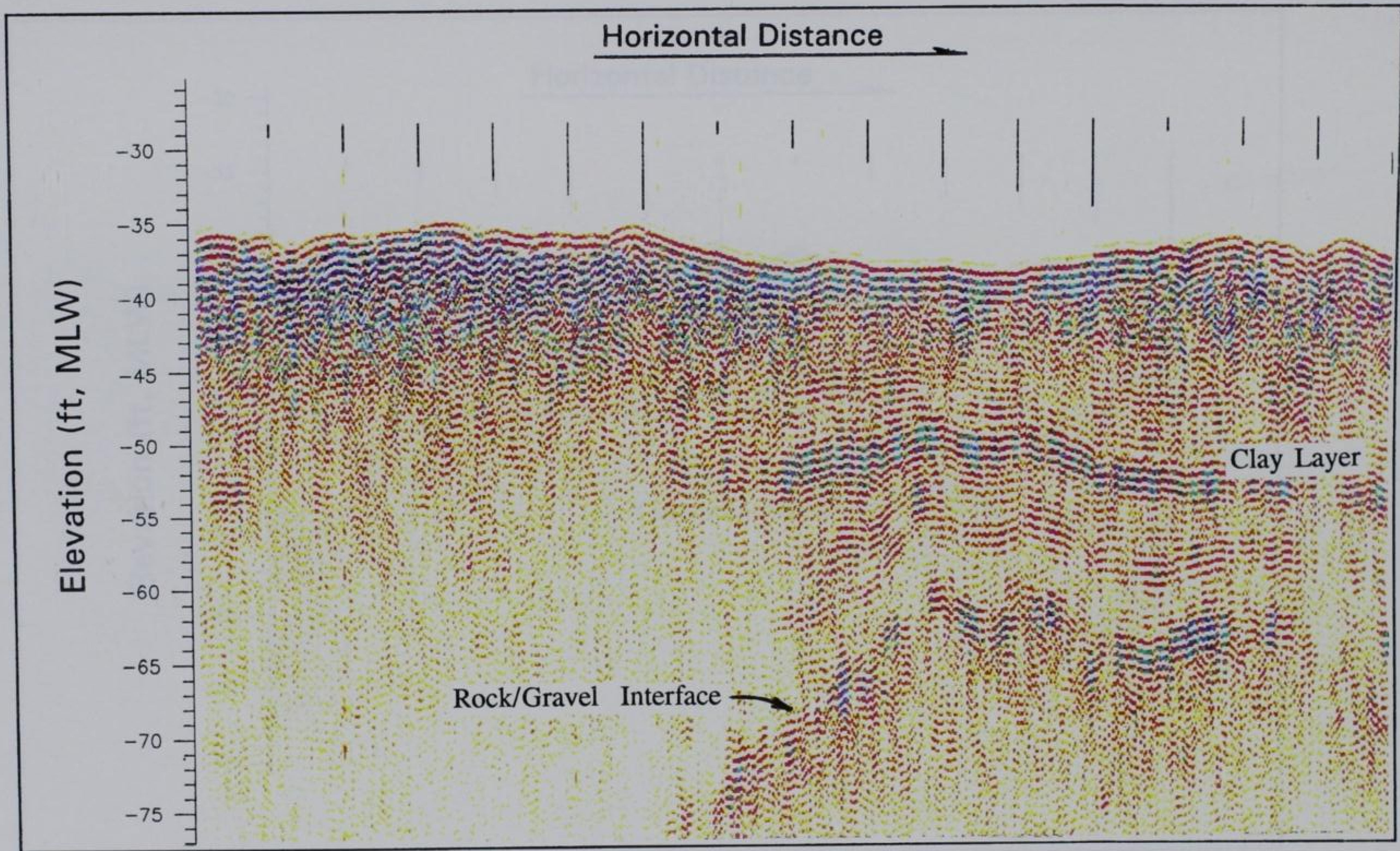

Figure 51. Subbottom seismic reflection record along Survey Line IP07 (files 000 - 023), Inner Confluence Area

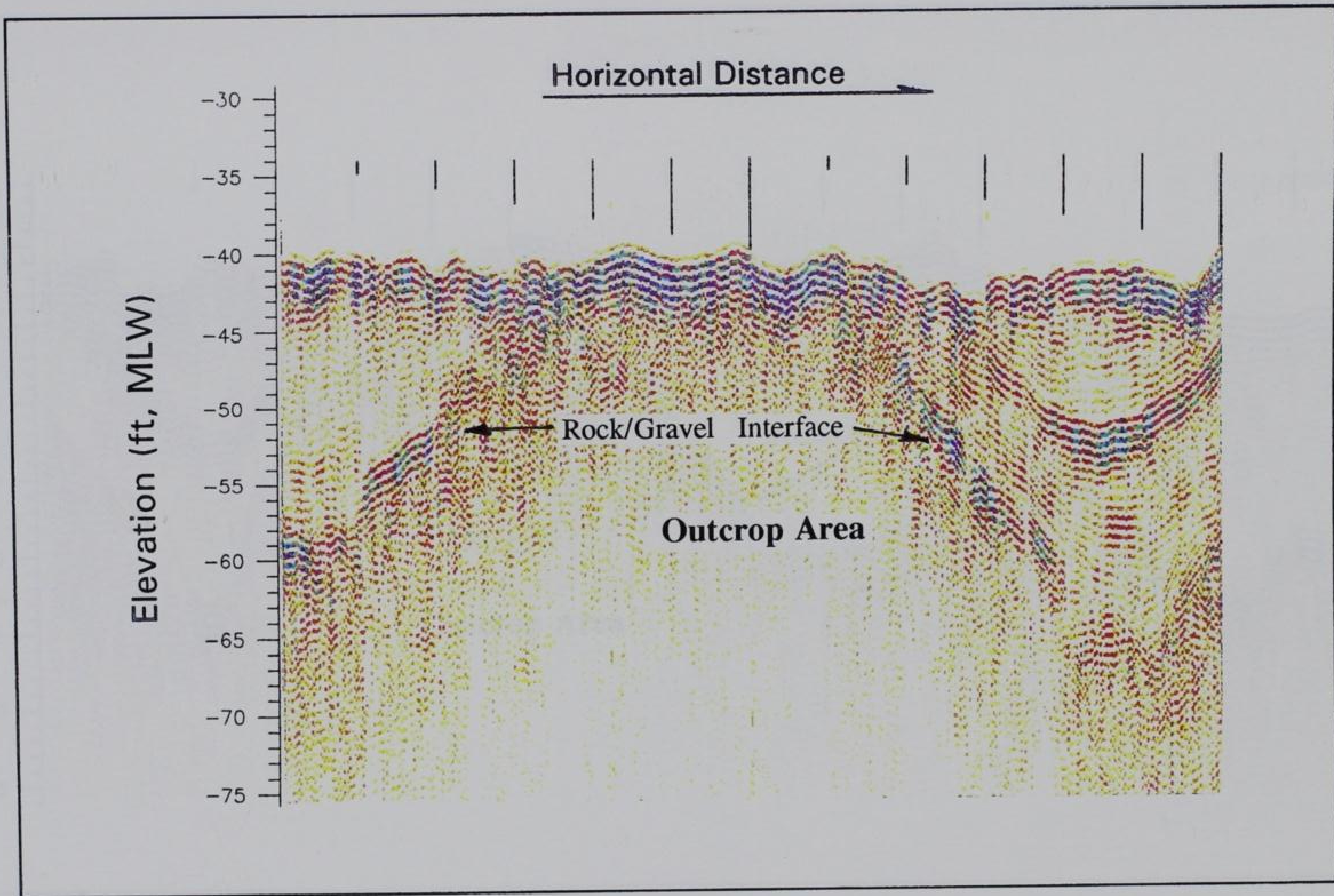

Figure 52. Subbottom seismic reflection record detecting a rock or gravel outcrop along Survey Line IP02 (files 020 - 040), Inner Confluence Area

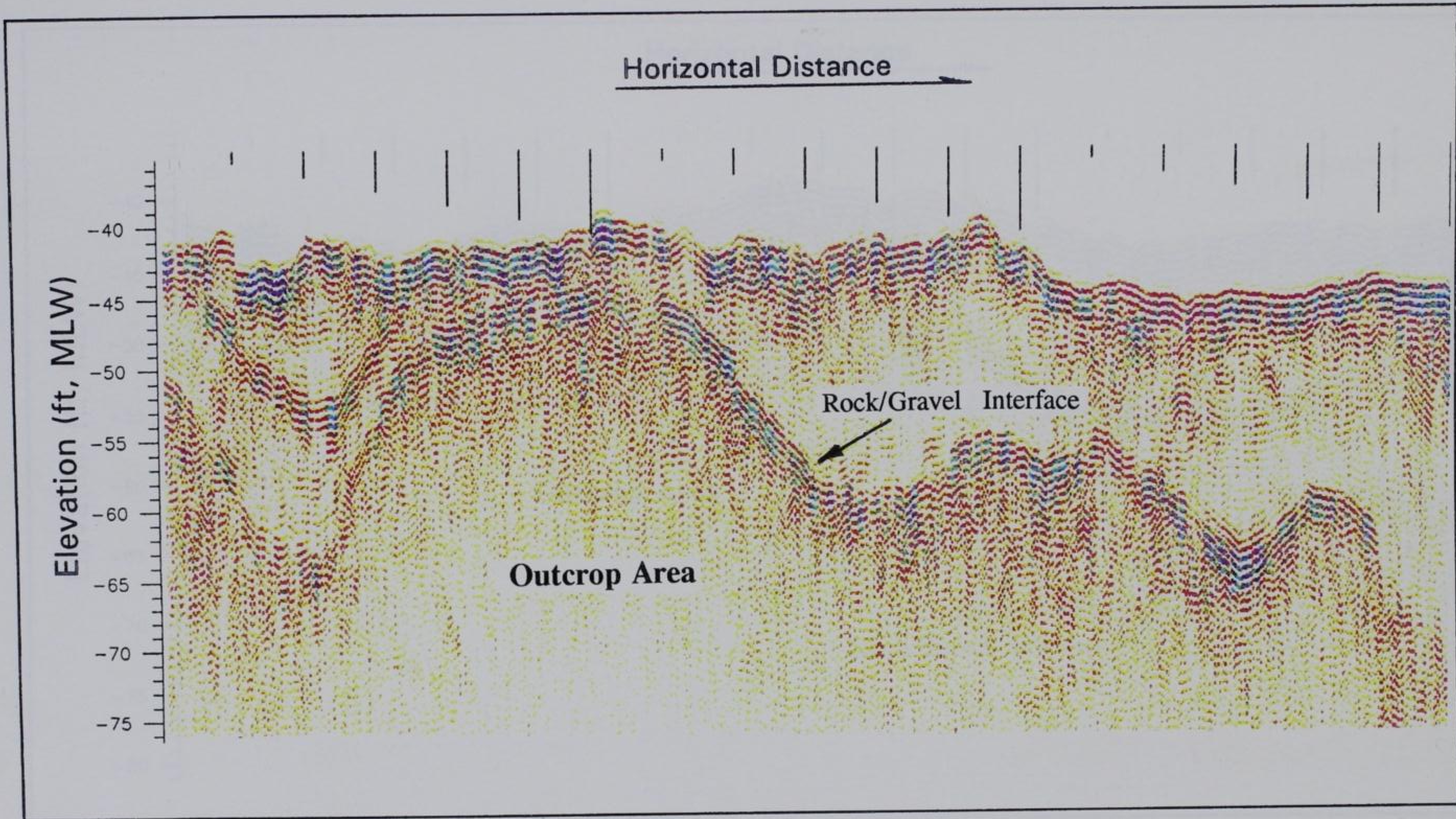

Figure 53. Subbottom seismic reflection record detecting a rock or gravel outcrop along Survey Line IP03 (files 010 - 040), Inner Confluence Area

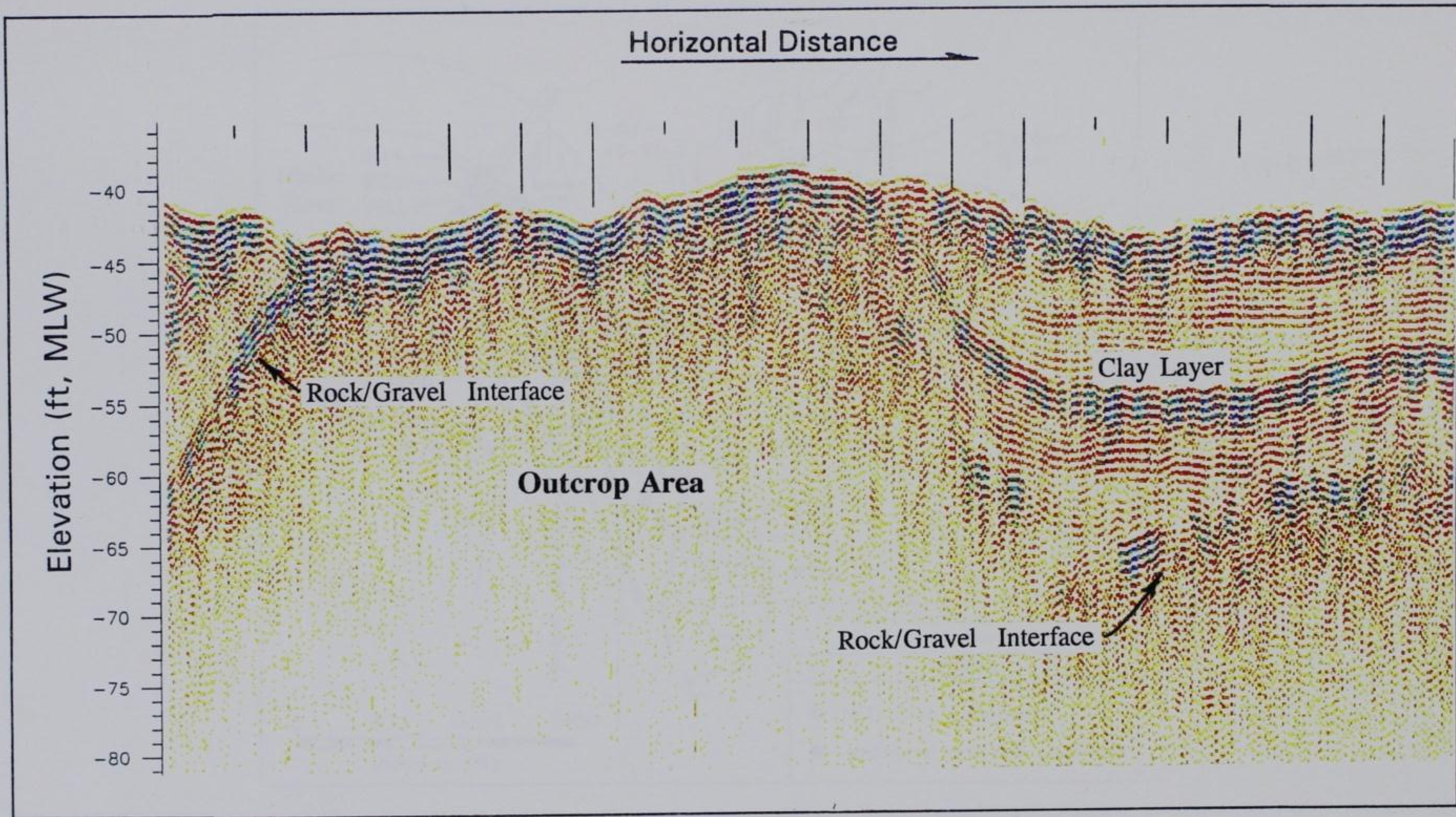

Figure 54. Subbottom seismic reflection record detecting a rock or gravel outcrop along Survey Line IP06 (files 010 - 040), Inner Confluence Area

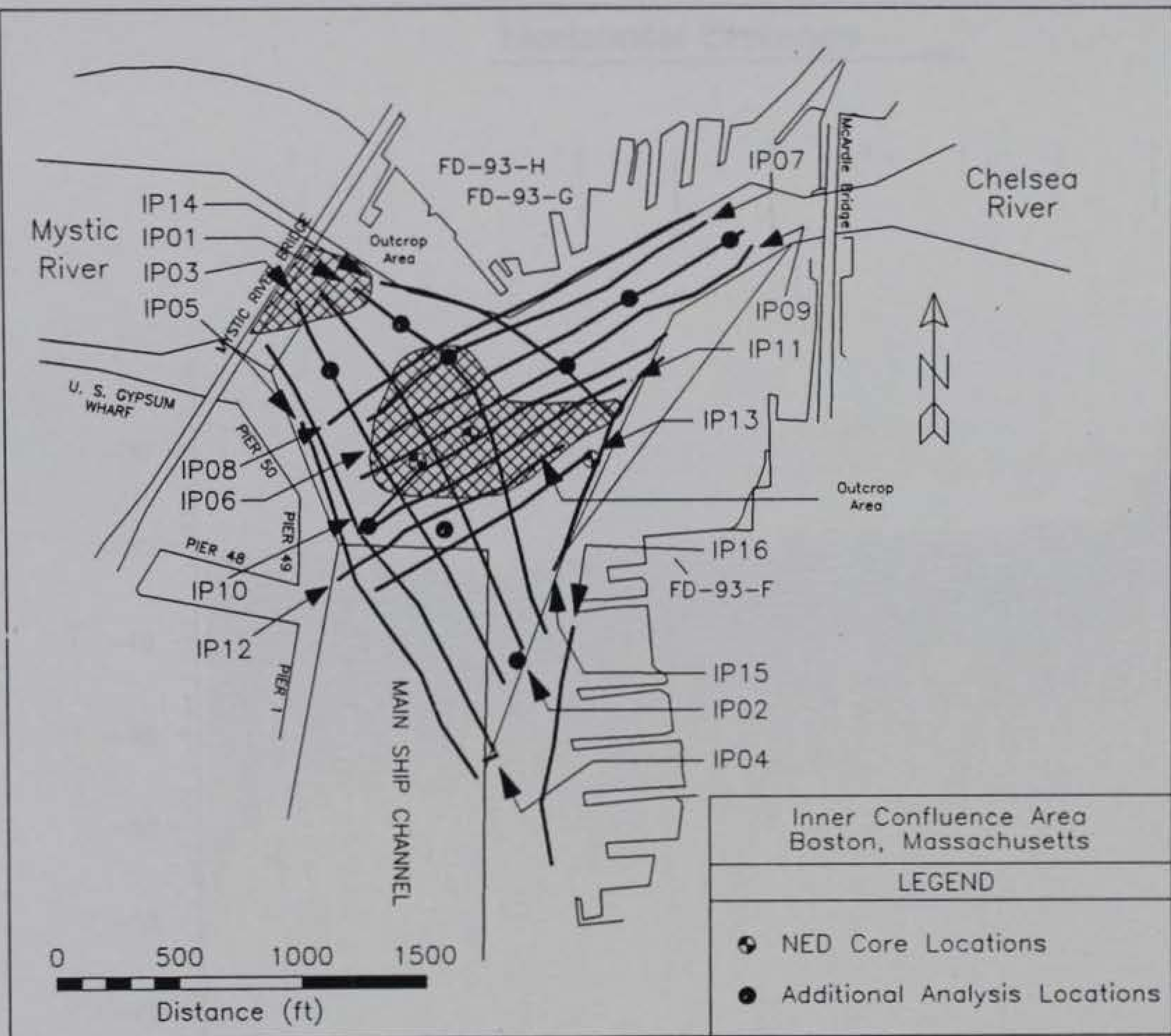

Figure 55. Site map of the Inner Confluence Area showing the locations of possible rock or gravel outcrop areas. Seismic survey lines and core locations are also shown

