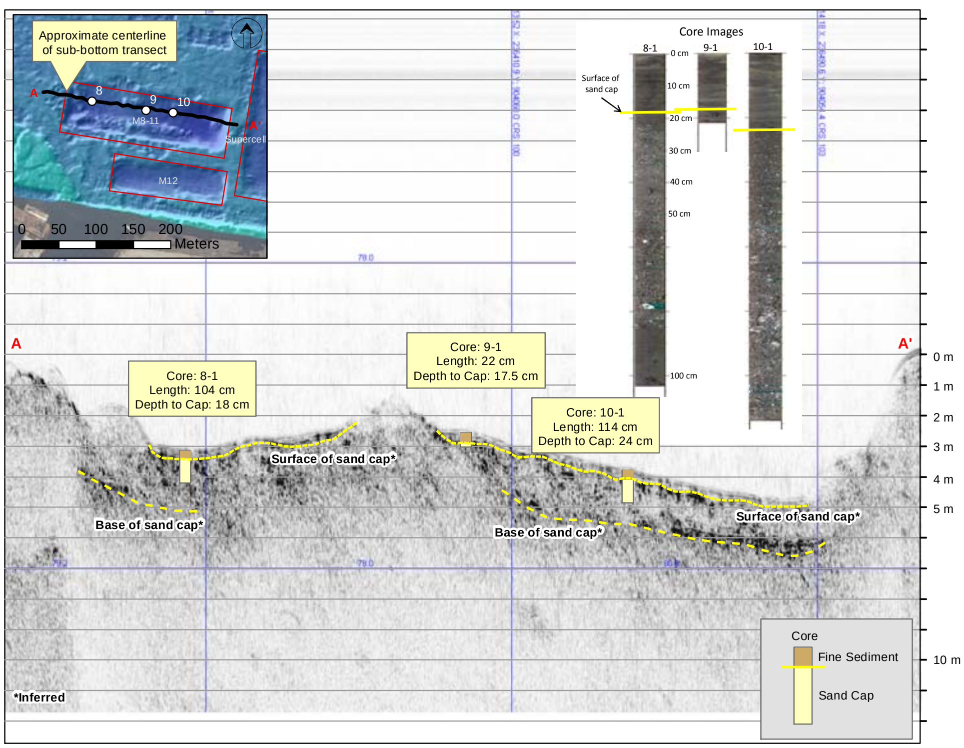
Monitoring Survey of the Boston Harbor CAD Cells
November 2009

# Disposal Area Monitoring System DAMOS




DISPOSAL AREA MONITORING SYSTEM

Contribution 186
March 2012

US Army Corps of Engineers®
New England District

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**13. ABSTRACT**

An investigation of the 11 confined aquatic disposal (CAD) cells in Boston Harbor was performed in November 2009 as part of the U.S. Army Corps of Engineers New England District Disposal Area Monitoring System (DAMOS) Program. Nine of the CAD cells were constructed beneath navigation channels as part of the Boston Harbor Navigation Improvement Project (BHNIP) from 1997–2000. Two additional cells were constructed as part of a separate dredging project in 2008. The CAD cells were created to contain dredged material deemed unsuitable for unconfined open water disposal (UDM). Completed cells were capped with a layer of sand to further isolate the UDM from the environment.

As the BHNIP marked the first major use of CAD cells in the United States, numerous studies were conducted during and following the project to assess potential impacts to water quality, to assess the effectiveness of capping, and to assess the long-term stability and benthic recovery of the CAD cells. The 2009 investigation was designed to assess the post-construction condition and performance of all 11 CAD cells for comparison with past and future surveys and to assess post-capping sedimentation rates and the depth of surficial mixing over select cells. This was achieved through a multibeam bathymetric survey of all 11 cells and the surrounding channel, a towed sub-bottom survey of three cells, and the collection of sediment cores from locations across the same three cells and adjacent reference areas.

The bathymetric data collected as part of the 2009 survey confirmed the stable topography of the older nine BHNIP cells and documented the dimensions of the two newer cells. Each of the BHNIP cells had well-defined side walls and surface features consistent with previous surveys. Comparison of the 2009 and 2004 bathymetric data did not identify any features indicative of erosional processes. The depth comparison did identify limited areas of deposition over some cells, but ongoing, long-term consolidation of material within the cells likely masked the majority of deposition expected to occur at the surface of the cells.

The data from the low disturbance cores confirmed that the sub-bottom profiling was able to accurately resolve the fine-grained deposition over coarse-grained cap layering, and deposition rates of 2.7 to 3.5 cm/yr were calculated over representative cells. The biological mixing zone, estimated by measuring the oxidized layer at the surface of sediment cores, averaged less than 2.6 cm for CAD cell and reference area stations. The shallow biological mixing documented in 2009 supported earlier findings of harbor-wide conditions limiting benthic recolonization to a state of perpetual early succession throughout the harbor. Very fine layering was also apparent at the surface of both CAD cell and reference cores further supporting the persistence of shallow sediment mixing in Boston Harbor.

The results of the 2009 survey, performed some nine to 12 years following completion of the BHNIP, identified all of the CAD cells as continued stable features on the harbor bottom. This stability, coupled with observed limited mixing of sediment at the surface of the cells, supports the effectiveness of sequestering material within the CAD cells. Further, the accelerated deposition rate over cells depressed below the surrounding harbor exceeded the observed biological mixing depth, indicating the ability of natural deposition to sequester cell material in a relatively short period of time. As the BHNIP identified that the cells required a consolidation period approaching a year in length before the sand cap could be effectively applied (during which time deposition was already occurring), the overall need for a cap, particularly one requiring non-ambient material (sand) transported over significant distances, is called into question. Rather, the specific requirements for placement of a cap over a CAD cell containing UDM should be evaluated on a case-by-case basis, taking into consideration the specific composition of the UDM as well as the physical and biological setting of the proposed CAD cell.

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An investigation of the 11 confined aquatic disposal (CAD) cells in Boston Harbor was performed in November 2009 as part of the U.S. Army Corps of Engineers New England District Disposal Area Monitoring System (DAMOS) Program. Nine of the CAD cells were constructed beneath the navigation channel in the Mystic and Chelsea Rivers and the Inner Confluence as part of the Boston Harbor Navigation Improvement Project (BHNIP) from 1997–2000. Two additional cells were constructed in the Mystic River and the Main Ship Channel of the Inner Confluence as part of a separate dredging project in 2008. The CAD cells were created to contain dredged material deemed unsuitable for unconfined open water disposal (UDM). With the exception of the Chelsea River cell, the original BHNIP cells were capped with a layer of sand to further isolate the UDM from the environment. The two newest cells were capped in early 2010, following the 2009 survey reported here.

As the BHNIP marked the first major use of CAD cells in the United States, numerous studies were conducted during and following the project to assess potential impacts to water quality, to assess the effectiveness of capping, and to assess the long-term stability and benthic recovery of the CAD cells. A 2004 investigation confirmed the stable topography and benthic recolonization (Stage 1 pioneering organisms) of the cells, consistent with previous studies and the surrounding harbor system (ENSR 2007). The 2004 survey also documented the deposition of a significant amount of fine-grained material on top of the cells' caps; however, the survey method (sediment-profile imaging) provided a limited number of point measurements over the cells and was not able to resolve the full thickness of deposition over the cap layer.

The 2009 investigation was designed to assess the post-construction condition and performance of all 11 CAD cells for comparison with past and future surveys and to assess post-capping sedimentation rates and the depth of surficial mixing over select cells. This was achieved through a multibeam bathymetric survey of all 11 cells and the surrounding channel, a towed sub-bottom survey of three cells in the Mystic River (M 8-11, M19, and the Supercell), and the collection of sediment cores from 15 locations across the same three CAD cells and reference areas in the Mystic River.

The bathymetric data collected as part of the 2009 survey confirmed the stable topography of the nine cells created during the BHNIP and documented the dimensions of the two newer cells created in 2008. Each of the BHNIP cells had well-defined side walls and surface features consistent with previous surveys. Comparison of the 2009 and 2004 bathymetric data did not identify any features indicative of erosional processes. The depth comparison did identify limited areas of deposition over some cells, but ongoing, long-term consolidation of material within

the cells likely masked the majority of deposition expected to occur at the surface of the cells.

The 2009 sediment coring and sub-bottom profiling efforts were designed to better characterize the thickness of accumulated fine material over the underlying sand caps in cells M8-11, M19, and the Supercell. These cells were selected for study because of the uniform sand layer that was identified across their surfaces at the end of BHNIP, making deposition tracking possible. The data from the low disturbance cores confirmed that the sub-bottom profiling was able to accurately resolve the fine-grained deposition over coarse-grained cap layering. Analysis of sub-bottom data indicated that cell M8-11 had accumulated an average of 0.24 m and the Supercell had accumulated an average of 0.35 m of material in the 9–10 years since capping, translating to deposition rates of 2.7 and 3.5 cm/yr, respectively. This calculated deposition rate is well in excess of a reported long term deposition rate of 0.5 cm/yr for the Mystic River, but is considered realistic given that the cells act as sediment traps depressed below the harbor bottom. Deposition of 0.65 m of material over the same time frame into cell M19 was considered inflated due to the recent excavation and filling of the Mystic River CAD cell that closely bordered two sides of cell M19.

The biological mixing zone, estimated by measuring the oxidized layer at the surface of sediment cores, averaged less than 2.6 cm for both CAD cell stations and reference cores. The shallow biological mixing documented in 2009 supported earlier findings of harbor-wide conditions limiting benthic recolonization to a state of perpetual early succession throughout the harbor. Very fine layering was also apparent at the surface of both CAD cell and reference cores further supporting the persistence of shallow sediment mixing in Boston Harbor.

The results of the 2009 survey, performed some nine to 12 years following completion of the BHNIP, identified all of the CAD cells as continued stable features on the harbor bottom. This stability coupled with observed limited mixing of sediment at the surface of the cells supports the effectiveness of sequestering material within the CAD cells. Further, the accelerated deposition rate over cells depressed below the surrounding harbor exceeded the observed biological mixing depth, indicating the ability of natural deposition to sequester cell material in a relatively short period of time. As the BHNIP identified that the cells required a consolidation period approaching a year in length before the sand cap could be effectively applied (during which time deposition was already occurring), the overall need for a cap, particularly one requiring non-ambient material transported over significant distances, is called into question. Rather, the specific requirements for placement of a cap over a CAD cell containing UDM should be evaluated on a case-by-case basis, taking into consideration specific composition of the UDM as well as the physical and biological setting of the proposed CAD cell.

# 1.0 INTRODUCTION

A monitoring survey was conducted at the eleven confined aquatic disposal (CAD) cells located in Boston Harbor, Massachusetts in November 2009 as part of the U.S. Army Corps of Engineers (USACE) New England District (NAE) Disposal Area Monitoring System (DAMOS) Program. DAMOS is a comprehensive monitoring and management program designed and conducted to address environmental concerns associated with use of aquatic disposal sites throughout the New England region. An introduction to the DAMOS Program and the Boston Harbor CAD cells, including a brief description of previous dredged material disposal activities and previous monitoring surveys, is provided below.

## 1.1 Overview of the DAMOS Program

For over 30 years, the DAMOS Program has conducted monitoring surveys at aquatic disposal sites throughout New England and evaluated the patterns of physical, chemical, and biological responses of seafloor environments to dredged material disposal activity. The DAMOS Program features a tiered disposal site management protocol designed to ensure that any potential adverse environmental impacts associated with dredged material disposal are promptly identified and addressed (Fredette and French 2004; Germano et al. 1994).

DAMOS monitoring surveys fall into two general categories. Confirmatory studies are designed to test hypotheses related to expected physical and ecological response patterns following placement of dredged material on the seafloor at established, active disposal sites. Confirmatory studies generally involve performance of bathymetric surveys to document the physical location and stability of dredged material placed into the aquatic environment and sediment-profile imaging (SPI) surveys to provide additional physical data and to evaluate the biological recovery of sites following cessation of placement activities. The data collected and evaluated during these studies provide input to help effectively manage the use of aquatic dredged material disposal sites. Focused studies are periodically undertaken within the DAMOS Program to evaluate inactive/historic disposal sites and contribute to the development and refinement of dredged material placement and capping techniques. Focused studies can incorporate a wide array of survey techniques depending on the specific objectives of the study. The investigation reported in this contribution included some confirmatory elements (providing baseline bathymetry of two recently completed CAD cells) but primarily represented a focused study of the older Boston Harbor CAD cells incorporating bathymetry, sediment coring, and sub-bottom profiling.

## 1.2 Introduction to CAD Cells

### 1.2.1 CAD Cell as an Alternative for UDM

Materials dredged during maintenance and improvement of navigation channels have limited disposal options when contaminant levels in the materials preclude unconfined open water placement. Options considered for disposal of dredged material deemed unsuitable for unconfined open water disposal (Unsuitable Dredged Material [UDM]; Fredette and French 2004) typically include upland placement, creation of shoreline/coastal confined disposal facilities, and aquatic (in water) placement followed by capping.

Upland placement can be a very costly option with not-insignificant potential impacts associated with shore-side transfer/staging, upland transportation (e.g., increased traffic and air emissions from numerous truck trips), and material handling and placement at the final disposal site. This option presents multiple potential contaminant transfer pathways including dermal contact, dust and volatile emissions, and groundwater contamination (Fredette 2006). The feasibility of upland disposal is also dependent on distance to placement sites and disposal site capacity. Treatment of sediment to remove, degrade, or stabilize contaminants can allow for reuse of material at upland sites (e.g. construction, roadbed) or allow for easier placement at disposal facilities, but treatment is generally not feasible for large volume navigation projects because of the logistics and costs associated with the additional handling and processing.

Confined disposal facilities (CDF) involve the construction of an upland, shoreline, or in-water dike system to contain dredged material that is typically hydraulically dredged and pumped into the CDF. For in-water CDFs, this ultimately creates a new upland area as an extension of the shoreline or an island. Following dewatering and capping, the CDF may be available for some light use (depending on the geotechnical properties of the consolidated dredged material) or for upland habitat creation. Given the extent of development of much of the New England coastline and concerns about losing existing aquatic habitat, CDF creation has limited applicability in the region.

Level-bottom capping is an option for aquatic disposal of UDM. This practice entails placing UDM directly on the seafloor and then covering it with a layer of material that is suitable for open-water disposal, resulting in sequestration of the unsuitable material. This option has the environmental advantage of not requiring land staging and transportation and is generally less costly than upland or CDF disposal. However, level-bottom capping in harbors is generally not feasible because of the need to maintain navigational depth requirements. Level-bottom capping in ocean waters can also face significant challenges in obtaining regulatory approval.

CAD cells are being selected as the disposal option of choice for a growing number of navigational dredging and sediment remediation projects throughout the world (USACE, MPA 1995; Whiteside et al. 1996; Shaw et al. 1998; USEPA 2000; USACE 2001, 2002; Alfageme et al. 2002; Moore et al. 2002; MPCA 2004). This technique involves placing the UDM within existing depressions or cells cut into the seafloor for containment and optionally placing a layer of cap material to further sequester the UDM. The CAD cell construction process begins with the removal of any unsuitable material over the cell footprint (Figure 1-1). This material is typically stored in barges for later placement into the cell upon completion of construction. After the footprint is uncovered, native parent material is excavated to construct the cell. Depending on the material type, the excavated parent material may have a beneficial use for beach nourishment or upland fill or may be placed at an open-water site. Following construction, UDM is placed into the cell, and the disposal operation is monitored by regular bathymetric surveys to determine remaining cell capacity. Depending on permit conditions, the cell may be allowed a period of consolidation time prior to capping with material suitable for open-water placement.

CAD cells have been used since the 1980's as a practical alternative for the placement of UDM. Factors that favor CAD cells over other options include regulatory considerations, public perceptions, relative ecological and human health risk, and cost (Driscoll et al. 2002, Fredette 2006, USACE 2001). Because CAD cells typically are located in the vicinity of the origin of the UDM, no new areas are impacted by their creation, and transportation and handling of material is minimized. CAD cells also can reduce the potential for human health and ecological risk presented by UDM by confining the material to a smaller footprint, sequestering the material more deeply beneath the sediment-water interface, and ultimately removing the UDM farther from the physical processes that can result in transport and exposure (Fredette 2006). These factors can minimize cost (compared to upland disposal) and risk, and therefore contribute to regulatory appeal and more favorable public acceptance of this option (Fredette 2006). For instance, an analysis by Driscoll et al. (2002) of disposal options for dredged sediment form New York/New Jersey Harbor determined that CAD cells presented one of the lowest ecological and human health risk options compared to other typical disposal alternatives (confined disposal facilities, landfill, treatment, and no action).

Within New England, CAD cells have been used at multiple locations, including Boston Harbor, New Bedford Harbor, and Hyannis in Massachusetts; Norwalk Harbor/River and Thames River (New London) in Connecticut; and Providence Harbor in Rhode Island. Because of their increased usage, CAD cells have been a focus of recent DAMOS investigations, with a survey of the Boston Harbor CAD cells presented in this report and a separate investigation of CAD cells in four other New England harbors (Norwalk, New London, Providence, and Hyannis) reported in USACE (2012).

### 1.2.2 Background on the Boston Harbor CAD Cells

Beginning in 1997, a total of 11 CAD cells have been constructed in Boston Harbor (Table 1-1). Nine of the cells were constructed between 1997 and 2000 in the Mystic River, the Chelsea River, and Inner Confluence at the junction of the two rivers (Figure 1-2) as part of the Boston Harbor Navigation Improvement Project (BHNIP). Two additional cells were constructed as part of a separate maintenance dredging project in 2008, with one cell in the Mystic River and one in the Inner Confluence.

The BHNIP involved maintenance and improvement dredging within a portion of Boston's inner harbor main ship channel as well as tributary channels and berths. The maintenance dredging was expected to generate approximately 800,000 $m^3$ (1,000,000 $yd^3$) of UDM. With the selection of CAD cells as the preferred disposal alternative for the UDM (USACE, MPA 1995), the BHNIP marked the first major use of CAD cells in the United States. Given the scale of the project and the innovative use of CAD cells beneath the footprint of the navigable channel, there were a number of concerns related to release of UDM during and following placement into the cells. As a result, the state-issued Water Quality Certification contained multiple conditions requiring monitoring of UDM disposal into the cells as well as capping of the cells with an approximately 1 m (3 ft) layer of well-graded sand to isolate the UDM from the overlying water column and reduce scour potential. Monitoring of other aspects of the project was also performed by a number of researchers given the novelty of the approach, and a summary of all the BHNIP related investigations is provided below in Section 1.2.3.

The BHNIP was performed in two phases between 1997 and 2000. This extended timeline allowed for review of the monitoring data and subsequent refinement of some aspects of cap placement. Because of concerns related to leaving a cell filled with UDM "open" to the water column, the initial Water Quality Certification required placement of the cap following only one to two weeks of consolidation. As the monitoring revealed no significant release of UDM, and that additional consolidation time was required for effective cap placement, the consolidation period was extended as the project progressed through four separate rounds of capping. Given the relevance to the investigation reported here, a summary of capping approach and results is provided below (from ENSR 1997, 2002):

Cell IC2 – This cell was capped in July 1997 within two weeks of completion of UDM disposal activities. Capping was performed with dry, quarry-derived sand that was released from a split-hulled scow positioned at a series of fixed locations over the cell. Post-cap investigations revealed that this technique resulted in cap coverage of variable thickness over the majority of the cell with an area in the southern portion of the cell receiving little to no cap material (SAIC 1999).

Cells M4, M5, M12 – Cells M4, M5, and M12 were capped as a group in November 1998 following 30 to 52 days of consolidation. Capping was performed with wet sand that had been hopper-dredged from the Cape Cod Canal. The sand was washed directly from the hopper dredge as its hopper was slowly opened, maneuvered over the cell under its own propulsion in a spiral pattern. Post-cap investigations revealed that the sand had been well distributed over the cell, but that mixing with the cell contents and/or settling beneath the surface of the cell material had occurred (Ocean Surveys 1999a, 1999b).

Cells M2 and Supercell – Cells M2 and the Supercell were capped together in November 1999 following approximately five months of consolidation. A hopper dredge was again used with Cape Cod Canal sand, but in addition to using its main propulsion for maneuvering, a tugboat was used to push the dredge sideways across the cell during sand placement for more even distribution. Post-cap investigations identified a distinct sand cap at the surface over the majority of both cells. Isolated areas were identified with silty material at the surface, considered to be more fluid material from within the cells that was displaced during capping (USACE 2000).

Cells M8-11 and M19 – Cells M8-11 and M19 were capped together in September 2000 after approximately eight months of consolidation, using the same Cape Cod Canal sand and hopper-tug approach as for cells M2 and the Supercell. Post-cap investigations identified a distinct sand cap at the surface of both cells with limited mixing into the underlying UDM and no significant accumulation of fine-grained material above the sand cap (Ocean Surveys 2000).

The last of the BHNIP cells, C12, was allowed to remain uncapped because of additional remaining capacity. This cell has periodically received additional dredged material, but still remains uncapped with additional capacity at the time of this report. The Mystic and Main Ship Channel cells constructed and filled in 2008 were capped in January 2010, after more than 12 months consolidation, using Cape

Cod Canal sand and the hopper and hopper-tug approach (note that these two cells were capped after completion of the November 2009 survey of this report).

### 1.2.3 Previous Boston Harbor CAD Cell Investigations

In addition to the capping investigations referenced above, there were multiple other investigations of the BHNIP related to compliance with the Water Quality Certification and related to its status as the first large scale application of CAD in the United States. Studies included bathymetric surveys, water quality monitoring, and post-capping investigations in support of BHNIP Phase 1 and Phase 2 operations as well as post-project investigations performed to assess the stability and benthic recovery of the CAD cells (Table 1-2).

Because the consolidation time was extended as the project progressed to improve cap placement, leaving the cells “open” for a longer time period, an investigation was performed to evaluate resuspension of sediments over an uncapped cell in March 2000 (Hales 2001, SAIC 2000). The investigation tracked the passage of a deep-draft, 275-m (975-ft) vessel over cell M8-11, approximately two months into its eight-month consolidation period. Resuspension was found to be limited in extent and duration, and the loss of material from the cell was not considered to be significant.

A geotechnical investigation performed in 2001 included the collection of deep cores, extending through the cap layer of each cell into the underlying UDM as part of the one-year post-project Water Quality Certification monitoring (SAIC 2001). This investigation determined that consolidation of the UDM was continuing, but the cells had maintained their original stratigraphy, i.e. no ongoing mixing of cell contents was identified. The stability of the cells was further supported by a pilot investigation in 2002 of sediment dynamics in the Mystic River using fluorescent tracers (SAIC 2003b), where the Supercell within the Mystic River was found to be receiving deposition from both upriver and downriver sources.

Benthic recolonization of the cells has also been investigated. Sediment-profile imaging (SPI) was performed over four cells in 2000 (ENSR 2001) and over all nine BHNIP cells in 2001 with supplemental grab sampling for benthic community analysis (SAIC 2001). These investigations revealed rapid recolonization of the cell surfaces with similar benthic characteristics to reference areas, consisting of mostly pioneering colonizers typical of a periodically stressed, industrialized harbor. A comprehensive survey conducted in 2004 to meet the five-year post-project requirements of the Water Quality Certification included both SPI and towed benthic video (ENSR 2007). This survey showed that the CAD cells had remained similar to the surrounding harbor in terms of benthic habitat and documented numerous small fish and crustaceans over the CAD cells. Bathymetric and side-scan surveys performed as part of the 2004 investigation revealed the cells as stable features with no indication of scour or significant disturbance. However, the sand cap was not identified in any of the sediment-profile images, with only fine-grained sediment apparent to a depth of up to 20 cm (8 in), attributed to the preferential deposition into the cells depressed below the surrounding harbor bottom (ENSR 2007).

## 1.3 Project Objectives

The November 2009 survey was designed with the overall objective of further assessing the long-term stability of the Boston Harbor CAD cells. Specific goals of the study for the older nine BHNIP cells were to:

- Determine changes in bathymetry in and around the cells that could be indicative of consolidation, deposition, or disturbance of cell contents; and

- Assess the extent of sediment deposition over the existing sand-capped cells and the potential for mixing of newly deposited material with deeper sediment

For the two newer cells constructed in 2008 and capped in 2010 (following completion of 2009 survey reported here), the specific goal was to:

- Provide baseline bathymetry partway through the consolidation period that can be used for comparison with future post-cap surveys

These goals were accomplished through performance of a multibeam bathymetric survey over all 11 CAD cell and performance of sub-bottom profiling and sediment coring over a subset of the cells in the Mystic River that had uniform and continuous surficial sand cap coverage at the completion of the BHNIP.

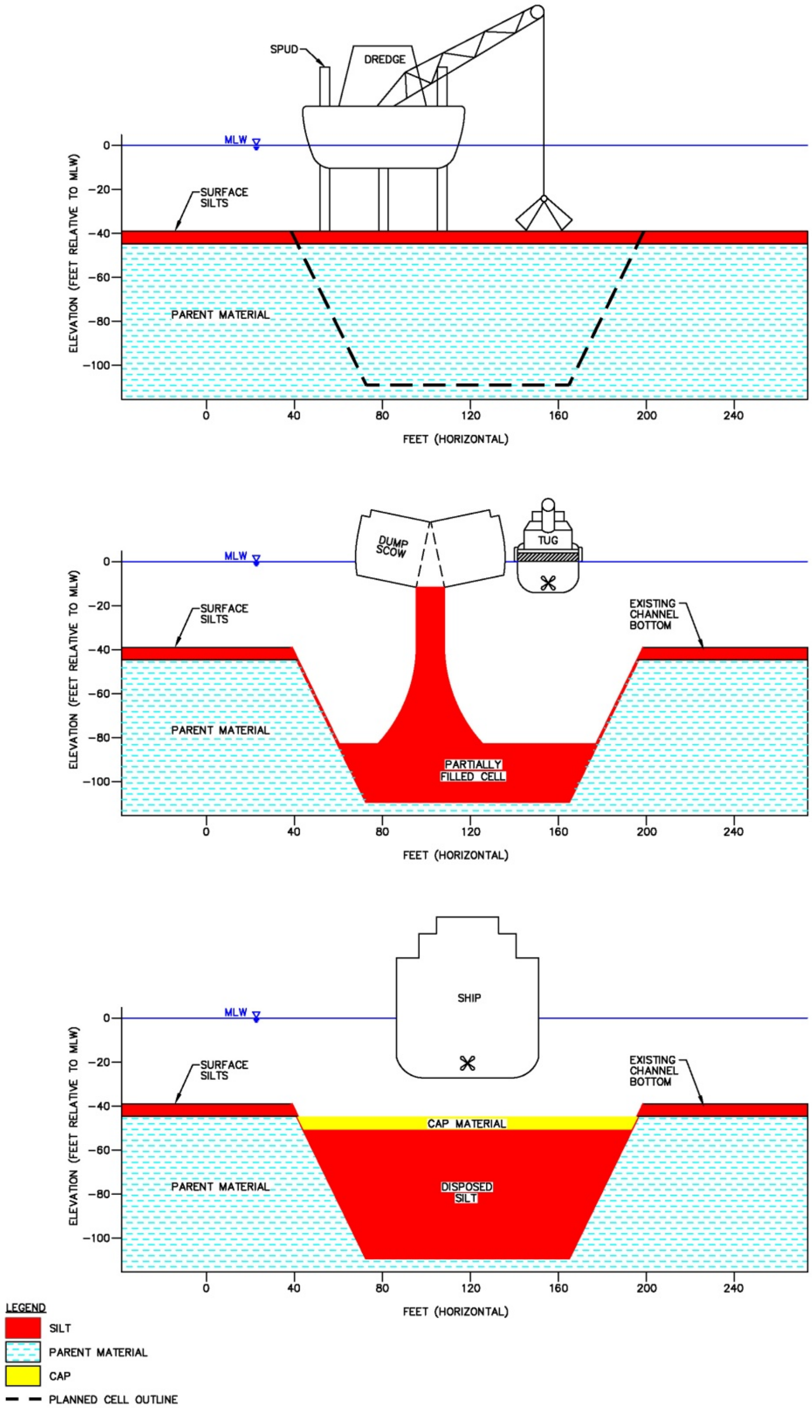
**Table 1-1.**
Boston Harbor CAD Cell Construction Sequence

| Location | Cell | Date Constructed | Date Filled | Capping Status | Consolidation Period Prior to Capping (Months) |
|---|---|---|---|---|---|
| **Main Ship Channel** | IC2 | June 1997 | June–July 1997 | July 1997 | 0 |
| | Main Ship Channel | July–August 2008 | September-November 2008 | January 2010* | 13 |
| **Mystic River** | M4 | September 1998 | September–October 1998 | November 1998 | 1 |
| | M5 | August 1998 | August–October 1998 | November 1998 | 2 |
| | M12 | August–September 1998 | September–October 1998 | November 1998 | 2 |
| | M2 | October 1998 | October 1998–June 1999 | November 1999 | 5 |
| | Supercell | October–December 1998 | January–August 1999 | November 1999 | 5 |
| | M8-11 | March–April 1999 | August 1999–December 1999 | September 2000 | 8 |
| | M19 | July–August 1999 | November 1999–January 2000 | September 2000 | 8 |
| | Mystic CAD | May–June 2008 | September-November 2008 | January 2010* | 13 |
| **Chelsea River** | C12 | February–March 1999 | April 1999–September 1999, May–August 2008 | Not Capped | ---- |

* Capping was performed after completion of the 2009 survey

**Table 1-2.**
Previous Investigations of the Boston Harbor CAD Cells

| Activity | Date | Details | Reference |
|---|---|---|---|
| **Phase 1 of BHNIP** | July–August 1997 | Dredging of Conley Terminal berth area; Construction, filling, and capping of IC2 | ENSR 1997 |
| Bathymetric surveys of IC2 | 1997 | Pre-construction, post-construction, post-fill and post-cap bathymetry | unpublished |
| Water quality monitoring of IC2 | 1997 | Evaluation of water column impacts during dredging and disposal | ENSR 1997 |
| Post-cap monitoring of IC2 | 1997 | Coring, bathymetry, sub-bottom profiling | SAIC 1997 |
| **Phase 2 of BHNIP** | 1998 – 2000 | Channel and berth dredging; construction of remaining 8 cells | ENSR 2002 |
| Dredge bucket comparison | August 1999 | Comparison of water column impacts of different dredge bucket types | Welp et al. 2001 |
| Sub-bottom profiling | 1999 | Sub-bottom survey of Mystic River cells | OSI 2000 |
| Resuspension investigation | March 2000 | Investigation of potential resuspension of cell material from vessel passage | Hales 2001; SAIC 2000 |
| Benthic survey | June 2000 | Benthic assessment of IC2, M2, M4, M8-11 | ENSR 2001 |
| Capping impact investigation | September 2000 | Evaluation of water column impacts during capping of cells M8-11, M19 | Battelle 2001 |
| Bathymetric surveys of Phase 2 cells | 1998-2000 | Pre-construction, post-construction, post-fill and post-cap bathymetry | unpublished |
| Water quality monitoring of Phase 2 cells | 1998-2000 | Evaluation of water column impacts during dredging and disposal | ENSR 2002 |
| **Post-cap Monitoring** | | | |
| One-year monitoring survey | Summer 2001 | Coring, SPI, bathymetry and benthic infauna assessment over all cells | SAIC 2001 |
| Monitoring over BHCAD cell M19 | Summer 2002 | Bathymetry, side-scan sonar, and video sled | SAIC 2003a |
| Sediment transport investigation | Summer–Fall 2002 | Pilot scale study of sediment transport in Mystic River area using fluorescent tracers | SAIC 2003b |
| Monitoring Survey | August 2004 | Bathymetry, side-scan sonar, video sled, SPI (incl. deep penetrating). Five-year post-construction monitoring requirement of WQC | ENSR 2007 |




Initial removal of surficial material overlying planned CAD cell

Placement of material into an excavated CAD cell using a split-hulled scow

Completed CAD cell with cap, typically remaining slightly depressed below the ambient seafloor

**Figure 1-1.** CAD cell schematic

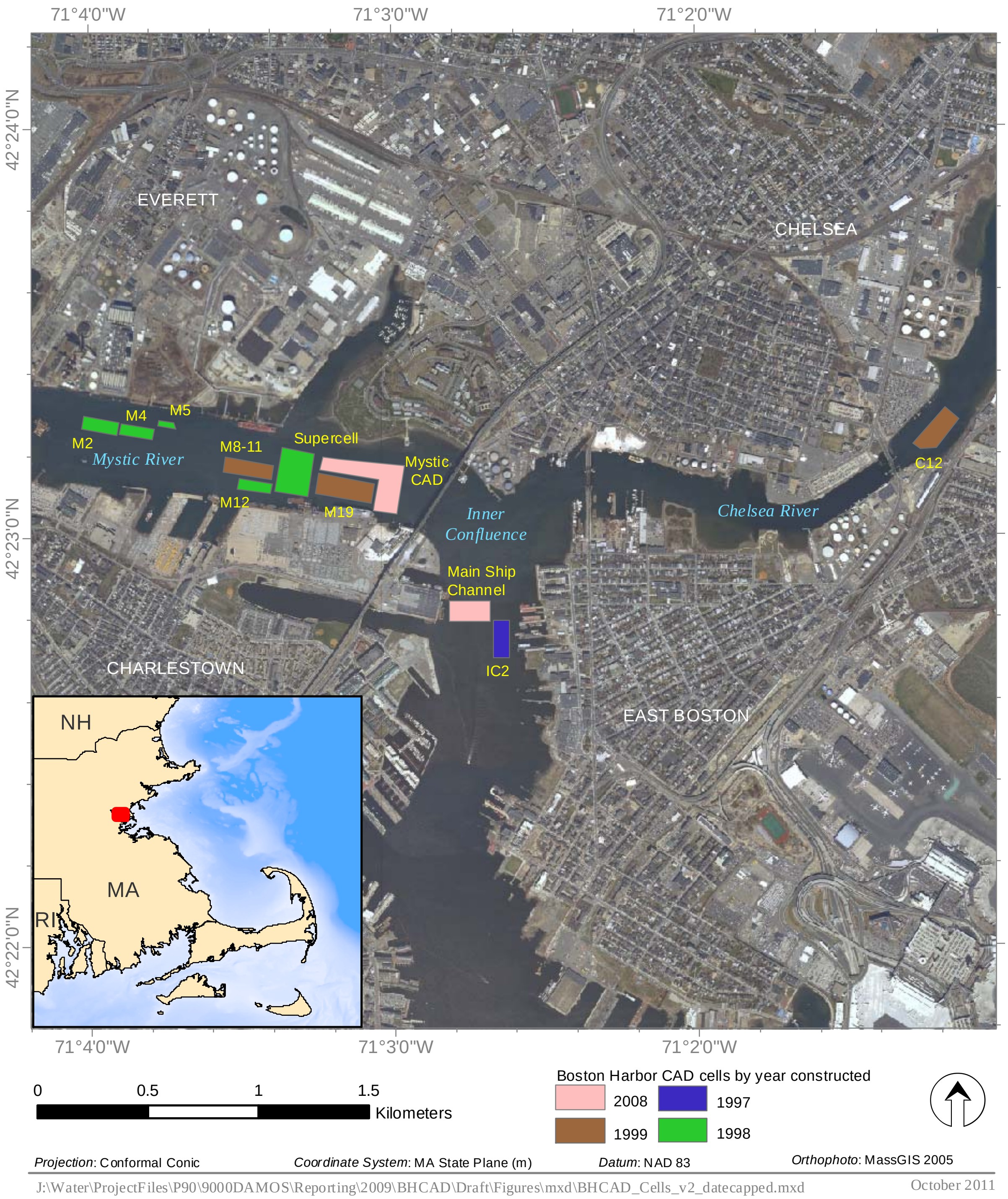



**Figure 1-2.** Boston Harbor CAD cells

# 2.0 METHODS

The November 2009 surveys conducted at the Boston Harbor CAD cells were performed by AECOM and CR Environmental (Table 2-1). The bathymetric survey was conducted 10–11 November 2009, sub-bottom transects were performed 12 November 2009, and sediment coring was conducted 12–13 November 2009. All survey operations were conducted aboard the F/V *Shanna Rose.* An overview of the methods used to collect, process, and analyze the survey data is provided in the sections below.

## 2.1 Navigation and On-Board Data Acquisition

Navigation and horizontal positioning were accomplished using a Trimble AG-132 Differential Global Positional System (DGPS) unit integrated with HYPACK®, a hydrographic survey package which provided a real-time display of vessel position on an electronic nautical chart. The accuracy of the system was validated at the beginning of each survey day by comparing the observed DGPS position to that of an established reference point with known coordinates. HYPACK® provided guidance to accurately maintain the position of the vessel along pre-established survey tracklines for the bathymetric and sub-bottom surveys and to the target stations for the sediment coring survey.

## 2.2 Bathymetry

Bathymetric surveys provide measurements of water depth that, when processed, can be used to map the seafloor topography. The processed data can also be compared to data from previous surveys to track changes in the size and location of seafloor features. This technique is the primary tool in the DAMOS Program for mapping the distribution of dredged material at disposal sites.

### 2.2.1 Bathymetric Data Collection

The 2009 multibeam bathymetric survey at the Boston Harbor CAD cells was conducted 10–11 November 2009 aboard the F/V *Shanna Rose*. The bathymetric survey was conducted over three separate areas (Mystic River, Inner Confluence, and Chelsea River) covering all 11 CAD cells (Figure 2-1). Lines were oriented in an upstream/downstream direction over the entirety of the survey areas, and additional tie-lines were oriented perpendicular to the main survey lines to assess data quality. In addition to multibeam bathymetric data, acoustic backscatter data were also collected.

The bathymetric and acoustic backscatter data were collected using a Reson 8125 Ultra High Resolution Echo Sounder outfitted with a 0.5°, 455 kHz transducer. The motion sensor was combined with the GPS to provide accurate heading and measurement of heave, pitch, and roll. The system was calibrated for local water mass speed of sound by performing conductivity-temperature-density (CTD) casts at frequent intervals throughout the day with a Seabird SBE-19 Seacat CTD profiler.

