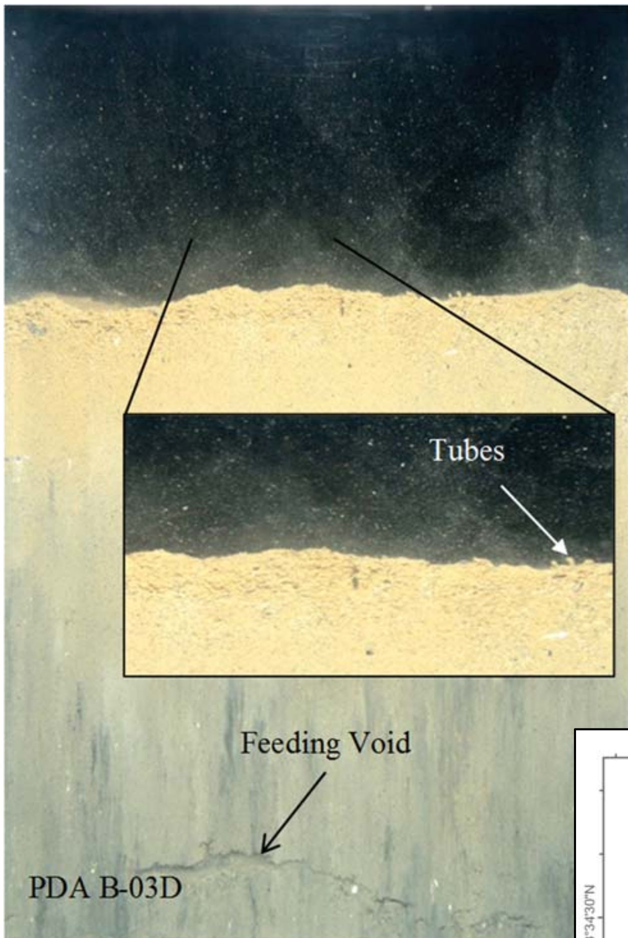
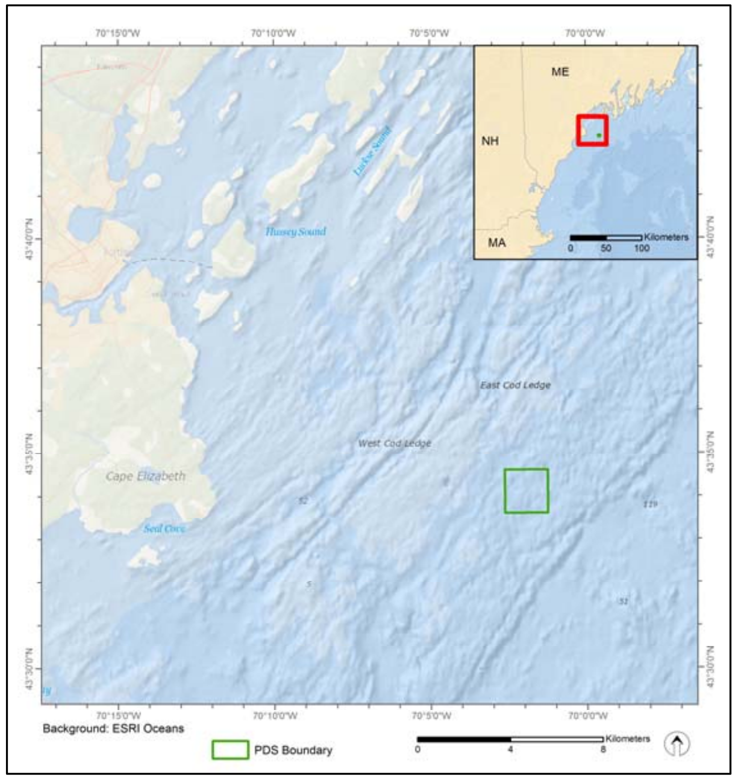
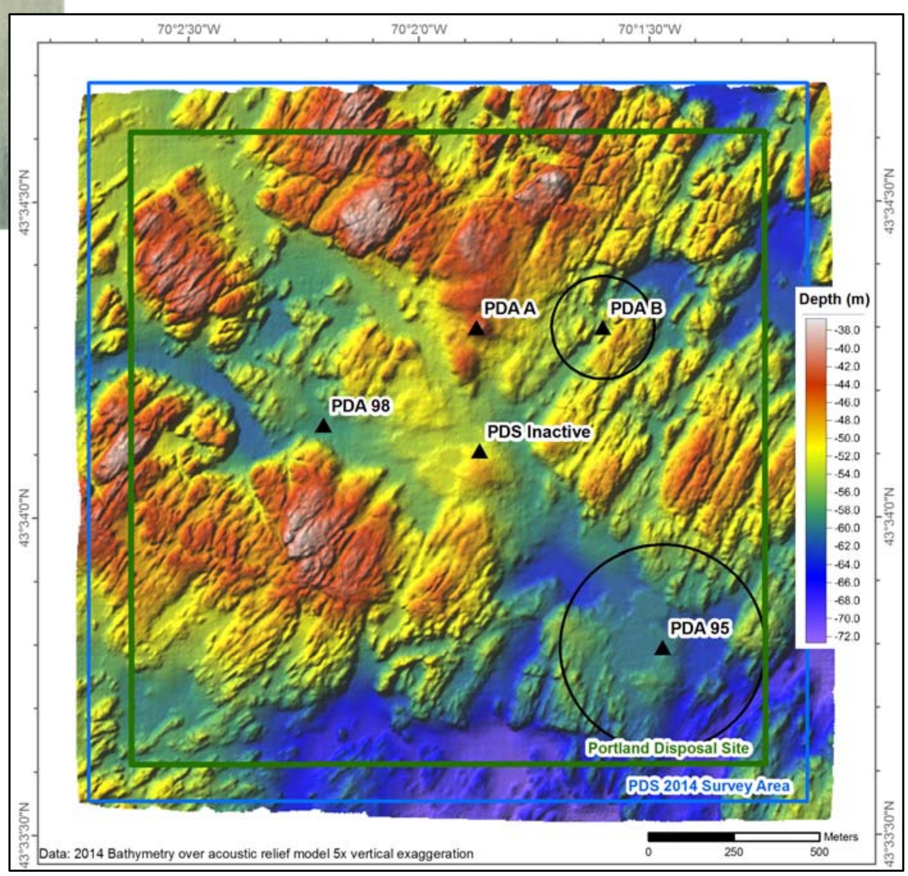
Disposal Area Monitoring System DAMOS







D A M O S

DISPOSAL AREA MONITORING SYSTEM

Contribution 200
April 2017

US Army Corps of Engineers®
New England District

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MONITORING SURVEY AT THE
PORTLAND DISPOSAL SITE
AUGUST 2014

CONTRIBUTION # 200

April 2017

Contract No. W912WJ-12-D-0004

Submitted to:

New England District
U.S. Army Corps of Engineers
696 Virginia Road
Concord, MA 01742-2751

Submitted by:

BATTELLE

141 Longwater Drive, Suite 202
Norwell, MA 02061

Prepared by:

DAMOSVision
A Small Business Joint Venture

215 Eustis Ave.
Newport, RI 02840

Note on units of this report: As a scientific data summary, information and data are presented in the metric system. However, given the prevalence of English units in the dredging industry of the United States, conversions to English units are provided for general information in Section 1. A table of common conversions can be found in Appendix A.

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EXECUTIVE SUMMARY

A monitoring survey was conducted in August 2014 at the Portland Disposal Site (PDS) as part of the Disposal Area Monitoring System (DAMOS) Program. The 2014 monitoring effort involved a high-resolution acoustic survey to characterize seafloor topography and dredged material distribution, as well as a combined sediment-profile imaging (SPI)/plan-view imaging (PV) survey and benthic grab sampling to provide additional physical characterization and to assess benthic recolonization. The results of the 2014 survey were used to document changes at PDS since the previous survey in 2007 and the subsequent placement of over 666,600 m^3 of dredged material at the site.

The high-resolution acoustic survey consisted of multibeam bathymetric, acoustic backscatter and side-scan sonar data acquisition. The survey was conducted over a 2,100 × 2,100 m area that incorporated the full PDS including the active disposal areas and past disposal target areas. The bathymetric data indicated that the site still displayed a highly irregular bottom topography, with a prominent northwest-southeast trending trough that split into two parallel troughs to the northwest. Much of the site was dominated by bedrock outcrops (ledges) while the deeper areas of the site were generally smooth except for irregular relief in the areas where dredged material placement had been targeted.

SPI and PV images were collected from two disposal target areas within PDS (PDA 95 and PDA B) and three reference areas. Evidence of Stage 3 successional status was present in at least one replicate image from all survey stations except one at PDA 95. Mean aRPD depths were statistically equivalent at the disposal sites compared to the reference locations despite shallower depths for PDA95 and the reference areas between 2007 and 2014. The results supported the conclusion that surface sediments at PDS have been colonized by a benthic community comparable to that in nearby reference areas but that both disposal sites and the reference areas may be recovering from some recent disturbance that has resulted in relatively shallow aRPDs.

Conditions at the three reference areas assessed from regional seafloor topography and SPI results suggest that one reference area, SEREF, is not considered representative of PDS given its significantly different bottom topography relative to that of PDS and the other reference areas. This reference area is in a location with dynamic bottom conditions, and it is just as likely that benthic conditions could mirror those of a disturbed system if sampling of this area closely follows deposition of a turbidite. Two reference areas are considered sufficient to serve as a control characterization if SEREF is removed from future monitoring.

1.0 INTRODUCTION

A monitoring survey was conducted at the Portland Disposal Site (PDS) as part of the U.S. Army Corps of Engineers (USACE) New England District (NAE) Disposal Area Monitoring System (DAMOS). 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 PDS, including a brief description of previous dredged material disposal activities and previous monitoring surveys, is provided below.

1.1 Overview of the DAMOS Program

The DAMOS Program features a tiered management protocol designed to ensure that any potential adverse environmental impacts associated with dredged material disposal are promptly identified and addressed (Germano et al. 1994). For over 35 years, the DAMOS Program has collected and evaluated disposal site data throughout New England. Based on these data, patterns of physical, chemical, and biological responses of seafloor environments to dredged material disposal activity have been documented (Fredette and French 2004).

DAMOS monitoring surveys fall into two general categories: confirmatory studies and focused studies. 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. The data collected and evaluated during these studies provide answers to strategic management questions in the disposal site management process. Focused studies are periodically undertaken within the DAMOS Program to evaluate inactive or historical disposal sites and contribute to the development of dredged material techniques and management planning. The 2014 PDS survey was in part a confirmatory study to monitor areas that had received dredged material since the last confirmatory survey of 2007 (AECOM 2009). The 2014 survey also included an expanded bathymetry footprint covering the entire site and reference areas in preparation for revision of the Site Management and Monitoring Plan (SMMP), a periodic requirement for U.S. Environmental Protection Agency (USEPA) designated offshore dredged material disposal sites.

Two primary goals of DAMOS confirmatory monitoring surveys are to document the physical location and stability of dredged material placed into the aquatic environment and to evaluate the biological recovery of the benthic community following placement of the dredged material. Several survey techniques are employed in order to characterize these responses to dredged material placement. Sequential acoustic monitoring surveys (including bathymetric, acoustic backscatter, and side-scan sonar measurements) are conducted to characterize the height and spread of discrete dredged material deposits or mounds created at open water sites, to assess the stability of deposits on the seafloor, and to provide inference on the physical characteristics of the surficial material.

Sediment-profile imaging (SPI) and plan-view underwater camera photography (referred to as plan-view [PV] imaging) surveys are performed to provide further physical characterization of the material and to support evaluation of seafloor (benthic) habitat conditions and recovery over time. Each type of data collection activity is conducted periodically at disposal sites, and the conditions found after a defined period of disposal activity are compared with the long-term data set at specific sites to determine the next step in the disposal site management process (Germano et al. 1994). Focused DAMOS monitoring surveys may also feature additional types of data collection activities as deemed appropriate to achieve specific survey objectives, such as grab sampling of sediment for physical and biological analysis, sub-bottom profiling, or sediment coring.

1.2 Introduction to the Portland Disposal Site

The Portland Disposal Site (PDS) is one of three regional dredged material disposal sites located in the waters of Maine. It covers a 3.4 km^2 (1 nmi^2) area of seafloor centered at 43° 34.105' N, 70° 01.969' W (NAD 83), approximately 13.2 km (7.1 nmi) east of Dyer Point, Cape Elizabeth, Maine (Figure 1-1). The topography at PDS is characterized by a rough, irregular bottom, a prominent northwest-southeast trending trough, and areas of soft sediment accumulation in the basins among bedrock outcrops (Figure 1-2). Water depths across the site range widely, from 37 to 71 m (121 to 230 ft).

PDS is located in a depositional environment. The various bedrock ridges surrounding deep basins provide a measure of protection from wave energy and subsurface currents, and thus act to contain the deposited dredged material. Dredged material disposal operations have specifically targeted these natural basins to enhance containment of dredged material. Sediments deposited at PDS have originated from dredging projects in Portland Harbor, Fore River, and many of the smaller rivers and harbors within the Casco Bay region. Regulated and monitored disposal of dredged material has occurred at PDS since 1977; however, use of the 17.7 km^2 (6.8 mi^2) region surrounding PDS for disposal dates back to 1947 (Morris et al. 1998).

1.3 Historical Dredged Material Disposal Activity

Records indicate that PDS has received approximately 1.8 million m^3 (2.35 million yd^3) of dredged material since the beginning of tracking at this site in 1982. Historically, the largest users of the site were the USACE Royal River and Portland Harbor Federal navigation projects in 1996-1997 and 1998-1999, respectively.

Five distinct disposal locations have been targeted at PDS: PDA (Portland Disposal Area) A Mound, B Mound, 98 Mound, 95 Mound and PDS Inactive. The PDA A Mound, previously referred to as the DG Mound because it was formed by disposal at the DG buoy, has received material from numerous dredging projects over many years (1984-1989, 1991-1992, 1995-1998, 2001-2007; Table 1-1). The PDA 98 Mound was developed in 1998 and 1999 by the placement of sediment dredged from the Federal channel and several marine terminals in the Fore River and Portland Harbor (Table 1-1). Approximately 315,700 m^3 (413,000 yd^3) of material was directed to the PDA 98 Mound, a natural seafloor containment basin in the west-central portion of the site.

The PDA 95 Mound, formerly known as the Royal River Mound, is a moderate-sized disposal mound in the southeast corner of PDS formed from the placement of 61,700 m^3 (80,700 yd^3) of material. It was formed between 1995 and 1997 in water depths of 64 m (Table 1-1) as part of a capping demonstration project. Sediment dredged from the upper reaches of the Royal River in Yarmouth, Maine, which was determined to be suitable for unconfined open water disposal, was used to simulate material requiring cover and sequestration from the overlying water column. Coarser grained sediment from the lower reaches of the same river was used as capping dredged material in the demonstration project (Morris et al. 1998, SAIC 2003).

The PDA B Mound has not developed a shape that can be distinguished from the rough topography of the ambient seafloor. This location has received relatively small volumes of dredged material (detailed below).

The Inactive PDS Mound forms a large irregular mound of dredged material in the center of the site. This location had disposal buoys from 1979 to 1984 and from 1990 to 1991 (SAIC 2002, Table 1-1).

1.4 Previous Monitoring Events

Confirmatory surveys were performed at the PDS in 2000, 2001 and 2007 (AECOM 2009) and a series of focused studies were conducted between 1991 and 2000 (Table 1-2). In addition to typical monitoring surveys employing bathymetry and sediment-profile imaging, the focused investigations have included mussel bioaccumulation studies, oceanographic surveys, and monitoring of capping projects. A review of these monitoring events was provided in AECOM (2009) and is summarized in Table 1-2.

In 2007, bathymetric, sediment-profile and plan-view imaging surveys were conducted around recent and historical disposal locations. Placement of a total of 369,000 m^3 (483,000 yd^3) of dredged material at the site marker buoy from 2001 to 2007 resulted in an increase in height and diameter of the PDA A Mound. The height of the mound increased approximately 4.5 m (15 ft), and the diameter increased 250 to 400 m (820 to 1313 ft). No other significant bathymetric changes were observed. Consolidation was not apparent at the historical mounds PDA 95 and PDA 98.

The August 2007 sediment-profile and plan-view imaging survey was performed at the PDA A Mound and the historical mounds PDA 95 and PDA 98. Recolonization at the older mounds (PDA 95 and PDA 98) had continued as expected, with mature, Stage 3 communities found at every station. The PDA A Mound displayed a recolonization pattern consistent with newly disturbed areas or recently formed disposal mounds. Little to no evidence of deep burrowing or bioturbation activity was detected in any of the profile images from this site, and successional stages were confined to initial opportunistic assemblages (Stage 1) or shallow-dwelling deposit feeders (Stage 2). No evidence of organic enrichment or subsurface methane was found at any of the stations on any of the three mounds, so there is little reason to suspect that recolonization on the PDA A Mound would not follow the same progression as that documented on the PDA 95 and PDA 98 Mounds.

1.5 Recent Dredged Material Disposal Activity

Since the most recent DAMOS survey in August 2007, approximately 666,600 m^3 (872,000 yd^3) of material has been deposited at PDS. The majority of this material originated from the Portland Federal Navigation Project (Table 1-3) and was placed centered on the PDA 95 Mound (Figure 1-3). Placement activity from 2008 through 2010 totaled 38,000 m^3 (50,000 yd^3) and was located at PDA A mound. From 2012 to 2013 a small amount of material [2783 m^3, (3640 yd^3)] from the Maine Yacht Center was placed a PDA B (Figure 1-3).

A detailed record of barge disposal activity at PDS for the period from August 2008 to August 2014, including the origin of dredged material, the volume deposited, and the disposal location, is provided in Appendix B.

1.6 2014 Survey Objectives

The August 2014 survey at PDS was designed as a confirmatory survey of recent disposal activities. The August 2014 survey was designed to:

- Characterize seafloor topography and surficial features of the full PDS with an acoustic survey (bathymetry, backscatter, and side-scan sonar);

- Use SPI and PV imaging to further define the physical characteristics of surface sediment and to assess the benthic recolonization status (community recovery of the bottom-dwelling animals) of the areas of the site with recent disposal activity and the older disposal mounds.

Table 1-1.

Historical Disposal Activity at PDS

Mound Designation	**Years of Disposal Activity**
PDS Inactive	1979-1984; 1990-1991
PDA A (formerly DG Buoy location)	1984-1989; 1991-1992; 1995-1998; 2001-2007
PDA 95	1995-1997
PDA 98	1998-1999

Table 1-2.

Overview of Survey Activities at PDS

Date	Purpose of Survey	Bathymetry Area	SPI Stations (location - #)	Additional Studies	DAMOS Report/Contribution No.	Reference
1977-1978	Confirmatory Monitoring	Single-beam 1900 x 2100 m	---	Currents, mussel chemistry, sediment chemistry, grabs, fisheries	Annual Data Report, Supp. B	NUSC 1979 Supp. B
1979-1981	Confirmatory Monitoring	---	---	Mussel chemistry	43	Feng 1984
January 1989	Confirmatory Monitoring	Single-beam 900 x 1100 m	PDA A - 43 REF - 39	---	78	SAIC 1990
July 1992	Capping demonstration (PDA A Area)	Single-beam 900 x 1100 m	PDA A - 42 REF - 39	Acoustic sediment density, grabs (chemistry)	108	Wiley 1996
1996	Oceanographic measurements	---	---	Tides, near-bottom currents, water temperature, turbidity, salinity	121	McDowell and Pace 1998
1995-1997	Capping demonstration (Royal River Project Area)	Single-beam 800 x 800 m (1995) Single-beam 1950 x 1000 m (1996)	PDA 95 - 33	Side-scan sonar, grabs, cores	123	Morris et al. 1998

Table 1-2. (continued)

Overview of Survey Activities at PDS

Date	Purpose of Survey	Bathymetry Area	SPI Stations (location - #)	Additional Studies	DAMOS Report/Contribution No.	Reference
1998-2000	Dredged material fate, release to water column	Multibeam 17.7 km² trapezoid (1998) Multibeam 2100 x 2100 m (2000)	PDA 98 - 28	Side-scan sonar, ADCP, sediment traps	153	SAIC 2004
July/September 2000	Confirmatory Monitoring	Multibeam 2100 x 2100 m	PDA 98 - 28 REF - 13	---	136	SAIC 2002
August 2001	Confirmatory Monitoring	---	PDA A - 25 PDA 98 - 28 PDA A - 25 REF - 13	---	140	SAIC 2003
August 2007	Confirmatory Monitoring	Multibeam 2100 x 2100 m	PDA 95 - 15 PDS 98 - 16 PDA A - 15 EREF - 7 SREF - 7 SEREF - 5	---	179	AECOM 2009

Table 1-3.

Disposal Activity at PDS since 2007 (per Scow Logs provided by USACE, October 2015)

Permit Number	Project Name	Target Site Code	Permittee Total (m^3)	Permittee Total (yd^3)
2008-2009 Disposal Season				
NAE200603991	Fore River	PDA A	5,486	7,175
NAE200702802	Casco Bay	PDA A	5,734	7,500
Total			**11,220**	**14,675**
2009-2010 Disposal Season				
NAE20042399	Fore River/Coast Guard Station	PDA A	26,729	34,960
Total			**26,729**	**34,960**
2012-2013 Disposal Season				
NAE-2007-2802	Maine Yacht Center	PDA B	2,783	3,640
Total			**2,783**	**3,640**
2013-2014 Disposal Season				
NAE-2013-779	Sprague Terminals	PDA 95	8,106	10,602
W912WJ-13-C-0012	Portland Harbor FNP	PDA 95	617,760	808,000
Total			**625,866**	**818,602**

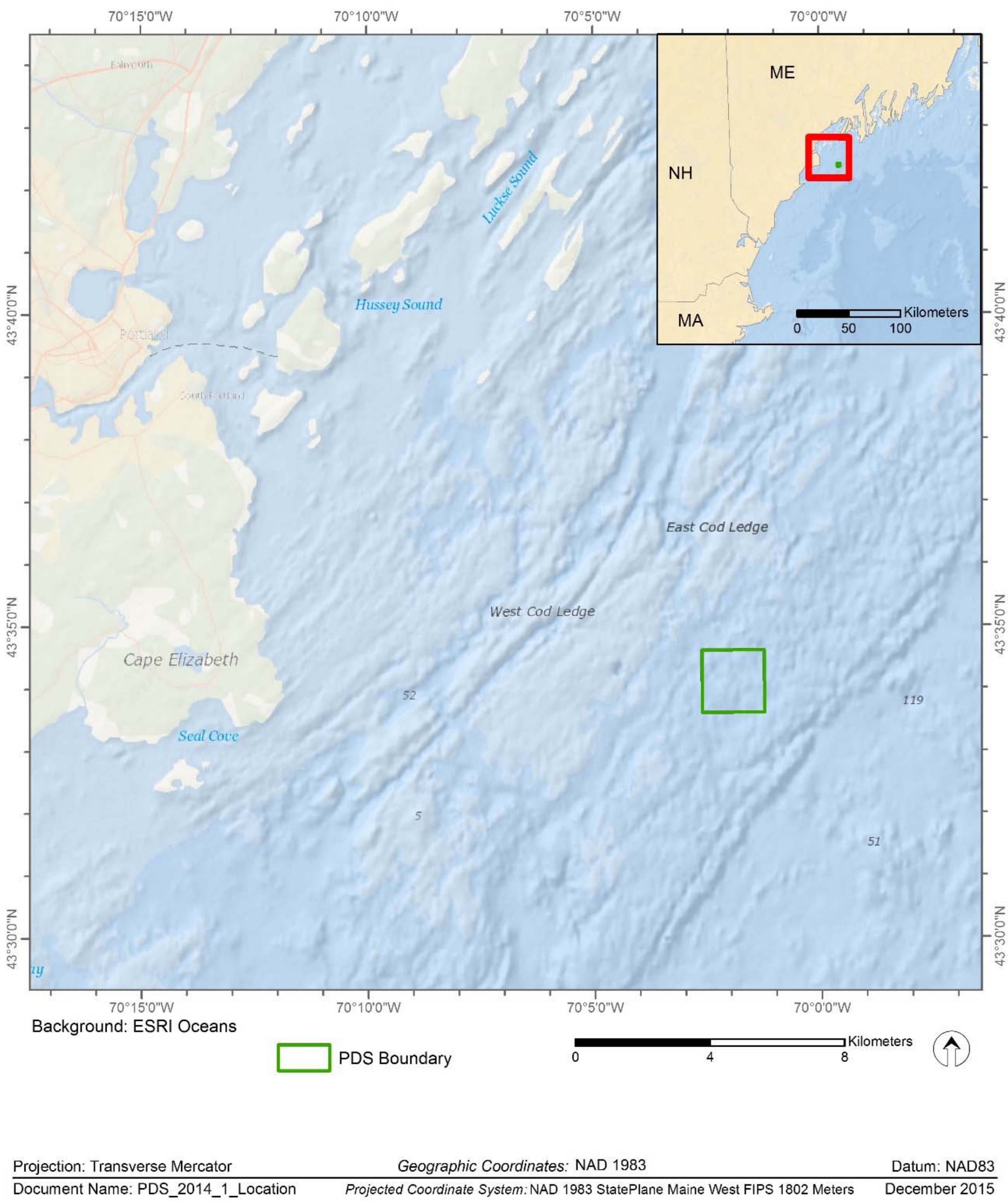


Figure 1-1. Location of the Portland Disposal Site (PDS)