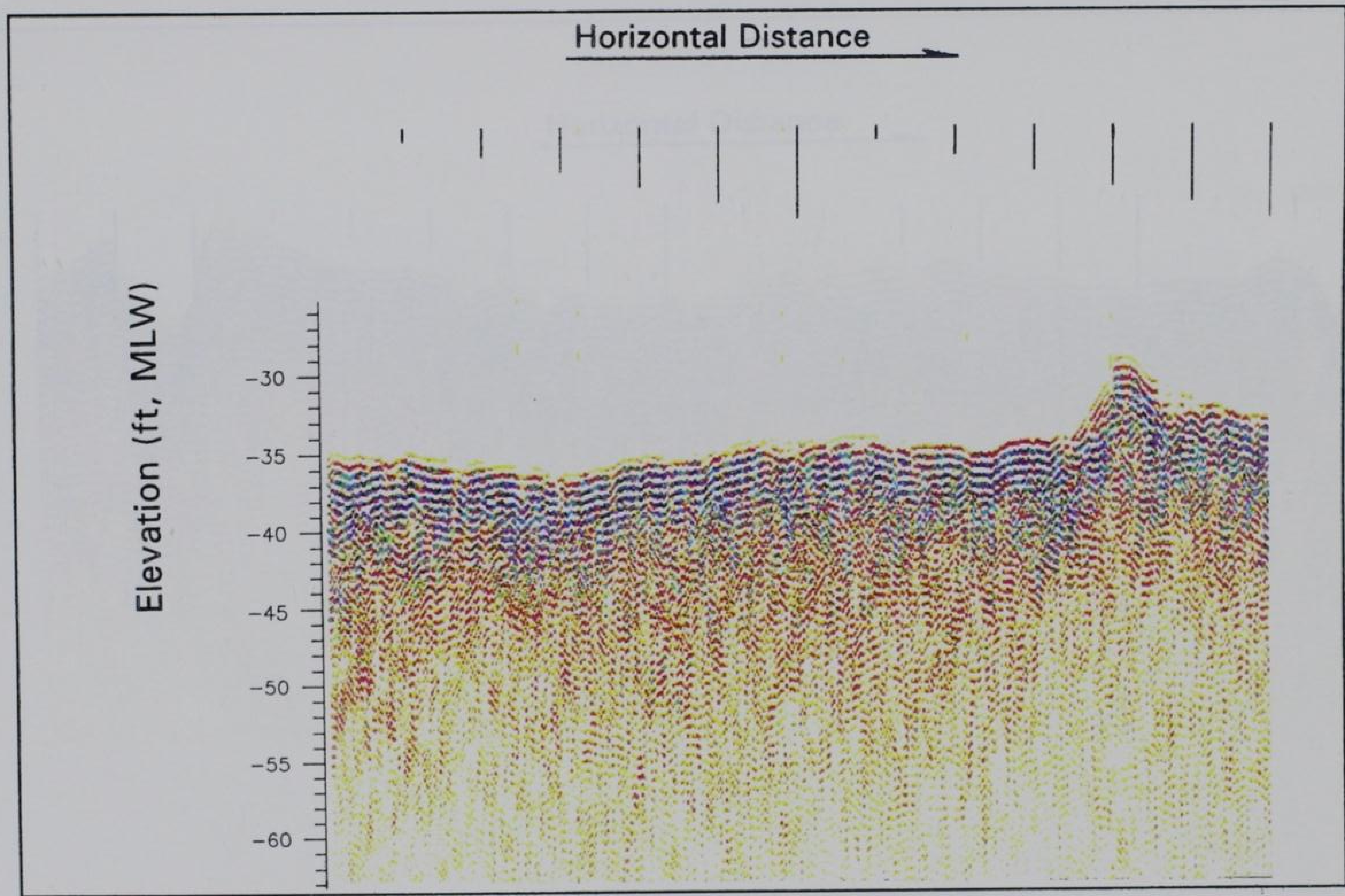

Figure 56. Subbottom seismic reflection record along Survey Line IP15 (files 000 - 020), Inner Confluence Area

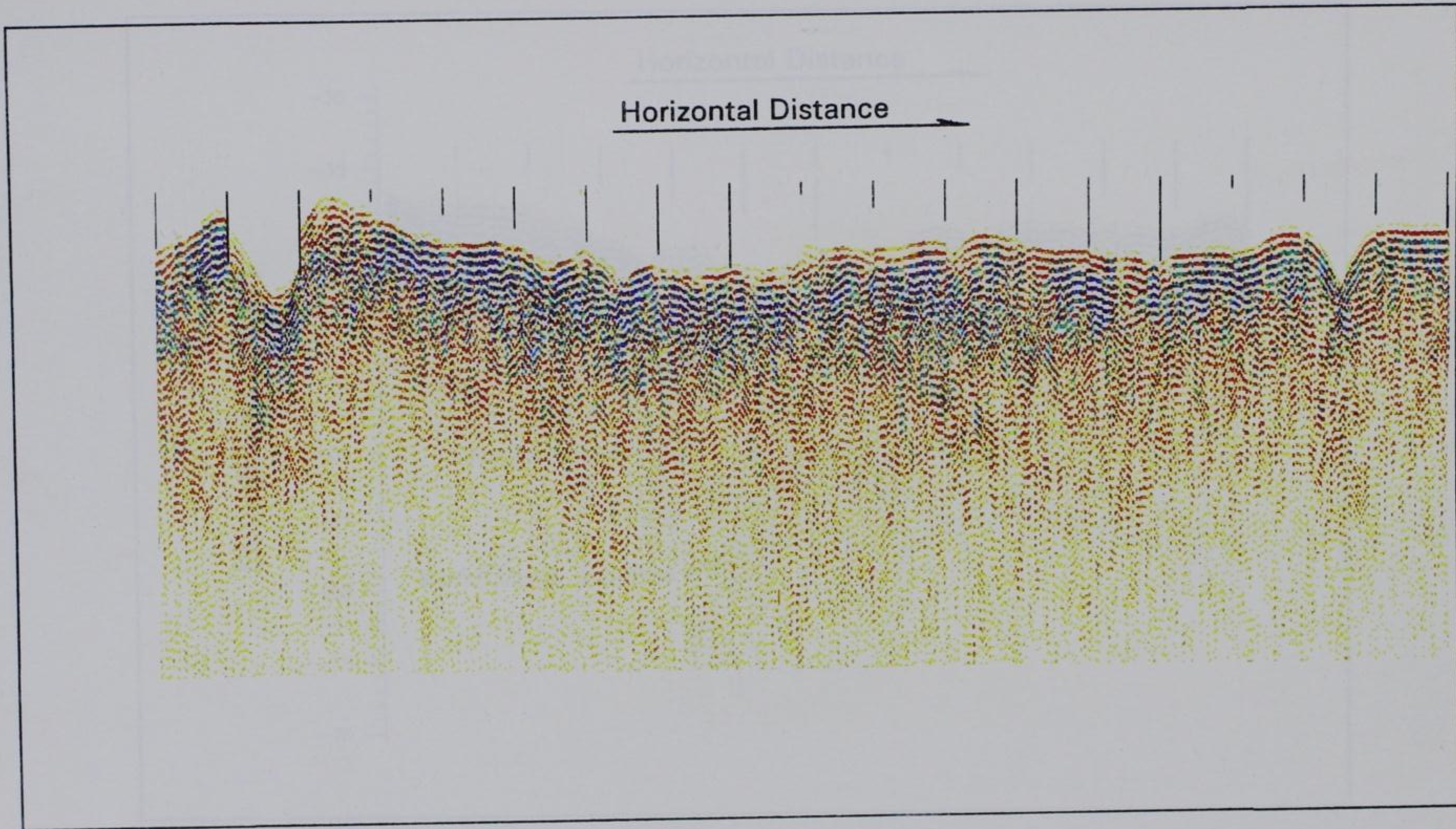

Figure 57. Subbottom seismic reflection record along Survey Line CP15N (files 074 - 103), Chelsea River

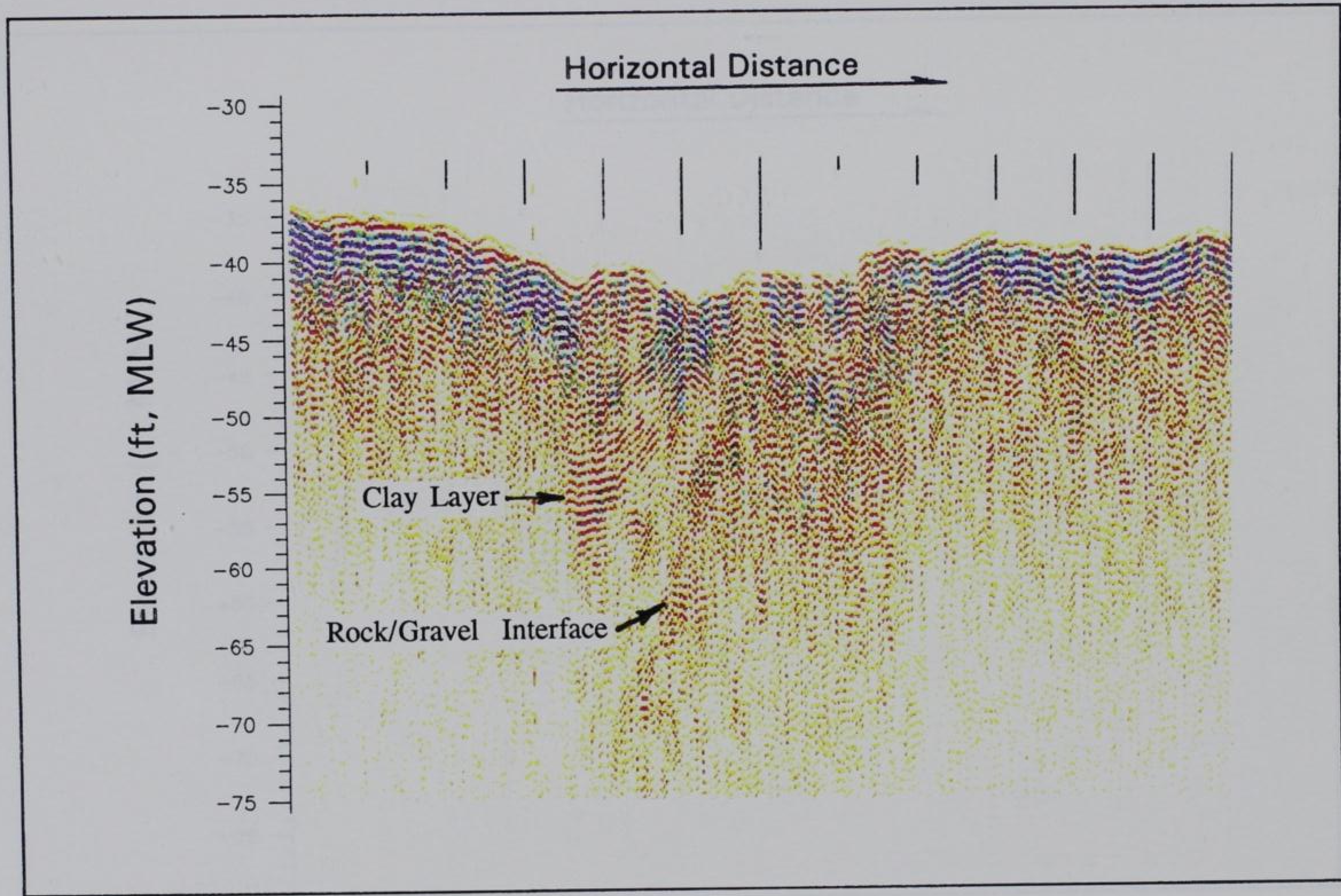

Figure 58. Subbottom seismic reflection record along Survey Line CP07 (files 010 - 030), Chelsea River

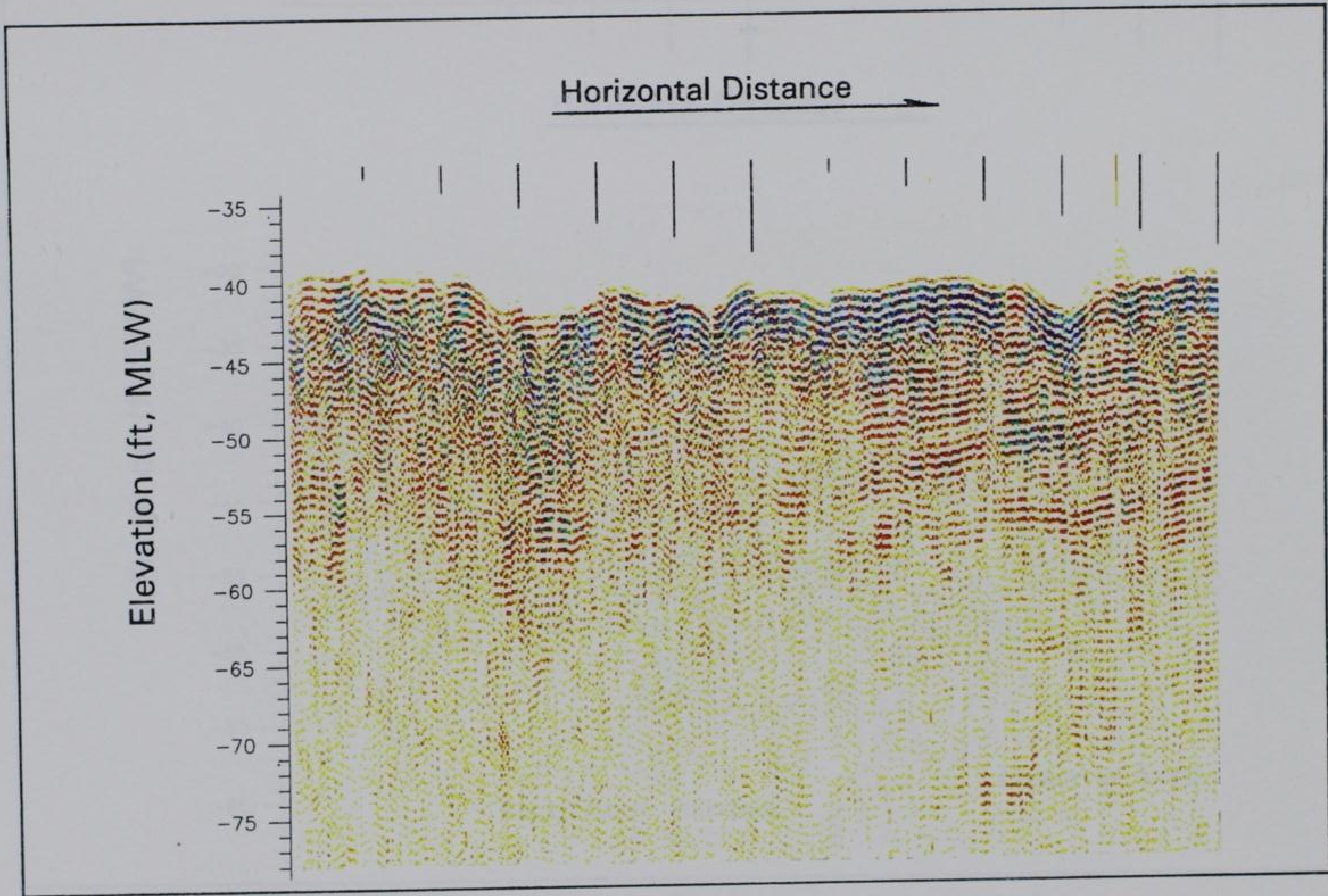

Figure 59. Subbottom seismic reflection record along Survey Line CP09 (files 020 - 040), Chelsea River