Water depths over the survey area were recorded in meters and referenced to mean lower low water (MLLW) based on water levels recorded at tide gages deployed on piers adjacent to each survey location. Hypack® software was used to manage data acquisition and storage of data from the echosounder and the navigation system. Hypack® also recorded depth, vessel heave, heading, position, and time along each survey transect line.

### 2.2.2 Bathymetric Data Processing

The bathymetric data were processed using the Hypack® software program and included corrections for tidal conditions, local speed of sound, and spurious data points. Tidal correction consisted of transforming the raw measurements of depth below the transducer to seafloor elevation measurements relative to MLLW using the locally collected tidal elevation data. Heave data supplied by the vessel's motion reference unit (MRU) were incorporated into the raw data to minimize the effects of vessel motion. The bathymetric data were also reviewed for spurious data points (clearly unrealistic measurements resulting from signal interference), and these points were removed. The final data set was averaged into 1.0 $m^2$ bins. All soundings located within a given bin were averaged, and the average value was assigned to the coordinates at the center of the bin.

The corrected bathymetric data were analyzed using the geographic information system software program ArcGIS® 9.3 (GIS). The processed bathymetric data were converted to rasters, and bathymetric contour lines were generated and displayed using GIS.

ArcGIS was also used to calculate depth-difference grids between the 2004 bathymetric data and the 2009 bathymetric data. The depth-difference grid was calculated by subtracting the 2004 survey depth estimates from the 2009 survey depth estimates at each point throughout the grid. The resulting depth differences were contoured and displayed using ArcGIS.

## 2.3 Sub-Bottom Profiling

The sub-bottom survey was conducted 12 November 2009 aboard the F/V *Shanna Rose*. The 2009 survey design included the collection of sub-bottom transects across selected CAD cells in the Mystic River. A total of six sub-bottom lines were run parallel to the channel, and 13 sub-bottom lines were run perpendicular to the channel across cells M8-11, M19, and the Supercell (Figure 2-2). These lines were selected to occupy the same profiles as sub-bottom transects collected over the cells in 2000 (OSI 2000).

A towed sub-bottom profiling system was used to acquire stratigraphic data along a series of lines which provided full coverage over the three CAD cells (spacing generally ranged between 20–30 m). The system consisted of a 2–15 kHz Edgetech FSSB CHIRP topside system and SB-216 transducer array. This 2–4 kW system was interfaced to an acquisition computer running Chesapeake Technology, Inc. Sonar WIZMAP® SBP software, and the acquisition computer was interfaced to a Trimble DGPS system via serial connection. Data were recorded in standard SEG-Y format.

Sub-bottom data were processed using Chesapeake Technology, Inc. SonarWeb® software. Processing included adjustment of towfish navigation data to account for layback and adjustment of time varied gain (TVG). The horizontal accuracy of processed data was estimated at 1–5 m. SonarWeb® was used to generate scaled profiles suitable for analysis in ArcGIS. SonarWeb® also generated HTML-navigable indices of sonar profiles and navigation data.

## 2.4 Sediment Coring

The 2009 sediment coring survey at the Boston Harbor CAD cells was conducted 12–13 November 2009 aboard F/V *Shanna Rose*. A total of 20 cores were collected and analyzed from 11 locations in cells M8-11, M19, and the Supercell, along with four reference locations outside of the cell footprints within the Mystic River (Table 2-2, Figure 2-2). The station targets were positioned along sub-bottom transects, where possible, to allow for subsequent data validation between sub-bottom profiles and sediment cores. At each station the vessel was positioned within 10 meters of the target.

A 0.0625-$m^2$ Gray O'Hara box corer was initially used to sample all locations in order to minimize surficial sediment disturbance during sample collection. The box corer was able to penetrate to a maximum of 56 cm. Upon retrieval of the box core, the sample was examined for acceptability (visual assessment of minimal sediment surface disturbance) and residual water was removed using plastic tubing. Penetration depth, sediment color and texture, odor, and biota were documented. Two to four 6.7 cm diameter core tubes were outfitted with caps equipped with tubes that could be attached to a gentle vacuum and manually driven into the box core sample until refusal (Figure 2-3). The vacuum reduced the pressure in the headspace above the sediment to minimize core compaction during subsampling. Core compaction was documented by measuring the difference between the original sediment surface and the sediment surface inside the plastic core barrel to determine the effectiveness of the vacuum method at collecting an undisturbed subsample. The tubes were then removed from the box core, capped, taped, and labeled.

If the box core was unable to successfully penetrate to the sand cap at CAD cell stations a deeper penetrating piston core was also collected. The piston core was outfitted with a 1.8 m, 8.9 cm diameter core barrel in order to penetrate into the CAD cell cap material. At two stations (5 and 6) visual inspection of the sample revealed that the initial head pressure of the piston core was disturbing the very fine surficial material during penetration; for these two stations the piston valve was removed to eliminate head pressure in the barrel and the core was used as a simple gravity core. The penetration depth was determined by measuring the extent of sediment smear on the outside of the core barrel while recovery was determined by measuring the actual sediment length in the core tube. All samples were stored vertically in a walk-in cooler at the Allerton Yacht Club in Hull, MA for the duration of the survey and then transported by truck to the University of Rhode Island Marine Geological Samples Laboratory (URI MGSL) for processing and analysis.

### 2.4.1 Core Processing

Cores were split vertically in half using a splitting device consisting of two opposing router bits designed to travel in parallel from the top to the bottom of the core tube until the plastic was severed. After the plastic core tube was severed, a wire was pulled through the sediment to complete the splitting process. Next, the two sediment halves were separated and sealed with plastic film for short term storage.

After splitting the core, one core half was transferred to the subsampling team, and the second half was transferred to the GeoTek™ logging laboratory for high resolution imaging and non-destructive analysis of bulk density, magnetic susceptibility, resistivity, and p-wave velocity. The subsampling team prepared descriptions of each core, photographed unique features, measured the apparent redox potential discontinuity (aRPD) depth, and collected samples for moisture, grain size, and specific gravity analysis in 2 cm intervals for the length of the core or until cap material was clearly captured (Table 2-3).

### 2.4.2 Core Logging

The sediment core halves designated for GeoTek™ logging were prepared for digital scanning by scraping the exposed sediment along the horizontal to provide a fresh, unaltered sediment surface. Next, the cores were scanned at a 100 dpi down-core resolution and a 143 dpi or 183 dpi cross-core resolution for the box cores and piston cores, respectively.

Sediment wet bulk density was estimated by passing gamma particles ($^{137}Cs$ source) through the sediment and counting the number of particles that passed through an opposing (Na-I) counter. The attenuation, or "scattering", of particles was proportional to the density of the material. The sensor was first calibrated using different thicknesses of water and aluminum because these substances encompass the typical range of sediment densities and have similar scattering properties.

Magnetic susceptibility profiles were measured along the length of the core using a Barrington Instruments® MS2E point sensor. Magnetic susceptibility refers to the magnetization of the sediment in the presence of a weak magnetic field and was used as an indicator of the amount of magnetic material (Fe) present in the sediment.

Resistivity profiles were developed using a non-contact resistivity sensor by generating a weak magnetic field that induced a current in the sediment porewater. Sensor calibration was performed using water of various salinities. In fresh sediment, resistivity may be used to characterize the amount and type of porewater, or in the case of dewatered sediments (often the case with split cores), resistivity more accurately characterizes porosity because the dewatering leaves void spaces filled with highly resistive air.

Compressional wave or P-wave profiles were measured using a pad-type transducer (positioned on the sediment surface) and an oil-filled, roller-bearing transducer on the opposing/underside of the core. Velocity through sediment is related to the sediment bulk density and porosity, but dewatered sediments or gas bubbles can interrupt P-wave travel time within selected core sections and affect results.

### 2.4.3 Core Analysis

Moisture data were collected by weighing sediment samples upon subsampling and again after the samples were dried overnight in a 105°C oven. Specific gravity was measured according to ASTM protocol 854. Grain size was measured using two methods; all samples were analyzed using a laser technique (ASTM D4464), which is able to utilize small sample volumes but tends to overestimate size ranges of sand-sized fractions due to the non-sphericity of the particles (Konert and Vandenberghe 1997). After initial review of laser grain size data, sample intervals which contained significant percentages of coarse material were reanalyzed with the sieve/hydrometer method (ASTM D422) for greater accuracy.

**Table 2-1.**

Summary of Field Activities for Boston Harbor CAD Cells Survey

| Survey | Location | Date | Summary |
|---|---|---|---|
| **Bathymetry** | Mystic River | 10 November 2009 | Area: 240 x 1700 m<br>Spacing: Variable |
| | Main Ship Channel | 11 November 2009 | Area: 300 x 425 m<br>Spacing: Variable |
| | Chelsea River | 11 November 2009 | Area: 180 x 300 m<br>Spacing: Variable |
| **Sub-bottom** | Cells M8-11, M19, Supercell | 12 November 2009 | 19 lines: M8-11, M19, Supercell |
| **Sediment Coring** | Cells M8-11, M19, Supercell | 12–13 November 2009 | 16 cores: M8-11, M19, Supercell<br>4 cores: reference stations |

**Table 2-2.**

Sediment Coring Locations

| Cell | Station | Core | Latitude | Longitude | Collection Method |
|---|---|---|---|---|---|
| Supercell | 1 | 1 | 71° 03.378' | 42° 23.123' | Box |
| | 2 | 1a | 71° 03.323' | 42° 23.153' | Box |
| | 3 | 1c | 71° 03.291' | 42° 23.193' | Box |
| | 4 | 1b | 71° 03.340' | 42° 23.174' | Box |
| | 13 | 1a | 71° 03.348' | 42° 23.130' | Box |
| M19 | 5 | 1a | 71° 03.199' | 42° 23.135' | Box |
| | 5 | 2 | 71° 03.200' | 42° 23.139' | Gravity |
| | 6 | 1b | 71° 03.164' | 42° 23.128' | Box |
| | 6 | 3 | 71° 03.163' | 42° 23.129' | Gravity |
| | 7 | 1b | 71° 03.132' | 42° 23.120' | Box |
| | 7 | 2 | 71° 03.132' | 42° 23.120' | Piston |
| M8-11 | 8 | 1 | 71° 03.530' | 42° 23.182' | Piston |
| | 8 | 2b | 71° 03.529' | 42° 23.182' | Box |
| | 9 | 1a | 71° 03.477' | 42° 23.176' | Box |
| | 10 | 1 | 71° 03.453' | 42° 23.174' | Piston |
| | 10 | 2b | 71° 03.449' | 42° 23.172' | Box |
| Reference Area | 16 | 1a | 71° 03.415' | 42° 23.196' | Box |
| | 17 | 1a | 71° 03.630' | 42° 23.208' | Box |
| | 19 | 1a | 71° 03.609' | 42° 23.190' | Box |
| | 20 | 1b | 71° 03.524' | 42° 23.213' | Box |

Coordinate System: NAD 83

**Table 2-3.**

Summary of Laboratory Measurements

| GeoTek™ Sensor Measurements | Notes/Method |
|---|---|
| Bulk Density | From gamma density measurements |
| High Resolution Photography | |
| Magnetic Susceptibility | Iron content/profile information |
| Resistivity | Sediment porewater or porosity |
| P-Wave Velocity | Also sediment density |
| **Discrete Analytical Measurements** | |
| Moisture | |
| Grain size | |
| Specific Gravity | |

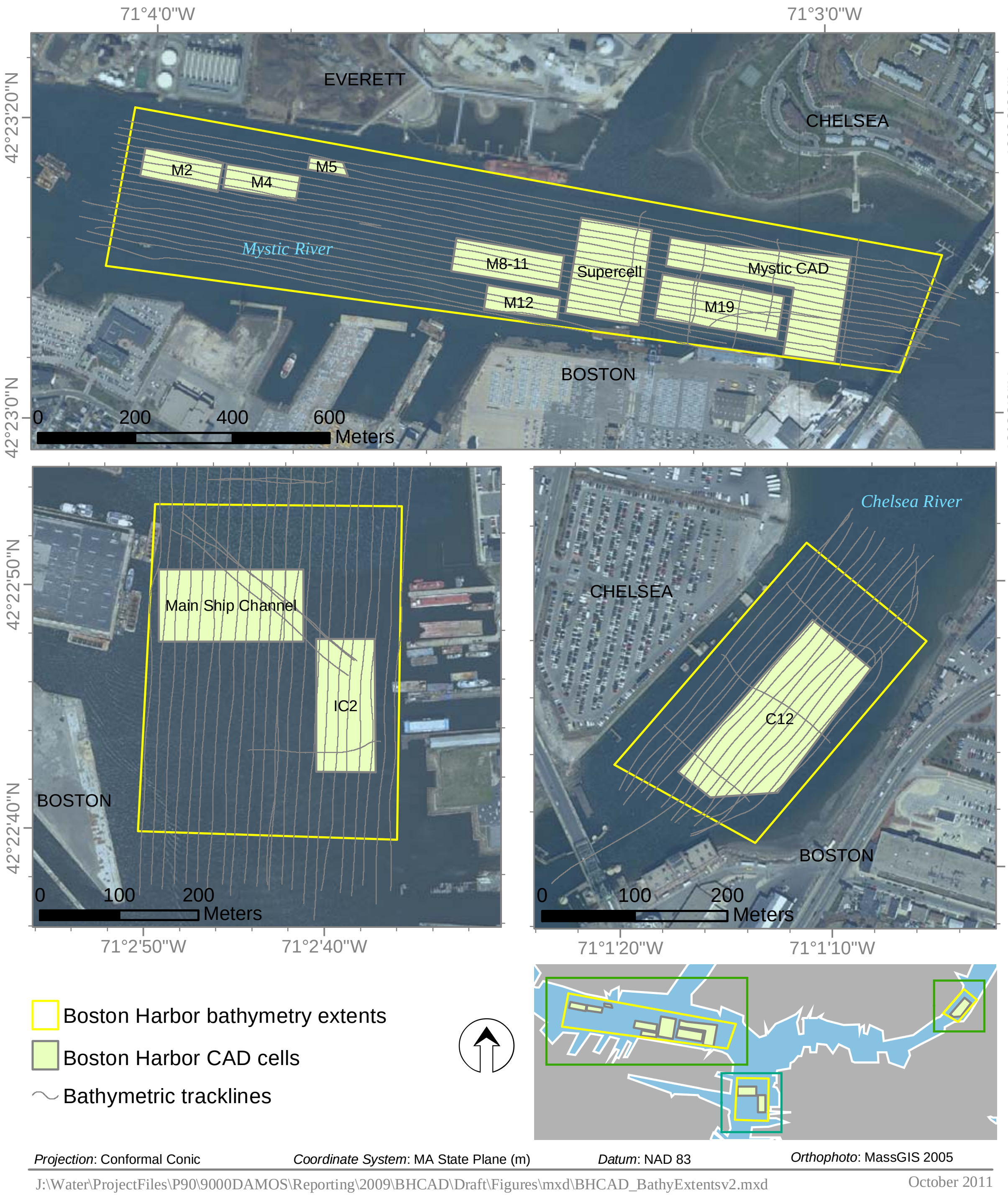



**Figure 2-1**. Bathymetric survey extents

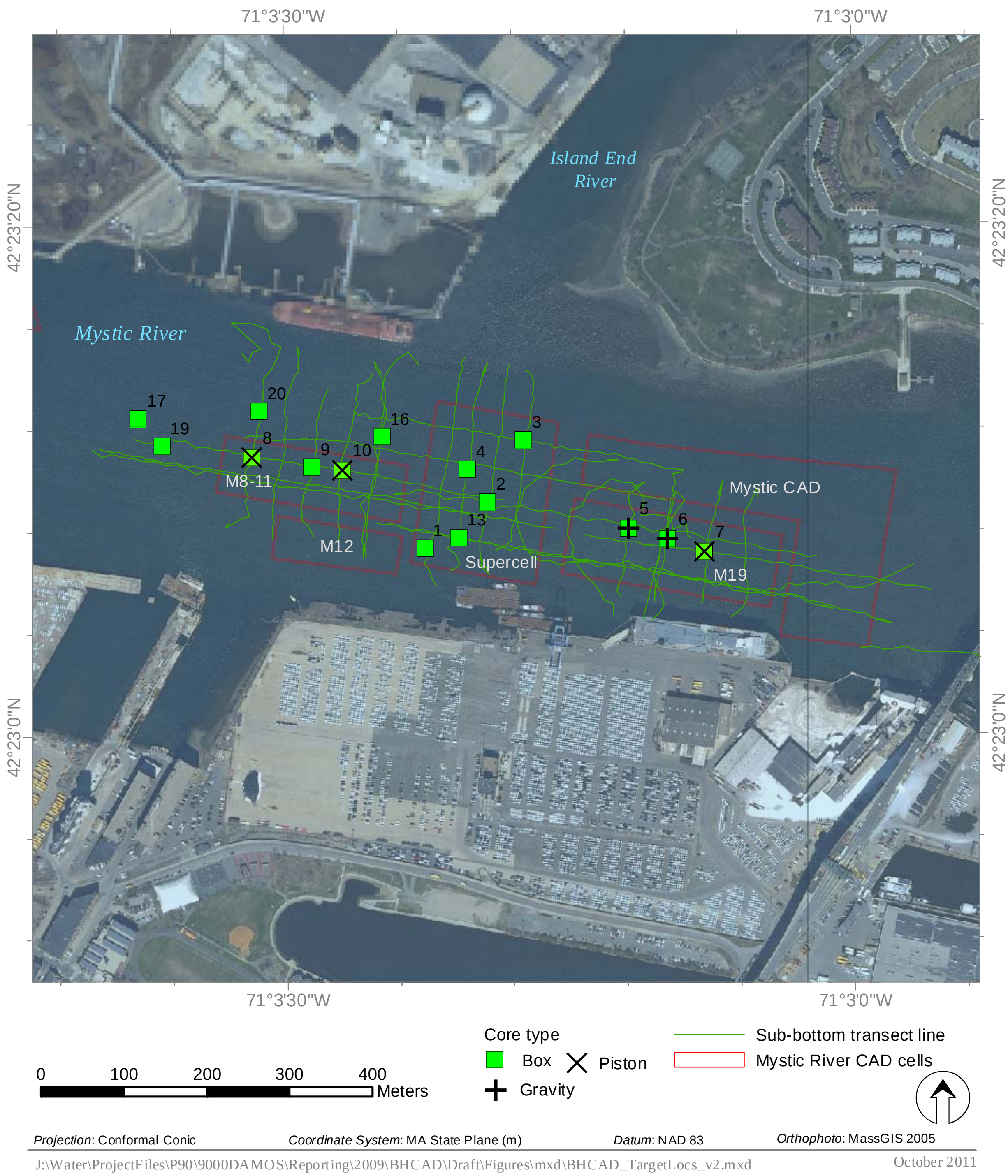



**Figure 2-2**. Sub-bottom profile transects and sediment coring locations

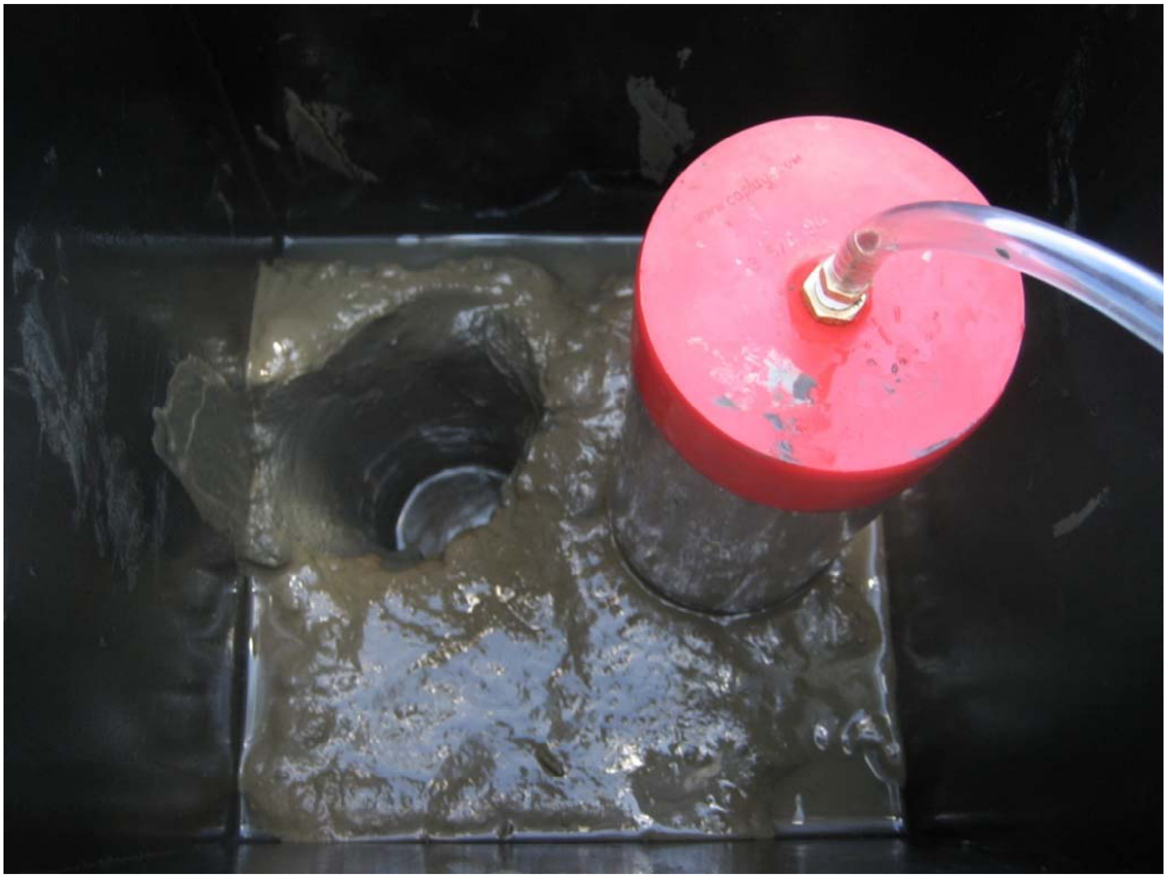


**Figure 2-3**. Box core subsampling with vacuum tube attached to core cap

# 3.0 RESULTS

## 3.1 Bathymetry

Bathymetric surveys were conducted over the CAD cells in the Mystic River, Chelsea River, and the Main Ship Channel of the Inner Confluence.

### 3.1.1 Mystic River

Channel depths in the survey area of the Mystic River ranged from 12 to 14 m MLLW outside of the CAD cell footprints (Figure 3-1). A steep bank with a 4:1 slope (horizontal:vertical) was noted between the Tobin Bridge and the Island End River entrance in the northeast corner of the survey area. A similar bank was noted where the channel narrows to the west, and depths in the southwestern corner of the survey area were 6–10 m MLLW.

All eight CAD cells in the Mystic River were apparent in the 2009 bathymetric data as distinct features depressed below the surrounding channel area (Figure 3-1). Cells M2, M4, and M5, at the western end of the survey area, all showed fairly regular flat surfaces with depths of 16–17 m for M2 and M4, and 15 m for M5 (Figure 3-2). All three cells had steep side walls (approximately 4:1 slope) that sharply rose to the surrounding channel depth of approximately 13 m. Comparison of the 2009 bathymetric data and the 2004 bathymetric data revealed no substantial changes in depth for these cells (Figure 3-3).

The other four previously existing Mystic River CAD cells (M8-11, M12, M19, and the Supercell) also showed steep side walls (approximately 4:1 slope) but, with the exception of the Supercell, had more irregular surface profiles (Figure 3-2). Cell M8-11 had the most irregular surface with a low berm (14 m) extending across the center of the cell separating a depression in the western end (15 m) from a depression in the eastern half (17 m). Cell M12 and the Supercell had surface depths of approximately 15 m over the majority of the cell footprints while the surface of cell M19 ranged in depth from 14–16 m (Figure 3-1). Depth difference analysis showed no areas of significant change in depth in cells M8-11, M12, or the Supercell since 2004 (Figure 3-3). In contrast, cell M19 showed an extensive amount of sediment deposition over the same time period with at least 1 m of accumulation over the majority of the cell footprint and more than 2 m of material evident in some areas (Figure 3-3).

The new Mystic CAD cell footprint was also apparent in the 2009 bathymetric data (Figure 3-1). The western half of the cell, north of cell M19, had a fairly uniform surface depth of 15–16 m but the eastern portion, adjacent to the Tobin Bridge, had an irregular eastern boundary and a shallower area in the center rising to 13.5 m. Depth difference analysis showed the cell surface more than 3 m below the 2004 surface (channel bathymetry prior to cell construction) in the western portion of the cell and 1–2 m below the 2004 surface over most of the eastern half of the cell (Figure 3-3).

### 3.1.2 Main Ship Channel

The previously existing IC2 cell and the recently excavated Main Ship Channel cell were both apparent in the 2009 bathymetric data (Figure 3-4). Cell IC2 had an irregular surface with numerous low relief ridges and troughs ranging in depth from 13–15 m (Figure 3-5). The walls of the cell were well defined and rose sharply 1.5–3 m to the surrounding channel depth of 13 m. Since the 2004 survey there has been no significant change in depth of cell IC2 (Figure 3-6).

The Main Ship Channel CAD cell was apparent as a 180 x 100 m rectangle to the northwest of cell IC2 (Figure 3-5). The surface of the Main Ship Channel cell was flat with a nearly uniform depth of 19 m. The walls of the cell rose 6 m to the surrounding channel bottom depth of 13 m (Figure 3-4). The area immediately south of the Main Ship Channel CAD cell showed regular surface cuts between 0.5–1.0 m deep, extending approximately 280 m to the south (Figure 3-5). These depressions are likely dredging scars from the removal of surface material from the original planned footprint of the cell which was modified based on capacity needs. The 2004 survey area only overlapped the southeastern corner of the new cell (additional pre-construction data were not available), but depth difference analysis confirmed that the new cell surface was approximately 6 m below the 2004 surface (Figure 3-6).

### 3.1.3 Chelsea River

The outline of CAD cell C12 was apparent in the 2009 bathymetric survey of the Chelsea River (Figure 3-7). Surface depths ranged from 16–17.5 m with several apparent topographical features visible (Figure 3-8). The walls rose sharply to the channel depth of 12 m, but an intermediate shelf was noted along a portion of the northwestern wall at a depth of approximately 15 m. A linear depression, approximately 13 m in depth, extended 30 m into the cell footprint from the southern boundary (Figure 3-8).

Comparison of the 2004 and 2009 bathymetric data revealed more than 1.0 m of sediment accumulation over the majority of cell C12 with isolated pockets of accumulation extending into the surrounding river channel (Figure 3-9). There was evidence of as much as 3 m of accumulation in some areas, reflecting recent disposal activity into the uncapped cell. A small area (300 $m^2$) outside the southeast corner of the cell footprint experienced 4 m of sediment loss over the same time period and may point to a localized slumping of that portion of the cell wall or slumping of the channel slope adjacent to the cell along this portion of the river.

## 3.2 Sub-bottom Profiling

Sub-bottom profiling is used to characterize sediment features below the sediment-water interface based on acoustic impedance. A sub-bottom profile survey was conducted over cells M8-11, M19, and the Supercell in the Mystic River (Figure 3-10). The sub-bottom acoustic signal was able to penetrate 5–10 m beneath the sediment surface revealing acoustic reflectors that represent the upper and lower boundary of the sand cap for many profiles (Figure 3-11). This information was used to assess sediment accumulation over the cells and the general condition of the cap. Surficial features of the sub-bottom data showed strong alignment with multibeam data from the bathymetric survey of the cells. Profiles that were representative of the conditions of each of the three cells are discussed below and presented in Figures 3-11, 3-12, and 3-13.

The profile of M8-11 confirmed the presence of a low berm across the center of the cell dividing two deeper basins (Figure 3-11). There was a sub-surface acoustic signal visible 0.25–0.5 m below the surface, across the majority of the cell, representing the interface between the fine surficial material and the coarse sand cap. A second signal was evident approximately 1 m below the first signal indicating the interface between the sand cap and the underlying UDM. Both signals were discontinuous and could not be identified beneath the central berm.

There was also a strong sub-bottom acoustic signal approximately 0.25–0.5 m deep in the Supercell, distinguishing the surface of the sand cap (Figure 3-12). Unlike cell M8-11, there was no clear acoustic signature at the lower boundary of the sand cap.

The profile of cell M19 highlighted the presence of a narrow berm, approximately 1.5 m high, along the western edge of the cell surface. A well-defined acoustic signal was evident approximately 0.5 m deep in the western end of the cell and over 1 m deep in the eastern portion of the cell (Figure 3-13). There was also a strong reflector approximately 1 m below the initial signal across the entire cell footprint, likely representing the base of the sand cap

## 3.3 Sediment Coring

Sediment cores were collected at a total of 15 stations including four reference stations, three stations in cell M8-11, four stations in the Supercell, and three stations in cell M19 (Figure 3-14). Core recovery varied from 22–103 cm and cap material was recovered at all but three CAD cell stations (Table 3-1).

### 3.3.1 Core Logging and Imaging

Each core was logged for the following parameters: bulk density, magnetic susceptibility, resistivity, and p-wave velocity. These data (density and magnetic susceptibility in particular) generally supported the definition of the fine sediment/sand transition, but as the transition was much clearer in the photographs and grain size data, the logging data were not analyzed further, but are presented in Appendices C and D for completeness.

High resolution imaging and lithology descriptions provided insight into both the sediment accumulation rate and the depth of the biological mixing zone (Appendices A and C). The cap was clearly identified in core images as a sand layer beneath the more recently accumulated fine silt and clay surficial material. The depth to the top of the cap in the cores collected within the CAD cells ranged from as shallow as 6 cm to greater than 56 cm (Table 3-1, Figure 3-15). The biological mixing zone was estimated from split cores as the depth of the lighter colored oxidized surface layer (aRPD). The oxidized layer was thin at both reference area and CAD cell stations with thickness ranging from 0.0–4.0 cm (Table 3-1, Figure 3-16). This shallow biological mixing zone was further supported by the preservation of very fine layering apparent in cores from reference areas and CAD cells.

### 3.3.2 Laboratory Analysis

Subsamples were collected from spilt cores and analyzed for moisture, grain size, and specific gravity (Appendix A). Moisture data were not useful in determining sediment accumulation rates or the biological mixing zone and are not discussed further but are presented in Appendix E for completeness.

Grain size data were also used in determining sedimentation rates over the cells. Vertical profiles of grain size data showed relatively low sand fractions (20–40%) in the surficial sediment layer of CAD cell cores and throughout the reference cores, compared to the coarse material of the sand cap (80–100% sand) observed in the deeper intervals of CAD cell cores. A sharp increase in coarse material was evident in the grain size profiles of most cores, which typically corresponded to the depth of the visually estimated interface between surface material and cap material (Figure 3-17).

**Table 3-1.**

Summary of Cores Collected

| Location | Station | Core | Type | Core Recovery (cm) | Depth of Oxidation (cm) | Depth of Cap (cm) |
|---|---|---|---|---|---|---|
| Supercell | 1 | 1 | Box | 39 | 1.5 | - |
| | 2 | 1a | Box | 54.5 | 1 | - |
| | 3 | 1c | Box | 33 | 0.5 | 15.5 |
| | 4 | 1b | Box | 40 | 0.5 | 35 |
| | 13 | 1a | Box | 56 | 0.5 | - |
| M19 | 5 | 1a | Box | 35.5 | 0.5 | - |
| | 5 | 2 | Gravity | 33 | 2 | 29 |
| | 6 | 1b | Box | 50.5 | 1 | ~50 |
| | 6 | 3 | Gravity | 37 | 1 | 28.5 |
| | 7 | 1b | Box | 53.5 | 1.5 | - |
| | 7 | 2 | Piston | 22 | 0 | 6 |
| M8-11 | 8 | 1 | Piston | 103 | 4 | 18 |
| | 8 | 2b | Box | 31.5 | 2 | 21.5 |
| | 9 | 1a | Box | 22 | 1 | 17.5 |
| | 10 | 1 | Piston | 114 | 4 | 24 |
| | 10 | 2b | Box | 31 | 2 | 27 |
| Reference Area | 16 | 1a | Box | 47.5 | 0 | N/A |
| | 17 | 1a | Box | 33 | 0.5 | N/A |
| | 19 | 1a | Box | 27.5 | 2 | N/A |
| | 20 | 1b | Box | 28.5 | 0 | N/A |