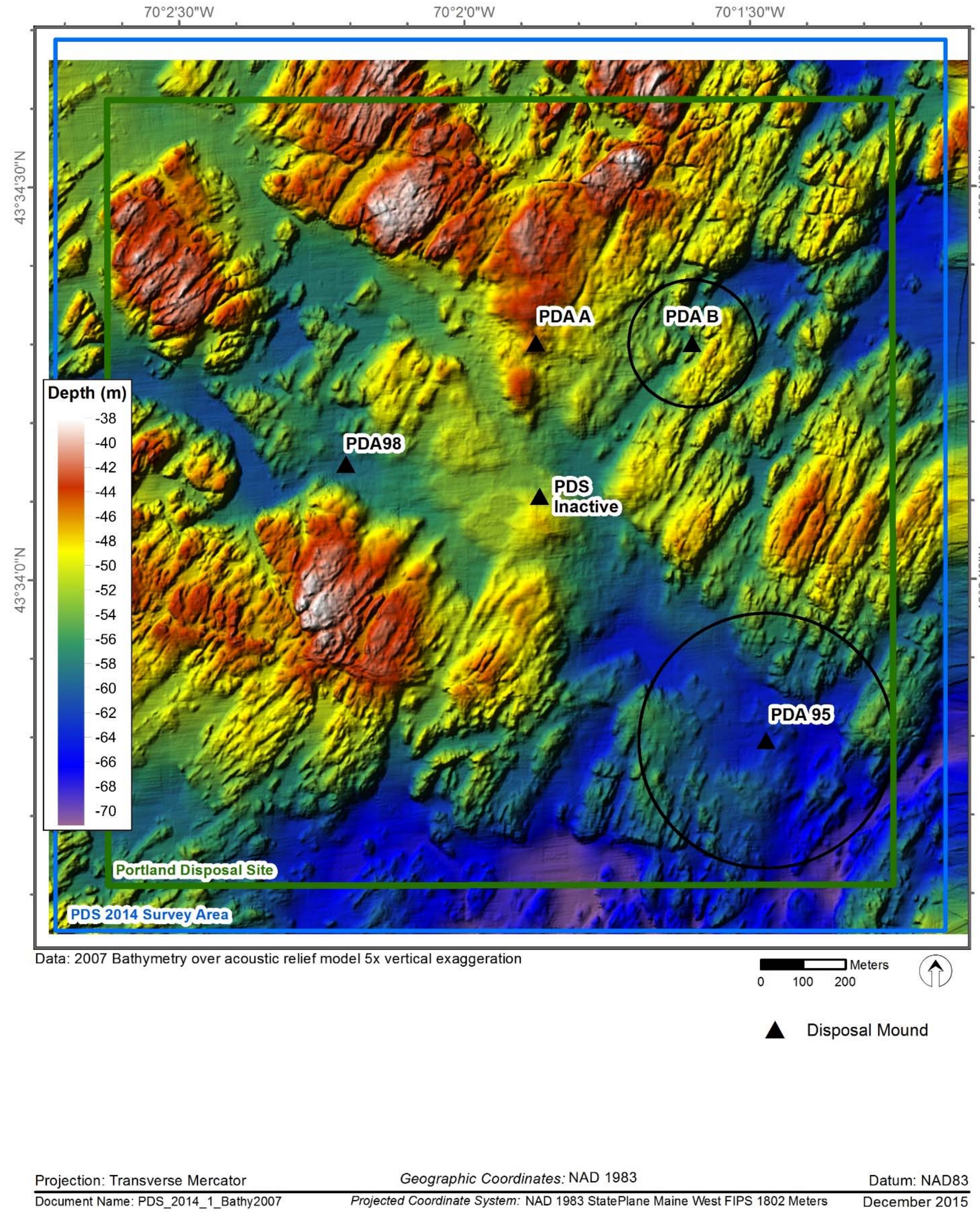


Figure 1-2. PDS 2007 bathymetry with target placement locations

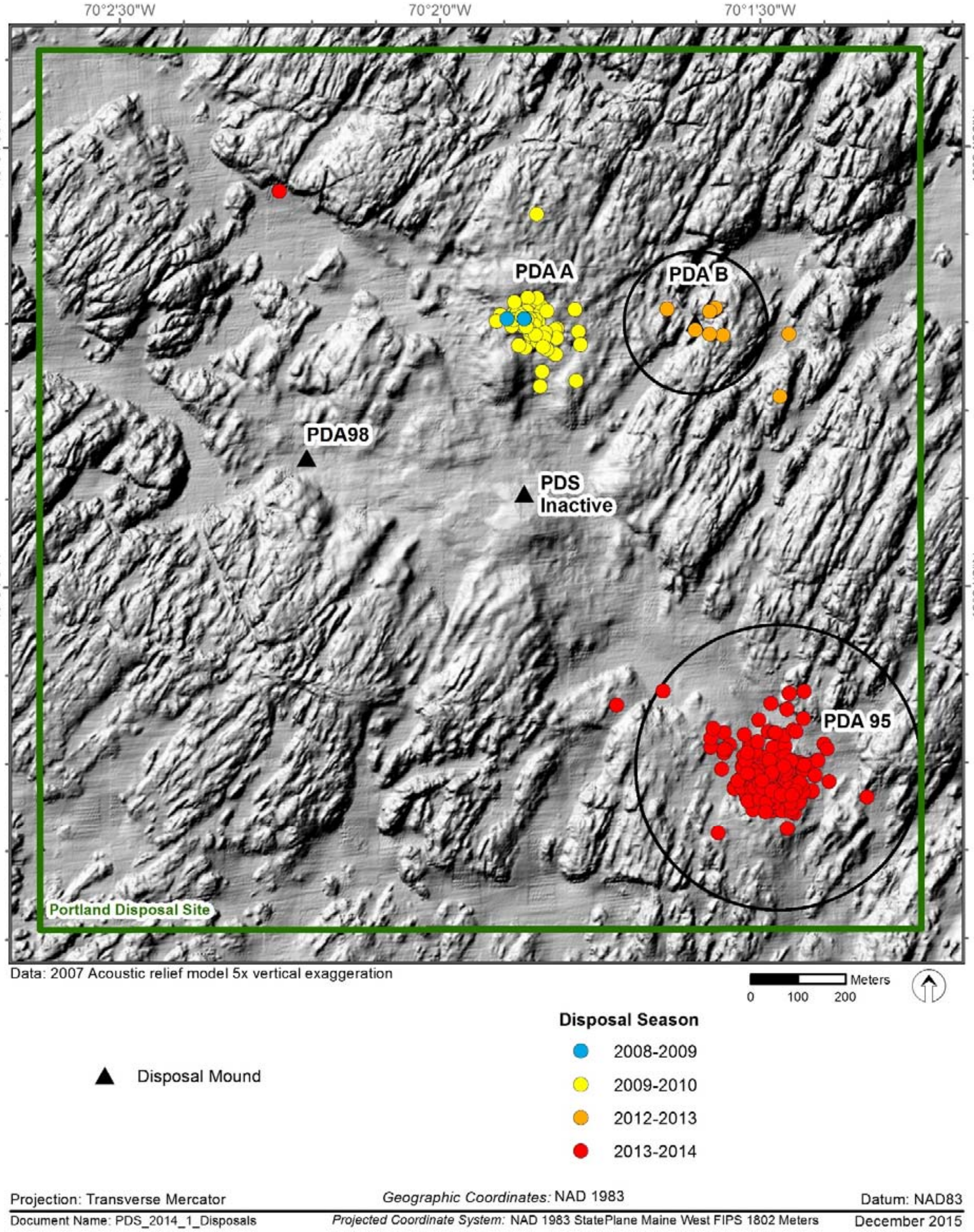


Figure 1-3. Location of reported disposal events at PDS by disposal seasons between 2008 and 2014

2.0 METHODS

The August 2014 survey at PDS was conducted by a team of investigators from DAMOSVision (CoastalVision, CR Environmental and Germano & Associates) and Battelle aboard the 55-foot *R/V Jamie Hanna*. The acoustic survey was conducted from 6 to 7 August, 2014, and the sediment-profile/plan-view (SPI/PV) imaging survey was conducted on 11 August, 2014. Detailed Standard Operating Procedures (SOPs) for data collection and processing are available in Carey et al. (2013).

2.1 Acoustic Survey

The acoustic survey in this study included bathymetric, backscatter, and side-scan sonar data collection and processing. The bathymetric data provided measurements of water depth that, when processed, were used to map the seafloor topography. The processed data were also compared with previous surveys to track changes in the size and location of seafloor features. This technique is the primary tool of the DAMOS Program for mapping the distribution of dredged material at disposal sites. Backscatter and side-scan sonar data provided images that supported characterization of surface topography, sediment texture, and bottom roughness. Backscatter data can be processed into a seamless mosaic image that is corrected for the effect of changing seafloor slope. Side-scan sonar data retains a higher resolution but correction for seafloor slope changes is not possible. The comparison of synoptic acoustic data types has the greatest utility for assessment of dredged material placement because it allows for evaluation and comparison of multiple properties of the seafloor.

2.1.1 Acoustic Survey Planning

The acoustic survey featured a high spatial resolution survey of PDS. DAMOSVision hydrographers coordinated with USACE NAE scientists and reviewed alternative survey designs. For PDS, a 2,100 × 2,100 m area was selected with a series of survey lines spaced 80 m apart and cross-tie lines spaced 250 m apart (Figure 2-1). The survey was designed to cover PDS entirely and provide greater than 100-percent coverage of the seafloor within the survey area. Hydrographers obtained site coordinates, imported them to ESRI geographic information system (GIS) software, and created planning maps. The proposed survey area encompassing the entire site was then reviewed and approved by NAE scientists.

2.1.2 Navigation and On-Board Data Acquisition

Navigation for the survey was accomplished using a Hemisphere VS-330 270-channel Real-Time Kinematic Global Positioning System (RTK GPS) and Digital Compass system which received on-the-fly corrections from the KeyNet GPS, Inc. Trimble Virtual Reference Station System (VRS). Trimble and Hemisphere differential GPS (DGPS) systems capable of receiving satellite-based differential corrections (SBAS) and USCG Beacon corrections were available as backups. The RTK GPS system is capable of subdecimeter horizontal and vertical position accuracy. The RTK GPS system was interfaced to a laptop computer running HYPACK MAX® hydrographic survey software. HYPACK MAX® continually recorded vessel position and RTK GPS satellite quality and provided a steering display for the vessel captain to accurately maintain the position of the vessel along pre-established survey transects and relative to intended targets. The pulse-per-second (PPS) signals from the RTK GPS system was hardware interfaced to the multibeam echo sounder (MBES) topside processor and provided microsecond level accuracy of data stream time-tagging from each sensor.

Vessel heading measurements were provided by a dual-antenna Hemisphere VS-110 Crescent Digital compass accurate to within 0.05° up to 20 times per second.

2.1.3 Acoustic Data Collection

Bathymetric, acoustic backscatter, and side-scan sonar data were collected using an Odom MB1 MBES. This 200-kHz system forms up to 512 3° beams distributed equiangularly or equidistantly across a 120° swath. The MBES transducer was mounted amidships to the port rail of the survey vessel using a high strength adjustable boom, and offsets between the primary RTK GPS antenna and the sonar were precisely measured and entered into HYPACK. The transducer depth below the water surface (draft) was checked and recorded at the beginning and end of data acquisition, and confirmed using the “bar check” method.

A TSS DMS 3-05 motion reference unit (MRU) and the Hemisphere compass system were interfaced to the MBES topside processor. Depth, motion, heading, side-scan and backscatter data were PPS time-stamped and transmitted to the HYPACK MAX® acquisition computer via Ethernet communications. Several patch tests were conducted during the surveys to allow computation of angular offsets between the MBES system components. The system was calibrated for local water mass speed-of-sound by performing sound velocity profiles (SVP) and conductivity-temperature-depth (CTD) casts at frequent intervals throughout the survey day with an Odom Digibar sound velocity profiler and a Seabird SBE-19 Seacat CTD profiler. Additional confirmations of proper calibration, including static draft, were obtained using the “bar check” method, in which a metal plate was lowered beneath the MBES transducer to a known depth (5.0 m) below the water surface. “Bar-check” calibrations were accurate to within 0.02 m in tests conducted at the beginning and end of each survey day.

2.1.4 Bathymetric Data Processing

Bathymetric data were processed using HYPACK HYSWEEP® software. Processing components are described below and included:

- Adjustment of data for tide fluctuations

- Correction of acoustic ray bending (refraction) due to density variation of the water column
- Removal of spurious points associated with water column interference or system errors
- Development of a grid surface representing depth solutions
- Statistical estimation of sounding solution uncertainty
- Generation of data visualization products

Tidal adjustments were accomplished using RTK GPS data merged with National Oceanic and Atmospheric Administration's (NOAA) Portland tide data when RTK fixes were compromised.

Correction of sounding depth and position errors associated with refraction due to water column stratification were conducted using a series of twenty-three SVPs acquired by the survey team. Data artifacts associated with refraction remain in the bathymetric surface model at a relatively fine scale (generally less than 5 to 10 cm) relative to the survey depth.

Data were filtered to accept only beams falling within an angular limit of 48° to minimize refraction artifacts while ensuring meaningful overlap between adjacent swaths. Spurious sounding solutions were flagged or rejected based on the careful examination of data on a sweep-specific basis.

The 219 kHz Odom MB1 MBES system has a published nadir beam width of 3°. The range precision of the MB1 is 3.8 cm with a sounding resolution of 1 cm. The MB1 uses a combination of electronic beam forming and interferometric beam forming methods. Both amplitude and phase bottom detection algorithms are used for each beam when calculating ranges (soundings), with a bias towards phase detection occurring very near nadir. Without consideration of interferometric capabilities, the theoretical spatial resolution of the MB1 would be entirely dependent upon the acoustic beam footprint, which is an ellipse formed by a 3 × 5 degree beam with semi-major axis orientation athwart ship. However, interferometric beam forming allows the system to maintain a static footprint across-track equal to the widest portion of the nadir beam ellipse. Thus, data collected at the PDS mean depth of 54 m would retain footprint widths of approximately 5 meters across the full swath width.

Data were reduced to a cell (grid) size of 3.0 × 3.0 m, acknowledging the system's fine range resolution and approximately 36 m depth range while accommodating beam position uncertainty. This data reduction was accomplished by calculating and exporting the average elevation for each cell in accordance with USACE recommendations (USACE 2013).

Statistical analysis of data showed negligible tide bias and vertical uncertainty substantially lower than values recommended by USACE (2013) or NOAA (2015). The National Ocean Service (NOS) standard for the PDS project depth (Order 1A/1B) would call for a 95th percentile confidence interval (95% CI) of 1.07 m at the maximum site depth (72.5 m) and 0.69 m at the mean site depth (36.8 m). Ninety-five percent of 2014 survey cell uncertainty values were less than 0.73 m. Areas and cells with uncertainty higher than performance standards were limited to higher relief seabed where slopes skewed statistical analysis (many ledge slopes at PDS approach vertical). The evaluation suggests that elevation comparisons between surveys should be accurate to approximately 70 cm at the 95^{th} percentile uncertainty level (Table 2-1).

Reduced data were exported in ASCII text format with fields for Easting, Northing, and MLLW Elevation (meters). All data were projected to the Maine State Plane (West), NAD83 (metric). A variety of data visualizations were generated using a combination of IVS3D Fledermaus (V.7), ESRI ArcMap (V.10.2.1), and Golden Software Surfer (V.12). Visualizations and data products included:

- ASCII data files of all processed soundings including MLLW depths and elevations
- Contours of seabed elevation (50-cm, 1.0-m and 2.0-m intervals) in a geospatial data file (SHP) format suitable for plotting using GIS and computer-aided design (CAD) software
- 3-dimensional surface maps of the seabed created using 5× vertical exaggeration and artificial illumination to highlight fine-scale features not visible on contour layers delivered in grid and tagged image file (TIF) formats, and
- Raster grid files for the bathymetric and uncertainty surfaces.

2.1.5 Backscatter Data Processing

Backscatter were extracted from cleaned files then use to provide an estimation of surface sediment texture based on sediment surface roughness. Mosaics of beam time-series (BTS) backscatter data were created using HYPACK®'s implementation of GeoCoder software developed by scientists at the University of New Hampshire's NOAA Center for Coastal and Ocean Mapping (UNH/NOAA CCOM). A seamless mosaic of unfiltered BTS data was developed and exported in grayscale TIF format. BTS data were also exported in ASCII format with fields for Easting, Northing, and backscatter (dB). A Gaussian filter was applied to backscatter data to minimize nadir artifacts and the filtered data were used to develop backscatter values on a 3-m grid. The backscatter grid was delivered in ESRI binary GRD format to facilitate comparison with other data layers.

Backscatter data collected in 2007 were normalized to the 2014 data by calculating the differences in dynamic ranges for each model, then applying a range correction multiplier to the 2007 data. After normalization, the adjusted 2007 model was subtracted from the 2014 model. Evaluation of differences in portions of the survey area unlikely to have received dredged material suggested that variations less than approximately 5-6 dB (+/-) were unlikely to be significant or physically meaningful.

2.1.6 Side-Scan Sonar Data Processing

The side-scan sonar data were processed using Chesapeake Technology SonarWiz software. A seamless mosaic of unfiltered side-scan sonar data was developed and exported in grayscale TIF format using a resolution of 0.2 m per pixel.

2.1.7 Acoustic Data Analysis

The processed bathymetric grids were converted to rasters. Bathymetric contour lines and acoustic relief models were generated and displayed using GIS. The backscatter mosaics and filtered backscatter grid were combined with acoustic relief models in GIS to facilitate visualization of relationships between acoustic datasets. This was done by rendering images and color-coded grids with sufficient transparency to allow three-dimensional acoustic relief model to be visible underneath.

2.2 Sediment-Profile and Plan-View Imaging Survey

SPI and PV imaging are monitoring techniques used to provide data on the physical characteristics of the seafloor and the status of the benthic biological community.

2.2.1 SPI and PV Survey Planning

For the PDS August 2014 survey, a total of 36 SPI/PV stations were surveyed; 24 stations within PDS focused on two disposal areas (PDA 95 and PDA B): and four randomly located stations in each of three reference areas (EREF, SREF, and SEREF; Figures 2-2 and 2-3). SPI/PV target station locations are provided in Table 2-2 and actual SPI/PV station replicate locations are provided in Appendix C.

2.2.2 Sediment-Profile Imaging

The SPI technique involves deploying an underwater camera system to photograph a cross-section of the sediment-water interface. In the 2014 survey at PDS, high-resolution SPI images were acquired using a Nikon® D7100 digital single-lens reflex camera mounted inside an Ocean Imaging® Model 3731 pressure housing. The pressure housing sat atop a wedge-shaped steel prism with a front faceplate and a back mirror. The mirror was mounted at a 45° angle to reflect the profile of the sediment-water interface. As the prism penetrated the seafloor, a trigger activated a time-delay circuit that fired an internal strobe to obtain a cross-sectional image of the upper 15–20 cm of the sediment column (Figure 2-4).

The camera remained on the seafloor for approximately 20 seconds to ensure that a successful image had been obtained. Details of the camera settings for each digital image are available in the associated parameters file embedded in each electronic image file. For this survey, the ISO-equivalent was set at 640, shutter speed was 1/250, f-stop was f9, and storage was in compressed raw Nikon Electronic Format (NEF) files (approximately 30 MB each). Electronic files were converted to high-resolution JPEG (8-bit) format files (4000 × 6000 pixels) using Nikon Capture® NX2 software (Version 2.4.7).

Test exposures of the Kodak® Color Separation Guide (Publication No. Q-13) were made on deck at the beginning and end of the survey to verify that all internal electronic systems were working to design specifications and to provide a color standard against which final images could be checked for proper color balance. After deployment of the camera at each station, the frame counter was checked to ensure that the requisite number of replicates had been obtained. In addition, a prism penetration depth indicator on the camera frame was checked to verify that the optical prism had actually penetrated the bottom to a sufficient depth. If images were missed or the penetration depth was insufficient, the camera frame stop collars were adjusted and/or weights were added or removed, and additional replicate images were taken. Changes in prism weight amounts, the presence or absence of mud doors, and frame stop collar positions were recorded for each replicate image and are available in Appendix D.

Each image was assigned a unique time stamp in the digital file attributes by the camera's data logger and cross-checked with the time stamp in the navigational system's computer data file. In addition, the field crew kept redundant written sample logs. Images were downloaded periodically to verify successful sample acquisition and/or to assess what type of sediment/depositional layer was present at a particular station. Digital image files were renamed with the appropriate station names immediately after downloading as a further quality assurance step.

2.2.3 Plan-View Imaging

An Ocean Imaging® Model DSC16000 PV underwater camera system with two Ocean Imaging® Model 400-37 Deep Sea Scaling lasers was attached to the sediment-profile camera frame and used to collect plan-view photographs of the seafloor surface; both SPI and PV images were collected during each "drop" of the system. The PV system consisted of a Nikon D-7000 encased in an aluminum housing, a 24 VDC autonomous power pack, a 500 W strobe, and a bounce trigger. A weight was attached to the bounce trigger with a stainless-steel cable so that the weight hung below the camera frame; the scaling lasers projected two red dots that are separated by a constant distance (26 cm) regardless of the field-of-view of the PV system. The field of view can be varied by increasing or decreasing the length of the trigger wire. As the camera apparatus was lowered to the seafloor, the weight attached to the bounce trigger contacted the seafloor prior to the camera frame hitting the bottom and triggered the PV camera (Figure 2-4). Details of the camera settings for each digital image are available in the associated parameters file embedded in each electronic image file; for this survey, the ISO-equivalent was set at 800. The additional camera settings used were as follows: shutter speed 1/30, f11, white balance set to flash, color mode set to Adobe RGB, sharpening set to none, noise reduction off, and storage in compressed raw NEF files (approximately 20 MB each). Electronic files were converted to high-resolution JPEG (8-bit) format files (3264 × 4928 pixels) using Nikon Capture® NX2 software.

Prior to field operations, the internal clock in the digital PV system was synchronized with the GPS navigation system and the SPI camera. Each PV image acquired was assigned a time stamp in the digital file and redundant notations in the field and navigation logs. Throughout the survey, PV images were downloaded at the same time as the SPI images after collection and evaluated for successful image acquisition and image clarity.

The ability of the PV system to collect usable images was dependent on the clarity of the water column. Water conditions at PDS allowed use of a 1½-m trigger wire, resulting in an area of bottom visualization approximately 2.0 × 1.2 m in size.

2.2.4 SPI and PV Data Collection

The SPI/PV survey was conducted at PDS on 11 August 2014 aboard the *R/V Jamie Hanna.* At each station, the vessel was positioned at the target coordinates and the camera was deployed within a defined station tolerance of 10 m. Four replicate SPI and PV images were collected at each of the stations (Figures 2-2 and 2-3; Appendix C). The three replicates with the best quality images from each station were chosen for analysis (Appendix D).

The DGPS described above was interfaced to HYPACK® software via laptop serial ports to provide a method to locate and record sampling locations. Throughout the survey, the HYPACK® data acquisition system received DGPS data. The incoming data stream was digitally integrated and stored on the PC’s hard drive. The system provided a steering display to enable the vessel captain to navigate to the pre-established survey target locations. The navigator electronically recorded the vessel’s position when the equipment contacted the seafloor and the winch wire went slack. Each replicate SPI/PV position was recorded and time stamped. Actual SPI/PV sampling locations were recorded using this system.

2.2.5 SPI and PV Data Analysis

Computer-aided analysis of the resulting images provided a set of standard measurements to allow comparisons between different locations and different surveys. The DAMOS Program has successfully used this technique for over 30 years to map the distribution of disposed dredged material and to monitor benthic recolonization at disposal sites (Germano et al. 2011).

Following completion of data collection, the digital images were analyzed using Adobe Photoshop® CC 2014 Version 15.0. Images were first adjusted in Adobe Photoshop® to expand the available pixels to their maximum light and dark threshold range.

Linear and areal measurements were recorded as number of pixels and converted to scientific units using the Kodak® Color Separation Guide for measurement calibration. Detailed results of all SPI and PV image analyses are presented in Appendix D.

2.2.5.1 SPI Data Analysis

Analysis of each SPI image was performed to provide measurement of the following standard set of parameters:

Sediment Type– The sediment grain size major mode and range were estimated visually from the images using a grain size comparator at a similar scale. Results were reported using the phi scale. Conversion to other grain size scales is provided in Appendix E. The presence and thickness of disposed dredged material were also assessed by inspection of the images.

Penetration Depth– The depth to which the camera penetrated into the seafloor was measured to provide an indication of the sediment density or bearing capacity. The penetration depth can range from a minimum of 0 cm (no penetration on hard substrata) to a maximum of 20 cm (full penetration on very soft substrata).

Surface Boundary Roughness– Surface boundary roughness is a measure of the vertical relief of features at the sediment-water interface in the sediment-profile image. Surface boundary roughness was determined by measuring the vertical distance between the highest and lowest points of the sediment-water interface. The surface boundary roughness measured over the width of sediment-profile images typically ranges from 0 to 4 cm, and may be related to physical structures (ripples, rip-up structures, mud clasts) or biogenic features (burrow openings, fecal mounds, foraging depressions).