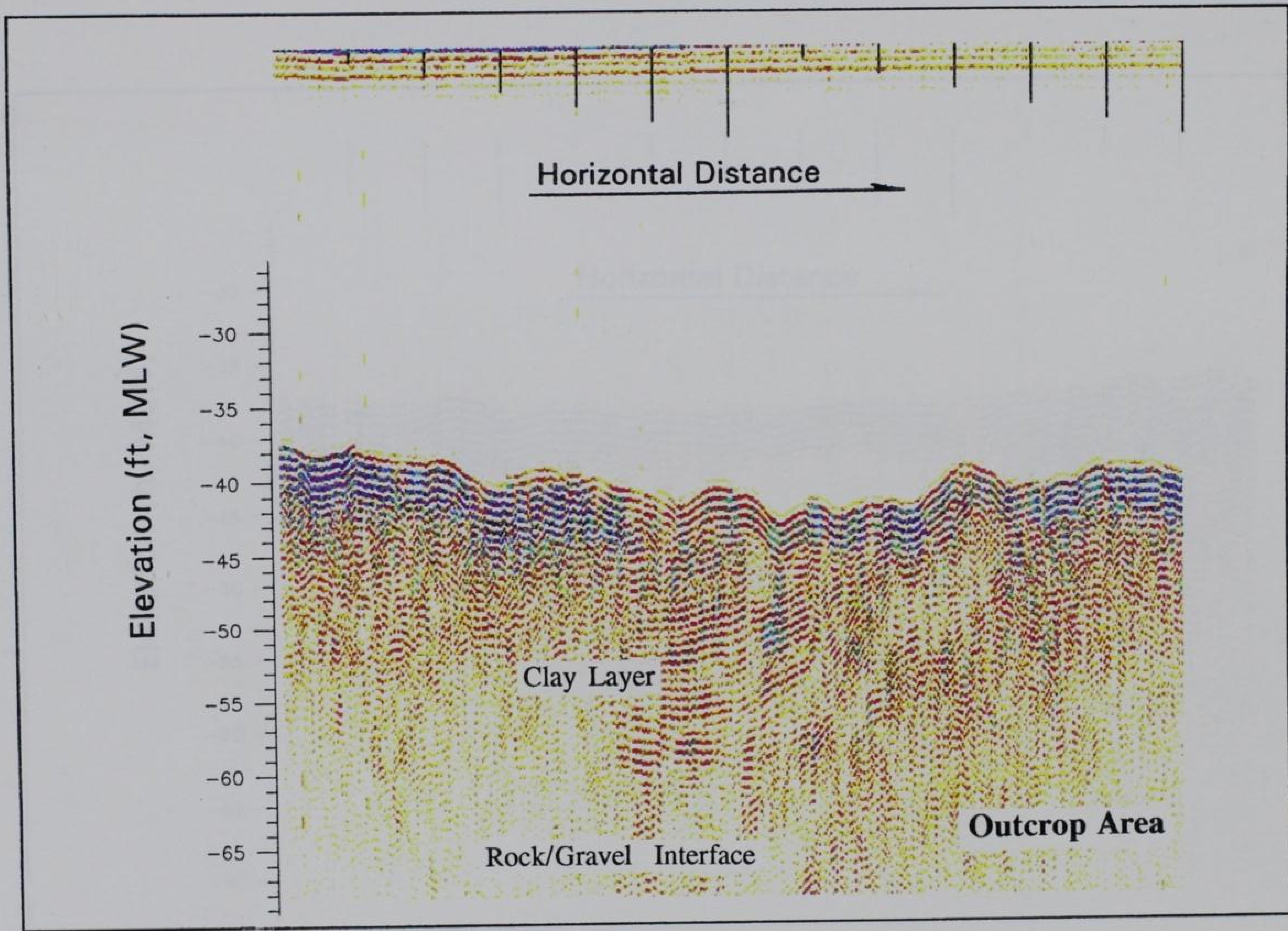

Figure 60. Subbottom seismic reflection record detecting a rock or gravel outcrop along survey line CP03 (files 010 - 030), Chelsea River

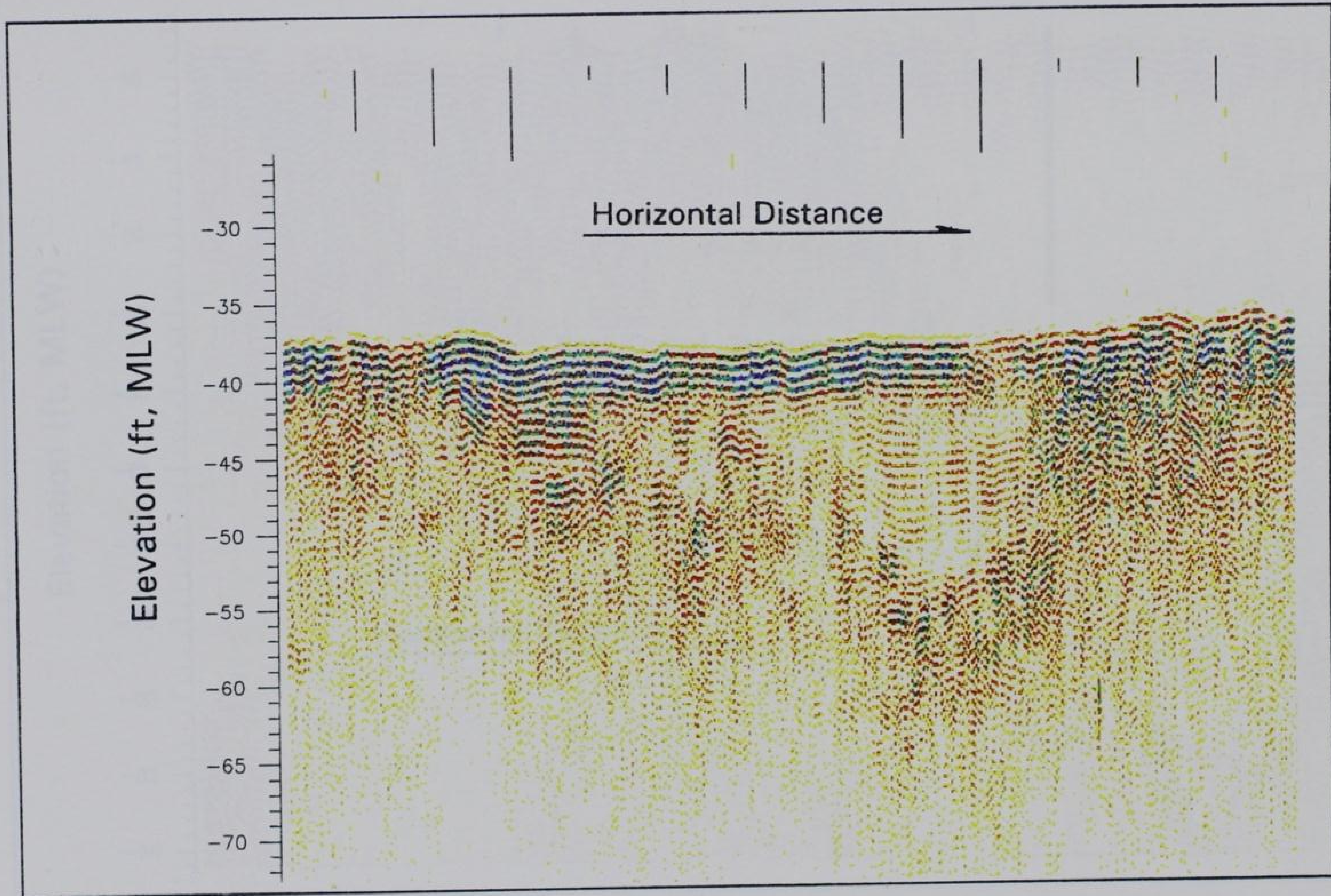

Figure 61. Subbottom seismic reflection record along Survey Line RP07 (files 053 - 073), across from Reserved Channel

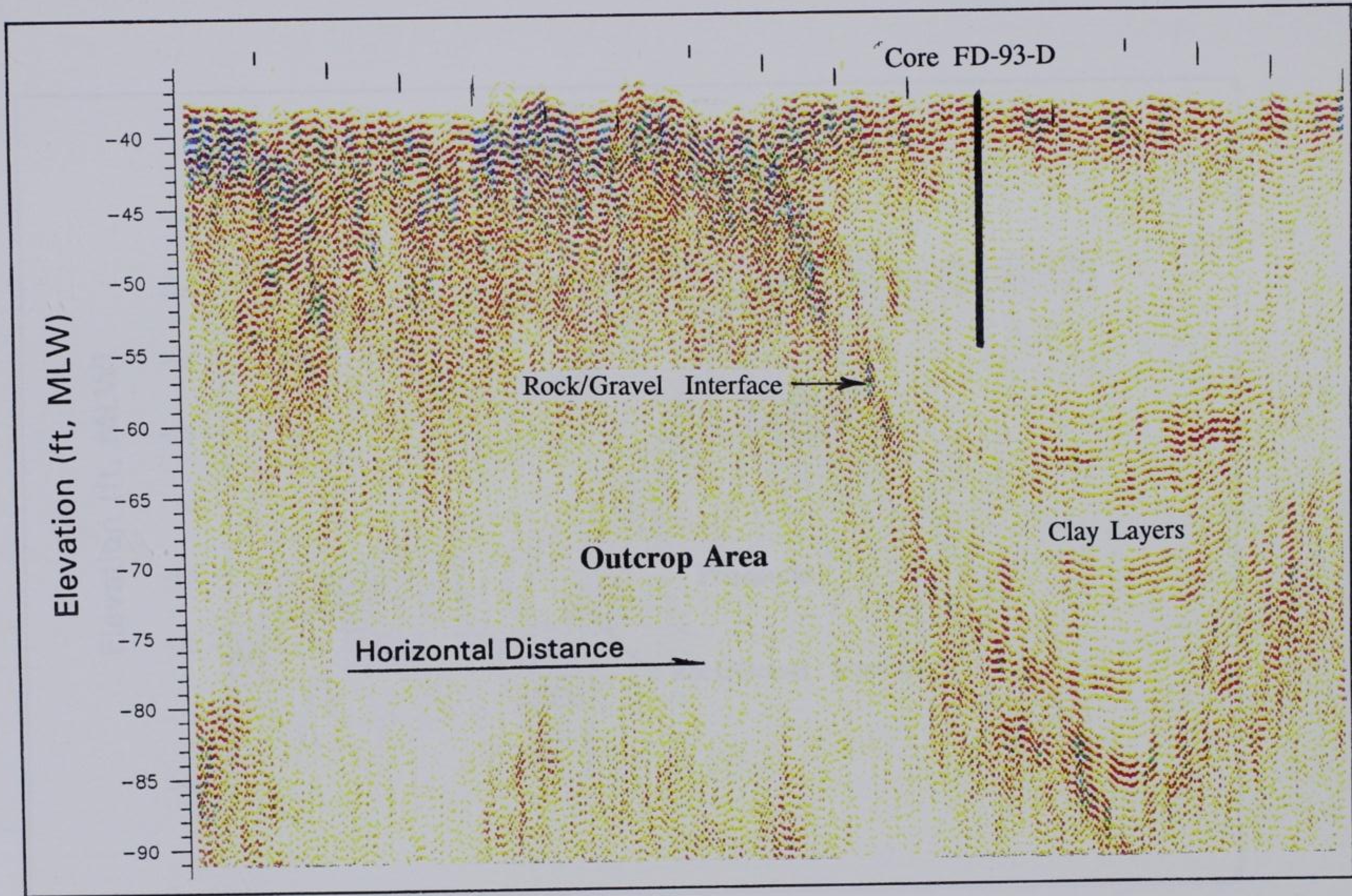

Figure 62. Subbottom seismic reflection record detecting a rock or gravel outcrop along Survey Line RP07 (file 000 - 023), across from Reserved Channel

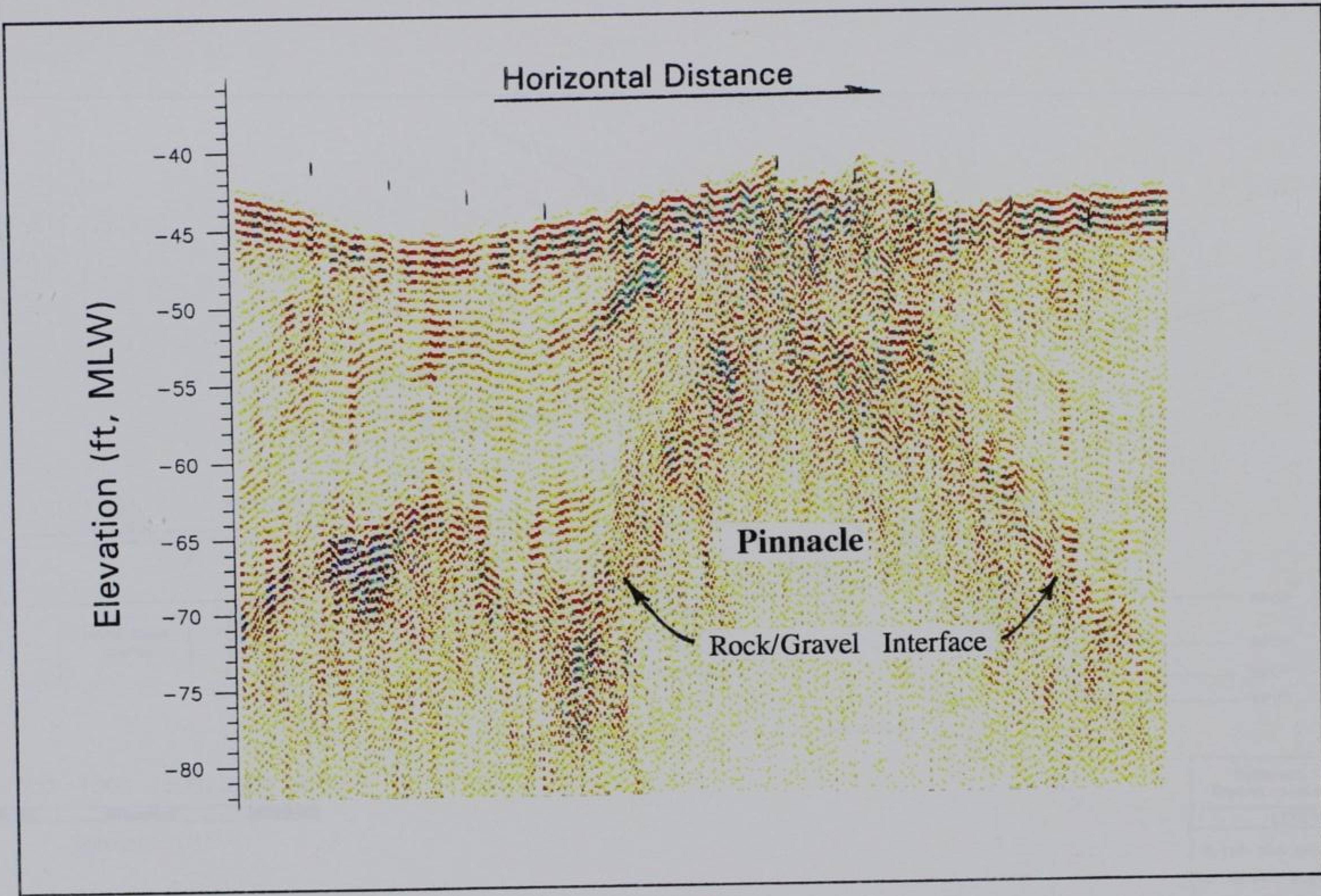

Figure 63. Subbottom seismic reflection record detecting a rock or gravel pinnacle along Survey Line RP05 (file 000 - 020), across from Reserved Channel

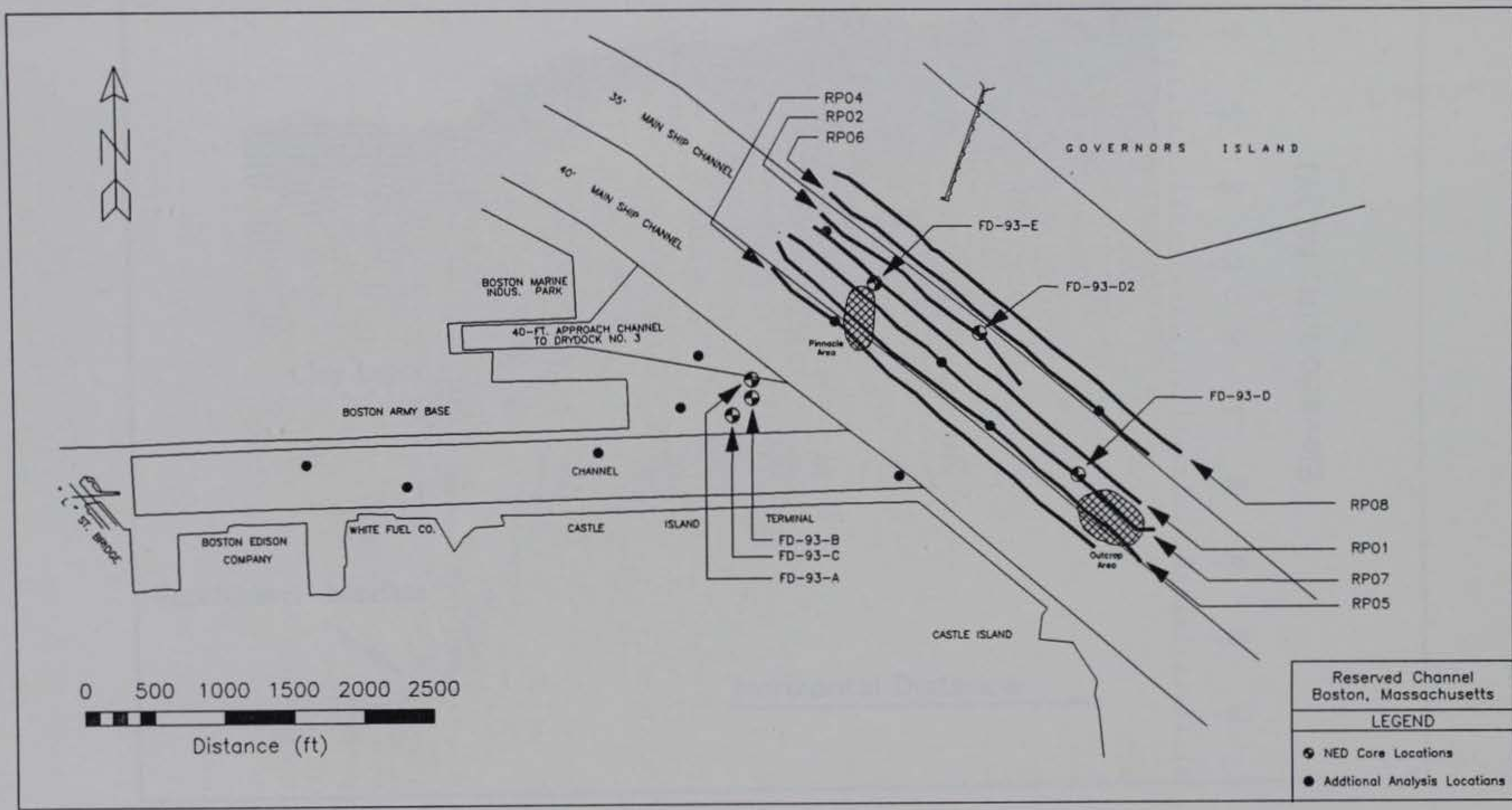

Figure 64. Site map of the area across from Reserved Channel showing the location of a rock or gravel outcrop area. Seismic survey lines and core locations are also shown

