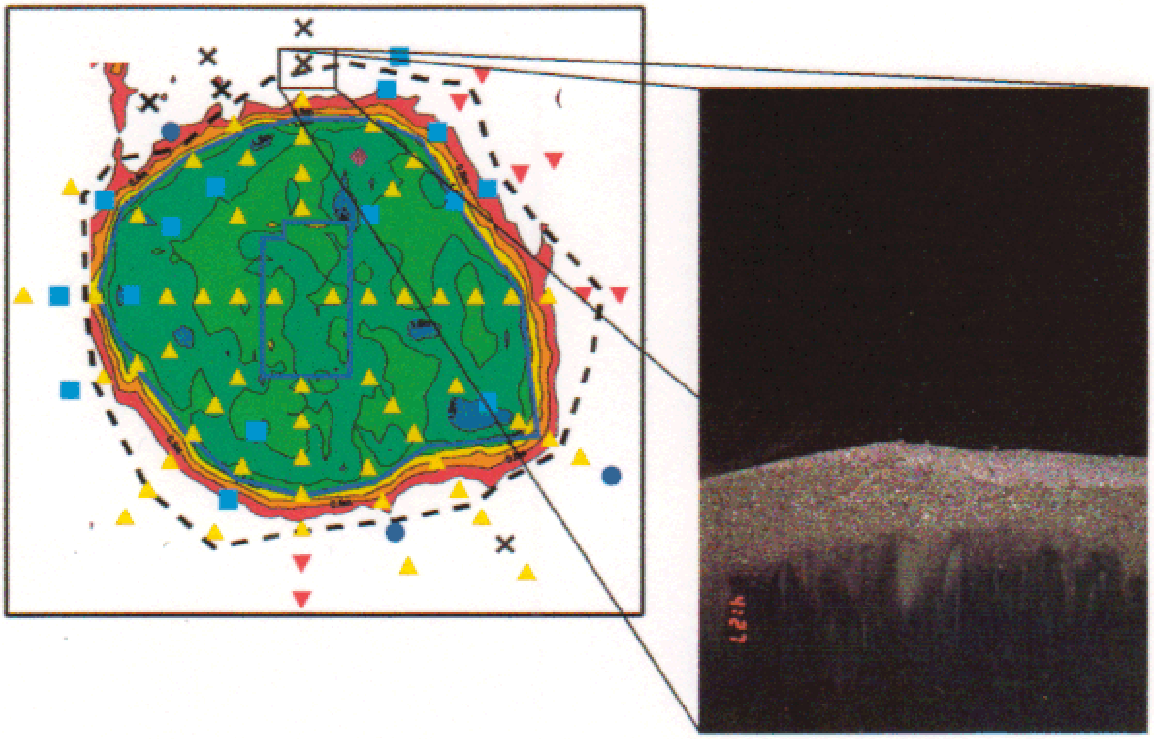
THE 1997 CATEGORY II CAPPING PROJECT AT THE NEW YORK MUD DUMP SITE: RESULTS FROM THE FIRST POSTCAP REMOTS® SURVEY OF APRIL 1998



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ACKNOWLEDGMENT

This report presents the results of a REMOTS® survey conducted following the completion of sand capping operations for the 1997 Category II Capping Project at the New York Mud Dump Site. This survey was completed in April 1998 by Science Applications International Corporation (SAIC) of Newport, RI, under Delivery Order 9 of SAIC's Indefinite Delivery Contract No. DACW51-97-D-0014 with the U.S. Army Corps of Engineers - New York District (NYD). Mr. Brian May is the manager of technical activities under the NYD contract; Dr. Scott McDowell is SAIC's program manager.

Logistical and planning support for the survey were provided by Mr. Brian May of the NYD, with assistance from Mr. Tim LaFontaine.

Messrs. Ray Valente, Jason Infantino and Ms. Melissa Swanson of SAIC were responsible for mobilizing the field equipment and conducting the survey operations aboard the Corps vessel M/V *Gelberman*. The crew of the M/V *Gelberman* are commended for their skill in vessel handling and dedication during long hours of field operations.

Ms. Melissa Swanson analyzed the REMOTS® images and produced graphic data products for this report. The report was co-authored by Ms. Swanson and Mr. Ray Valente. Dr. McDowell provided technical review of the report, while Mr. Tom Fox was responsible for report production.

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1.0 INTRODUCTION

1.1 Background of the 1997 Category II Capping Project

Prior to 1996, sediments dredged from the Port of New York and New Jersey (PANY/NJ) were placed in an ocean disposal site in the New York Bight known as the Mud Dump Site (MDS). This site is located six miles off the coast of northern New Jersey; it is a 2.2 square mile rectangular area in approximately 12-27 m of water (Figure 1-1).

During the early 1990's, there were growing concerns about both the remaining capacity of the site and the environmental effects of historic and contemporary disposal of contaminated dredged material. In response to these concerns, EPA Administrator Carol Browner, Secretary of Transportation Frederico Pena, and Secretary of the Army Togo West, Jr. issued a "3 Party Letter" in 1996 announcing that the MDS would close by September 1, 1997. The "3 Party Letter" further states that simultaneous with the closure of the MDS, the site and surrounding areas which have been used historically for disposal of contaminated material will be redesignated as the Historic Area Remediation Site (HARS). On August 26, 1997, the U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers finalized the rule providing for simultaneous closure of the MDS and designation of the HARS.

The planned closure of the MDS on September 1, 1997 left the PANY/NJ with a limited period of time to dispose a finite volume of contaminated (i.e., Category II) dredged sediments at the site and cover these sediments with a layer of clean (i.e., Category I) sediment. Through the collaborative efforts of the U.S. Army Engineer Waterways Experiment Station (WES), Science Applications International Corporation (SAIC), and the Corps of Engineers' New York District (NYD), a plan was developed in early 1997 to address dredging, ocean disposal and subsequent capping of the Category II material at the MDS prior to the September 1 closure. This capping project is referred to as the 1997 Category II Capping Project.

The Category II project material was dredged from selected berthing facilities at Port Newark and Port Elizabeth, New Jersey. Placement of this material in a carefully selected rectangular area located within the southeast quadrant of the MDS began in late May 1997 and continued until August 10, 1997. During this period, roughly 700,000 yd^3 of material were placed, creating a distinct mound on the bottom. Immediately following the completion of the placement operation, capping of the project material with clean sand began on August 21, 1997. The capping operation continued intermittently until January 18, 1998, when it was demonstrated through high-resolution bathymetric surveys that a 1-m thick layer had been placed over the entire project material footprint. An estimated 2.4 million cubic yards of Ambrose Channel sand was placed.

As part of the project, the NYD contracted SAIC to perform a series of oceanographic studies to characterize the seafloor in the area of the MDS selected for placement of the Category II material. Baseline surveys were conducted prior to placement of the dredged material, as well as during and after both the disposal and capping operations (Figure 1-2). The following monitoring techniques were utilized: high-resolution bathymetry, seafloor video reconnaissance,

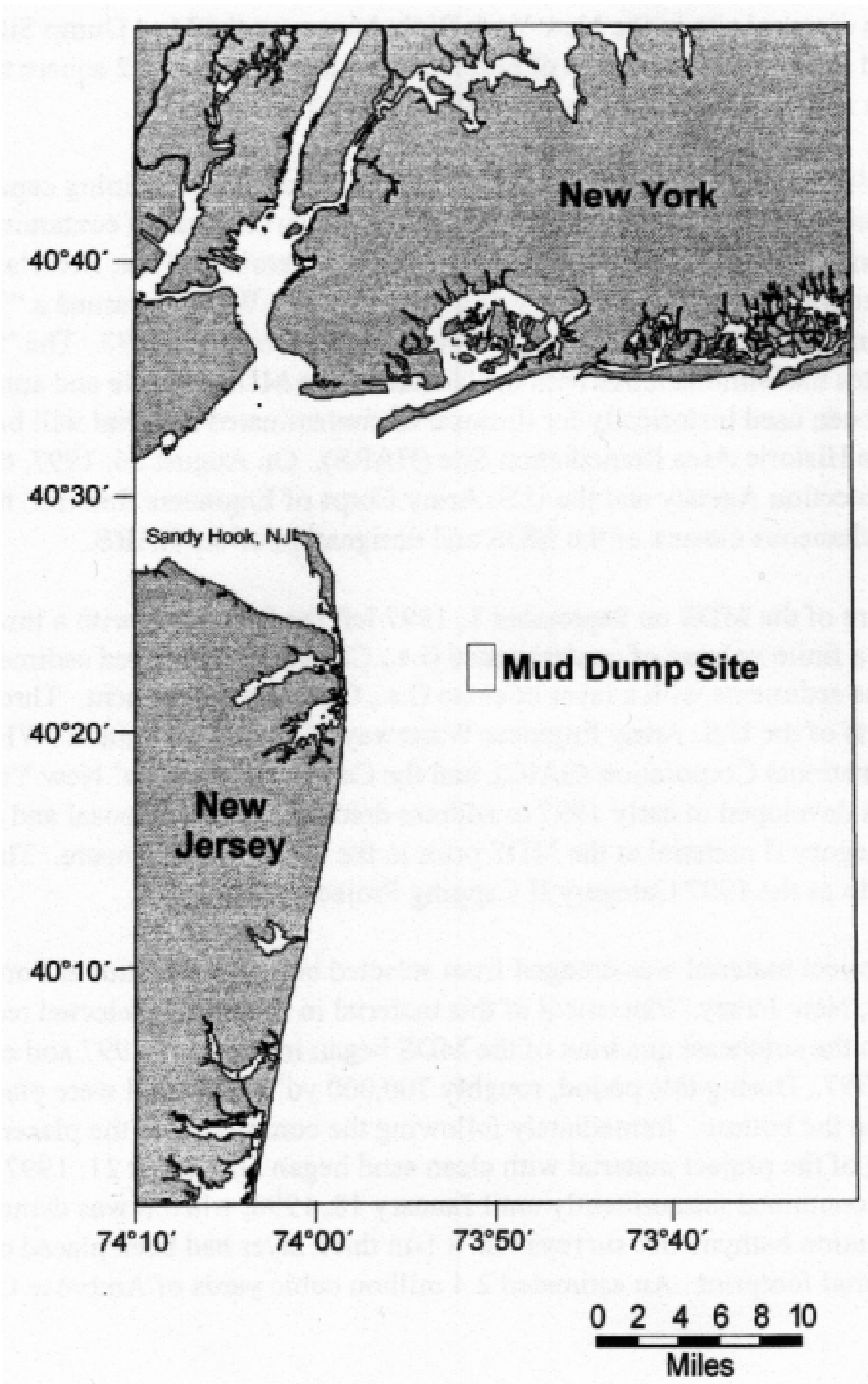

Figure 1-1. Location of the Mud Dump Site in the New York Bight.

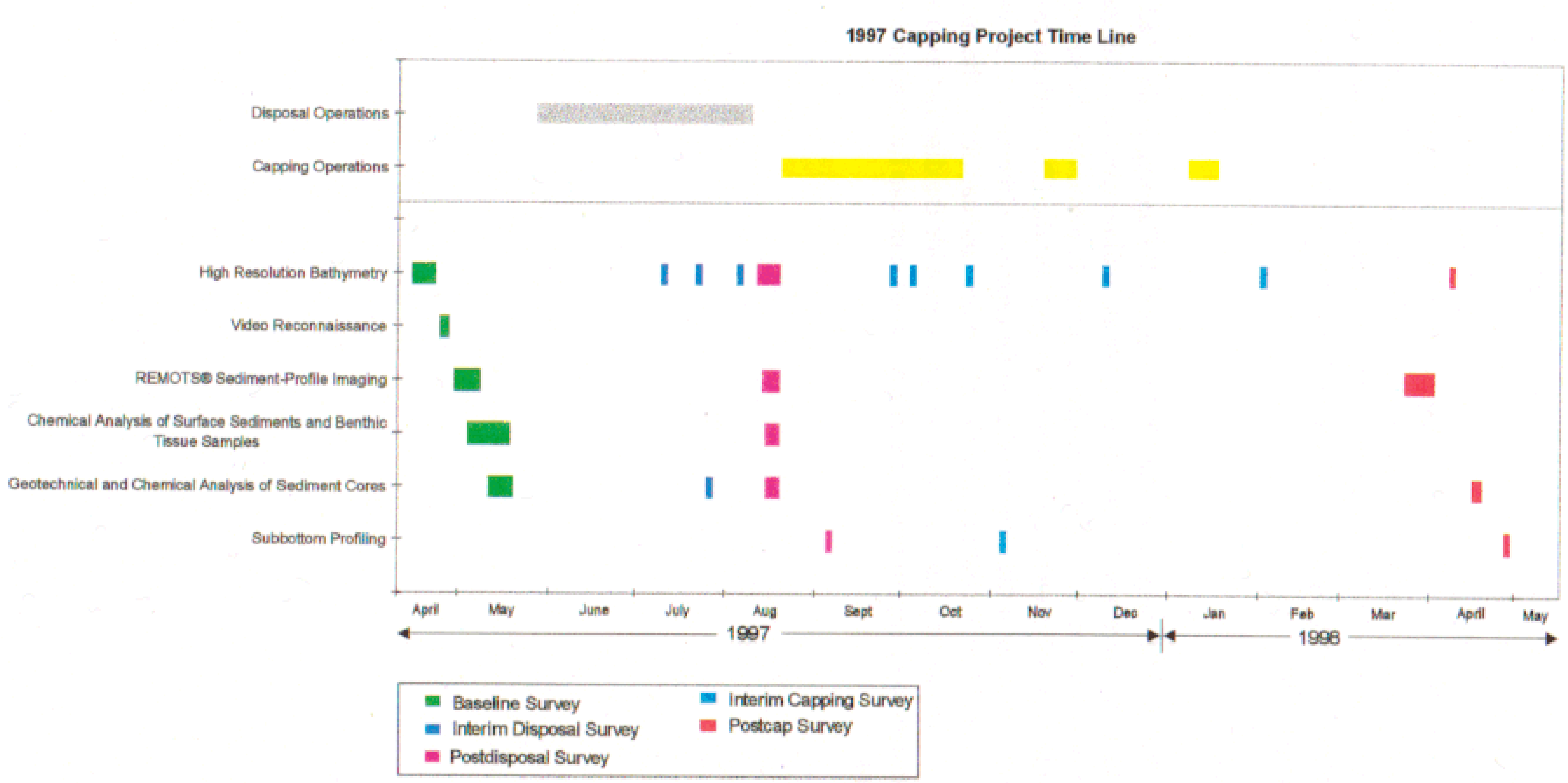

Figure 1-2. 1997 Category II Capping Project time line.

chemical analysis of surface sediment and biological tissue samples, sediment coring, subbottom profiling, and REMOTS® sediment-profile imaging. The results of REMOTS® surveys conducted prior to the dredged material placement operations (i.e., baseline survey), as well as immediately following the completion of the disposal operation in August 1997 (i.e., postdisposal survey), have been reported previously (SAIC 1997a and b). This report presents the results of the first postcap REMOTS® survey of the 1997 Category II Capping Project. This survey was completed in early April of 1998, roughly two months following the completion of the sand capping operation.

1.2 Objectives

The first postcap REMOTS® survey for the 1997 Category II Capping Project had two objectives. The first objective was to provide micro-scale sedimentary characterization of the seafloor on and around the recently capped project mound. In particular, the survey was designed to provide disposal site managers from the NYD and the EPA with information pertaining to the distribution of the clean sand used for capping of the mound, as well as provide an assessment of overall benthic habitat quality both on the sand cap and in the area surrounding the capped mound. The second survey objective was to provide the disposal managers with an assessment of the degree, if any, to which the newly placed sand cap had become colonized by benthic organisms.

2.0 METHODS

2.1 Navigation

The April 1998 postcap REMOTS® survey was conducted aboard the NYD’s 85-ft harbor tug, M/V *Gelberman*. SAIC installed its Portable Integrated Navigation and Survey System (PINSS) on the vessel to provide navigational support for the crew and to digitally store survey data. Vessel positioning at predetermined stations was accomplished using a Magnavox 4200D GPS positioning system interfaced to the PINSS. The PINSS utilized a Toshiba 3200DX personal computer to provide real-time navigation, as well as to collect position, depth, and time data for subsequent analyses. One to five-meter accuracy was achieved by applying a differential correction to the GPS signals from an FM modem receiving Differential Corrections Incorporated (DCI) premium service. Vessel position was displayed on two monitors, one for the survey navigator and the second for the helmsman to aid in steering the vessel toward target station locations. In addition, a Hewlett Packard 7475A plotter tracked the vessel's position during survey operations, allowing the navigator to assess the vessel's location relative to target station locations. An HP Thinkjet printer generated a hard copy of position fixes. Each fix incorporated time of day, the vessel's position in Latitude and Longitude and UTM coordinates, signal quality, and station and replicate identification.

All differential GPS navigation data were received, logged and displayed in the North American Datum 1983 (NAD 83) geographic coordinate system. While SAIC Standard Operating Procedures have previously involved applying a correction for an offset to NAD 27 prior to submission of coordinate data to the NYD, the coordinate data in this report are presented in NAD 1983 to conform with side-scan sonar, sediment grab sampling, and other data recently collected by SAIC.

2.2 Field Sampling Design

The rectangular area within the southeast quadrant of the MDS selected for placement of the 1997 Category II project material is called the 1997 Base Mound Area (Figure 2-1). This area is located slightly to the east of the area used for the 1993 Dioxin Capping Project (Figure 2-1). A REMOTS® survey conducted in August 1997, immediately following the completion of the dredged material placement phase of the 1997 Category II Project, was used to delineate the footprint of the project material mound. It was found that the 1997 dredged material footprint encompassed a roughly circular area surrounding the Base Mound Area, as expected based on predisposal modeling, and some of the 1997 project material overlaid the 1993 Dioxin Capping Project sand cap (Figure 2-1). The sand capping operations which began in August 1997 occurred within the polygon delineating the dredged material footprint. A series of bathymetric and subbottom profiling surveys conducted during and immediately following the capping phase were used to confirm that a sand layer measuring at least one meter in thickness was placed over the entire dredged material footprint.

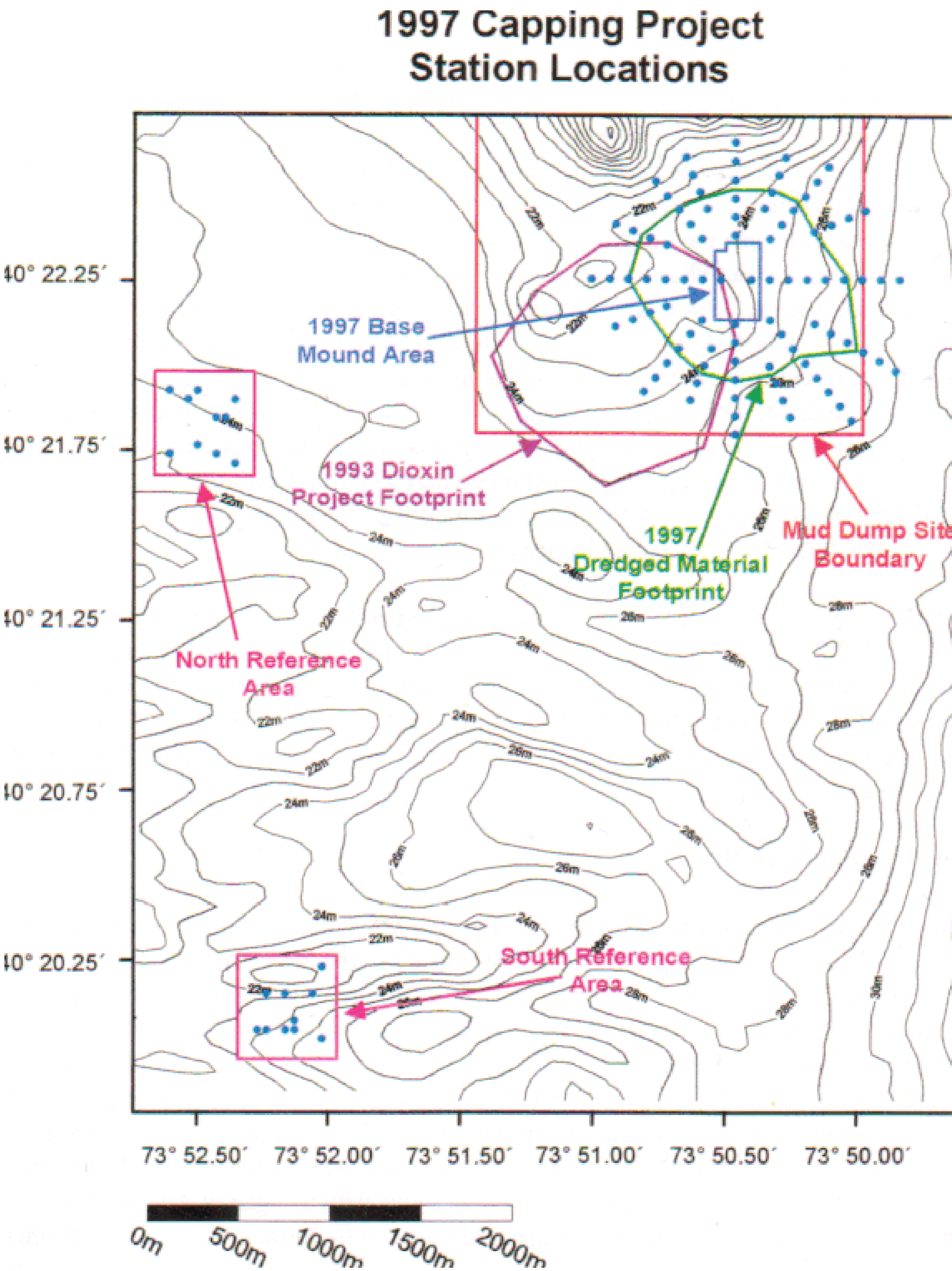

Figure 2-1. Map showing the locations of the 1997 Base Mound Area, the 1997 dredged material footprint, and the 1993 Dioxin Capping Project footprint in the southern half of the Mud Dump Site.