Apparent Redox Potential Discontinuity (aRPD) Depth– The aRPD depth provides a measure of the integrated time history of the balance between near-surface oxygen conditions and biological reworking of sediments. Sediment particles exposed to oxygenated waters oxidize and lighten in color to brown or light gray. As the particles are buried or moved down by biological activity, they are exposed to reduced oxygen concentrations in subsurface pore waters and their oxic coating slowly reduces, changing color to dark gray or black. When biological activity is high, the aRPD depth increases; when it is low or absent, the aRPD depth decreases. The mean aRPD depth was determined for each image by assessing color and reflectance differences visible in the sediment matrix and measuring the discernable area that indicates the apparent depth of oxidized sediments.

Low Dissolved Oxygen– Under conditions of high organic loading and hypoxia or anoxia in the water column, dark gray or black reduced sediments are in contact with the sediment-water interface.

Sedimentary Methane– If organic loading is extremely high, porewater sulfate is depleted and methanogenesis occurs. The process of methanogenesis is indicated by the appearance of methane bubbles in the sediment column. These gas-filled voids are readily discernable in SPI images because of their irregular, generally circular aspect and glassy texture (due to the reflection of the strobe off the gas bubble).

Infaunal Successional Stage– Infaunal successional stage is a measure of the biological community inhabiting the seafloor. Current theory holds that organism-sediment interactions in fine-grained sediments follow a predictable sequence of development after a major disturbance (such as dredged material disposal), and this sequence has been divided subjectively into four stages (Rhoads and Germano 1982, 1986). Successional stage was assigned by assessing which types of species or organism-related activities were apparent in the images (Figure 2-5).

Additional components of the SPI analysis included calculation of means and ranges for the parameters listed above and mapping of means of replicate values from each station. Station means were calculated from three replicates from each station and used in statistical analysis.

2.2.5.2 PV Data Analysis

The PV images provided a much larger field-of-view than the SPI images and provided valuable information about seascape ecology and sediment topography in the area where the pinpoint "optical core" of the sediment profile was taken. Unusual surface sediment layers, textures, or structures detected in any of the sediment-profile images can be interpreted in light of the larger context of surface sediment features; i.e., is a surface layer or topographic feature a regularly occurring feature and typical of the bottom in this general vicinity or just an isolated anomaly? The scale information provided by the underwater lasers allows for accurate density counts (number per square meter) of attached epifaunal colonies, sediment burrow openings, or larger macrofauna or fish which may have been missed in the sediment-profile cross section. Information on sediment transport dynamics and bedform wavelength were also available from PV image analysis. Analysts calculated the image size and field-of-view and noted sediment type; recorded the presence of bedforms, burrows, tubes, tracks, trails, epifauna, mud clasts, and debris; and included descriptive comments (Appendix D).

2.2.6 Statistical Methods

In order to meet the objective of this survey to assess the status of benthic community recolonization of the sediment at disposal areas relative to reference area conditions, statistical analyses were conducted to compare key SPI variables between sampled disposal locations (PDA B and PDA 95) and reference areas (SREF, EREF, and SEREF). The aRPD depth and successional stage measured in each image are the best indicators of infaunal activity measured by SPI and were, therefore, used in this comparative analysis. Standard boxplots were generated for visual assessment of the central tendency and variation in each of these variables within each disposal area and each reference area. Tests rejecting the inequivalence between the reference and disposal areas were conducted, as described in detail below.

The objective to look for differences has conventionally been addressed using a point null hypothesis of the form, “There is no significant difference in benthic conditions between the reference area and the disposal target areas.” However, there is always some difference (perhaps only to a very small decimal place) between groups, but the statistical significance of this difference may or may not be ecologically meaningful. On the other hand, differences may not be detected due to insufficient statistical power. Without a power analysis and specification of what constitutes an ecologically meaningful difference, the results of conventional point null hypothesis testing often provide inadequate information for ecological assessments (Germano 1999). An approach using an inequivalence null hypothesis will identify when groups are statistically similar, within a specified interval, which is more suited to the objectives of the DAMOS monitoring program.

For an inequivalence test, the null hypothesis presumes the difference is great; this is recognized as a “proof of safety” approach because rejection of the inequivalence null hypothesis requires sufficient proof that the difference was actually small (McBride 1999). The null and alternative hypotheses for the inequivalence hypothesis test are:

$$H_0: \; d < -\delta \text{ or } d > \delta \text{ (presumes the difference is great)}$$

$$H_A: \; -\delta < d < \delta \text{ (requires proof that the difference is small)}$$

where d is the difference between a reference mean and a site mean. If the inequivalence null hypothesis is rejected, then it is concluded that the two means are equivalent to one another within $\pm\delta$ units. The size of δ should be determined from historical data, and/or best professional judgment, to identify a maximum difference that is within background variability and is therefore not ecologically meaningful. Primarily differences greater than δ are of ecological interest. Previously established δ values of 1 cm for aRPD depth, and 0.5 for successional stage rank (on the 0–3 scale) were used.

The test of this inequivalence (interval) hypothesis can be broken down into two one-sided tests (TOST) (McBride 1999, Schuirmann 1987). Assuming a symmetric distribution, the inequivalence hypothesis is rejected at α of 0.05 if the 90% confidence interval for the measured difference (or, equivalently, the 95% upper limit <u>and</u> the 95% lower limit for the difference) is wholly contained within the equivalence interval $[-\delta, +\delta]$. The statistics used to test the interval hypotheses shown here are based on the Central Limit Theorem (CLT) and basic statistical properties of random variables. A simplification of the CLT states that the mean of any random variable is normally distributed. Linear combinations of normal random variables are also normal so a linear function of means is also normally distributed.

When a linear function of means is divided by its standard error the ratio follows a t-distribution with degrees of freedom associated with the variance estimate. Hence, the t-distribution can be used to construct a confidence interval around any linear function of means.

In this survey, five distinct locations were sampled, three were categorized as reference areas (EREF, SREF, and SEREF) and two were disposal locations (PDA B and PDA 95). The difference equation of interest was the linear contrast of the average of the three reference means minus each disposal area mean, or

$$\hat{d} = [1/3 \times (\text{Mean}_{\text{EREF}} + \text{Mean}_{\text{SEREF}} + \text{Mean}_{\text{SREF}}) - (\text{Mean}_{\text{Disposal}})] \qquad \text{[Eq.1]}$$

where $\text{Mean}_{\text{Disposal}}$ was the mean for one of the disposal areas (PDA B or PDA 95).

The three reference areas collectively represented ambient conditions, but if the means were different among these three areas, then pooling them into a single reference group would inflate the variance estimate because it would include the variability between areas, rather than only the variability between stations within each single homogeneous area. The effect of keeping the three reference areas separate had no effect on the grand reference mean when sample size was equal among these areas, but it ensured that the variance is truly the residual variance within a single population with a constant mean.

The difference equation, $\hat{d}$, for the comparison of interest was specified in Eq. 1and the standard error of each difference equation used the fact that the variance of a sum is the sum of the variances for independent variables, or:

$$SE(\hat{d}) = \sqrt{\sum_j \left(S_j^2 c_j^2 / n_j\right)} \qquad \text{[Eq.2]}$$

where:

cj = coefficients for the j means in the difference equation, $\hat{d}$ [Eq. 1] (i.e., for equation 1 shown above, the coefficients were 1/3 for each of the 3 reference areas, and -1 for the disposal area).

S_j^2 = variance for the jth area. If equal variances are assumed, the pooled residual variance estimate equal to the mean square error from an *ANOVA based* on all groups involved, can be used for each S_j^2.

nj = number of stations for the jth area.

The inequivalence null hypothesis was rejected (and equivalence concluded) if the confidence interval on the difference of means, $\hat{d}$, was fully contained within the interval [–δ , + δ]. Thus the decision rule was to reject H_0 (the two groups were inequivalent) if:

$$D_L = \hat{d} - t_{\alpha,\upsilon} SE(\hat{d}) > -\delta \qquad \text{and} \qquad D_U = \hat{d} + t_{\alpha,\upsilon} SE(\hat{d}) < \delta \qquad \text{[Eq. 3]}$$

where:

$\hat{d}$ = observed difference in means between the Reference and Disposal Area.

$t_{\alpha,\upsilon}$ = upper (1-α)*100th percentile of a Student's t-distribution with υ degrees of freedom (α = 0.05)

$SE(\hat{d})$ = standard error of the difference ([Eq. 2])

υ = degrees of freedom for the standard error. If a pooled residual variance estimate was used, this was the residual degrees of freedom from an ANOVA on all groups (total number of stations minus the number of groups); if separate variance estimates were used, degrees of freedom were calculated based on the Welch-Sattherthwaite estimation (Satterthwaite 1946, Zar 1996).

Validity of normality and equal variance assumptions was tested using Shapiro-Wilk's test for normality on the area residuals (α = 0.05) and Levene's test for equality of variances among areas (α =0.05). If normality was not rejected but equality of variances was, then normal parametric confidence bounds were calculated, using separate variance estimates for each group. If normality was rejected, then non-parametric bootstrapped estimates of the confidence bounds were calculated.

Table 2-1.

Accuracy and Uncertainty Analysis of Bathymetric Data

		Results (m)		
Survey Date(s)	**Quality Control Metric**	**Mean**	**95% Uncertainty**	**Range**
8/6-8/7/2014	Cross-Line Nadir Comparisons	0.04	0.67	-1.02 - 1.62
	Cross-Line Swath Comparisons	-0.05	0.68	
	Within Cell Uncertainty	0.18	0.36	0.00 - 4.40
	Beam Angle Uncertainty (0 – 50 d)	-0.01	0.67	0.00 - 7.70

Notes:
1. The mean of cross-line nadir and full swath comparisons are indicators of tide bias.
2. 95% uncertainty values were calculated using the sums of mean differences and standard deviations expressed at the 2-sigma level.
3. Within cell uncertainty values include biases and random errors.
4. Beam angle uncertainty was assessed by comparing cross-line data (50-degree swath limit) with a reference surface created using mainstay transect data.
5. Swath and cell based comparisons were conducted using 3 m x 3 m cell averages. These analyses do not exclude sounding variability associated with extreme (near vertical) terrain slopes. Uncertainties associated with slope are depicted on maps within the report.

Table 2-2.

PDS 2014 Survey Target SPI/PV Station Locations

PDS August 2014 SPI Target Station Locations					
Site Station	**Latitude (N)**	**Longitude (W)**	**Reference Station**	**Latitude (N)**	**Longitude (W)**
PDA 95-1	43.56199787	-70.02730421	EREF-1	43.57517509	-69.99560879
PDA 95-2	43.56543030	-70.02385666	EREF-2	43.57177771	-69.99670217
PDA 95-3	43.56360600	-70.02150247	EREF-3	43.57373551	-69.99665452
PDA 95-4	43.56453191	-70.02503741	EREF-4	43.57314453	-69.99368878
PDA 95-5	43.56304192	-70.02282453	SREF-5	43.55560995	-70.02808172
PDA 95-6	43.56296959	-70.02731834	SREF-6	43.55819419	-70.02909135
PDA 95-7	43.56310435	-70.02626744	SREF-7	43.55564341	-70.03152063
PDA 95-8	43.56271460	-70.02407640	SREF-8	43.55387795	-70.02902978
PDA 95-9	43.56456098	-70.02607481	SEREF-9	43.54724057	-70.00303198
PDA 95-10	43.56370001	-70.02374622	SEREF-10	43.54502666	-70.00170578
PDA 95-11	43.56447454	-70.02407429	SEREF-11	43.54892366	-70.00291471
PDA 95-12	43.56306799	-70.02142016	SEREF-12	43.54730724	-70.00541187
PDA 95-13	43.56446674	-70.02723581			
PDA 95-14	43.56550381	-70.02499750			
PDA 95-15	43.56358046	-70.02535684			
PDA 95-16	43.56118735	-70.02518395			
PDA 95-17	43.56124040	-70.02408491			
PDA 95-18	43.56463419	-70.02275915			
PDA B-1	43.57146068	-70.02660929			
PDA B-2	43.57238333	-70.02736348			
PDA B-3	43.57237909	-70.02597107			
PDA B-4	43.57113614	-70.02560512			
PDA B-5	43.57108433	-70.02644038			
PDA B-6	43.57141522	-70.02798379			