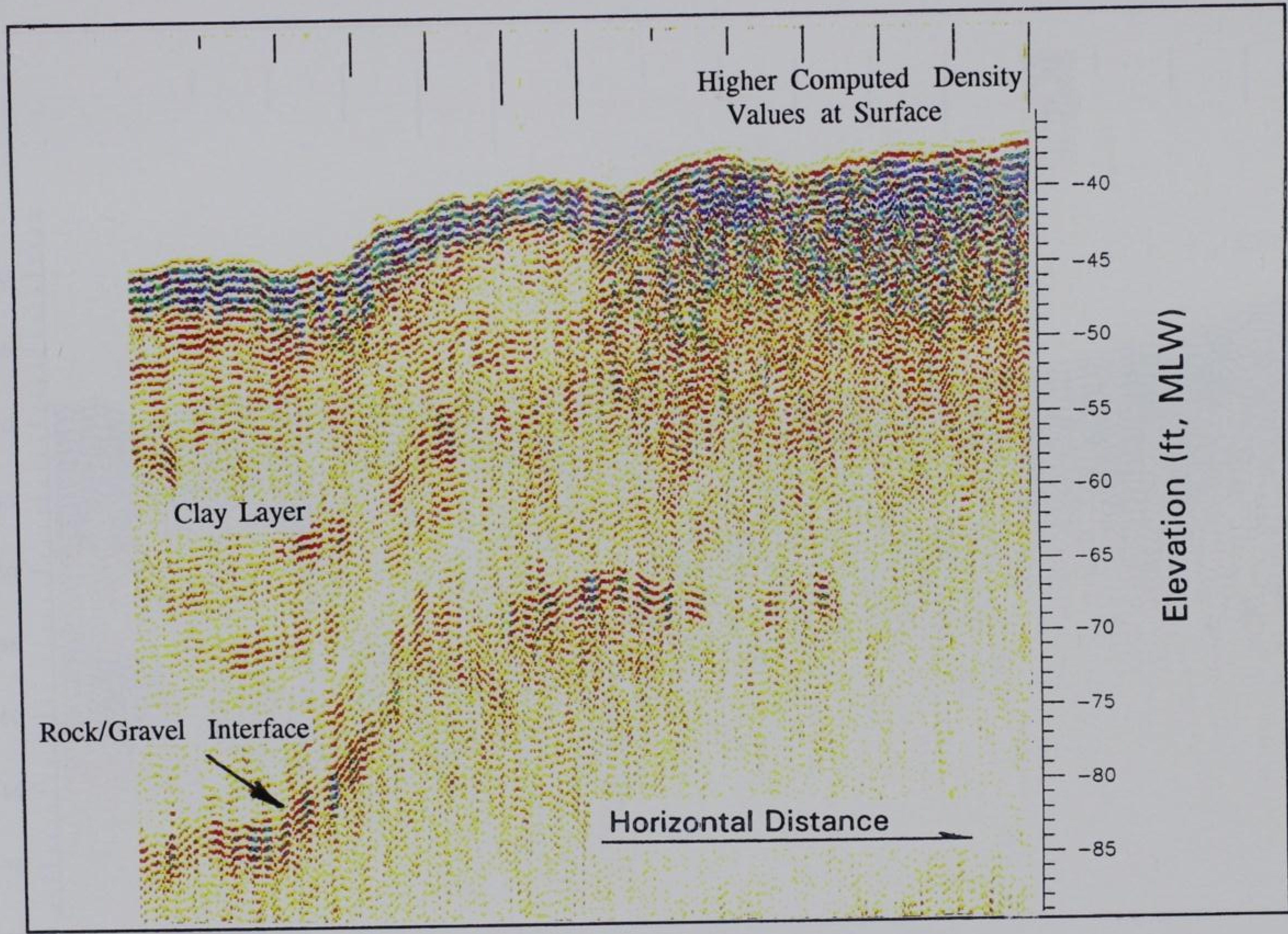

Figure 65. Subbottom seismic reflection record along Survey Line RP18 (files 010 - 030), Reserved Channel

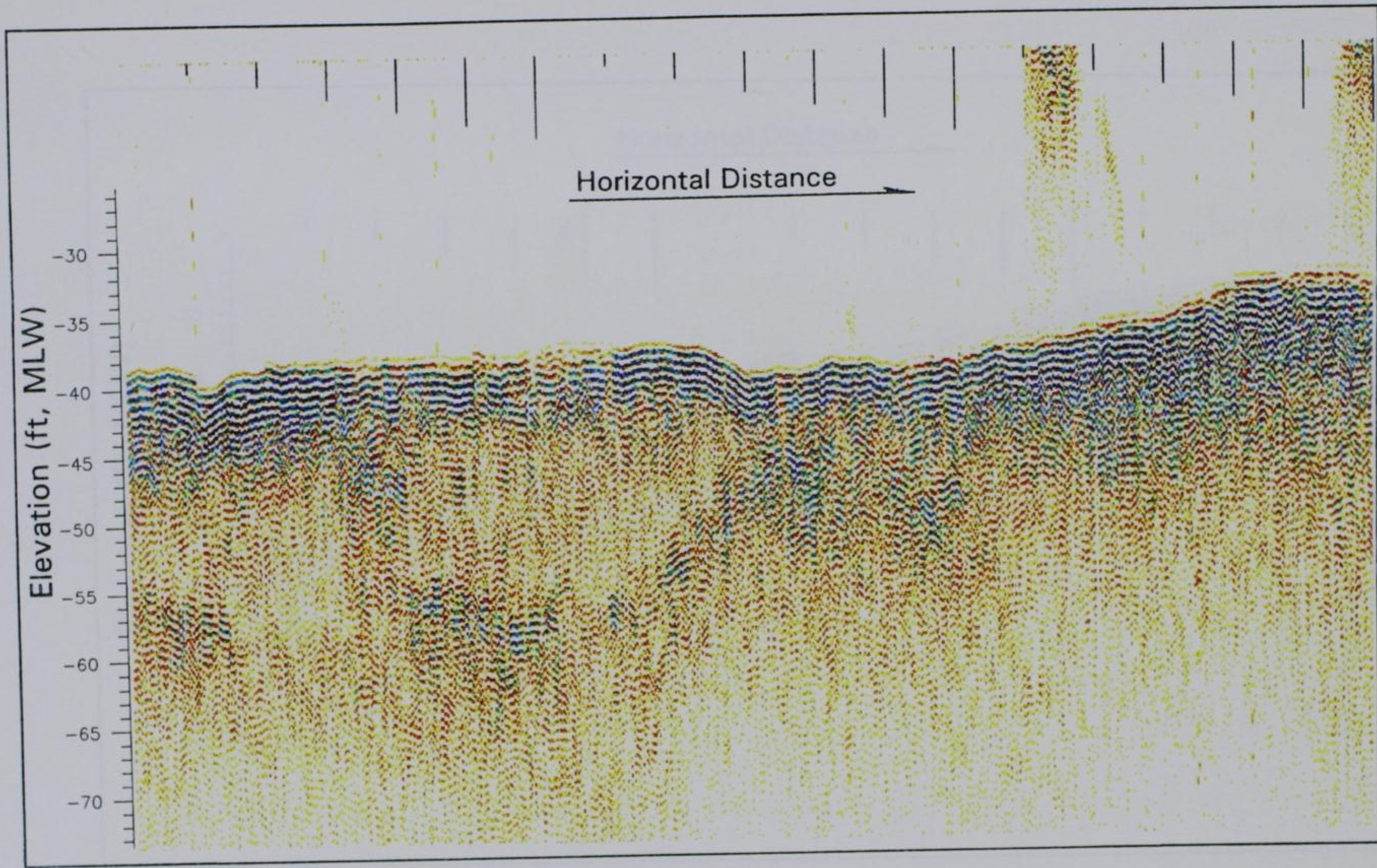

Figure 66. Subbottom seismic reflection record along Survey Line RP20 (files 050 - 080), Reserved Channel

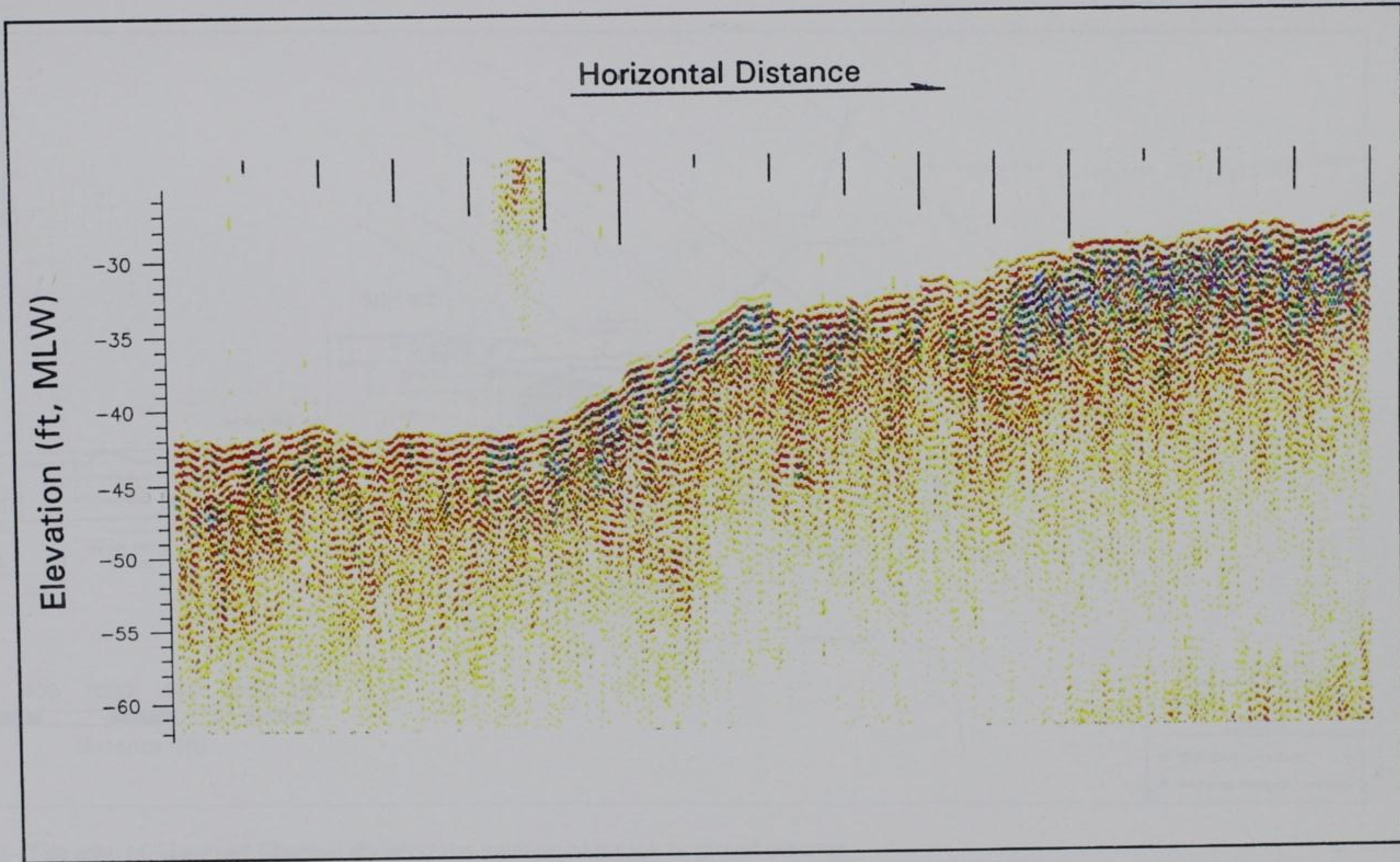

Figure 67. Subbottom seismic reflection record along Survey Line RP12 (files 030 - 053), Reserved Channel

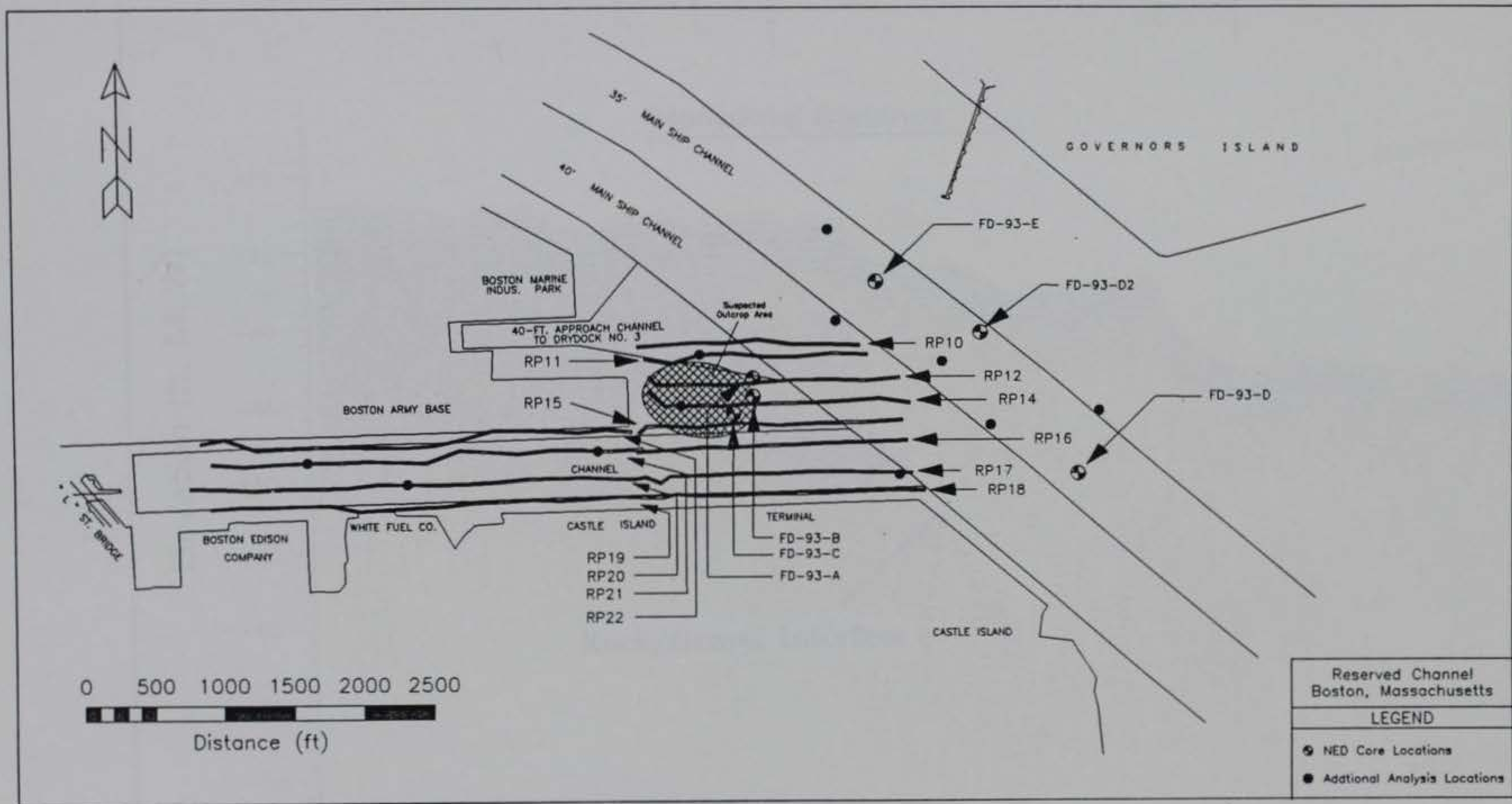

Figure 68. Site map of Reserved Channel showing the location of a rock or gravel outcrop area. Seismic survey lines and core locations are also shown

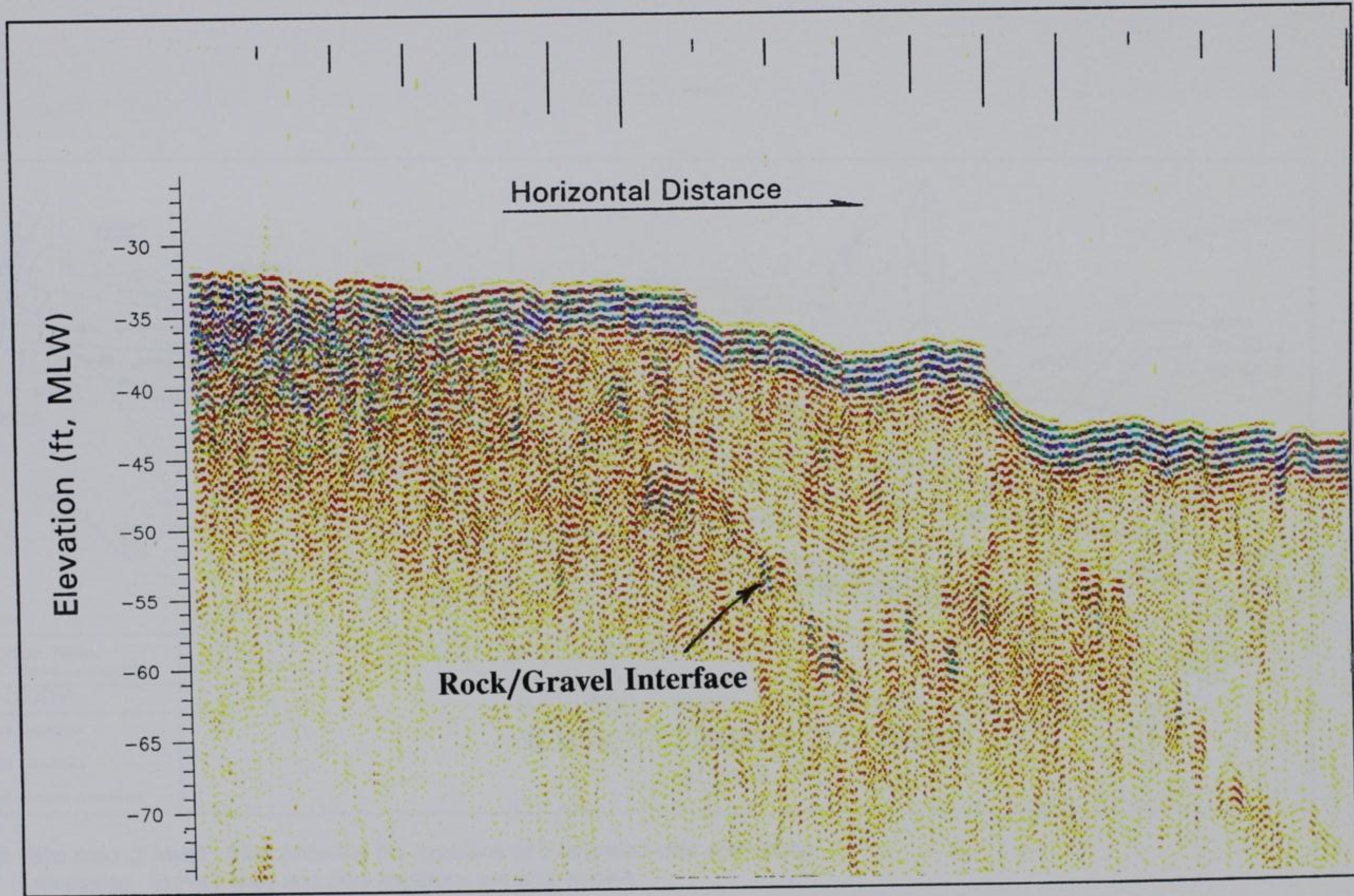

Figure 69. Subbottom seismic reflection record detecting a rock or gravel interface along survey line RP15 (files 010 - 033), Reserved Channel