For the April 1998 postcap REMOTS® survey, a total of 110 stations were sampled in three field days during the period March 24 to April 2. Ninety (90) of the stations were arranged in a series of radial transects centered at the 1997 Base Mound Area and extending out in all directions, to achieve the objective of sampling both the newly placed 1997 project sand cap (as delineated using high-resolution bathymetry and subbottom profiling) and the area immediately surrounding this cap (Figures 2-1 and 2-2). There were an additional 20 stations sampled within two reference areas located adjacent to the Mud Dump Site (Figure 2-1). These are the same two reference areas sampled in previous REMOTS® surveys conducted under the 1997 Category II Capping Project (baseline and postdisposal), as well as under the 1993 Dioxin Capping Monitoring Program (e.g., April 1994, July 1995, October 1996, and May 1997). Ten stations were sampled within each reference area (Figures 2-3 and 2-4); these stations were chosen randomly from the pool of 20 stations in each area sampled in previous REMOTS® surveys.

The 90 REMOTS® stations centered at the 1997 Base Mound Area were spaced 100 m apart along the radial transects and were distributed as follows (refer to Figures 2-1 and 2-2):

1) Roughly 22 of the stations comprising the west (W), west-southwest (WSW), southwest (SW), and south-southwest (SSW) transects occurred within or near the boundary of the 1993 Dioxin Capping Project.

2) The outer stations of the northwest (NW), north (N) and northeast (NE) transects were located on or near several former disposal mounds located in the mid-section of the MDS.

3) The east (E) and east-southeast (ESE) transects included both the southeast corner of the MDS and areas up to 200 m to the east of the MDS boundaries.

The REMOTS® camera was lowered multiple times at each station in an attempt to collect at least two replicate REMOTS® images and corresponding planview photographs suitable for subsequent analysis. Color slide film was used and developed at the end of each field day to verify proper equipment operation and image acquisition.

2.3 Planview Photography

2.3.1 Planview Photograph Acquisition

Planview (i.e., horizontal plane) photographs of approximately 0.3 m^2 of the seafloor surface were obtained in conjunction with the REMOTS® images. The photographs were acquired with a PhotoSea 1000a 35mm Underwater Camera System and a PhotoSea 1500s Strobe Light attached to the REMOTS® camera frame. The photographs were taken immediately prior to the landing of the frame, providing an undisturbed record of the sediments before penetration of the REMOTS® prism. Once the camera frame was

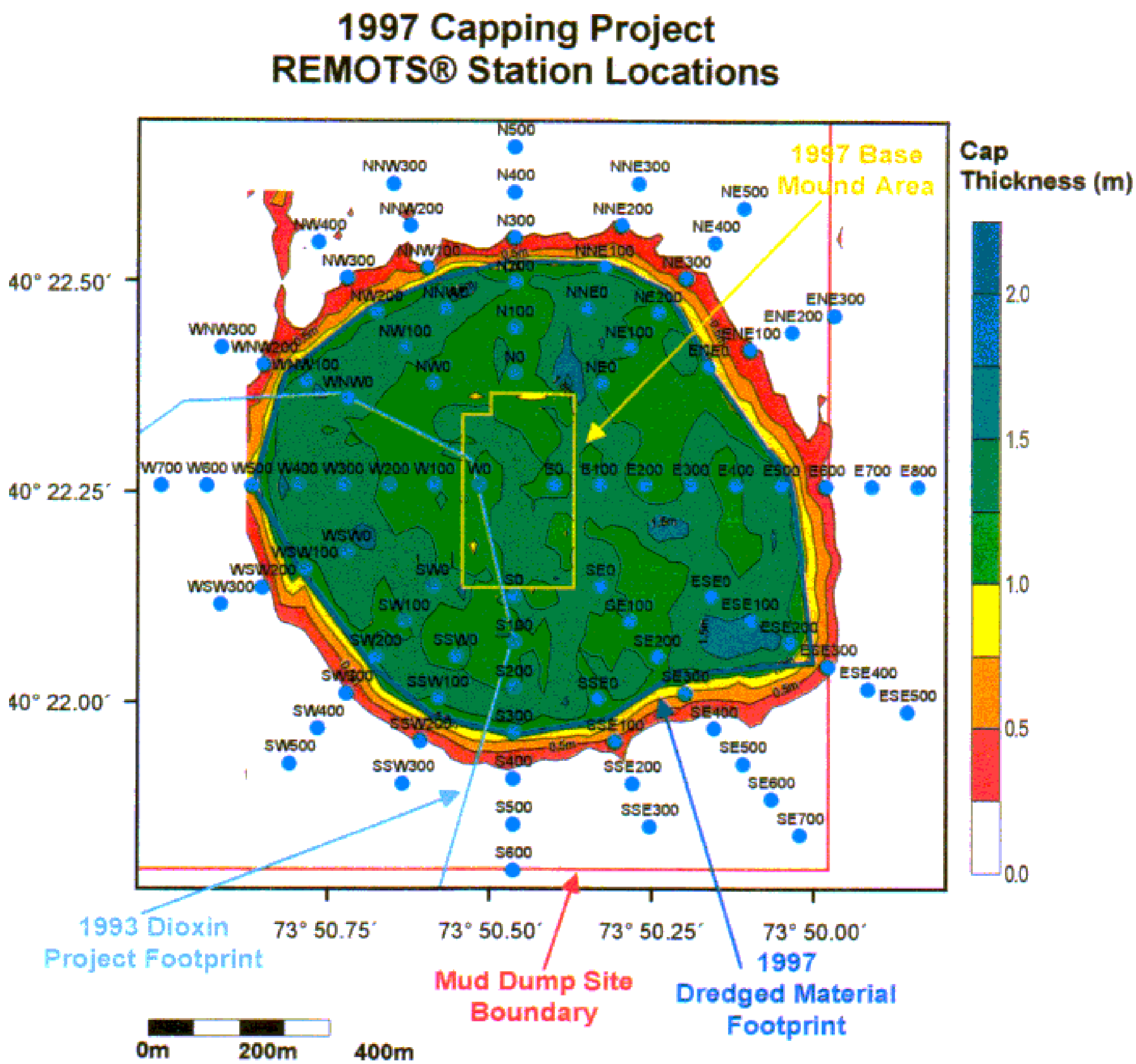

Figure 2-2. Map showing the locations of radial transect stations covering the capped project mound and surrounding area.

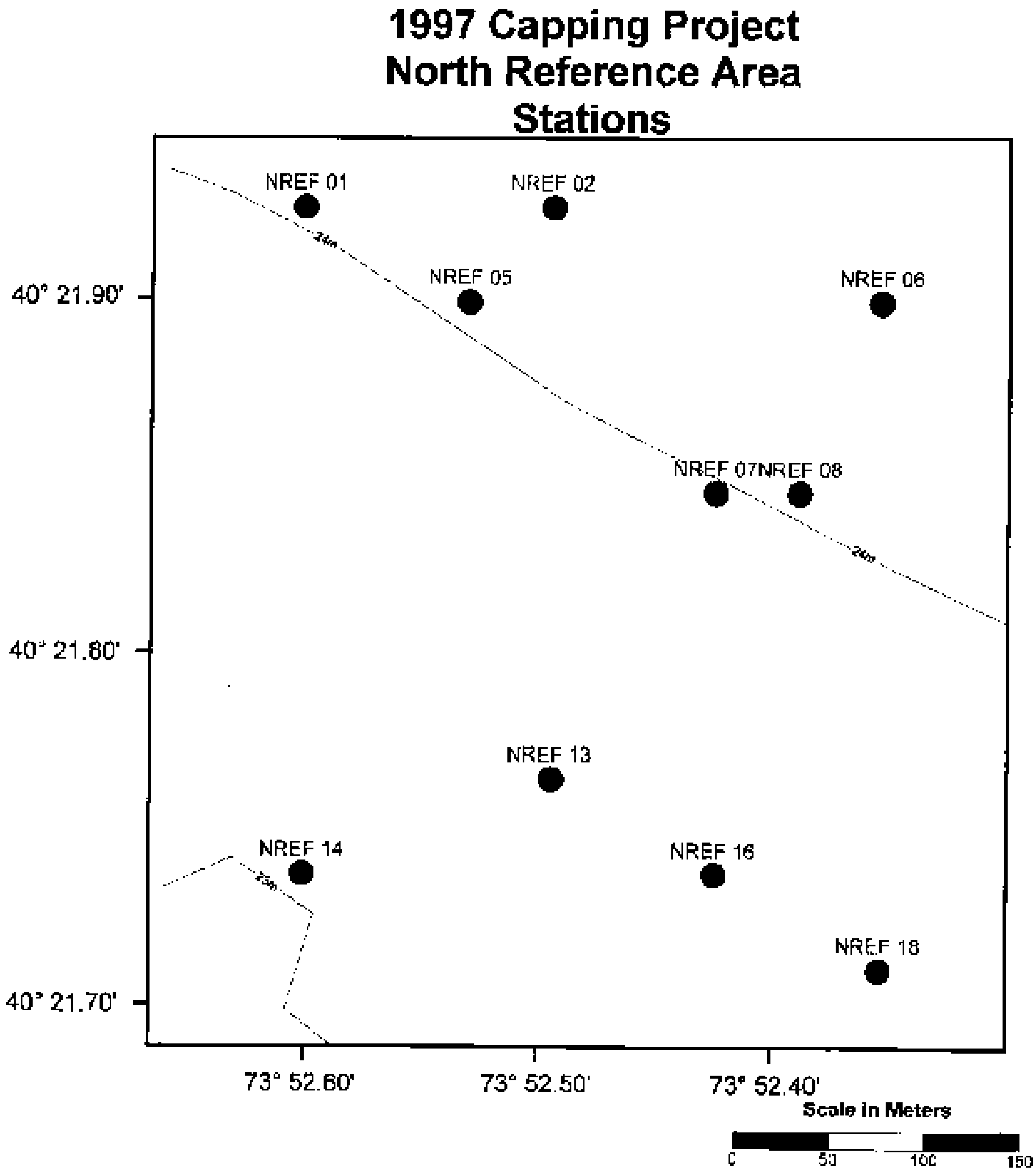

Figure 2-3. Station locations at the North Reference Area.

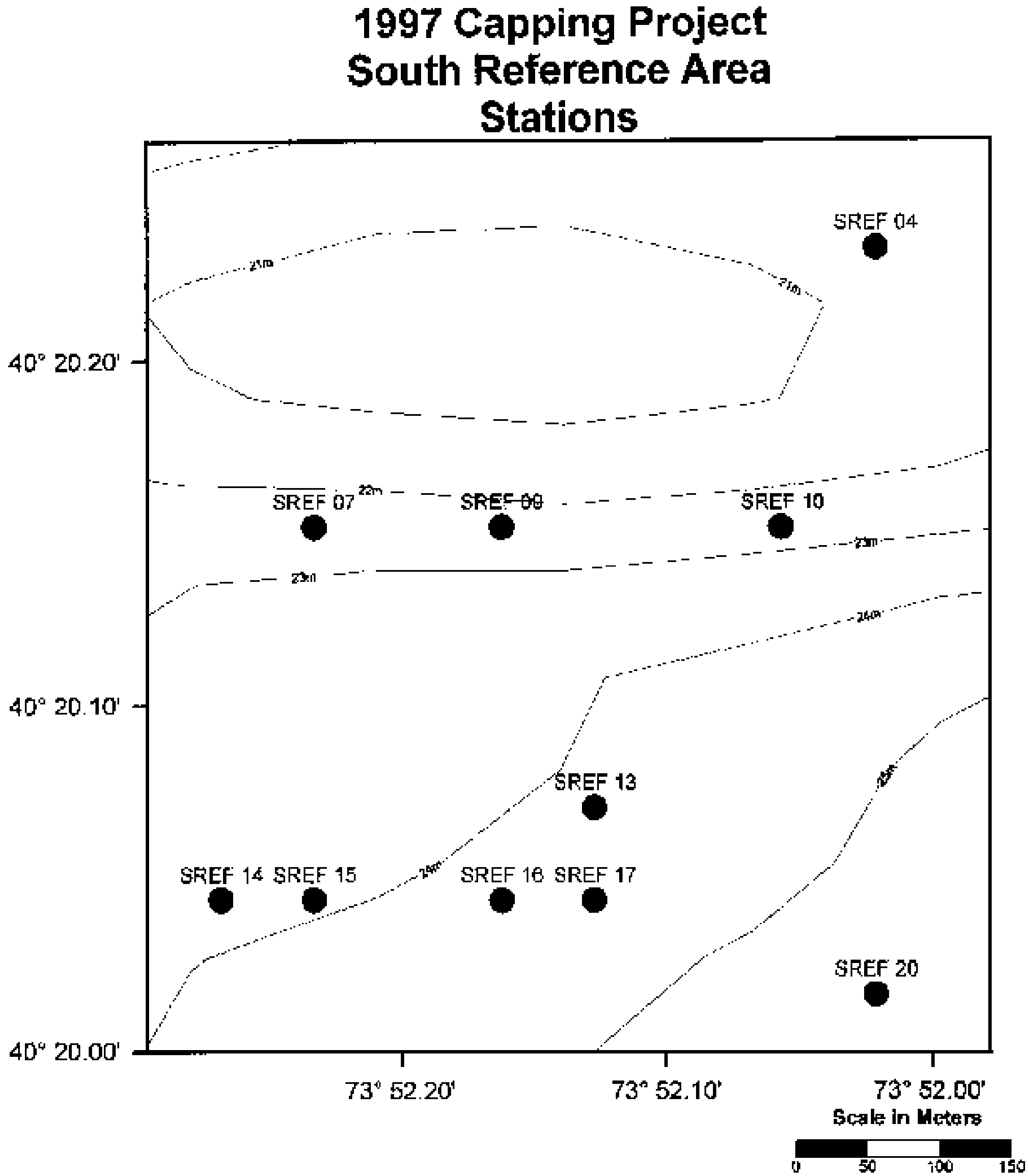

Figure 2-4. Station locations at the South Reference Area.

lifted above the sediments, the PhotoSea camera system automatically cycled film and recharged the strobe in preparation for the next photograph. In this manner, a corresponding planview photograph was usually obtained for each REMOTS® image acquired.

2.3.2 Planview Photograph Analysis

Analysis of the planview images included screening all the replicates taken at the stations sampled. Poor water clarity and lack of contrast eliminated some of the images from further consideration. Of the remaining, a representative collection was made, which included one image from each set of station replicates successfully photographed.

The purpose of the planview image analysis was to supplement the more detailed and comprehensive REMOTS® characterization of the seafloor. The planview analysis consisted of qualitative descriptions of key sediment characteristics (e.g., sediment type, bedforms and biological features) based on careful scrutiny of the projected 35mm slides. Since the surface sediment descriptions were based on visual observations and therefore are somewhat subjective, only the obvious presence of rock, gravel, sand and/or fines was noted. Likewise, the presence of shell debris and any evidence of epifaunal or infaunal organisms (e.g., tubes, burrow openings, etc.) were recorded. Recent dredged material was evident from black, grey or rust-colored deposits of poorly sorted or over-consolidated sediments. The presence of dredged material from past disposal was sometimes indicated by angular rocks and/or anthropogenic materials. A scale bar was not present in the photographs; however, each photograph covers an area of seafloor measuring roughly 0.4 m x 0.7 m (roughly 0.3 m^2).

2.4 REMOTS® Sediment-Profile Imaging

REMOTS® is a formal and standardized technique for sediment-profile imaging and analysis (Rhoads and Germano 1982; 1986). A Benthos Model 3731 Sediment Profile Camera (Benthos, Inc., North Falmouth, MA; Figure 2-5) was used in this study. The camera is designed to obtain *in situ* profile images of the top 20 cm of sediment. Functioning like an inverted periscope, the camera consists of a wedge-shaped prism with a front faceplate and a back mirror mounted at a 45-degree angle to reflect the profile of the sediment-water interface facing the camera. The prism is filled with distilled water, the assembly contains an internal strobe used to illuminate the images, and a 35mm camera is mounted horizontally on top of the prism. The prism assembly is moved up and down into the sediments by producing tension or slack on the winch wire. Tension on the wire keeps the prism in the up position, out of the sediments.

2.4.1 REMOTS® Image Acquisition

The camera frame is lowered to the seafloor at a rate of about 1 m/sec (Figure 2-5). When the frame settles onto the bottom, slack on the winch wire allows the prism to penetrate the seafloor vertically. A passive hydraulic piston ensures that the prism enters the bottom slowly (approximately 6 cm/sec) and does not disturb the sediment-water

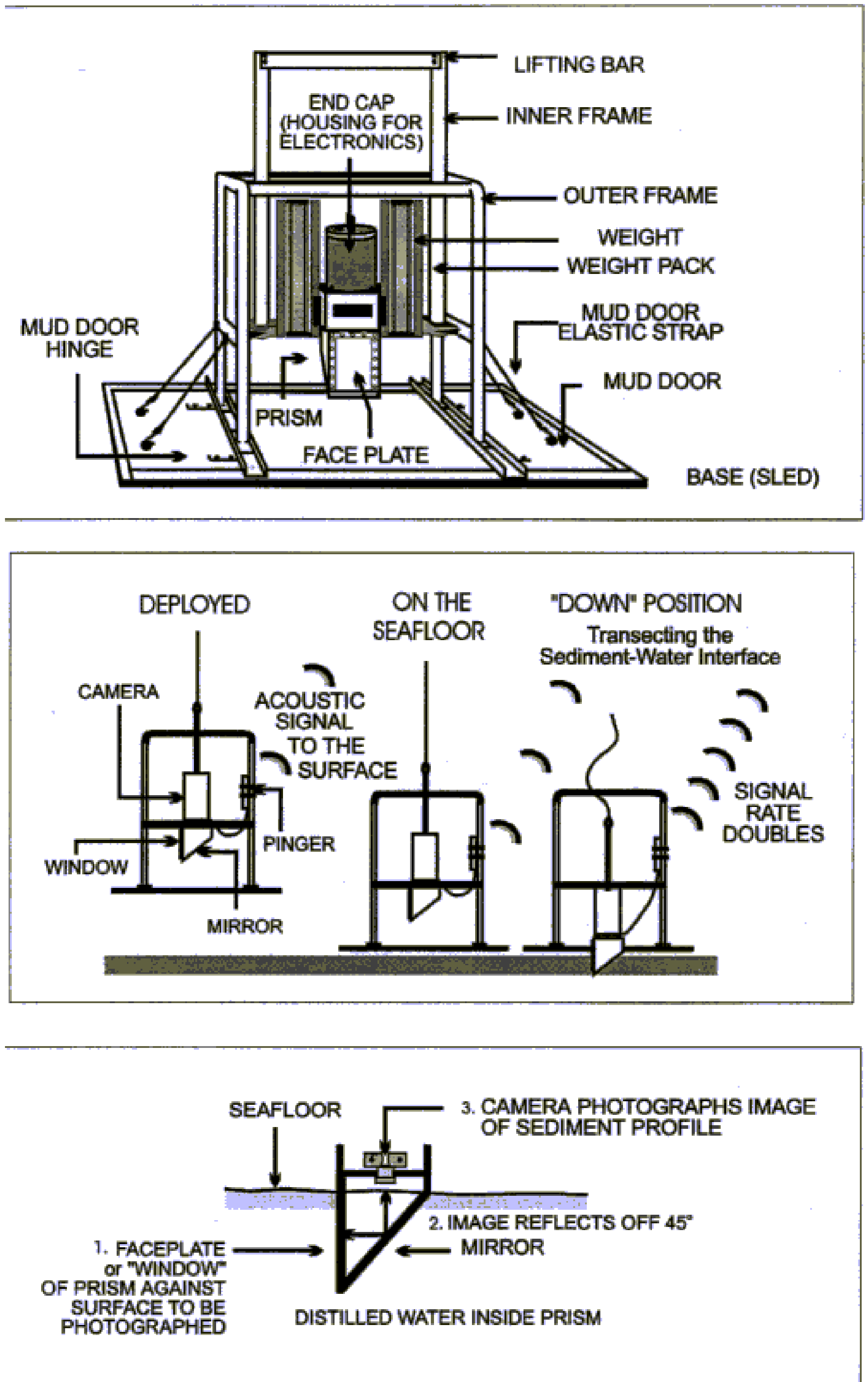

Figure 2-5. Schematic diagram of Benthos, Inc. Model 3731 REMOTS sediment-profile camera and sequence of operation on deployment.

interface. As the prism starts to penetrate the seafloor, a trigger activates a 13-second time delay on the shutter release to allow maximum penetration before a photo is taken. A Benthos Model 2216 Deep Sea Pinger is attached to the camera and outputs a constant 12 kHz signal of one ping per second; upon discharge of the camera strobe, the ping rate doubles for 10 seconds. Monitoring the signal output on deck provides confirmation that a successful image was obtained. Because the sediment photographed is directly against the faceplate, turbidity of the ambient seawater does not affect image quality. When the camera is raised, a wiper blade cleans off the faceplate, the film is advanced by a motor drive, the strobe is recharged, and the camera can be lowered for another image.