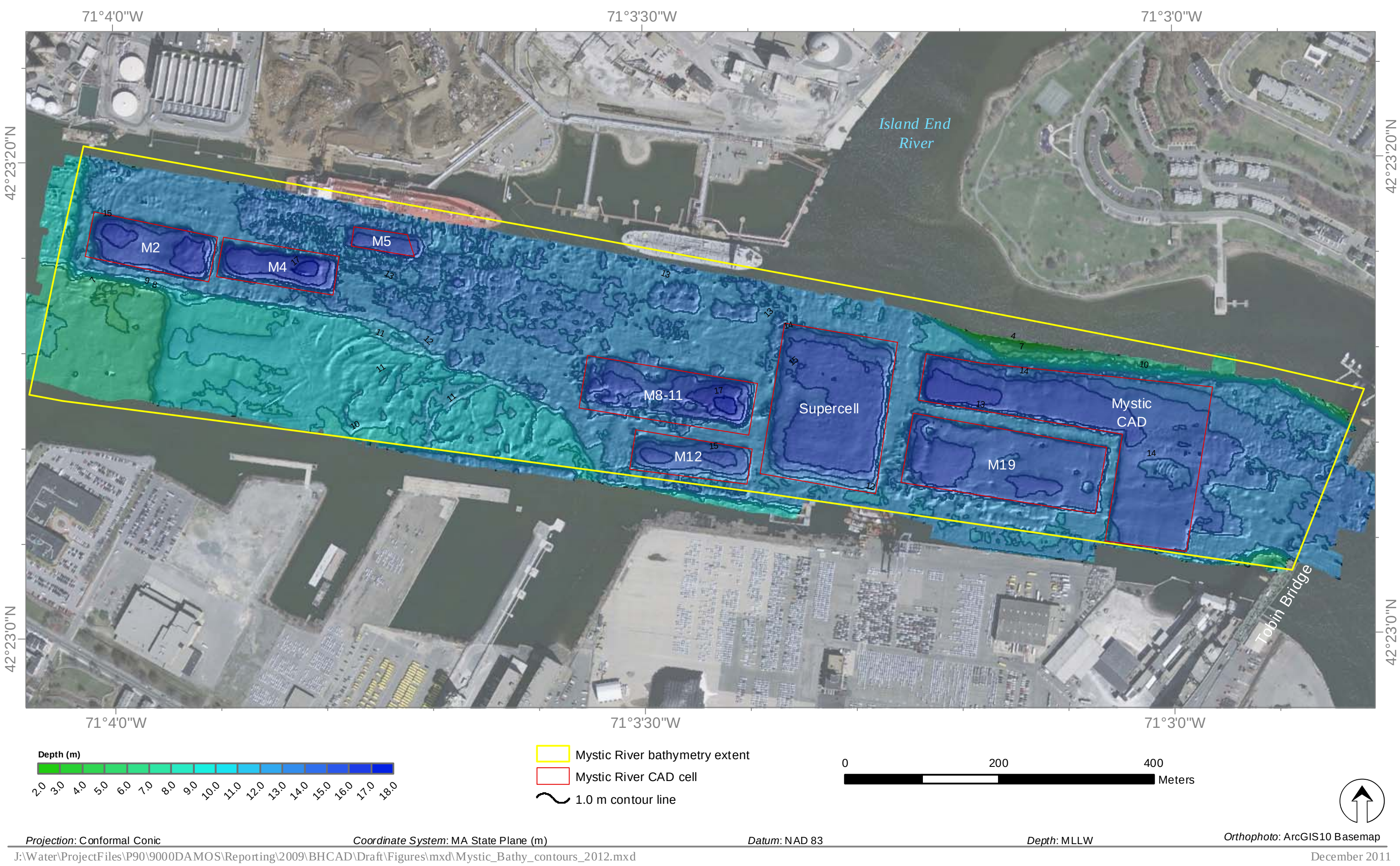



**Figure 3-1**. Mystic River bathymetric contour map with hillshaded relief, November 2009

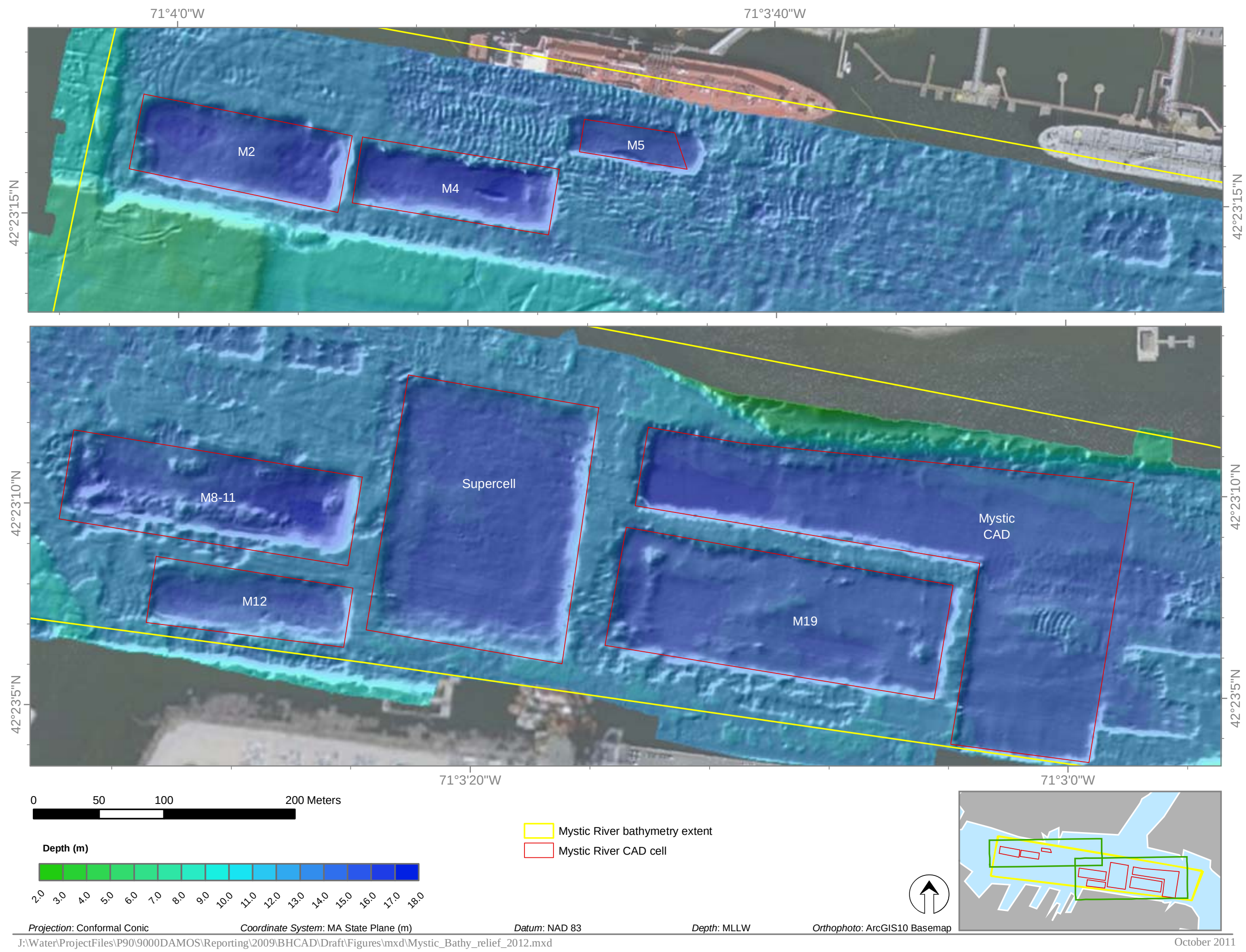



**Figure 3-2**. Mystic River bathymetric map with hillshaded relief, November 2009

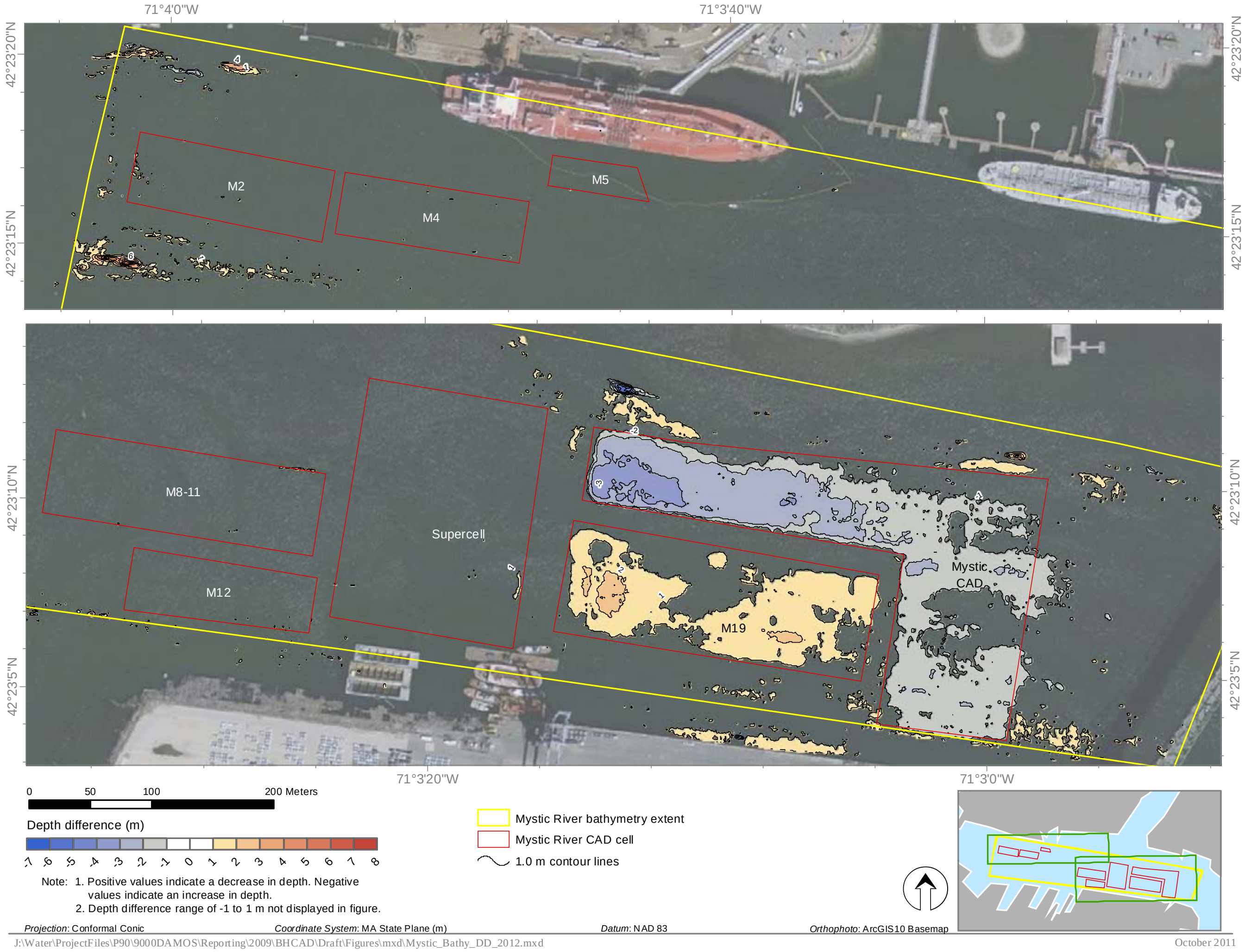



**Figure 3-3**. Mystic River depth difference map, 2004–2009

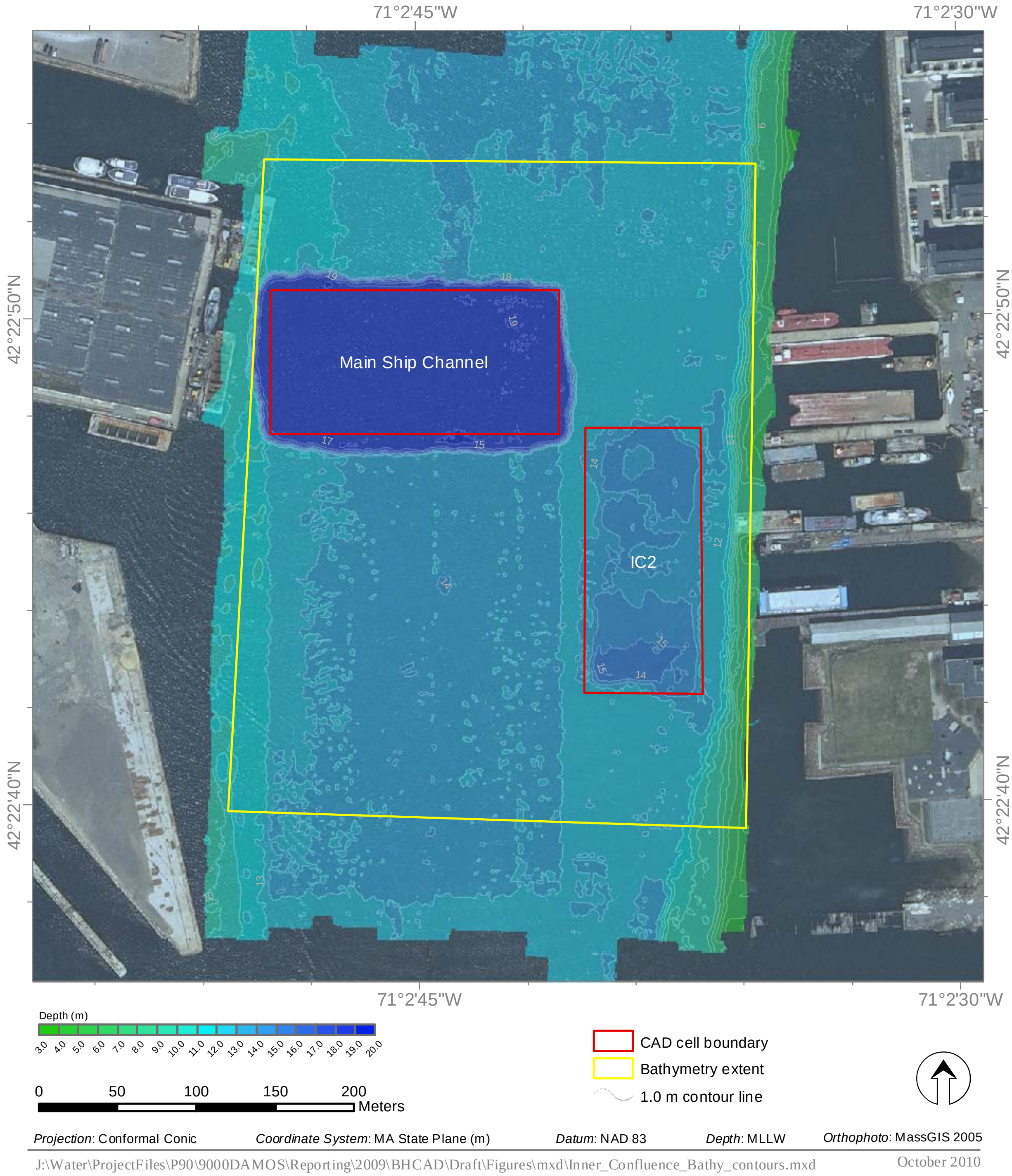



**Figure 3-4**. Main Ship Channel bathymetric contour map, November 2009

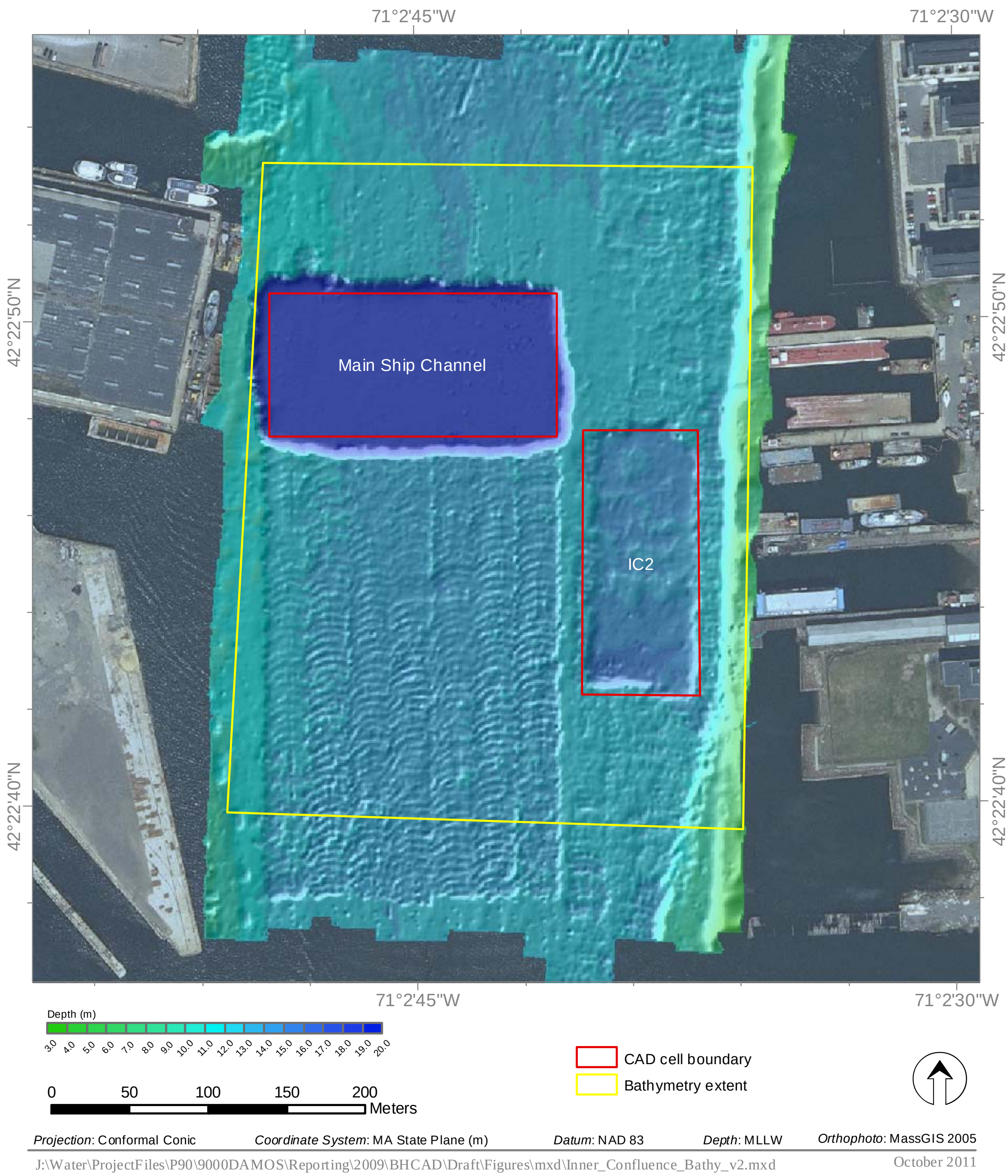



**Figure 3-5.** Main Ship Channel bathymetric map with hillshaded relief, November 2009


**Figure 3-6.** Main Ship Channel depth difference map, 2004–2009

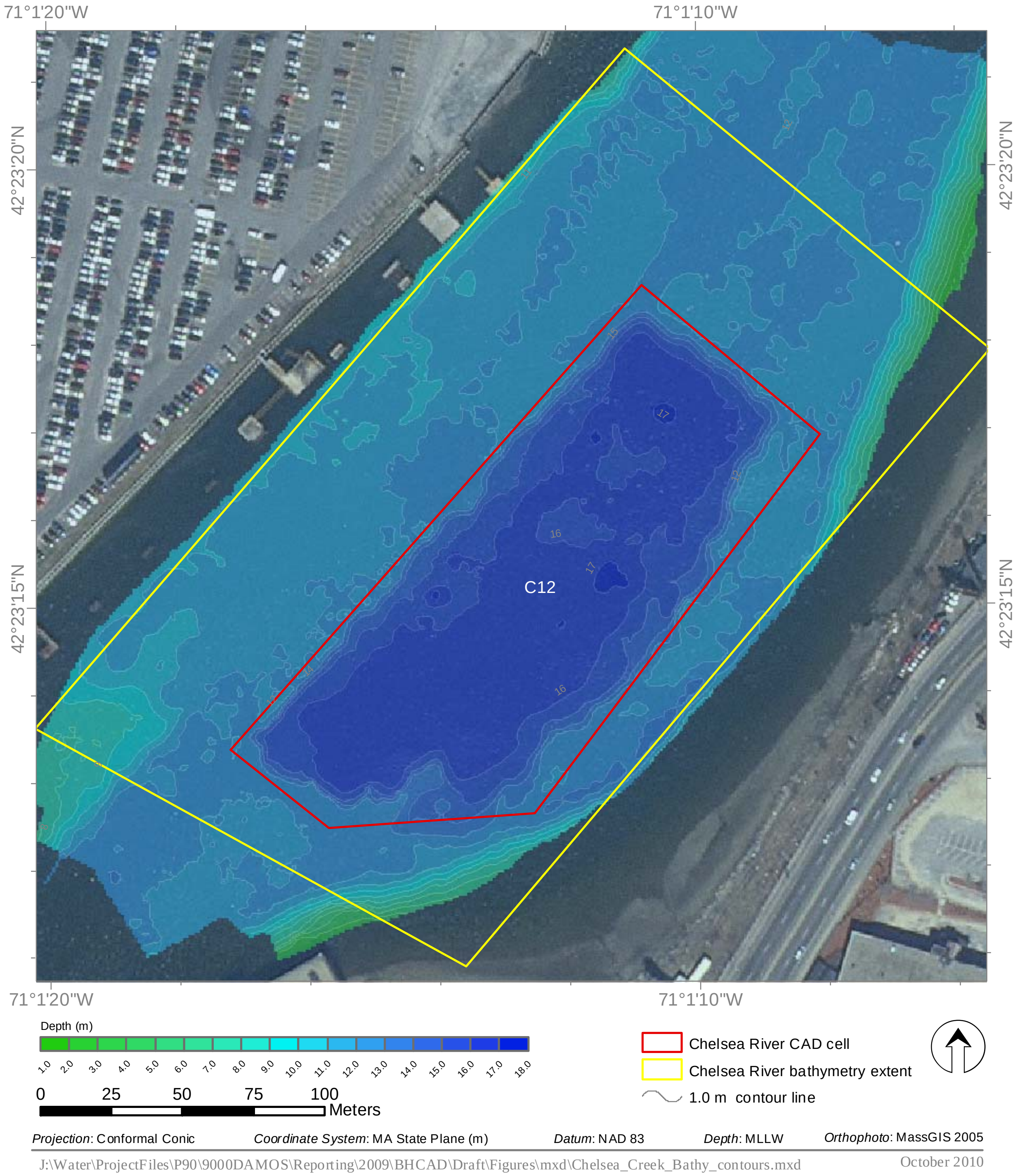



**Figure 3-7.** Chelsea River bathymetric contour map, November 2009

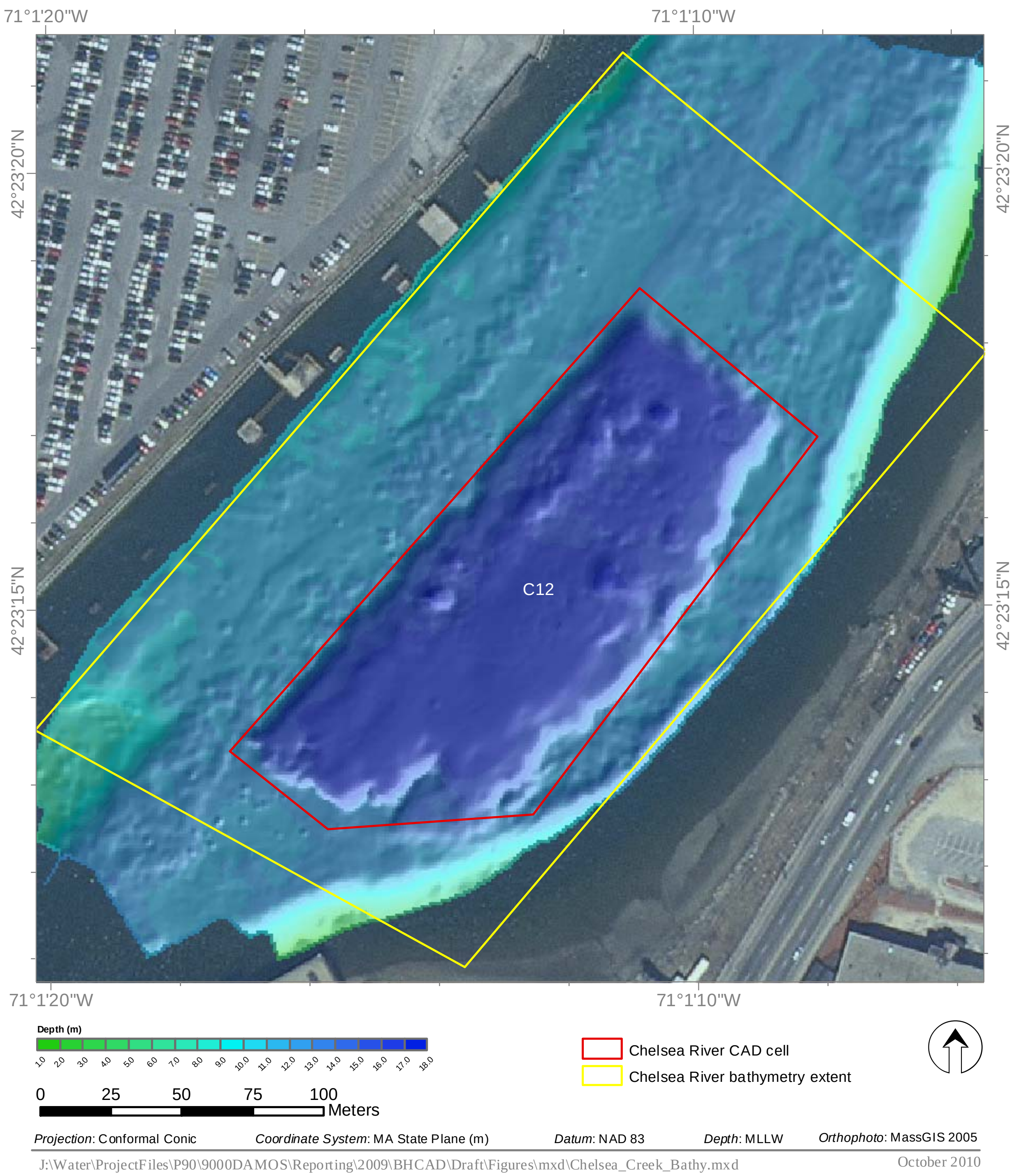



**Figure 3-8.** Chelsea River bathymetric map with hillshaded relief, November 2009

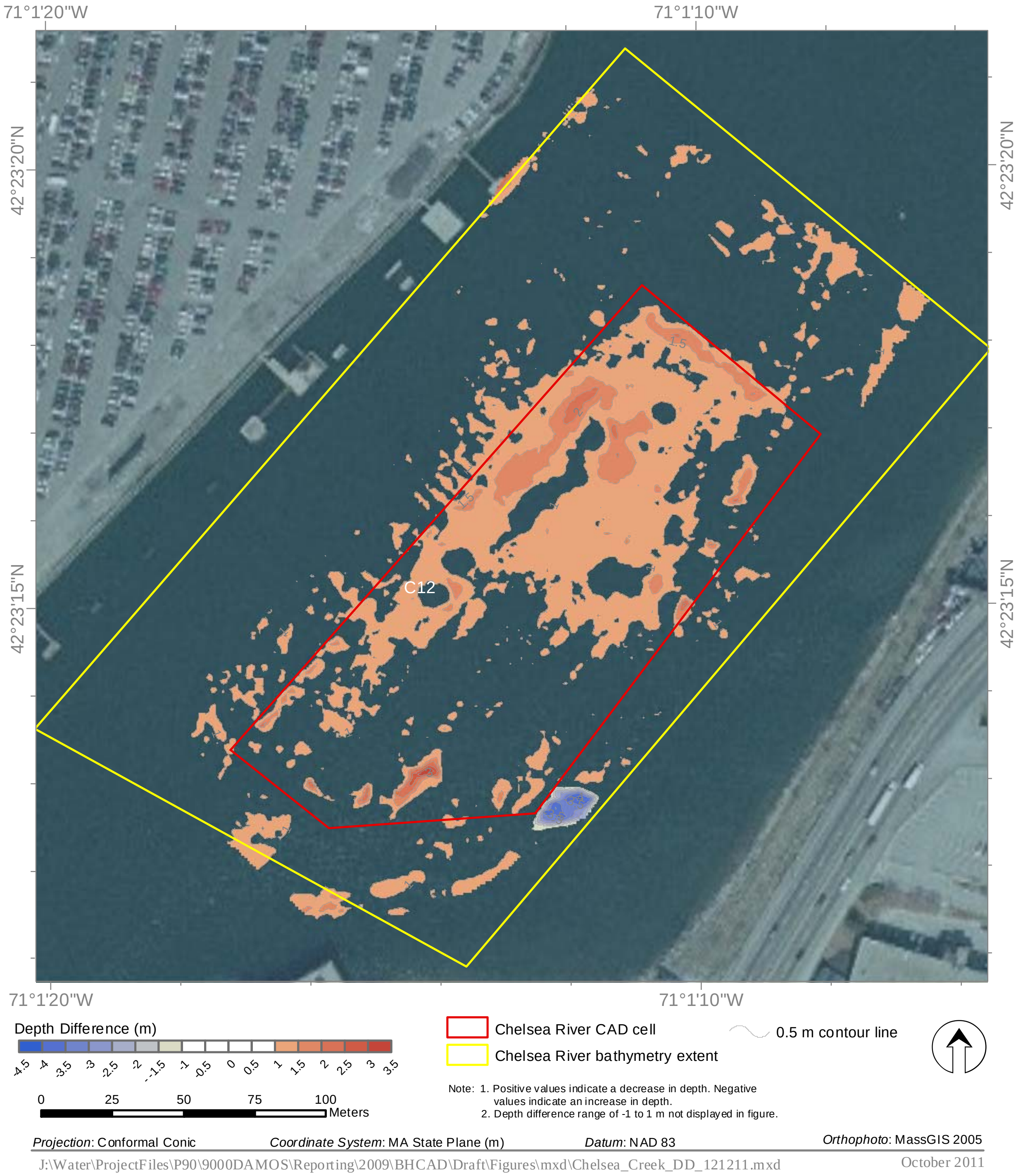



**Figure 3-9.** Chelsea River depth difference map, 2004–2009.

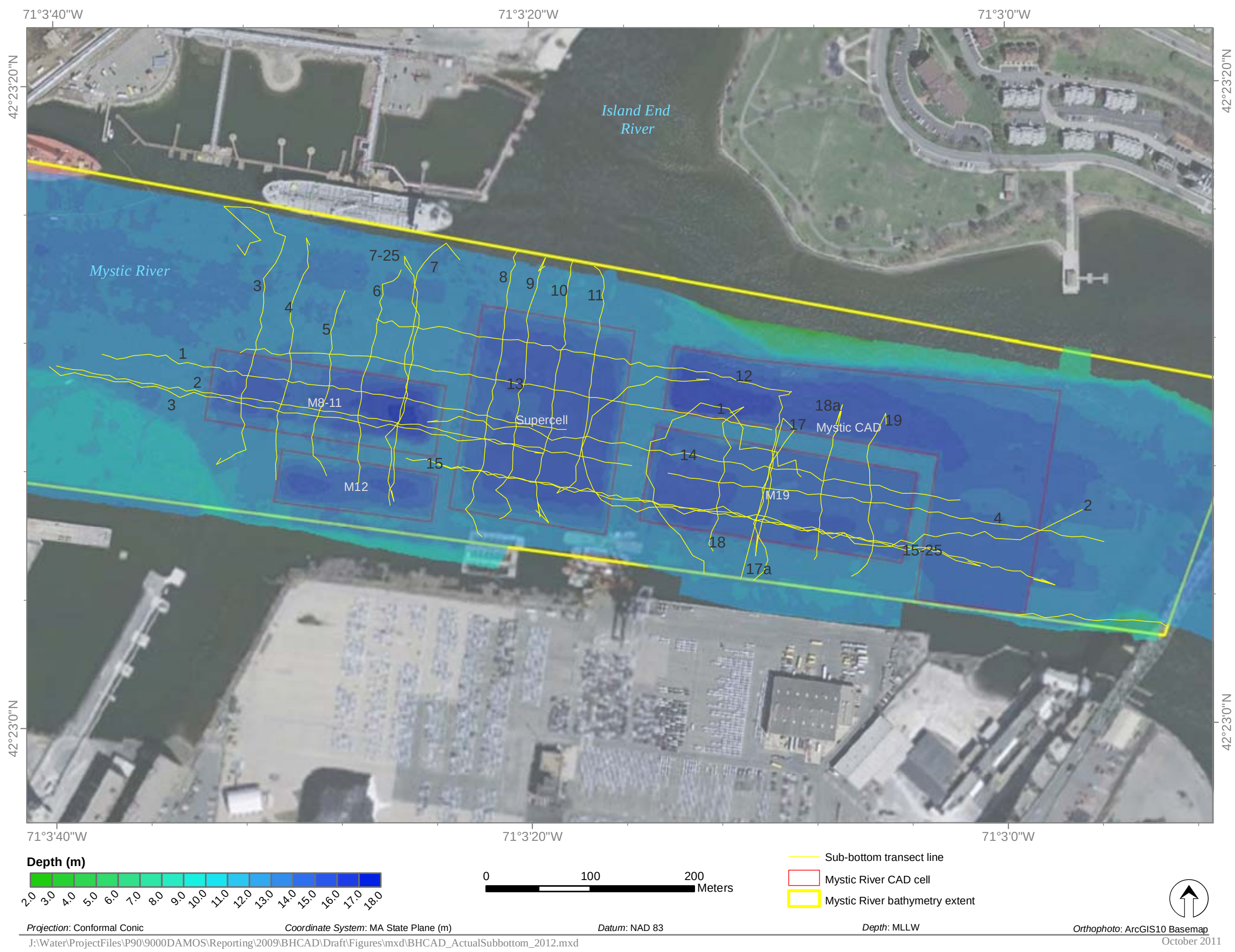



**Figure 3-10**. Sub-bottom transect lines, November 2009

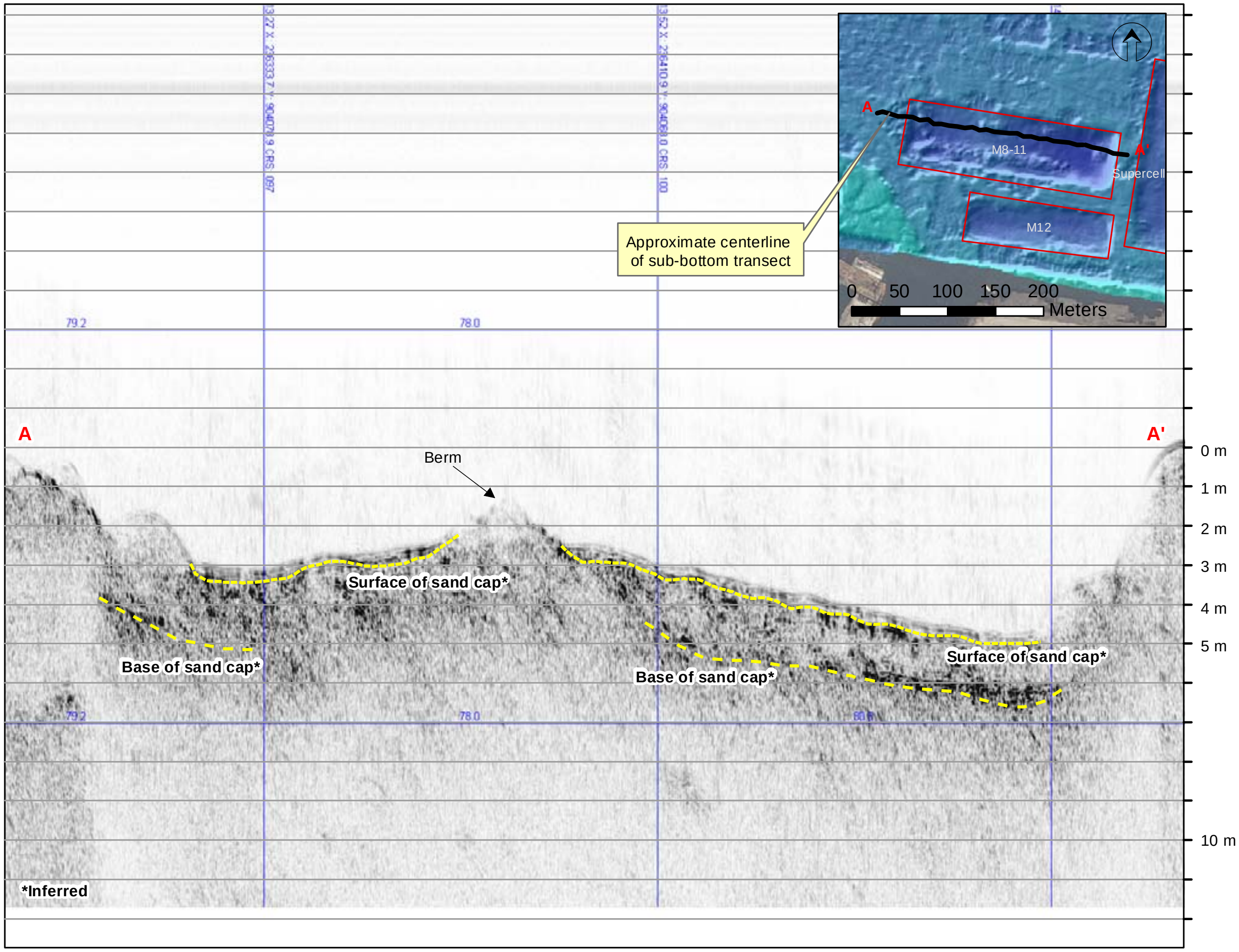



**Figure 3-11**. Cell M8-11 sub-bottom profile, November 2009

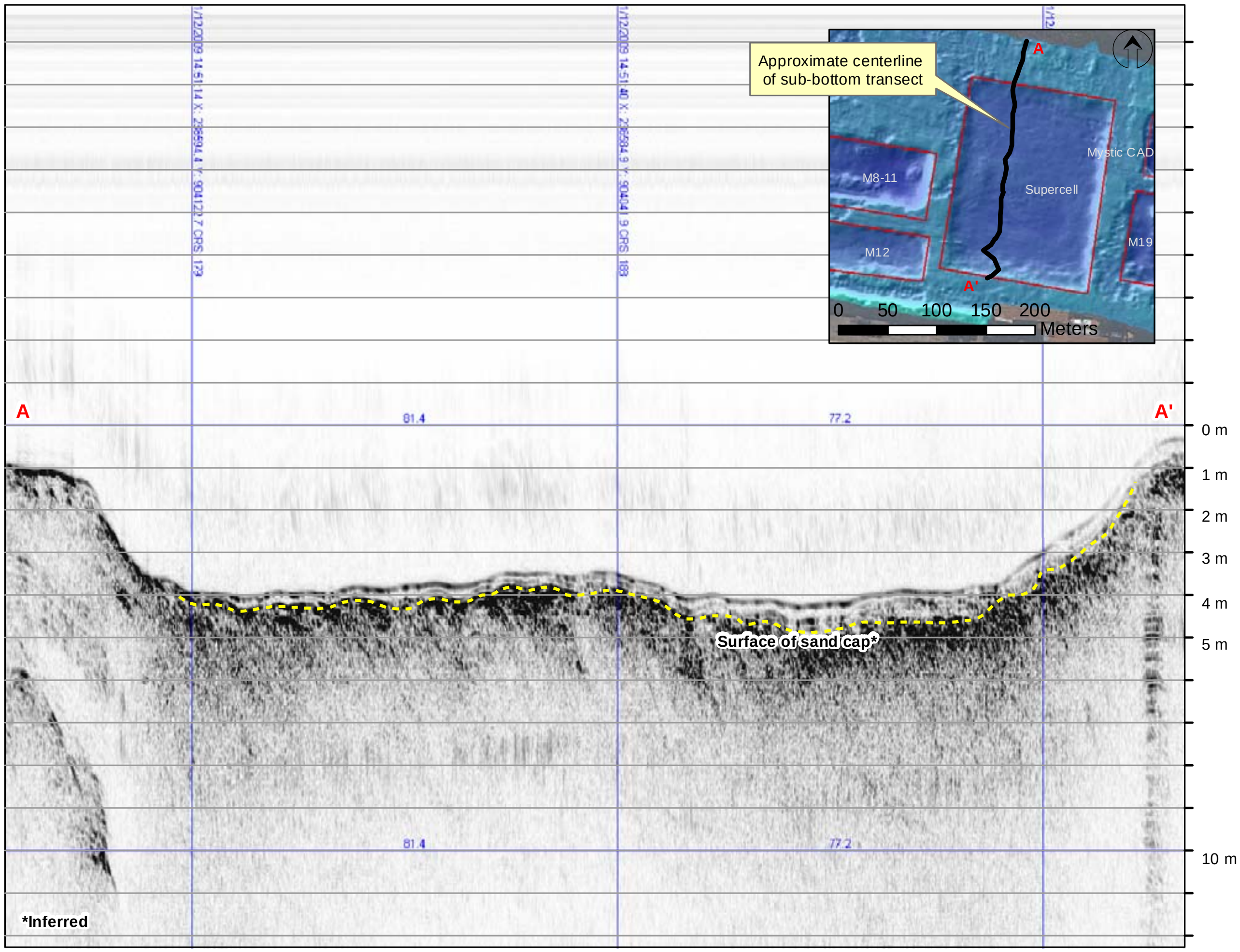



**Figure 3-12**. Supercell sub-bottom profile, November 2009

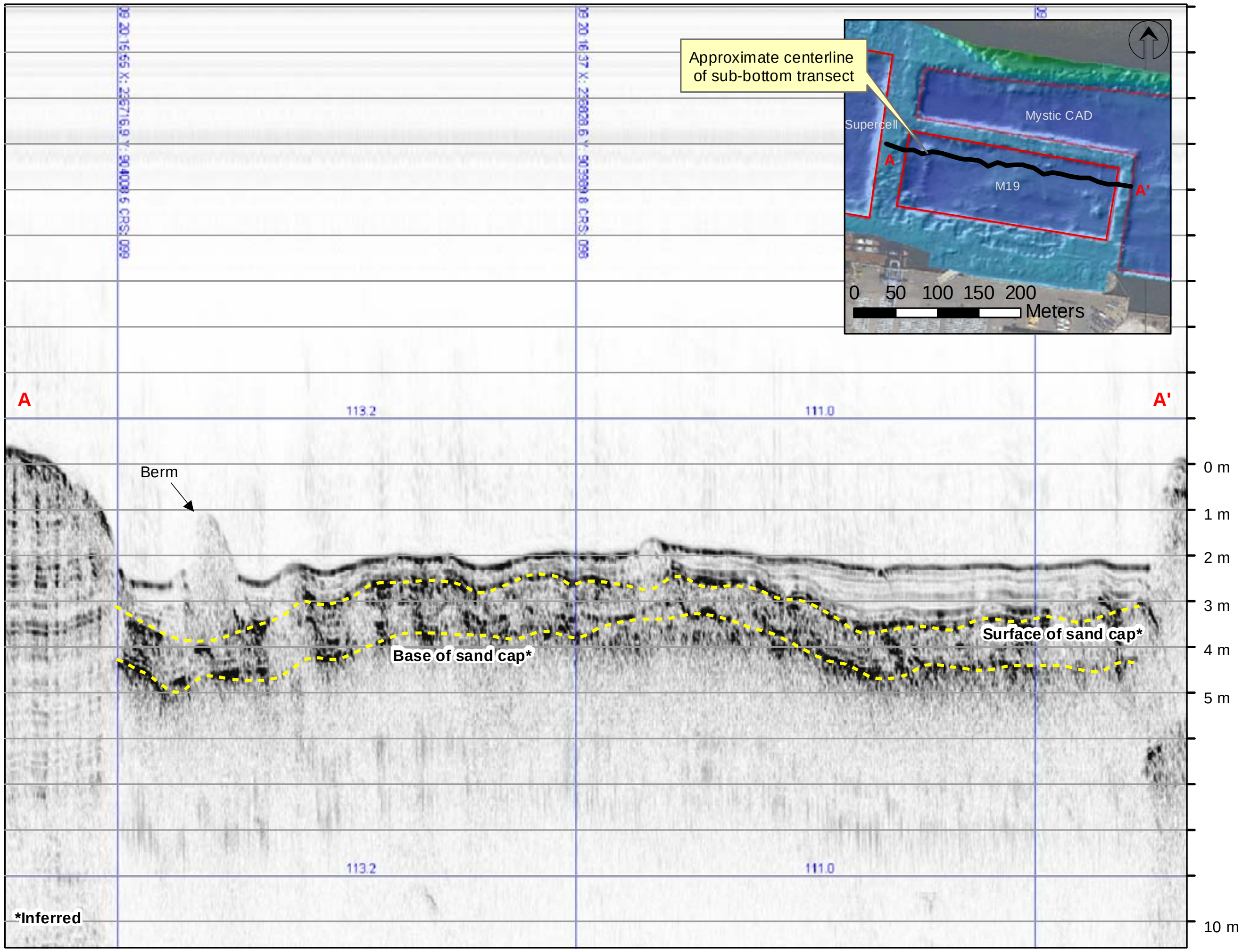



**Figure 3-13**. Cell M19 sub-bottom profile, November 2009

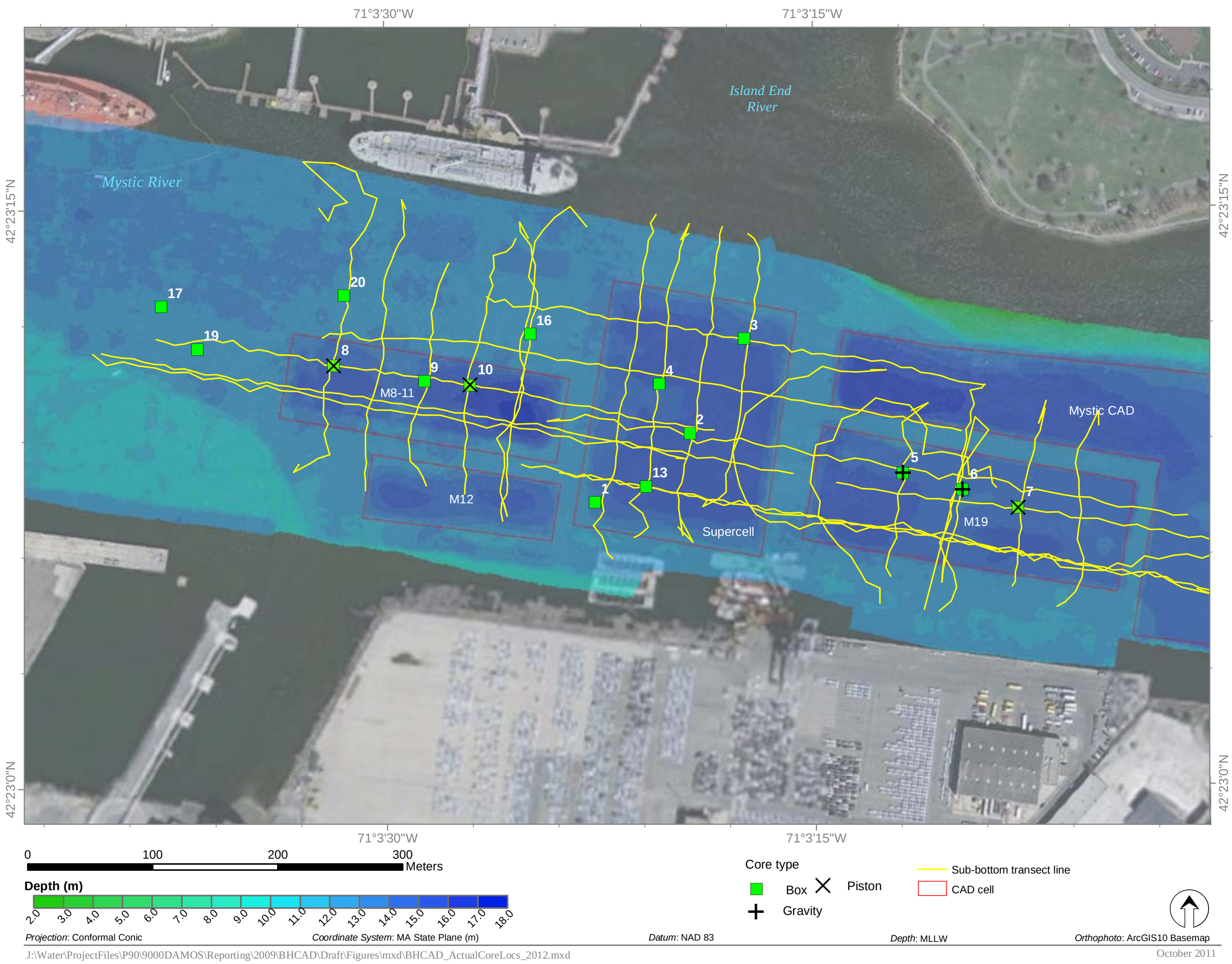



**Figure 3-14**. Core locations with sub-bottom profile lines

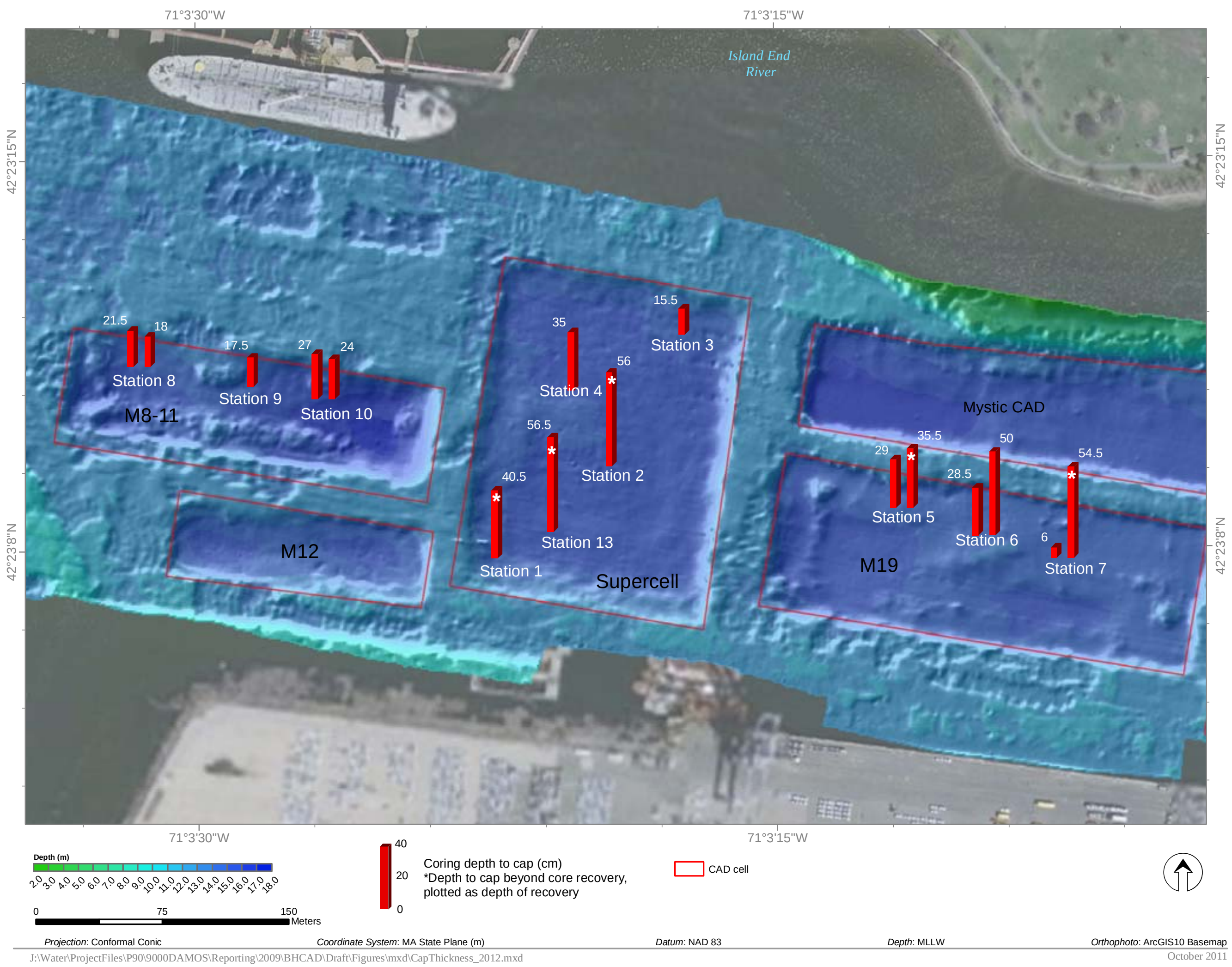



**Figure 3-15**. Depth to sand cap in sediment cores

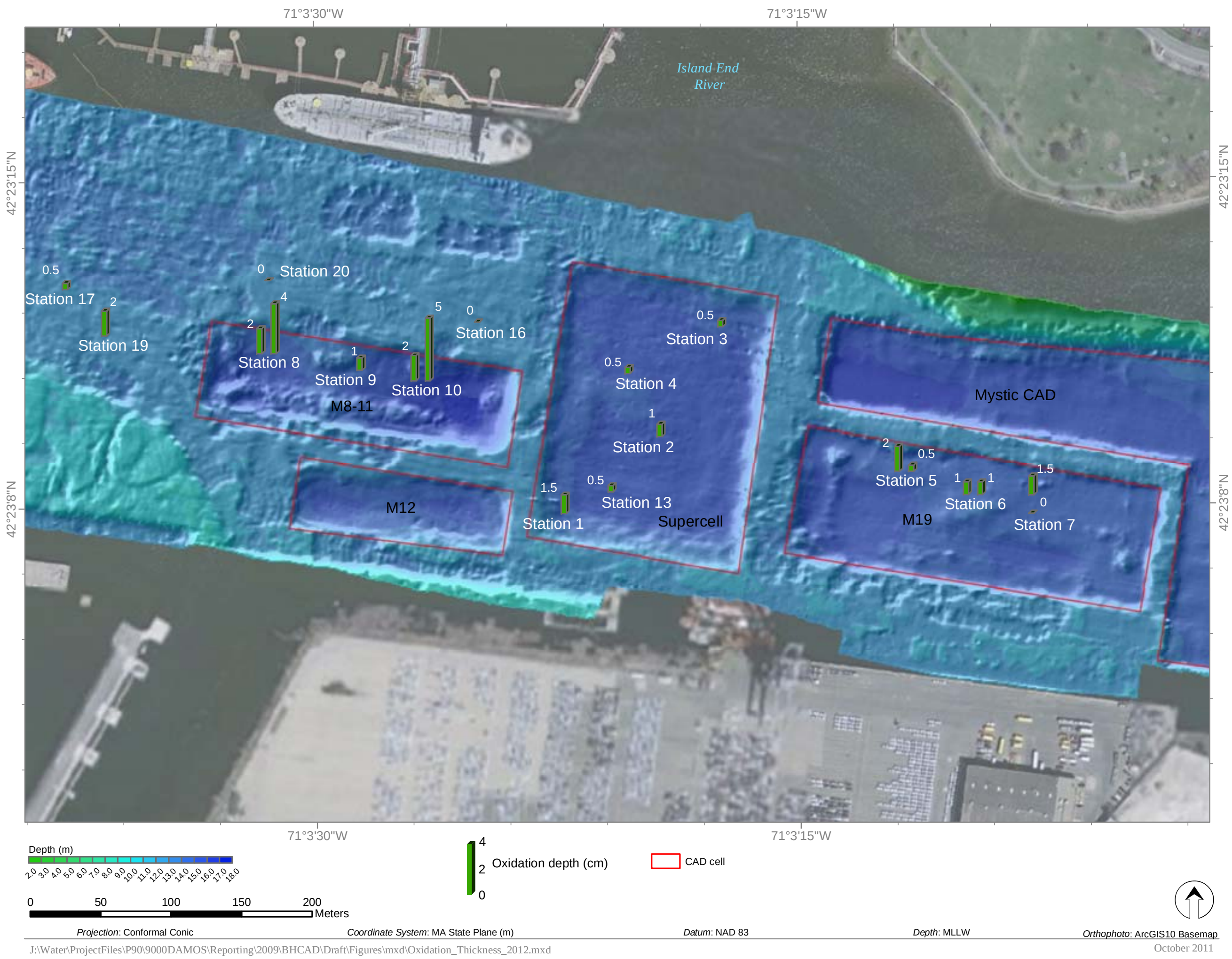



**Figure 3-16**. Oxidation depth in CAD cell and reference area sediment cores

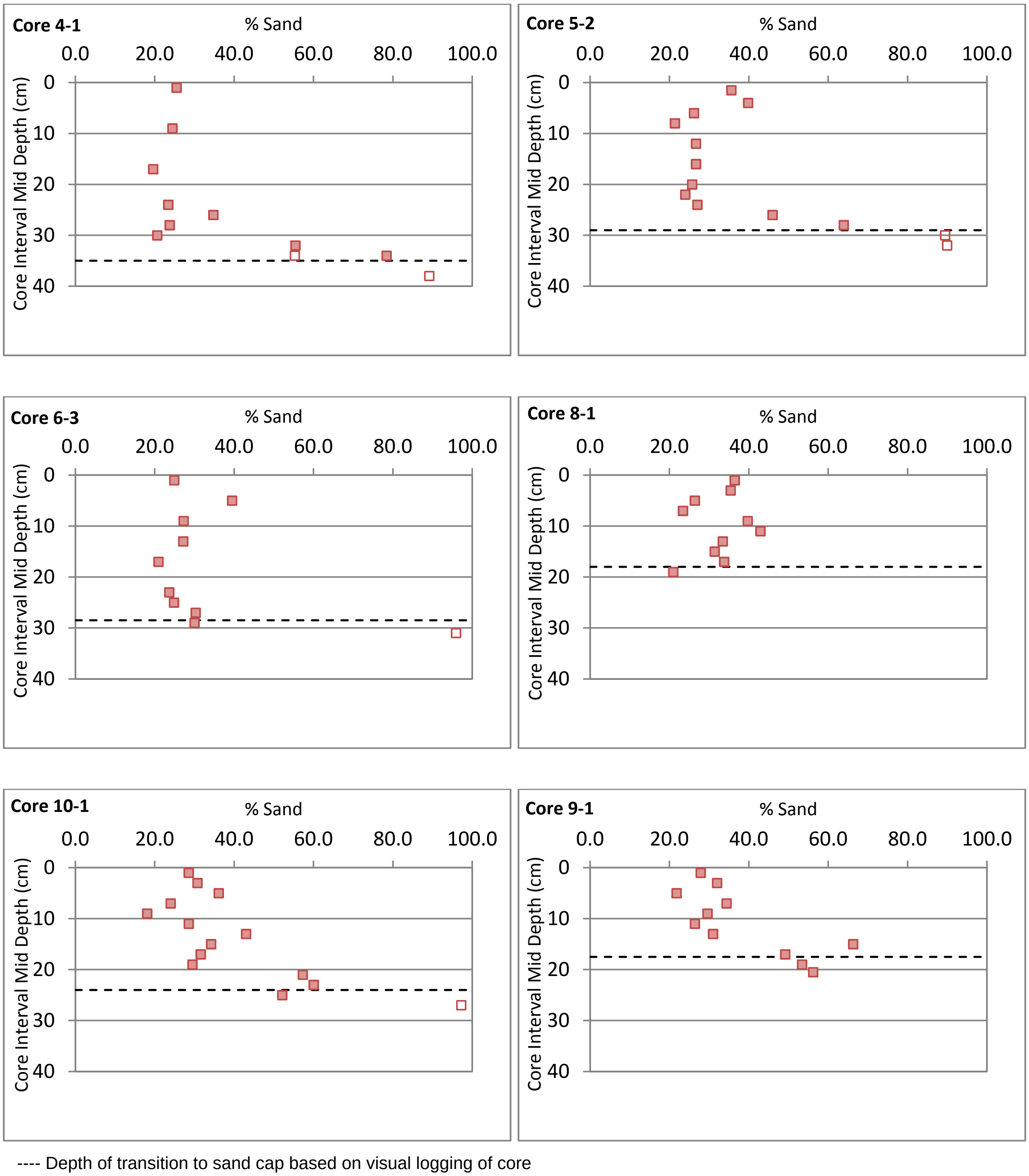



**Figure 3-17.** Selected grain size plots. Filled symbols represent grain size determination using the laser method and open symbols represent the sieve method.

## 4.0 DISCUSSION

Confined aquatic disposal (CAD) was developed as a practical alternative for the disposal of sediments deemed unsuitable for unconfined open-water placement (termed unsuitable dredged material or UDM, Fredette and French 2004). The technique involves isolating the UDM within naturally occurring depressions or cells constructed into the seafloor and optionally capping with a layer of material suitable for open-water placement. The first constructed CAD cell in New England dates back to 1981 and usage has increased over the past two decades with over 20 cells constructed in six harbors (USACE 2012).

The most noteworthy of the New England CAD cell projects is the Boston Harbor Navigation Improvement Project (BHNIP), with nine cells constructed beneath the Federal navigation channel between 1997 and 2000. The BHNIP involved maintenance and improvement dredging within a portion of Boston's inner harbor main ship channel as well as tributary channels and berths. The maintenance dredging was expected to generate approximately 800,000 $m^3$ of UDM. With the selection of CAD cells as the preferred disposal alternative for the UDM (USACE, MPA 1995), the BHNIP marked the first major use of CAD cells in the United States. Given the scale of the project and the innovative use of CAD cells beneath the footprint of the navigable channel, there were a number of concerns related to release of UDM during and following placement into the cells. As a result, the state-issued Water Quality Certification contained multiple conditions requiring monitoring of UDM disposal into the cells as well as capping the cells with a 1 m layer of well-graded sand to further isolate the UDM from the overlying water column and reduce scour potential.

Monitoring occurred throughout the BHNIP, and the results were used to modify CAD cell filling and capping operations as the project progressed (ENSR 2002). The Water Quality Certification required continued monitoring following completion of the overall project. At one year post-project, the cells were determined to be stable structures with continued consolidation of the cell contents, with some deposition of fine-grained material over the cell surfaces, and with a benthic community recovered to one similar to the surrounding harbor area (SAIC 2001). Changes in bathymetry over cell M19 in 2002 led to concerns of potential instability of UDM and cap material (SAIC 2003). However, the five-year post-project monitoring performed in 2004 reaffirmed the cells as stable structures, and determined the bathymetry change in cell M19 was the result of longer term consolidation (ENSR 2007). The consolidation had caused the surface topography of the cell to mirror the underlying bathymetry of the cell floor (i.e., the cell was constructed with an irregular bottom). The sediment-profile imaging (SPI) and towed video conducted in 2004 also demonstrated the continued recovery of the benthic community to one similar to the surrounding harbor area. However, coarse-grained material (sand cap) was not identified in any of the SPI images over the cells. These images extended to a depth of 20 cm into the sediment layer at some stations, supporting the view of the cells depressed below the harbor bottom as preferential depositional areas (ENSR 2007).

The 2009 survey reported here was designed to verify the overall stability of the nine BHNIP CAD cells, some 9–12 years following completion of individual cells and to provide baseline, pre-capping bathymetry of two additional CAD cells constructed in 2008. In addition, the 2009 survey included elements to better understand the rate of deposition onto the surface of previously capped cells and the potential for mixing of deposited material with the underlying cell cap/contents.

## 4.1 CAD Cell Stability

### BHNIP CAD Cells

The Chelsea River Cell, C12, was allowed to remain uncapped at the end of the BHNIP because the cell had significant remaining capacity. Since completion of the BHNIP, cell C12 has received additional UDM periodically, most recently in 2008 with surficial material removed during construction of the new Mystic and Main Ship Channel cells. The 2009 bathymetry of the cell showed it as a distinct feature, depressed 4–6 m below the surrounding channel with additional capacity. Comparison of the 2009 and 2004 bathymetry clearly showed the accumulation of material within the cell related to the additional placement activities, and there was no evidence of scour or loss of material from the cell. The depth differencing did identify a small area of depth increase from 2004 to 2009 just outside of the southeastern corner of the cell (Figure 3-9). This was not considered an indication of overall cell instability; rather it was attributed to slumping along the steeper slope that the BHNIP dredging left along the edge of the channel.

Cell IC2 in the Inner Confluence was the first cell constructed as part of the BHNIP. More than 12 years after its capping, the 2009 survey revealed that cell IC2 remained a distinct feature, depressed 1.5–3 m below the surrounding channel bottom (Figure 3-5). Comparison of the 2009 and 2004 bathymetry revealed no significant measureable changes with no evidence of scour or loss of material from the cell.

The seven BHNIP cells in the Mystic River included the deepest constructed cells of the BHNIP, with four cells dug to -30 m MLLW or deeper (ENSR 2002). The thicker UDM deposits in these deep cells required longer consolidation times to support cap placement, and consolidation continued after placement of the caps. All seven of the cells were identified as stable and distinct features in the 2004 survey, depressed well below the surrounding channel bottom. The seven cells remained as distinct and stable features in the 2009 survey as well, depressed 2–4 m below the surrounding channel bottom. Cells M2, M4, M5, and the Supercell continued to show the relatively flat cell surfaces and steep sidewalls apparent in previous surveys. Cells M8-11, M12, and M19 continued to show more irregular cell surfaces apparent in previous surveys attributed to the cell surface taking on the topography of the cell bottom and/or to the limited placement of more consolidated dredged material on top of the cap (ENSR 2007). No evidence of scour or material loss was noted in any of the Mystic River cells. Accumulation of material based on the bathymetry measurements was only identified in one cell (M19), but deposition was noted in the cores and sub-bottom profiles of other cells as discussed below in Section 4.2.

Some infilling over cell M19 was identified in the comparison of the 2009 bathymetry with the previous 2004 survey. A broad area of the cell experienced approximately 1 m of sediment accumulation with the depression in the western portion of the cell showing more than 2 m of accumulation (Figure 3-3). A comparison of a sub-bottom profile performed over the cell just after capping in 2000 with a profile performed in the 2009 survey highlighted the deposition over the depressed portions of this cell (Figure 4-1). This accumulation of material was attributed to deposition associated with the significant 2008 construction and filling operations of the large Mystic CAD cell that was located immediately adjacent to the northern and eastern boundaries of cell M19.

**2008 Mystic and Main Ship Channel CAD Cells**

At the time of the November 2009 survey, the newer Mystic and Main Ship Channel cells had been constructed, had received UDM, had been allowed to consolidate for nearly 12 months, but had not yet been capped yet. The Main Ship Channel CAD cell was very distinct with steep side slopes and the surface of the cell depressed approximately 6 m below the surrounding harbor bottom. The newer Mystic River CAD cell is now the largest cell in terms of footprint and has the most irregular configuration of the Boston Harbor cells (Figure 3-1). Although well-defined on the western and southern boundaries, the northern boundary of the cell is less defined, merging with the edge of the channel that slopes upward to a shoal area. The eastern boundary of the cell is not discernible with bathymetry as the original construction of the cell proceeded farther east anticipating an even larger cell footprint. As harder parent material was encountered, the cell footprint was reduced leaving a gradual slope on the east with no defined break (Figure 3-2). This anomaly will be an important consideration in the interpretation of future surveys of this cell.