Note: Geographic coordinates are WGS84 decimal degrees

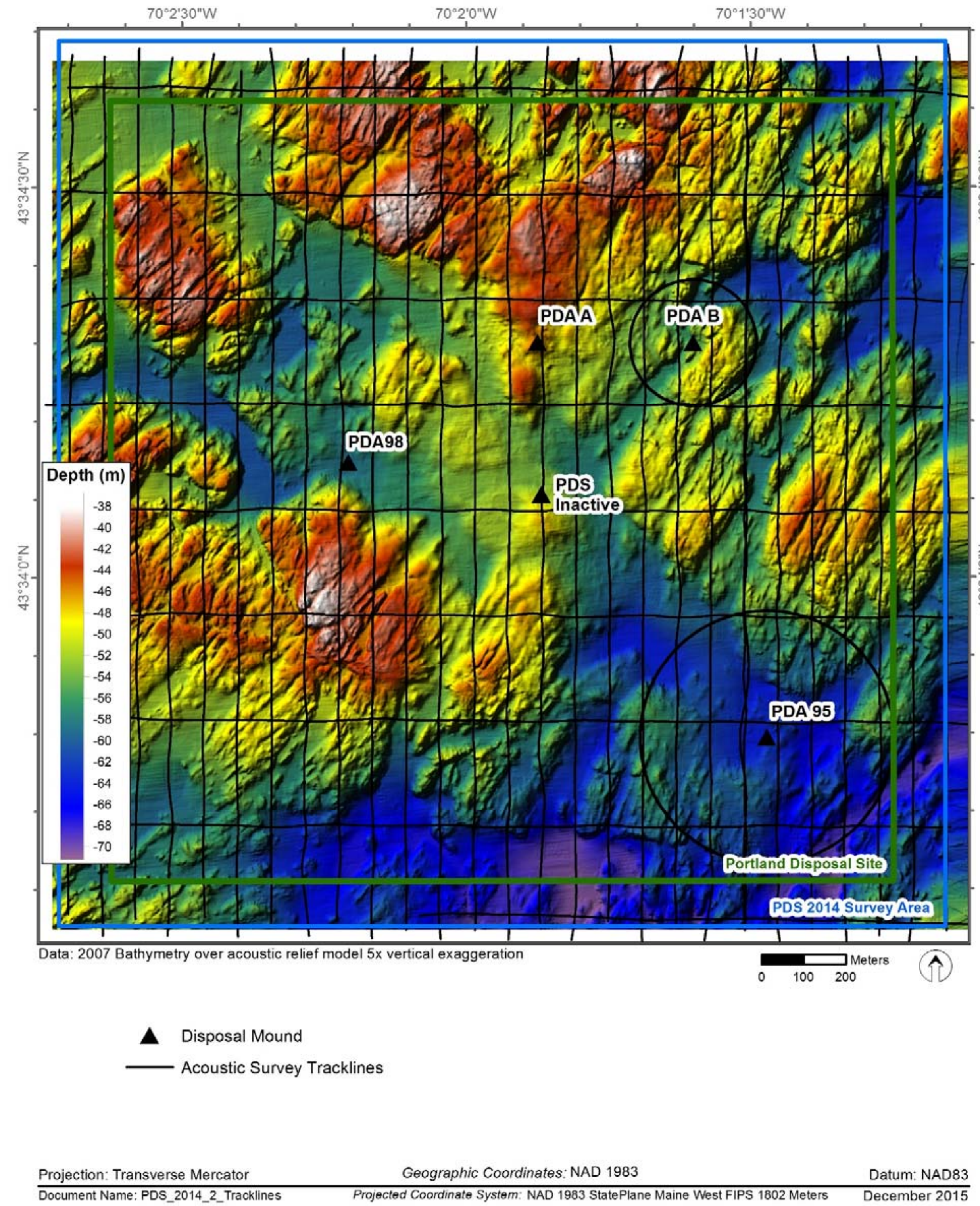


Figure 2-1. PDS bathymetric survey area and tracklines

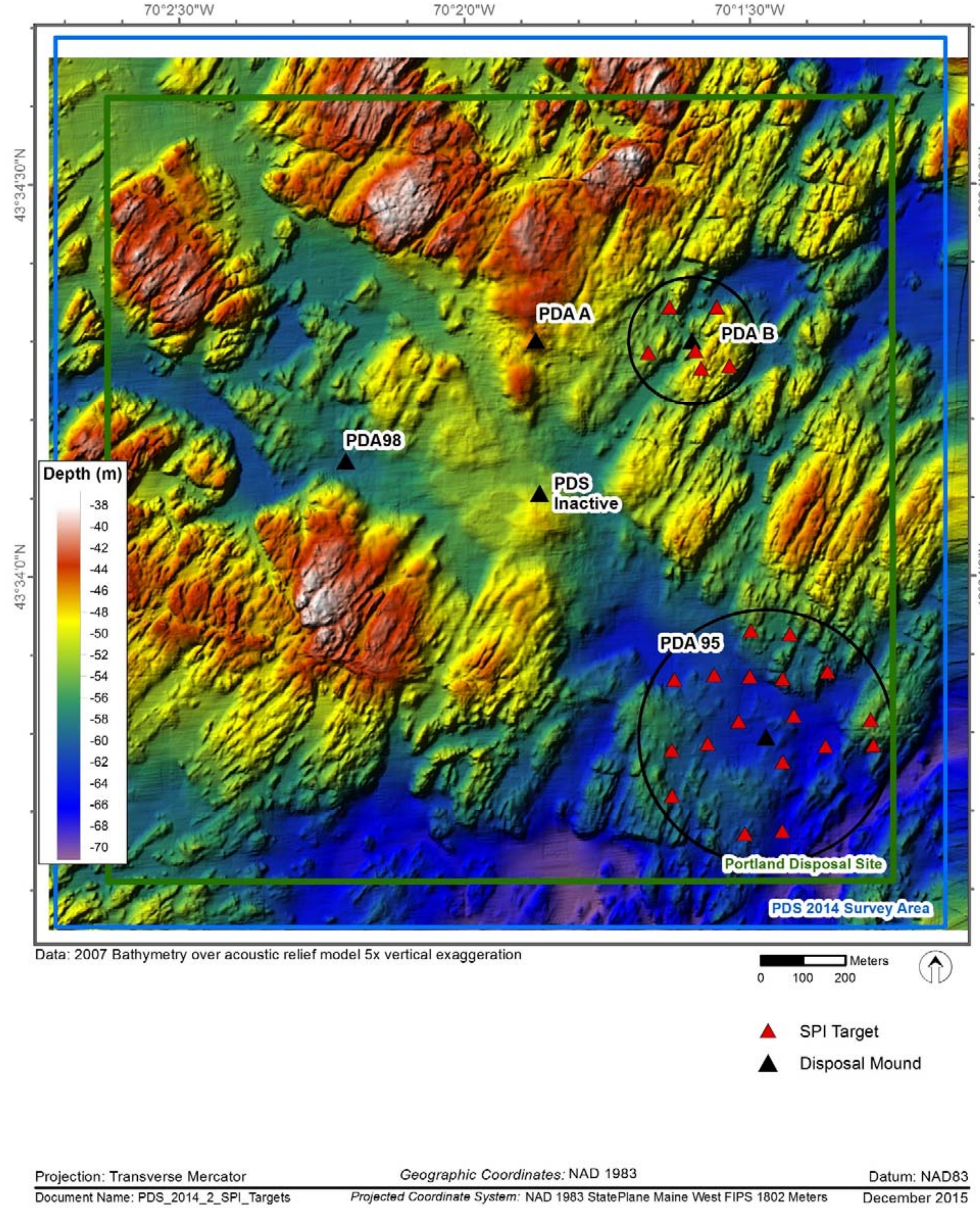


Figure 2-2. PDS disposal mounds with target SPI/PV stations indicated

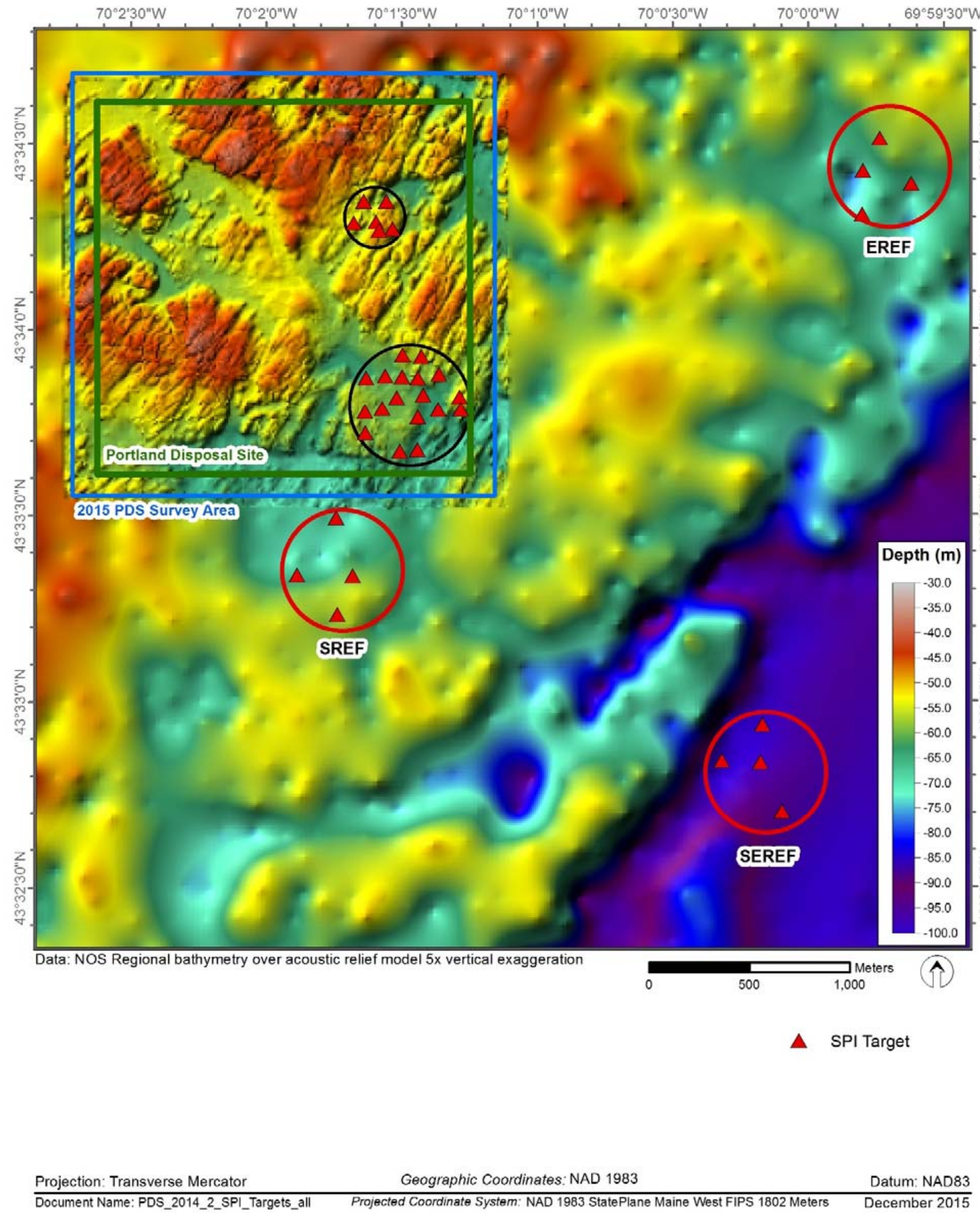


Figure 2-3. PDS reference areas with target SPI/PV stations indicated

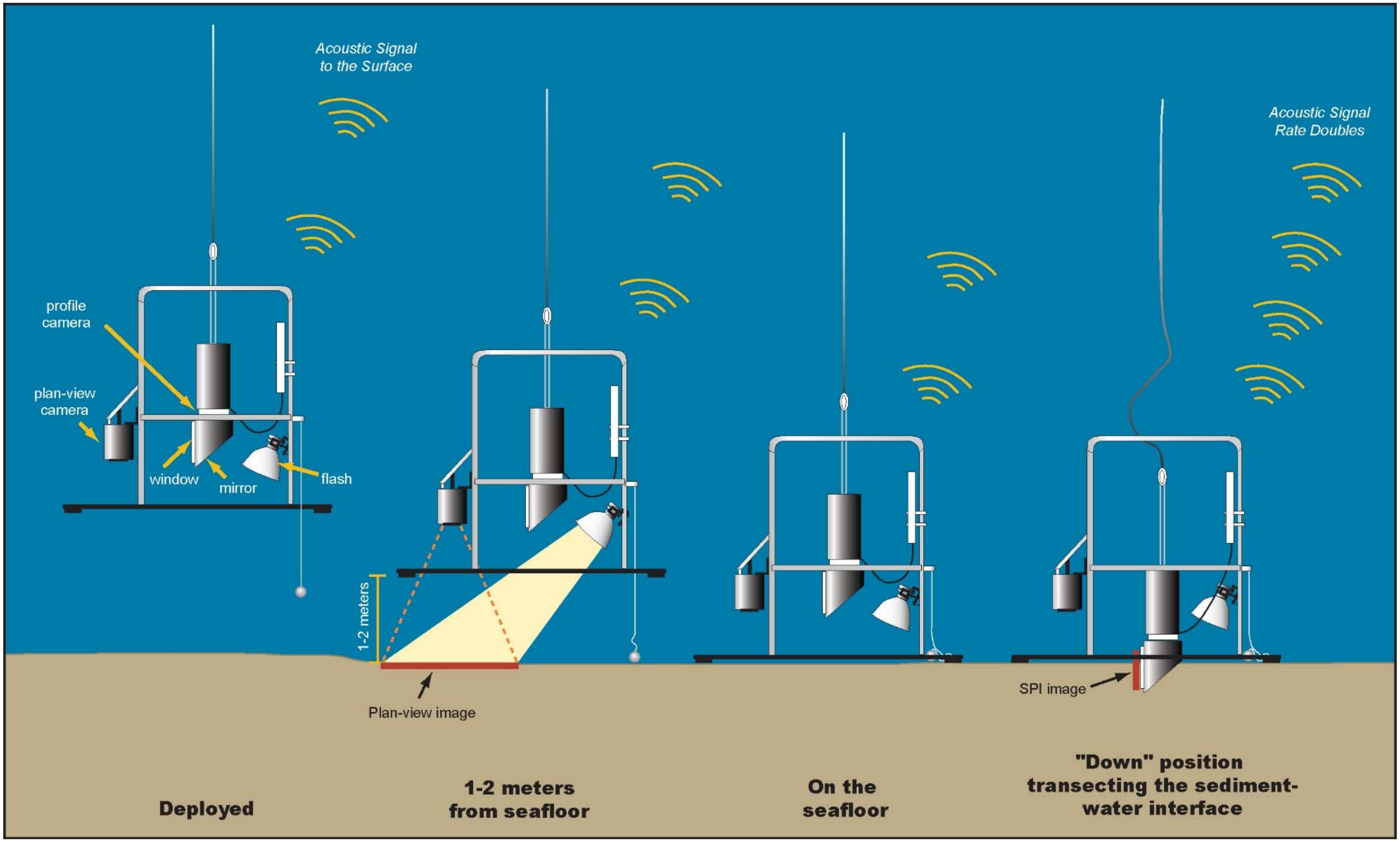


Figure 2-4. Schematic diagram of the SPI/PV camera deployment

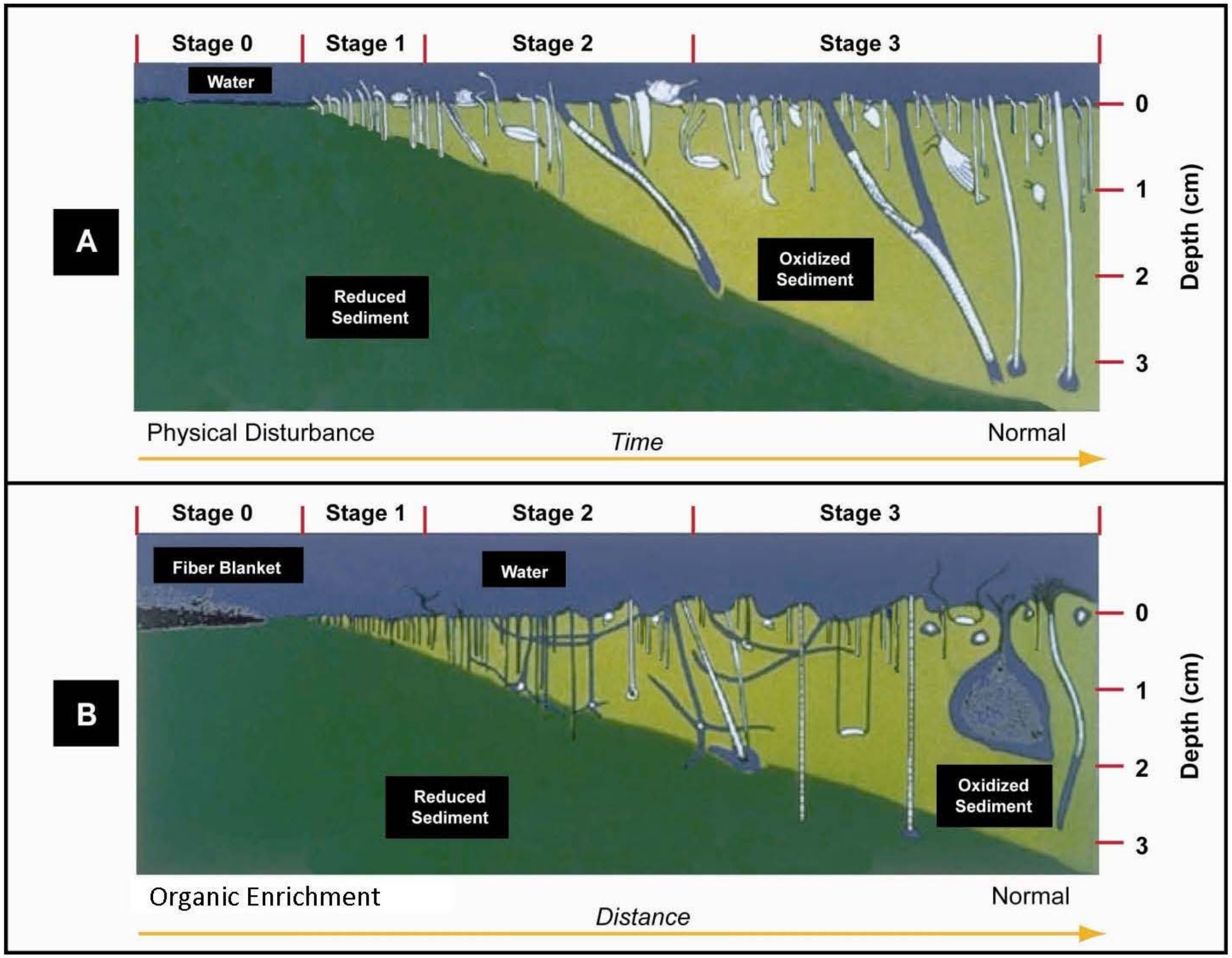


Figure 2-5. The stages of infaunal succession as a response of soft-bottom benthic communities to (A) physical disturbance or (B) organic enrichment; from Rhoads and Germano (1982)

3.0 RESULTS

3.1 Existing Bathymetry

The bathymetry of PDS as surveyed in August 2014 indicated a highly irregular bottom topography, with a prominent northwest-southeast trending trough that bifurcated in the center of the site into two parallel troughs to the northwest (Figure 3-1). Water depths at the site ranged from approximately 37 m to 73 m. (Figure 3-1). The site is dominated by bedrock outcrops (ledges) with a strong northeast-southwest fracture pattern and several apparent east-west dikes (Barnhardt et al. 1996). The deeper areas of the site (in basins between rock outcrops) were smooth, but the central trough had irregular relief in the areas that have received dredged material.

Multibeam bathymetric data rendered as a depth-scaled acoustic relief model (color scale with hillshading) provided a more detailed representation of the site topography (Figure 3-2). Patterns consistent with placement of dredged material were visible as raised isolated mounds with circular impact features or as a smoothed surface compared to adjacent rock. The central portion of the site had a mound (PDS Inactive) with an irregular surface and depths from 48 m to 59 m. The northwest side of this PDS Inactive mound had two large circular features (~60-70 m in diameter) with a scalloped outline and the southeast side had numerous circular impact features. The southeast corner had an area at PDA 95 with smoothed rock surfaces at 60 m depth (Figure 3-2).

3.1.1 Acoustic Backscatter and Side-Scan Sonar

Unfiltered backscatter imagery of the disposal site revealed several areas throughout the site with patterns of dredged material disposal. Each of these areas was associated with weaker backscatter returns (Figure 3-3). Strong backscatter returns with sharp outlines that were consistent with rock or coarse grain sediments were evident on the rock outcrops (light areas in Figure 3-3). Weaker returns were found in the trough and some basins indicating finer-grained sediment typical of both the dredged material placed at PDS and ambient sediment deposited in basins (dark areas in Figure 3-3). At PDA 95 a pattern of very weak backscatter matched the recent placement activity. One distinct area of smooth returns slightly weaker than the surrounding rock was seen in the vicinity of the PDA A mound, but the mound was not distinct. A curved line of four circular deposits with elevated backscatter was observed just north of the Inactive PDS mound (Figure 3-3).

Filtered backscatter, which presents a quantitative assessment of surface characteristics independent of slope effects, showed that the strongest backscatter returns (-39 to -28 dB) occurred along the rock platforms (ledge outcrops, Figure 3-4). The weakest backscatter returns (-56 to -50 dB) were measured in the deepest basins (Figure 3-4). Some elevated backscatter was seen at the Inactive PDS mound compared to other parts of the trough, and the four circular patterns (-38 to -30 dB) were also distinct.

Side-scan sonar results also provide a clear representation of disposal activity over the central and eastern portions of the site. Side-scan results confirmed observations from the backscatter results, but with additional detail (Figure 3-5). The side-scan sonar results have a higher resolution and are more responsive to minor surface textural features and slope than backscatter results. Details of rock surfaces were more apparent in the detailed images from side-scan sonar results (Figure 3-6).

3.1.2 Comparison with Previous Bathymetry and Backscatter

The bathymetric results in August 2014 were consistent with earlier survey results for PDS (Table 1-1, SAIC 2002, AECOM 2009). A depth difference comparison between depths measured in 2007 and 2014 demonstrated that dredged material accumulated at the PDA 95 and PDA A mounds with no net change in the rest of the site (Figure 3-7).

Comparison of filtered backscatter results revealed that large areas of the trough surrounding PDA 95 had weaker returns in 2015 than they did in 2007 whereas the rock outcrops had harder returns (Figure 3-8).

3.2 Sediment-Profile and Plan-View Imaging

The following sections summarize the results for the reference areas (EREF, SREF, and SEREF) and for each of the disposal mounds surveyed (PDA 95 and PDA B). Detailed SPI and PV image analysis results are provided in Appendix D. Comparisons between reference areas and disposal mounds, as well as to the survey from 2007 is also provided below. Key ecological measures (aRPD and successional stage) were also evaluated for statistical equivalence between reference and disposal areas sampled during the 2014 survey effort. All locations were surveyed on the 17 of August 2014. Replicate stations for SPI and PV images were collected at the disposal mound and reference area (Figures 2-2 and 2-3). The area of seafloor captured in the PV images ranged from 2.1 to 3.0 m^2.

3.2.1 Reference Area Stations

<u>Physical Sediment Characteristics</u>

The majority of all three reference areas were characterized by relatively soft mud (silt/clay), with most stations having a grain size major mode of >4 phi and mean camera prism penetration depths for the reference areas of 12 cm (Table 3-1, Figures 3-9, 3-10, and 3-11). One station at EREF (Station 1) was indeterminate due to rock but all other replicates contained ambient sediments. There was no evidence of dredged material at any of the stations sampled in the reference areas, and no evidence of low dissolved oxygen (DO) or sedimentary methane (Figure 3-11).

Mean replicate camera prism penetration values among the reference area stations ranged from 0.0 to 20.4 cm (Table 3-1, Figure 3-10). All stations at SEREF were softer than each of the other reference locations with deeper average penetration depths (Figure 3-11) and an overall average penetration depth of 16.6 cm, compared to 9.3 cm at SREF and 10.1

cm at EREF (Table 3-1). The SEREF area is located in deeper waters (mean depths of 97 m) than the SREF and EREF areas (mean depths of 63 and 65 m, respectively). Each of the EREF and SREF areas had at least one station averaging less than 10 cm for camera penetration depth (Table 3-1, Figure 3-10), indicating coarser and/or more compact sediment grains.

Means of replicate small-scale boundary roughness ranged from 0.7 to 2.0 cm at the reference stations (Table 3-1, Figure 3-12); all of this small-scale topography can be attributed to the surface and sub-surface activity of benthic organisms evidenced as small burrowing openings, pits, mounds, etc. (Figure 3-13). Mean boundary roughness was slightly lower at SEREF, 1.0 cm, compared to 1.2 cm at both EREF and SREF (Table 3-1, Figure 3-12); this distinction did not appear to result from any systematic difference in reference areas. PV images support the SPI findings; in all images that could be classified the sediment was identified as fine sand with no bedforms resulting from sediment transport. SEREF had a distinctive layered appearance indicating the active depositional nature of the location (Figure 3-14).

Biological Conditions

The means of replicate aRPD depths ranged from 1.2 to 1.9 cm (Table 3-1, Figures 3-15) and averaged 1.5 cm across all reference area stations. The mean aRPD depths were shallowest at SREF (1.2 cm) and were deepest at EREF at 1.9 cm. Despite the somewhat softer sediment and higher boundary roughness values at SEREF, the aRPD depth did not differ discernibly from the other reference areas (Table 3-1).

Stage 3 infauna were present across all three reference areas. Most images were classified as Stage 3 or Stage 1 on 3 (Table 3-1, Figure 3-16). Evidence for the presence of Stage 3 fauna included large-bodied infauna, deep subsurface burrows, and/or deep feeding voids; opportunistic Stage 1 taxa were indicated by the presence of small tubes at the sediment-water interface (Figure 3-17). There were also numerous occurrences of Stage 2 on 3 successional designation. These instances occurred primarily at SEREF where a majority of the stations had Stage 2 on 3 (Table 3-1, Figure 3-18). Stage 2 on 3 was not observed at EREF, and was observed in only one image at SREF. Stage 2 fauna are smaller than Stage 3 taxa and are active in the zone 2 - 4 cm below the sediment surface, they can coexist with the larger, deep feeding Stage 3 organisms. The number of subsurface feeding voids, indicating Stage 3 fauna, ranged from 0 to 3 across all reference stations, and the mean number of voids per reference station ranged from 0.7 to 1.0 (Table 3-1).

Further indications of subsurface faunal activity from Stage 2 and 3 taxa are seen in the PV images as the presence of burrows, ranging from sparse at SEREF to present at all three reference areas (Figure 3-13). The presence of tubes ranged from present to abundant at all three reference areas. Tracks across the seafloor often created by epifauna (crabs, gastropods) were seen at all the reference areas (Figure 3-13). The presence of fish was noted in a few images. Additionally, shell fragments were seen in PV images at SEREF and

EREF, but none were observed at SREF. No flora were present in the PV images across reference areas (Appendix D).

3.2.2 Disposal Site Stations

3.2.2.1 Physical Sediment Characteristics

PDA B and PDA 95 occupied slightly overlapping depth ranges with PDA B located over a narrow cleft in an outcrop and PDA 95 on a large flat area. PDA B stations had a mean depth of 51 m and ranged from 48 to 55 m, and PDA 95 stations had a mean depth of 60 m and ranged from 52 to 65 m (Table 3-2). Sediments at both mounds were generally soft very fine, sandy silt/clay, with most stations having a grain size major mode of 4 to 3 phi (Table 3-2, Figure 3-19). A majority of the stations at PDA B and PDA 95 had a thin layer of medium to fine sand overlaying this very fine silt/clay (Table 3-2, Figure 3-20). Mean camera prism penetration values were deeper at PDA 95 at 15.7 cm compared to PDA B at 9.8 cm. Mean replicate camera prism penetration values ranged from 9.8 to 21.4 cm at PDA 95, and 0.0 to 16.0 cm at PDA B (Table 3-2, Figure 3-21). All stations at PDA B exhibited dredged material within the silt/clay portion of the sediment (Figure 3-22) with instances of the presence of dredged material extending below the camera penetration depth. Stations closest to the disposal mound at PDA 95 exhibited dredged material, and those stations furthest away were not documented to have dredged material (Appendix D). There was no evidence of low DO or sedimentary methane at either disposal mound.

The two mounds were similar in small-scale boundary roughness values, with means of 1.3 cm at PDA 95 and 1.7 at PDA B. Means of replicate small-scale boundary roughness ranged from 0.5 to 3.9 cm at PDA 95 and 0.7 to 3.0 cm at PDA B (Table 3-2, Figure 3-23); 100% of this small-scale topography can be attributed to the surface and sub-surface activity of benthic organisms evidenced as small burrowing openings, and pits, etc. (Figure 3-24 and 3-25). PV images support the SPI findings; in all images that could be classified the sediment was identified as oxidized with no bedforms resulting from physical disturbance.

3.2.2.2 Biological Conditions

The mean of replicate aRPD depths ranged from 0.8 to 2.1 cm at PDA 95 and from 1.7 to 2.3 cm at PDA B (Table 3-2, Figure 3-26). All stations at PDA B averaged aRPD depths of over 1.6 cm, and only 17% of those at PDA 95 did (Table 3-2, Figure 3-22). Physical characteristics at both mounds were very similar; thus, difference in aRPD depth can be attributed primarily to a difference in the activity level of infaunal communities at these two locations.

Most images at PDA 95 had evidence of Stage 3 fauna, with the exceptions occurring at Stations 3, 4, 8, and 15, which were predominantly classified as Stage 1 on 2 (Table 3-2, Figures 3-27 and 3-24). Similarly, most images at PDA B had evidence of Stage 3 fauna (when they could be determined) with the lone exception occurring in one image at Station 5, which had a successional designation of Stage 1 on 2. Successional stage could not be determined at Station 4 and from two of the images at Station 3 (Table 3-2). Most images at PDA 95 and PDA B were classified as Stage 1 on 3 (Table 3-2, Figure 3-28). The mean number of subsurface feeding voids, indicating Stage 3 fauna, ranged from 0 to 2.3 across all disposal mound stations. The mean number of voids ranged from 0 to 2.0 at PDA 95 and from 0.3 to 2.3 at PDA B (Table 3-2).

PV images indicated biological activity present at both PDA 95 and PDA B. Burrows, indicating subsurface activity by Stage 2 and 3 fauna, were present and sparse to abundant, with 72% of the images at PDA 95 containing abundant burrows, and 50% of the images at PDA B (Figure 3-25). Sparse tubes were observed in PV images at PDA B and were present to abundant at several stations at PDA 95. Tracks across the seafloor, often created by epifauna (crabs, gastropods), were seen at a several stations at PDA 95. Although tracks were not observed at PDA B, at least one lobster was seen on the surface (Figure 3-25). Fish were noted in a few images at PDA 95. No flora were present in the PV images across both mounds (Appendix D).

3.2.3 Comparison to Reference Areas

3.2.3.1 Mean aRPD Variable

Area mean aRPD depths at PDA B and PDA 95 disposal areas were 2.2 and 1.6 cm, respectively, comparable to the grand mean of the reference areas (1.5 cm, Table 3-3). Area mean aRPD values in the reference areas ranged from 1.2 to 1.9 cm, and were deepest at EREF (1.9 cm compared to 1.7 and 1.2 cm at SEREF and SREF, respectively). The standard deviation among stations of aRPD depths was 0.5 cm or less at all areas (Table 3-3).

A statistical inequivalence test was performed to determine whether or not the differences observed in mean aRPD values between the three reference areas and each of the two disposal areas were significantly similar. The station mean aRPD data from all five locations were combined to assess normality and estimate pooled variance. Results for the normality test indicated that the area residuals, i.e., each observation minus the area mean, were not significantly different from a normal distribution (Shapiro-Wilk's test p-value = 0.55, with alpha = 0.05). Levene's test for equality of variances was not rejected ($p = 0.13$), so a single pooled variance estimate was used for all groups. The confidence interval for the difference equations were constructed using parametric normal equations, with equal variances.

The confidence regions for the difference between the mean of the reference areas versus PDA B disposal area, and versus PDA 95 disposal area were each contained within the interval [-1 cm, +1 cm] (Table 3-4). The conclusion was that the aRPD values from each of the two disposal areas were significantly equivalent to reference in the 2014 survey. The difference in means between reference and PDA B was -0.6 cm, and between reference and

PDA 95 was 0.01 cm, with reference areas having shallower aRPD values than PDA B and roughly equivalent to PDA 95 (Table 3-4).

3.2.3.2 Successional Stage Rank Variable

Across the reference areas and both disposal areas examined, Stage 3 fauna were consistently found, often along with Stage 1 fauna (Table 3-1, Table 3-2, Figures 3-18 and 3-28). To evaluate these successional stages numerically, a successional stage rank variable was applied to each image. A value of 3 was assigned to Stage 3, 2 on 3, or 1 on 3 designations, a value of 2 was applied to Stage 2 or 1 on 2, a value of 1 was applied to Stage 1, and images from which the stage could not be determined were excluded from calculations. The maximum successional stage rank among replicates was used to represent the station value.

The successional stage rank variable was uniformly 3 across all three reference areas and both disposal areas, with only two exceptions. Two stations from PDA 95 had successional stages that were less than Stage 3 equivalent: Station 8 had Stage 2, and Station 15 had a successional stage transitional between Stage 2 and 3. No statistics were required to conclude that PDA B successional stage was equivalent to reference (a constant Stage 3 versus a constant Stage 3). Bootstrapping was used to construct a confidence interval between the successional stage at disposal area PDA 95 and a constant Stage 3 (the reference area value).

The confidence region for the difference between the mean of the reference areas (a constant successional stage rank of 3) versus PDA 95 disposal area was [-0.03, 0.15] (Table 3-5). This interval is fully contained within the region [-0.5, +0.5] thereby indicating that the successional stage at PDA 95 was statistically equivalent to reference.

3.2.4 Temporal Comparisons

3.2.4.1 Mean aRPD Variable

Area mean aRPD depths at PDA 95 disposal area in 2007 and 2014 were 2.4 and 1.6 cm, respectively, a decrease over time of 0.8 cm. The reference areas all had lower aRPD values in 2014 compared to 2007, ranging from a 0.9 cm decrease at EREF, to a 2.3 cm decrease at SEREF (Table 3-3).

Confidence intervals for the change over time (2014 minus 2007) were calculated for disposal area PDA 95 and for each of the reference areas. The residuals within each area for the two time periods were approximately normally distributed (Shapiro-Wilks, $p > 0.05$). The residuals for SEREF failed the normality test ($p = 0.04$) due to one extreme value. However, with the small sample sizes (5 in 2007 and 4 in 2014) an extreme value can have a greater influence on bootstrapping than on the normal parametric equations. The effect of the parametric equations would be to underestimate the confidence interval; if parametric equations indicate that the temporal change is not significantly similar, then using an alternative approach would not change that conclusion. Equal variances were used for PDA 95 (Levene's test, $p > 0.05$); but small sample sizes in the reference areas resulted in the variance assessment to be based primarily on the boxplots (Figure 3-29). Equal variances were assumed for SREF, but separate variances were used for EREF and SEREF.

The 90% confidence interval for the change over time at the disposal area PDA 95 was [-1.1 cm to - 0.6 cm] (Table 3-6). The two disposal area surveys had results that were not significantly equivalent within +/- 1 cm. All of the reference areas also showed decreases in aRPD values between 2007 and 2014, with results from the two surveys that were not significantly equivalent within +/- 1 cm (Table 3-6).

Table 3-1.

Summary of PDS Reference Station Sediment-Profile Imaging Results (station means), August 2014

Mound	Station	Water Depth (m)	Grain Size Major Mode (phi)	Mean Prism Penetration Depth (cm)	Mean Boundary Roughness (cm)	Dominant Type of Boundary Roughness	Mean aRPD Depth (cm)	Mean # of Subsurface Feeding Voids	Methane Present?	Successional Stages Present		
EREF	1	65	Ind	0.0		Physical	Ind	Ind	Ind	Ind	Ind	Ind
EREF	2	75	>4	14.4	0.9	Biological	1.9	2.0	No	1 on 3	1 on 3	3
EREF	3	79	>4	16.2	0.7	Biological	1.8	0.0	No	1 on 3	1 on 3	1 on 3
EREF	4	72	>4	9.6	2.0	Biological	1.9	0.0	No	1 on 3	1 on 3	Ind
	Max	79			2		2	2				
EREF	**Min**	65			1		2	0				
	Mean	**73**		**10.1**	**1.2**		**1.9**	**0.7**				
SREF	5	69	>4	4.1	0.7	Biological	0.8	0.0	No	1 on 3	Ind	Ind
SREF	6	73	>4	19.0	1.2	Biological	1.0	1.3	No	1 on 3	1 on 3	1 on 3
SREF	7	73	>4	7.7	1.6	Biological	1.9	4.0	No	1 on 3	3	Ind
SREF	8	68	>4	6.1	1.2	Biological	1.1	0.0	No	2 on 3	3	Ind
	Max	73		19	2		2	4				
SREF	**Min**	68		4	1		1	0				
	Mean	**71**		**9.3**	**1.2**		**1.2**	**1.3**				
SEREF	9	99	>4	16.7	1.4	Biological	1.7	1.7	No	1 on 3	2 on 3	2 on 3
SEREF	10	92	>4	17.2	1.0	Biological	1.8	0.7	No	2 on 3	2 on 3	3
SEREF	11	102	>4	20.4	0.8	Biological	1.7	1.0	No	3	3	3
SEREF	12	102	>4	12.1	1.1	Biological	1.4	0.7	No	2 on 3	2 on 3	3
	Max	102		20	1		1	2				
SEREF	**Min**	92		12	1		1	1				
	Mean	**99**		**16.6**	**1.0**		**1.7**	**1.0**				
ALL	**Max**	**102**		**20.4**	**2.0**		**1.9**	**4.0**				
REF	**Min**	**65**		**0.0**	**0.7**		**0.8**	**0.0**				
AREAS	**Mean**	**81**		**12.0**	**1.1**		**1.5**	**1.0**				

Ind = Indeterminate

a Grain Size: "/" indicates layer of one phi size range over another (see Appendix D)

b Successional Stage: "on" indicates one Stage is found on top of another Stage (i.e., 1 on 3);"→" indicates one Stage is progressing to another Stage (i.e., 2→3)

Table 3-2.