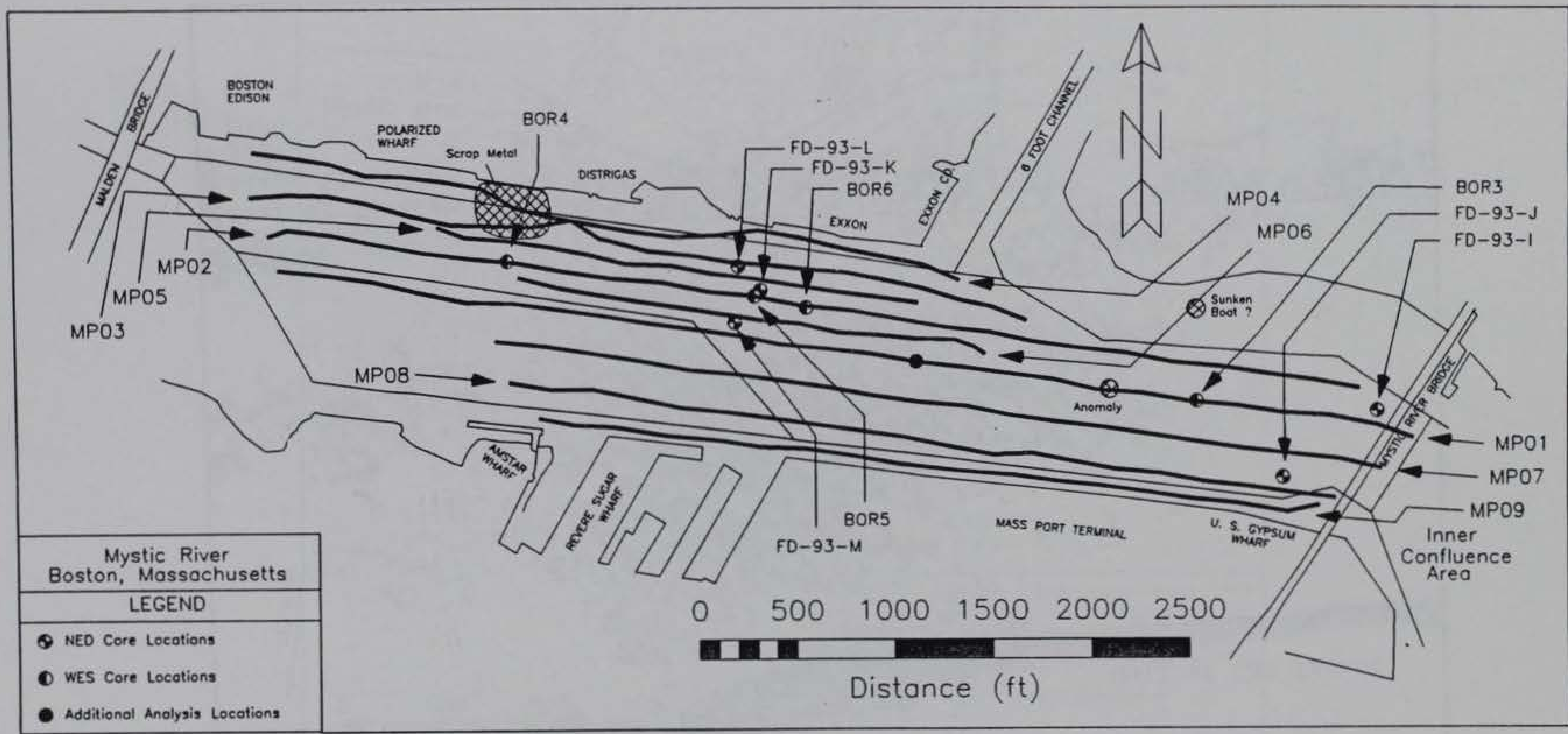

Figure 70. Site map of Mystic River showing the locations of interpreted side scan sonar anomalies. Survey lines and core locations are also shown

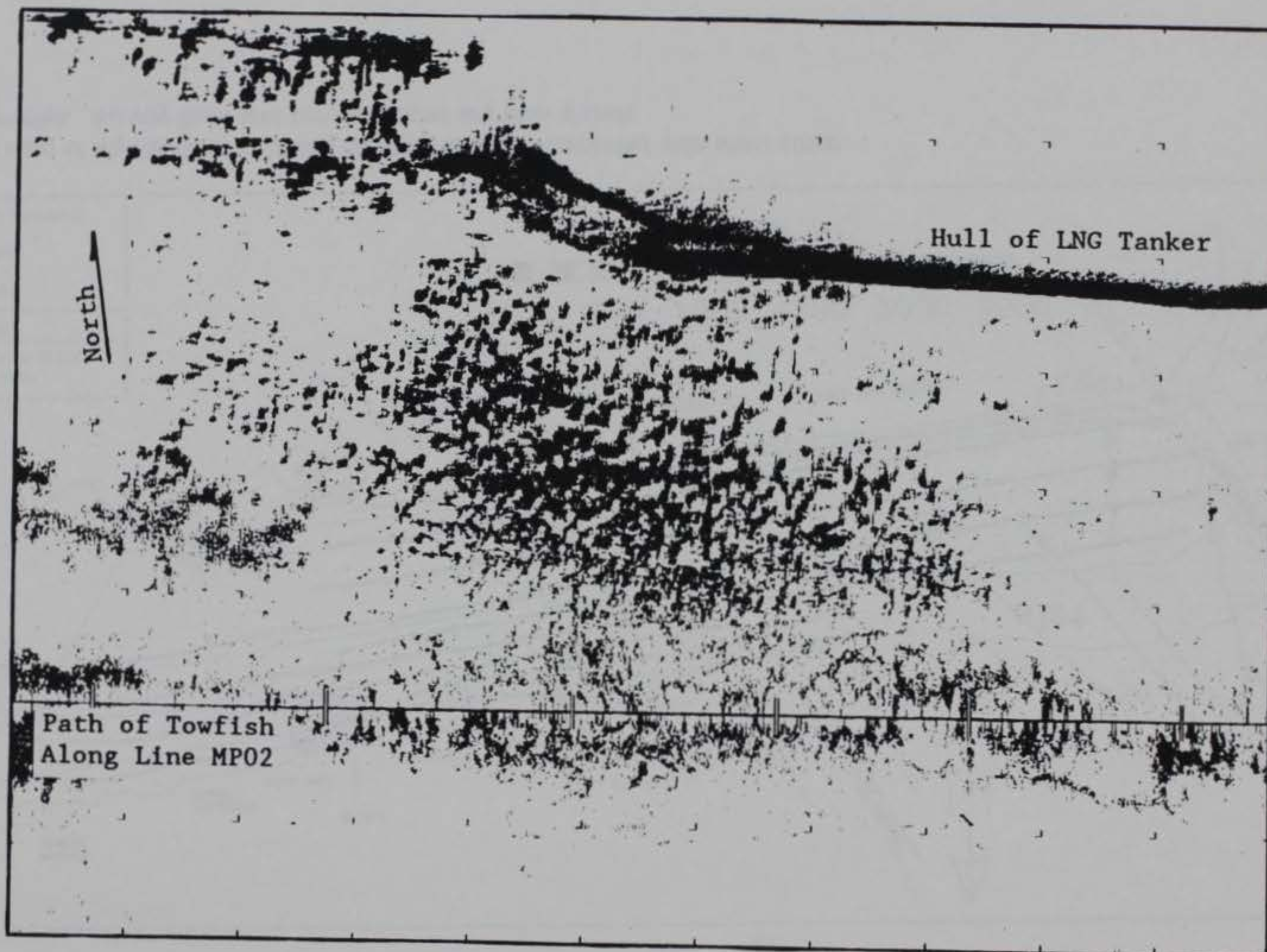

Figure 71. Scattered debris detected on the channel bottom west of the Distrigas Pier, Mystic River

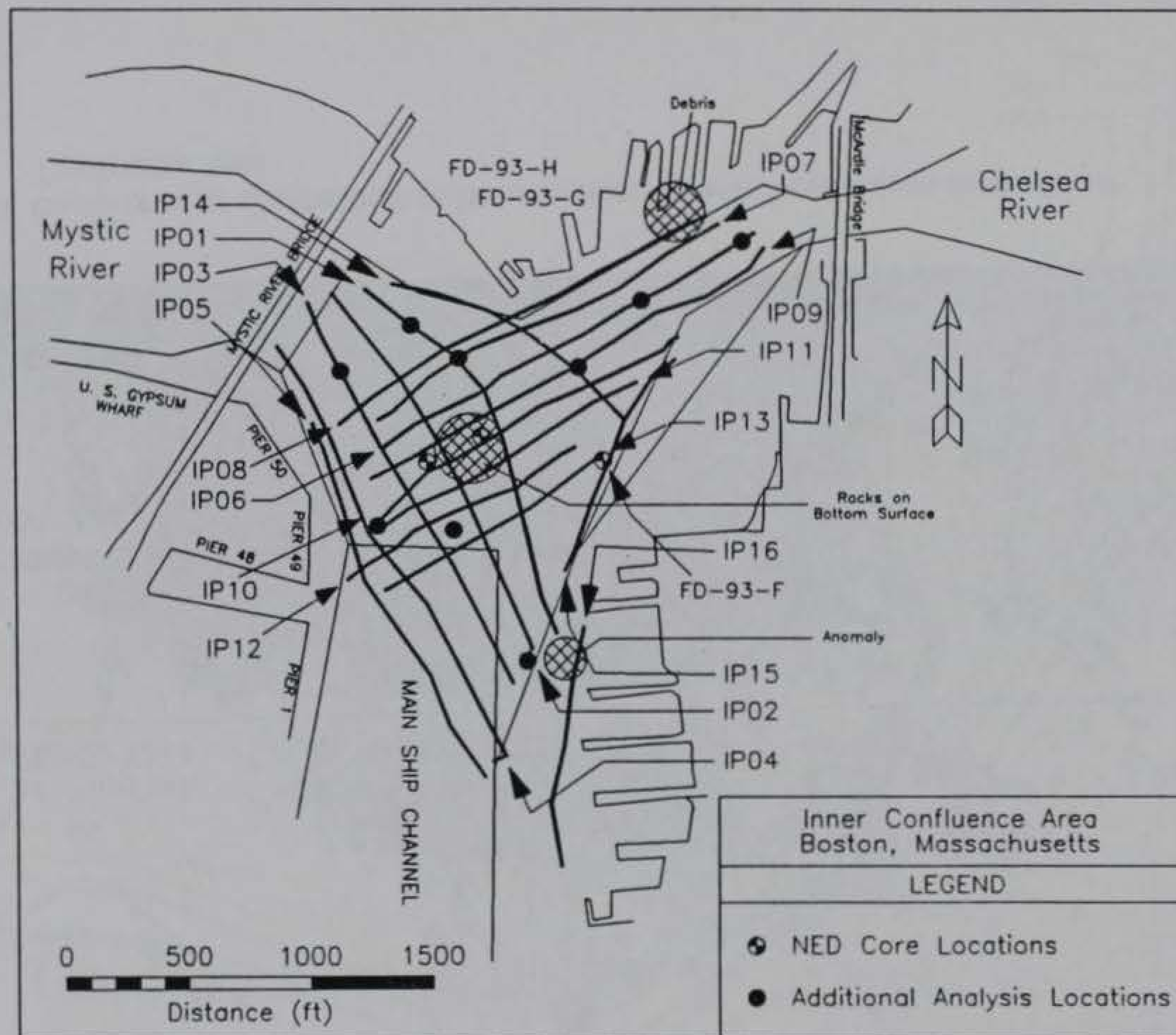

Figure 72. Site map of the Inner Confluence Area showing the locations of interpreted side scan sonar anomalies. Survey lines and core locations are also shown

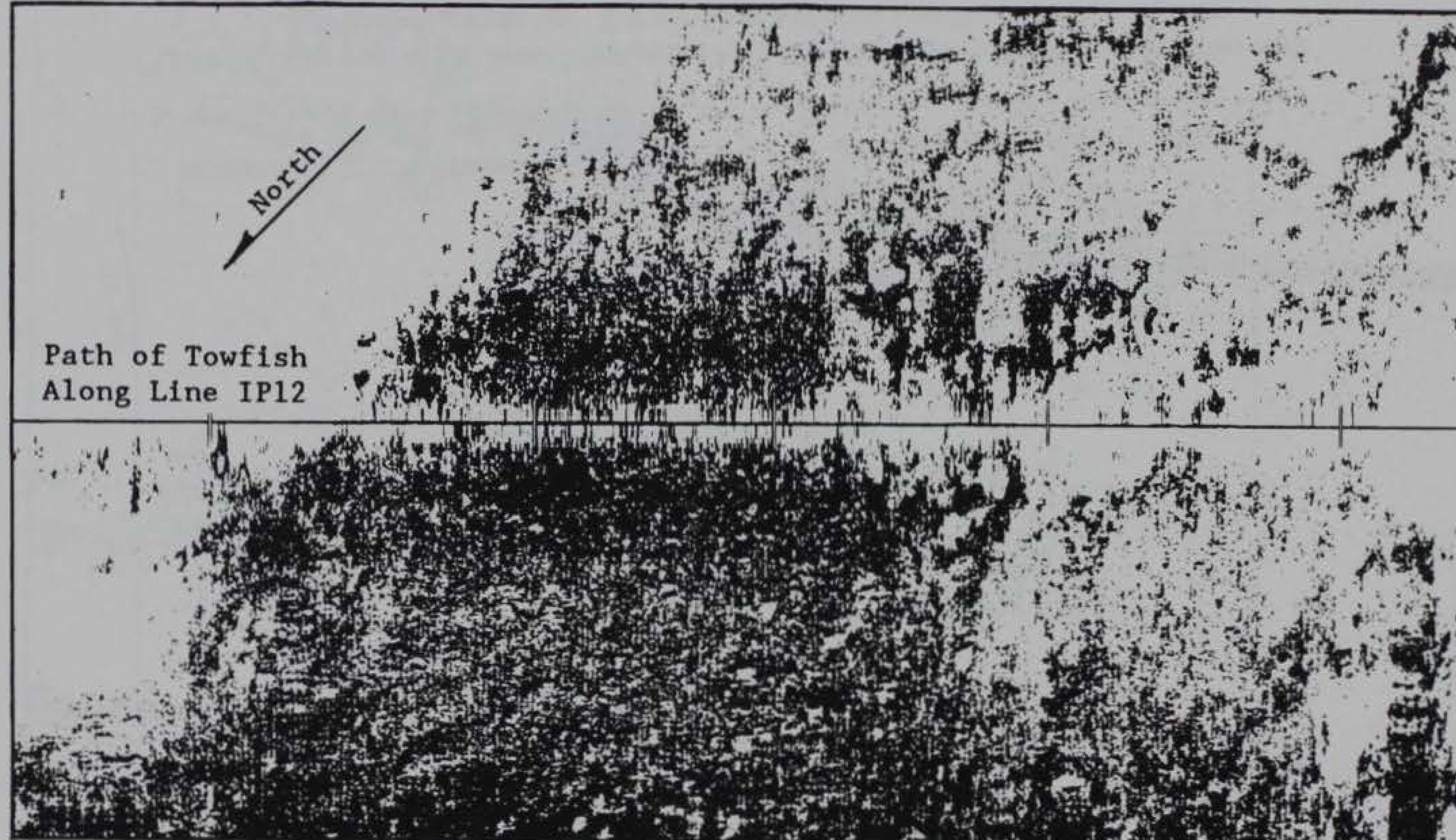

Figure 73. Rocks or other channel bottom features detected with the side scan sonar, Inner Confluence Area

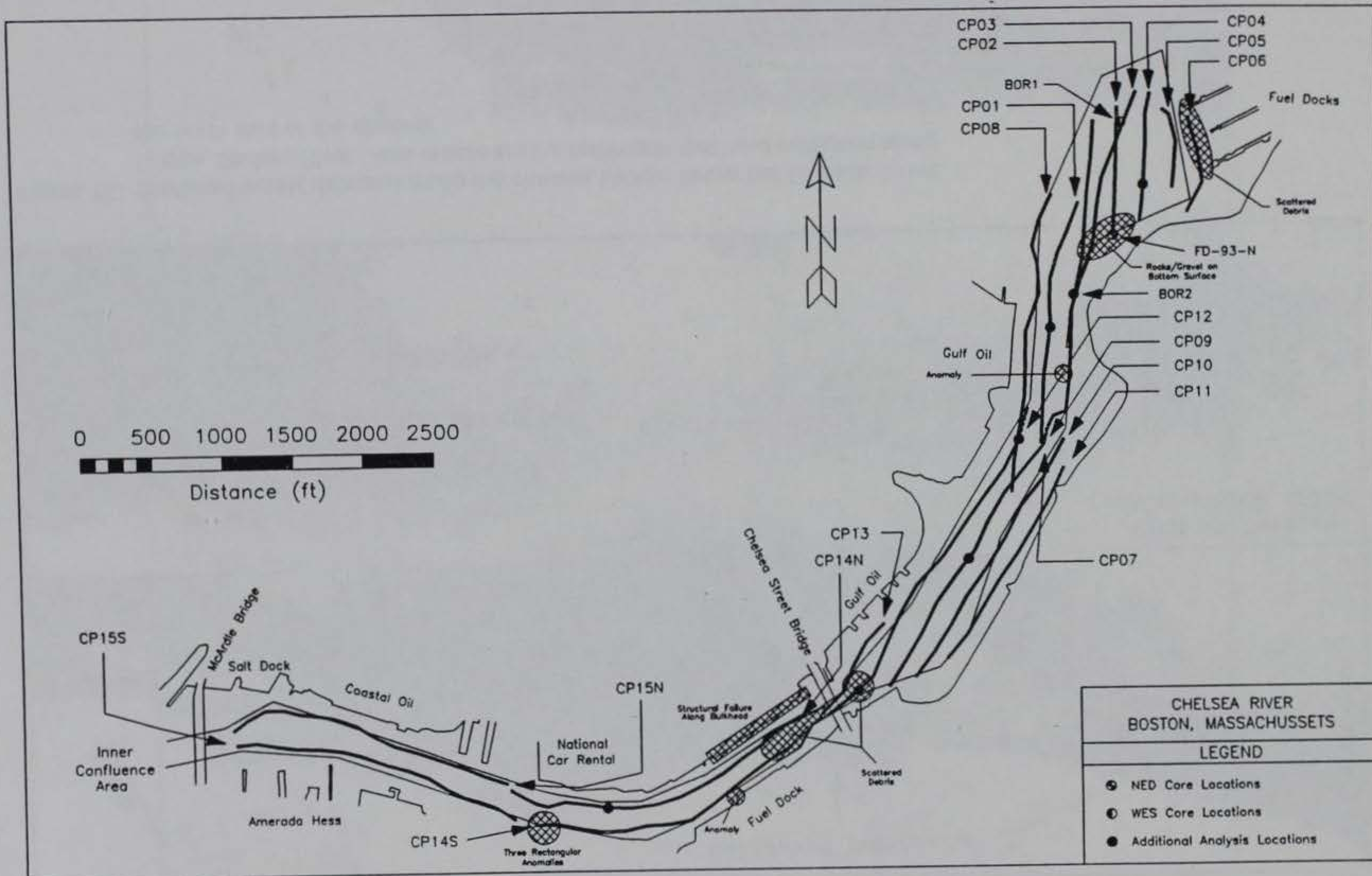

Figure 74. Site map of Chelsea River showing the locations of interpreted side scan sonar anomalies. Survey lines and core locations are also shown