## 4.2 Deposition over CAD Cells

As noted in Section 1.2.2, cells M2, M8-11, M19, and the Supercell were allowed sufficient consolidation such that capping operations resulted in a near-continuous (M2 and Supercell in 1999) or continuous (M8-11 and M19 in 2000) sand layer over the surface of the cells (OSI 2000, SAIC 2001). The 2001 post-project survey identified a thin layer of fine-grained material covering the cells (SAIC 2001), consistent with the location of all BHNIP cells in a known depositional area (this is why the harbor requires periodic dredging). A pilot scale tracer study in the Mystic River performed in 2002 provided further insight into sediment dynamics, documenting preferential deposition into the Supercell from both upriver and downriver sources. It was anticipated that the uniform sand layer at the surface of cells M2, M8-11, M19, and the Supercell would provide a good benchmark from which to measure future deposition. The results of the comprehensive, five-year post-project survey in 2004 were somewhat surprising; although the bathymetry revealed the cells as stable, the sediment-profile imaging (penetrating to a maximum of 20 cm into the surface of the cells) did not reach the sand layer in any of the images collected over cells M2, M8-11, M19, and Supercell implying an accelerated rate of deposition. Using the 2004 sediment-profile image data, the deposition rate was estimated at greater than 7 cm/yr over the cells.

The 2009 survey included design elements to better quantify this deposition rate, targeting cells M8-11, M19, and the Supercell in the portion of the Mystic River that experiences greater vessel traffic (Figure 1-2). The survey included sub-bottom profiling and collection of shallow, low disturbance cores to resolve the interface between the fine-grained accumulated sediment and the sand cap. Visual determination of the depth to cap from examination of the core images was very straightforward, given the sharp transition from fine to coarse grained material, and grain size analysis of core subsamples confirmed the visual assessment, providing a measurement of sediment accumulation since capping. These data provided verification for the sub-bottom profiling, demonstrating very good acoustic resolution of the fine over coarse grained strata (Figures 4-2, 4-3, and 4-4). The multiple sub-bottom lines run over each of the three cells confirmed that although the fine-grained surficial layer varied somewhat in thickness, it was present over most of the cells' surface. This thickness was interpolated over the surface of each of the three cells (Figure 4-5), and an average thickness was calculated (Table 4-1). The average thickness over each cell, coupled with the period of time since the cell was capped, was used to estimate the deposition rate over each cell (Table 4-2).

The estimated deposition rate for cell M19 (7.2 cm/yr) was considered biased high with likely input from the construction and filling of the adjacent 2008 Mystic River cell. The estimated deposition rates for the other two cells were similar (2.7 cm/yr for M8-11 and 3.5 cm/yr for the Supercell). Although these rates were higher than the overall average deposition rate reported for the Mystic River based on previous dredging cycles (0.5 cm/yr [USACE and MPA 1995]), they are considered realistic given that the cells, depressed below the surrounding harbor bottom, act as sediment traps (Fredette 2006).

## 4.3 Stability of CAD Cell Contents

In addition to bathymetry measurements that allowed for assessment of the overall CAD cell stability (e.g. large scale material loss or gain, side wall collapse), the sub-bottom profiling and core collection over three CAD cells in the 2009 survey (M8-11, M19, Supercell) allowed for assessment of the longer term stability of the cell contents. Processes that could affect the cells' contents include shifting of the UDM during consolidation and mixing at the surface of the cells due to physical and biological sources.

In addition to resolving the thickness and interface of the fine-grained deposition on top of the coarse-grained cap material, the 2009 sub-bottom profiling was able to resolve the thickness and general structure of the cap across the cells. Comparison of the sub-bottom profiles of the three cells surveyed in 2009 with those of the surveys performed soon after capping in 1999-2000 revealed no significant changes to the cap layer (e.g. Figure 4-1). This preservation of structure indicated that longer term consolidation had not resulted in overturn or large-scale shifting of the cell contents. The preservation of structure also indicated that despite the location of the cells in an active area of the harbor, large scale disturbance of the upper layer of the cells had not occurred, confirming the results of the vessel passage study performed during the BHNIP (SAIC 2003).

Biological mixing at the surface of cells M8-11, M19, and the Supercell as well as at four reference stations within the channel outside of the cell footprints, estimated by measuring the oxidized layer (apparent redox potential discontinuity [aRPD]) at the surface of the collected cores, was shallow, averaging 1.4 cm in thickness over the cells and 0.6 cm over the channel reference stations. These shallow oxidation depths were similar to the aRPD depths measured during previous SPI surveys and were consistent with the low degree of biogenic reworking and absence of Stage 3 organisms found in those surveys (SAIC 2001, ENSR 2007). Ambient water quality and the high organic loading from watershed sources likely limit biological succession in the harbor benthic community resulting in a long-term state of limited biological mixing for the entire harbor area.

In further support of the shallow biological mixing, very fine layering was evident in the upper portion of the cores from both CAD cell and reference stations (Figure 4-6). Layering such as this is likely caused by localized minor sediment disturbance events in the channel such as the passage of a vessel or input from suspended material in stormwater discharge. This layering could only persist in a depositional area with both shallow biological mixing as well as limited physical disturbance.

## 4.4 Implications for Capping Requirements

Because the BHNIP was the first major use of CAD cells in the United States, there were concerns related to the potential release of UDM to the water column both during placement of material into cells using split-hulled scows and following placement in a tidal environment with active shipping. The initial Water Quality Certification for the BHNIP reflected those concerns, with significant monitoring requirements of disposal events and a requirement that capping be initiated within two weeks following completion of UDM placement into the cell. Sand was specified as the capping material as it was considered easiest to apply evenly and it would be less prone to scour than finer grained material, with a requirement of a 3 ft (approximately 1 m) layer over the cell surface.

The water column monitoring revealed the scows were an effective means for dredged material placement, but the cap monitoring revealed that additional consolidation time was required for successful placement of cap. As the BHNIP progressed through four separate rounds of capping, each with follow up monitoring to assess cap placement, the Water Quality Certification was amended to allow for longer consolidation time. The most successful capping (where success was defined as placement of a uniform layer of cap material with limited displacement of or mixing into the underlying UDM) occurred for the last two cells which were allowed approximately eight months consolidation time.

Follow up monitoring of the BHNIP CAD cells has demonstrated rapid biological recovery to surrounding harbor conditions over the cells (ENSR 2001, SAIC 2001), long term stability of those cells (this report and ENSR 2007), an enhanced deposition rate over the cells (2+ cm/yr), and limited biological and physical mixing of the surficial sediment within the cells. Based on this present understanding, by the time the final two BHNIP cells were capped following eight months of consolidation, they were stable and supported benthic communities similar to the surrounding harbor. Further, given their footprints were depressed well below the surrounding harbor bottom, deposition had likely already occurred over the cells to a thickness greater than the biological mixing depth. This draws into question the overall benefit of capping as weighed against the environmental costs (re-establishment of the benthic community following cap placement plus the significant energy expenditure to collect, transport, and place the cap material) and against the actual project costs (explicit capping costs are not available for the BHNIP, but for the two most recent cells completed in Boston Harbor, capping the cells with sand increased project costs by $3.4 million or over 20%). The practice also potentially diverts the sand from being used in other productive uses such as beach nourishment.

The specific requirements for placement of a cap over a CAD cell containing UDM should be evaluated on a case-by-case basis, taking into consideration specific composition of the UDM as well as the physical and biological setting of the proposed CAD cell. On one end of the range of possible capping scenarios is a highly contaminated UDM in an environment prone to scour or other physical disturbance, biological mixing, or advective transport (e.g. groundwater discharging through the cell) that would require an engineered and potentially armored cap. On the other end of the range, allowing a cell to remain uncovered and to “self cap” may be sufficient for UDM with moderate contaminant levels and a cell located in a depositional environment. Between those endpoints a number of approaches exist that may be effective for a given site: sequencing UDM placement such that the least contaminated material is placed on top; use of material suitable for open water placement from another dredging project as capping material; or placement of a thin-layer cap of coarse grained material soon after UDM placement to accelerate consolidation.

**Table 4-1.**

Depth to Cap Calculations from Sediment Coring and Sub-bottom Analysis

| | Sub-bottom | | | Coring |
|---|---|---|---|---|
| **Location** | **Minimum Depth to Cap (m)** | **Maximum Depth to Cap (m)** | **Mean Depth to Cap (m)** | **Mean Depth to Cap (m)** |
| **M19** | 0.00 | 1.88 | 0.65 | 0.28 |
| **M8-11** | 0.00 | 1.06 | 0.24 | 0.22 |
| **Supercell** | 0.00 | 0.82 | 0.35 | 0.25 |

**Table 4-2.**

Oxidation Depth and Sedimentation Rates at the Boston Harbor CAD Cells

| Location | 2009 Mean aRPD from Cores (cm) | 2004 Mean aRPD from SPI (cm) | 2009 Sedimentation Rate from Sub-bottom Analysis (cm/year) | 2004 Sedimentation Rate (cm/yr)* |
|---|---|---|---|---|
| M19 | 1.0 | 1.0 | 7.2† | > 7.5 |
| M8-11 | 2.6 | 0.6 | 2.7 | > 7.5 |
| Supercell | 0.8 | 0.8 | 3.5 | > 7 |
| Reference | 0.6 | 0.8 | | |

*Sand cap was not observed in 2004 SPI or deep penetrating camera images (30 cm)
†Rate likely influenced by nearby dredging of new cell (see text)

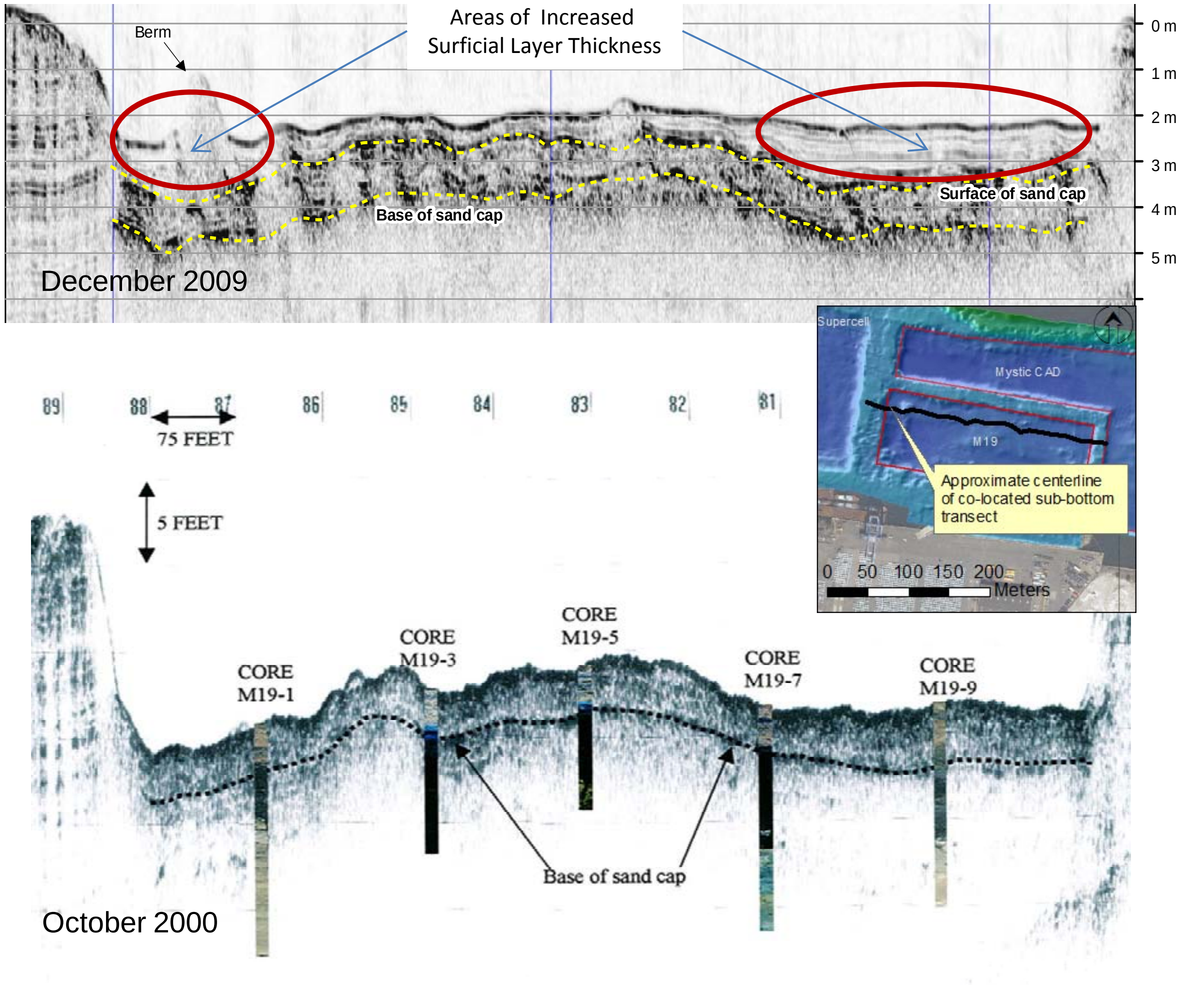



**Figure 4-1.** Approximately co-located sub-bottom transects of cell M19. Upper profile from November 2009, lower profile from October 2000 (OSI 2000).