Summary of PDS Disposal Areas PDA B and PDA 95 Sediment-Profile Imaging Results (station means), August 2014

Mound	Station	Water Depth (m)	Grain Size Major Mode (phi)	Mean Prism Penetration Depth (cm)	Mean Boundary Roughness (cm)	Dominant Type of Boundary Roughness	Mean aRPD Depth (cm)	Mean # of Subsurface Feeding Voids	Methane Present?	Successional Stages Present		
PDA B	1	52	>4	11.1	3.0	Biological	1.8	1.5	No	2 on 3	2 on 3	Ind
PDA B	2	53	>4	16.0	1.8	Biological	2.4	2.3	No	2 on 3	2 on 3	3
PDA B	3	55	4 to 3	15.1	0.7	Biological	2.9	0.3	No	1 on 3	1 on 3	1 on 3
PDA B	4	48	4 to 3	4.0	2.0	Biological	1.7	2.0	No	3	Ind	Ind
PDA B	5	48	Ind	0.0	Ind	Ind	Ind	Ind	Ind	Ind	Ind	Ind
PDA B	6	52	4 to 3	12.7	1.2	Biological	2.2	0.3	No	1 on 2	1 on 3	1 on 3
	Max	**55**		**16.0**	**3.0**		**2.9**	**2.3**				
PDA B	**Min**	**48**		**0.0**	**0.7**		**1.7**	**0.3**				
	Mean	**51**		**9.8**	**1.7**		**2.2**	**1.3**				

Ind = Indeterminate
a Grain Size: “/” indicates layer of one phi size range over another (see Appendix D)
b Successional Stage: “on” indicates one Stage is found on top of another Stage (i.e., 1 on 3);“→” indicates one Stage is progressing to another Stage (i.e., 2→3)

Table 3-2. (continued)

Summary of PDS Disposal Areas PDA B and PDA 95 Sediment-Profile Imaging Results (station means), August 2014

Mound	Station	Water Depth (m)	Grain Size Major Mode (phi)	Mean Prism Penetration Depth (cm)	Mean Boundary Roughness (cm)	Dominant Type of Boundary Roughness	Mean aRPD Depth (cm)	Mean # of Subsurface Feeding Voids	Methane Present?	Successional Stages Present		
PDA 95	1	59	4 to 3	21.0	3.9	Biological	0.8	1.7	No	3	3	3
PDA 95	2	59	4 to 3	13.7	1.0	Biological	1.9	1.0	No	3	3	3
PDA 95	3	56	4 to 3	15.3	0.5	Biological	1.8	0.0	No	1 on 2	2	3
PDA 95	4	62	4 to 3	17.5	1.8	Biological	1.8	0.3	No	1 on 2	1 on 2	1 on 3
PDA 95	5	65	4 to 3	13.1	2.1	Biological	1.8	0.0	No	1 on 3	1 on 3	1 on 3
PDA 95	6	59	4 to 3	17.3	0.8	Biological	1.4	1.7	No	1 on 3	1 on 3	1 on 3
PDA 95	7	61	4 to 3	12.1	0.7	Biological	1.4	0.7	No	1 on 3	1 on 3	1 on 3
PDA 95	8	62	4 to 3	12.4	1.5	Biological	1.6	0.0	No	1 on 2	1 on 2	1 on 2
PDA 95	9	65	4 to 3	14.5	0.5	Biological	1.5	0.7	No	3	3	3
PDA 95	10	63	4 to 3	14.1	1.6	Biological	1.5	0.0	No	2	1 on 3	3
PDA 95	11	61	4 to 3	16.2	0.9	Biological	1.6	0.0	No	1 on 3	1 on 3	1 on 3
PDA 95	12	58	4 to 3	19.2	1.2	Biological	1.4	1.0	No	3	3	3
PDA 95	13	65	4 to 3	12.2	0.9	Biological	1.9	0.7	No	1 on 3	1 on 3	1 on 3
PDA 95	14	59	4 to 3	18.2	1.4	Biological	1.5	0.7	No	1 on 3	3	3
PDA 95	15	61	4 to 3	15.1	1.6	Biological	1.5	0.0	No	2	2	2 -> 3
PDA 95	16	61	4 to 3	20.1	0.7	Biological	1.6	2.0	No	1 on 3	3	n/a
PDA 95	17	52	4 to 3	21.4	1.5	Biological	2.1	0.3	No	3	3	Ind
PDA 95	18	61	4 to 3	9.8	1.4	Biological	1.3	0.3	No	1 on 3	1 on 3	3
	Max	**65**		**21.4**	**3.9**		**2.1**	**2.0**				
PDA 95	**Min**	**52**		**9.8**	**0.5**		**0.8**	**0.0**				
	Mean	**60**		**15.7**	**1.3**		**1.6**	**0.6**				

Ind = Indeterminate; n/a = only 2 replicate images taken.
a Grain Size: "/" indicates layer of one phi size range over another (see Appendix D)
b Successional Stage: "on" indicates one Stage is found on top of another Stage (i.e., 1 on 3);"→" indicates one Stage is progressing to another Stage (i.e., 2→3)

Table 3-3.

Summary of Station Means by Sampling Location

Site	N[1]	Mean aRPD (cm)		Maximum Successional Stage Rank		Number of Feeding Voids		Maximum Feeding Void Depth	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean (n)[2]	Standard Deviation
2014									
Reference Areas									
EREF	4[1]	1.9	0.06	3	0	0.7	1.2	12.1 (1)	n/c
SEREF	4	1.7	0.17	3	0	1.0	0.5	10.9 (4)	3.2
SREF	4	1.2	0.50	3	0	1.3	1.9	10.2(2)	2.4
Mean		1.5		3		1.0		10.9	
Disposal Areas									
PDA B	6[1]	2.2	0.5	3	0	1.3	0.9	11.8(5)	2.6
PDA 95	18	1.6	0.3	2.9	0.3	0.6	0.6	9.7(12)	3.6
Mean		1.9		3.0		1.0		10.7	
2007									
Reference Areas									
EREF	5	2.7	0.2	3	0	0.4	0.4	4.8 (3)	2.4
SEREF	6	4.0	0.6	3	0	1.3	0.8	9.2 (5)	3.0
SREF	6	2.6	0.6	3	0	0.7	1.5	7.9 (2)	0.5
Mean		3.1		3		0.8			
Disposal Areas									
PDA 95	15	2.4	0.4	3	0	1.4	0.8	9.6 (15)	1.8

[1] Number of stations surveyed per area, including any stations which had no penetration (and indeterminate results). Useable N was 3 for EREF and 5 for PDA B.

[2] The mean among stations for the maximum feeding void depth when feeding voids were observed. The sample size (n) shown is the number of stations with one or more feeding voids observed.

Table 3-4.

Summary Statistics and Results of Inequivalence Hypothesis Testing for aRPD Values

Difference Equation	Observed Difference (d)	SE (d)	df for SE	Confidence Bounds (D_L to D_U)[1]	Results
$Mean_{REF} – Mean_{PDA\ B}$	-0.65	0.18	29	-0.95 to -0.34	s
$Mean_{REF} – Mean_{PDA\ 95}$	0.01	0.13	29	-0.21 to 0.23	s

[1] D_L and D_U as defined in [Eq. 3]
[2] s = Reject the null hypothesis of inequivalence: the two group means are significantly equivalent, within ± 1 cm.
d = Fail to reject the null hypothesis of inequivalence between the two group means, the two group means are different.

Table 3-5.

Summary Statistics and Results of Inequivalence Hypothesis Testing for Successional Stage Values

Difference Equation	**Observed Difference (d)**	**SE (d)**	***df* for SE**	**Confidence Bounds (D_L to D_U)[1]**	**Results**
$Mean_{REF} - Mean_{PDA\ B}$	0	0	12	0 to 0	s
$Mean_{REF} - Mean_{PDA\ 95}$	0.08	0.06	25	-0.03 to 0.15	s

[1] D_L and D_U as defined in [Eq. 3]
[2] s = Reject the null hypothesis of inequivalence: the two group means are significantly equivalent, within ± 1 cm.
d = Fail to reject the null hypothesis of inequivalence between the two group means, the two group means are different.

Table 3-6.

Summary Statistics and Results of Inequivalence Hypothesis Testing for Temporal Change in aRPD Values

Difference Equation	**Observed Difference (d)**	**SE (d)**	***df* for SE**	**Confidence Bounds (D_L to D_U)[1]**	**Results**
PDA 95_{2014} – PDA 95_{2007}	-0.8	0.1	31	-1.1 to -0.6	d
$EREF_{2014}$ – $EREF_{2007}$	-0.9	0.1	4.8	-1.1 to -0.7	d
$SEREF_{2014}$ – $SEREF_{2007}$	-2.3	0.3	4.7	-2.9 to -1.7	d
$SREF_{2014}$ – $SREF_{2007}$	-1.4	0.4	8	-2.0 to -0.7	d

[1] D_L and D_U as defined in [Eq. 3]
[2] s = Reject the null hypothesis of inequivalence: the two group means are significantly equivalent, within ± 1 cm.
d = Fail to reject the null hypothesis of inequivalence between the two group means, the two group means are different.

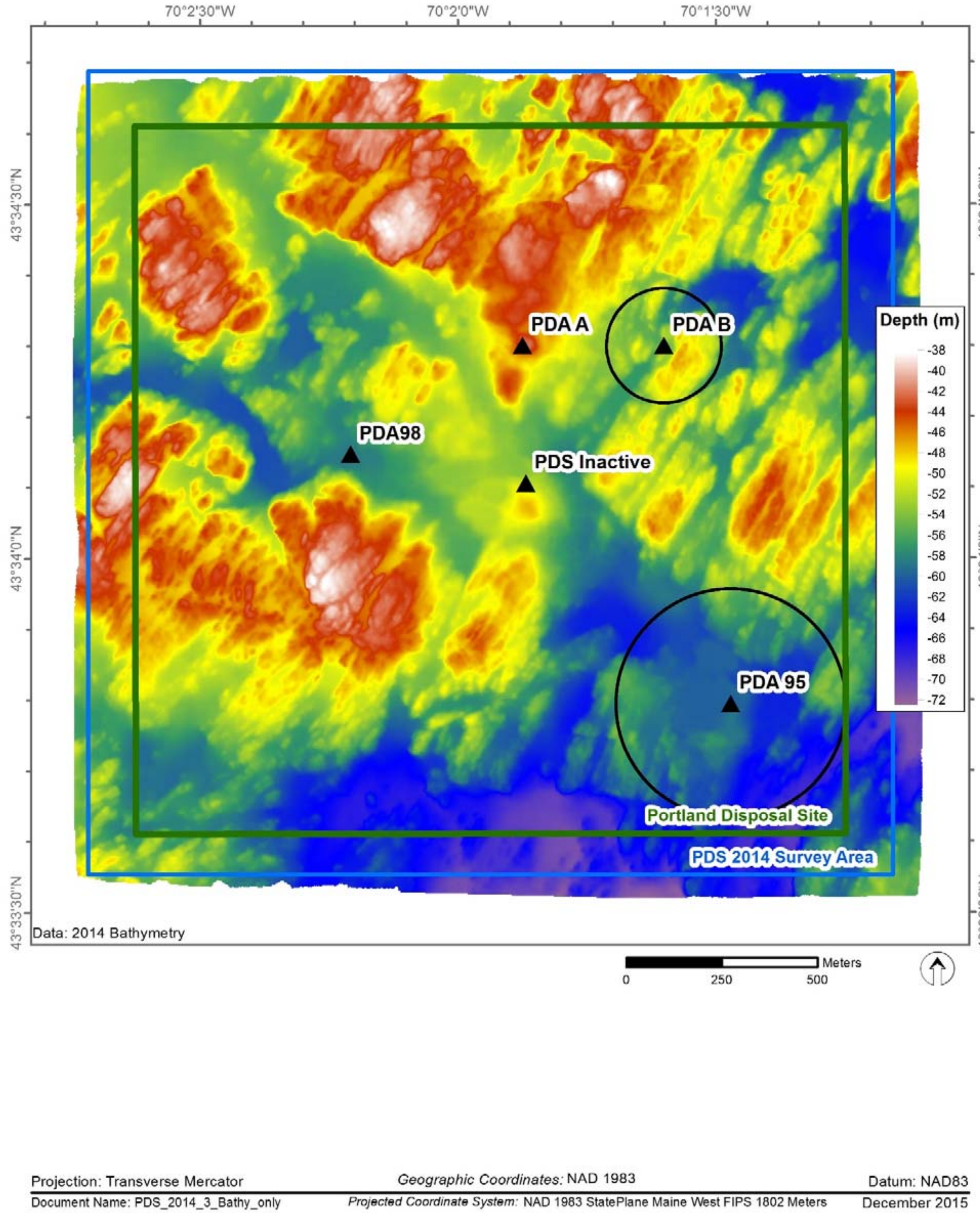


Figure 3-1. Bathymetric contour map of PDS – August 2014

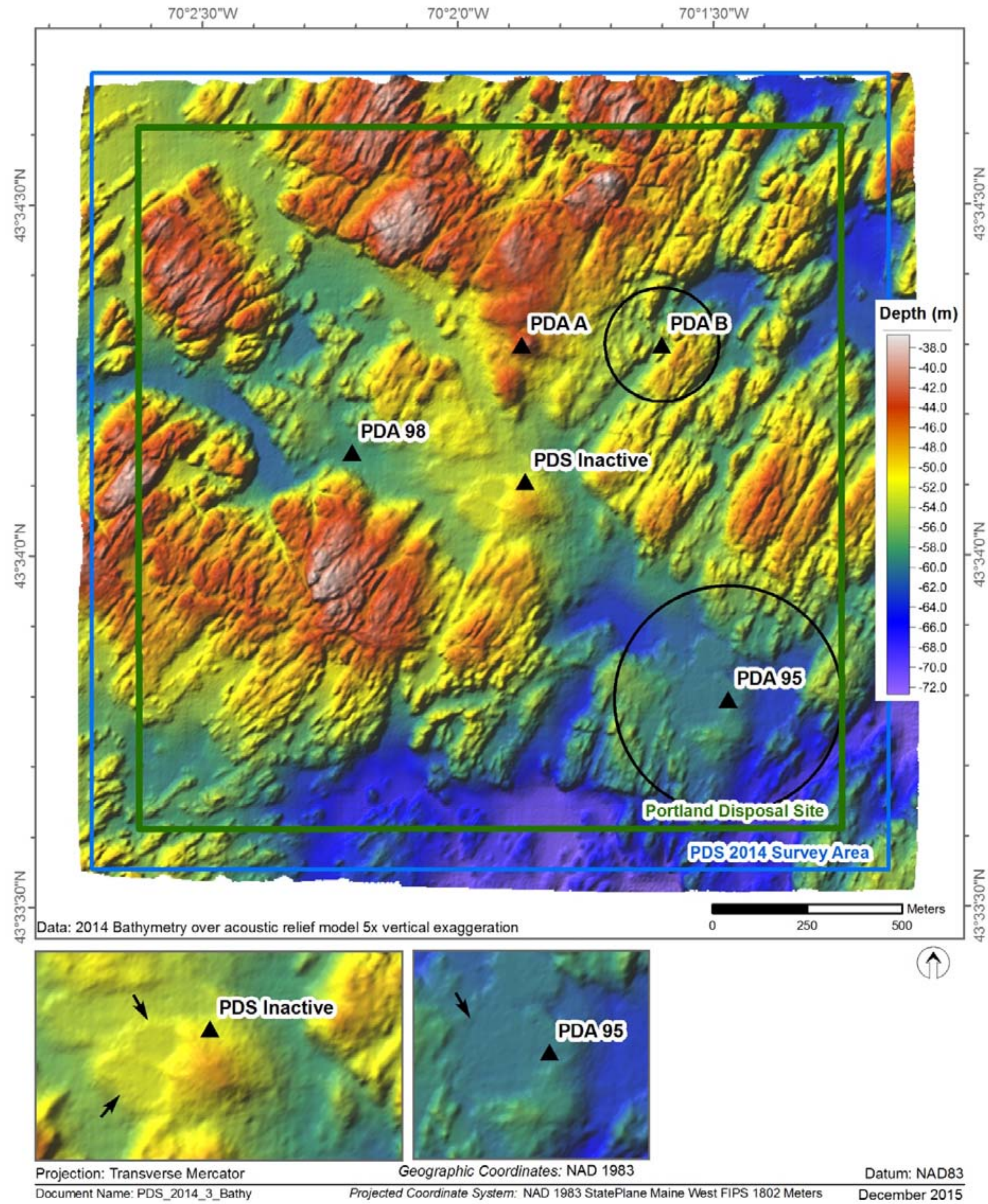


Figure 3-2. Bathymetric depth data over acoustic relief model of PDS – August 2014. In insets below figure, arrows indicate patterns consistent with placement of dredged material.