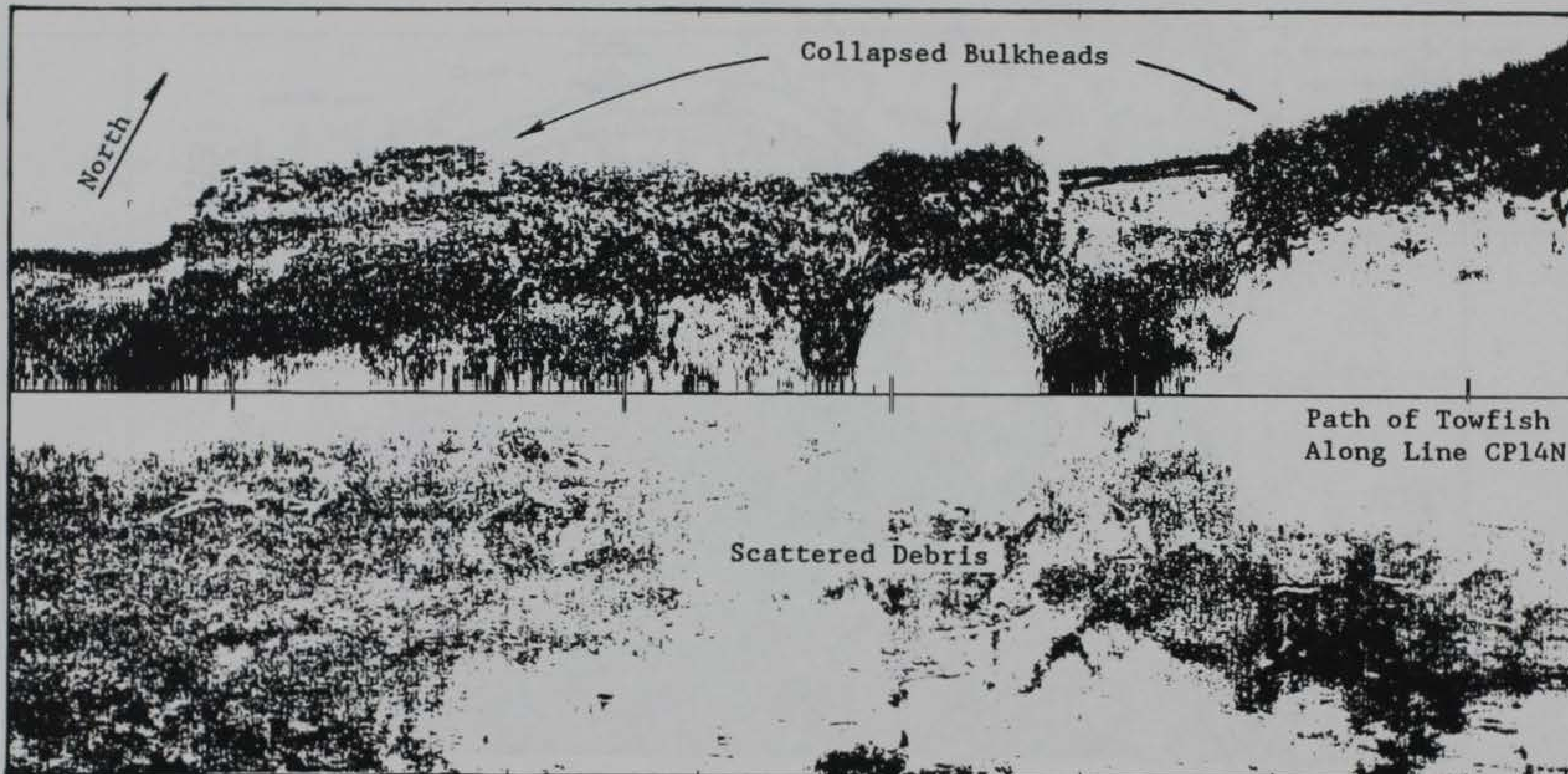

Figure 75. Scattered debris detected along the channel bottom below the Chelsea Street Bridge, Chelsea River. Also of note are the bulkheads that have collapsed along the north side of the channel

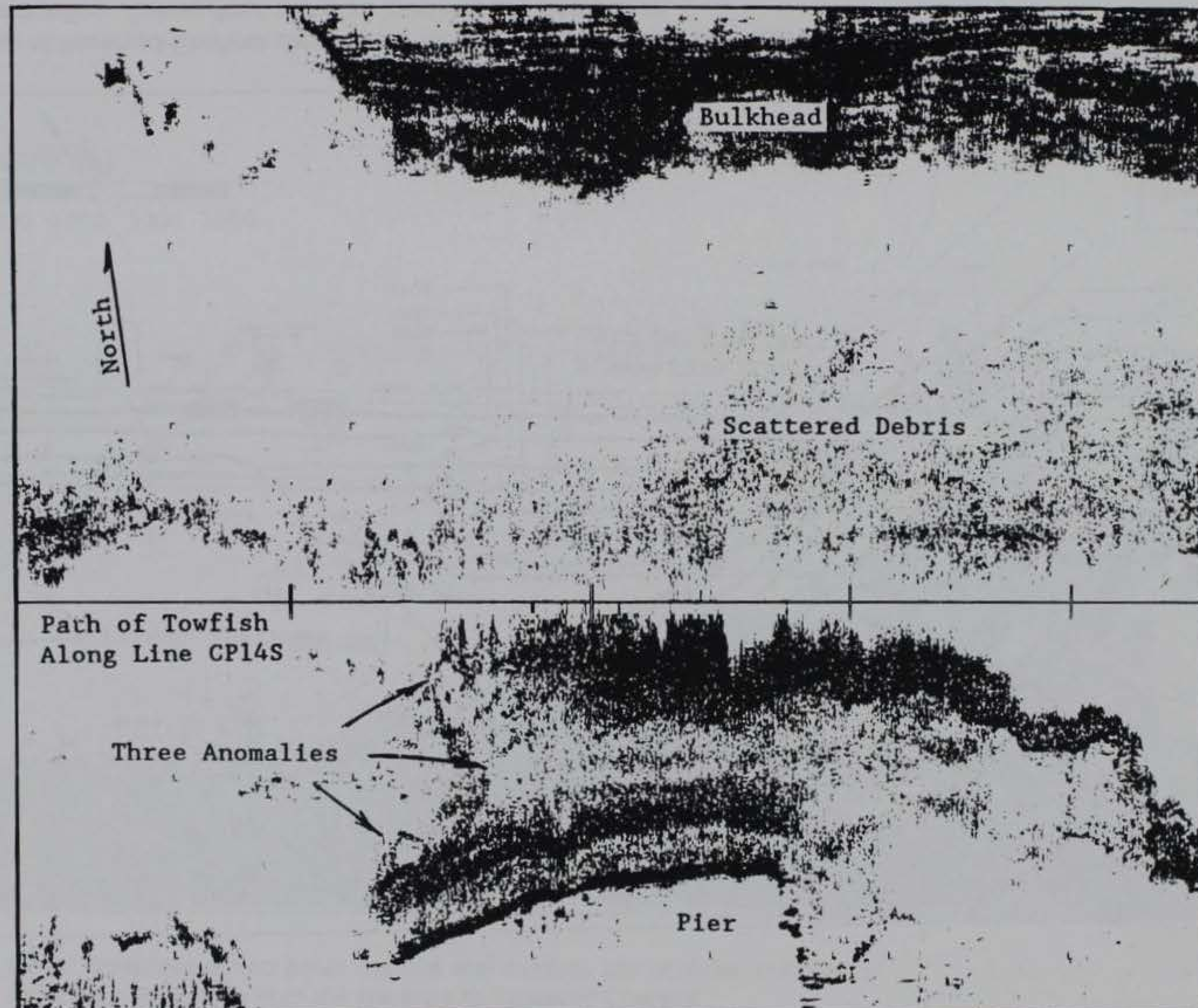

Figure 76. Sonar signatures of three anomalies, thought to be submerged vehicles, in Chelsea River

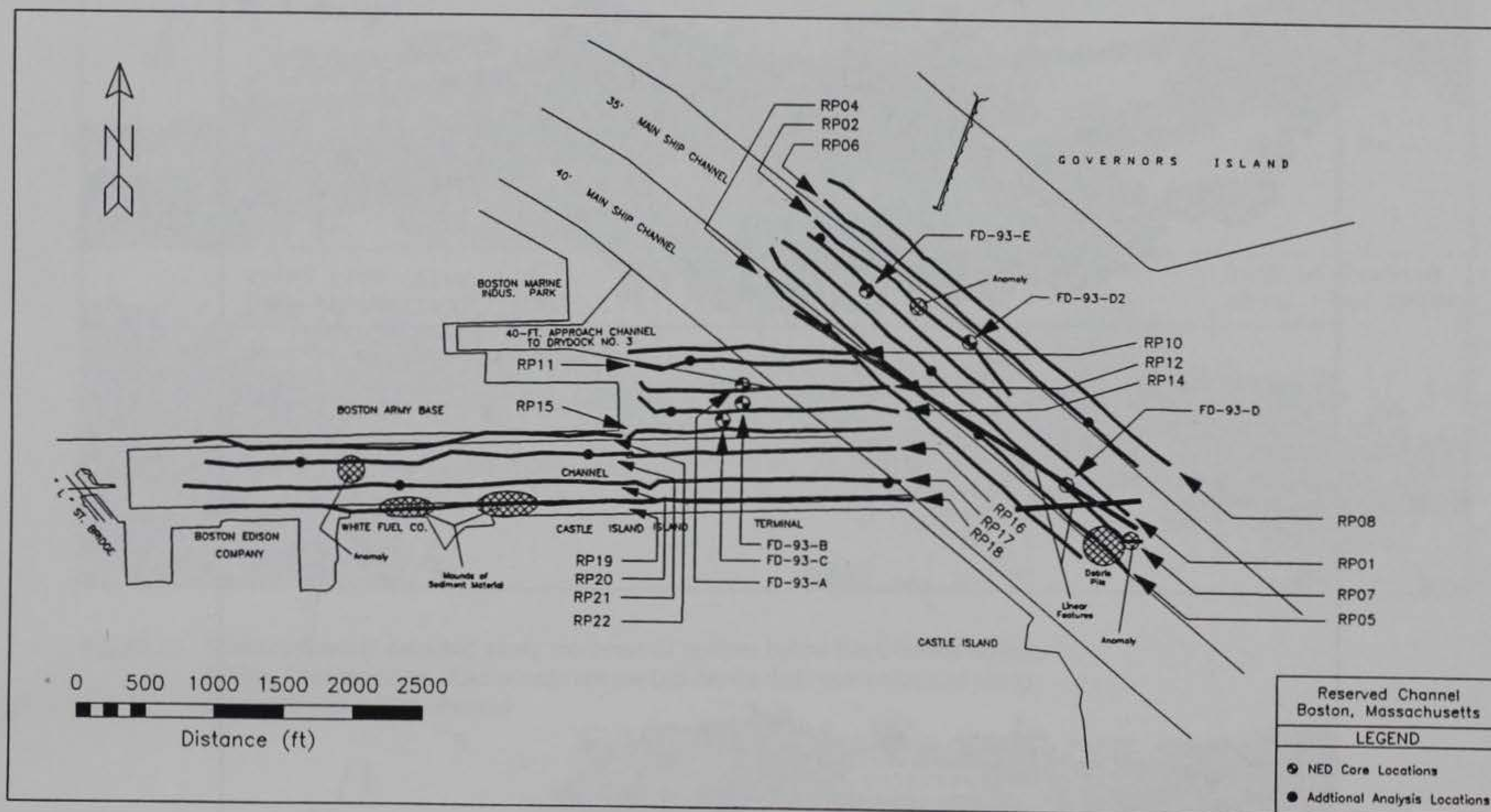

Figure 77. Site map of Reserved Channel showing the locations of interpreted side scan sonar anomalies. Survey lines and core locations are also shown

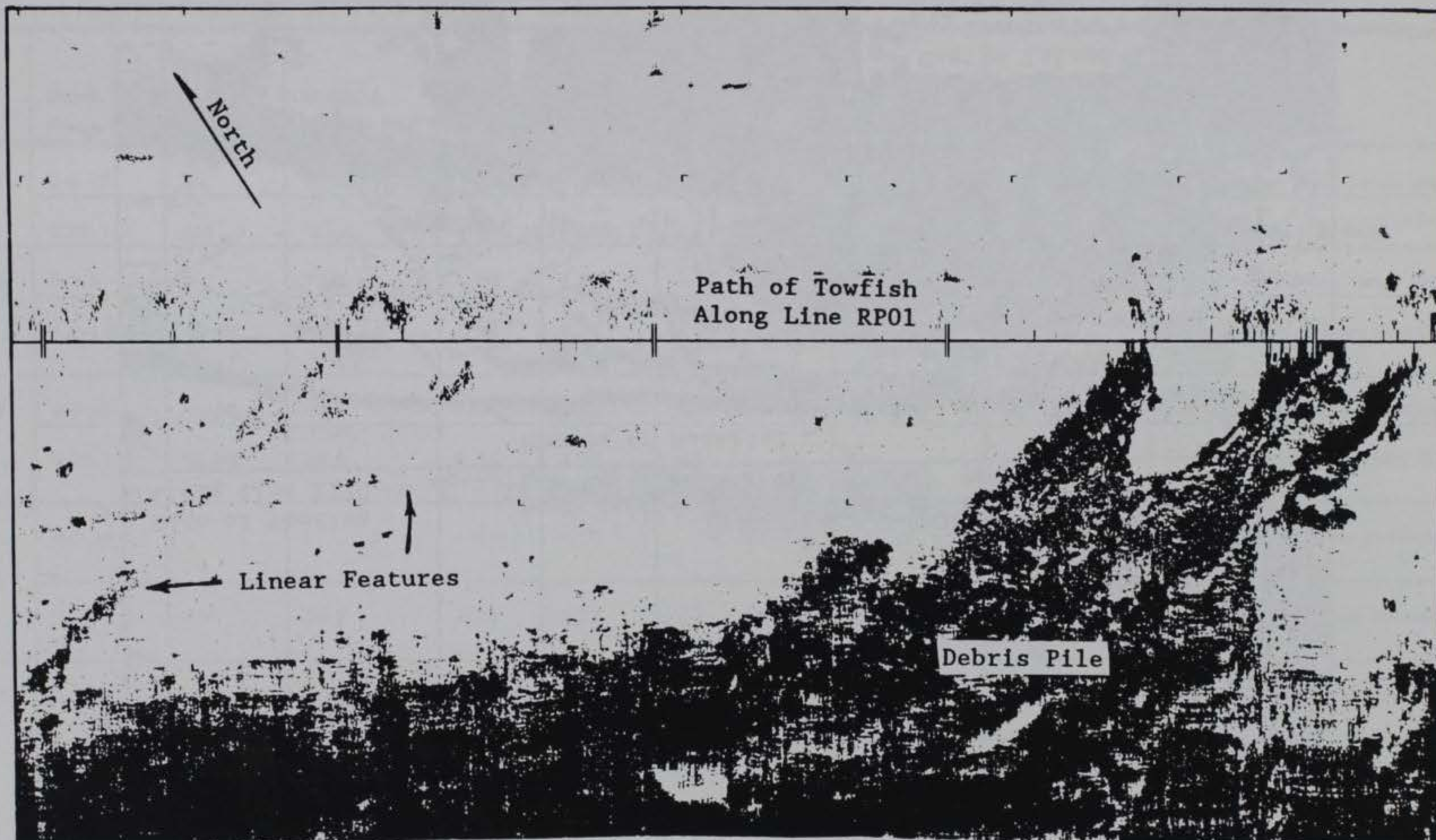

Figure 78. Sonar signatures of two linear features and a debris pile of rocks, cobbles, or other material across from the entrance to Reserved Channel