2.4.2 REMOTS® Image Analysis

The REMOTS® images were analyzed with the full-color, SAIC Image Analysis System. This is a PC-based system integrated with a Javelin CCTV video camera and frame grabber. Color slides are digitally recorded as color images on computer disk. The image analysis software is a menu-driven program that incorporates user commands via keyboard and mouse. The system displays each color slide on the CRT while measurements of physical and biological parameters are obtained. Proprietary SAIC software allows the measurement and storage of data on up to 21 different variables for each REMOTS® image obtained. Automatic disk storage of all measured parameters allows data from any variables of interest to be compiled, sorted, displayed graphically, contoured, or compared statistically. All measurements were printed out on data sheets for a quality assurance check by SAIC Senior Scientist Dr. Donald Rhoads, one of the inventors of REMOTS® technology, before being approved for final data synthesis, statistical analyses, and interpretation. A summary of the major categories of REMOTS® data is presented below.

2.4.3 Sediment Type Determination

The sediment grain size major mode and range are estimated visually from the photographs by overlaying a grain size comparator which is at the same scale. This comparator was prepared by photographing a series of Udden-Wentworth size classes (equal to or less than coarse silt up to granule and larger sizes) through the REMOTS® camera. Seven grain size classes are on this comparator: $>4\ \phi$, $4\text{-}3\ \phi$, $3\text{-}2\ \phi$, $2\text{-}1\ \phi$, $1\text{-}0\ \phi$, $0\text{-}(-1\ \phi)$, and $<-1\ \phi$. The lower limit of optical resolution of the photographic system is about 62 microns ($4\ \phi$), allowing recognition of grain sizes equal to or greater than coarse silt. The accuracy of this method has been documented by comparing REMOTS® estimates with grain size statistics determined from laboratory sieve analyses.

The major modal grain size that is assigned to an image is the dominant grain size as estimated by area within the imaged sediment column. In those images that show layering of sand and mud, the dominant major mode assigned to a replicate therefore depends on how much area of the photograph is represented by sand versus mud. These textural assignments may or may not correspond to traditional sieve analyses depending on how closely the vertical sampling intervals are matched between the grab or core sample and the depth of the imaged sediment.

2.4.4 Boundary Roughness

Small-scale surface boundary roughness is measured from an image with the computer image analysis system. This vertical measurement is from the highest point at the sediment-water interface to the lowest point. This measurement of vertical relief is made within a horizontal distance of 15 cm (the total width of the optical window). Because the optical window is 20 cm high, the greatest possible roughness value is 20 cm. The source of the roughness is described if known. In most cases this is either biogenic (mounds and depressions formed by bioturbation or foraging activity) or relief formed by physical processes (ripples, scour depressions, rip-ups, mud clasts, etc.).

2.4.5 Optical Prism Penetration Depth

The optical prism penetrates the bottom under a static driving force imparted by the weight of the descending optical prism, camera housing, supporting mechanism, and weight packs. The penetration depth into the bottom depends on the force exerted by the optical prism and the bearing strength of the sediment. If the weight of the camera prism is held constant, the change in penetration depth over a surveyed site will reflect changes in geotechnical properties of the bottom. In this sense, the camera prism acts as a static-load penetrometer. The depth of penetration of the optical prism into the bottom can be a useful parameter, because dredged and capped materials often will have different shear strengths and bearing capacities.

2.4.6 Mud Clasts

When fine-grained, cohesive sediments are disturbed, either by physical bottom scour or faunal activity (e.g., decapod foraging), intact clumps of sediment are often scattered about the seafloor. These mud clasts can be seen at the sediment-water interface in REMOTS® images. During analysis, the number of clasts is counted, the diameter of a typical clast is measured, and their oxidation state is assessed. Depending on their place of origin and the depth of disturbance of the sediment column, mud clasts can be reduced or oxidized. Also, once at the sediment-water interface, these sediment clumps are subject to bottom-water oxygen levels and bottom currents. Based on laboratory microcosm observations of reduced sediments placed within an aerobic environment, oxidation of reduced surface layers by diffusion alone is quite rapid, occurring within 6-12 hours (Germano 1983). Consequently, the detection of reduced mud clasts in an obviously aerobic setting suggests a recent origin. The size and shape of mud clasts, e.g., angular versus rounded, are also considered. Mud clasts may be moved about and broken by bottom currents and/or animals (macro- or meiofauna; Germano 1983). Over time, large angular clasts become small and rounded. Overall, the abundance, distribution, Oxidation State, and angularity of mud clasts are used to make inferences about the recent pattern of seafloor disturbance in an area.

2.4.7 Measurement of Dredged Material and Cap Layers

The recognition of dredged material from REMOTS® images is usually based on the presence of anomalous sedimentary materials within an area of ambient sediment. The ability to distinguish between ambient sediment and dredged or cap material demands that the survey extend well beyond the margins of a disposal site so that an accurate characterization of the ambient bottom is obtained. The distributional anomalies may be manifested in topographic roughness, differences in grain size, sorting, shell content, optical reflectance, fabric, or sediment compaction (i.e., camera prism penetration depth). Second-order anomalies may also provide information about the effects of dredged material on the benthos and benthic processes such as bioturbation (see following sections).

2.4.8 Apparent Redox Potential Discontinuity (RPD) Depth

Aerobic near-surface marine sediments typically have higher reflectance values relative to underlying anoxic sediments. Sand also has higher optical reflectance than mud. These differences in optical reflectance are readily apparent in REMOTS® images; the oxidized surface sediment contains particles coated with ferric hydroxide (an olive color when associated with particles), while reduced and muddy sediments below this oxygenated layer are darker, generally grey to black. The boundary between the colored ferric hydroxide surface sediment and underlying grey to black sediment is called the apparent redox potential discontinuity (RPD).

The depth of the apparent RPD in the sediment column is an important time-integrator of dissolved oxygen conditions within sediment pore waters. In the absence of bioturbating organisms, this high reflectance layer (in muds) will typically reach a thickness of 2 mm (Rhoads 1974). This depth is related to the supply rate of molecular oxygen by diffusion into the bottom and the consumption of that oxygen by the sediment and associated microflora. In sediments that have very high sediment-oxygen demand, the sediment may lack a high reflectance layer even when the overlying water column is aerobic.

In the presence of bioturbating macrofauna, the thickness of the high reflectance layer may be several centimeters. The relationship between the thickness of this high reflectance layer and the presence or absence of free molecular oxygen in the associated pore waters must be made with caution. The boundary (or horizon) which separates the positive Eh region (oxidized) from the underlying negative Eh region (reduced) can only be determined accurately with micro-electrodes. For this reason, we describe the optical reflectance boundary, as imaged, as the “apparent” RPD, and it is mapped as a mean value.

The depression of the apparent RPD within the sediment is relatively slow in organic-rich muds (on the order of 200 to 300 micrometers per day); therefore, this parameter has a long time constant (Germano and Rhoads 1984). The rebound in the apparent RPD is also slow (Germano 1983). Measurable changes in the apparent RPD depth using the REMOTS® optical technique can be detected over periods of one or two months. This

parameter is used effectively to document changes (or gradients) which develop over a seasonal or yearly cycle related to water temperature effects on bioturbation rates, seasonal hypoxia, sediment oxygen demand, and infaunal recruitment. In sediment-profile surveys of ocean disposal sites sampled seasonally or on an annual basis throughout the New England region performed under the DAMOS (Disposal Area Monitoring System) Program for the U.S. Army Corps of Engineers, New England Division, SAIC repeatedly has documented a drastic reduction in apparent RPD depths at disposal sites immediately after dredged material disposal, followed by a progressive post-disposal apparent RPD deepening (barring further physical disturbance). Consequently, time-series RPD measurements can be a critical diagnostic element in monitoring the degree of recolonization in an area by the ambient benthos.
The depth of the mean apparent RPD also can be affected by local erosion. The peaks of disposal mounds commonly are scoured by divergent flow over the mound. This can result in washing away of fines, development of shell or gravel lag deposits, and very thin apparent RPD depths. During storm periods, erosion may completely remove any evidence of the apparent RPD (Fredette et al. 1988).

Another important characteristic of the apparent RPD is the contrast in reflectance values at this boundary. This contrast is related to the interactions among the degree of organic-loading, bioturbational activity in the sediment, and the levels of bottom-water dissolved oxygen in an area. High inputs of labile organic material increase sediment oxygen demand and, subsequently, sulfate reduction rates (and the abundance of sulfide end-products). This results in more highly reduced (lower reflectance) sediments at depth and higher RPD contrasts. In a region of generally low RPD contrasts, images with high RPD contrasts indicate localized sites of relatively high past inputs of organic-rich material (e.g., organic or phytoplankton detritus, dredged material, sewage sludge, etc.).

2.4.9 Sedimentary Methane

At extreme levels of organic-loading, pore-water sulphate is depleted, and methanogenesis occurs. The process of methanogenesis is detected by the appearance of methane bubbles in the sediment column. These gas-filled voids are readily discernible in REMOTS® images because of their irregular, generally circular aspect and glassy texture (due to the reflection of the strobe off the gas). If present, the number and total areal coverage of all methane pockets are measured.

2.4.10 Infaunal Successional Stages

The mapping of successional stages, as employed in this project, is based on the theory that organism-sediment interactions in fine-grained sediments follow a predictable sequence after a major seafloor perturbation (e.g., passage of a storm, disturbance by bottom trawlers, dredged material deposition, hypoxia). This theory states that primary succession results in "the predictable appearance of macrobenthic invertebrates belonging to specific functional types following a benthic disturbance. These invertebrates interact with sediment in specific ways. Because functional types are the biological units of interest, our definition does not demand a sequential appearance of particular invertebrate species or genera" (Rhoads and Boyer 1982). This theory is formally developed in Rhoads and Germano (1982; 1986) and Rhoads and Boyer (1982).

The term disturbance is used here to define natural processes, such as seafloor erosion, changes in seafloor chemistry, and foraging disturbances which cause major reorganization of the resident benthos; disturbance also includes anthropogenic impacts, such as dredged material or sewage sludge disposal, thermal effluent from power plants, bottom trawling, pollution impacts from industrial discharge, etc. An important aspect of using this successional approach to interpret benthic monitoring results is relating organism-sediment relationships to the dynamical aspects of end-member successional stages (i.e., Stage I, II, or III communities as defined in the following paragraphs). This involves deducing dynamics from structure, a technique pioneered by R. G. Johnson (1972) for marine soft-bottom habitats. The application of this approach to benthic monitoring requires *in situ* measurements of salient structural features of organism-sediment relationships as imaged through REMOTS® technology.

Pioneering assemblages (Stage I assemblages) usually consist of dense aggregations of near-surface living, tube-dwelling polychaetes; alternately, opportunistic bivalves may colonize in dense aggregations after a disturbance (Rhoads and Germano 1982, Santos and Simon 1980a). These functional types are usually associated with a shallow redox boundary; bioturbation depths are shallow, particularly in the earliest stages of colonization. In the absence of further disturbance, these early successional assemblages are eventually replaced by infaunal deposit feeders; the start of this "infaunalization" process is designated arbitrarily as Stage II. Typical Stage II species are shallow dwelling bivalves or, as is common in New England waters, tubicolous amphipods. In studies of hypoxia-induced benthic defaunation events in Tampa Bay, Florida, ampeliscid amphipods appeared as the second temporal dominant in two of the four recolonization cycles (Santos and Simon 1980a, 1980b).

Stage III taxa, in turn, represent high-order successional stages typically found in low-disturbance regimes. These invertebrates are infaunal, and many feed at depth in a head-down orientation. The localized feeding activity results in distinctive excavations called feeding voids. Diagnostic features of these feeding structures include a generally semicircular shape with a flat bottom and arched roof, and a distinct granulometric change in the sediment particles overlying the floor of the structure. This granulometric change is caused by the accumulation of coarse particles that are rejected by the animals feeding selectively on fine-grained material. Other subsurface structures, such as burrows or methane gas bubbles, do not exhibit these character-istics and therefore are quite distinguishable from these distinctive feeding structures. The bioturbational activities of these deposit-feeders are responsible for aerating the sediment and causing the redox horizon to be located several centimeters below the sediment-water interface. In the retrograde transition of Stage III to Stage I, it is sometimes possible to recognize the presence of relic (i.e., collapsed and inactive) feeding voids.

The end-member stages (Stages I and III) are easily recognized in REMOTS® images by the presence of dense assemblages of near-surface polychaetes and the presence of subsurface feeding voids, respectively; both types of assemblages may be present in the same image. Additional information on REMOTS® image interpretation can be found in Rhoads and Germano (1982, 1986).

2.4.11 Organism-Sediment Index (OSI)

The multi-parameter REMOTS® Organism-Sediment Index (OSI) has been constructed to characterize habitat quality. Habitat quality is defined relative to two end-member standards. The lowest value is given to those bottoms which have low or no dissolved oxygen in the overlying bottom water, no apparent macrofaunal life, and methane gas present in the sediment (see Rhoads and Germano 1982, 1986, for REMOTS® criteria for these conditions). The OSI for such a condition is -10. At the other end of the scale, an aerobic bottom with a deeply depressed RPD, evidence of a mature macrofaunal assemblage, and no apparent methane gas bubbles at depth will have an OSI value of +11.

The OSI is a sum of the subset indices shown in Table 2-1. The OSI is calculated automatically by SAIC software after completion of all measurements from each REMOTS® photographic negative. The index has proven to be an excellent parameter for mapping disturbance gradients in an area and documenting ecosystem recovery after disturbance (Germano and Rhoads 1984, Revelas et al. 1987, Valente et al. 1992).

The OSI may be subject to seasonal changes because the mean apparent RPD depths vary as a result of temperature-controlled changes of bioturbation rates and sediment oxygen demand. Furthermore, the successional status of a station may change over the course of a season related to recruitment and mortality patterns or the disturbance history of the bottom. The sub-annual change in successional status is generally limited to Stage I (Polychaete-dominated) and Stage II (amphipod-dominated) seres. Stage III seres tend to be maintained over periods of several years unless they are eliminated by increasing organic loading, extended periods of hypoxia, or burial by thick layers of dredged material. The recovery of Stage III seres following abatement of such events may take several years (Rhoads and Germano 1982). Stations that have low OSI values (+6) are indicative of recently disturbed areas and tend to have greater temporal and spatial variation in benthic habitat quality than stations with higher OSI values (> +8).

Table 2-1

Calculation of REMOTS® Organism Sediment Index Value

A. CHOOSE ONE VALUE:

Mean RPD Depth	Index Value
0.00 cm	0
> 0 - 0.75 cm	1
0.75 - 1.50 cm	2
1.51 - 2.25 cm	3
2.26 - 3.00 cm	4
3.01 - 3.75 cm	5
> 3.75 cm	6

B. CHOOSE ONE VALUE:

Successional Stage	Index Value
Azoic	-4
Stage I	1
Stage I ® II	2
Stage II	3
Stage II ® III	4
Stage III	5
Stage I on III	5
Stage II on III	5

C. CHOOSE ONE OR BOTH IF APPROPRIATE:

Chemical Parameters	Index Value
Methane Present	-2
No/Low Dissolved Oxygen**	-4

REMOTS® ORGANISM-SEDIMENT INDEX = Total of above subset indices (A+B+C)

RANGE: -10 - +11

** Note: This is not based on a Winkler or polarigraphic electrode measurement. It is based on the imaged evidence of reduced, low reflectance (i.e., high oxygen demand) sediment at the sediment-water interface.

3.0 RESULTS

A total of 225 REMOTS® sediment-profile images from the 90 project area stations and 20 reference stations were analyzed for the April 1998 postcap survey reported here. One of the multiple planview photographs obtained at each station also was analyzed for this report. The results of the REMOTS® and planview image analyses are presented below.

3.1 Planview Photograph Analysis

The planview images indicated that surface sediments over most of the survey area were primarily sandy and inhabited to varying degrees by both epifauna and surface-dwelling infaunal organisms. Of the 90 radial transect stations located on and around the capped project mound, 48 were described as being sandy with epifauna and 32 stations were described as being sandy only, with no visible epifauna (Figure 3-1). The remaining 10 stations were described as having various combinations of sand, cobbles and epifauna. In particular, cobbles were seen on the outer edges of the sampling area on the NW, NNW and SE radial transects (Figure 3-1). These outer stations were off the capped region, and the observed cobbles were either a lag deposit resulting from historic dredged material disposal or were naturally occurring (i.e., ambient sediments). It did not appear that silt-clay was present at the sediment surface at any of the planview images.

A large number of stations in the western half of the capped mound had sand only, particularly those comprising the inner halves of the NNW, WNW, W, WSW, and SW transects, although there were stations having sand only in every compass transect sampled (Figure 3-1). Overall, the area was considered to be of medium-energy, as suggested by the widespread presence of sand ripples.

There were a variety of organisms visible in the planview images, including hermit crabs, snails, sea stars, and the tubes of surface-dwelling marine worms (polychaetes). Some of the organisms were solitary and occurred on top of the rippled sand surface, such as the sea star in Figure 3-2a. Brown, cylindrical, filamentous structures believed to be polychaete worm tubes (possibly the genus *Diopatra*) also were observed either singularly or in dense mats on top of the sand surface (Figure 3-2b). Other images showed long, smooth, grey/white worm tubes among the sand ripples (Figure 3-2c). Where cobbles and rocks were encountered, they were typically covered with encrusting epifauna (e.g., hydroids and bryozoans), along with mobile foragers like sea stars, snails and hermit crabs (Figure 3-2d). Additional varieties of organisms observed in a few of the images included a rock crab, shrimp, sand dollars, and a small skate.