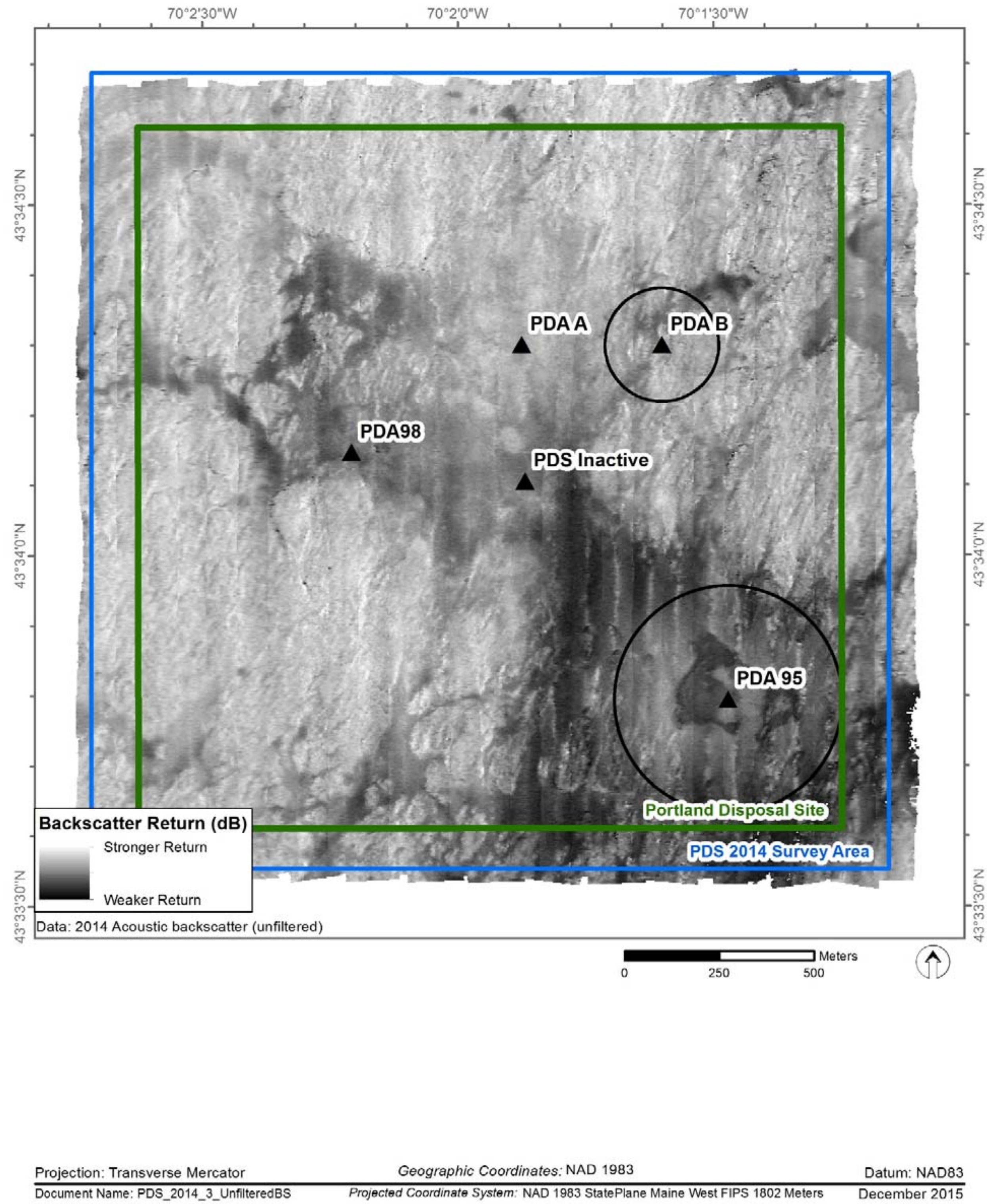


Figure 3-3. Mosaic of unfiltered backscatter data of PDS – August 2014

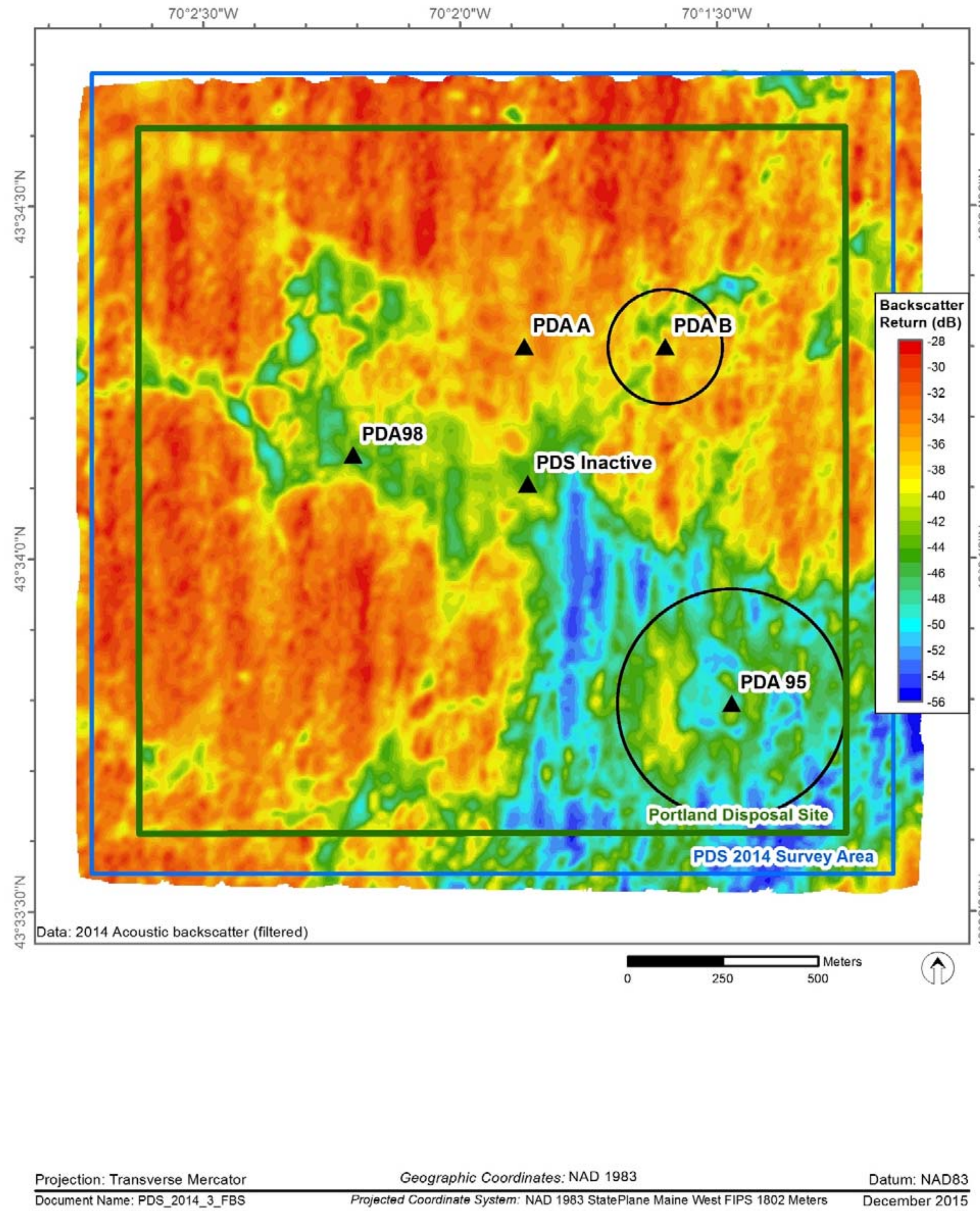


Figure 3-4. Filtered backscatter of PDS – August 2014

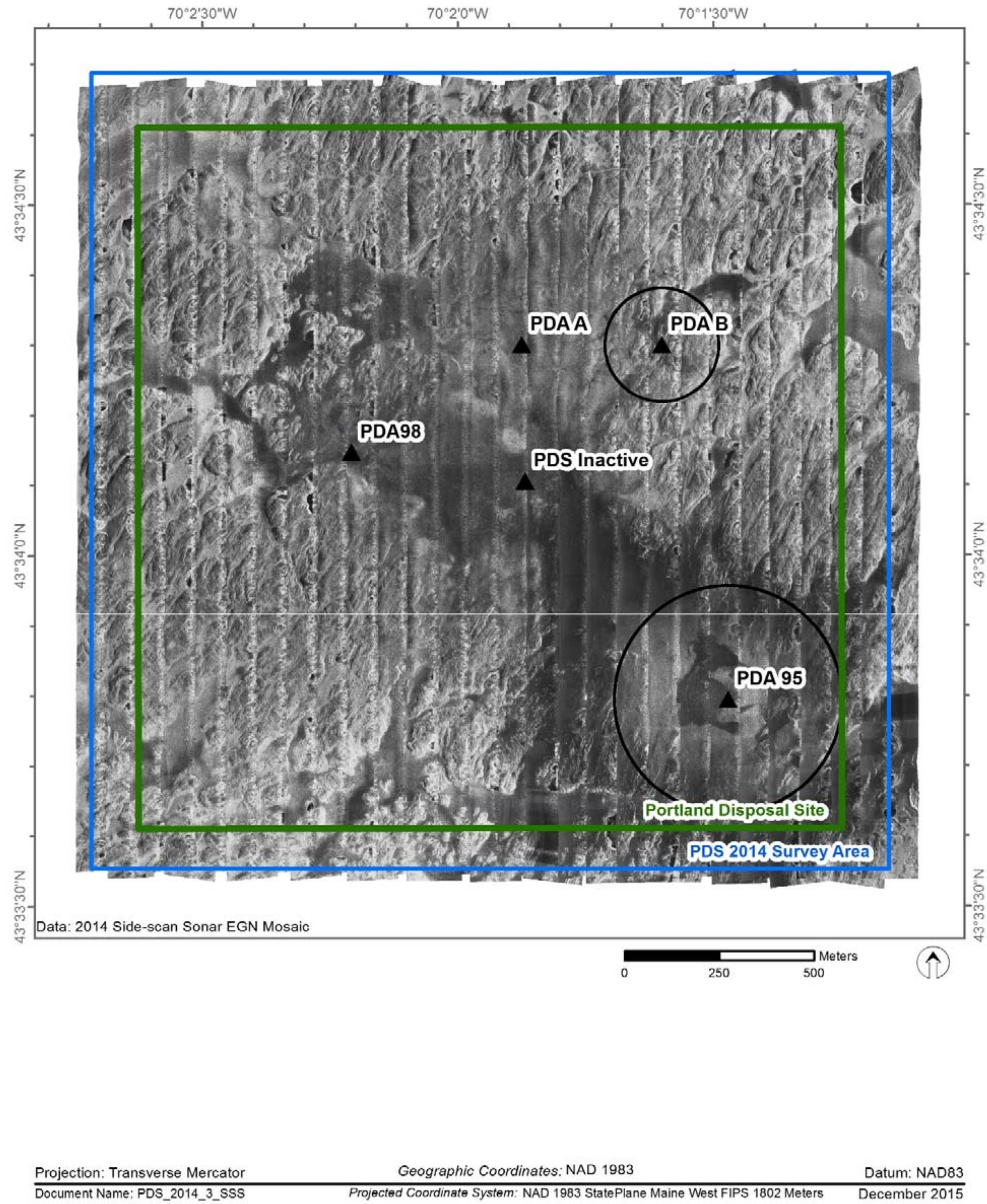


Figure 3-5. Side-scan mosaic of PDS – August 2014

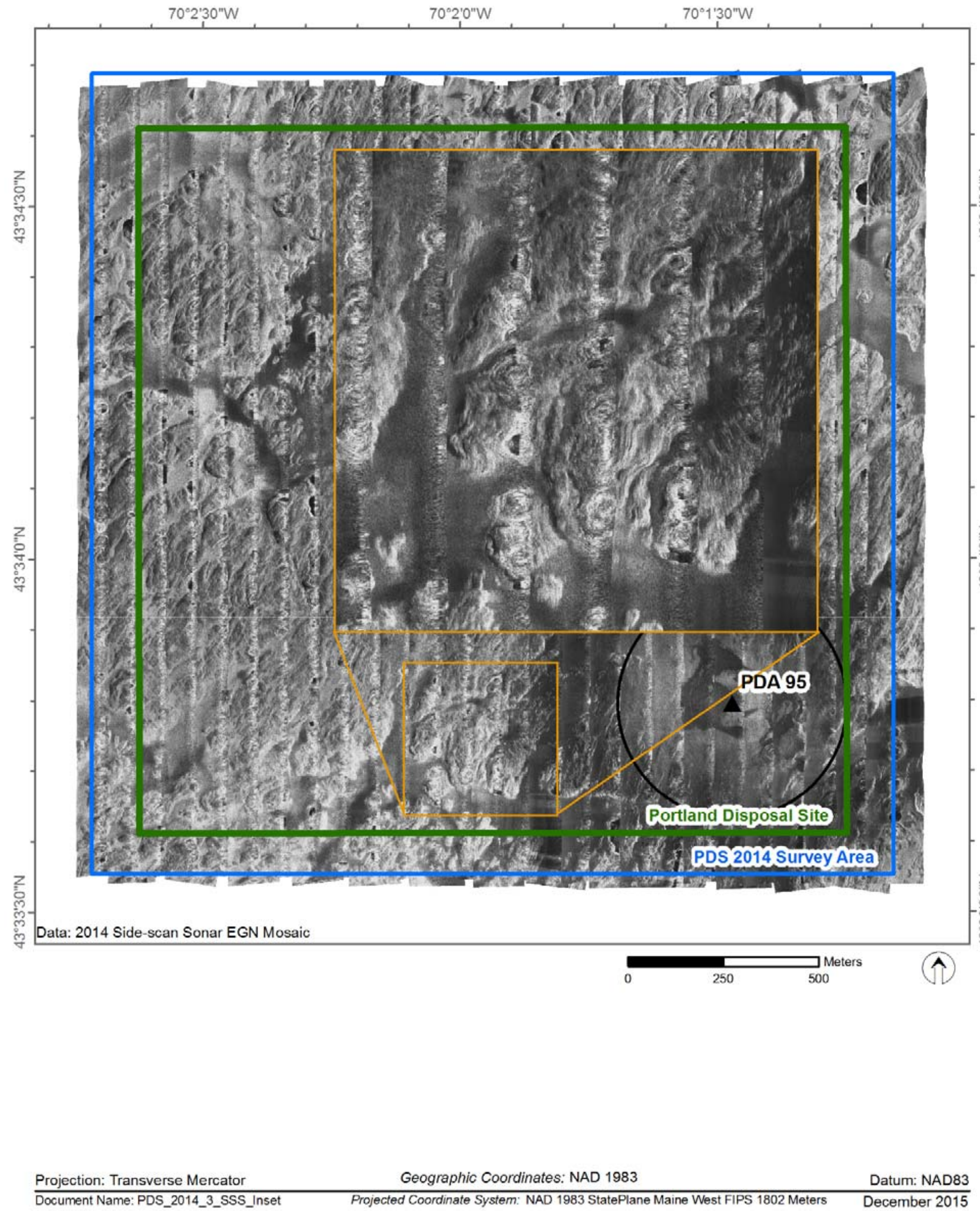


Figure 3-6. Details of small features represented in side-scan mosaic

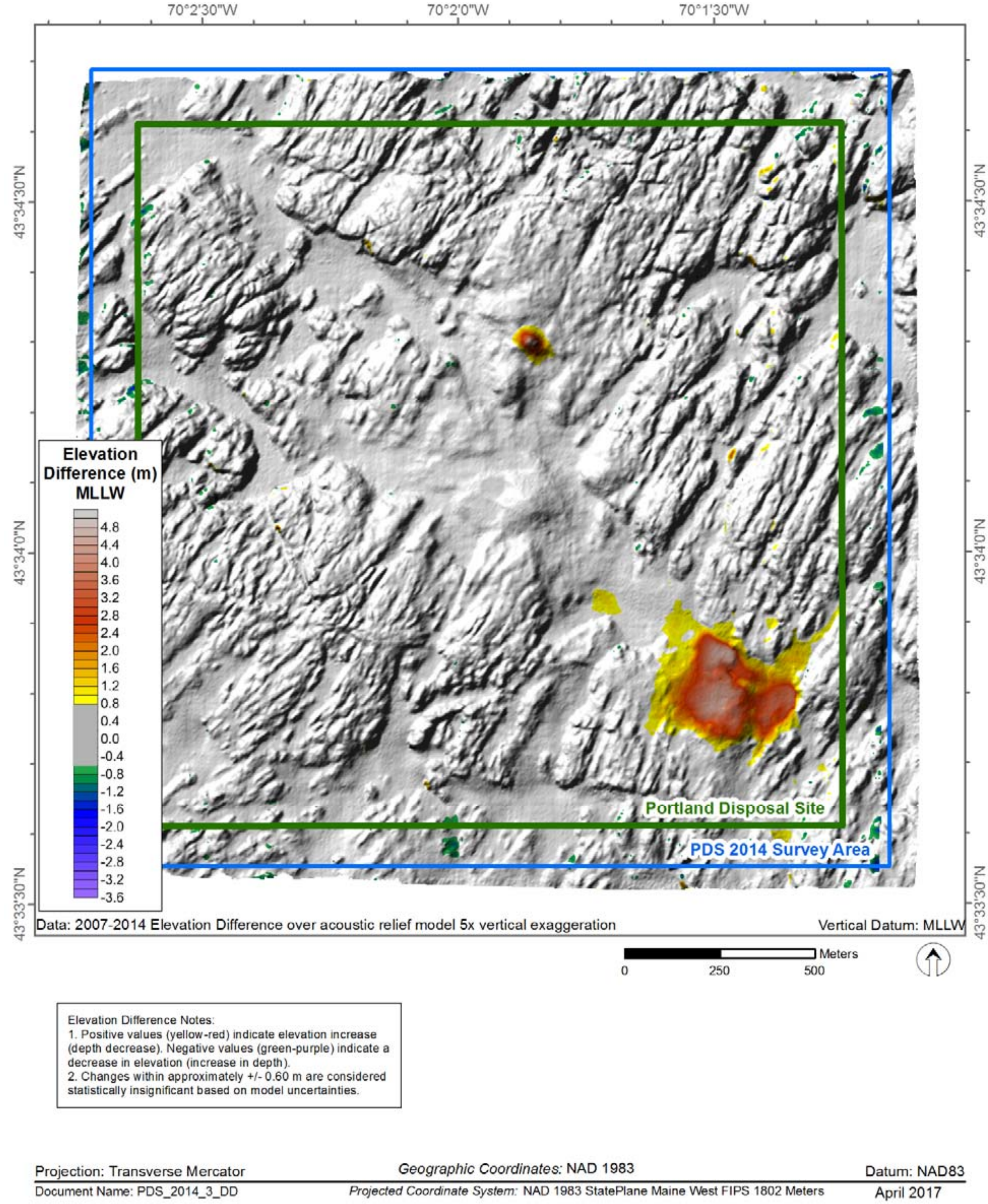


Figure 3-7. PDS depth difference: 2007 vs. 2014

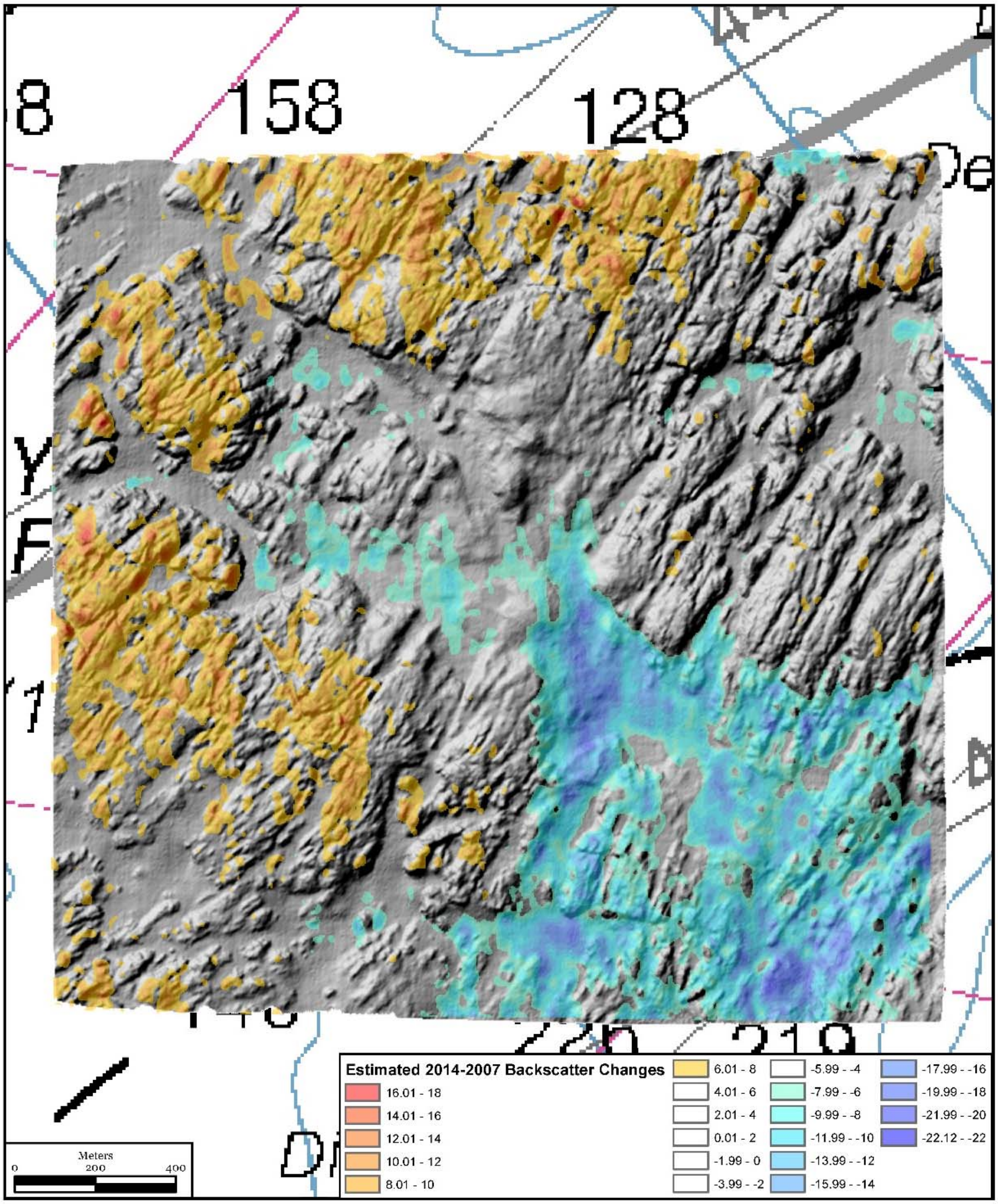


Figure 3-8. PDS estimated backscatter differences: 2007 vs. 2014

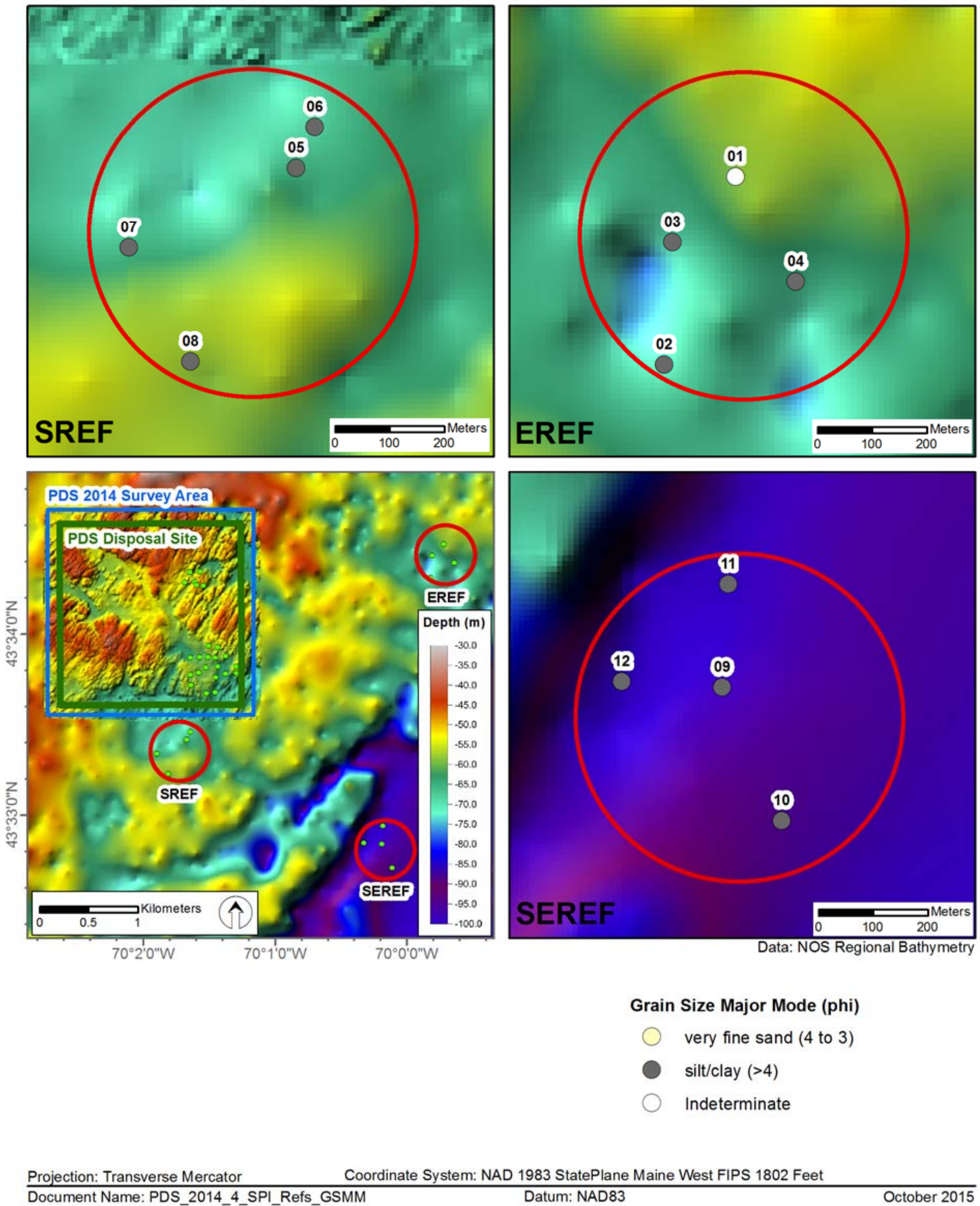


Figure 3-9. Sediment grain size major mode (phi units) at the PDS reference areas

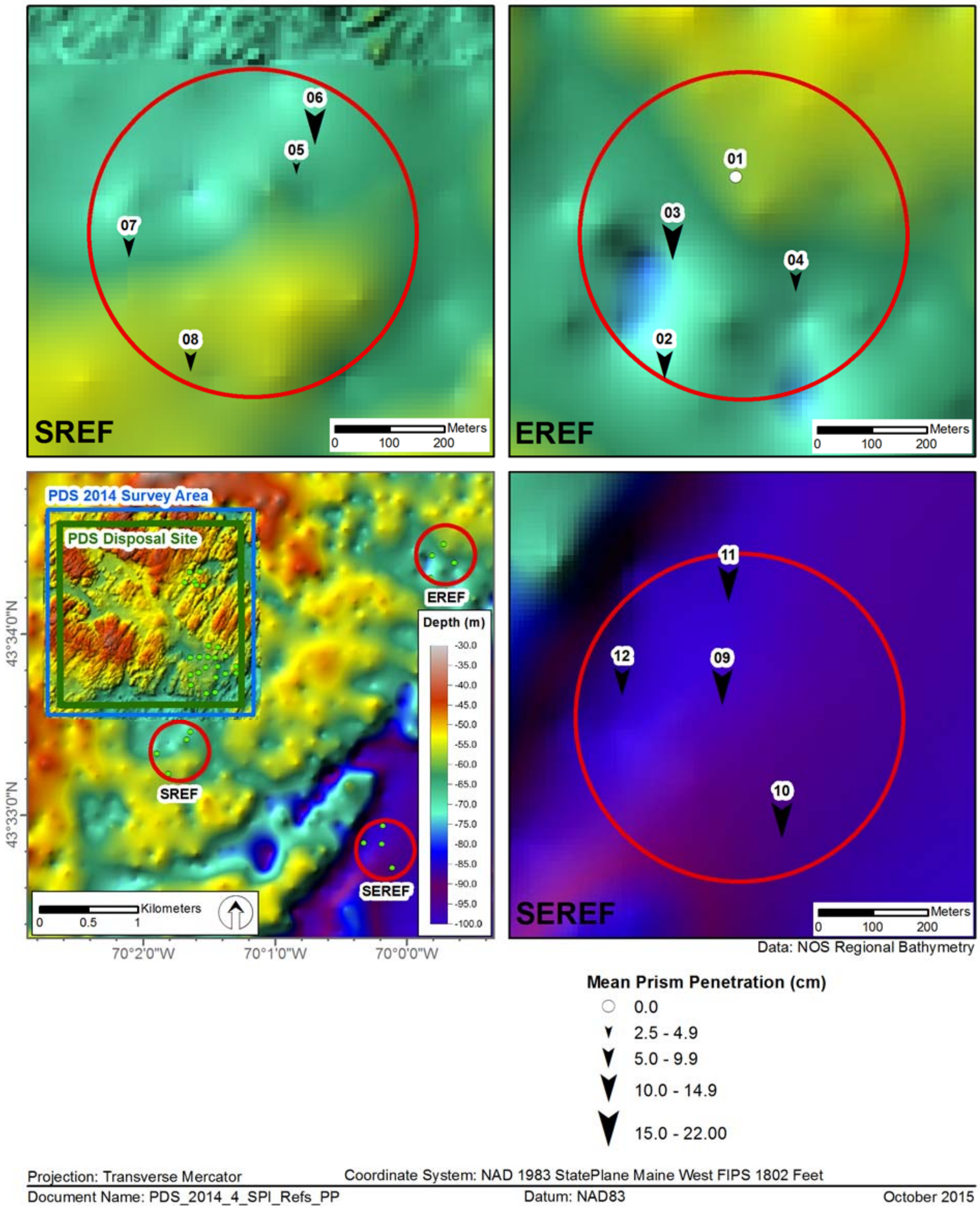


Figure 3-10. Mean station camera prism penetration depths (cm) at the PDS reference areas

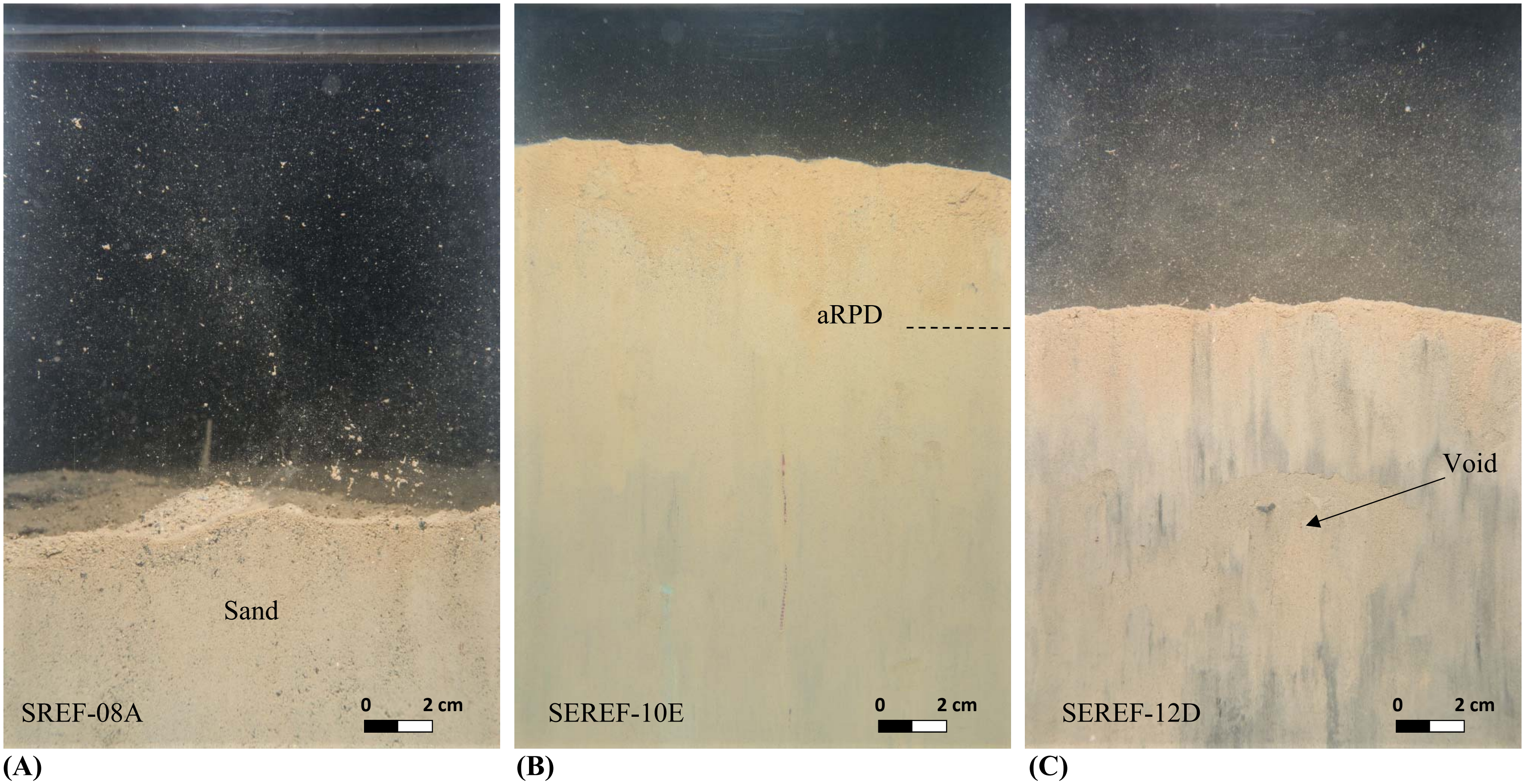


Figure 3-11. Sediment-profile images from reference areas; (A) SREF-08 with sand horizon; (B) SEREF-10 with well-developed aRPD; and (C) SEREF-12 with evidence of clay layers from slump deposits and large feeding void