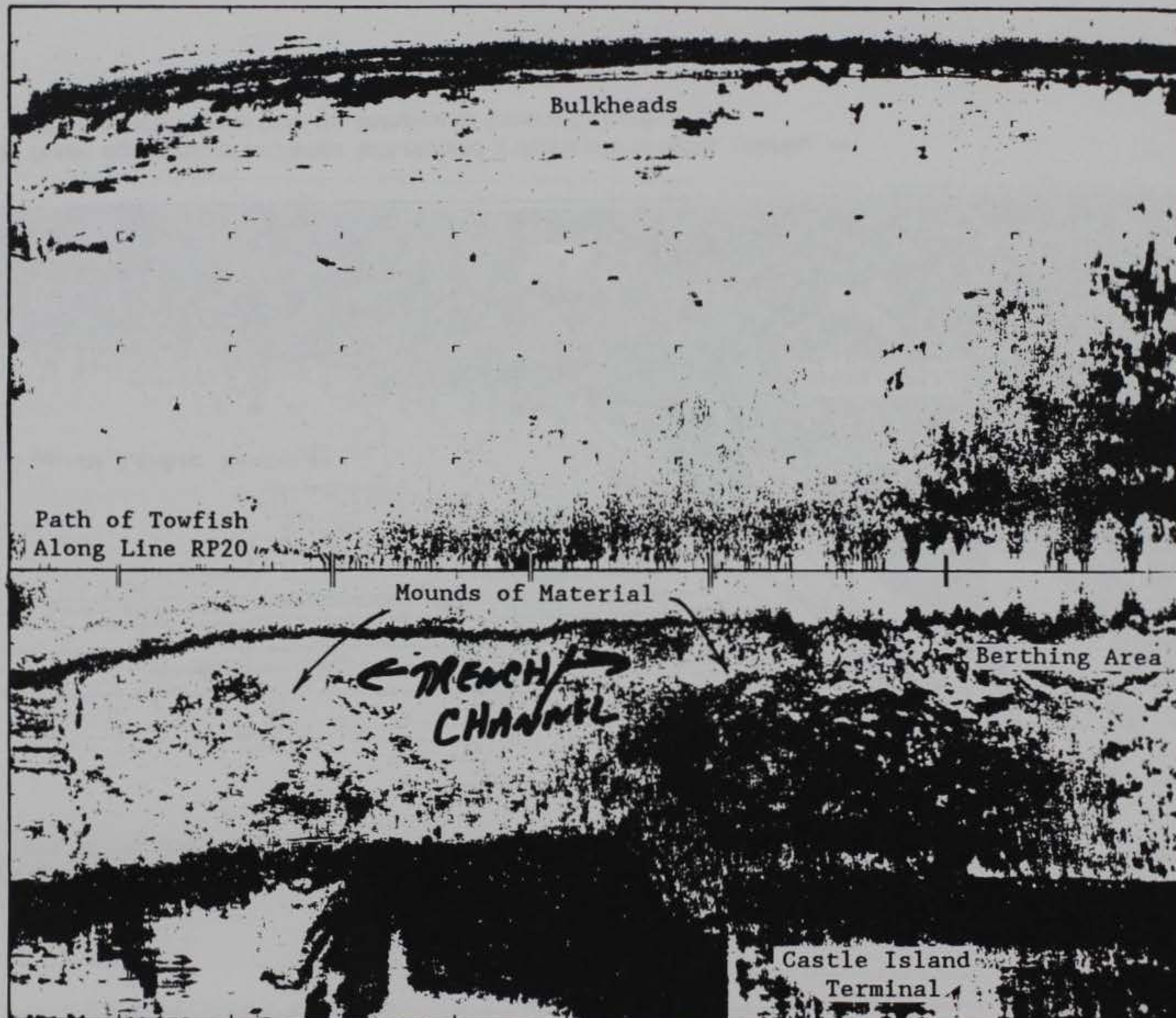

Figure 79. Two mounds of material detected in the berthing area west of the Castle Island Terminal bulkhead, Reserved Channel

Table 1
Sediment Sample Analysis, WES Cores BOR1 through BOR6

Core	Depth Range (ft)	USCS Soil Class.	Moisture Content (%)	Wet Density (g/cm^3)	Specific Gravity	Percent Gravel	Percent Sand	Percent Fines	Visual Classification
BOR1	0-0.75	ML	101.3	1.50	2.71	<1	40	60	Dark Gray to Black Sandy Silt
	0.75-1.7	SM	35.6	1.50	2.68	<1	56	34	Medium Gray Silty Sand
BOR2	0-1.6	ML	76.0	1.58	2.70	<1	36	64	Dark Gray to Black Sandy Silt
	1.6-1.9	CL-ML	12.3	1.58	2.72	<1	29	71	Light to Medium Gray Silty Clay w/Sand
BOR3	0-0.35	CL-ML	43.8	1.84	2.70	<1	46	54	Medium Gray Sandy Silty Clay
	0.35-1.6	CL-ML	38.0	1.84	2.72	<1	16	84	Light to Medium Gray Silty Clay w/Sand
BOR4	0-0.25	-	-	-	-	-	-	-	Mostly water w/Gray to Black Lean Clay
	0.25-2.0	CH	36.2	1.74	2.73	<1	26	74	Light to Medium Gray Cohesive Clay
BOR5	0-1.3	CL	107.3	1.38	2.68	<1	23	77	Dark Gray to Black Lean Clay w/Sand
	1.3-1.8	GC	-	-	-	-	-	-	Dark Gray to Black Clayey Gravel (contains 4 pieces of gravel and some clay)
BOR6	0-0.25	CL	55.3	1.82	2.70	<1	44	56	Medium Gray Sandy Lean Clay
	0.25-1.9	CL	35.4	1.82	2.73	<1	17	83	Light to Medium Gray Lean Clay w/Sand

Table 2
Density Range versus Basic Marine Sediment Description

Density Range (g/cm^3)	Sediment Description
1.0 - 1.4	Muds, Clay - Silty Clay
1.4 - 1.6	Clayey Silt - Sandy Silt
1.6 - 1.8	Clayey, Silty Sands
1.8 - 2.2	Sands (Loose or Compacted), Moderate to Stiff Clay, Glacial Till
> 2.2	Stiff Clay, Cemented Sand, Rock, Shells

Table 3
Volumetric Estimates of Marine Sediment Above Dredging Limits

Project Area	Loosely Compacted Sediment (yd^3)	Stiff, Cohesive Clay/ Sandy Material (yd^3)	Rock, Gravel, and Till Material (yd^3)	Total (yd^3)
Mystic River	105,700	530,200	14,600	650,500
Inner Confluence Area[1]	175,700	221,400	31,500	428,600
Chelsea River	185,400	234,800	0	420,200
Reserved Channel	111,900	311,100	33,500	456,500
Total (yd^3)	578,700	1,297,500	79,600	1,955,800

[1] Volumetric estimates do not include the approximate 229,400 yd^3 of sediment material to be removed during the proposed channel widening along the eastern side of the Inner Confluence Area.

Appendix A
Mystic River Positioning Information

MYSTIC RIVER, BOSTON HARBOR, MA
WES Survey Line MP01

Direction: N 82 W

File #	Easting	Northing	Elevation (ft, MLW)
050	722275	505021	-36.1
053	722089	505090	-36.2
060	721845	505135	-36.5
063	721605	505151	-38.7
070	721367	505184	-38.8
073	721126	505210	-38.6
080	720887	505255	-38.5
090	720429	505322	-37.8
093	720203	505354	-37.7
100	719974	505389	-37.1
103	719742	505415	-37.8
110	719511	505454	-38.3
113	719277	505486	-38.4
120	719049	505511	-36.5
123	718821	505558	-35.5
130	718593	505586	-36.3
133	718361	505618	-37.1
140	718139	505661	-37.0
143	717909	505688	-37.0
150	717676	505720	-36.6
153	717443	505732	-35.9
160	717204	505775	-36.0
163	716967	505835	-26.4
170	716726	505870	-27.5
173	716481	505894	-28.9

MYSTIC RIVER, BOSTON HARBOR, MA
WES Survey Line MP02

Direction: S 82 E

File #	Easting	Northing	Elevation (ft, MLW)
000	716435	506068	-34.0
003	716531	506102	-35.5
010	716759	506076	-34.9
013	716984	506027	-35.4
020	717218	505988	-35.9
023	717465	505957	-37.4
030	717702	505926	-38.2
033	717938	505884	-39.9
040	718182	505848	-38.3
043	718438	505824	-37.6

MYSTIC RIVER, BOSTON HARBOR, MA
WES Survey Line MP02 (cont.)

Direction: S 82 E

File #	Easting	Northing	Elevation (ft, MLW)
050	718674	505782	-36.4
053	718900	505752	-38.4
060	719148	505708	-37.1
063	719409	505674	-37.5
070	719646	505638	-38.9
073	719881	505600	-38.0
080	720108	505575	-37.7
083	720328	505521	-37.3
090	720561	505489	-37.3
093	720798	505453	-37.8
100	721045	505410	-34.9
103	721286	505388	-36.8
110	721521	505358	-37.2
113	721766	505317	-37.5
120	722000	505276	-37.2

MYSTIC RIVER, BOSTON HARBOR, MA
WES Survey Line MP03

Direction: S 82 E

File #	Easting	Northing	Elevation (ft, MLW)
003	716335	506272	-35.5
010	716530	506284	-35.4
013	716737	506277	-35.8
020	716936	506243	-35.5
023	717152	506174	-35.0
030	717361	506124	-38.5
033	717599	506120	-39.1
040	717790	506112	-39.4
043	717985	506146	-39.3
050	718174	506043	-37.4
053	718371	505987	-37.1
060	718607	505961	-38.9
063	718784	505925	-37.4
070	718986	505912	-37.0
073	719180	505891	-38.3
080	719381	505878	-37.0
083	719576	505842	-38.3
090	719771	505795	-39.5
093	719953	505742	-39.3
100	720123	505698	-36.1
103	720301	505631	-37.7

MYSTIC RIVER, BOSTON HARBOR, MA
WES Survey Line MP04

Direction: N 82 W

File #	Easting	Northing	Elevation (ft, MLW)
000	719964	505829	-38.4
003	719775	505917	-43.9
010	719571	505962	-42.7
013	719351	506005	-40.7
020	719149	506056	-41.1
023	718933	506092	-38.0
030	718715	506065	-36.0
033	718508	506062	-36.2
040	718302	506087	-37.0
043	718095	506125	-37.5
050	717893	506161	-37.9
053	717697	506208	-38.7
060	717530	506306	-41.7
063	717317	506351	-38.8
070	717109	506375	-34.4
073	716937	506380	-35.9
080	716751	506439	-36.5
083	716547	506475	-35.2
090	716359	506499	-35.6
093	716359	506499	-35.6

MYSTIC RIVER, BOSTON HARBOR, MA
WES Survey Line MP05

Direction: S 82 E

File #	Easting	Northing	Elevation (ft, MLW)
000	717165	506166	-38.1
003	717298	506114	-38.4
010	717435	506061	-38.6
013	717645	506047	-37.6
020	717868	506010	-39.1
023	718081	505974	-39.9
030	718257	505927	-38.0
033	718484	505912	-36.6
040	718701	505873	-37.4
043	718910	505844	-36.7
050	719118	505813	-37.2
053	719327	505782	-37.6
060	719538	505754	-38.7
063	719752	505722	-39.5

MYSTIC RIVER, BOSTON HARBOR, MA
WES Survey Line MP06

Direction: N 82 W

File #	Easting	Northing	Elevation (ft, MLW)
000	720037	505494	-39.2
003	720096	505446	-39.1
010	719940	505526	-38.3
013	719738	505533	-38.1
020	719543	505555	-38.7
023	719343	505571	-38.7
030	719143	505614	-37.1
033	718948	505637	-37.5
040	718752	505663	-36.3
043	718542	505700	-37.5
050	718336	505730	-38.3
053	718133	505761	-37.2
060	717928	505800	-38.4
063	717715	505856	-36.9

MYSTIC RIVER, BOSTON HARBOR, MA
WES Survey Line MP07

Direction: N 82 W

File #	Easting	Northing	Elevation (ft, MLW)
000	722112	504859	-39.7
003	721903	504915	-37.6
010	721658	504937	-38.5
013	721413	504963	-39.5
020	721167	505006	-38.4
023	720923	505042	-38.6
030	720679	505081	-38.3
033	720448	505104	-39.5
040	720226	505141	-39.5
043	720004	505183	-38.4
050	719752	505211	-39.2
053	719526	505240	-40.3
060	719294	505283	-39.4
063	719044	505323	-36.6
070	718808	505357	-36.9
073	718572	505378	-36.7
080	718328	505426	-36.7
083	718089	505468	-36.7
090	717842	505506	-37.1
093	717594	505527	-39.2

MYSTIC RIVER, BOSTON HARBOR, MA
WES Survey Line MP08

Direction: S 82 E

File #	Easting	Northing	Elevation (ft, MLW)
000	717658	505317	-36.5
003	717871	505279	-35.7
010	718087	505274	-36.5
013	718315	505230	-36.3
020	718540	505185	-35.4
023	718767	505164	-34.7
030	719001	505130	-37.1
033	719224	505096	-36.1
040	719452	505065	-38.1
043	719677	505025	-37.6
050	719906	504983	-36.8
053	720132	504946	-41.4
060	720320	504944	-39.0
063	720527	504902	-39.2
070	720751	504865	-39.3
073	720988	504840	-40.3
080	721209	504799	-40.9
083	721430	504764	-35.0
090	721652	504743	-37.7
093	721875	504711	-25.0

MYSTIC RIVER, BOSTON HARBOR, MA
WES Survey Line MP09

Direction: N 82 W

File #	Easting	Northing	Elevation (ft, MLW)
000	720605	504869	-38.2
003	720413	504877	-40.4
010	720202	504855	-42.2
013	720014	504838	-39.2
020	719819	504859	-37.9
023	719623	504883	-36.1
030	719416	504914	-37.6
033	719217	504936	-36.7
040	719013	504959	-35.8
043	718811	504986	-33.8
050	718632	504991	-33.5
053	718395	505040	-34.0
060	718195	505083	-34.6
063	717996	505110	-35.9
070	717798	505137	-37.3
073	717605	505163	-38.1

Appendix B
Inner Confluence Area Positioning Information

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP01

Direction: S 35 E

File#	Easting	Northing	Elevation (ft, MLW)
000	722453	504954	-36.0
003	722592	504818	-38.4
010	722756	504703	-37.4
013	722887	504552	-37.2
020	722963	504350	-38.2
023	723025	504160	-37.1
030	723063	503934	-37.6
033	723114	503707	-35.0
040	723178	503553	-35.7
043	723178	503553	-35.7

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP02

Direction: N 30 W

File#	Easting	Northing	Elevation (ft, MLW)
000	723096	503471	-36.4
003	723038	503428	-37.4
010	722981	503643	-40.2
013	722885	503884	-44.3
020	722745	504090	-39.8
023	722624	504330	-39.8
030	722535	504578	-40.5
033	722368	504772	-41.7
040	722248	504994	-36.5
043	722234	505008	-36.9

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP03

Direction: S 30 E

File#	Easting	Northing	Elevation (ft, MLW)
000	722191	504942	-39.2
003	722172	504913	-40.2
010	722225	504780	-41.0
013	722345	504553	-39.7
020	722467	504320	-38.8
023	722604	504089	-39.8
030	722764	503827	-43.4
033	722892	503573	-43.8
040	723003	503350	-38.9
043	723003	503350	-38.9

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP04

Direction: N 60 W

File#	Easting	Northing	Elevation (ft, MLW)
000	722973	503053	-40.2
003	722917	503031	-42.8
010	722873	503242	-43.9
013	722765	503456	-42.4
020	722652	503676	-43.1
023	722530	503904	-41.8
030	722404	504134	-36.9
033	722267	504348	-38.8
040	722157	504567	-35.5
043	722048	504734	-38.2

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP05

Direction: S 25 E

File#	Easting	Northing	Elevation (ft, MLW)
000	722194	504405	-37.8
003	722233	504318	-37.7
010	722303	504099	-34.2
013	722415	503845	-39.6
020	722515	503599	-43.2
023	722665	503387	-43.6
030	722746	503176	-42.4
033	722890	502961	-42.8

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP06

Direction: N 60 E

File#	Easting	Northing	Elevation (ft, MLW)
010	722477	504318	-40.7
013	722616	504418	-39.9
020	722788	504502	-38.3
023	722954	504611	-37.2
030	723127	504703	-41.5
033	723298	504787	-40.1
040	723461	504885	-40.0
043	723648	504984	-40.0
050	723816	505087	-41.3
053	723990	505193	-40.6

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP07

Direction: S 60 W

File#	Easting	Northing	Elevation (ft, MLW)
000	723839	505232	-35.5
003	723782	505195	-34.8
010	723635	505111	-36.9
013	723434	504967	-37.8
020	723254	504883	-35.5
023	723039	504801	-40.5
030	722842	504724	-37.4
033	722664	504601	-39.0
040	722518	504466	-40.2
043	722455	504430	-39.6

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP08

Direction: N 30 E

File#	Easting	Northing	Elevation (ft, MLW)
000	722299	504412	-37.3
003	722303	504431	-38.0
010	722439	504524	-41.2
013	722586	504624	-39.7
020	722732	504721	-37.4
023	722889	504799	-38.2
030	723048	504876	-37.9
033	723208	504950	-33.1
040	723348	505032	-33.8
043	723494	505105	-33.7
050	723646	505194	-34.2
053	723791	505262	-34.4

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP09

Direction: S 60 W

File#	Easting	Northing	Elevation (ft, MLW)
000	724024	505135	-35.6
003	723963	505046	-34.5
010	723787	504936	-36.5
013	723586	504870	-37.8
020	723423	504761	-37.5
023	723232	504633	-40.3
030	723011	504520	-39.8
033	722794	504399	-38.6
040	722596	504279	-40.4
043	722429	504195	-38.3

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP10

Direction: N 60 E

File#	Easting	Northing	Elevation (ft, MLW)
000	722417	503966	-39.5
003	722439	503969	-39.2
010	722528	504086	-39.2
013	722654	504217	-41.2
020	722787	504281	-39.9
023	722946	504380	-38.2
030	723109	504484	-38.0
033	723242	504541	-38.2
040	723386	504607	-35.2
043	723538	504679	-33.0
050	723678	504776	-19.5
053	723678	504776	-19.5

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP11

Direction: S 60 W

File#	Easting	Northing	Elevation (ft, MLW)
000	723642	504750	-28.7
003	723616	504719	-32.0
010	723509	504587	-32.3
013	723329	504502	-36.3
020	723141	504382	-38.4
023	722960	504262	-38.0
030	722777	504153	-39.9
033	722584	504071	-39.3
040	722402	503993	-37.2
043	722402	503993	-37.2

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP12

Direction: N 60 E

File#	Easting	Northing	Elevation (ft, MLW)
000	722330	503777	-39.9
003	722400	503771	-41.5
010	722501	503860	-43.7
013	722603	503980	-38.1
020	722752	504050	-39.5
023	722916	504120	-37.9
030	723066	504197	-37.6
033	723197	504291	-37.1

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP13

Direction: S 60 W

File#	Easting	Northing	Elevation (ft, MLW)
000	723252	504206	-35.2
003	723121	504104	-36.5
010	722912	504045	-39.1
013	722687	503949	-39.6
020	722473	503837	-41.2
023	722368	503749	-37.5