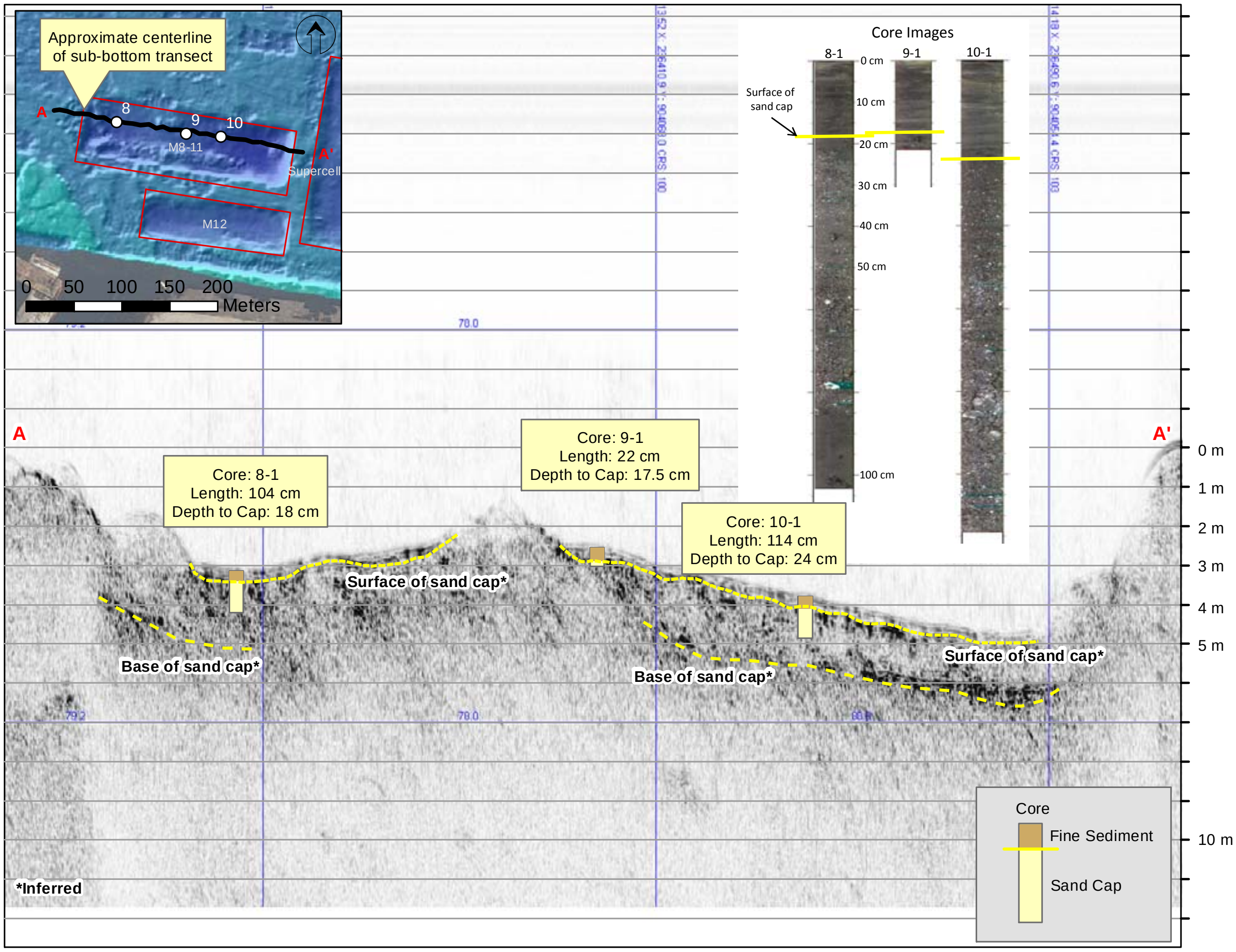



**Figure 4-2.** Sub-bottom profile and sediment cores (2009) from cell M8-11

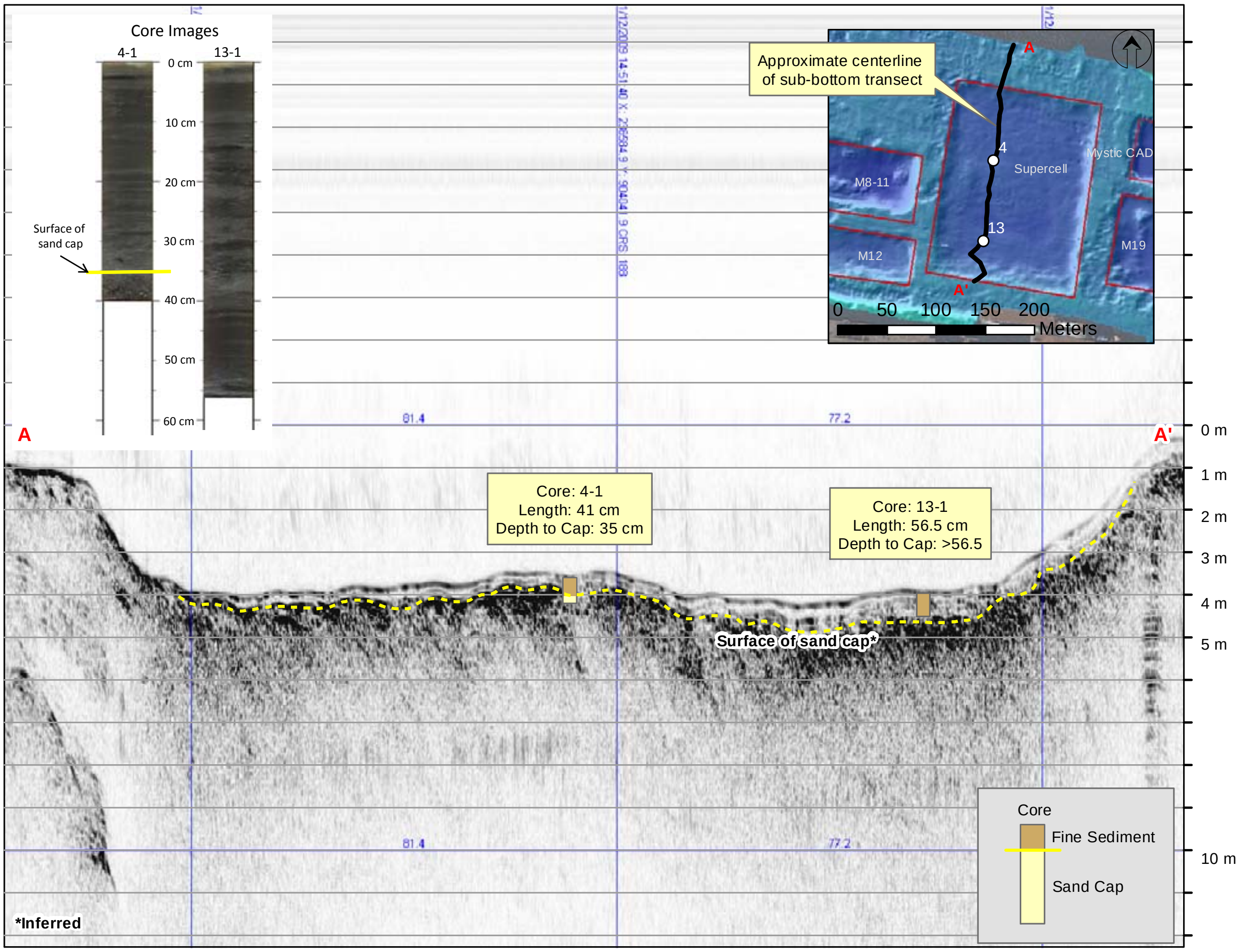



**Figure 4-3.** Sub-bottom profile and sediment cores (2009) from the Supercell

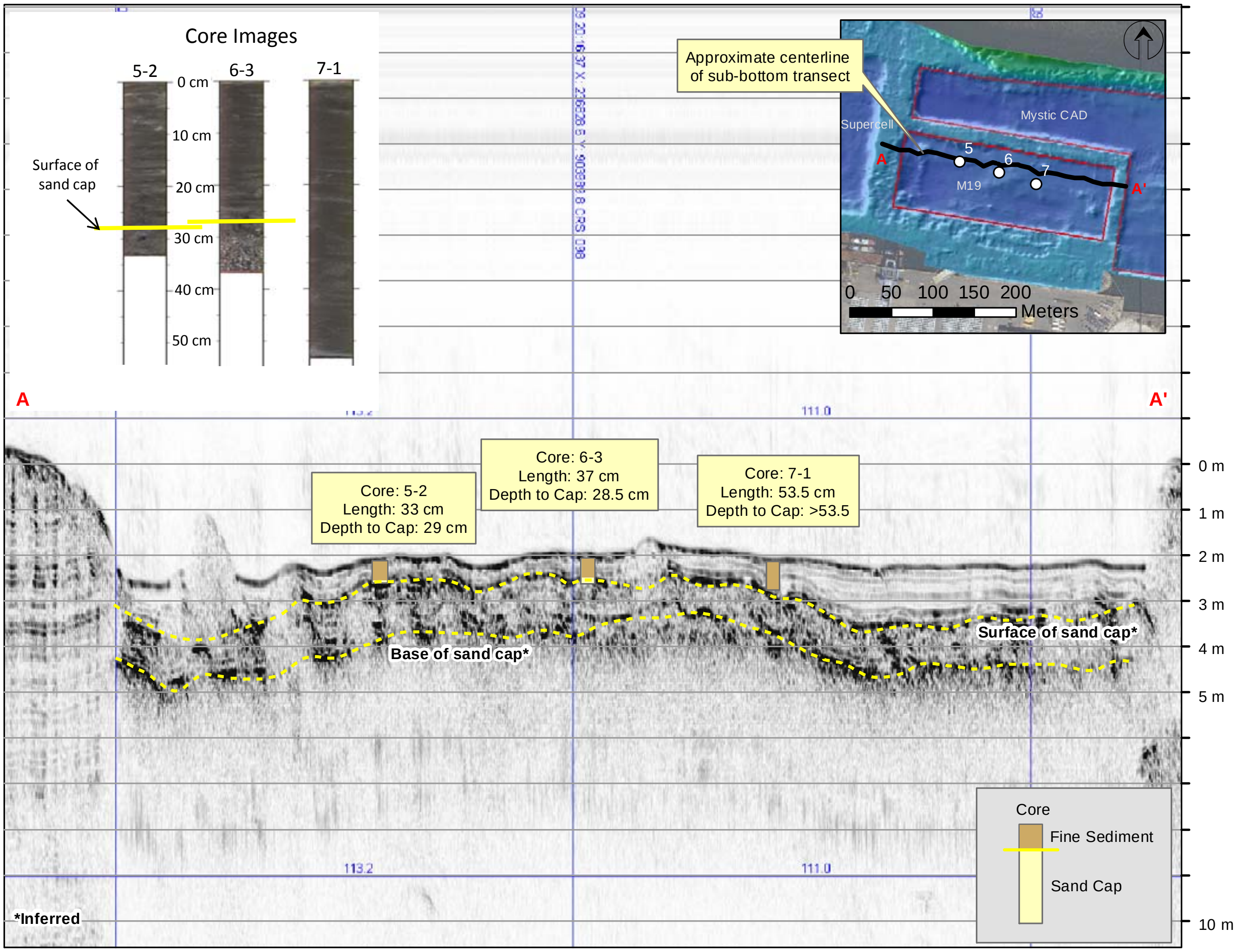



**Figure 4-4.** Sub-bottom profile and sediment cores (2009) from cell M19

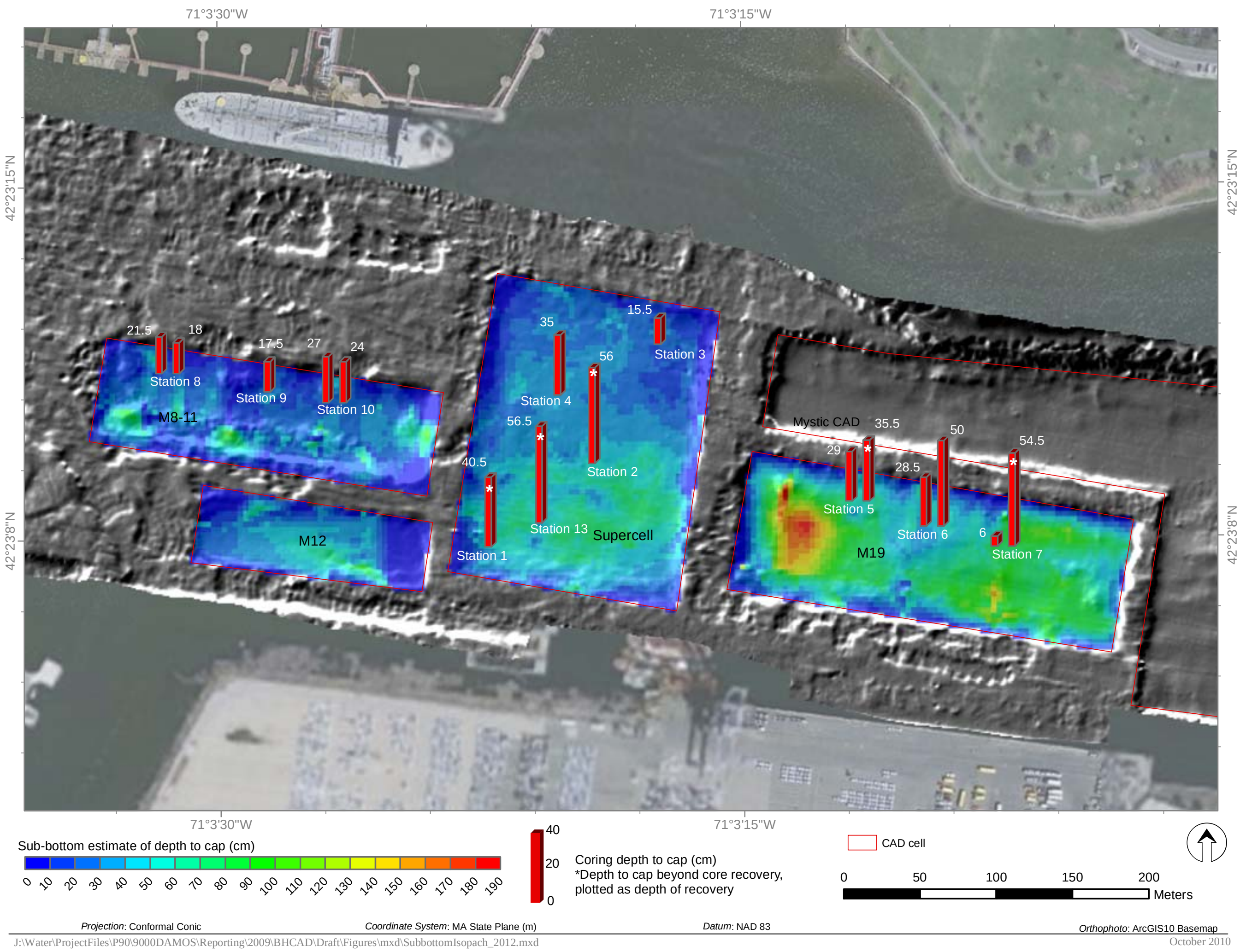



**Figure 4-5.** Sub-bottom and sediment coring estimates of depth to sand cap over hillshaded relief

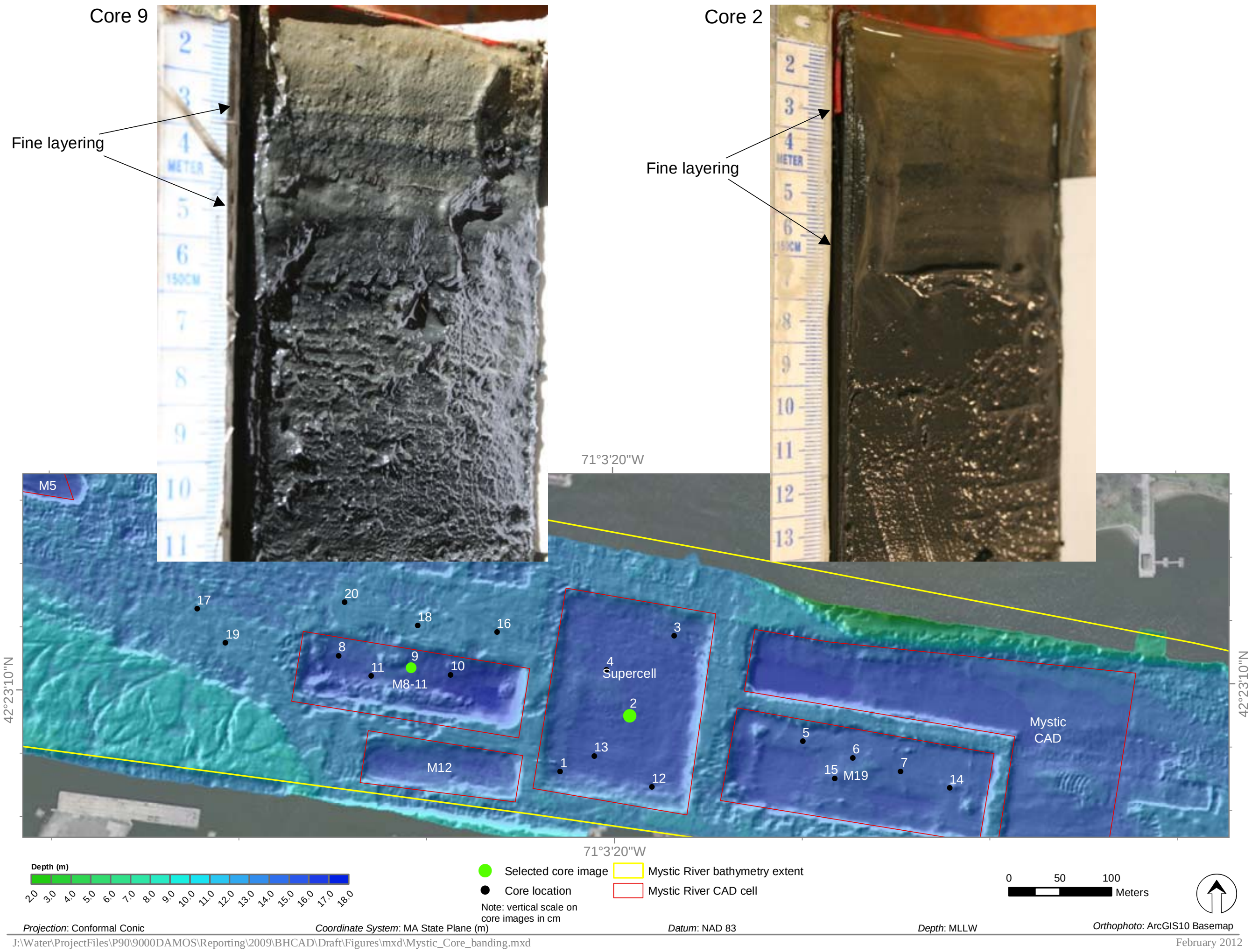



**Figure 4-6.** Fine layering in sediment cores

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

The nine CAD cells constructed as part of the Boston Harbor Navigation Improvement Project (BHNIP) represented the first large-scale application of CAD technology in the United States with cells constructed beneath the footprint of the navigable channel. The cells were constructed with varying dimensions and were capped following varying lengths of consolidation with a requirement for a 1 m sand cap. Given the scale and novelty of the project, there was monitoring performed both during and following the project that furthered the understanding of this management approach for dredged material unsuitable for open water placement.

The 2009 survey reported here provided a long-term assessment some 9–12 years following completion of individual BHNIP CAD cells. It also provided an initial look at two additional cells constructed and filled in 2008, but not yet capped at the time of the 2009 survey. The 2009 bathymetric survey revealed that all nine BHNIP cells remained as stable features on the harbor floor. Consolidation that had been noted over the cells previously had slowed such that it could no longer be resolved through bathymetric measurements or was being masked by ongoing deposition into the cells.

The sub-bottom profiling performed over three cells in the Mystic River that had well-defined sand caps at the end of the BHNIP was able to resolve the cap layer, indicating long term stability of the material within the cells. In addition, the sub-bottom profiling, together with the collection of shallow, minimally disturbed cores, confirmed the expectation of enhanced deposition over the cells depressed below the surrounding harbor bottom. Deposition rates of 2+ cm/yr were estimated over these cells. This deposition, coupled with an observed shallow biological mixing depth and evidence of limited physical disturbance, indicate that by the time the cells had consolidated sufficiently to allow effective placement of the sand cap, sequestration of the material within the cells was already taking place through ongoing deposition. Hence, future CAD cell projects should take into account the physical and biological environment the cell is being placed into, and the need for a cap or type of cap required should be weighed against expected environmental and project costs.

Given the record of physical stability and benthic recovery of the BHNIP CAD cells, only long-term bathymetry monitoring is recommended as a periodic check on cell stability. For the two additional cells capped after completion of the 2009 survey, performance of bathymetry and sediment-profile imaging is recommended as confirmation of completion and benthic recovery.

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Appendix A

Core Log Sheets for BHCAD
November 2009 Survey

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program | CORE NO: 1-1 |
| | Project Number: 60133145 | |
| | Station Location: Boston Harbor | |
| | GPS Coordinates: 236536.79, 903969.71 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 10:50 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration: 39.0 | Recovery: 39.0 | % Recovery: 100 | No. Attempts: 2 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10<br>20<br>30<br>40<br>50<br>60 | | Top 0 – 1.5 cm light brown / tan oxidized soft<br>followed by 1.5 cm light green to 3 cm with black<br>striation at 2 cm (few mm thick)<br><br>Followed by 1.5 cm darker grey layer to 4.5 cm followed by<br>black layer to 5.5 cm<br>followed by lighter grey layer to 7.5 cm<br>Followed by nearly uniform darker grey layer to 15 cm<br>Followed by black layer to 16.5 cm<br>Followed by slightly lighter layer to 20.5 cm<br>then darker (very slight) to 23 cm then<br>nearly uniform to EOC at 39 cm<br><br>No coarse material observed anywhere within the core<br><br>Very high liquid content to 0.5 cm<br>More competent to 3.5 cm<br>More competent to 8 cm<br>Water content continues to 15 cm<br>Less sheen 15 to 30 cm<br>less water / sheen visual 30 – EOC at 39 cm |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program | CORE NO: 2-1 A |
| | Project Number: 60133145 | |
| | Station Location: Boston Harbor | |
| | GPS Coordinates: 236612.78, 904025.32 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 10:12 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 55.9 | Recovery (cm): 54.5 | % Recovery: 98 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10<br>20<br>30<br>40<br>50<br>60 | | Oxidized surface layer to 1 cm<br>Followed by grading to grey material<br>with faint dark horizontal striations to 6.5cm<br>Then darker grey uniform to 13.5<br>then light, dark, light to 17 cm then<br>very dark to 18.5cm then lighter to 20 cm<br>followed by very light layer 20-21 cm<br>then very dark 21.5 to 22.5 cm<br>then lighter to 25 cm<br>then very dark to 25 to 26 cm<br>Followed by nearly uniform grey layer to 36.5 cm<br>then very dark to 36.5 to 38 cm<br>followed by lighter grey to 44 cm then<br>grades into dark grey to EOC at 54.5 cm<br><br>Moisture:<br>liquid to 0.5 cm<br>then grades into slightly less moisture to about 9.5 cm<br>then less to about 40cm<br>then uniform to EOC<br><br>Presence of coarse material 40-42 cm<br><br>Also shell obscured at 30.5 cm – small mussel shell |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program<br>Project Number: 60133145<br>Station Location: Boston Harbor | CORE NO:<br>3-1 C |
| | GPS Coordinates: 236656.07, 904101.01 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 9:54 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 33.3 | Recovery (cm): 33.0 | % Recovery: 99 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10 | | 0-.5 cm of brown oxidized sediment at this station<br>then light green to 4 cm followed by very dark black<br>then darker grey to 1.5 followed by<br>slightly lighter (dark) grey to 15.5 |
| 20 | | Below 15.5 the sediment character changes<br>Lighter in color (grey)<br>Coarse material is present below interface at 15.5 cm |
| 30 | | Material continues to 18.5 cm; below this a very dark band is encountered<br>although texture seems unchanged (still coarse) to 20 cm |
| 40 | | Then lighter in color to 22.5 cm then<br>very coarse with shell hash to 25 cm<br><br>Then less coarse material below to 31 cm |
| 50 | | Then greater coarse content from 31 cm to EOC at 33 cm<br><br>Interface is pronounced (See photo attempt with arrow) |
| 60 | | |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program | CORE NO: 4-1 B |
| | Project Number: 60133145 | |
| | Station Location: Boston Harbor | |
| | GPS Coordinates: 236588.27, 904064.57 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 10:12 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 41.0 | Recovery (cm): 40.0 | % Recovery: 98 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10 | | 0-.5 cm oxidized tan liquid/water rich material<br>at surface followed by light grey material to 6 cm<br>then nearly uniform / dark grey below 6 cm to 19 cm |
| 20 | | At 19 cm narrow .5 light grey band<br>followed by nearly uniform dark grey to 23.5<br>then very slight coloration shift (lighter) to 24.5 cm<br>then darker to 26cm<br>then lighter layer to 35 cm with minor dark band 29-29.5 cm |
| 30 | | Very sharp interface to sand/cap at 35 cm<br>with pebble 1.5 cm, sand and shell hash to EOC at 40 cm |
| 40 | | Water: Very high water content to 0.5 cm<br>high water content to about 6 cm<br>then grades to less water to cap interface (35 cm)<br>then dryer sand and coarse later to EOC at 40 cm |
| 50 | | |
| 60 | | |

% Recovery = [ (Recovery) / (Penetration) ] x 100:

AECOM

| | | |
|---|---|---|
| Client: ACOE DAMOS Program | | CORE NO: 5-1 A |
| Project Number: 60133145 | | |
| Station Location: Boston Harbor | | |
| GPS Coordinates: 236783.00, 903993.46 | | |
| Geographic Reference: MA State Plane Meters | | Sheet: 1 of 1 |
| Water Depth (MLLW, m, ft): | | Core Size (in.): 2 5/8 |
| Weather: 50°, windy | | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 11:10 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 34.9 | Recovery (cm): 35.5 | % Recovery: 102 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10 | | 0-0.5 cm tan/highly oxidized layer followed by<br>grey / dark grey banding to 4 cm (1 cm grey, triangular black band )<br>followed by grey with black striations at 3 cm<br><br>below 4 cm, black silt to 6 cm<br>then density increases at 6 cm with continued very dark black silt below |
| 20 | | Small clay clasts at 12, 14, and 18 cm<br>12 – 0.5 and 1 cm<br>14 – 1 and 1 cm<br>18 – 1 and 2 cm |
| 30 | | Uniform dark grey below (14 cm) to 31 cm<br>lighter grey band 31 to 33 cm, 2 cm thick<br>lighter grey material to EOC at 35.5 cm |
| 40 | | Very soft to 0.4 cm then more competent to 6cm<br>then more competent to 16 to 28 cm<br>ten very competent to EOC at 35.5 cm |
| 50 | | |
| 60 | | |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program | CORE NO: 5-2 |
| | Project Number: 60133145 | |
| | Station Location: Boston Harbor | |
| | GPS Coordinates: 236783.00, 903993.66 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| | | | | |
|---|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 15:14 | |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | | |
| Sampling Equipment: Gravity Core | | | | |
| Actual Penetration (cm): >41.3 | Recovery (cm): 33.0 | % Recovery: >80 | No. Attempts: 1 | |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10<br>20<br>30<br>40<br>50<br>60 | | Oxidized layer to 2 cm possibly tan with light grey immediately below to 2 cm<br>Followed by black layer to 4 cm into light grey and black irregular about 6 – 8 cm<br><br>Then nearly uniform dark grey to 16 cm<br>Followed by lighter grey horizon 1 cm thick to 17 cm<br>then .5 cm horizon<br>Then 1.5 cm lighter grey to 19 cm then<br>.5 cm black then lighter grey to 22 cm then<br>.5 black then lighter grey to 25 cm then<br>1 cm black then lighter grey to 29 cm then<br><br>strong coarse interface at 29-29.5 cm<br>very coarse below to EOC at 33 cm<br><br>Moisture<br>Very wet<br>More competent below 2<br>More competent below 5<br>More competent below 13 to EOC |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| AECOM | Client: ACOE DAMOS Program | | | CORE NO: 6-1 B |
|---|---|---|---|---|
| | Project Number: 60133145 | | | |
| | Station Location: Boston Harbor | | | |
| | GPS Coordinates: 236830.72, 903980.29 | | | |
| | Geographic Reference: MA State Plane Meters | | | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | | | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | | | |
| Survey Vessel: Shanna Rose | | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 12:33 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | | |
| Sampling Equipment: Box core | | | | |
| Actual Penetration (cm): 50.8 | | Recovery (cm): 50.5 | % Recovery: 99 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| | | Tan oxidized to 1 cm light grey below<br>with some very dark interbands to 4cm |
| 10 | | Then very dark 4-8 cm below where material appears<br>more competent, fairly uniform to 17 cm |
| 20 | | Then lighter horizontal 17-18 cm<br>darker to 18027 cm<br>light to 29 cm<br>darker to 31 cm<br>lighter to 31-32.5 cm<br>very dark / black to 32.5 to 33.5 cm<br>very light 33.5 to 34 then darker at 35 cm |
| 30 | | then nearly uniform to 43 cm<br>very dark 43-44 cm followed by<br>lighter layer to 46 cm<br>darker to 47.5 cm<br>then lighter to EOC at 50.5 |
| 40 | | Some coarse lateral appears at EOC,<br>also shell fragments (about 2 cm dia) noted at 47 cm (see photo) |
| 50 | | Moisture:<br>0.5 cm water<br>more competent to 4 cm<br>less competent to 8 cm<br>more competent to 16 cm |
| 60 | | more competent to 22 cm<br>very competent below to EOC |

% Recovery = [ (Recovery) / (Penetration) ] x 100:

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program<br>Project Number: 60133145<br>Station Location: Boston Harbor | CORE NO:<br>6-3 |
| | GPS Coordinates: 236830.72, 903980.29 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 15:32 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Gravity Core | | | |
| Actual Penetration (cm): 46.3 | Recovery (cm): 37.0 | % Recovery: >80 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10 | | Tan oxidize to 1 am; light grey below to 2 cm<br>followed by very dark/uniform material to 8 cm with<br>black to 16 cm then "lighter" to 17.5; black to 18cm<br>then lighter to 19 cm then lighter to 21 cm then black to 22cm<br>blending to nearly uniform dark to 25 cm |
| 20 | | Some coarse material mixed to strong cap/<br>coarse compact interface at 28.5 cm |
| 30 | | Then very coarse / uniform below (as cap) to EOC at 37 cm |
| 40 | | High liquid to 1.5 cm<br><br>Then more competent to 4 cm |
| 50 | | Then lighter to 13 cm<br><br>Then lighter below to layer about 25 cm |
| 60 | | |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program<br>Project Number: 60133145<br>Station Location: Boston Harbor | CORE NO:<br>7-1 |
| | GPS Coordinates: 236875.29, 903966.04 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 12:52 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 58.4 | Recovery (cm): 53.5 | % Recovery: 92 | No. Attempts: 2 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10<br>20<br>30<br>40<br>50<br>60 | | 0-1.5 cm tan oxidized layer<br>followed by thin black layer 0.5 cm thick<br>followed by lighter grey layer to 5cm<br>then darker grey layer to 8cm<br>then uniformly grey to 20.5 cm<br><br>with 1 cm lighter grey band then nearly<br>uniform dark grey to EOC at 53.5 cm<br><br>Moisture:<br>Very liquid/ high water to 1 cm<br>more competent below to 5 cm<br>less competent below to 6.5 cm<br>more competent below to 20 cm<br>more competent below to EOC at 53.5 cm<br><br>No coarse material identified at base |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| AECOM | Client: ACOE DAMOS Program | | | CORE NO: 7-2 |
|---|---|---|---|---|
| | Project Number: 60133145 | | | |
| | Station Location: Boston Harbor | | | |
| | GPS Coordinates: 236875.29, 903966.04 | | | |
| | Geographic Reference: MA State Plane Meters | | | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | | | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | | | |
| Survey Vessel: Shanna Rose | | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 14:31 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | | |
| Sampling Equipment: Piston Core | | | | |
| Actual Penetration (cm): 27.5 | | Recovery (cm): 22.0 | % Recovery: >80 | No. Attempts: 2 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10 | | Very mild oxidized film observed before splitting<br>(post coring / collection oxidation?)<br><br>Very fine silt, very liquid surface, dark grey to 6 cm<br><br>very strong coarse / cap interface below 6 cm to EOC at 22 cm<br>with fine silt/clay “clast”2 cm to 3 cm and 18 to 20 cm |
| 20 | | |
| 30 | | |
| 40 | | |
| 50 | | |
| 60 | | |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program<br>Project Number: 60133145<br>Station Location: Boston Harbor | CORE NO:<br>8-1 |
| | GPS Coordinates: 236327.67, 904079.10 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 45°, windy, cloudy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/12/2009 | Time: 16:07 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Piston Core | | | |
| Actual Penetration (cm): 29.2 | Recovery (cm): 103.0 | %Recovery: 353 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10<br>20<br>30<br>40<br>50<br>60 | | Oxidized layer 0 – 4 cm very prominent<br>grades into dark grey below<br><br>Also density interface at about 2 cm to 4 cm<br><br>Cap material interface at 18 cm<br><br>Coarse sand with shells in cap 18 cm to about 87.5 cm<br><br>With silt and black material below<br><br>*Crepidula fornicata* shell embedded (Slipper shell)<br><br>End at 103 cm |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program | CORE NO: 8-2 B |
| | Project Number: 60133145 | |
| | Station Location: Boston Harbor | |
| | GPS Coordinates: 236327.67, 904079.10 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 8:29 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 29.2 | Recovery (cm): 31.5 | % Recovery: 108 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| | | 0 – 2 cm oxidized tan fine sediment |
| | | Grades into black soft sticky material |
| 10 | | Below see vertical photo banding apparent<br>black bands about 1 cm think dark green or lighter grey |
| | | 3 prominent dark bands apparent at about 7 – 8 cm, 10-11 cm, and 12.5-13.5 cm |
| 20 | | Sand cap interface at 21.5 cm |
| 30 | | 31.5 cm EOC |
| 40 | | |
| 50 | | |
| 60 | | |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| AECOM | | | CORE NO: 9-1 A |
|---|---|---|---|
| | Client: ACOE DAMOS Program | | |
| | Project Number: 60133145 | | |
| | Station Location: Boston Harbor | | |
| | GPS Coordinates: 236400.32, 904067.01 | | |
| | Geographic Reference: MA State Plane Meters | | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): 58’ | | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | | |
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 7:18 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 23.5 | Recovery (cm): 22.0 | % Recovery: 94 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10 | | Oxidized/tan layer 0 - .8 cm or 0 – 1 cm<br>then light grey below to 2 cm then<br>sharp banding as black / grey intervals<br>to 4 cm then 1 cm grey followed by<br>1-2 cm darker black band to 6.2 cm followed by<br>charcoal grey nearly uniform to 13 cm then<br>slightly lighter horizon to 15.5 cm |
| 20 | | Coarse horizon observed 15.5 to 16 am<br>then mostly fine with some coarse material along one<br>core tube wall extending about 2 cm from wall |
| 30 | | Then layer of coarse material below 17.5 cm to EOC at 22 cm |
| 40 | | |
| 50 | | |
| 60 | | |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program<br>Project Number: 60133145<br>Station Location: Boston Harbor | CORE NO:<br>10-1 |
| | GPS Coordinates: 236436.70, 904063.79 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): 52’ | Core Size (in.): 2 5/8 |
| | Weather: 45°, windy, cloudy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/12/2009 | Time: 13:50 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 114.0 | Recovery (cm): 114.0 | % Recovery: 100 | No. Attempts: 3 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10<br>20<br>30<br>40<br>50<br>60 | | High water content 1 – 1.5 cm<br>Dense to about 4.5 cm<br>Water content grading to dryer to 8 cm<br>Then uniform (water content)<br><br>Color : Grey at surface to oxidized layer<br>at 4.5 to 7.5 cm tan then grades to grey / dark grey below<br>Some banding apparent (see photo) Not as pronounced at 8-1<br><br>Presence of sand at 18 cm (about 1 cm)<br>Sand appears 21-23 cm (irregular)<br>Strong sand interface at 24 cm<br><br>Coarse material below to EOC at 114 cm |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program | CORE NO: 13-1 A |
| | Project Number: 60133145 | |
| | Station Location: Boston Harbor | |
| | GPS Coordinates: 236577.67, 903982.63 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 13:07 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 58.4 | Recovery (cm): 56.0 | % Recovery: 96 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10 | | 0-0.5 cm light brown followed by light grey to 3.5 cm<br>followed by darker grey uniform layer to 8.5 cm<br>then lighter grey layer to 10.5 cm<br>then darker layer to 12 cm then heterogeneous<br>(horizontal gradations) light with depth increasing to 14.5 cm |
| 20 | | very dark black 14.5 to 15 cm<br>then lighter grey to 18 cm<br>then very dark to 19 cm |
| 30 | | Below 19 cm material color is nearly uniform<br>to 30.5 cm but with possible texture character changes<br>(22-24 and 27-29 cm)<br>-perhaps clay vs silt ratio changes |
| 40 | | Then dark layer 30.5 to 35.5 cm<br>then lighter to 41.5 cm<br>then thin darker to 42 cm<br>then lighter to 42.5 cm<br>then nearly uniform dark grey to EOC at 56 cm |
| 50 | | Moisture:<br>very high water to 0.5 cm<br>then slightly less to 4 cm<br>then sheen to 7.5 cm<br>then grades to less sheen at 18 cm |
| 60 | | Then less again at 18 to 36 cm<br>then slightly more sheen to EOC at 56 cm |