3.2 REMOTS® Image Analysis

3.2.1 Horizontal Distribution of Sediment Grain Size

The first postcap bathymetric survey conducted in April 1998 revealed that cap thickness within the 1997 dredged material footprint polygon (i.e., capping boundary) was generally between 1.0 and 1.75 m (Figure 3-3). Analysis of the REMOTS® images from

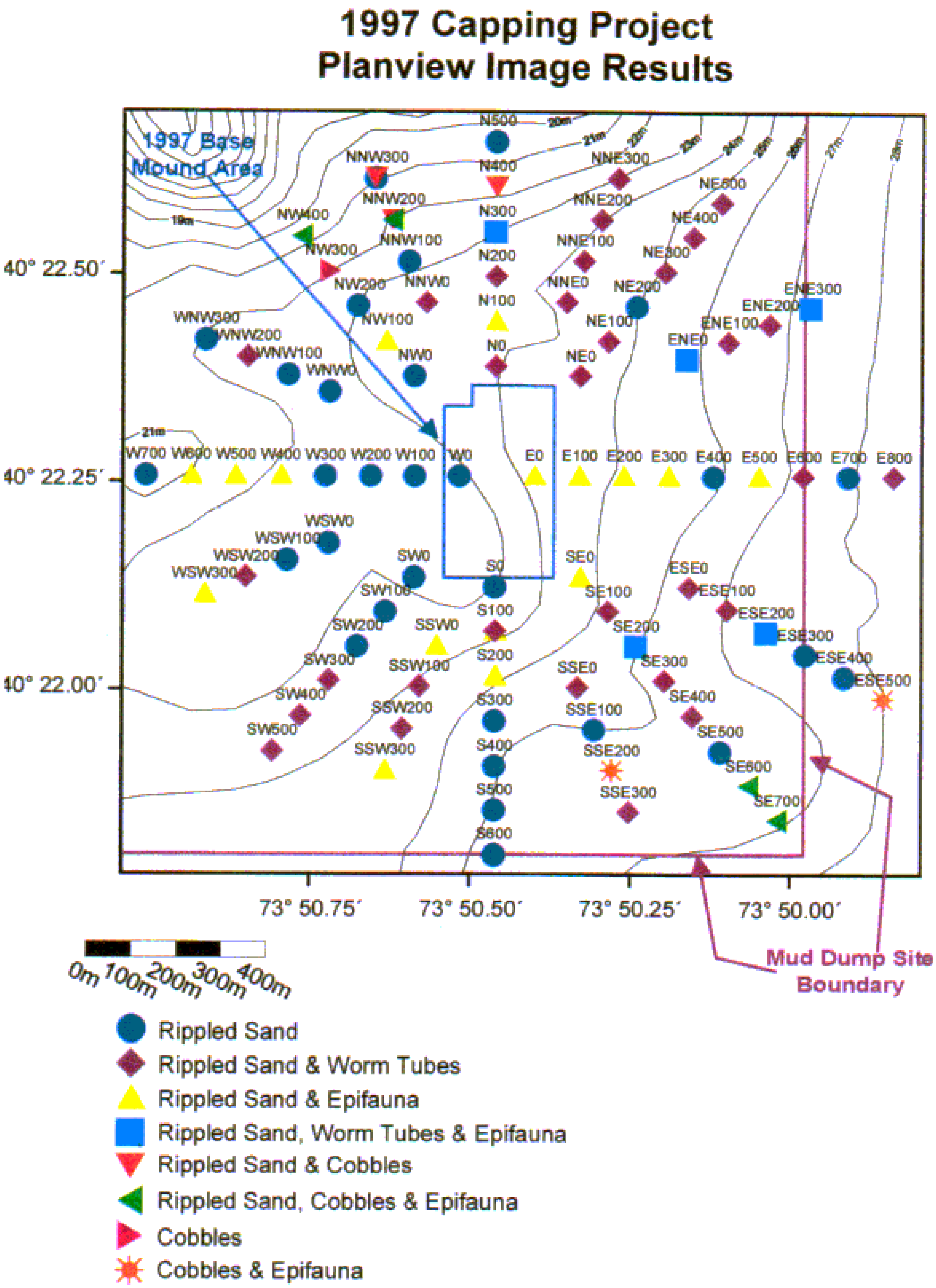

Figure 3-1. Sediment types and biological features at the radial transect stations based on analysis of the planview photographs.

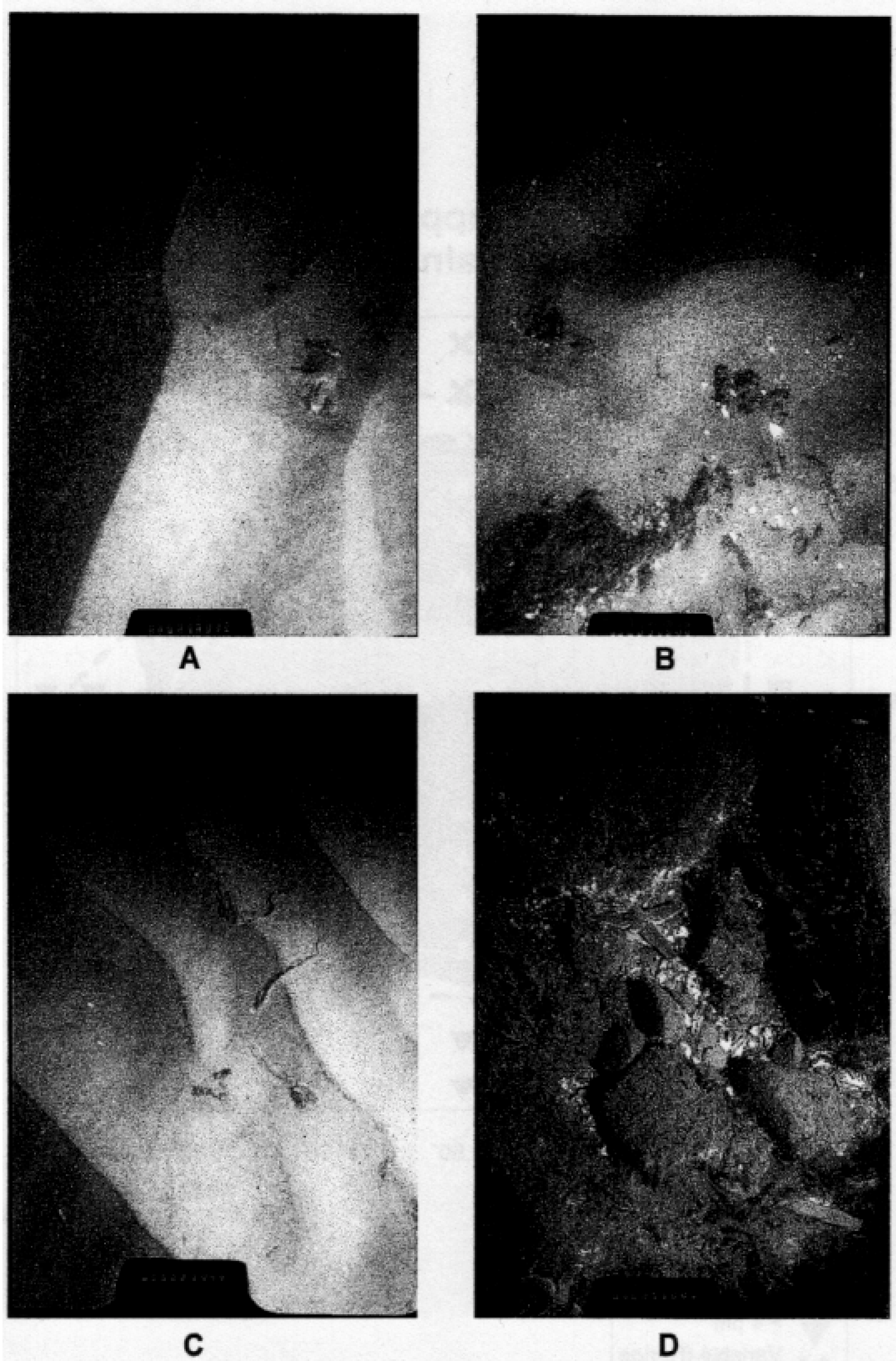

Figure 3-2 Representative planview photographs showing a variety of organisms at the sediment

the April 1998 postcap survey surface confirmed that surface sediments at the majority of stations within this capping boundary consisted of rippled, well-sorted, fine sand having a major modal size of 3-2 phi (Figures 3-3 and 3-4). This clean, fine sand is assumed to be the cap sand from Ambrose Channel placed systematically within the capping boundary over the period August 1997 to January 1998.

In most of the REMOTS® images acquired at stations on the sand cap, the sand extended from the surface to below the imaging depth of the REMOTS® camera prism (e.g., Figure 3-4). There was some minor variability in grain size major mode on the sand cap: while images at most stations showed fine sand (3-2 phi), there were some stations dominated by very fine sand (4-3 phi), and one station with medium (2-1 phi; Figure 3-3). This probably reflects natural variability in the cap material from Ambrose Channel.

The cap sand was generally well-sorted and had high albedo (i.e., a bright white color in sediment profile images, see Figure 3-4). This sand was similar in appearance to the sand used for capping of the 1993 Dioxin Capping Project (SAIC 1995); this is not surprising since Ambrose Channel was the source of the sand in both cases. At the time of the April 1998 survey, roughly two months following completion of the capping operations, the sand at most stations exhibited ripples which were a few centimeters in height and both symmetric and asymmetric in profile (Figure 3-4). The widespread presence of ripples suggests that the sand comprising the surface of the cap is subject to some bed-load transport. Similar capillary ripples have been observed consistently on the surface of the 1993 Dioxin Capping Project sand cap during each of three postcap REMOTS® surveys (SAIC 1995, 1997c and d).

The footprint of the sand cap, as defined by REMOTS®, covered a slightly more extensive area than that defined in the postcap high-resolution bathymetry survey (Figure 3-3). In general, the REMOTS® footprint extended roughly 50 to 200 meters beyond the footprint defined through high-resolution bathymetry (Figure 3-3). This is not surprising, since REMOTS® is able to detect depositional layers of sand on the flanks of the cap which are too thin (i.e., less than about 0.5 m thick) to be detected using acoustic methods. In REMOTS® images obtained at several stations in flank regions near the outer edge of the sand cap (e.g., N400, WSW200, E700, NE400, NNE200), the cap sand was visible as a thin surface layer overlying fine-grained, relic dredged material at depth (Figure 3-5). The REMOTS® images from three consecutive NE radial transect stations (NE300, NE400, and NE500) serve to illustrate the transition in sediment type typically encountered at the outer edge of the sand cap (Figure 3-6).

Compared to the uniform distribution of clean, rippled, fine sand on the surface of the newly-placed cap, the area surrounding the sand cap showed greater variability in sediment grain size. Surface sediments ranging in size from <-1 phi (gravel) to >4 phi (silt-clay) were found in this area (Figure 3-3). In general, areas to the east and northeast of the sand cap were dominated by fine-grained sediments (>4 phi) representing relic dredged material (Figure 3-3 and 3-6c). Likewise, the outer two stations of the S radial transect (S400, S500 and S600) were dominated by fine-grained, relic dredged material

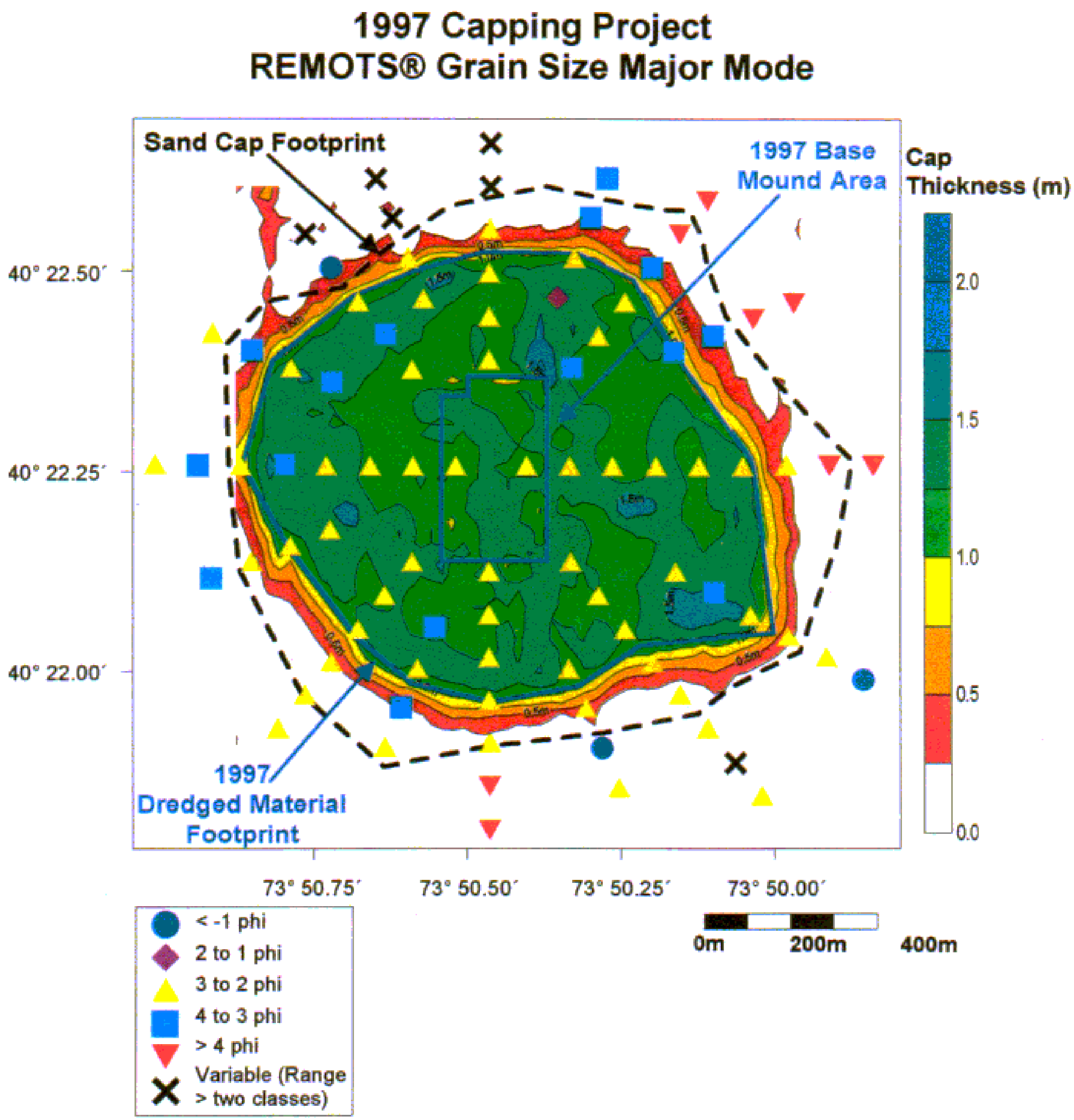

Figure 3-3. Grain size major mode at the radial transect stations, presented in relation to sand cap thickness as determined in the March 1998 postcap bathymetric survey. The broken black line denotes the footprint of the sand cap based on the REMOTS grain size results.

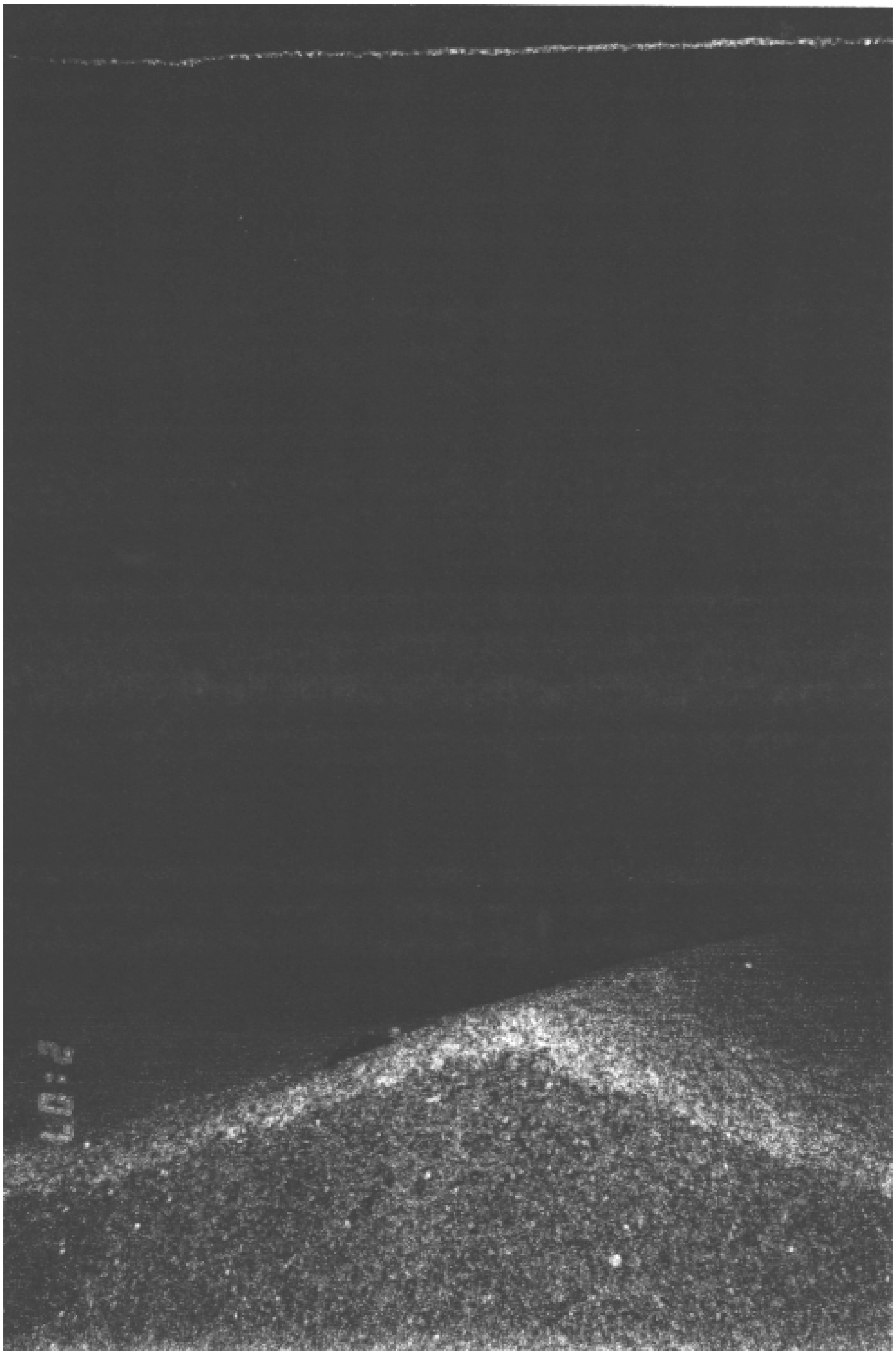

Figure 3-4. REMOTS image from station NW-100 illustrating the clean, rippled, fine sand comprising the sand cap. The sand generally exhibited high albedo and a major modal grain size of 3-2 phi. A sand ripple has been transected in this image.

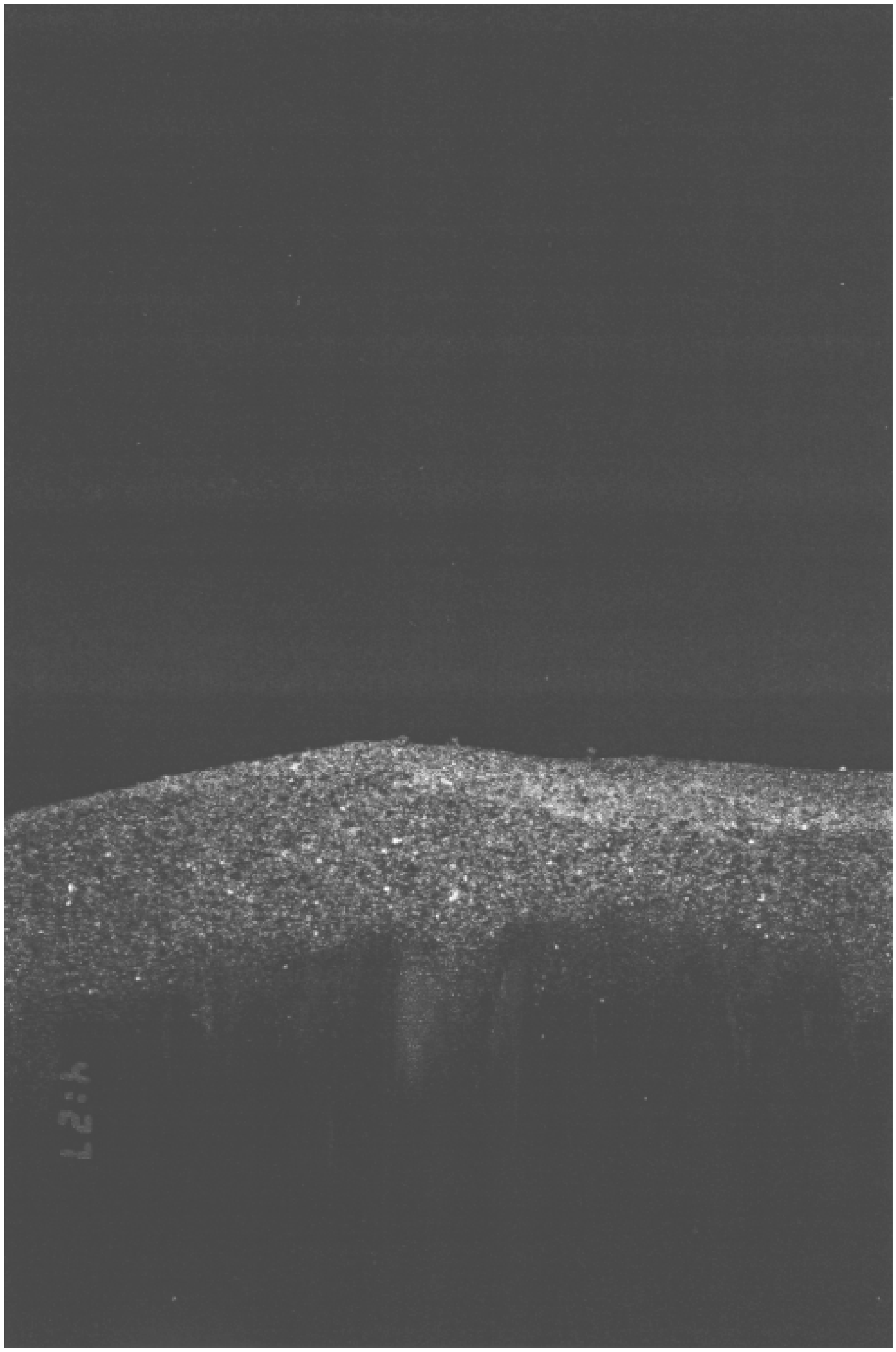

Figure 3-5. A thin surface layer of clean cap sand overlies black, fine-grained, relic dredged material in this REMOTS image from N-400.