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP14

Direction: S 60 E

File#	Easting	Northing	Elevation (ft, MLW)
050	722493	505032	-36.2
053	722687	504950	-36.8
060	722909	504890	-38.0
063	723092	504763	-41.3
070	723267	504645	-39.8
073	723382	504526	-35.7

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP15

Direction: N 25 E

File#	Easting	Northing	Elevation (ft, MLW)
000	723210	503812	-34.7
003	723250	503891	-35.7
010	723325	504104	-34.0
013	723394	504264	-27.8
020	723456	504431	-32.3
023	723559	504590	-32.8

INNER CONFLUENCE AREA, BOSTON HARBOR, MA
WES Survey Line IP16

Direction: S 10 W

File#	Easting	Northing	Elevation (ft, MLW)
050	723288	503583	-30.2
053	723239	503348	-35.2
060	723207	503095	-36.0
063	723153	502856	-35.6
070	723195	502600	-35.2
073	723195	502600	-35.2

Appendix C
Chelsea River Positioning Information

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP01

Direction: S 10 W

File#	Easting	Northing	Elevation (ft. MLW)
013	730614	509050	-39.3
020	730533	508839	-39.6
023	730465	508692	-37.6
030	730414	508507	-38.7
033	730408	508342	-38.1
040	730412	508174	-38.0
043	730389	507998	-38.6
050	730358	507819	-38.6
053	730354	507656	-38.5
060	730353	507479	-39.5
063	730333	507303	-36.5

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP02

Direction: N 08 E

File#	Easting	Northing	Elevation (ft. MLW)
000	730383	507439	-37.1
003	730422	507537	-38.5
010	730481	507756	-41.0
013	730531	508020	-38.6
020	730560	508272	-35.4
023	730629	508524	-37.3
030	730718	508764	-38.1
033	730745	509015	-38.8
040	730780	509223	-39.9
043	730780	509223	-39.9

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP03

Direction: S 05 W

File#	Easting	Northing	Elevation (ft, MLW)
000	731155	509910	-37.9
003	731031	509827	-38.0
010	730890	509693	-37.0
013	730874	509458	-38.9
020	730879	509259	-40.2
023	730869	509055	-39.3
030	730858	508847	-38.5
033	730858	508847	-38.5

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP04

Direction: S 05 W

File#	Easting	Northing	Elevation (ft, MLW)
000	731118	509821	-38.1
003	731085	509672	-37.7
010	731089	509460	-38.8
013	731077	509243	-37.7
020	731062	509035	-38.7
023	731044	508912	-36.1

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP05

Direction: S 10 E

File#	Easting	Northing	Elevation (ft, MLW)
000	731202	509707	-37.3
003	731259	509665	-39.0
010	731305	509476	-39.6
013	731290	509258	-37.8
020	731278	509146	-38.9
023	731278	509146	-38.9

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP06

Direction: South

File#	Easting	Northing	Elevation (ft, MLW)
000	731387	509649	-19.5
003	731461	509401	-32.7
010	731490	509186	-39.9
013	731383	508976	-39.1

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP07

Direction: S 08 W

File#	Easting	Northing	Elevation (ft, MLW)
000	730962	509684	-37.0
003	730888	509726	-36.2
010	730721	509626	-36.4
013	730703	509367	-40.5
020	730676	509134	-38.8
023	730658	508900	-39.2
030	730641	508669	-38.8
033	730597	508464	-35.3
040	730564	508249	-38.2
043	730556	508025	-38.7
050	730541	507804	-38.2
053	730518	507575	-37.7
060	730499	507372	-36.6
063	730499	507372	-36.6

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP08

Direction: S 08 W

File#	Easting	Northing	Elevation (ft, MLW)
053	730424	509114	-34.7
060	730331	508921	-19.1
063	730287	508747	-1.5
070	730320	508608	-5.2
073	730334	508406	-32.3

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP08 (cont.)

Direction: S 08 W

File#	Easting	Northing	Elevation (ft, MLW)
080	730235	508134	-35.4
083	730228	507909	-35.7
090	730223	507685	-36.3
093	730182	507458	-35.5
100	730141	507219	-40.0
103	730128	506985	-39.1

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP09

Direction: S 33 W

File#	Easting	Northing	Elevation (ft, MLW)
000	730337	507339	-35.8
003	730213	507161	-40.4
010	730071	506985	-37.6
013	729956	506782	-38.8
020	729866	506580	-39.8
023	729728	506399	-40.7
030	729593	506212	-40.8
033	729488	505999	-40.3
040	729371	505802	-40.1
043	729247	505606	-39.6

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP10

Direction: S 31 W

File#	Easting	Northing	Elevation (ft, MLW)
000	730357	507336	-35.6
003	730433	507302	-37.3
010	730346	507091	-38.6
013	730190	506897	-37.6
020	730080	506670	-38.9
023	729946	506456	-35.7
030	729803	506255	-35.5
033	729689	506042	-37.2
040	729565	505850	-39.5
043	729436	505675	-37.1

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP11

Direction: S 33 W

File#	Easting	Northing	Elevation (ft, MLW)
000	730476	507389	-36.4
003	730496	507164	-6.1
010	730383	506921	-0.8
013	730268	506730	-4.2
020	730153	506541	-4.2
023	730024	506357	-12.6
030	729914	506167	-34.7
033	729804	505979	-36.6
040	729662	505802	-37.3
043	729662	505802	-37.3

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP12

Direction: S 35 W

File#	Easting	Northing	Elevation (ft, MLW)
000	730184	507448	-38.8
003	730242	507594	-39.3
010	730179	507368	-40.1
013	730077	507166	-37.9
020	729930	506964	-33.9
023	729783	506749	-31.6
030	729641	506538	-31.1
033	729447	506334	-42.1
040	729322	506120	-40.4
043	729222	505888	-39.0
050	729130	505679	-39.2
053	728973	505531	-35.7
060	728798	505401	-36.4
063	728627	505363	-37.2

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP13

Direction: S 30 W

File#	Easting	Northing	Elevation (ft, MLW)
000	729327	506118	-40.4
003	729215	506064	-41.6
010	729088	505928	-42.2
013	728987	505751	-29.3
020	728925	505574	-30.3
023	728764	505414	-36.6

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP14N (North Toe of Channel)

Direction: Towards McArdle Bridge

File#	Easting	Northing	Elevation (ft, MLW)
000	728643	505391	-36.7
003	728643	505391	-36.7
010	728461	505273	-36.1
013	728326	505153	-33.5
020	728176	505051	-33.7
023	728041	504944	-34.0
030	727888	504858	-30.3
033	727730	504778	-34.7
040	727565	504727	-32.7
043	727395	504706	-33.8
050	727226	504712	-35.9
053	727077	504734	-33.1
060	726910	504752	-37.6
063	726782	504722	-30.8
070	726699	504743	-29.8
073	726613	504791	-27.6
080	726529	504839	-25.4
083	726554	504934	-20.0

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP14S (South Toe of Channel)

Direction: Towards McArdle Bridge

File#	Easting	Northing	Elevation (ft, MLW)
100	728407	505294	-38.7
103	728642	505316	-40.9
110	728557	505132	-34.2
113	728420	505052	-41.4
120	728290	504956	-39.6
123	728155	504849	-39.6
130	728018	504737	-38.6
133	727857	504623	-38.1
140	727698	504593	-37.7
143	727538	504586	-38.4
150	727378	504553	-37.1
153	727218	504547	-37.6
160	727057	504570	-36.8
163	726893	504608	-38.8
170	726740	504605	-38.7
173	726740	504605	-38.7

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP15N (North Toe of Channel)

Direction: Towards McArdle Bridge

File#	Easting	Northing	Elevation (ft, MLW)

Positioning Data Unavailable

CHELSEA RIVER, BOSTON HARBOR, MA
WES Survey Line CP15S (South Toe of Channel)

Direction: Towards Chelsea Street Bridge

File#	Easting	Northing	Elevation (ft, MLW)

Positioning Data Unavailable

Appendix D
Reserved Channel Positioning Information

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP01

Direction: N 50 W

File#	Easting	Northing	Elevation (ft, MLW)
003	732779	489325	-37.2
010	732607	489470	-36.2
013	732450	489612	-36.7
020	732284	489751	-36.1
023	732131	489880	-35.6
030	732003	489991	-37.8
033	731770	490214	-38.6
040	731620	490323	-38.2
043	731437	490487	-37.4
050	731265	490637	-38.7
053	731103	490780	-41.1
060	730937	490920	-37.6
063	730775	491078	-37.6
070	730590	491237	-35.7
073	730465	491325	-35.4
080	730473	491323	-35.3
083	730473	491323	-35.3

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP02

Direction: S 50 E

File#	Easting	Northing	Elevation (ft, MLW)
000	730555	491296	-34.5
003	730562	491294	-34.4
010	730675	491270	-35.7
013	730899	491125	-38.4
020	731098	490994	-40.3
023	731271	490809	-39.3
030	731465	490661	-36.6
033	731678	490512	-37.1
040	731790	490363	-38.2
043	731931	490182	-37.0

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP04

Direction: S 50 E

File#	Easting	Northing	Elevation (ft, MLW)
000	730164	491036	-41.7
003	730303	490869	-42.1
010	730488	490735	-42.4
013	730672	490602	-41.9
020	730830	490434	-41.5
023	730995	490263	-42.1
030	731184	490121	-43.1
033	731359	489946	-43.9
040	731525	489819	-43.9
043	731703	489657	-44.0
050	731882	489510	-44.4
053	732058	489335	-44.2
060	732253	489183	-44.6
063	732451	489012	-44.6

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP05

Direction: N 50 W

File#	Easting	Northing	Elevation (ft, MLW)
000	732778	488906	-42.3
003	732710	488992	-41.3
010	732548	489151	-38.8
013	732379	489280	-40.8
020	732228	489435	-39.4
023	732049	489577	-41.5
030	731887	489738	-39.7
033	731711	489891	-40.7
040	731525	490024	-40.3
043	731346	490164	-39.7
050	731169	490300	-38.9
053	731006	490421	-38.4
060	730840	490577	-38.3
063	730674	490699	-38.4
070	730512	490775	-37.0
073	730364	490768	-37.5
080	730215	490673	-35.8
083	730215	490673	-35.8

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP06

Direction: S 50 E

File#	Easting	Northing	Elevation (ft, MLW)
000	730486	491346	-34.1
003	730518	491420	-33.9
010	730550	491492	-33.8
013	730582	491566	-33.6
020	730770	491479	-31.9
023	730899	491326	-32.8
030	731069	491207	-33.4
033	731247	491031	-37.0
040	731415	490907	-35.1
043	731586	490743	-34.3
050	731765	490596	-37.1
053	731961	490445	-38.2
060	732127	490284	-35.9
063	732310	490145	-33.3
070	732488	489992	-33.4
073	732669	489815	-37.0
080	732838	489679	-37.1
083	732838	489679	-37.1

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP07

Direction: N 50 W

File#	Easting	Northing	Elevation (ft, MLW)
000	732878	489138	-37.8
003	732749	489137	-38.7
010	732601	489276	-38.6
013	732444	489428	-37.9
020	732281	489566	-38.4
023	732103	489707	-38.3
030	731934	489849	-38.7
033	731769	490011	-39.4
040	731581	490147	-39.3
043	731418	490299	-38.7
050	731264	490453	-37.3
053	731064	490595	-37.6
060	730918	490745	-38.2
063	730747	490891	-38.1
070	730547	491066	-37.2
073	730385	491207	-35.7

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP08

Direction: S 50 E

File#	Easting	Northing	Elevation (ft, MLW)
110	733070	489692	-23.0
113	732932	489790	-35.9
120	732783	489911	-34.7
123	732653	490032	-34.3
130	732495	490185	-34.0
133	732333	490317	-34.2
140	732156	490455	-33.2
143	731997	490599	-18.9
150	731837	490733	-14.8
153	731683	490860	-29.0
160	731520	491008	-29.5
163	731342	491147	-34.6
170	731185	491295	-32.6
173	731011	491437	-30.9
180	730869	491574	-28.9
183	730772	491585	-29.0

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP10

Direction: West

File#	Easting	Northing	Elevation (ft, MLW)
000	730781	490471	-42.1
003	730539	490477	-42.4
010	730297	490479	-42.2
013	730048	490512	-41.1
020	729815	490485	-39.9
023	729572	490489	-36.1
030	729342	490472	-34.4
033	729189	490462	-33.7

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP11

Direction: East

File#	Easting	Northing	Elevation (ft, MLW)
000	729239	490374	-33.1
003	729427	490337	-34.7
010	729633	490404	-36.7
013	729871	490411	-38.8
020	730100	490388	-40.8
023	730328	490387	-41.8
030	730576	490410	-42.5
033	730837	490402	-41.2
040	731092	490388	-40.6
043	731252	490398	-37.3

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP12

Direction: West

File#	Easting	Northing	Elevation (ft, MLW)
000	731282	490276	-39.2
003	731289	490245	-39.7
010	731297	490213	-40.2
013	731064	490231	-42.4
020	730828	490212	-42.4
023	730583	490220	-42.6
030	730323	490218	-42.0
033	730098	490202	-39.7
040	729847	490183	-33.2
043	729584	490187	-29.2
050	729337	490183	-28.5
053	729307	490202	-28.4

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP14

Direction: West

File#	Easting	Northing	Elevation (ft, MLW)
003	731136	490050	-43.3
010	730919	490084	-41.7
013	730680	490067	-42.9
020	730450	490053	-40.8
023	730230	490051	-36.3
030	730009	490046	-33.5
033	729785	490029	-31.2
040	729558	490034	-29.1
043	729387	490028	-28.1

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP15

Direction: East

File#	Easting	Northing	Elevation (ft, MLW)
000	729252	489886	-33.3
003	729361	489891	-30.0
010	729628	489880	-31.5
013	729905	489910	-33.2
020	730199	489893	-34.1
023	730498	489908	-37.7
030	730796	489913	-43.2
033	731084	489930	-44.6

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP16

Direction: West

File#	Easting	Northing	Elevation (ft, MLW)
000	731117	489784	-45.2
003	730768	489772	-43.1
010	730540	489765	-41.6
013	730318	489753	-39.5
020	730106	489748	-41.0
023	729885	489735	-40.1
030	729666	489738	-36.0
033	729447	489718	-36.9
040	729229	489724	-37.6
043	729229	489724	-37.6

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP17

Direction: West

File#	Easting	Northing	Elevation (ft, MLW)
050	730888	489520	-43.5
053	731019	489531	-44.0
060	731147	489542	-44.5
063	731154	489548	-44.1
070	730908	489570	-39.6
073	730661	489558	-38.5
080	730421	489557	-37.8
083	730179	489547	-37.2
090	729924	489546	-38.0
093	729685	489533	-37.5
100	729422	489527	-37.7
103	729174	489509	-38.2

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP18

Direction: West

File#	Easting	Northing	Elevation (ft, MLW)
013	731243	489419	-42.0
020	731011	489423	-39.2
023	730781	489417	-37.6
030	730520	489405	-36.7
033	730323	489400	-36.0
040	730082	489399	-39.1
043	729852	489386	-39.1
050	729615	489386	-38.4
053	729375	489376	-39.9

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP19

Direction: West

File#	Easting	Northing	Elevation (ft, MLW)
003	729459	489398	-39.3
010	729260	489373	-40.4
013	729066	489381	-41.0
020	728857	489368	-39.5
023	728639	489352	-41.9
030	728433	489360	-43.7
033	728232	489350	-44.2
040	728023	489342	-42.4
043	727812	489316	-42.2
050	727616	489307	-42.4
053	727420	489296	-44.6
060	727191	489284	-36.5
063	726987	489326	-31.9
070	726783	489323	-33.5
073	726569	489318	-33.0
080	726350	489316	-33.9
083	726130	489302	-33.6

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP20

Direction: West

File#	Easting	Northing	Elevation (ft, MLW)
023	729247	489520	-40.8
030	729036	489510	-42.3
033	728824	489519	-38.8
040	728614	489518	-38.9
043	728406	489511	-39.9
050	728185	489491	-38.8
053	727961	489478	-36.7
060	727750	489475	-36.4
063	727541	489477	-38.3
070	727331	489480	-36.0
073	727110	489455	-33.0
080	726883	489450	-32.9
083	726666	489451	-33.4
090	726438	489436	-34.0
093	726207	489449	-34.5
100	725980	489455	-34.5
103	725980	489455	-34.5

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP21

Direction: West

File#	Easting	Northing	Elevation (ft, MLW)
003	729183	489703	-36.8
010	728978	489711	-36.2
013	728761	489719	-36.2
020	728566	489721	-37.3
023	728332	489694	-34.8
030	728117	489710	-35.2
033	727912	489721	-38.3
040	727679	489633	-36.0
043	727467	489639	-37.3
050	727256	489646	-33.6
053	727049	489638	-33.7
060	726823	489636	-33.9
063	726593	489627	-33.7
070	726368	489611	-34.4
073	726137	489630	-33.6

RESERVED CHANNEL, BOSTON HARBOR, MA
WES Survey Line RP22

Direction: West

File#	Easting	Northing	Elevation (ft, MLW)
000	729192	489831	-35.3
003	729149	489850	-35.4
010	728962	489866	-33.9
013	728764	489844	-33.4
020	728567	489857	-35.4
023	728362	489863	-33.0
030	728152	489863	-34.8
033	727935	489802	-35.3
040	727734	489756	-35.0
043	727534	489743	-36.4
050	727325	489744	-34.6
053	727120	489748	-34.2
060	726909	489751	-33.5
063	726680	489741	-35.9
070	726456	489728	-36.3
073	726234	489808	-35.9
080	726057	489777	-34.4
083	726057	489777	-34.4

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13. ABSTRACT *(Maximum 200 words)*

A waterborne seismic reflection and side scan sonar survey of three tributaries to Boston Harbor, Massachusetts, is reported. The geophysical studies were performed in the Mystic and Chelsea Rivers, Reserved Channel, and the Inner Confluence Area in order to characterize and quantify bottom and subbottom sediments in support of proposed channel deepening. Two high resolution subbottom profiling systems with specially designed data acquisition and analysis software packages were utilized to meet the primary project objectives. A dual frequency side scan sonar was used to provide increased bottom coverage and detect any possible dredging hazards. The survey results provide estimates of the material density and volume of materials to be removed through dredging. In addition, the information supplements previously obtained soil borings by providing continuous profile line coverage along each project area, particularly in areas of suspected rock outcroppings.

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