% Recovery = [ (Recovery) / (Penetration) ] x 100:

| AECOM | Client: ACOE DAMOS Program | | | CORE NO: 16-1 |
|---|---|---|---|---|
| | Project Number: 60133145 | | | |
| | Station Location: Boston Harbor | | | |
| | GPS Coordinates: 236484.90, 904104.61 | | | |
| | Geographic Reference: MA State Plane Meters | | | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | | | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | | | |
| Survey Vessel: Shanna Rose | | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 9:06 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | | |
| Sampling Equipment: Box core | | | | |
| Actual Penetration (cm): 48.3 | | Recovery (cm): 47.5 | % Recovery: 98 | No. Attempts: 2 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10 | | Very soft to about 1 cm<br>denser below<br>some sand apparent at 2.5 cm, continues to 4.5 cm<br>then back to soft dark silt right below<br>1 x 2 cm wood 9 to 11 cm depth<br>embedded black silt to 18 cm<br>then narrow horizon of sand at 18 cm (18-18.5cm) |
| 20 | | Then uniform black silt / soft below to EOC at 47.5 cm |
| 30 | | |
| 40 | | |
| 50 | | |
| 60 | | |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program<br>Project Number: 60133145<br>Station Location: Boston Harbor | CORE NO:<br>17-1 A |
| | GPS Coordinates: 236189.89, 904126.14 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): 51’ | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 8:44 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 33.0 | Recovery (cm): 33.0 | % Recovery: 100 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10<br>20<br>30<br>40<br>50<br>60 | | Tan/oxidized at surface to about .5 cm then light grey below to<br>about 6 cm; then very dark black to 15 cm<br>then not so black / dark grey to EOC at 33 cm<br><br>2 and 4 cm Boston blue clay clast at 15-17 cm<br>Very small Boston blue clay embedded (scattered) then another*<br>1.5 x 4 cm clast 27 to 29 cm and then very large cross core / about full diameter core clay clast at base<br>( about 3 cm x core diameter)<br><br>Density changes at 0.5, 3 cm<br><br>Surface sheen(decreasing) ~0-3; 3-15 or 17; 17-EOC at 33 cm<br><br>*small engrained pebbles |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| | | |
|---|---|---|
| AECOM | Client: ACOE DAMOS Program<br>Project Number: 60133145<br>Station Location: Boston Harbor | CORE NO:<br>19-1 A |
| | GPS Coordinates: 236218.68, 904092.29 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| | | | |
|---|---|---|---|
| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 9:35 |
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 33.7 | Recovery (cm): 27.5 | %Recovery: 82 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10<br>20<br>30<br>40<br>50<br>60 | | Water content sheen:<br>-very high 0-1 to 0-0 .5 cm<br>-high 1 – 6 cm<br>-uniform to clay clast at base, moderately high<br><br>Coloration<br>Tan oxidize 0 – 2 cm<br>then very dark black to clay<br><br>2 x 3 cm clay 11.5 to 15 cm<br>angular clay full core plug 16.5 to 18.5 cm<br>3 cm thick, then .5 cm break in clay<br>filled in with very dark or black silt<br><br>Followed by clay from 22.5 to EOC at 27.5 |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

| AECOM | Client: ACOE DAMOS Program | CORE NO: 20-1 B |
|---|---|---|
| | Project Number: 60133145 | |
| | Station Location: Boston Harbor | |
| | GPS Coordinates: 236335.92, 904135.22 | |
| | Geographic Reference: MA State Plane Meters | Sheet: 1 of 1 |
| | Water Depth (MLLW, m, ft): | Core Size (in.): 2 5/8 |
| | Weather: 50°, windy | |

| Survey Vessel: Shanna Rose | Logged By: A.Hopkins | Date: 11/13/2009 | Time: 13.22 |
|---|---|---|---|
| Survey Personnel: A. Hopkins, D. Lewis, J Goodwin, Chris Cheney, Eli Perrone, Don Boye | | | |
| Sampling Equipment: Box core | | | |
| Actual Penetration (cm): 30.5 | Recovery (cm): 28.5 | %Recovery: 93 | No. Attempts: 1 |

| Depth (cm) | SKETCH | DESCRIPTION |
|---|---|---|
| 10<br>20<br>30<br>40<br>50<br>60 | | Veneer of light grey material at surface (post collection oxidation?)<br><br>moderately soft 6 cm, slight density increase<br>at 6cm then nearly uniform to 20 to 23 cm where<br>a coarse horizon (about .5 cm thick) cut across the core<br><br>Slight density increase appears below sand and coarse horizon to EOC at 28.5 cm<br><br>Water content appears nearly uniform throughout |
| | | % Recovery = [ (Recovery) / (Penetration) ] x 100: |

# Appendix B

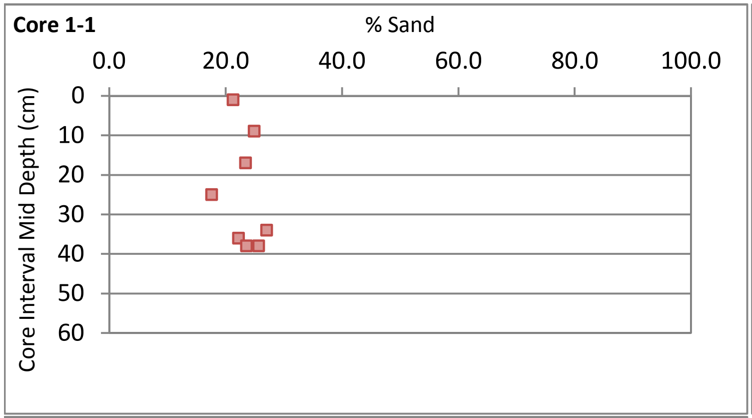
## Grain Size Plots for BHCAD
## November 2009 Survey

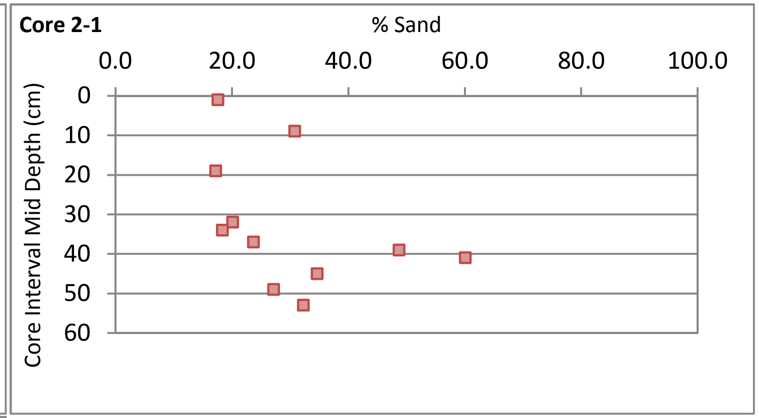
US Army Corps of Engineers
New England District

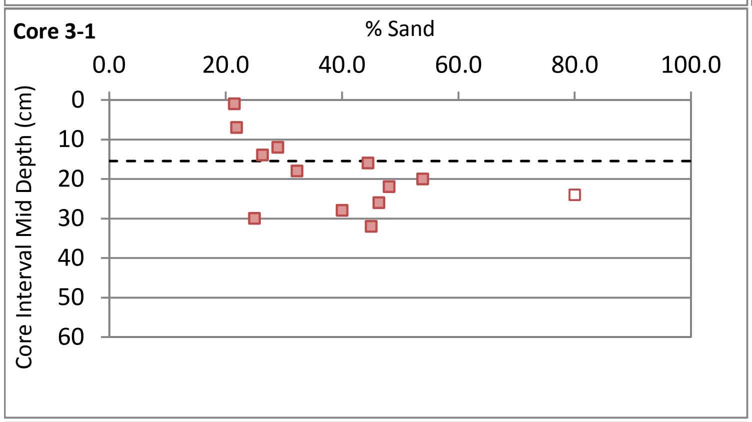
Boston Harbor CAD Cell Survey
Grain Size Data
November 2009

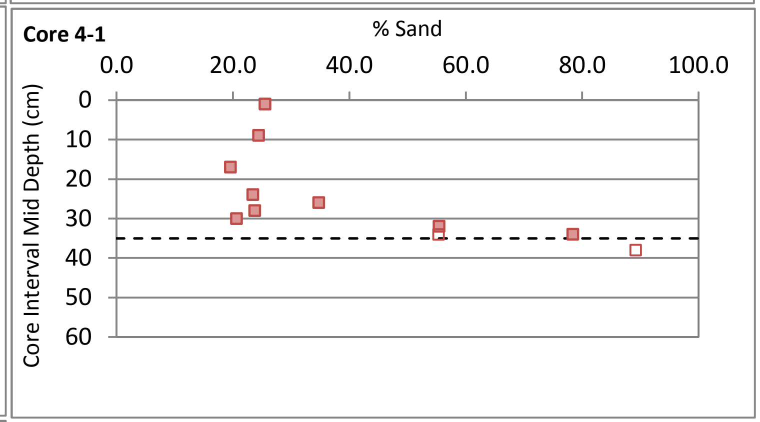
AECOM

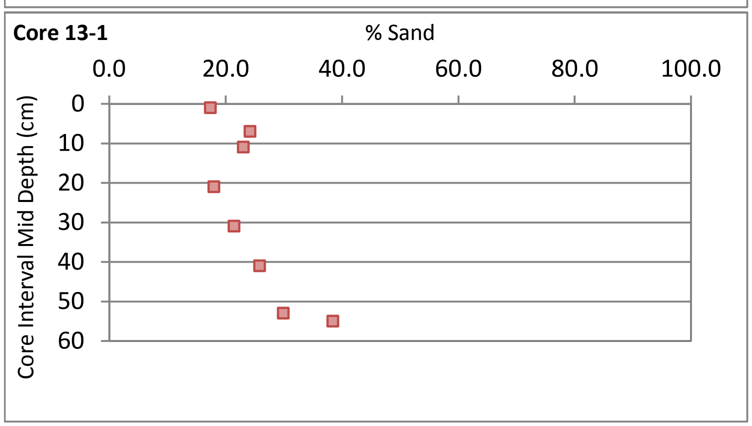
Core location: Supercell



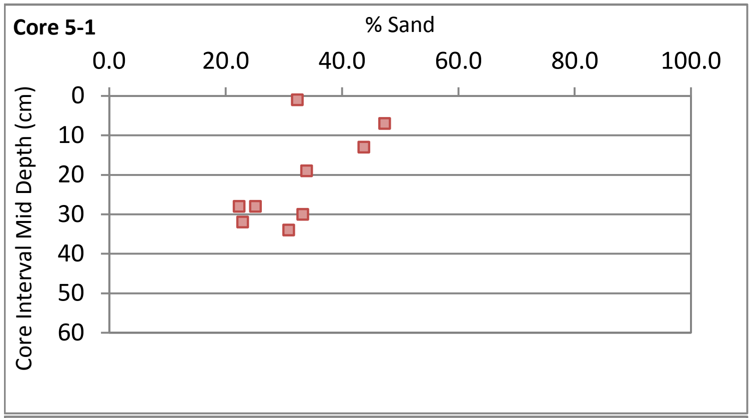



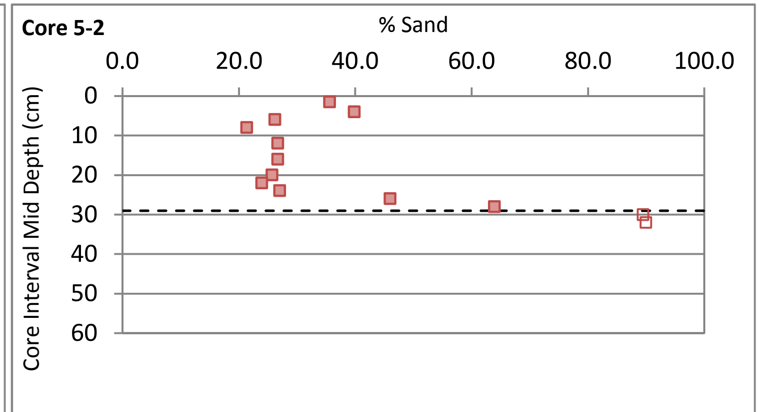

----- Depth of transition to sand cap based on visual logging of core

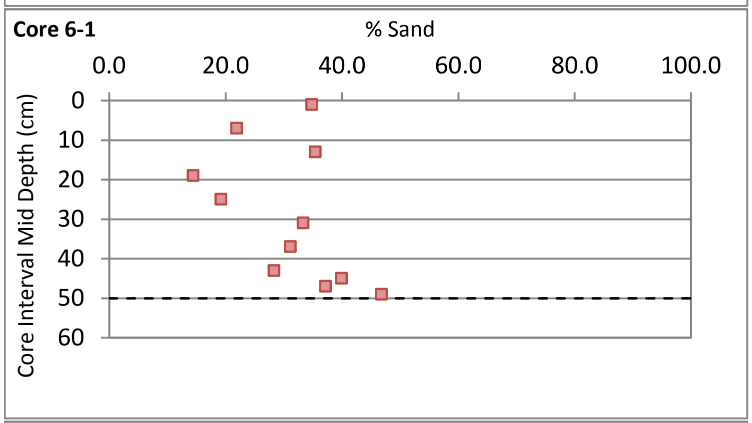
Solid symbols = laser method, Hollow symbols = sieve method

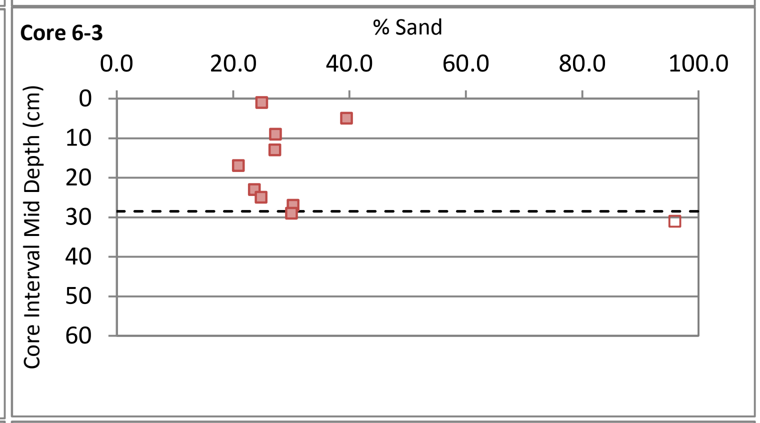
* = Average of 2 samples

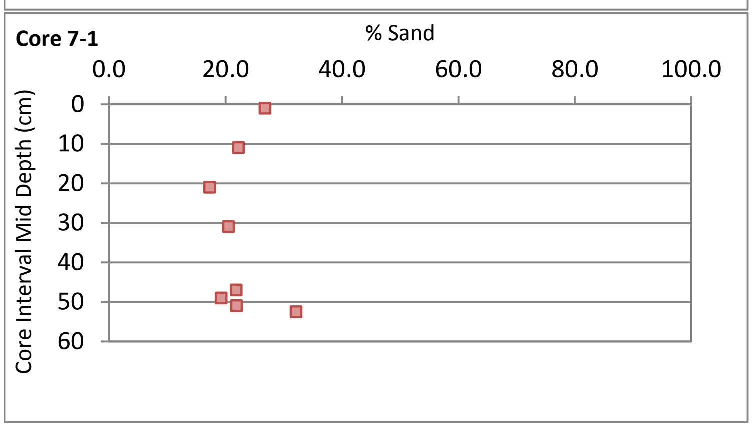
Core location: M19

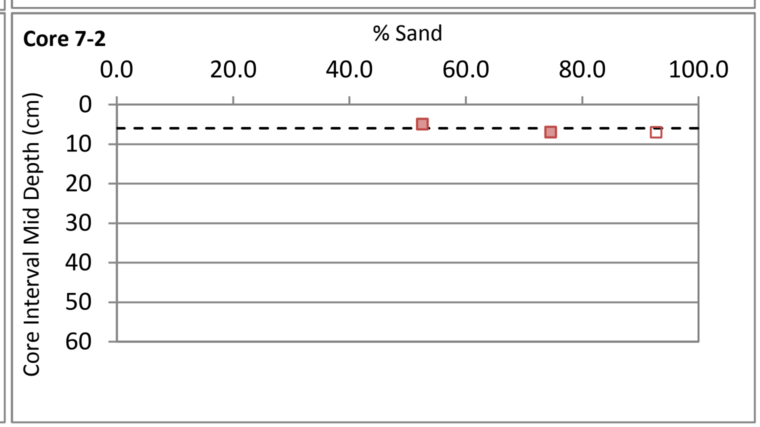


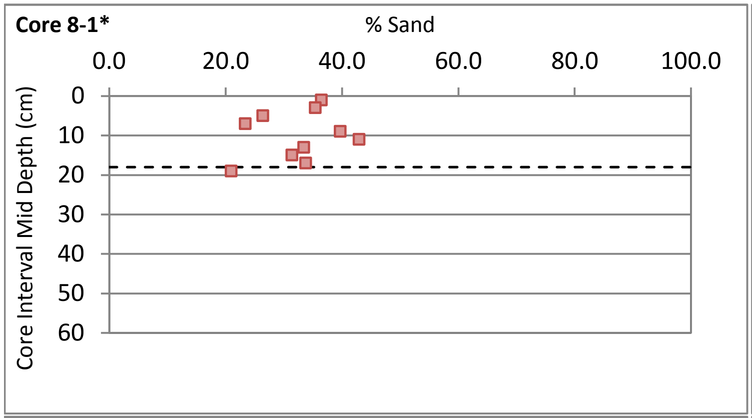



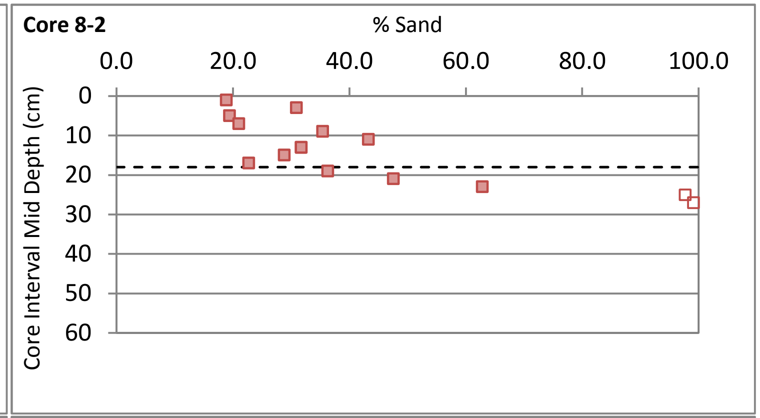



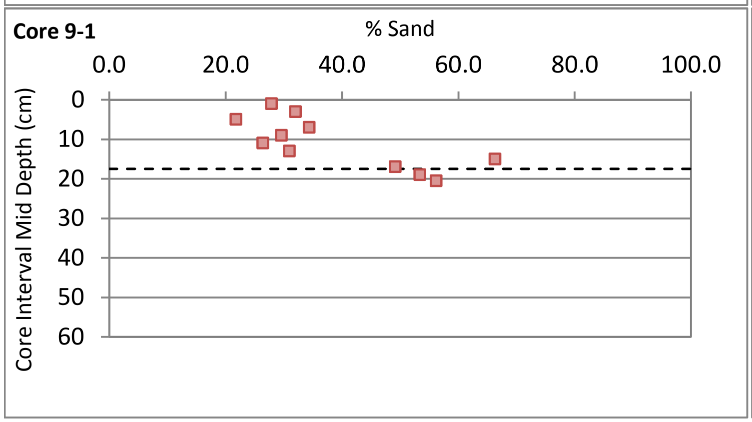



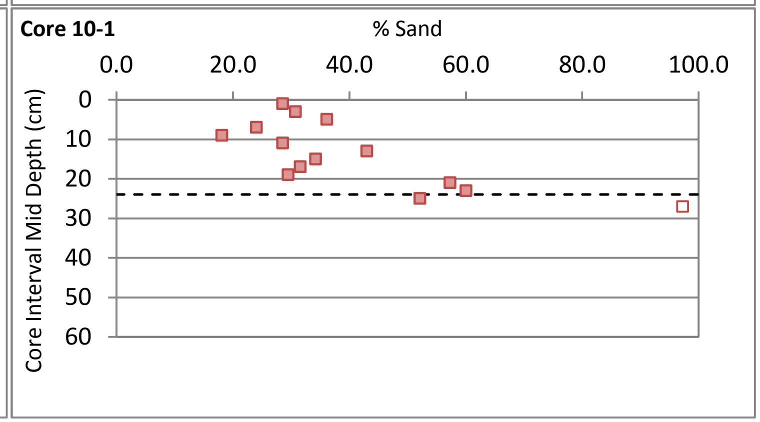

----- Depth of transition to sand cap based on visual logging of core
Solid symbols = laser method, Hollow symbols = sieve method
* = Average of 2 samples

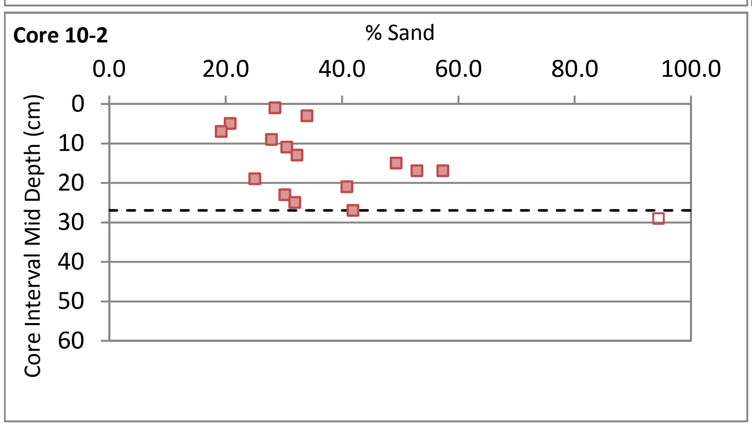
Core location: M8-11



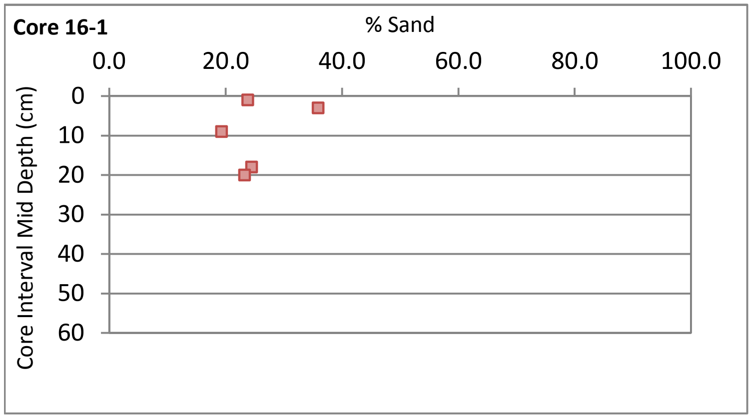



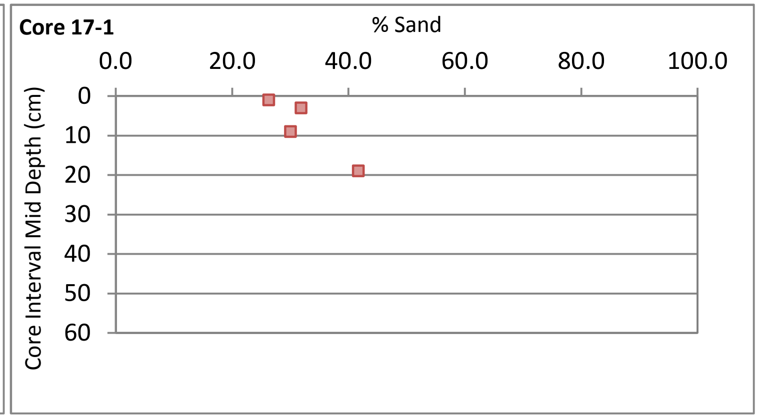



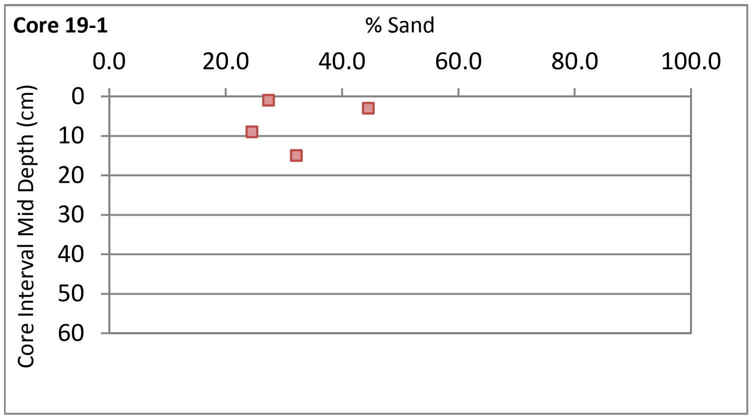



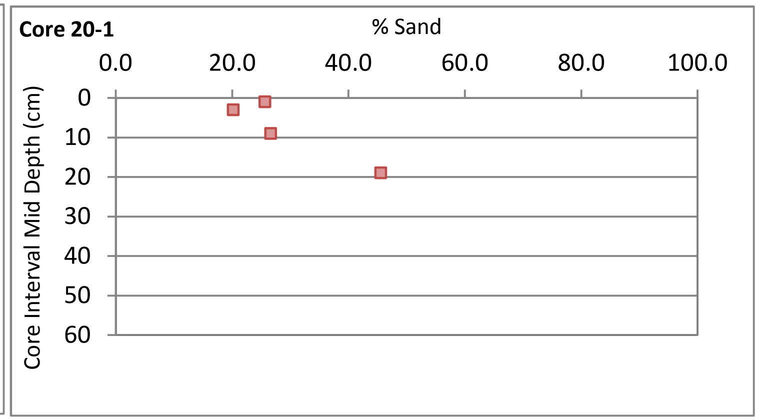

----- Depth of transition to sand cap based on visual logging of core
Solid symbols = laser method, Hollow symbols = sieve method
* = Average of 2 samples

Core location: Outside CAD cell



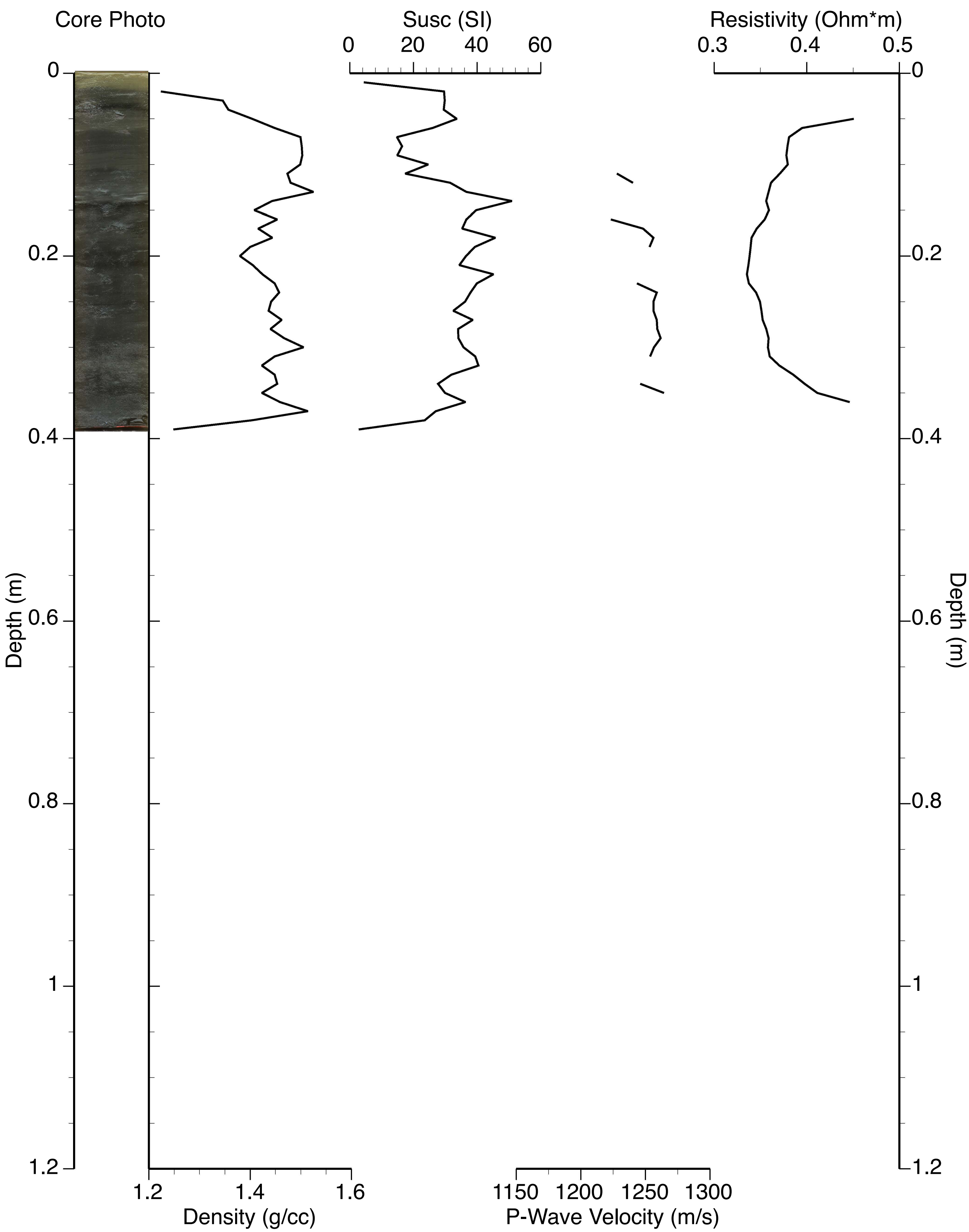




----- Depth of transition to sand cap based on visual logging of core
Solid symbols = laser method, Hollow symbols = sieve method
* = Average of 2 samples

Appendix C

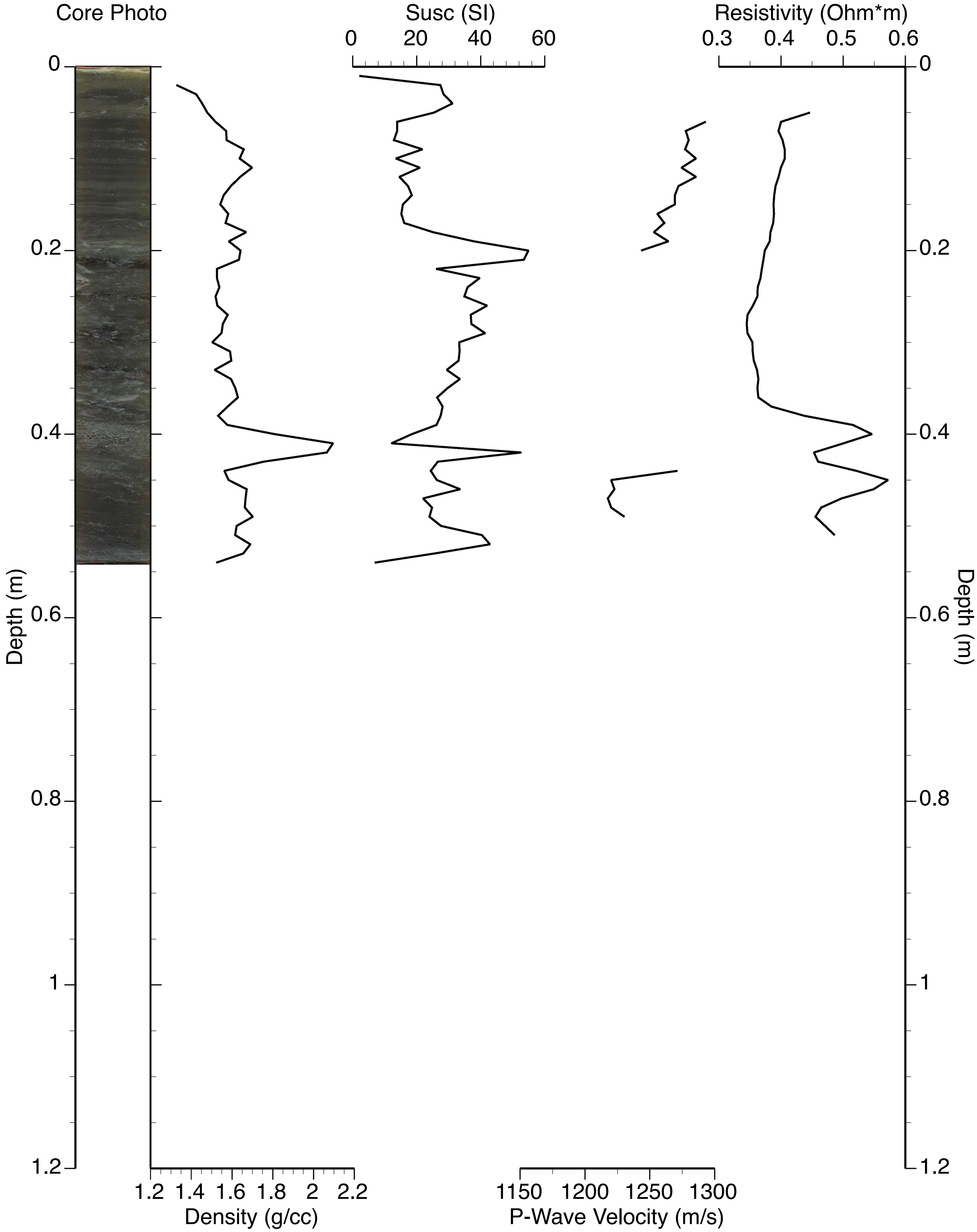
Core Images and Logging Data for BHCAD
November 2009 Survey

# Core 1-1A



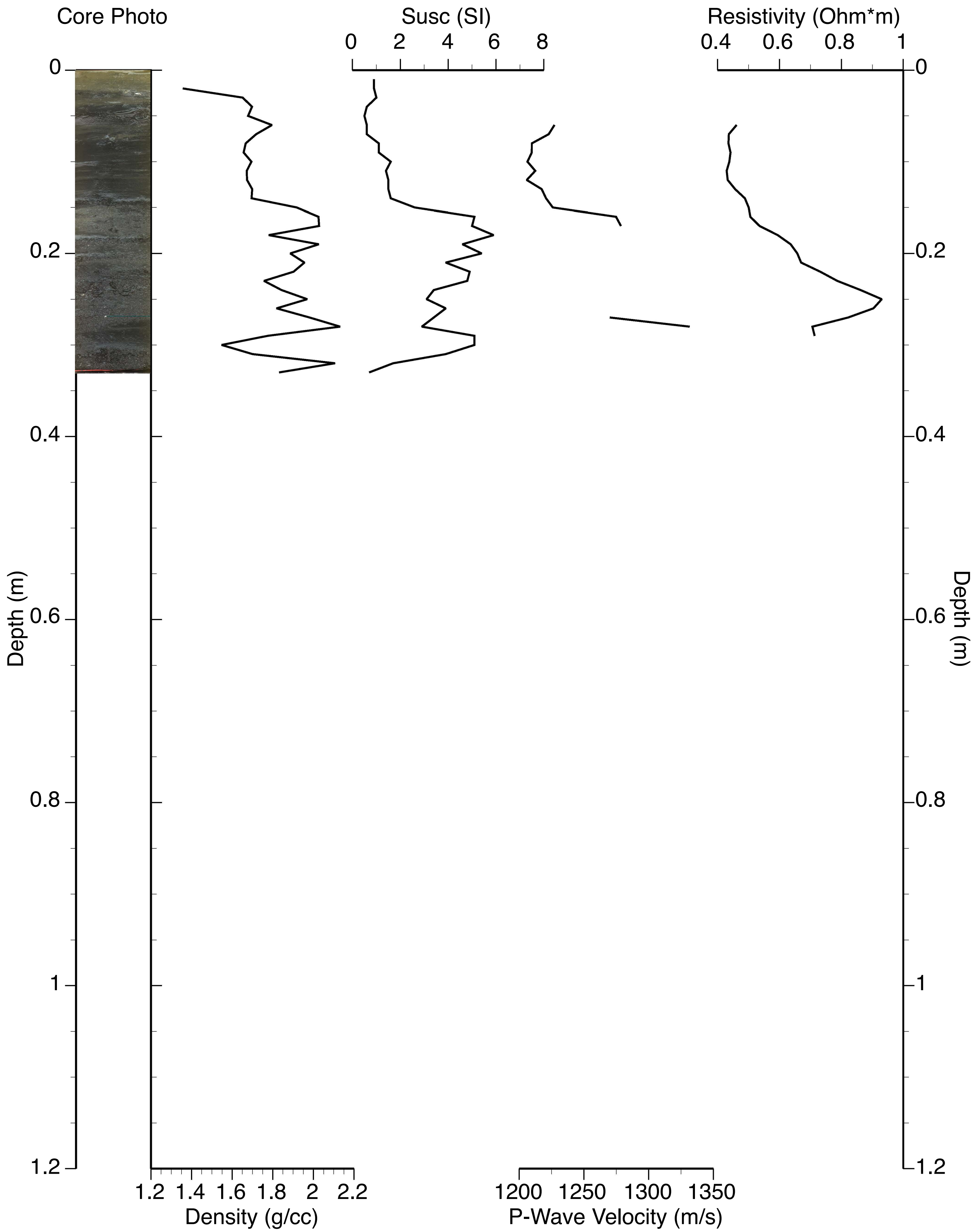
Core Photo
Susc (SI)
0 20 40 60
Resistivity (Ohm*m)
0.3 0.4 0.5
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
1.2 1.4 1.6
Density (g/cc)
1150 1200 1250 1300
P-Wave Velocity (m/s)
Depth (m)

# Core 2-1A



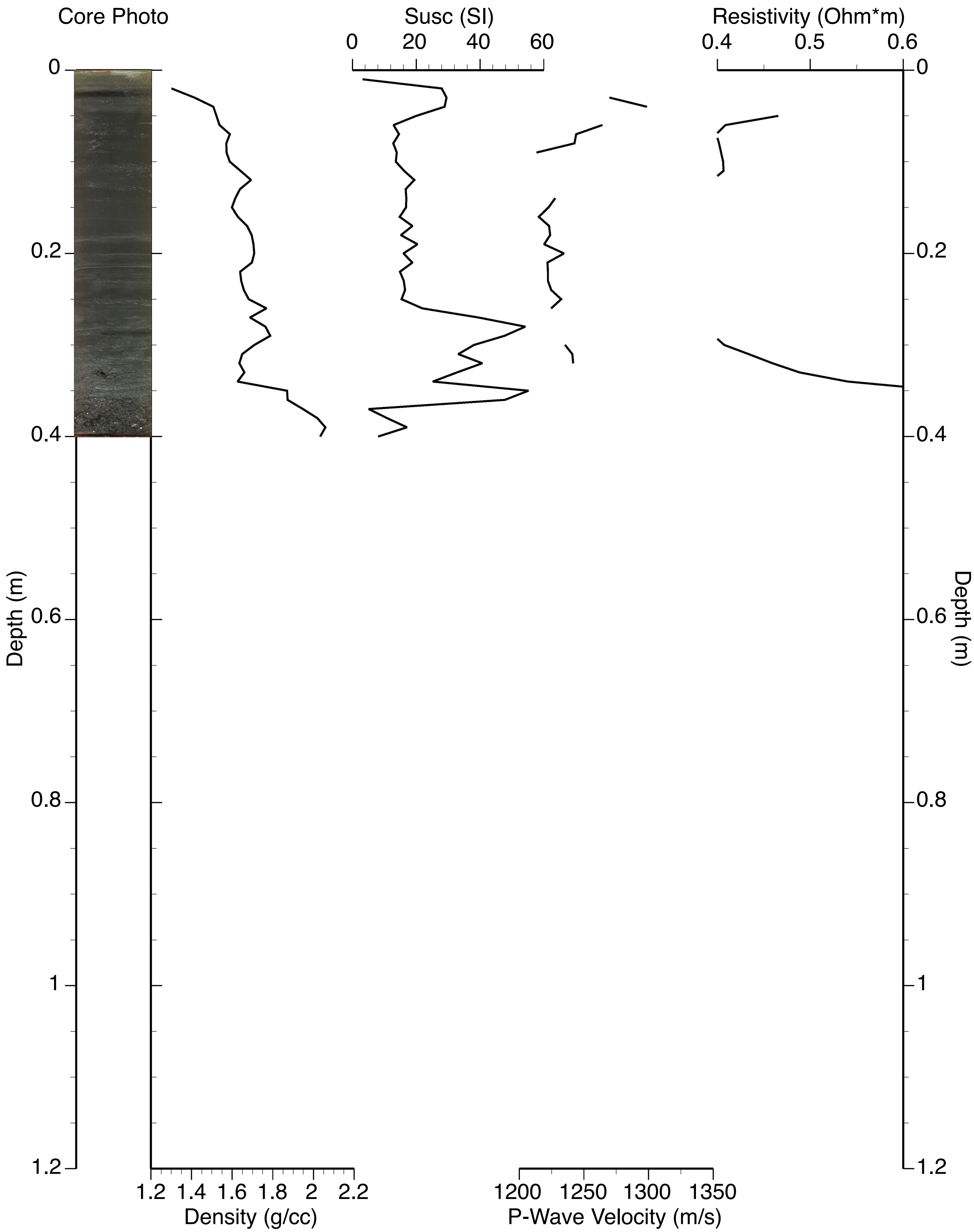
Core Photo
Susc (SI)
0 20 40 60
Resistivity (Ohm*m)
0.3 0.4 0.5 0.6
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
Depth (m)
1.2 1.4 1.6 1.8 2 2.2
Density (g/cc)
1150 1200 1250 1300
P-Wave Velocity (m/s)