(Figure 3-3). The area to the north and northwest of the sand cap was characterized by sediments having variable grain size; this is generally an area of hard bottom characterized by a mixture of sand, pebbles and cobbles. The rippled, fine sand found at stations to the west and southwest of the 1997 sand cap is presumed to be cap material from the 1993 Dioxin Capping Project. The fine sand and cobbles on the sloping bottom southeast of the sand cap are presumed to be naturally occurring (i.e., ambient) sediment types in this location (Figure 3-3).

The grain-size frequency distribution illustrates how the majority of stations were dominated by sediments having a major mode of 3-2 phi (Figure 3-7). This is not surprising because most of the stations were located on the sand cap, which was comprised predominantly of fine sand. The North Reference Area was dominated by medium sand (2-1 phi), followed by fine sand (3-2 phi; Figure 3-8), with the images from all stations showing sand ripples to be present. There was no clear spatial pattern to the distribution of the medium versus the fine sand within the North Reference Area. The finer sand fraction was found at Stations NREF-05 and NREF-18, while the remaining stations had moderately- to well-sorted medium sand (Figure 3-8).

Rippled, fine sand (3-2 phi) was the dominant sediment type at the South Reference Area (Figure 3-9). The sand tended to be well-sorted and was distributed uniformly throughout the area, except at station SREF-16 where very fine sand (4-3 phi) was the dominant grain size major mode. Layered stratigraphy in which fine sand covered black, fine-grained sediment at depth was observed at station SREF-16; the same sediment layering has been observed at this station in several past REMOTS® surveys (SAIC 1997a, c and d). The underlying black sediment is presumed to be relic dredged material resulting from historic disposal outside the MDS boundaries. The frequency distribution of grain size major mode values reflects the dominance of medium sand (2-1 phi) at the North Reference Area and the dominance of fine sand (3-2) at the South Reference Area (Figure 3-10).

3.2.2 Dredged Material Distribution

In REMOTS® images, dredged material typically is identified based on the following characteristics: it is fine-grained (i.e., silt-clay), has low optical reflectance (i.e., dark-colored), and often has distinct color or textural properties (e.g., chaotic sedimentary fabric, poor sorting, over-consolidation, or layered stratigraphy). In the April 1998 postcap REMOTS® survey, there was no dredged material observed at any of the radial transect stations located on the capped project mound (Figure 3-11). At these stations, the sand layer, representing the surface of the cap, was sufficiently thick that no underlying dredged material was observed in any of the replicate REMOTS® images (Figure 3-4).

A number of stations outside the perimeter of the capped project mound had dredged material present (Figure 3-11). In particular, dredged material was found in areas to the north, northeast and east of the capped project mound, as well as at three stations on the outer end of the S station transect. The dredged material typically consisted of low-reflectance, fine-grained sediment (silt-clay or very fine sand) which extended from the seabed surface to below the camera's imaging depth (Figure 3-12). At some of the stations (indicated in Figure 3-11), a distinct sand-over-dredged material stratigraphy was present (Figures 3-5 and 3-6b).

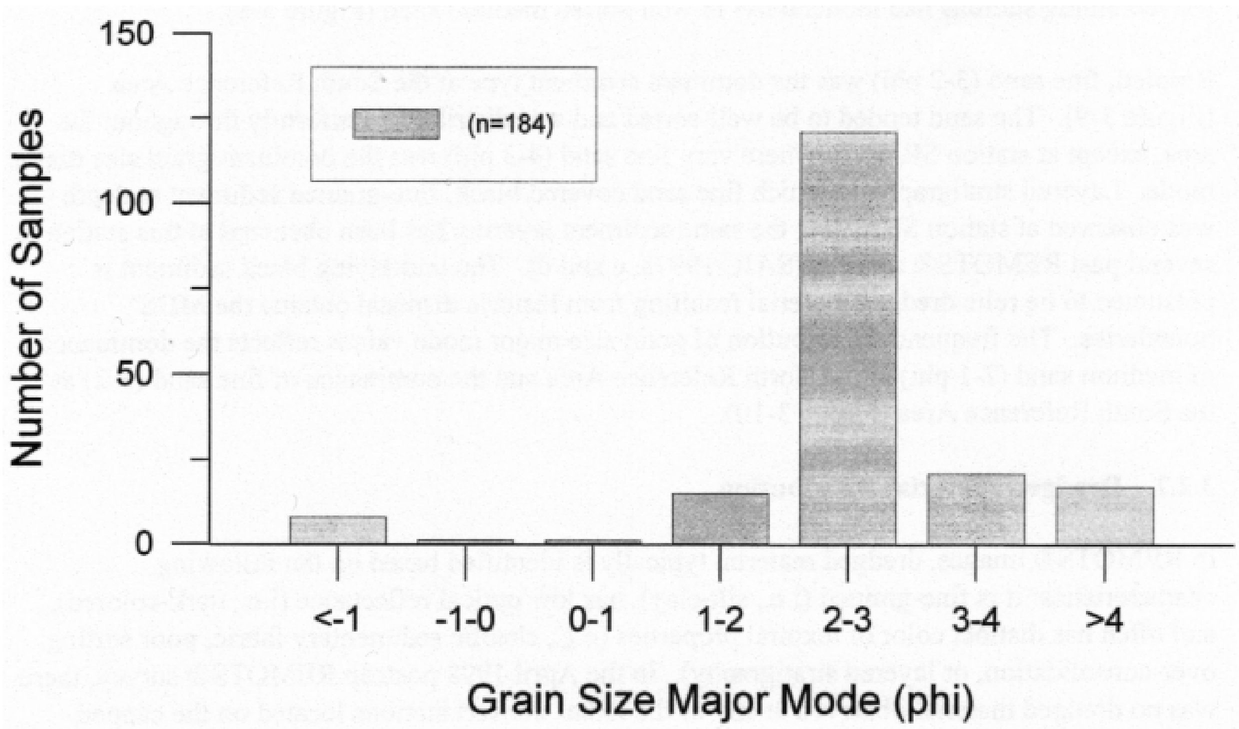

Figure 3-7. Frequency distribution of grain size major mode for REMOTS images obtained on and around the 1997 Category II capped project mound.

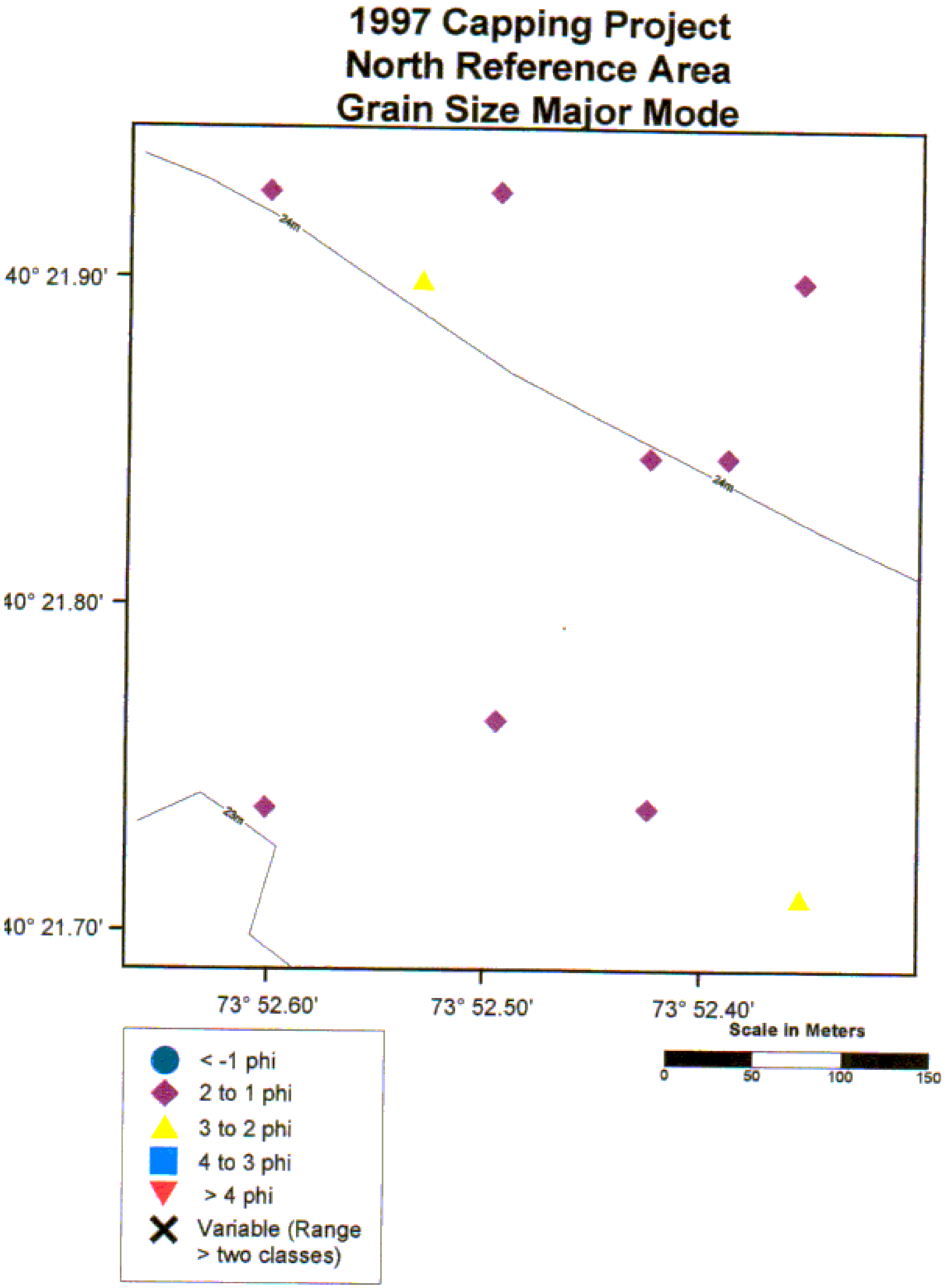

Figure 3-8. Grain size major mode at North Reference Area stations as determined from analysis of REMOTS images.

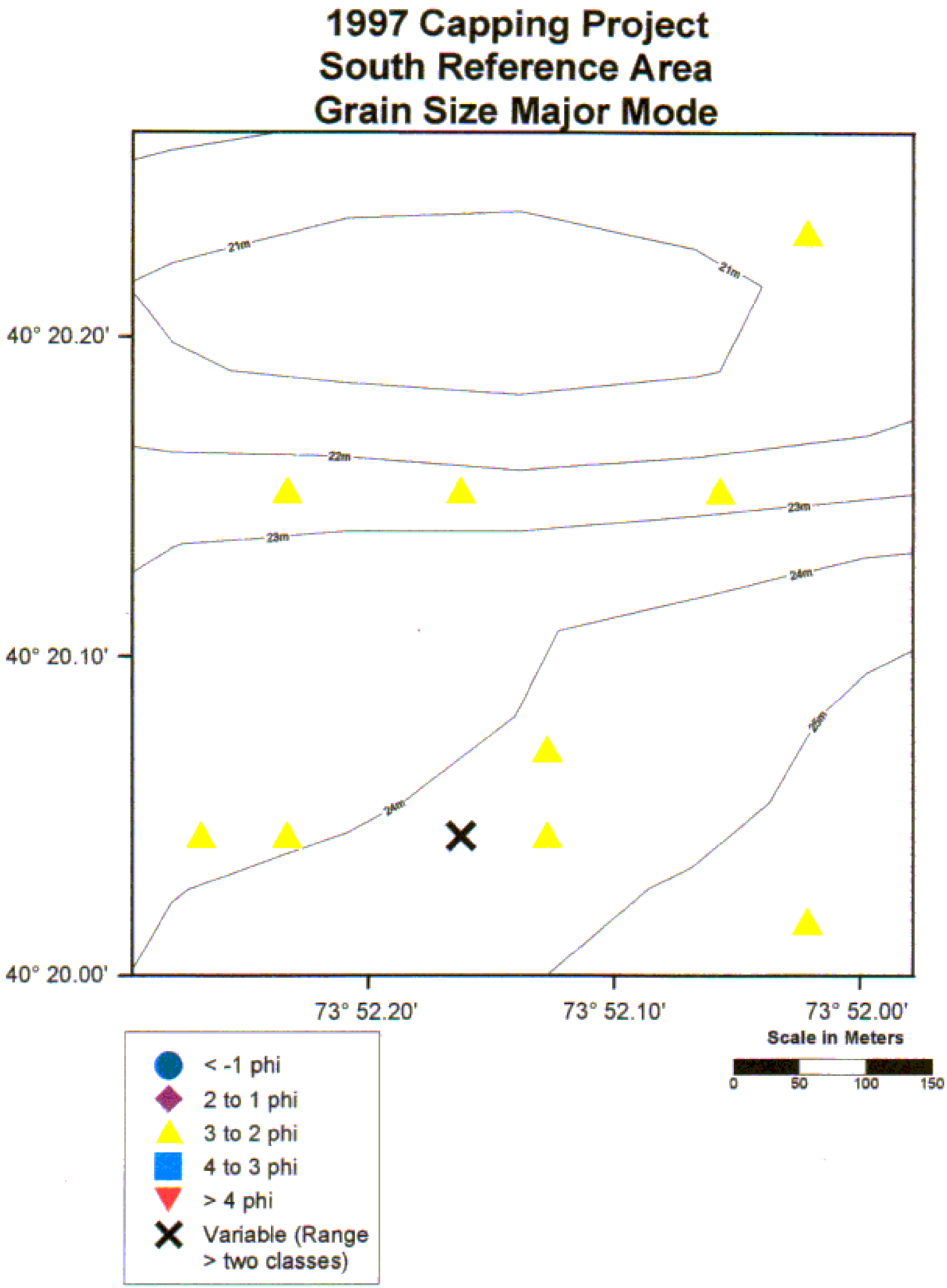

Figure 3-9. Grain size major mode at South Reference Area stations as determined from analysis of REMOTS images.

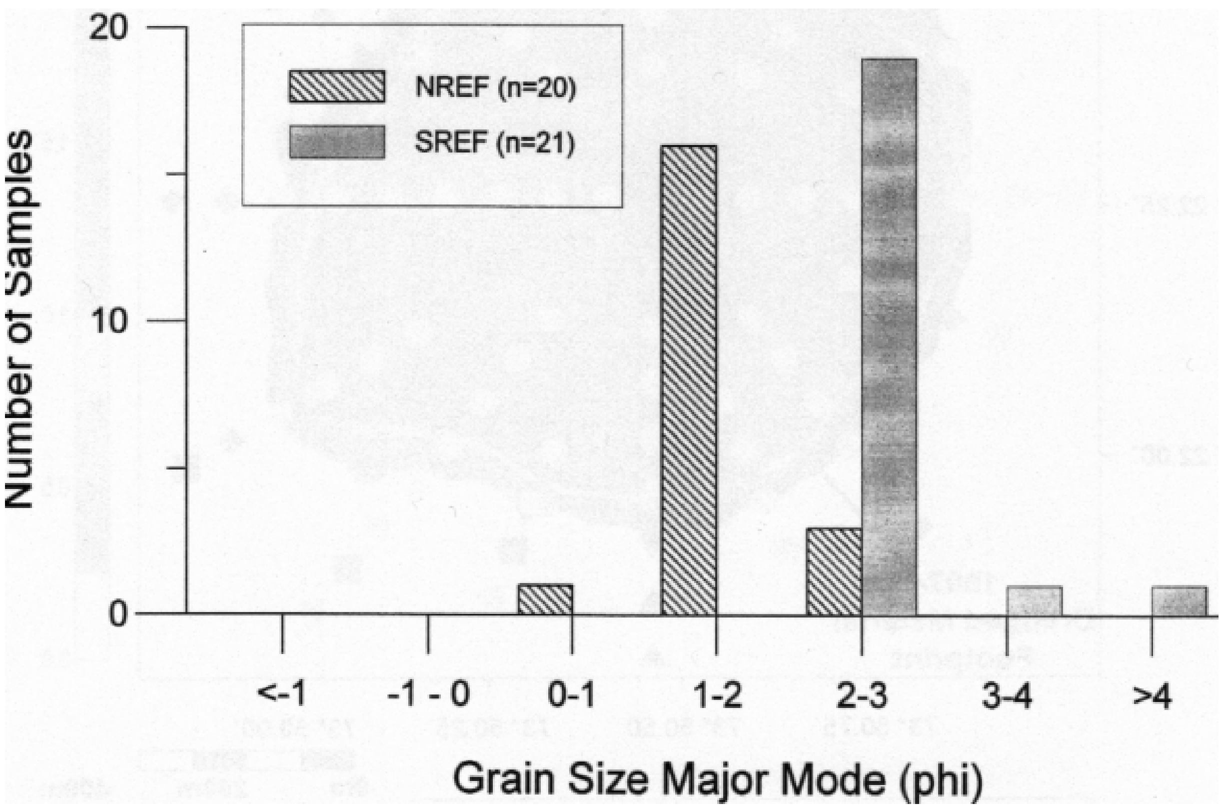

Figure 3-10. Frequency distribution of grain size major mode for REMOTS images obtained at the North and South Reference Areas.

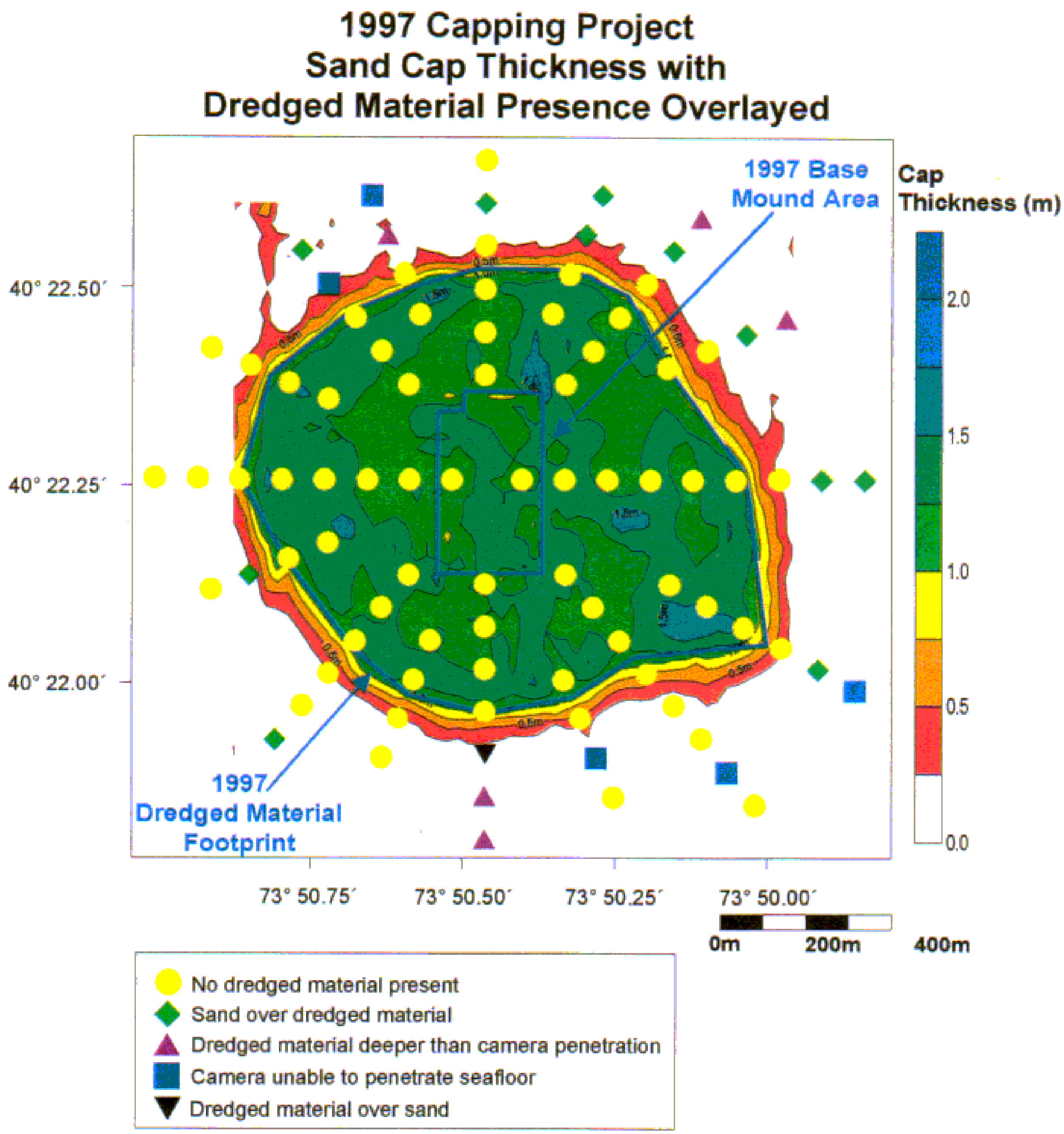

Figure 3-11. Dredged material distribution in the survey area as determined from REMOTS images.