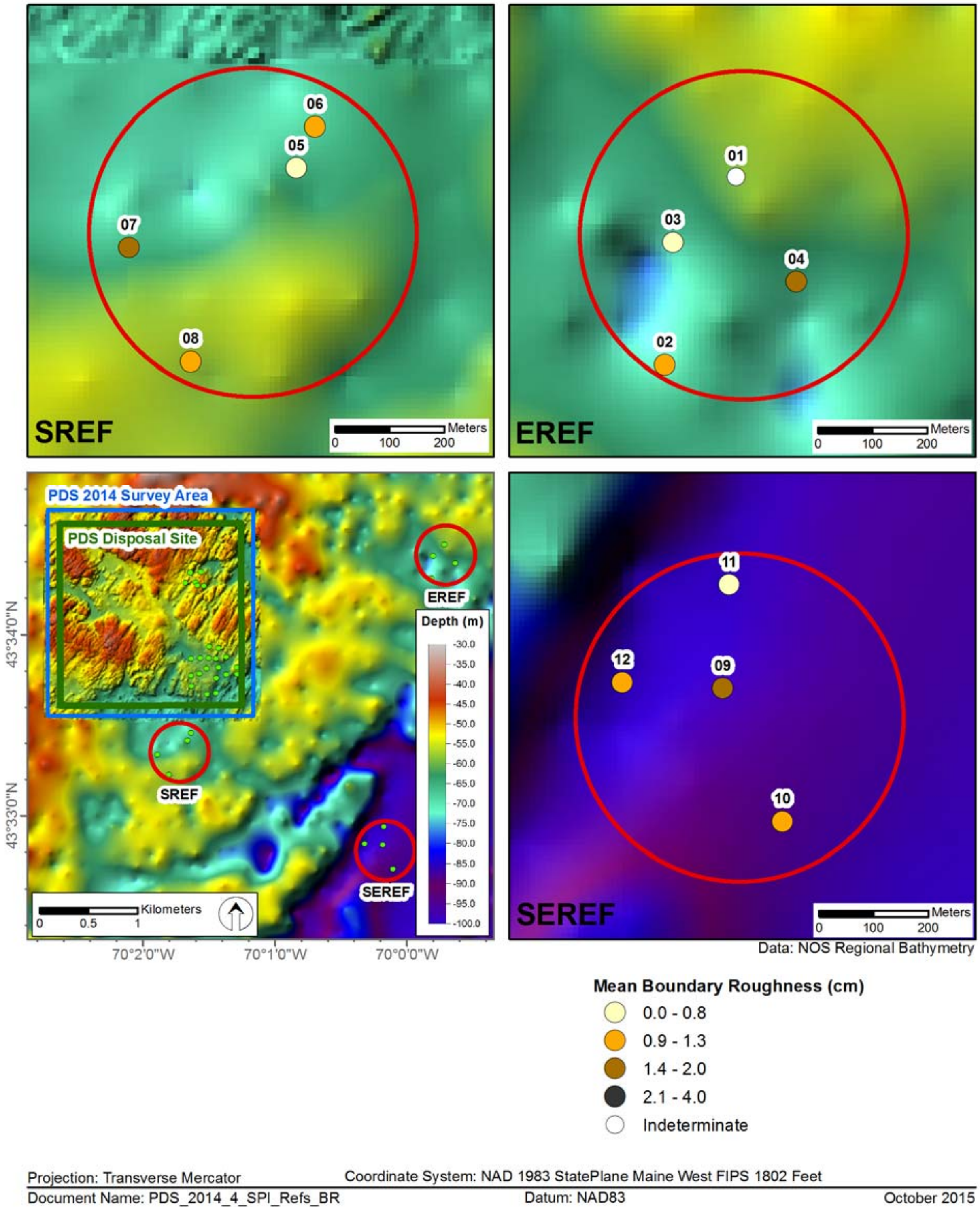


Figure 3-12. Mean station small-scale boundary roughness values (cm) at the PDS reference areas

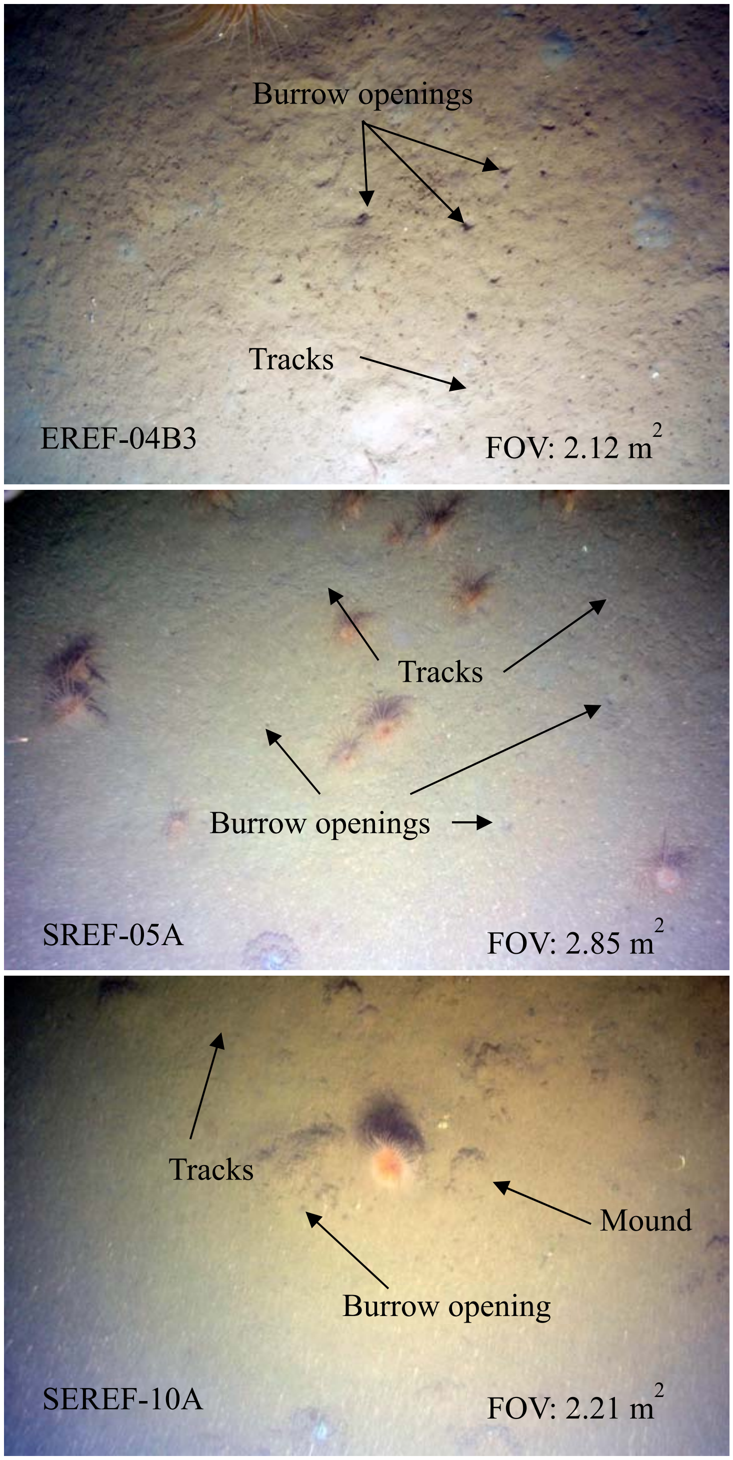


Figure 3-13. Plan-view images from the reference areas depicting small burrow openings, mounds, and tracks at (A) EREF-04; (B) SREF-05, and SEREF-10

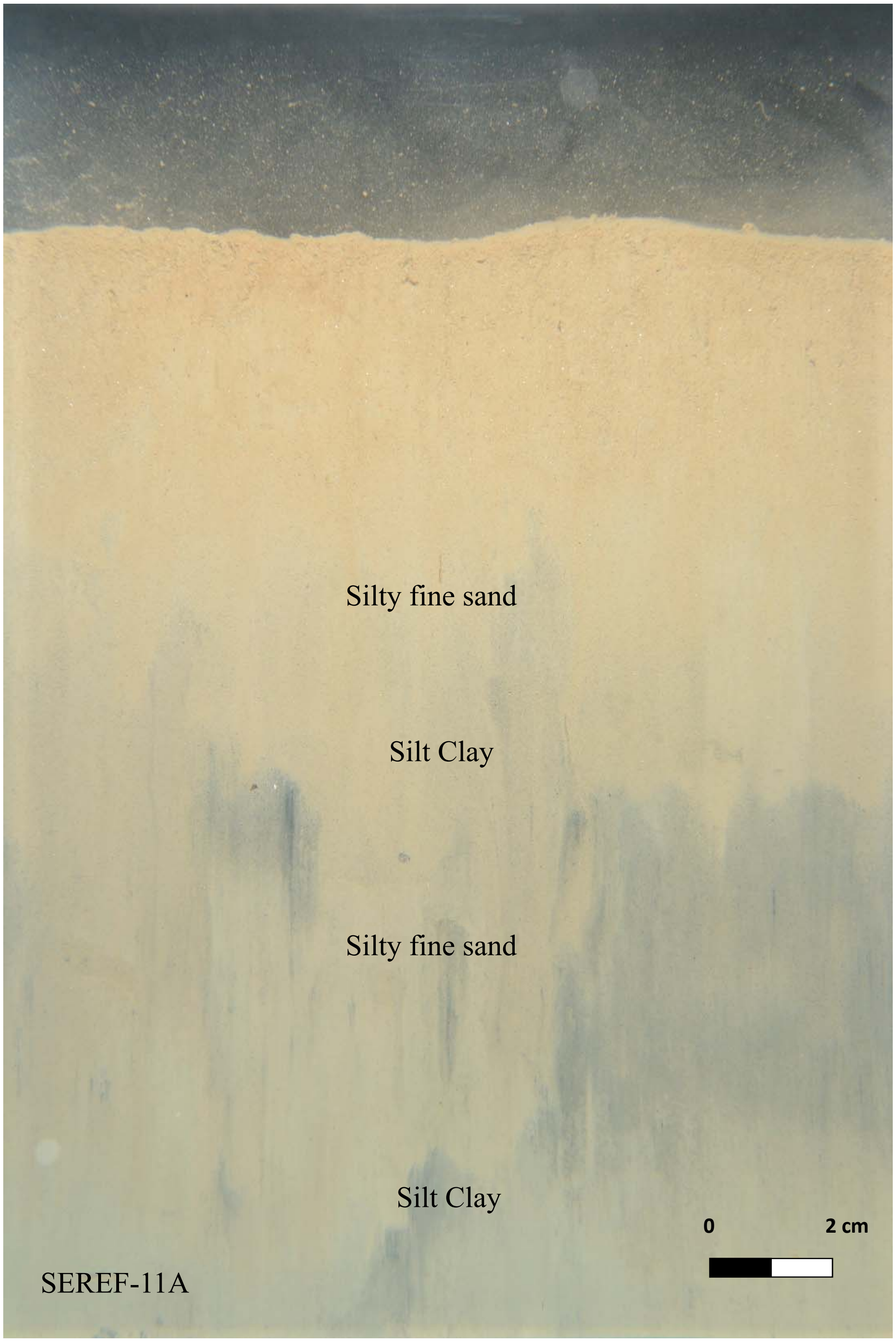


Figure 3-14. Sediment-profile image from SEREF-11 depicting sediment depositional layering

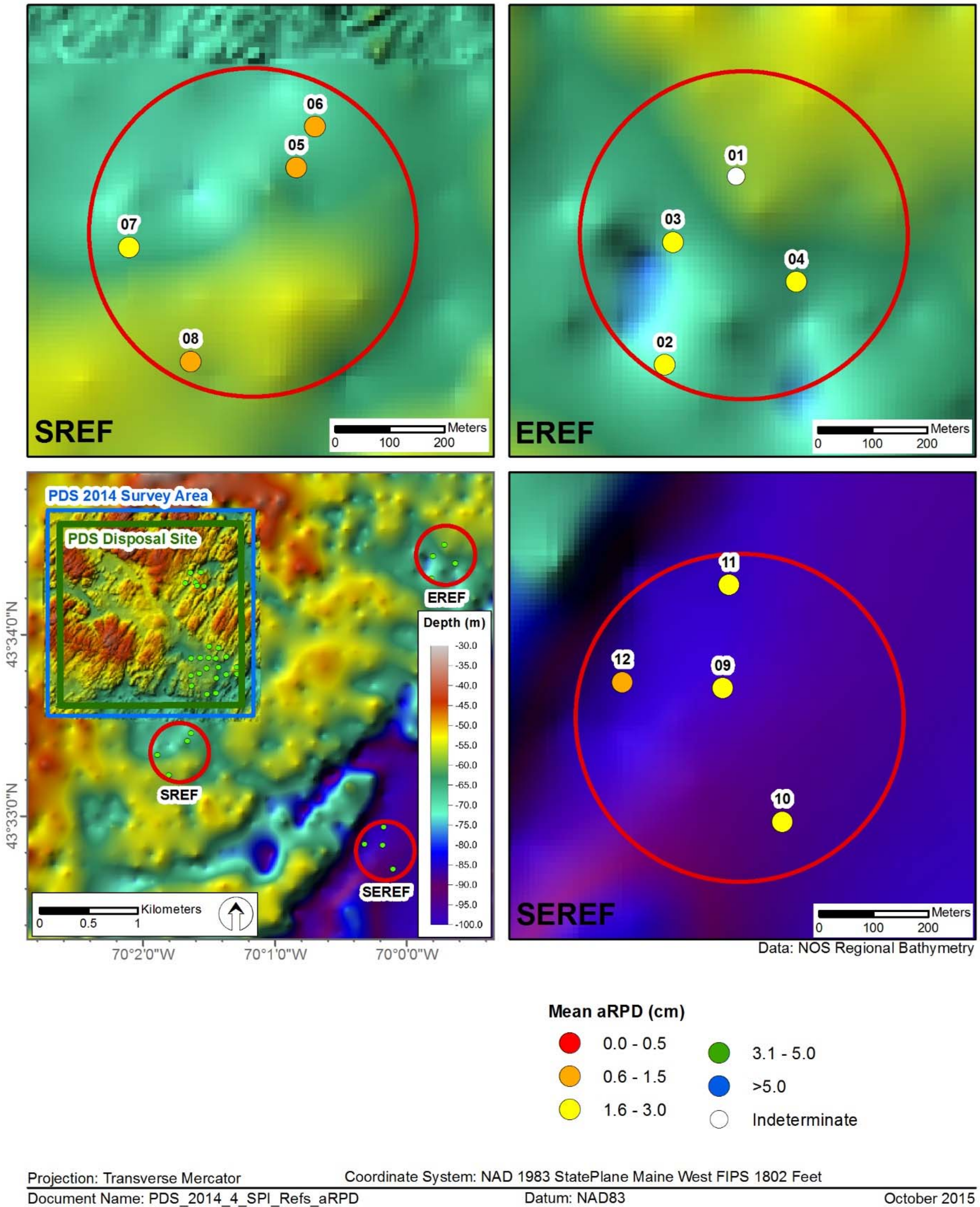


Figure 3-15. Mean station aRPD depth values (cm) at the PDS reference areas

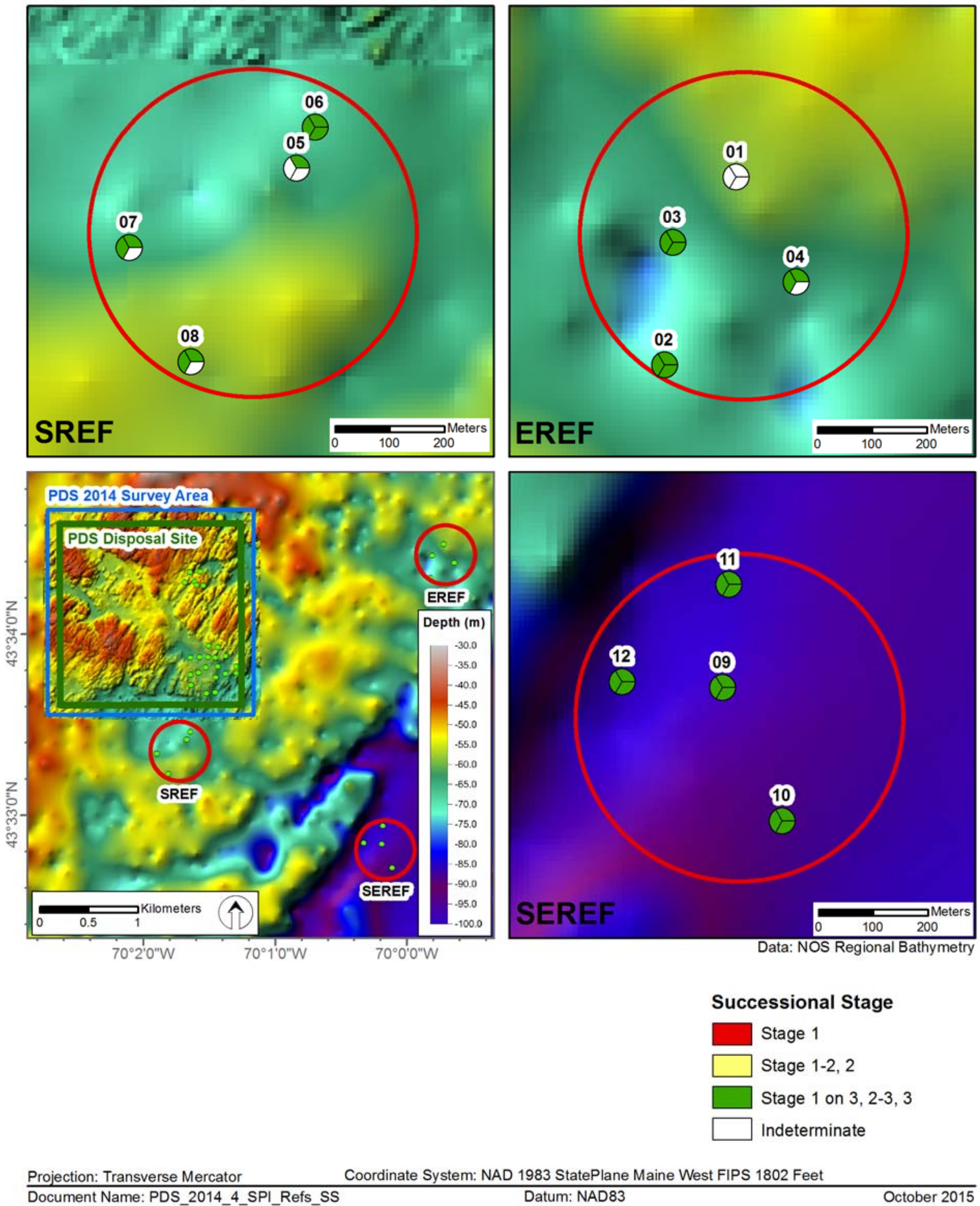


Figure 3-16. Infaunal successional stages found at the PDS reference areas

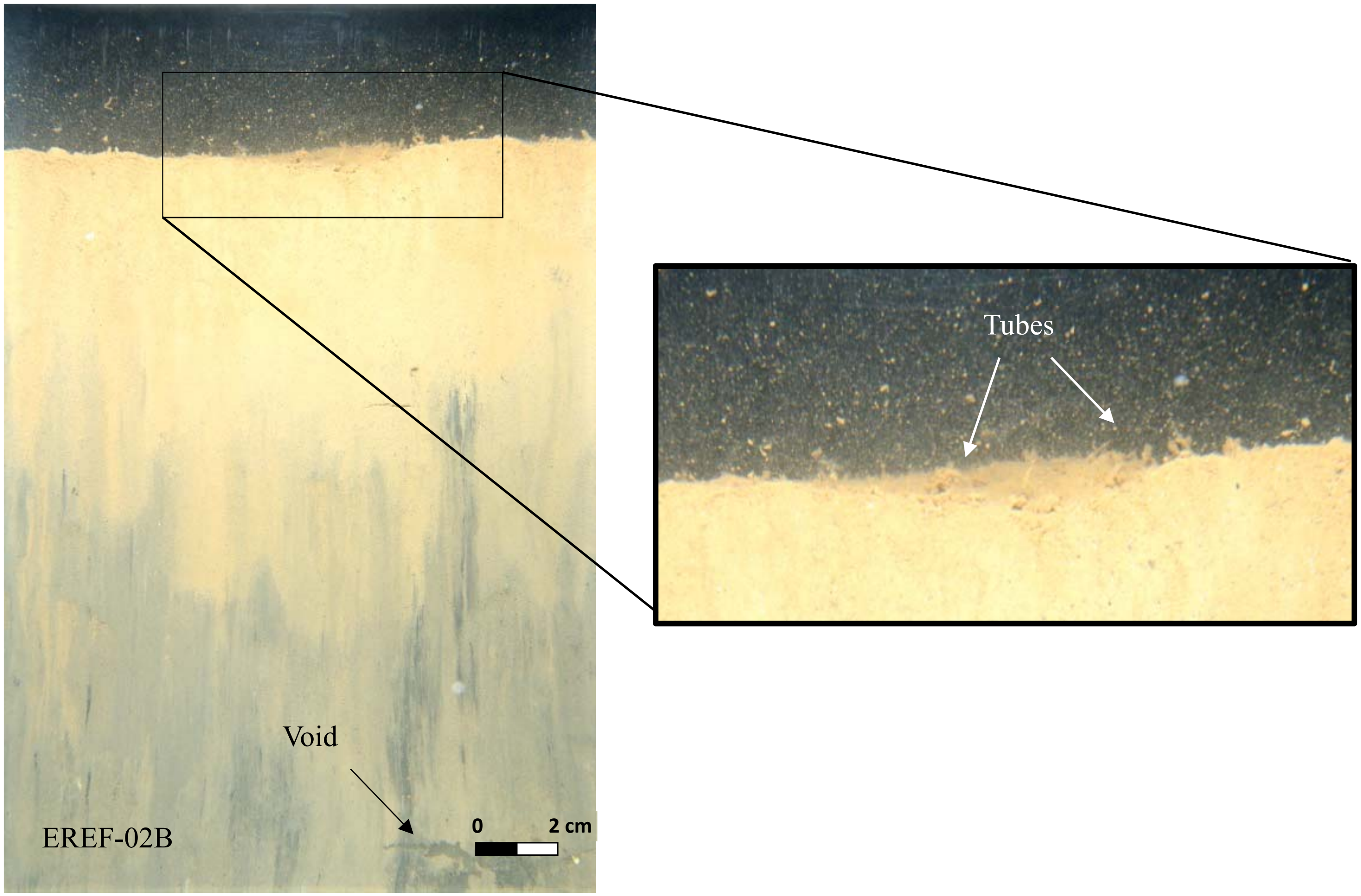


Figure 3-17. Sediment-profile image from EREF-02 indicating Stage 1 on 3 fauna represented by small tubes at the sediment-water interface and feeding void at depth