# Core 3-1C

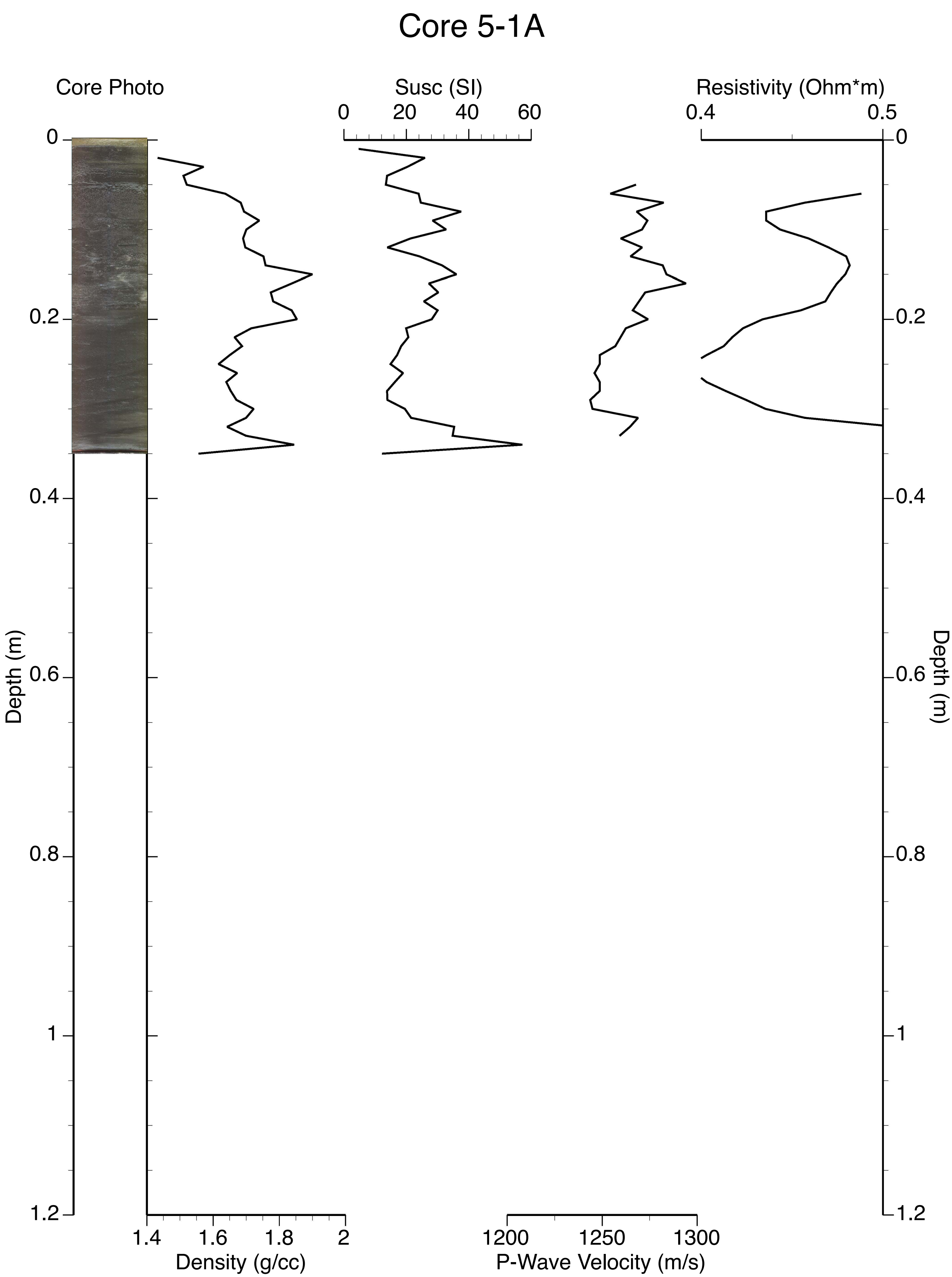


Core Photo
Susc (SI)
0 2 4 6 8
Resistivity (Ohm*m)
0.4 0.6 0.8 1
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
1.2 1.4 1.6 1.8 2 2.2
Density (g/cc)
1200 1250 1300 1350
P-Wave Velocity (m/s)

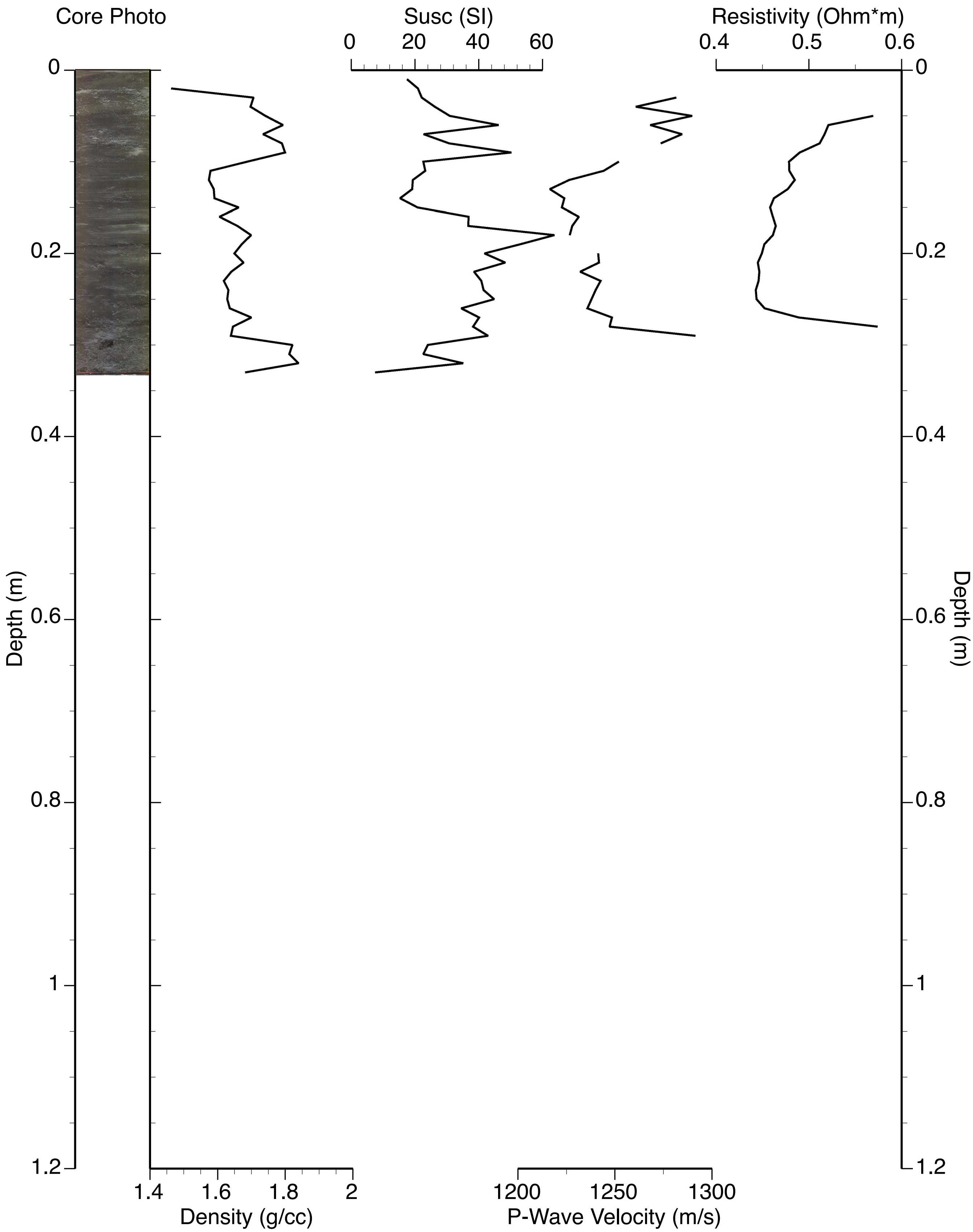
# Core 4-1B



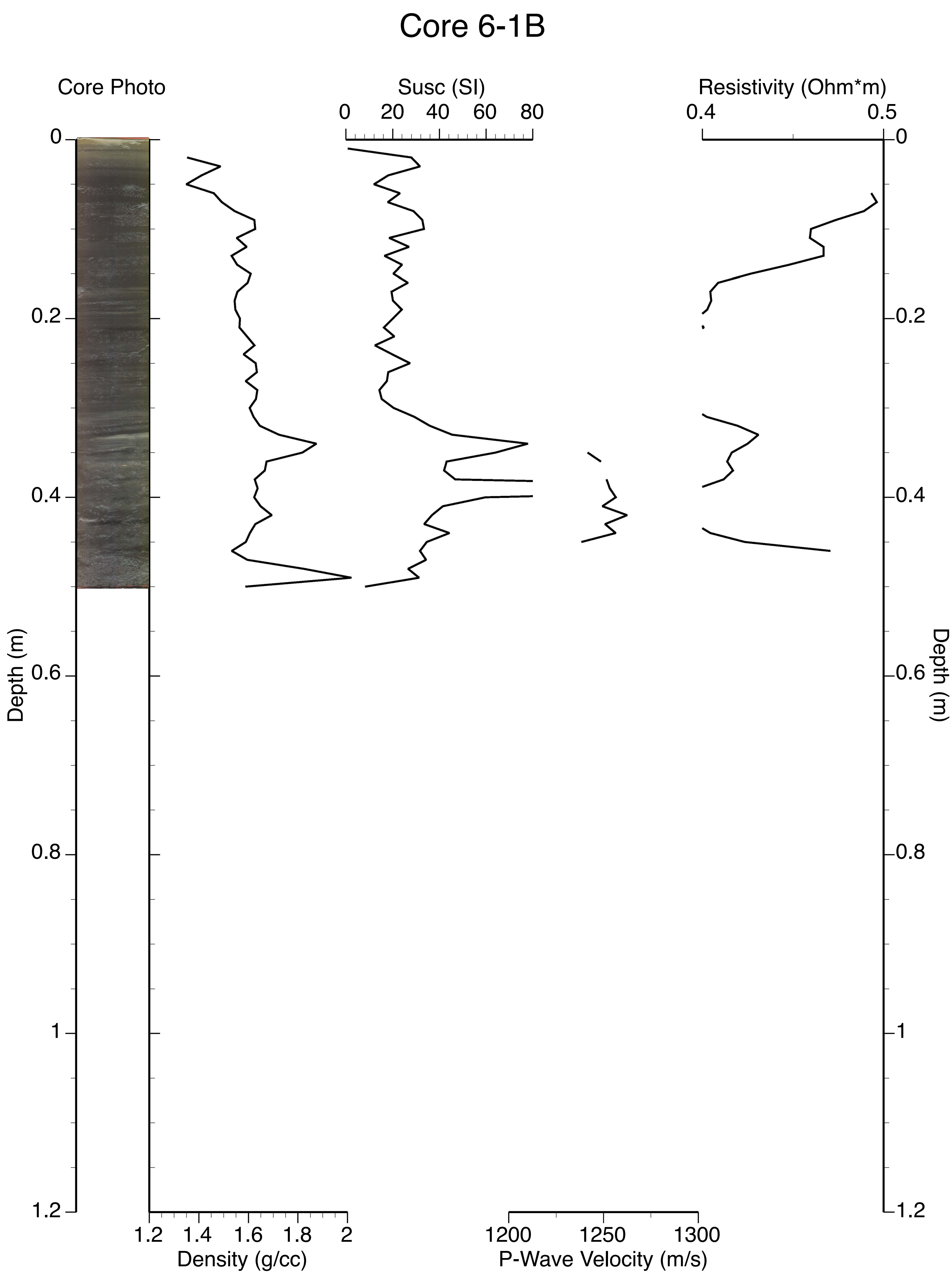
Core Photo
Susc (SI)
0 20 40 60
Resistivity (Ohm*m)
0.4 0.5 0.6
0 0.2 0.4 0.6 0.8 1 1.2
Depth (m)
1.2 1.4 1.6 1.8 2 2.2
Density (g/cc)
1200 1250 1300 1350
P-Wave Velocity (m/s)


Core 5-1A
Core Photo
Susc (SI)
0 20 40 60
Resistivity (Ohm*m)
0.4 0.5
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
1.4 1.6 1.8 2
Density (g/cc)
1200 1250 1300
P-Wave Velocity (m/s)

# Core 5-2

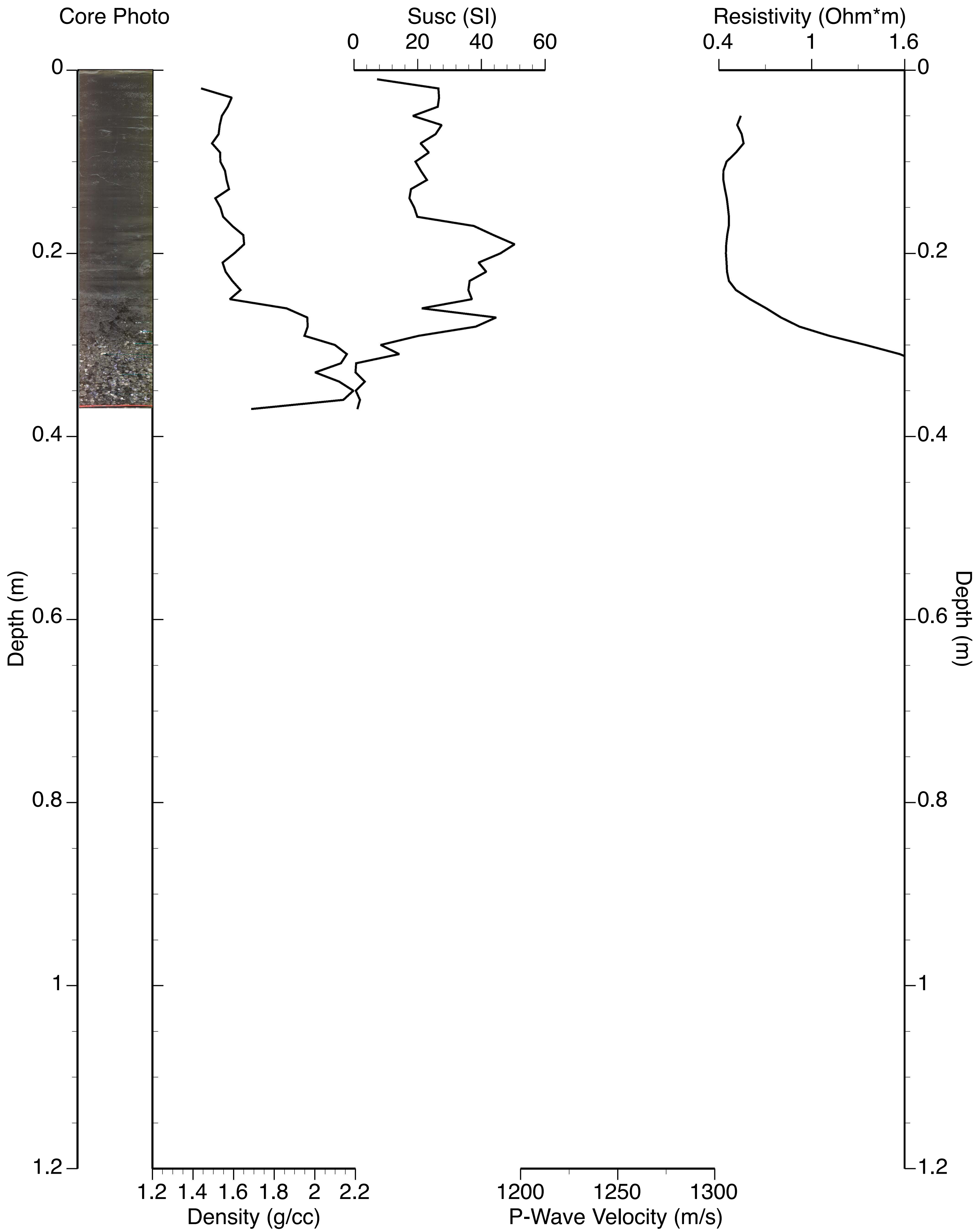


Core Photo
Susc (SI)
0 20 40 60
Resistivity (Ohm*m)
0.4 0.5 0.6
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
1.4 1.6 1.8 2
Density (g/cc)
1200 1250 1300
P-Wave Velocity (m/s)



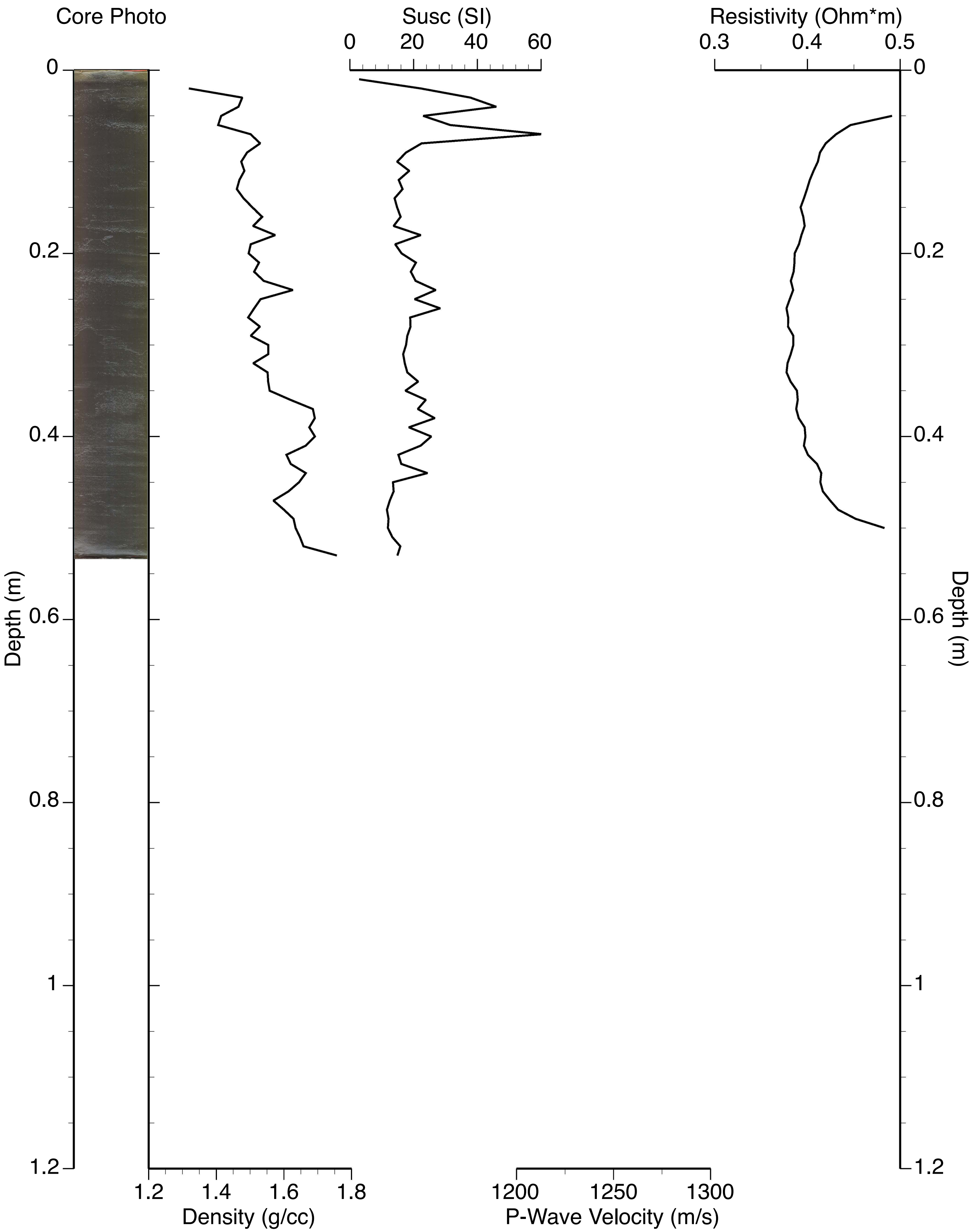
Core 6-1B
Core Photo
Susc (SI)
0 20 40 60 80
Resistivity (Ohm*m)
0.4 0.5
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
1.2 1.4 1.6 1.8 2
Density (g/cc)
1200 1250 1300
P-Wave Velocity (m/s)

# Core 6-3



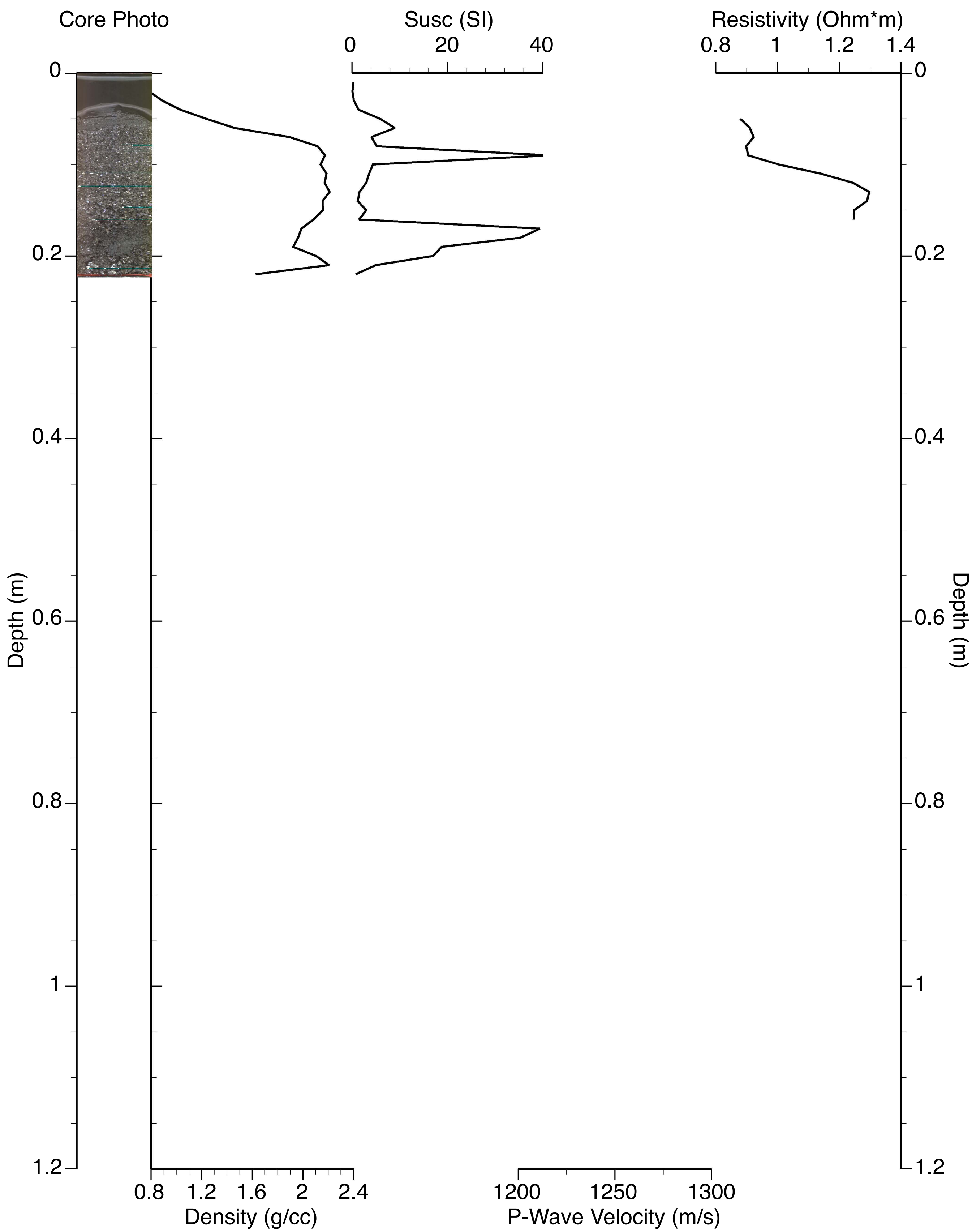
Core Photo
Susc (SI)
0 20 40 60
Resistivity (Ohm*m)
0.4 1 1.6
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
1.2 1.4 1.6 1.8 2 2.2
Density (g/cc)
1200 1250 1300
P-Wave Velocity (m/s)

# Core 7-1



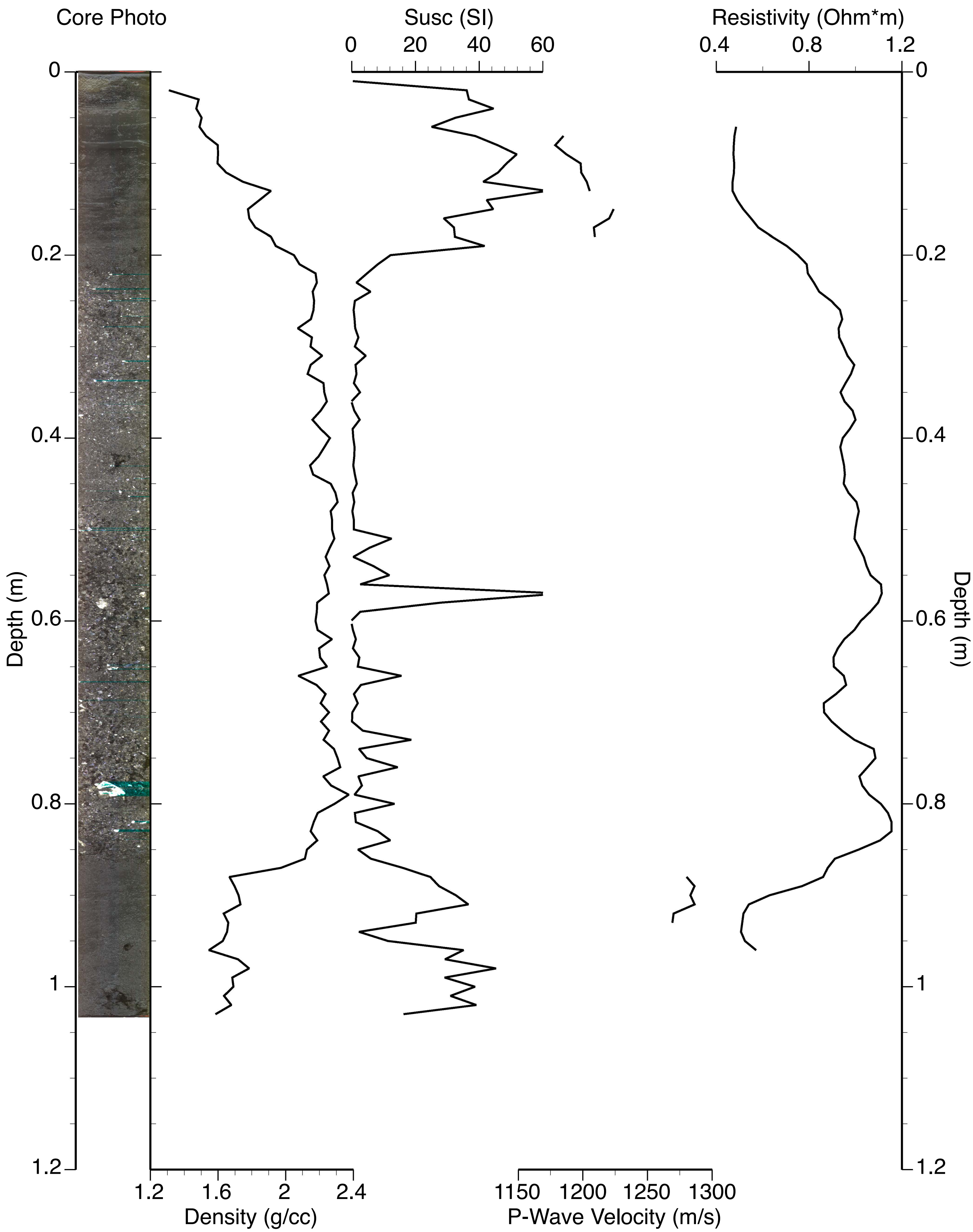
Core Photo
Susc (SI)
0 20 40 60
Resistivity (Ohm*m)
0.3 0.4 0.5
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
Depth (m)
1.2 1.4 1.6 1.8
Density (g/cc)
1200 1250 1300
P-Wave Velocity (m/s)

# Core 7-2



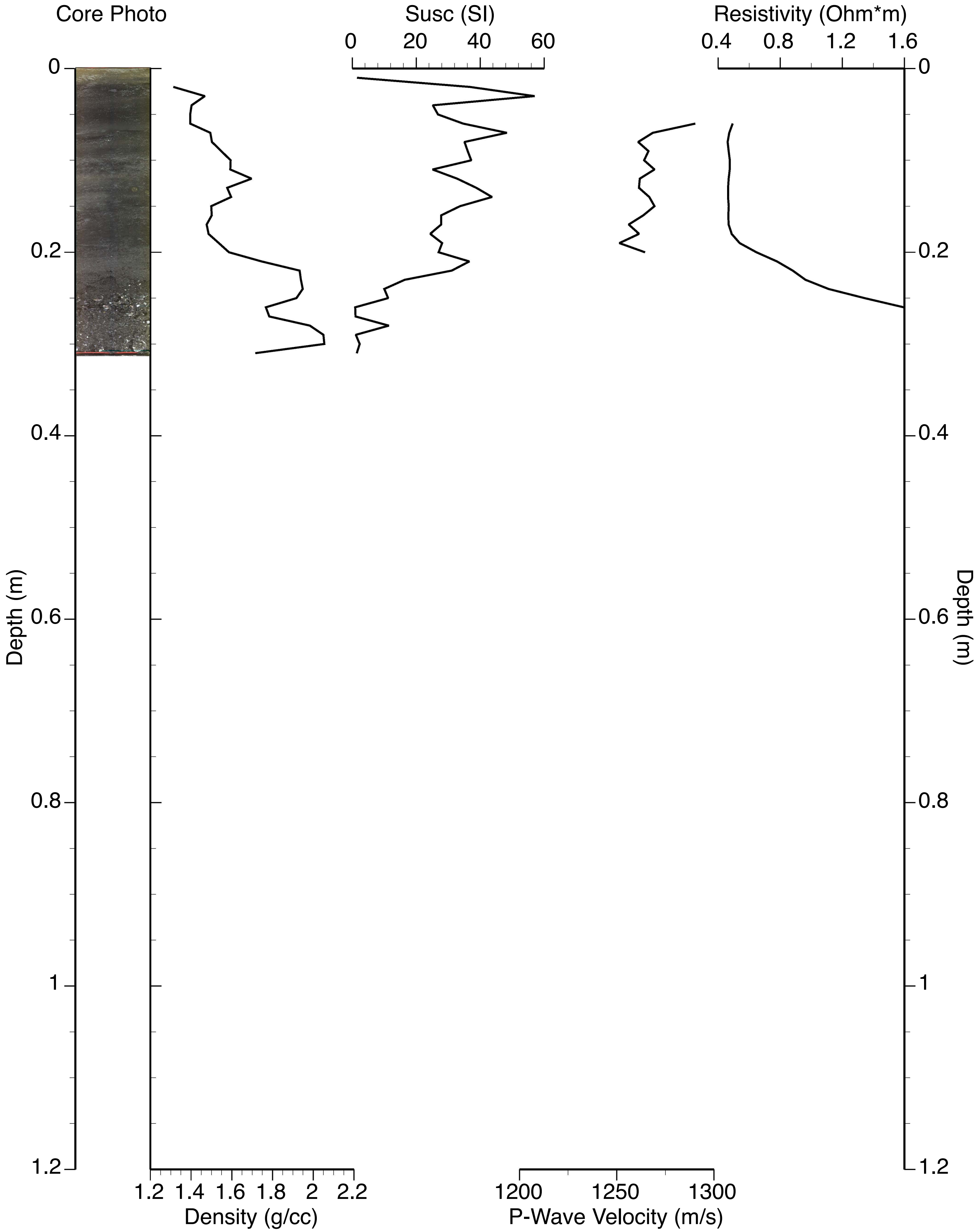
Core Photo
Susc (SI)
0
20
40
Resistivity (Ohm*m)
0.8
1
1.2
1.4
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
0.8
1.2
1.6
2
2.4
Density (g/cc)
1200
1250
1300
P-Wave Velocity (m/s)

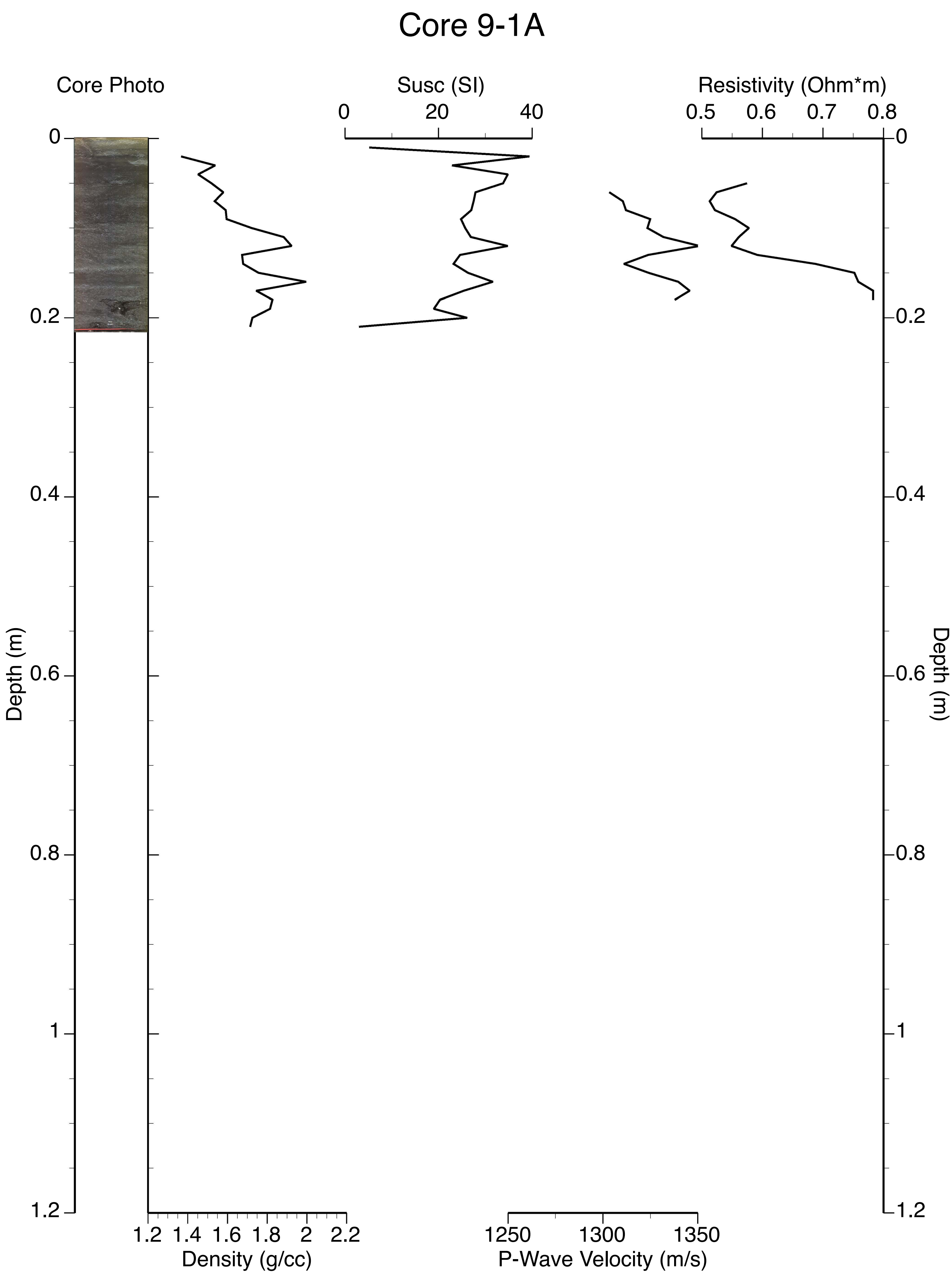
# Core 8-1



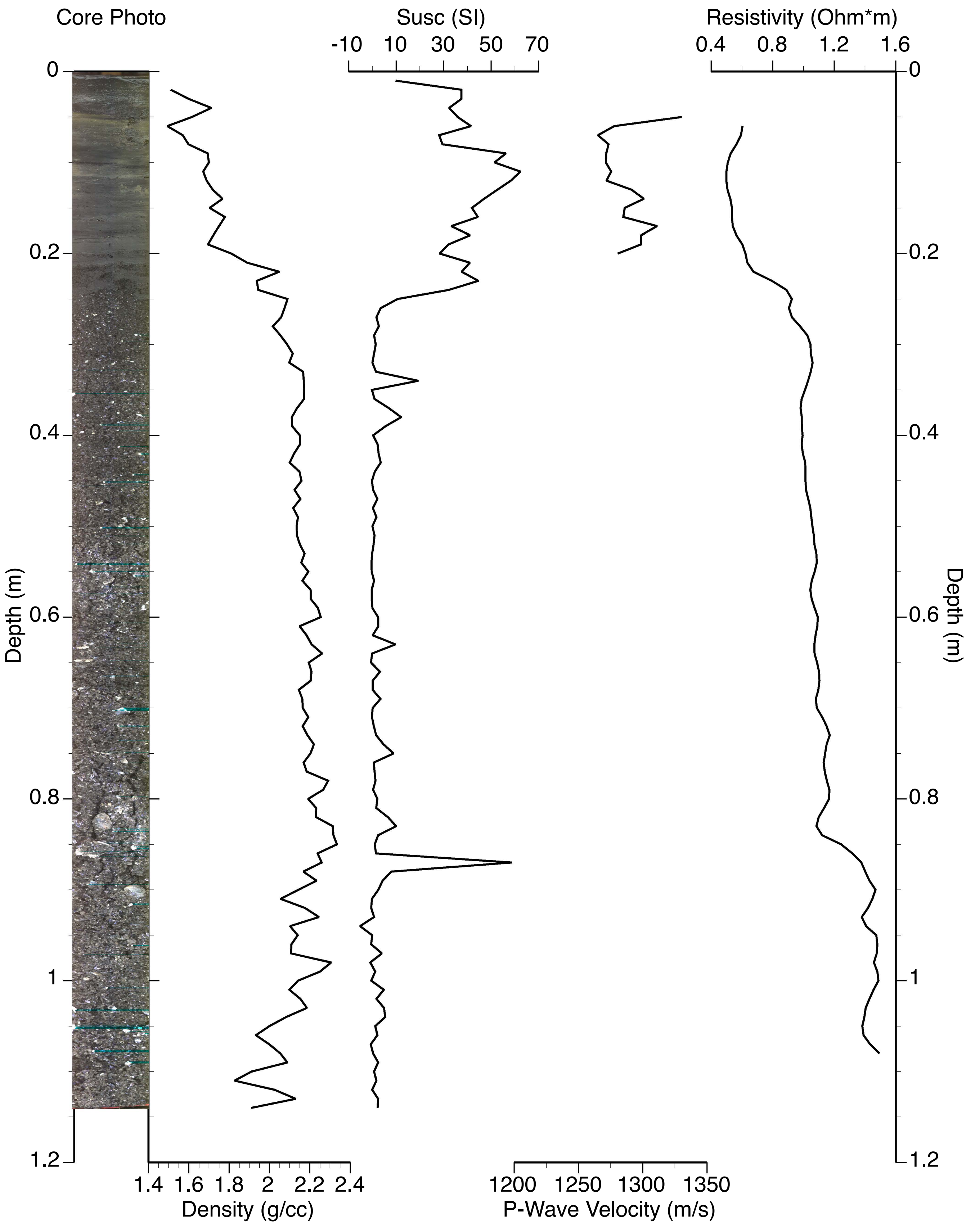
Core Photo
Susc (SI)
0 20 40 60
Resistivity (Ohm*m)
0.4 0.8 1.2
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
1.2 1.6 2 2.4
Density (g/cc)
1150 1200 1250 1300
P-Wave Velocity (m/s)