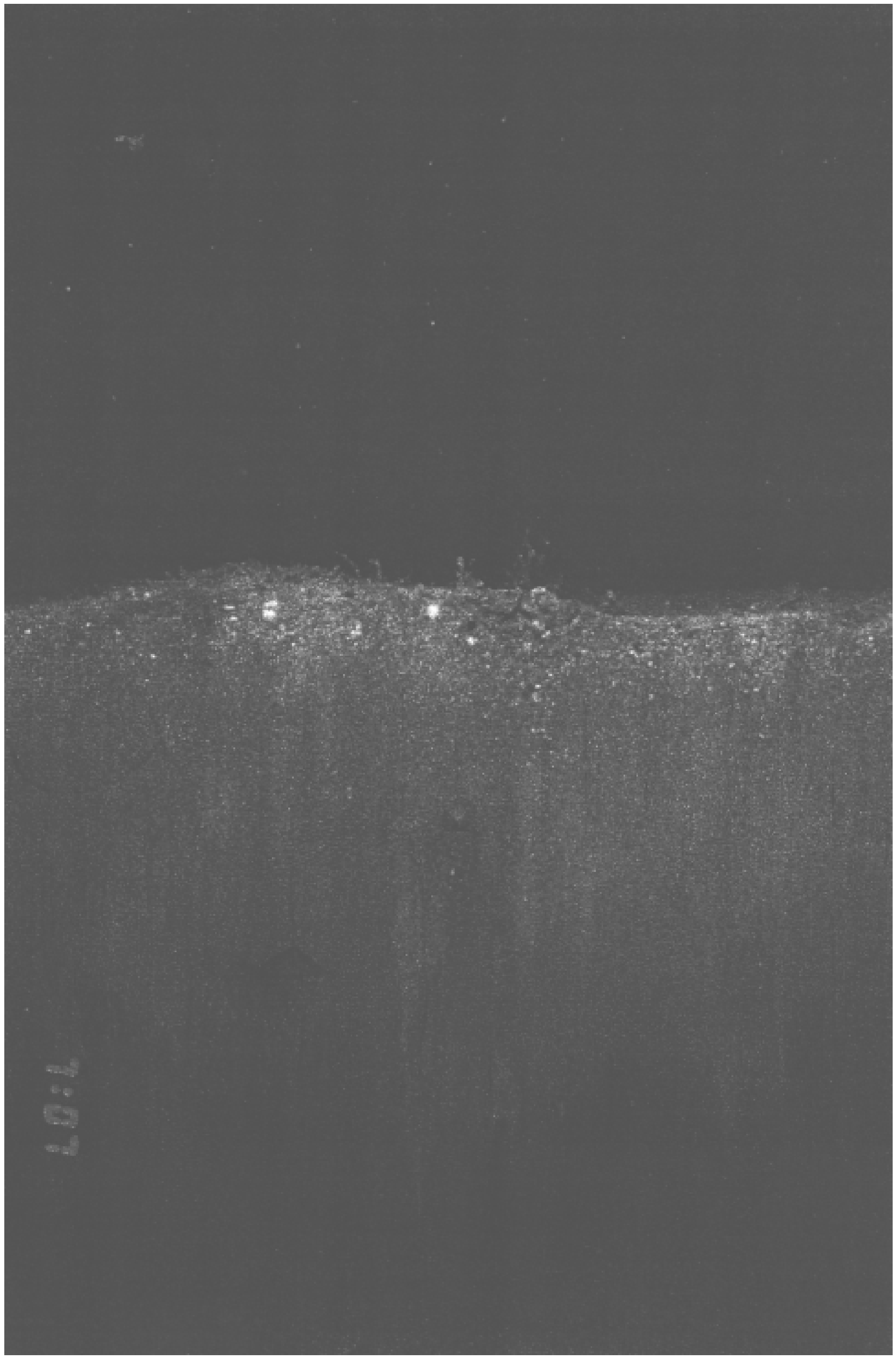

Figure 3-12. REMOTS image from station ENE-200 showing fine-grained, relic dredged material extending from the sediment surface to below the camera's imaging depth. A number of Stage I polychaete tubes are visible at the sediment surface, and Stage III feeding voids occur at depth, resulting in a Stage I on III successional designation. The redox layer (RPD) is moderately well-developed in this relic dredged material.

Almost all of the dredged material observed at the stations indicated in Figure 3-11 is presumed to be relic material, the result of past disposal at the MDS which had occurred well in advance of the 1997 Category II Capping Project. This is based on the characteristic black color of this material (e.g., Figures 3-5, 3-6c and 3-12) and the fact that it was found outside the footprint of the 1997 project material. Furthermore, this relic dredged material had been observed in the areas to the northeast and south of the 1997 Base Mound Area in the baseline REMOTS® survey conducted prior to the disposal operations for the 1997 Capping Project (SAIC 1997a).

In one of the replicate images obtained at station S-400, located just on the perimeter of the sand cap as mapped in Figure 3-3, there was a thin surface layer of light grey, fine-grained material that was very similar in appearance to the 1997 project material (Figure 3-13). This layer was less than 3 cm thick, and its surface had been colonized by numerous small white bivalves, possibly *Nucula* or *Mulinia* sp. The fine sand observed underneath this surface layer might represent cap material from the 1993 Dioxin Project. Since the surface layer of fine-grained material was observed in only one of the replicate images at station 400-S and was not seen at any of the surrounding REMOTS® stations, it is assumed that the material did not cover a very large area of the seafloor. Rather, the REMOTS® results suggest that a laterally discontinuous and very thin layer of uncapped 1997 project material (i.e., a small patch) was present at the very edge of the sand cap in the vicinity of station 400-S.

Dredged material was not observed in any of the replicate REMOTS® images obtained in the North Reference Area. At the South Reference Area, station SREF-16 exhibited sand-over-dredged material stratigraphy similar to that observed at some of the disposal site stations (e.g., Figures 3-5 and 3-6b). Stations SREF-16 and nearby stations are located in a topographic depression (trough) near the southern border of the South Reference Area; relic dredged material has been observed in this area in numerous previous REMOTS® surveys (SAIC 1995, 1997a, c, and d).

3.2.3 Boundary Roughness

Measurements of small-scale surface boundary roughness are limited by the size of the REMOTS® camera window (15 × 20 cm). When small-scale surface features predominate (e.g., sand ripples with amplitudes less than the width of the camera window), the camera can provide an accurate measure of boundary roughness. However, the camera cannot provide an accurate measurement of boundary roughness when large-scale features predominate (e.g., sand ripples with amplitudes exceeding the width of the REMOTS® camera window), making it difficult to provide a complete assessment of boundary roughness across most surveyed areas. Therefore, boundary roughness measurements must be interpreted with caution.

Figure 3-14 shows the spatial distribution of small-scale boundary roughness in the project area; the mapped values are averages for the replicate images obtained at each station. Because these measurements are for small-scale features (e.g., sand ripples with

Figure 3-13. REMOTS image from station S-400 showing a thin surface layer of light grey, fine-grained material overlying fine sand. The material comprising the surface layer may be project material from the 1997 Category II Capping Project. Numerous small white bivalves, possibly *Nucula* sp., have colonized the surface of this material.

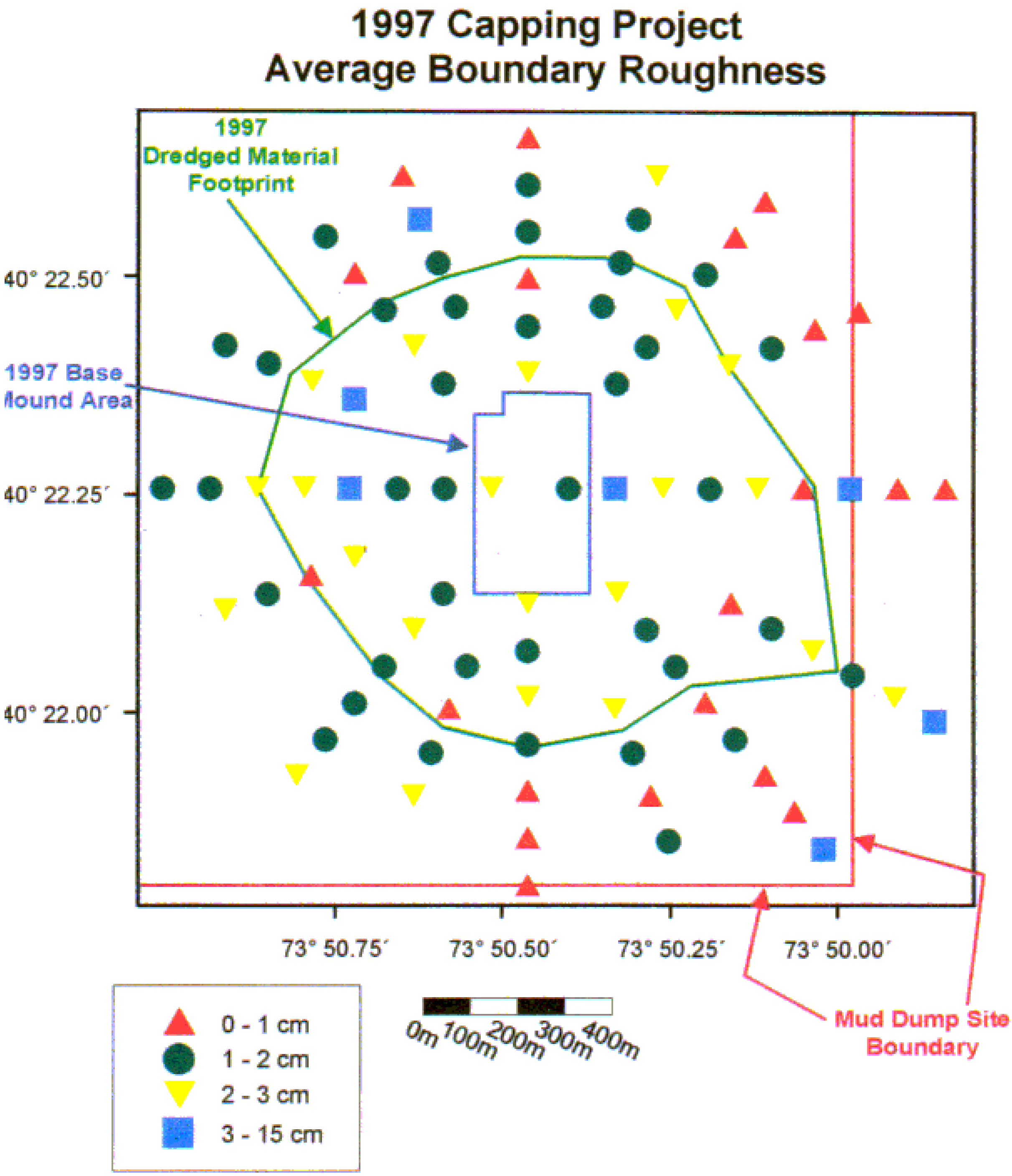

Figure 3-14. Average small-scale boundary roughness at the radial transect stations as determined from REMOTS analysis.

amplitudes less than the width of the camera window), they are considered to be accurate. It is not surprising that due to the ubiquitous presence of sand ripples, the capped area had higher small-scale boundary roughness than surrounding areas, where many of the stations were characterized by fine-grained historic dredged material having little or no small-scale surface relief. The majority of boundary roughness values in the capped area were in the 1.5-2.0 cm range, while most of the values measured in adjacent areas ranged from 0 to 1.5 cm. An anomolously high boundary roughness value of 5.46 cm at station NNW-200 was related to the presence of a large sand ripple in one of the replicate images from this station. Overall, the mean boundary roughness value for all radial transect stations was 1.75 cm, with measured values ranging from 0 to 5.46 cm (Figure 3-15).

There was a wide range of boundary roughness values for the replicate images obtained in the North Reference Area, while the majority of values in the South Reference Area were less than 3.0 cm, with a peak in the 1.5 to 2.0 cm size class (Figure 3-16). The North Reference Area was dominated by coarser-grained sediments which would be expected to form larger amplitude ripples compared with the fine sand found at the South Reference Area and within the project area.

3.2.4 Camera Prism Penetration Depth

The depth of penetration of the REMOTS® camera prism can be used to map gradients in the bearing strength (hardness) of the sediment. This hardness parameter is useful for distinguishing between a relatively thick (>20 cm) layer of sand cap material or soft bottom related to the presence of thin caps or underlying silt/clay. Freshly deposited sediments or older, highly bioturbated sediments tend to be soft, while compacted sands are hard and resist camera prism penetration. During the April 1998 survey, weight was added to or removed from the REMOTS® camera frame to optimize penetration in the diverse types of sediment encountered across the surveyed areas. Therefore, it is not possible to use camera prism penetration depth as a direct comparative measure of sediment bearing strength or density among different stations. Nevertheless, some broad qualitative comparisons of average prism penetration among stations are possible.

As might be expected, the deepest prism penetration (in the range of 10 to 20 cm) was found at stations with uncapped, bioturbated, relic dredged material on the NNE, NE, ENE and S transects (Figure 3-17). Intermediate penetration values (5 to 10 cm) were found at stations throughout the area, particularly on transects W through S, as well as NNE (Figure 3-17). Most of the stations on the sand cap had relatively low prism penetration (0 to 5 cm), indicating that a relatively dense and compact layer of sand was present. The relatively narrow range of values at the sand cap stations (0 to 10 cm) suggests spatial uniformity in the geotechnical properties of the sand cap (Figure 3-17).

Penetration depths at the North and South Reference Areas ranged between 4 and 7 cm. These values are consistent with those obtained on the rippled fine sand comprising the sand cap. The highest penetration values were associated with fine-grained sediments, presumed to be relic dredged material, found to be underlying the surface sand near the southeast corner of the South Reference Area. No other consistent patterns or gradients

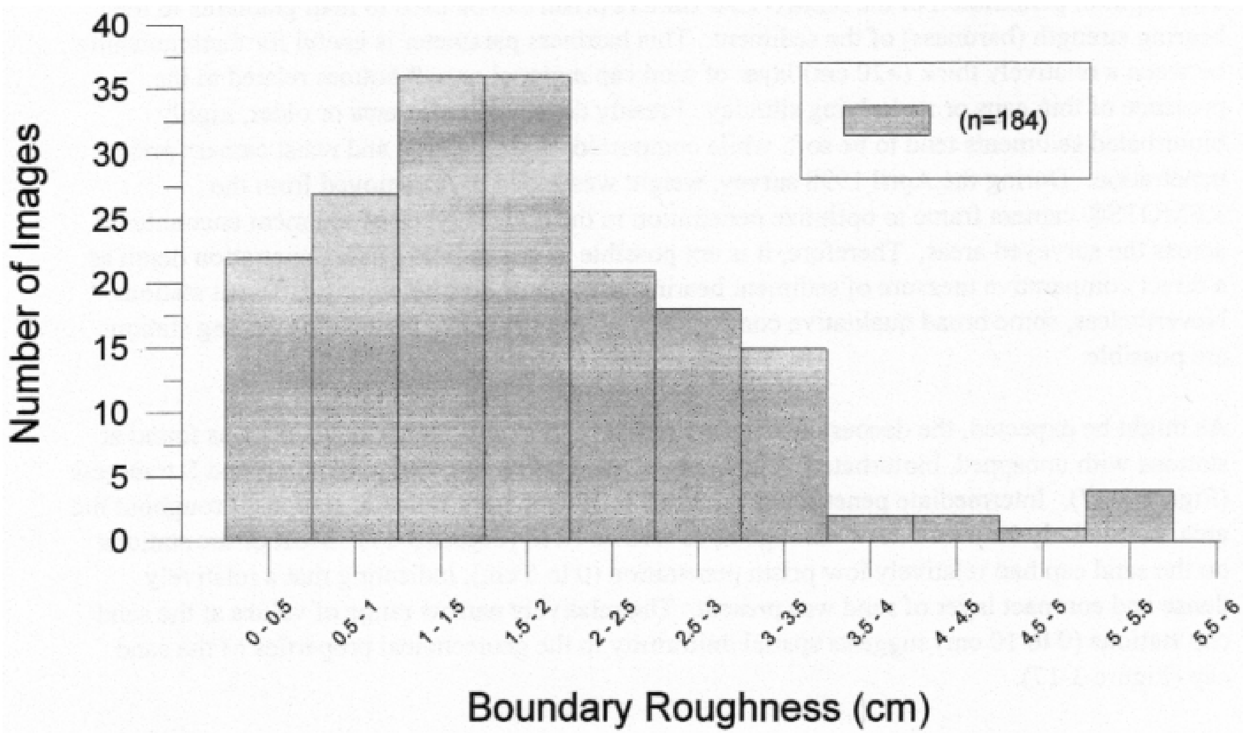

Figure 3-15. Frequency distribution of boundary roughness values (cm) for all replicate REMOTS images obtained at the radial transect stations.

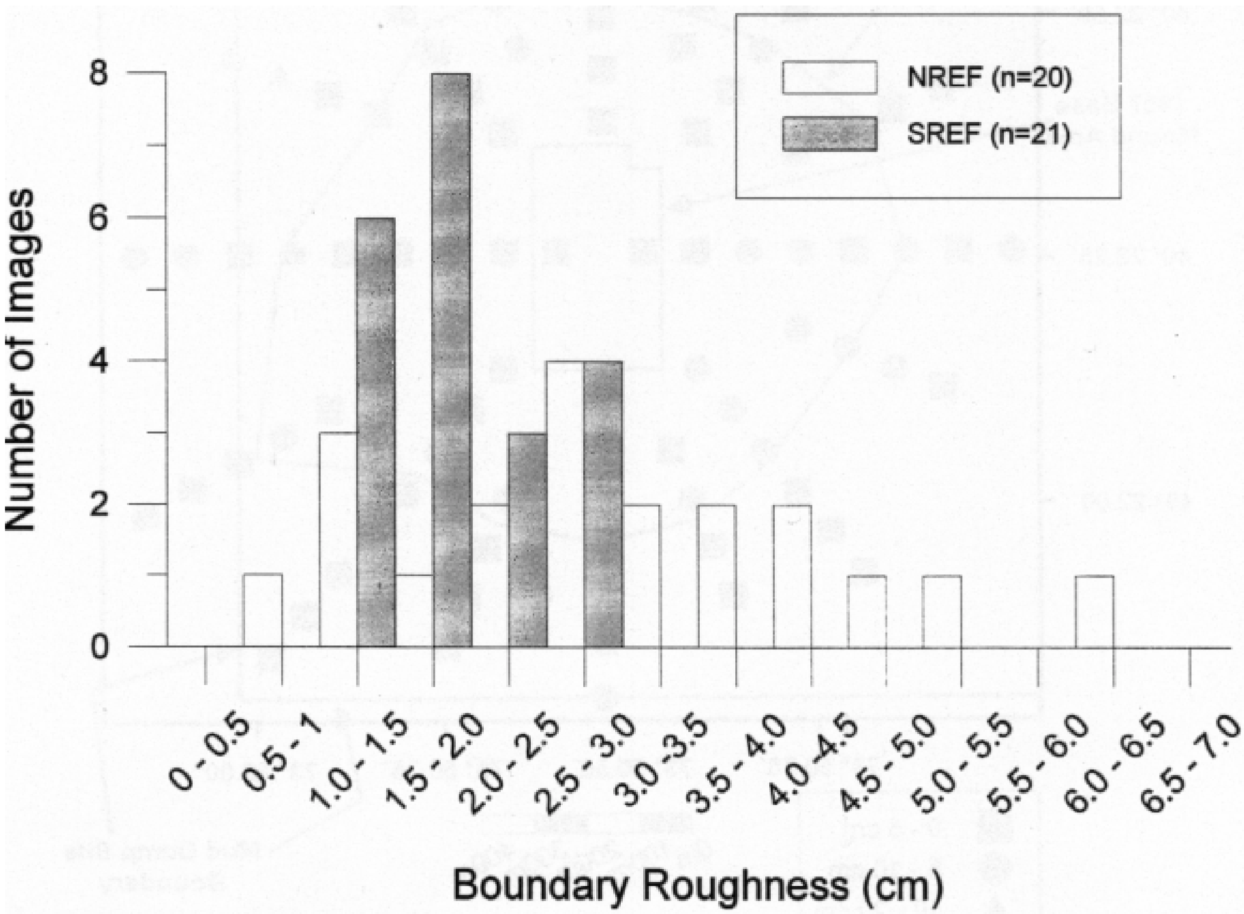

Figure 3-16. Frequency distribution of boundary roughness values (cm) for all replicate REMOTS images obtained in the North and South Reference Areas.

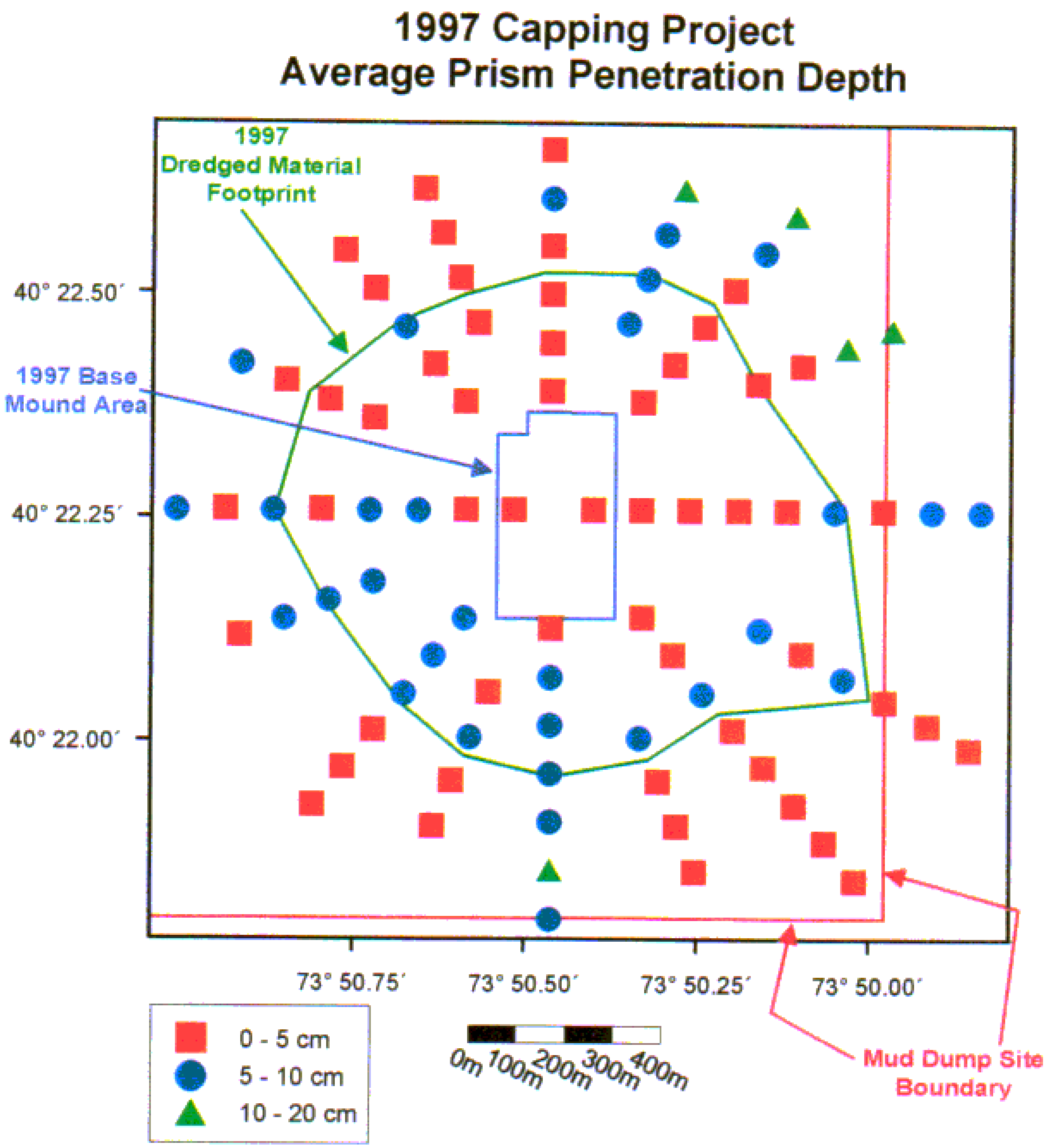

Figure 3-17. Average prism penetration depths at the radial transect stations.

in penetration depth were apparent within the sandy sediments of the North and South Reference Areas.

3.2.5 Infaunal Successional Stage

Due to the widespread presence of sand, especially on the sand cap, the penetration of the REMOTS® camera prism was limited to less than about 5 cm at a significant number of the radial transect stations. Because of this relatively shallow penetration, it was not possible to determine with certainty whether or not deeper dwelling organisms were present. Therefore, the successional stage was considered indeterminate at a number of the radial transect stations (Figure 3-18).

Stage I, in the form of polychaete tubes at the sediment surface, was found at 35 of the 90 (39%) radial transect stations (Figure 3-18). This included a significant number of the stations located on the sand cap. At some of the stations, the Stage I tubes were relatively smooth and occurred either singly or in small groups (Figure 3-19). Unless otherwise indicated, the Stage I stations mapped in Figure 3-18 had these types of tubes present. At other stations, the surface tubes were brown in color and appeared to be constructed of a combination of organic detritus and shells. Some of these tubes occurred in an upright position and some appeared to be recumbent on the sediment surface, either in groups or singly (Figure 3-20; see also the planview image showing the brown tubes, Figure 3-2b). These tubes possibly belong to a polychaete within the family Onuphidae, most likely in the genus *Diopatra*. Because members of this family are generally considered to be surface-dwelling omnivores (Fauchald and Jumars, 1979), they are classified as REMOTS® successional stage I. Figure 3-18 indicates the stations at which the putative Stage I *Diopatra* tubes were observed in REMOTS® images.

Stage I on III and Stage III were found exclusively at radial transect stations having organic-rich, fine-grained dredged material. This included two stations on each of the NE and ENE transects, and Station E-800 (Figures 3-12 and 3-18). The three southern-most stations on the S transect were given a Stage I going to Stage II designation due to the presence of the shallow-dwelling, infaunal bivalve *Nucula* sp. at these stations (Figure 3-18).

The successional stage at most (9 of 10) of the North Reference Area stations could not be determined adequately due to low prism penetration in the rippled medium to coarse sands. At the South Reference Area, 2 of the 10 stations were given an indeterminate successional stage designation. All of the other stations at the North and South Reference Areas were given a Stage I designation, reflecting the ability of Stage I polychaetes to maintain populations on the physically unstable rippled sands in these areas.

3.2.6 Apparent RPD Depths

Sands generally are characterized by low concentrations of ferrous hydroxides and organic material and therefore tend to lack an obvious color contrast to mark the division between aerobic and anaerobic zones in the sediment column. The lack of color contrast

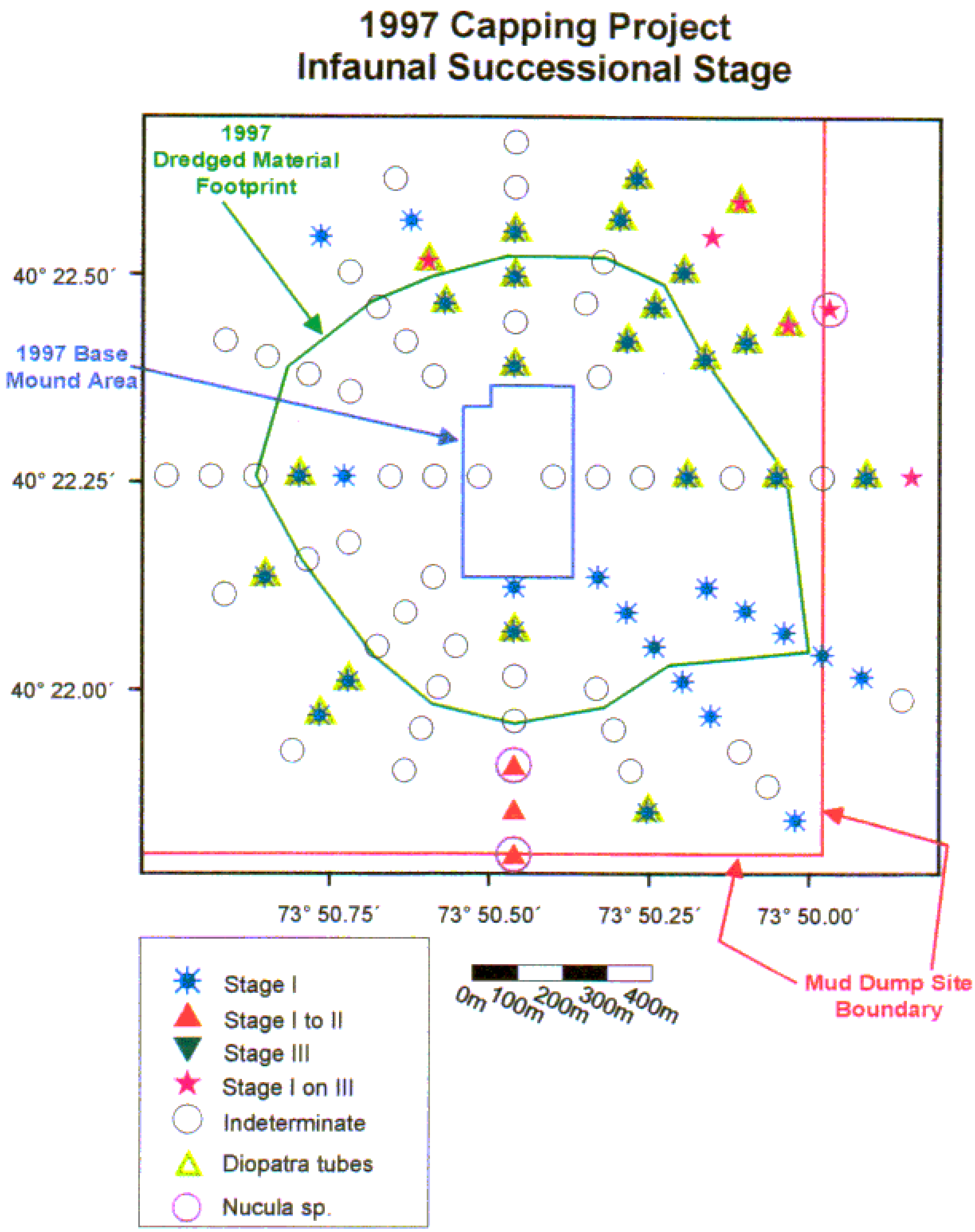

Figure 3-18. Infaunal successional stages at the radial transect stations.

Figure 3-19. REMOTS image from station E-500 showing several small Stage I polychaete tubes on the surface of the sand cap.

makes it difficult to measure the depth of the apparent RPD in REMOTS® images of sand. However, it is assumed that rippled sands in the New York Bight generally are well aerated as a result of both diffusion of oxygen from the overlying water and physical mixing associated with periodic bedload transport. Therefore, in REMOTS® images of sandy sediments, the depth of the apparent RPD typically is measured as being equal to or greater than the prism penetration depth. This is considered preferable to designating the RPD as "indeterminate" because such a desig-nation would result in an indeterminate Organism-Sediment Index value as well (i.e., for each image, the RPD must be measured for the OSI to be calculated). If too many stations in an area have indeterminate RPD and OSI values, the resultant seafloor maps become greatly reduced in value.

At stations located on the sand cap, average RPD depths generally ranged from 3 cm to greater than 5 cm (Figure 3-21). These relatively deep RPD depths reflect the widespread presence of the clean, rippled cap sand, which is assumed to be well-aerated to a depth exceeding the depth of prism penetration. Likewise, average RPD depths at the reference area stations were relatively deep (> 3 cm) due to the widespread presence of sand. At the off-cap stations located on the outer reaches of several transects, relic dredged material was the principal sediment type encountered. Although the relic dredged material generally was very dark colored (e.g., Figure 3-12), suggesting high organic content, the average RPD values at most of these outer transect stations ranged from 2 to 5 cm (Figure 3-21). These are intermediate to deep RPD values which suggest that the surface sediments were well-oxygenated at these stations. This is attributed to bioturbation by Stage III organisms inhabiting the fine-grained, organic-rich relic dredged material.

3.2.7 Organism-Sediment Index

A significant number of the radial transect stations (56 of 90, or 62%) had indeterminate OSI values (Figure 3-22). This was due primarily to low prism penetration preventing reliable determination of the infaunal successional stage. The frequency distribution of measured OSI values for the radial transect stations has a major mode of +7, with most values ranging from +6 to +11 (Figure 3-23). Overall, these are high OSI values considered to be indicative of relatively healthy benthic habitat conditions. The highest OSI values were found at stations located on older, uncapped dredged material in the northeast corner of the surveyed area (Figure 3-22). These stations had a combination of deep RPD depths and a mature Stage I on III benthic community comprised of both surface dwelling opportunistic taxa and "equilibrium" head-down deposit-feeders (e.g., Figure 3-12).

At the majority of North Reference area stations, the OSI could not be calculated due to an indeterminate successional stage. For the stations within the North and South Reference Areas where an OSI was determined, the frequency distribution of values had a range of +3 to +7, with the majority of values falling at +7 (Figure 3-24). These are intermediate to high values reflecting the presence of Stage I organisms and the deep RPD depths determined in the rippled sand at these stations.

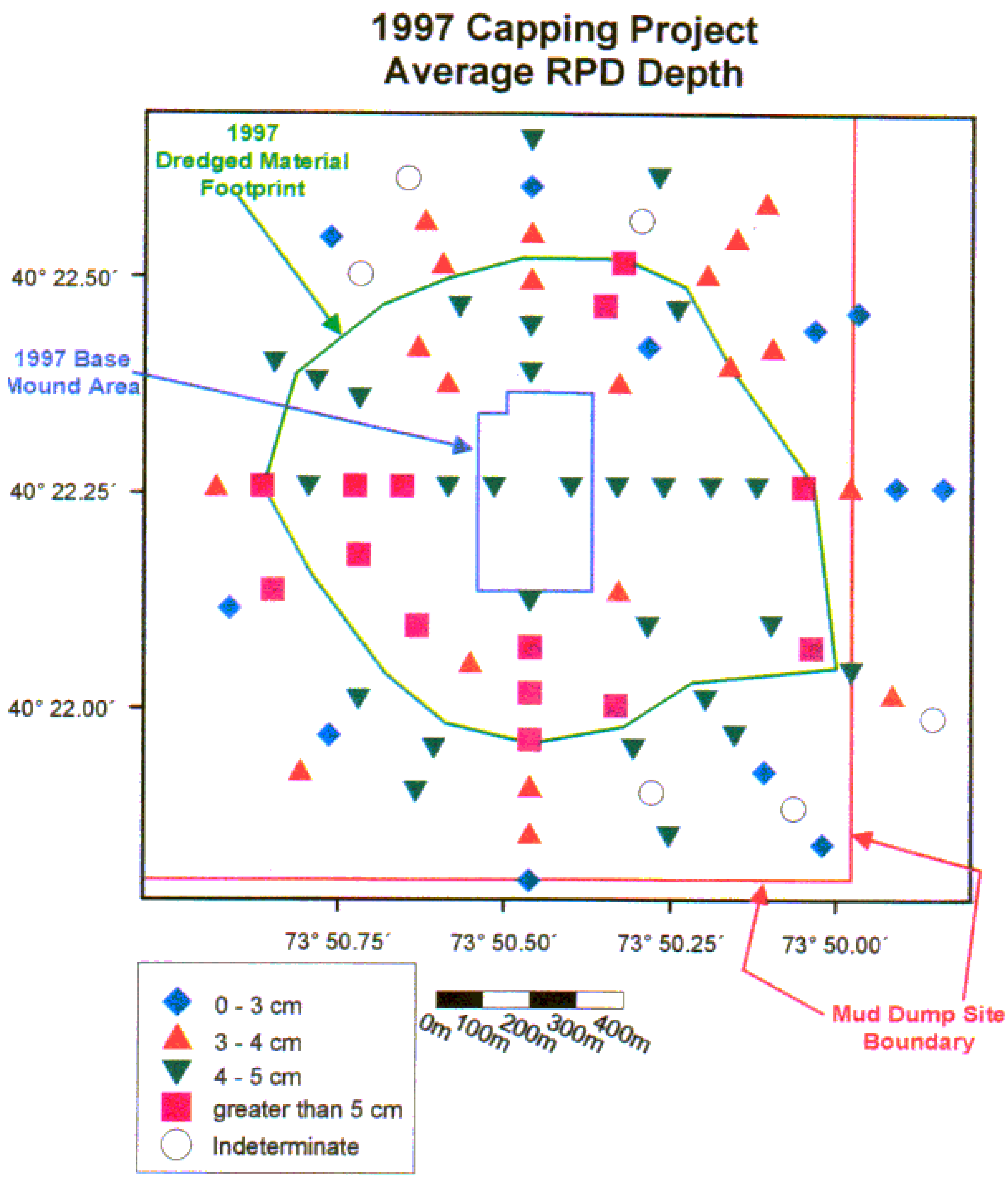

Figure 3-21. Average RPD depths at the radial transect stations.

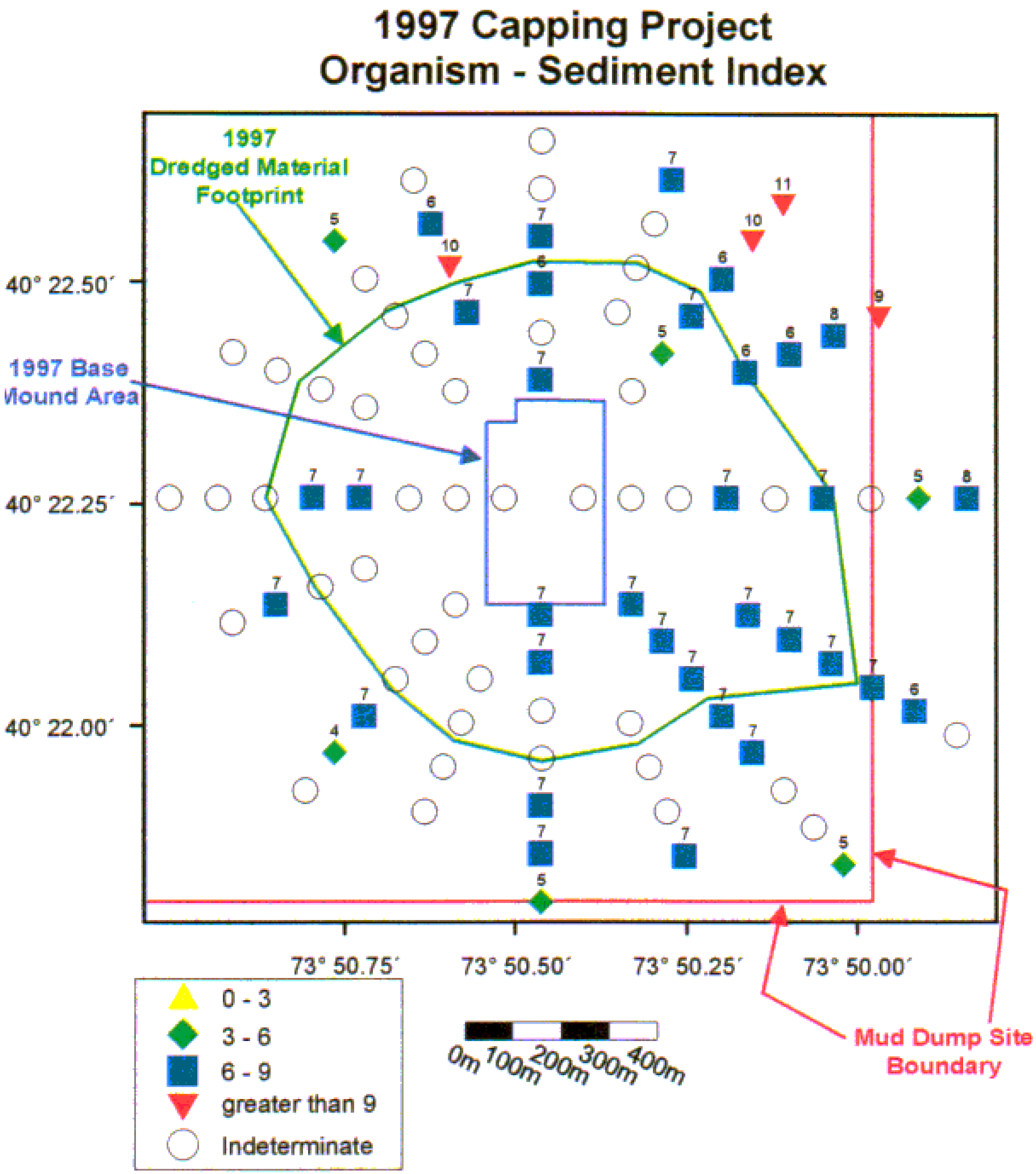

Figure 3-22. Average Organism-Sediment Index (OSI) values at the radial transect stations.