# Core 8-2B


Core Photo
Susc (SI)
0 20 40 60
Resistivity (Ohm*m)
0.4 0.8 1.2 1.6
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
1.2 1.4 1.6 1.8 2 2.2
Density (g/cc)
1200 1250 1300
P-Wave Velocity (m/s)

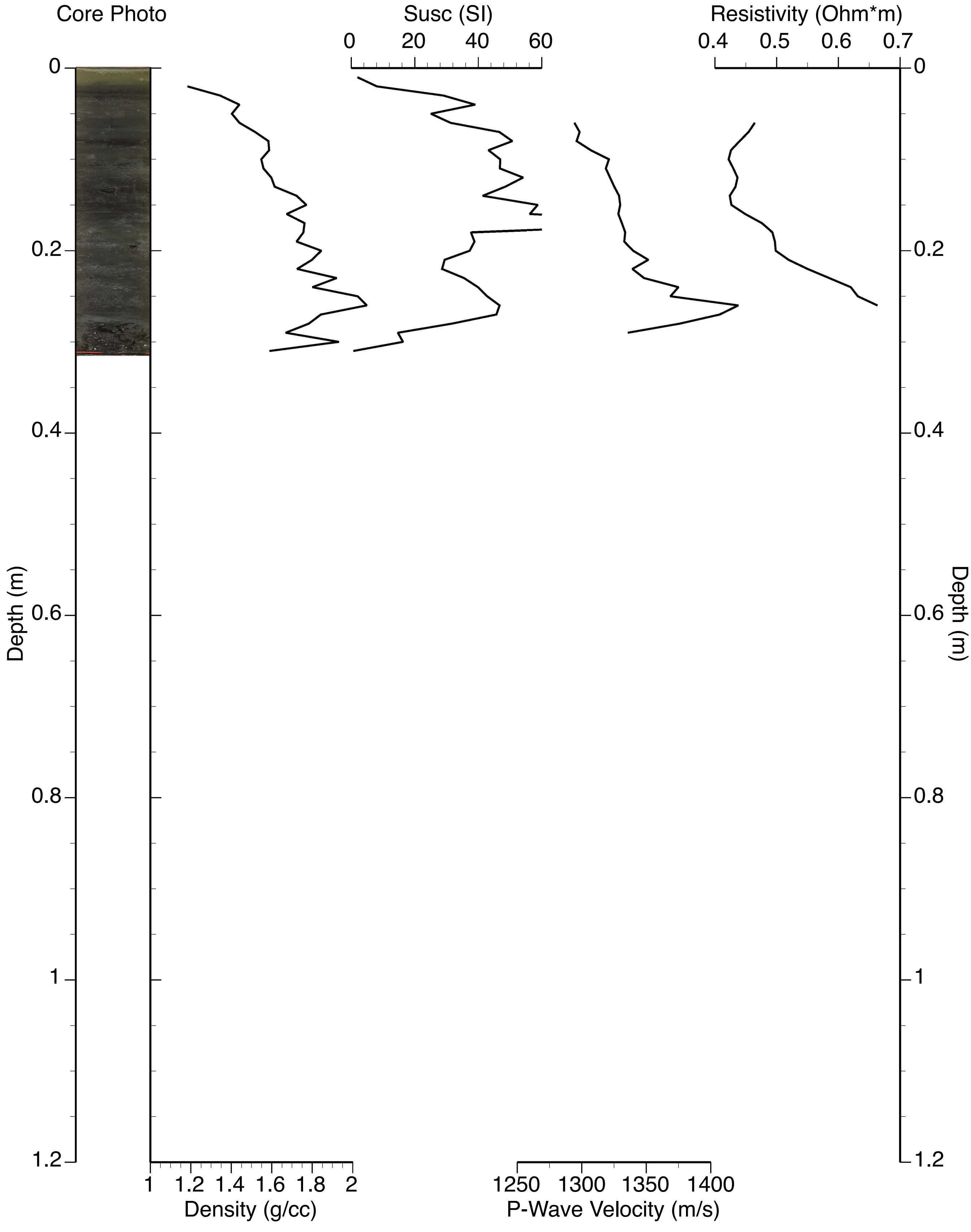

Core 9-1A
Core Photo
Susc (SI)
0
20
40
Resistivity (Ohm*m)
0.5
0.6
0.7
0.8
Depth (m)
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
1.2
1.4
1.6
1.8
2
2.2
Density (g/cc)
1250
1300
1350
P-Wave Velocity (m/s)

# Core 10-1



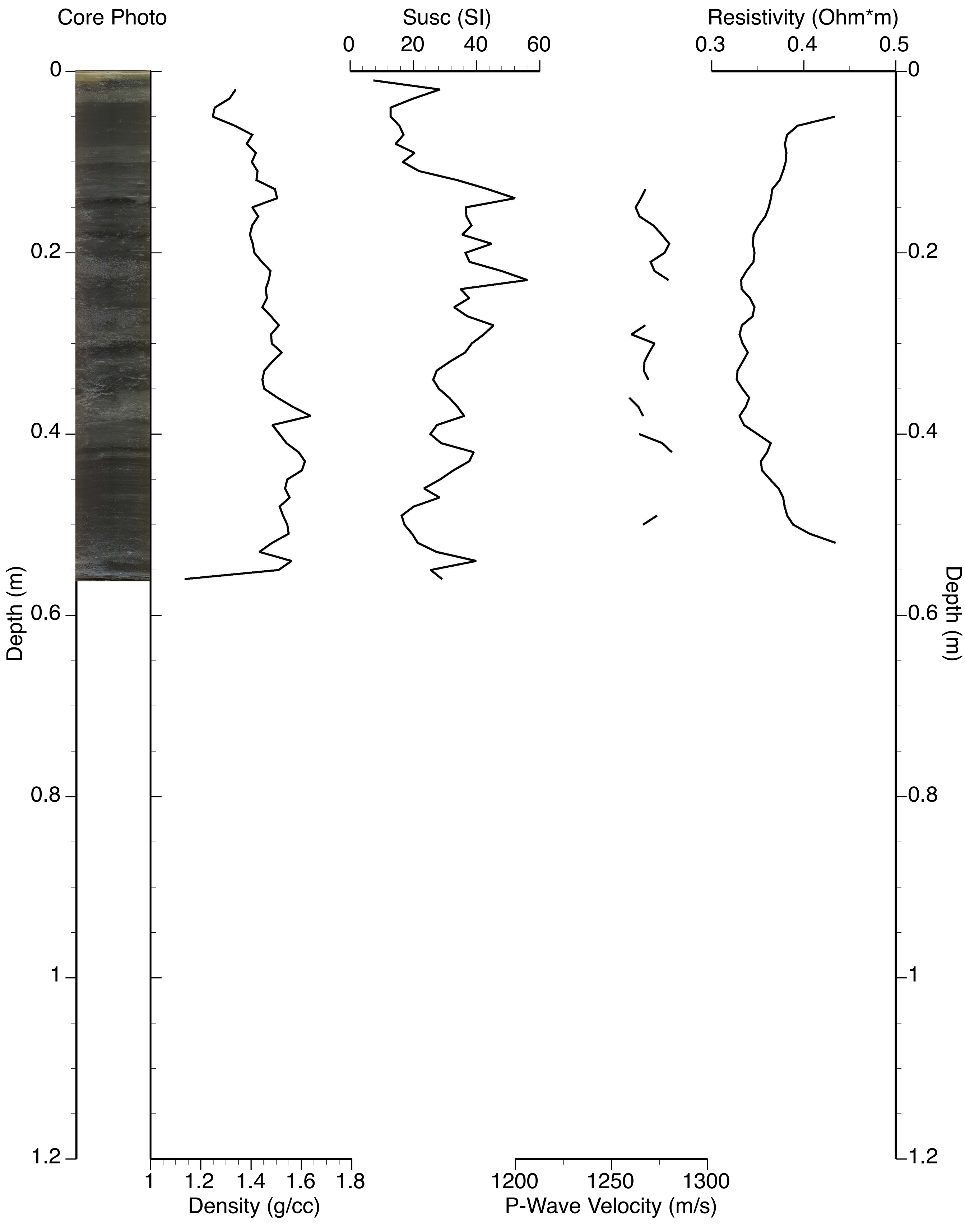
Core Photo
Susc (SI)
-10 10 30 50 70
Resistivity (Ohm*m)
0.4 0.8 1.2 1.6
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
1.4 1.6 1.8 2 2.2 2.4
Density (g/cc)
1200 1250 1300 1350
P-Wave Velocity (m/s)

# Core 10-2B



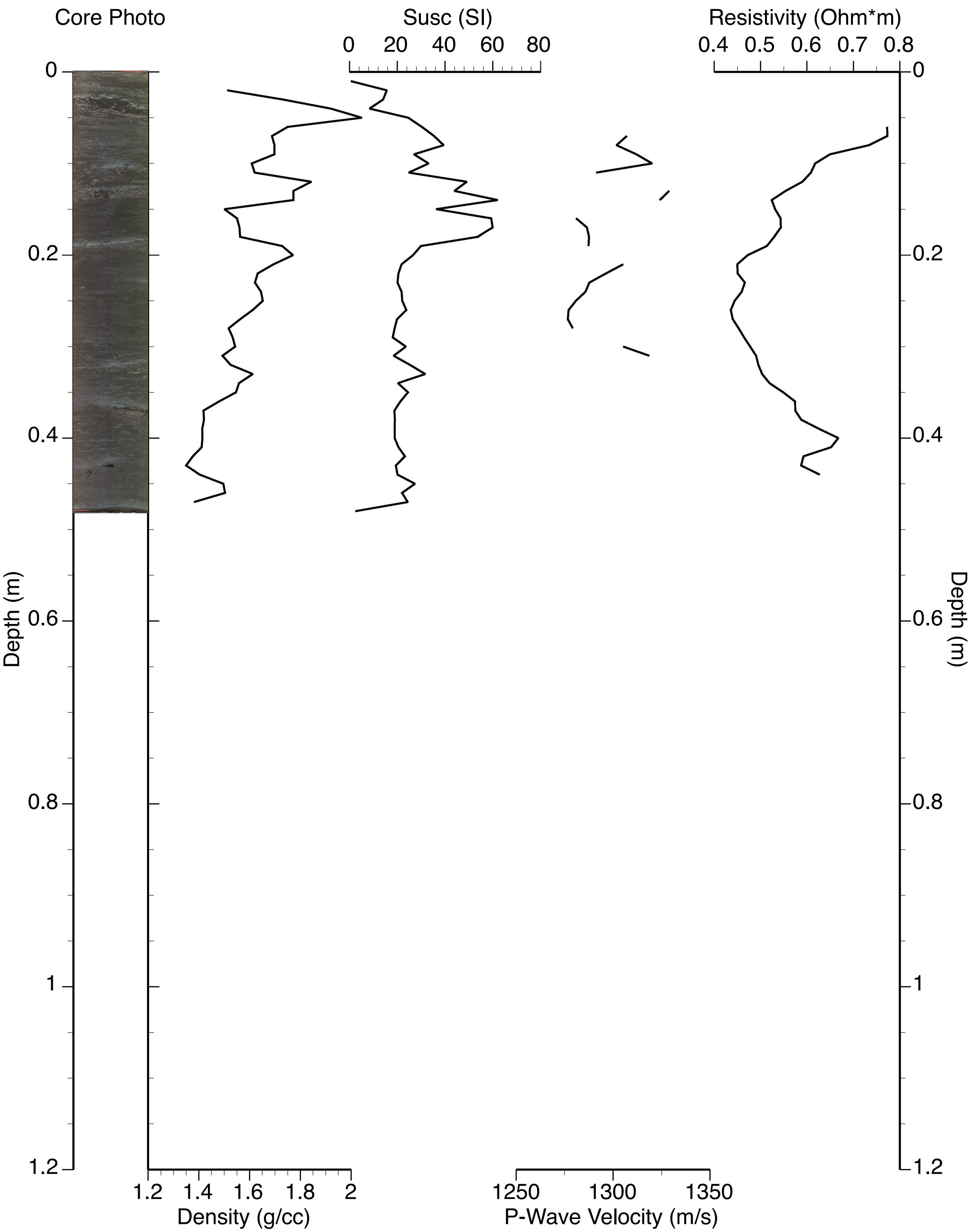
Core Photo
Susc (SI)
0 20 40 60
Resistivity (Ohm*m)
0.4 0.5 0.6 0.7
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
1 1.2 1.4 1.6 1.8 2
Density (g/cc)
1250 1300 1350 1400
P-Wave Velocity (m/s)

# Core 13-1A



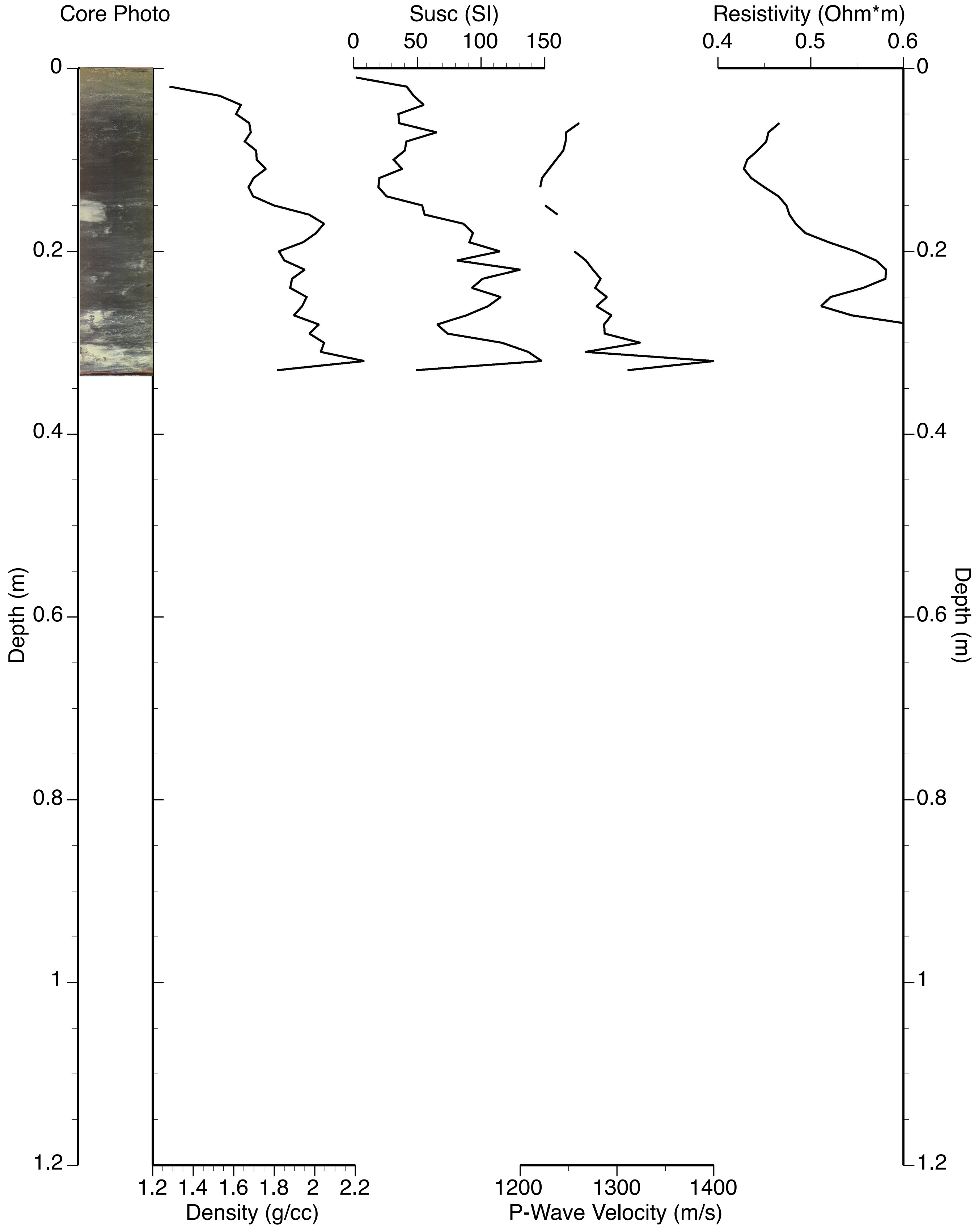
Core Photo
Susc (SI)
0 20 40 60
Resistivity (Ohm*m)
0.3 0.4 0.5
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
Depth (m)
1 1.2 1.4 1.6 1.8
Density (g/cc)
1200 1250 1300
P-Wave Velocity (m/s)

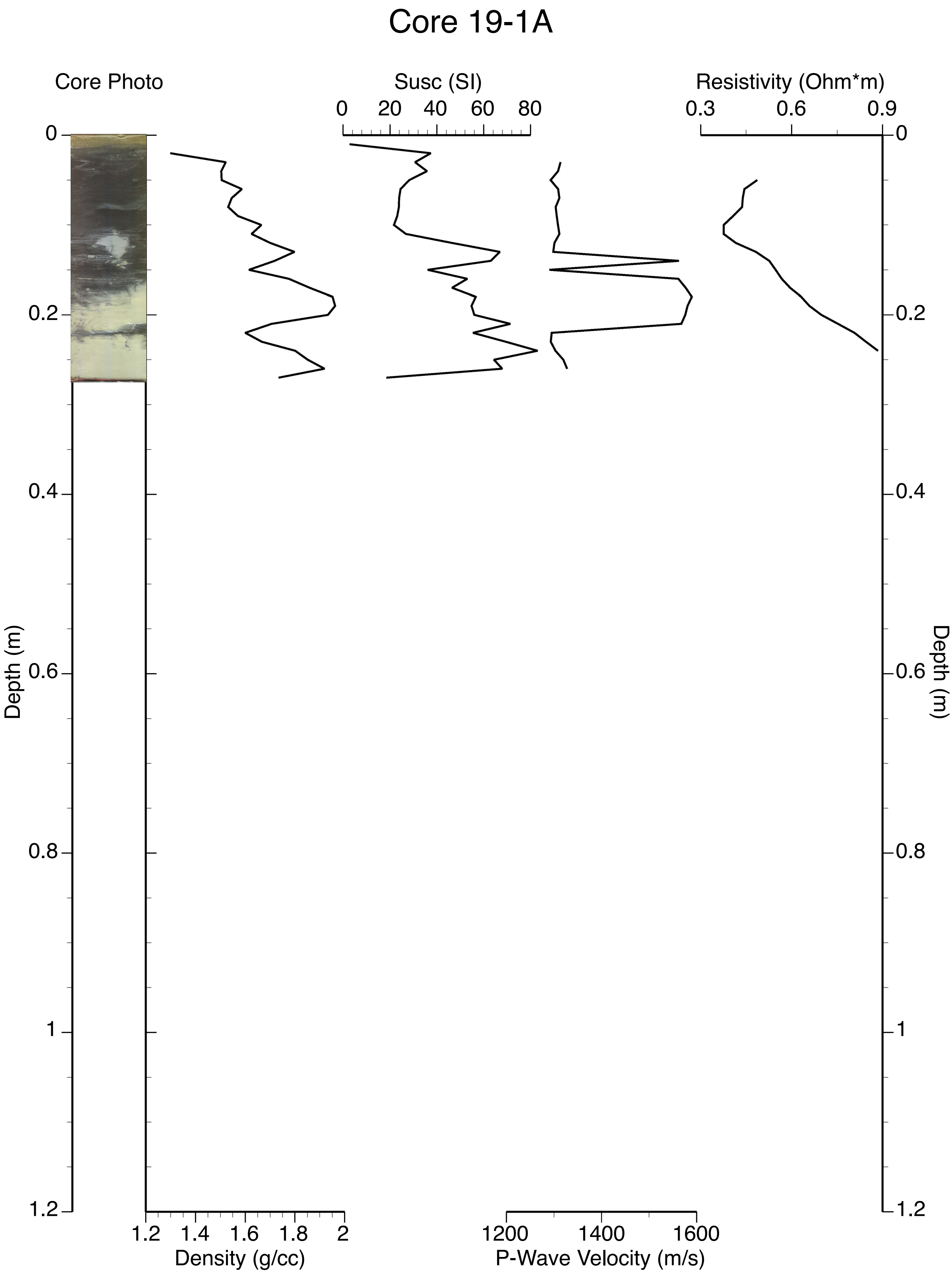
# Core 16-1A



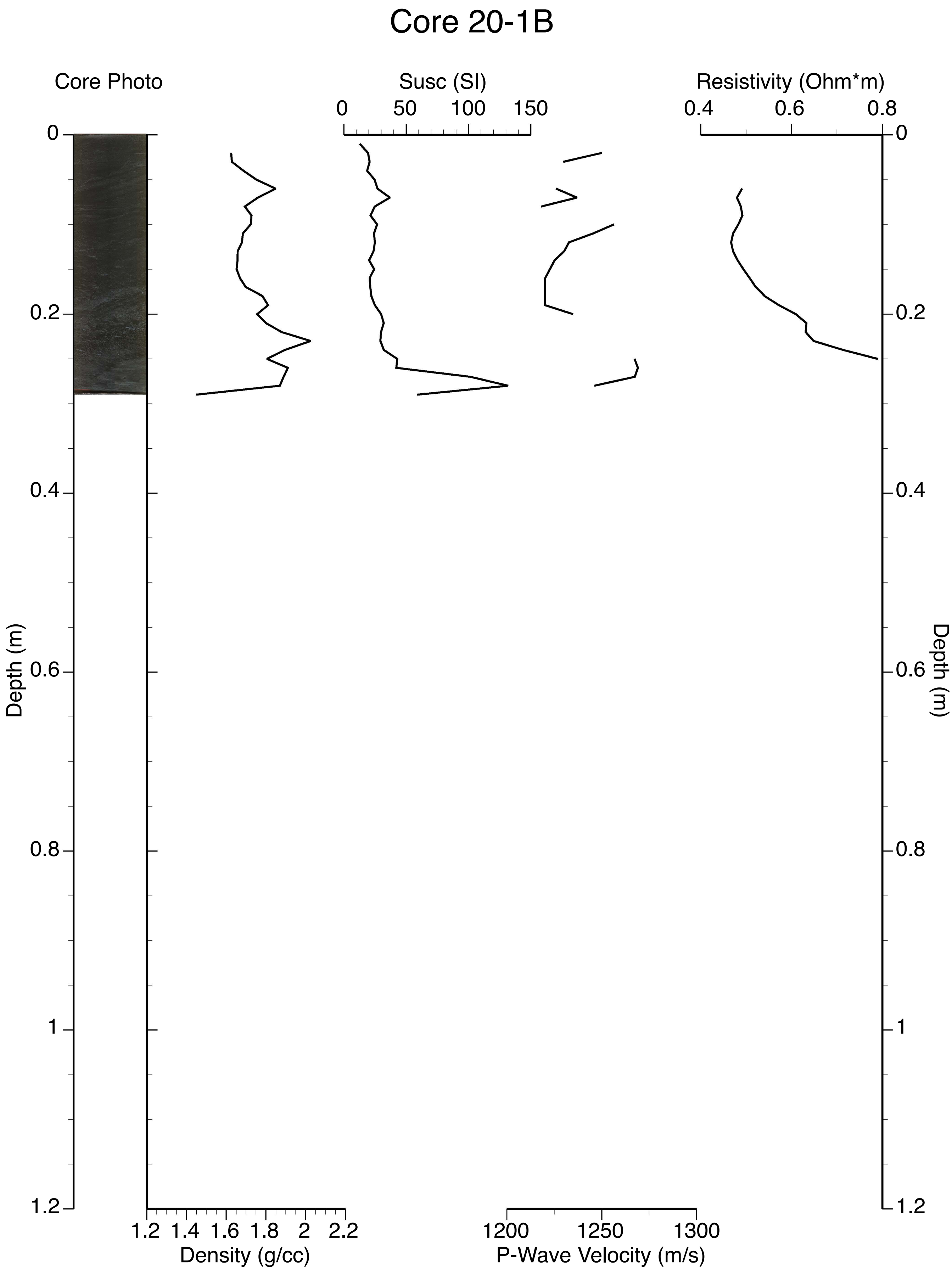
Core Photo
Susc (SI)
0 20 40 60 80
Resistivity (Ohm*m)
0.4 0.5 0.6 0.7 0.8
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
1.2 1.4 1.6 1.8 2
Density (g/cc)
1250 1300 1350
P-Wave Velocity (m/s)

# Core 17-1A


Core Photo
Susc (SI)
0
50
100
150
Resistivity (Ohm*m)
0.4
0.5
0.6
Depth (m)
0
0.2
0.4
0.6
0.8
1
1.2
Depth (m)
1.2
1.4
1.6
1.8
2
2.2
Density (g/cc)
1200
1300
1400
P-Wave Velocity (m/s)



Core 19-1A
Core Photo
Susc (SI)
0 20 40 60 80
Resistivity (Ohm*m)
0.3 0.6 0.9
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
Depth (m)
0 0.2 0.4 0.6 0.8 1 1.2
1.2 1.4 1.6 1.8 2
Density (g/cc)
1200 1400 1600
P-Wave Velocity (m/s)


Core 20-1B
Core Photo
Susc (SI)
0
50
100
150
Resistivity (Ohm*m)
0.4
0.6
0.8
Depth (m)
0
0.2
0.4
0.6
0.8
1
1.2
1.2
1.4
1.6
1.8
2
2.2
Density (g/cc)
1200
1250
1300
P-Wave Velocity (m/s)

Appendix D

Density Data for BHCAD
November 2009 Survey

Sample Volume= 1 cc

| Core ID | 1-1 | 2-1A | 3-1C | 4-1B | 5-1A | 5-2 | 6-1B | 6-3 | 7-1B | 7-2 | 8-1 | 8-2B | 9-1A | 10-1 | 10-2B | 13-1A | 16-1A | 17-1A | 19-1A | 20-1B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Interval (cm) | Wet Weight (g) | | | | | | | | | | | | | | | | | | | |
| 0-1 | 1.24 | 1.34 | 1.27 | 1.32 | 1.36 | 1.14 | 1.3 | 1.47 | 1.39 | | 1.19 | 1.36 | 1.33 | 1.2 | 1.24 | 1.29 | 1.3 | 1.4 | 1.35 | 1.48 |
| 1-2 | 1.32 | 1.38 | 1.25 | 1.49 | 1.25 | 1.31 | 1.39 | 1.28 | 1.28 | | 1.12 | 1.22 | 1.36 | 1.68 | 1.14 | 1.47 | 1.19 | 1.37 | 1.32 | 1.17 |
| 2-3 | 1.26 | 1.14 | 1.25 | 1.44 | 1.36 | 1.47 | 1.32 | 1.52 | 1.37 | | 1.27 | 1.2 | 1.45 | 1.37 | 1.5 | 1.41 | 1.23 | 1.58 | 1.54 | 1.3 |
| 3-4 | 1.38 | 1.34 | 1.38 | 1.1 | 1.4 | 1.56 | 1.51 | 1.64 | 1.61 | | 1.09 | 1.56 | 1.47 | 1.16 | 1.42 | 1.13 | 1.27 | 1.57 | 1.43 | 1.38 |
| 4-5 | 1.26 | 1.29 | 1.41 | 0.91 | 1.36 | 1.49 | 1.42 | 1.58 | 1.31 | 1.39 | 1.26 | 1.13 | 1.53 | 1.31 | 1.15 | 1.01 | 1.07 | 1.45 | 1.29 | 1.48 |
| 5-6 | 1.42 | 1.55 | 1.31 | 1.38 | 1.53 | 1.54 | 1.41 | 1.32 | 1.31 | | 1.25 | 1.23 | 0.985 | 1.37 | 0.97 | 1.29 | 1.15 | 1.39 | 1.36 | 1.42 |
| 6-7 | 1.38 | 1.4 | 1.18 | 1.34 | 1.43 | 1.45 | 1.06 | 1.7 | 1.47 | 1.66 | 1.35 | 1.41 | 1.55 | 1.3 | 1.09 | 1.28 | 1.33 | 1.44 | 1.35 | 1.34 |
| 7-8 | 1.28 | 1.31 | 1.34 | 1.3 | 1.61 | 1.52 | 1.38 | 1.61 | 1.43 | | 1.33 | 1.5 | 1.62 | 1.19 | 1.16 | 1.27 | 1.23 | 1.56 | 1.32 | 1.14 |
| 8-12 | 1.38 | 1.47 | 1.28 | 1.47 | 1.43 | 1.44 | 1.33 | 1.5 | 1.29 | | 1.28 | 1.26 | 1.48 | 1.14 | 1.6 | 1.13 | 1.36 | 1.37 | 1.11 | 1.25 |
| 12-16 | 1.6 | 1.37 | 1.37 | 1.44 | 1.68 | 1.28 | 1.3 | 1.35 | 1.38 | | 1.4 | 1.54 | 1.48 | 1.52 | 1.21 | 1.18 | 1.04 | 1.6 | 1.47 | 1.21 |
| 16-18 | 1.36 | 1.45 | 1.46 | 1.34 | 1.54 | 1.27 | 1.31 | 1.63 | 1.44 | | 1.24 | 1.17 | 1.17 | 1.29 | 1.45 | 1.3 | 1.36 | 1.34 | | 1.35 |
| 18-20 | | | | | | | | | | | | | | | | | | | | |
| 20-24 | 1.34 | 1.3 | | 1.32 | 1.41 | 1.49 | 1.43 | 1.26 | 1.27 | | | 1.65 | | 1.71 | 1.58 | 1.06 | | | | |
| 24-28 | 1.11 | 1.21 | | 1.37 | 1.41 | 1.39 | 1.52 | | 1.36 | | | | | | 1.19* | 1.34 | | | | |
| 28-30 | 1.36 | | | 1.14 | 1.34 | | | | | | | | | | | 1.41 | | | | |
| 30-32 | | | | | | | | | | | | | | | | | | | | |
| 32-36 | 1.29 | | | | 1.44* | | | | | | | | | | | | | | | |
| 36-39.5 | 1.09 | | | | | | | | | | | | | | | | | | | |

Intervals of irregular core segments

*32-35 (cm)

**24-27 (cm)

# Appendix E

# Moisture Data for BHCAD
# November 2009 Survey

Sample Volume= 1 cc

| Core ID | 1-1 | 2-1A | 3-1C | 4-1B | 5-1A | 5-2 | 6-1B | 6-3 | 7-1B | 7-2 | 8-1 | 8-2B | 9-1A | 10-1 | 10-2B | 13-1A | 16-1A | 17-1A | 19-1A | 20-1B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Interval (cm) | % Water | | | | | | | | | | | | | | | | | | | |
| 0-1 | 86.6 | 84.1 | 84.4 | 84.4 | 82.7 | 85.2 | 83.8 | 79.8 | 83.6 | | 84.7 | 79.7 | 82.5 | 84.8 | 83.9 | 83.4 | 75.8 | 82.2 | 80.9 | 80.2 |
| 1-2 | 84.4 | 83.2 | 81.2 | 81.7 | 80.0 | 82.4 | 82.2 | 81.0 | 82.6 | | 80.6 | 81.0 | 77.8 | 77.5 | 83.6 | 78.0 | 71.9 | 78.7 | 71.8 | 79.6 |
| 2-3 | 84.4 | 84.4 | 80.4 | 78.5 | 80.1 | 76.9 | 77.1 | 74.5 | 79.4 | | 82.1 | 78.4 | 76.7 | 79.0 | 75.0 | 79.7 | 61.7 | 77.8 | 77.3 | 76.9 |
| 3-4 | 82.1 | 81.8 | 78.7 | 82.5 | 81.5 | 73.4 | 79.7 | 68.7 | 74.9 | | 80.3 | 83.6 | 78.3 | 76.0 | 79.8 | 82.3 | 63.4 | 72.8 | 79.2 | 70.9 |
| 4-5 | 84.0 | 80.7 | 74.9 | 85.1 | 81.6 | 75.6 | 82.0 | 68.8 | 80.5 | | 80.5 | 82.3 | 74.9 | 73.2 | 81.2 | 83.1 | 75.9 | 74.9 | 79.3 | 70.2 |
| 5-6 | 79.8 | 79.3 | 76.2 | 80.2 | 70.3 | 78.5 | 79.0 | 75.6 | 80.5 | 78.8 | 82.0 | 81.4 | 61.9 | 78.7 | 83.7 | 79.2 | 75.5 | 78.1 | 80.4 | 77.3 |
| 6-7 | 80.2 | 79.6 | 82.3 | 80.3 | 76.2 | 77.1 | 82.6 | 68.3 | 74.0 | | 81.1 | 77.1 | 74.7 | 72.7 | 78.7 | 79.8 | 71.1 | 79.6 | 81.7 | 80.7 |
| 7-8 | 82.6 | 82.0 | 81.1 | 81.9 | 72.5 | 77.3 | 71.3 | 72.5 | 79.1 | 55.7 | 79.5 | 75.7 | 75.7 | 79.9 | 78.9 | 81.7 | 74.3 | 76.6 | 81.3 | 78.8 |
| 8-12 | 81.3 | 75.8 | 80.2 | 76.2 | 74.0 | 78.1 | 78.7 | 78.2 | 81.5 | | 75.2 | 77.0 | 68.7 | 79.1 | 73.8 | 81.9 | 75.2 | 77.5 | 78.7 | 81.3 |
| 12-16 | 75.5 | 80.9 | 80.5 | 78.1 | 68.5 | 79.5 | 76.2 | 79.6 | 80.6 | | 74.1 | 77.1 | 71.9 | 71.6 | 80.5 | 84.3 | 80.3 | 62.4 | | 71.7 |
| 16-18 | 81.2 | 79.6 | 69.6 | 79.9 | 70.8 | 78.6 | 80.8 | 71.0 | 78.5 | | 68.9 | 81.4 | 66.8 | 75.3 | 75.3 | 84.2 | 76.7 | 72.7 | | |
| 18-20 | | | | | | | | | | | | | | | | | | | | |
| 20-24 | 81.4 | 80.8 | | 79.4 | 79.7 | 77.4 | 76.2 | 80.9 | 79.4 | | | 65.8 | | 59.1 | 71.5 | 81.4 | | | | |
| 24-28 | 82.6 | 81.7 | | 77.2 | 77.9 | 78.8 | 78.0 | | 80.5 | | | | | | 73.5** | 81.8 | | | | |
| 28-30 | 81.2 | | | 81.6 | 79.5 | | | | | | | | | | | 79.7 | | | | |
| 30-32 | | | | | | | | | | | | | | | | | | | | |
| 32-36 | 79.2 | | | | 73.4* | | | | | | | | | | | | | | | |
| 36-39.5 | 83.3 | | | | | | | | | | | | | | | | | | | |

Intervals of irregular core segments

*32-35 (cm)

**24-27 (cm)