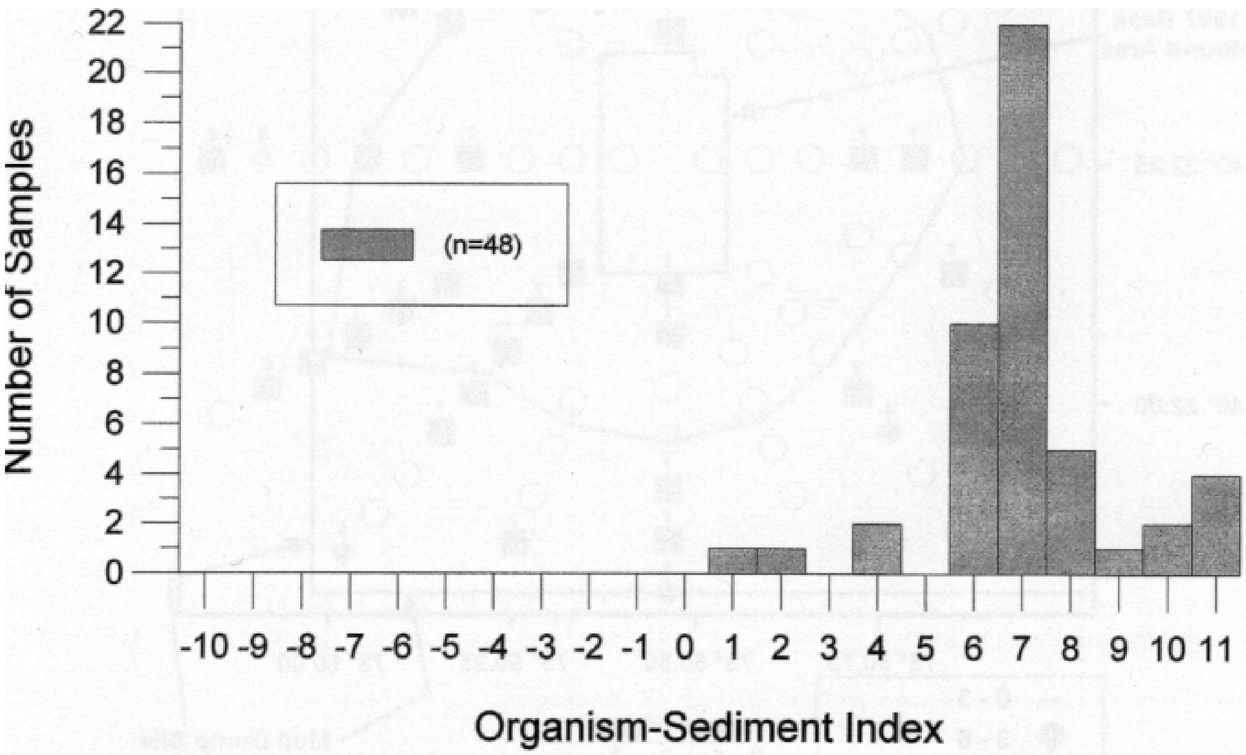

Figure 3-23. Frequency distribution of Organism-Sediment Index values for all replicate REMOTS images obtained at the radial transect stations.

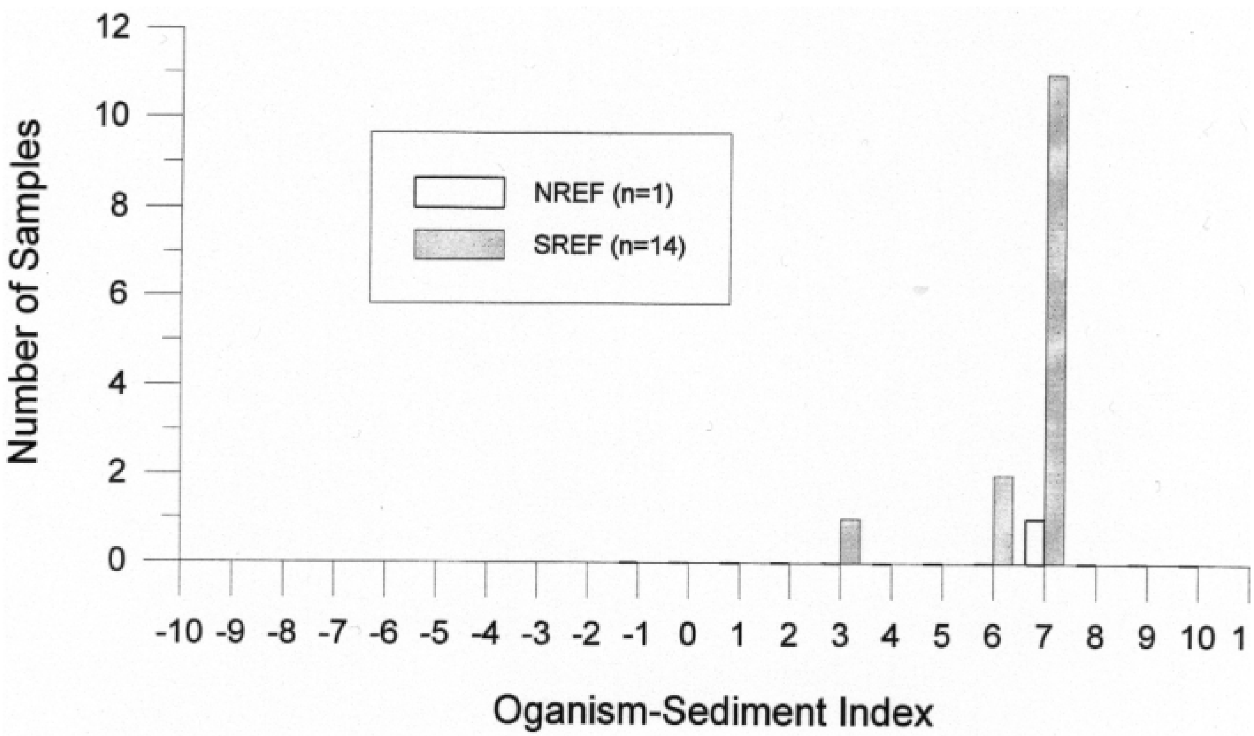

Figure 3-24. Frequency distribution of Organism-Sediment Index values for all replicate REMOTS images obtained at the North and South Reference Area stations.

4.0 DISCUSSION

In the April 1998 REMOTS® survey of the 1997 Category II Capping Project, stations were arranged in a series of radial transects to provide coverage of the 1997 dredged material footprint and the surrounding area. The primary objective of this first postcap survey was to assess physical and biological seafloor characteristics on and around the recently capped project mound. In particular, the sampling design allows both for mapping the horizontal distribution of the sand used for capping and evaluating overall benthic habitat quality on the sand cap and in surrounding areas. The REMOTS® information collected within the 1997 Category II project area and at two nearby reference areas should provide a comparative basis for assessing conditions in this region, particularly in terms of monitoring the long-term stability of the sand cap and the process of recolonization by benthic organisms.

4.1 REMOTS® Characterization of the Capped Mound

The April REMOTS® survey, performed two months after cap placement, confirmed that stations within the capping area were dominated by rippled fine sand having an average grain size major mode of 3-2 phi. This clean, well-sorted sand, presumed to be the capping material from Ambrose Channel, was found at the sediment surface throughout the capping area. As illustrated in Figure 3-3, there was good agreement between the April 1998 REMOTS® and high-resolution bathymetric surveys in terms of mapping the horizontal distribution of the cap sand. Because REMOTS® can detect thin layers of sand on the outer flanks of the cap, the sand cap footprint defined using this technique extended roughly 50 to 200 meters beyond the footprint defined through high-resolution bathymetry (Figure 3-3).

Both the REMOTS® and planview photographs indicated that the surface of the sand cap was rippled, suggesting that some bedload transport had taken place since placement of this sand was completed in January of 1998. Similar sand ripples have been observed consistently at the surface of the 1993 Dioxin Capping Project sand cap, but no significant net loss of this sand cap has been detected over the course of numerous monitoring surveys conducted between 1992 and 1997 (SAIC 1998). Based on these results, it might be predicted that while the sand at the surface of the 1997 Category II cap may experience periodic bedload transport, long-term loss of this capping material due to erosion is not expected.

All the REMOTS® stations within the capped area had a sufficiently thick surface layer of sand that no underlying dredged material was observed. Of the 44 REMOTS® stations located within the 1997 dredged material footprint, all showed homogenous, hard-packed sand extending from the sediment-water interface to the maximum penetration depth of the prism (from 0 to 10 cm at these stations). One of the replicate images obtained at station S-400, located just on the perimeter of the sand cap as mapped in Figure 3-3, showed a relatively thin (< 3 cm in thickness) surface layer of light grey, fine-grained material similar in appearance to the 1997 project material (Figure 3-13). Because this layer was observed in only one of the replicate images at station 400-S and was not seen at any of the surrounding REMOTS® stations, it is assumed that the material did not cover a very large area of the seafloor. Rather, these results suggest that a very small surface patch of fine-grained material that may be 1997 project material was present at the very edge of the sand cap in the vicinity of station 400-S. This material was probably transported outside the 1997 dredged material footprint after the post-disposal REMOTS® survey of August 1997. In particular, this thin surface layer may represent fine-grained project material which was resuspended during the sand capping operations, transported laterally, and deposited just outside the original footprint as mapped in August 1997.

Both the planview and REMOTS® results indicate that benthic organisms had begun to colonize the surface of the sand cap at the time of the survey, two months following the completion of the capping operation. In the planview images, the colonizing organisms included a variety of mobile epifauna (e.g., sea stars, hermit crabs), as well as Stage I polychaete tubes visible at the sediment surface (Figures 3-1 and 3-2). Likewise, the REMOTS® results indicated that areas of the sand cap had been successfully colonized by surface-dwelling, opportunistic, Stage I polychaetes (e.g., Figure 3-19). Surface tubes presumed to be of the polychaete *Diopatra* were observed at a number of the REMOTS® stations, both on and off the sand cap (Figures 3-18 and 3-20). These putative *Diopatra* tubes had not been observed previously on the 1993 Dioxin sand cap during the three postcap REMOTS® surveys conducted under the 1993 Dioxin Capping Project. Their occurrence on the surface of the 1997 Category II sand cap therefore may represent a transient phenomenon, resulting from a short-term recruitment event (i.e., larval settlement or adult migration). Future postcap monitoring surveys will help determine the long-term viability of this *Diopatra* population as part of the recolonizing benthic community on the 1997 Category II sand cap.

Based on the long-term monitoring results obtained under the 1993 Dioxin Capping Project, surface-dwelling, Stage I polychaetes are the type of infauna expected to colonize the sand cap surface. These organisms typically have high population turnover rates, making them capable of rapidly exploiting new habitats like the sand cap as part of the early colonizing community. Their presence on the 1997 Category II Project sand cap in early April 1998, relatively soon after the completion of the capping operations, therefore is not surprising. The 1993 Dioxin Project monitoring results furthermore showed that the successional status of the sand cap remained at Stage I over the course of many years. This stage is adapted to the physical disturbance resulting from periodic bedload transport of the cap sand. Because Stage III taxa typically have a preference for feeding in organic-rich muds, the sand cap represents an unsuitable habitat for them. Therefore, it is likely that the benthic successional sequence on the 1997 Category II sand cap will not progress beyond the pioneering stage (Stage I) observed in the April 1998 postcap survey.

4.2 REMOTS® Characterization of Areas Adjacent to the Capped Mound

Stations located outside the main capping area were more heterogeneous in sediment type than the cap, ranging from < -1 phi (gravel) to >4 phi (silt-clay). This heterogeneity reflects the wide variety of sediment types associated with earlier disposal projects. Some stations located outside the capping boundary showed a sand-over-mud layering that probably reflects coverage of historic dredged material by a thin layer of cap material (e.g., Figure 3-5). Uncapped relic dredged material was found at a number of stations to the northeast of the capping area, as well as at stations S-500 and S-600 on the south transect. Fine-grained, relic dredged material had been observed in both of these general locations during the May 1997 baseline (i.e., pre-disposal) REMOTS® survey for the 1997 Category II Capping Project (SAIC 1997a).

A few of the stations to the northwest of the capped mound had variable grain size, due to the presence of rocks, brick fragments and coarse sand. This coarse material is presumed to be part of a broad lag deposit known to occur in the shallow mid-section of the MDS, near the peaks of several former disposal mounds. Camera prism penetration depths were greatest at off-cap stations located to the northeast and south of the capped mound, where the uncapped or thinly capped, soft dredged material from prior disposal projects was encountered. Prism penetration at some of these stations may have been enhanced by the bioturbation activities of Stage III infauna, leading to increased sediment water content and decreased compactness. The stations with relic dredged material were the only ones in this survey to have Stage III infauna present (Figures 3-11 and 3-18). Stage III taxa, in addition to requiring a physically stable habitat, also require a significant organic fraction in the sediment column for feeding. These requirements are best met on the older, cohesive silt-clay deposits in the areas adjacent to the capped mound.

Rippled fine to medium sand was the dominant grain size at both the North and South Reference areas; this sediment type is typical of ambient sediments throughout the New York Bight Apex. Consistent with the results of numerous previous surveys, the sand at the North Reference area was slightly coarser in texture (i.e., medium sand) than the fine sand found at the South Reference area. REMOTS® prism penetration depths at the North and South Reference areas were similar to those on the sand cap.

4.3 Assessment of Benthic Habitat Quality

The widespread distribution of fine to medium rippled sands at the reference areas reflects a kinetic energy regime that is capable of moving sands as bedload transport. This physical process is important for preventing the accumulation of natural muddy deposits and defining the successional status of the ambient bottom. The successional designation in both reference areas was either Stage I or indeterminate, reflecting the physical instability of the benthic habitat in the broad region surrounding the disposal site. Unstable sands washed free of particulate organics tend to preclude the establishment of well-developed Stage III seres. These same factors are operating at the 1997 Category II Capping Project and are thus responsible for the convergence in sedimentary and biological properties of the sand cap material with characteristics of the reference areas.

Organism-Sediment Index values (OSIs) for both the radial transect and reference stations had a major mode of +7. In particular, an OSI of +7 was found at a number of stations located on the sand cap (Figure 3-22), reflecting relatively deep apparent RPD depths and the presence of Stage I recolonizing benthic organisms at these stations. The similarity in OSI values between these sand cap stations and many of the reference stations suggests that portions of the sand cap had become comparable to the ambient bottom outside of the Mud Dump Site in terms of overall benthic habitat quality.

OSI values were not be calculated for a significant number of stations on the sand cap and in the reference areas because the successional stage was indeterminate. Overall, these results suggest that Stage I organisms had a patchy distribution on the sand cap at the time of the survey, two months following the completion of capping operations. This type of variable spatial distribution is typical of Stage I organisms, particularly during the early stages of recolonization. As recolonization proceeds and Stage I organisms become more widespread on the sand cap, it is expected that they will be found at a higher percentage of stations in future monitoring surveys.

Because bottom sediments in this part of the inner continental shelf are dominated by physical processes, OSI values at the upper range of the scale (e.g., +9, +10, and +11) are not expected to be achieved on either the sand cap or in the reference areas. Benthic succession beyond Stage I is arrested by physical instability of the bottom, and Redox Potential Discontinuity (RPD) depths are dominantly controlled by physical rather than biological factors. Thus, in becoming comparable to the ambient bottom, areas of the 1997 Category II sand cap have likely reached their highest potential as benthic habitat.

Off-cap stations in the area surrounding the sand cap had average OSI values ranging between +5 and +11, with most values greater than +6 (Figure 3-22). These OSI values are generally considered to be indicative of intermediate to high benthic habitat quality. In the baseline REMOTS® survey of May 1997, stations in the area surrounding the 1997 base mound area had intermediate OSI values ranging from +3 to +7, suggesting intermediate benthic habitat quality. These results suggest that benthic habitat quality in the area surrounding the capped project mound was not adversely affected by the capping operations, and may even have improved slightly between the May 1997 baseline and April 1998 postcap surveys. This may be related to deepening of average RPD depths as a result of bioturbation by Stage III organisms at a number of stations, particularly those having relic dredged material to the northeast of the capped project mound.

5.0 SUMMARY

The first postcap REMOTS® survey conducted under the 1997 Category II Capping Project at the New York Mud Dump Site took place in April 1998, approximately two months following the completion of capping operations. The objectives of this survey were to characterize physical and biological conditions on the newly-placed sand cap and assess benthic infaunal colonization of this cap.

The REMOTS® survey confirmed that stations within the capping area were dominated by rippled fine sand having an average grain size major mode of 3-2 phi. This clean, well-sorted sand, presumed to be the capping material from Ambrose Channel, was found at the sediment surface throughout the capping area. There was good agreement between the April 1998 postcap REMOTS® and high-resolution bathymetric surveys in terms of mapping the horizontal distribution of the cap sand. The REMOTS® images showed that thin layers of the cap sand extended roughly 50 to 200 meters beyond the sand cap footprint defined through high-resolution bathymetry.

The REMOTS® results suggested that a small patch of fine-grained material, possibly 1997 project material, was present in a thin layer at the sediment surface at the edge of the sand cap near station 400-S. This thin surface layer may represent fine-grained project material which was resuspended during the sand capping operations, transported laterally, and deposited just outside the original footprint as mapped in August 1997.

Both the planview and REMOTS® results indicated that benthic organisms had begun to colonize the surface of the sand cap at the time of the survey, two months following the completion of the capping operation. In the planview images, the colonizing organisms included a variety of mobile epifauna, as well as Stage I polychaete tubes visible at the sediment surface. Likewise, the REMOTS® results indicated that areas of the sand cap had been successfully colonized by surface-dwelling, opportunistic, Stage I polychaetes. Surface tubes presumed to be of the polychaete *Diopatra* were observed at a number of the REMOTS® stations, both on and off the sand cap. Future postcap monitoring surveys will help determine the long-term viability of the recolonizing Stage I benthic community on the 1997 Category II sand cap.

Sediments in areas immediately adjacent to the sand cap ranged from gravel to silt-clay, reflecting a wide variety of sediment types associated with past disposal activities in the southeast corner of the Mud Dump Site. Uncapped relic dredged material was found in some of the adjacent areas, particularly to the northeast of the sand cap. This fine-grained, relic dredged material was covered by a thin surface layer of cap sand at some of the stations near the sand cap perimeter. Rippled fine to medium sand, typical of ambient sediments throughout the New York Bight Apex, was found to be the dominant grain size at both the North and South Reference areas.

An average Organism-Sediment Index value of +7 was found at a significant number of stations on the sand cap and in the reference areas. OSI values greater than +6 generally indicate good overall benthic habitat quality. On the sand cap and in the reference areas, the OSI values greater than +6 reflected relatively deep apparent RPD depths and the presence of Stage I benthic organisms. The similarity in OSI values between the sand cap stations and many of the reference stations suggests that portions of the sand cap had become comparable to the ambient bottom outside of the Mud Dump Site in terms of overall benthic habitat quality. OSI values greater than +6 also were found consistently at stations surrounding the sand cap. These results suggest that benthic habitat quality in the areas adjacent to the capped project mound were not adversely affected by the capping operations.

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