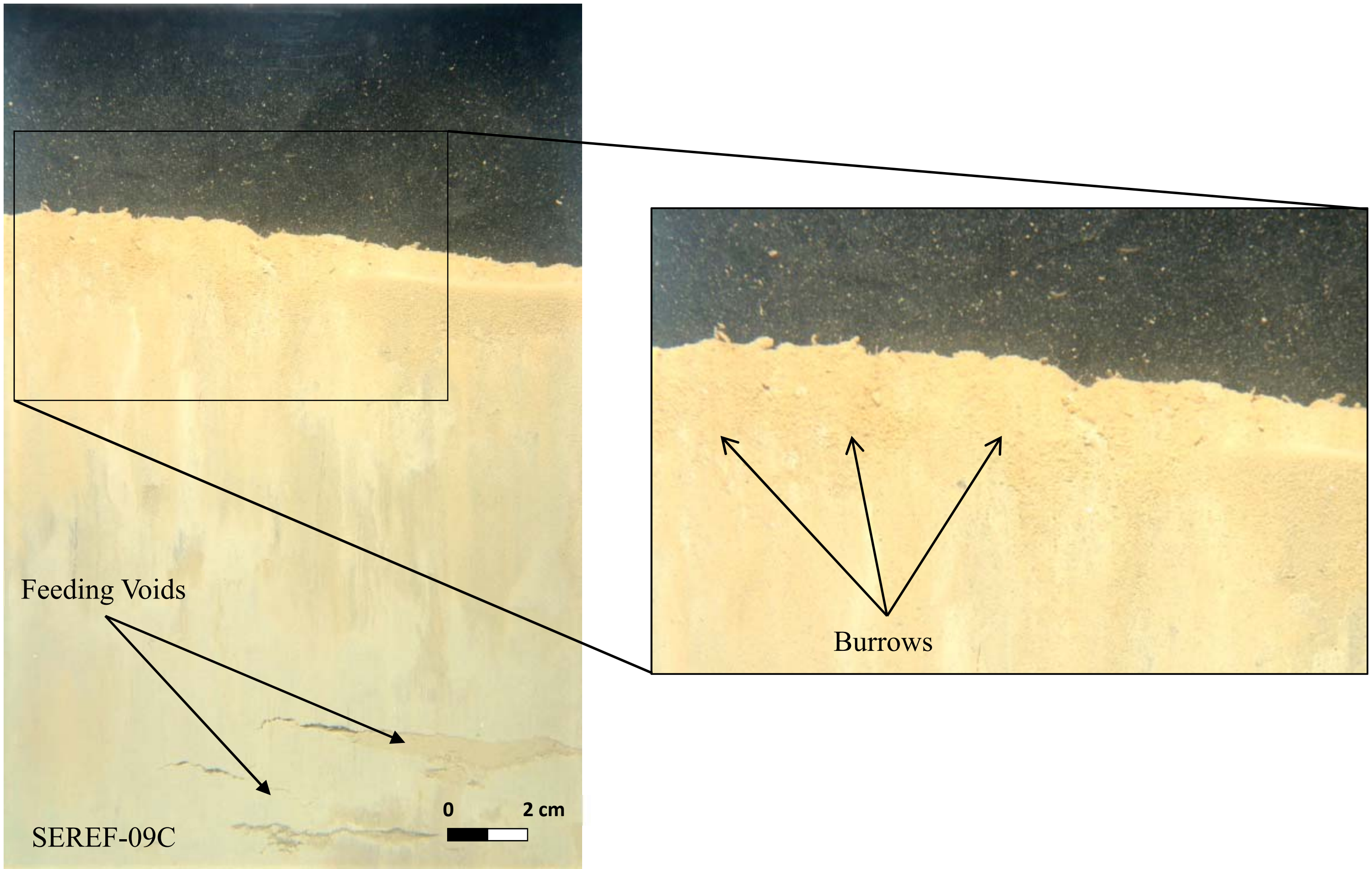


Figure 3-18. Sediment-profile image from SEREF-09 indicating Stage 2 on 3 fauna with shallow burrows and deep feeding voids

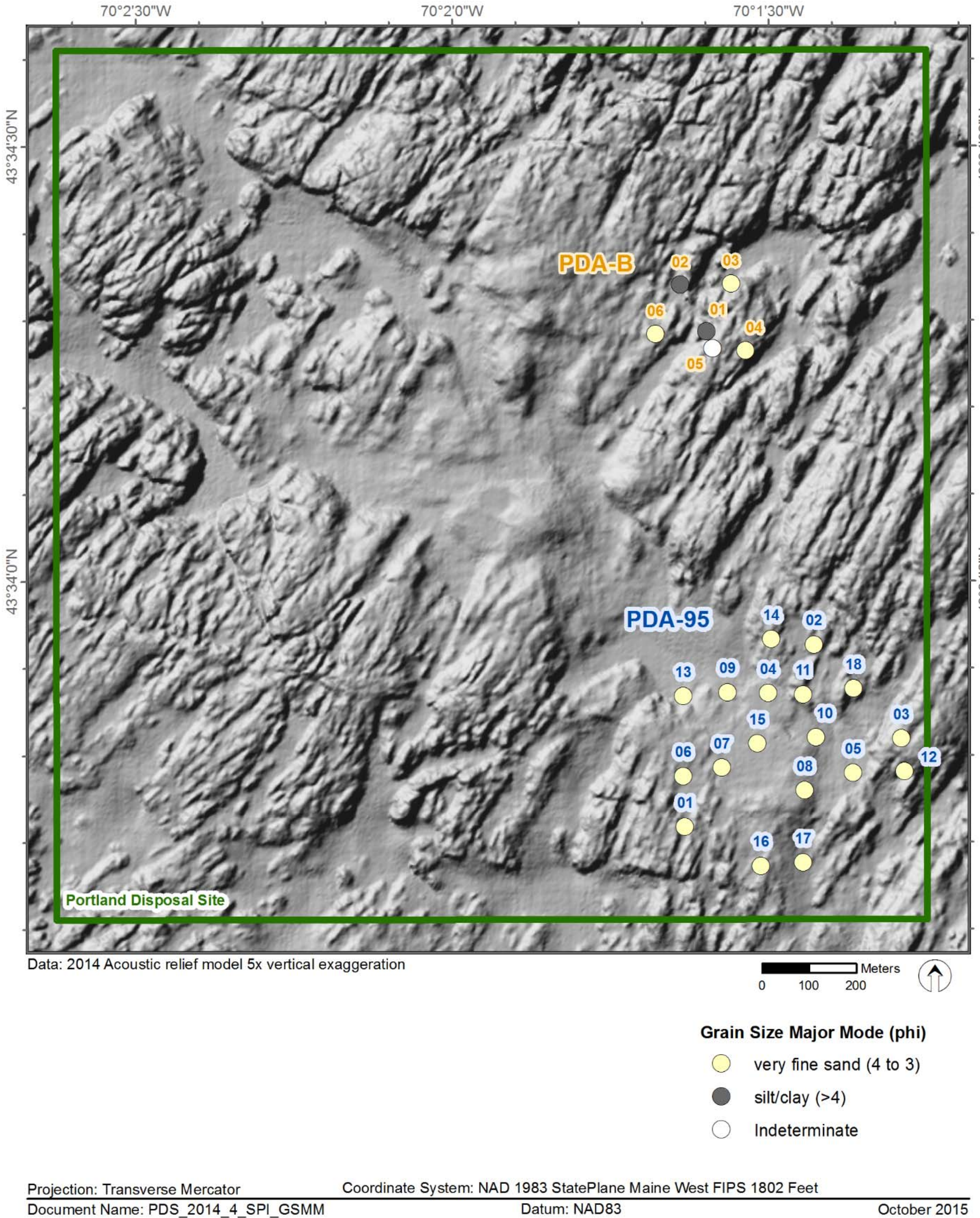
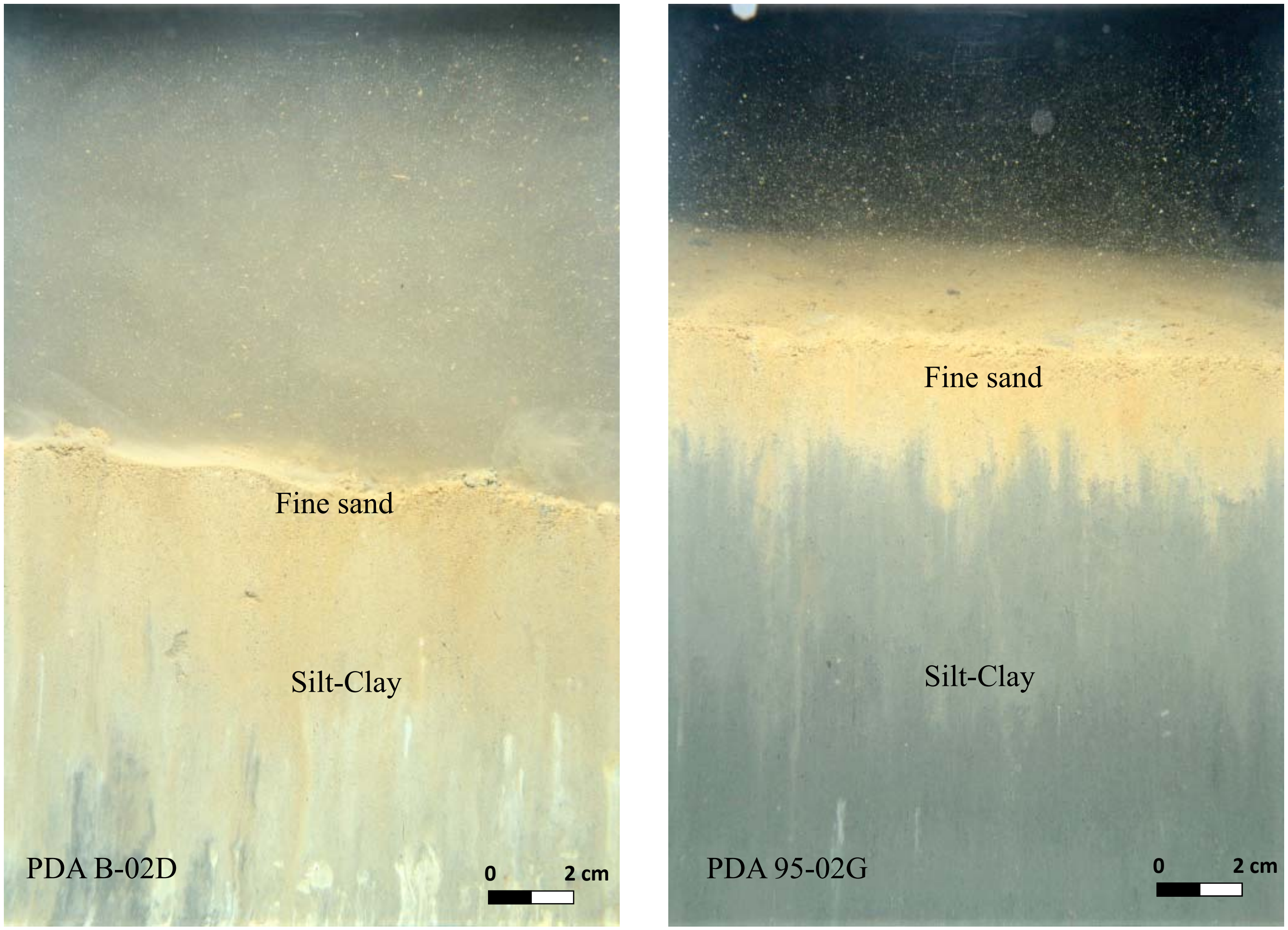


Figure 3-19. Sediment grain size major mode (phi units) at stations sampled at PDS



(A) **(B)**

Figure 3-20. Sediment-profile images from (A) PDA B-02 and (B) PDA 95-02 with medium fine sand overlaying silt-clay

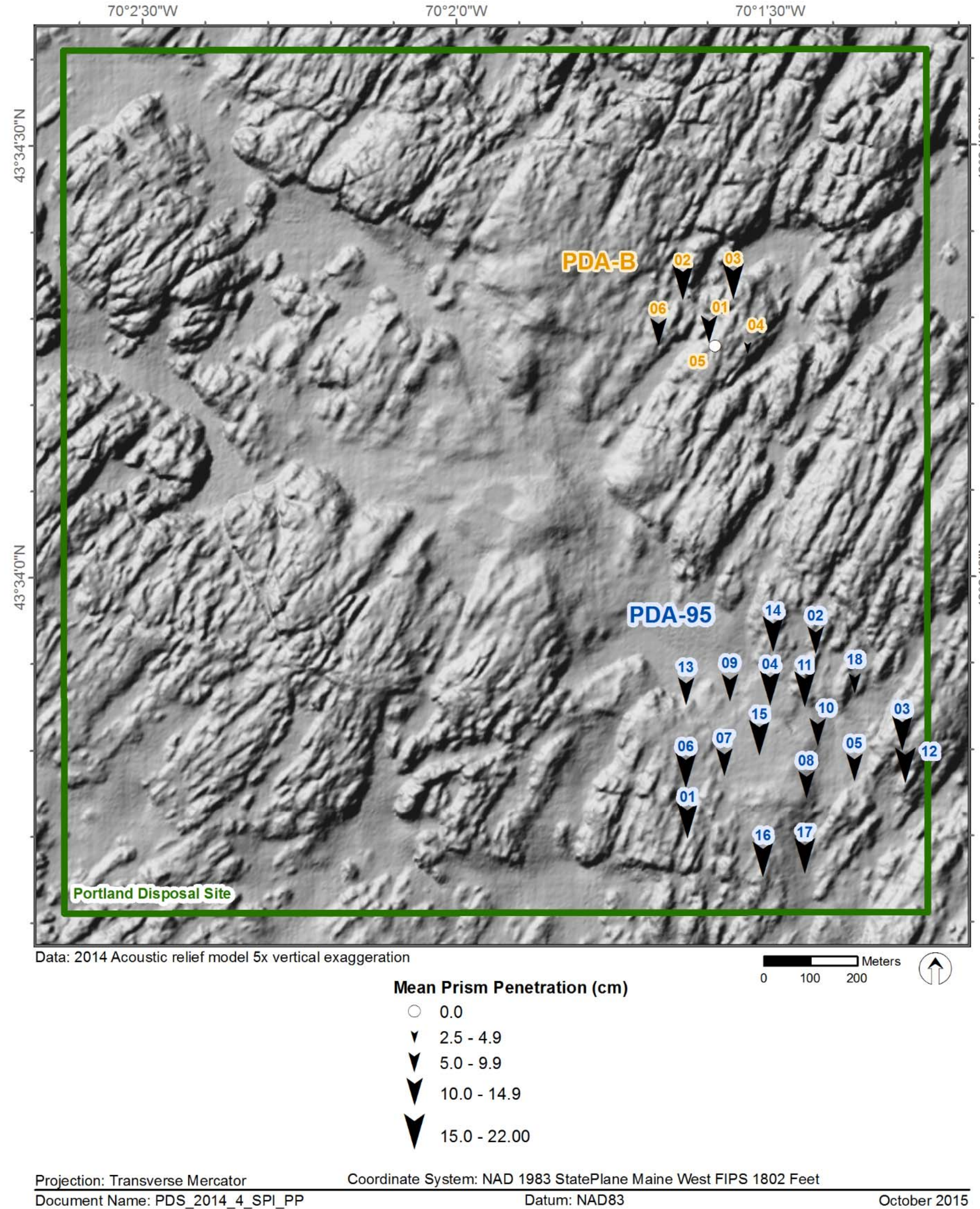
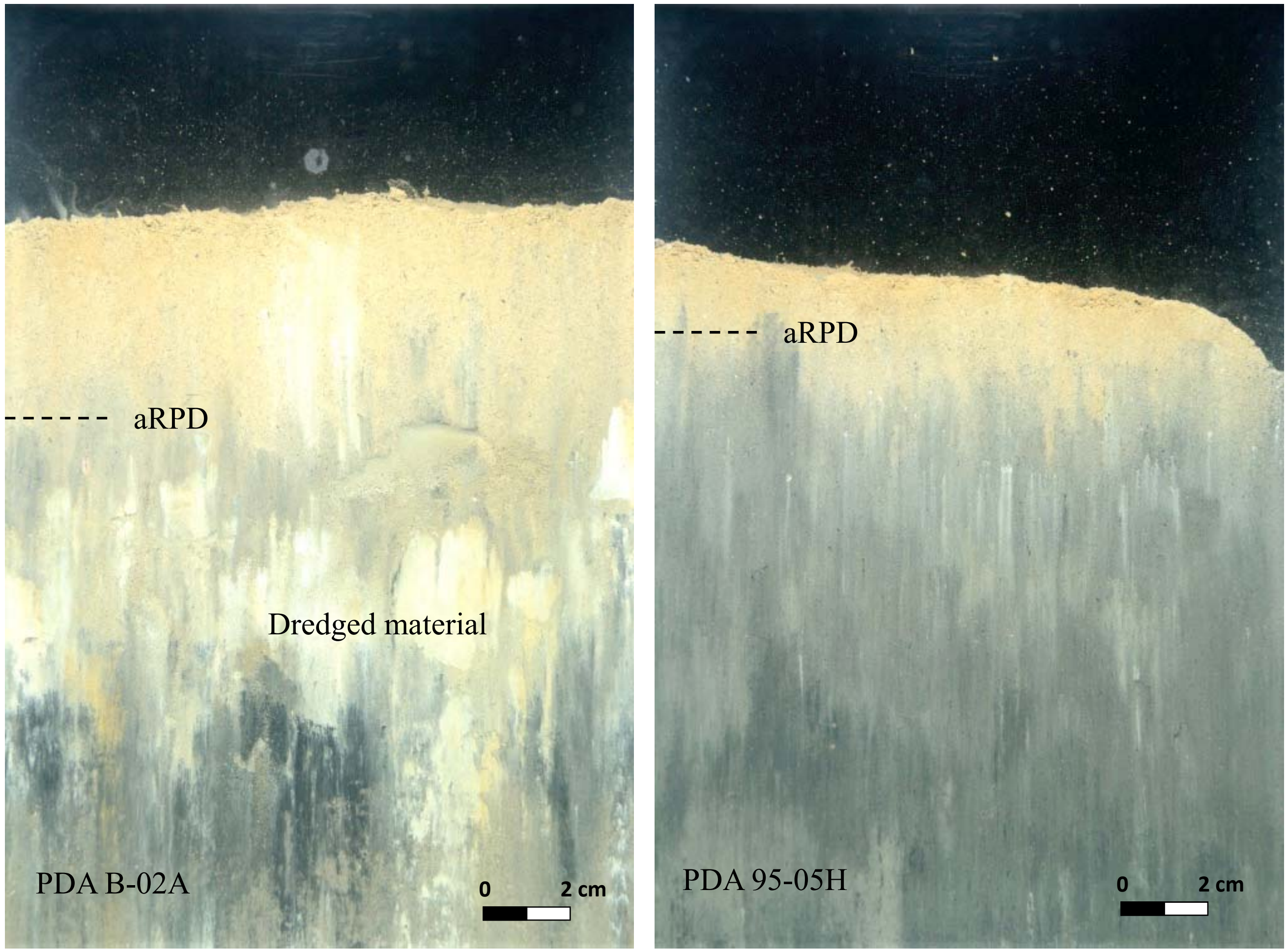


Figure 3-21. Mean station camera prism penetration depths (cm) at stations sampled at PDS



(A) **(B)**

Figure 3-22. Sediment-profile images depicting sediment features at the disposal stations (A) aRPD depth and the presence of dredged material extending below the camera penetration depth at PDA B-02, and (B) aRPD depth at PDA 95-05

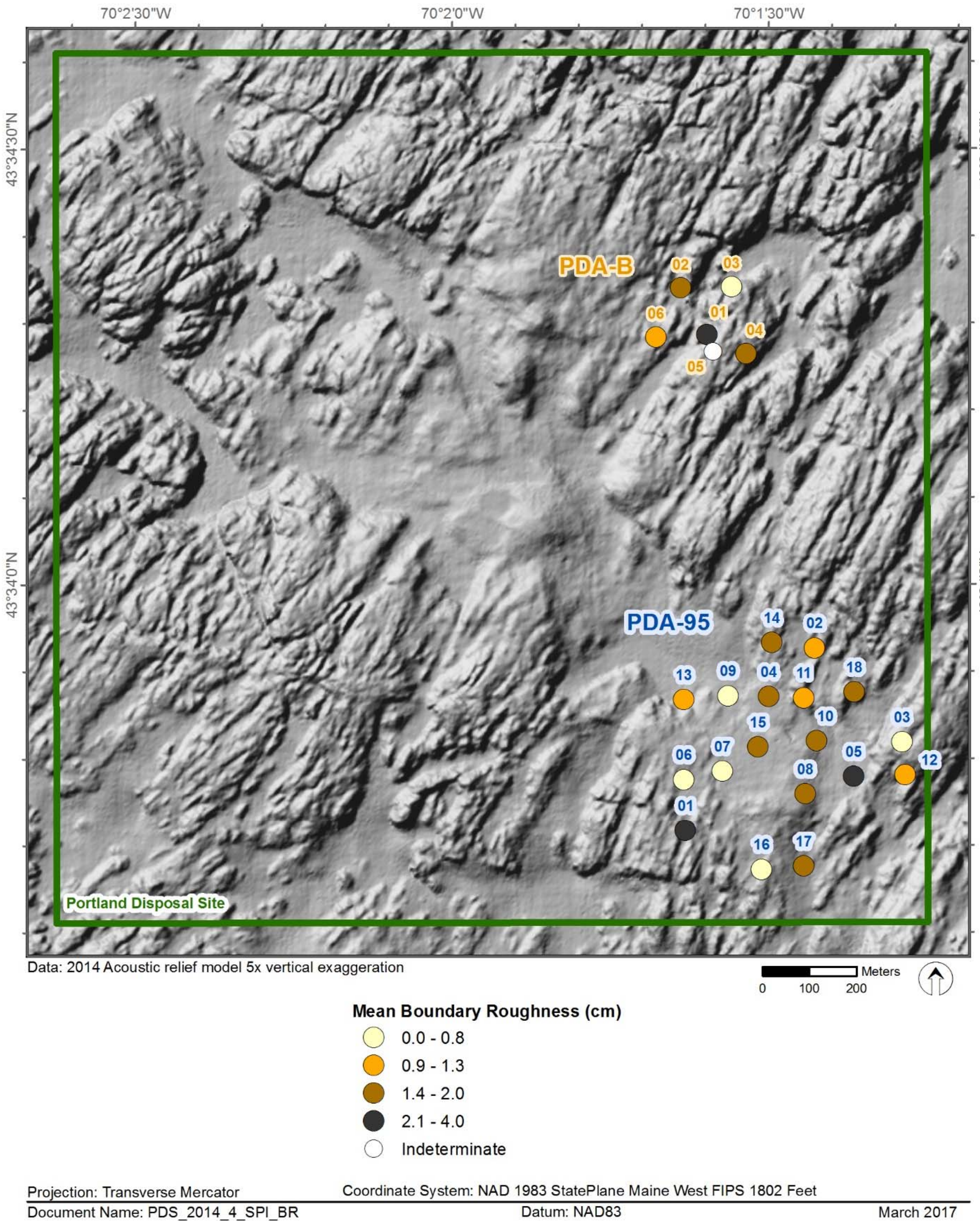


Figure 3-23. Mean station small-scale boundary roughness values (cm) at stations sampled at PDS

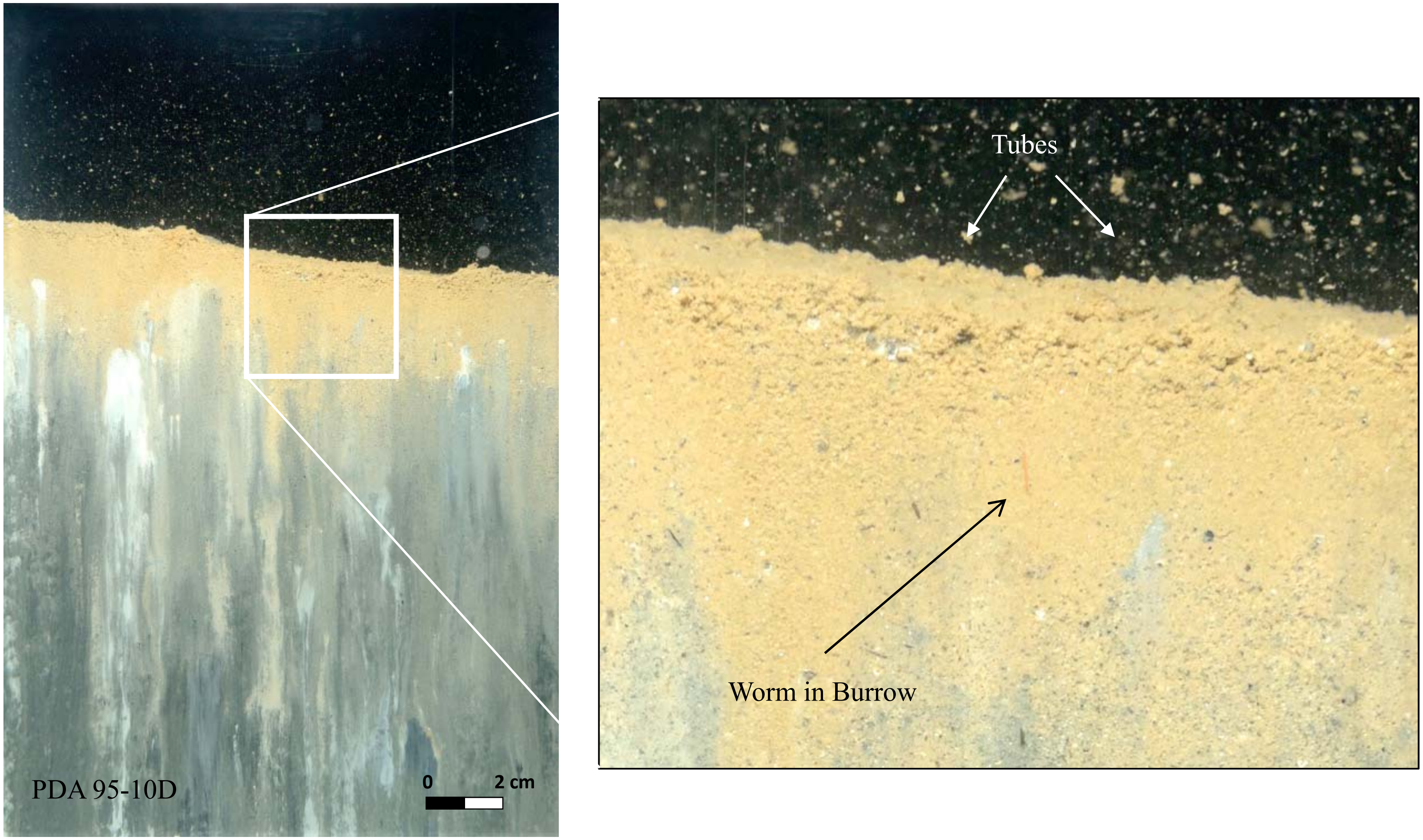
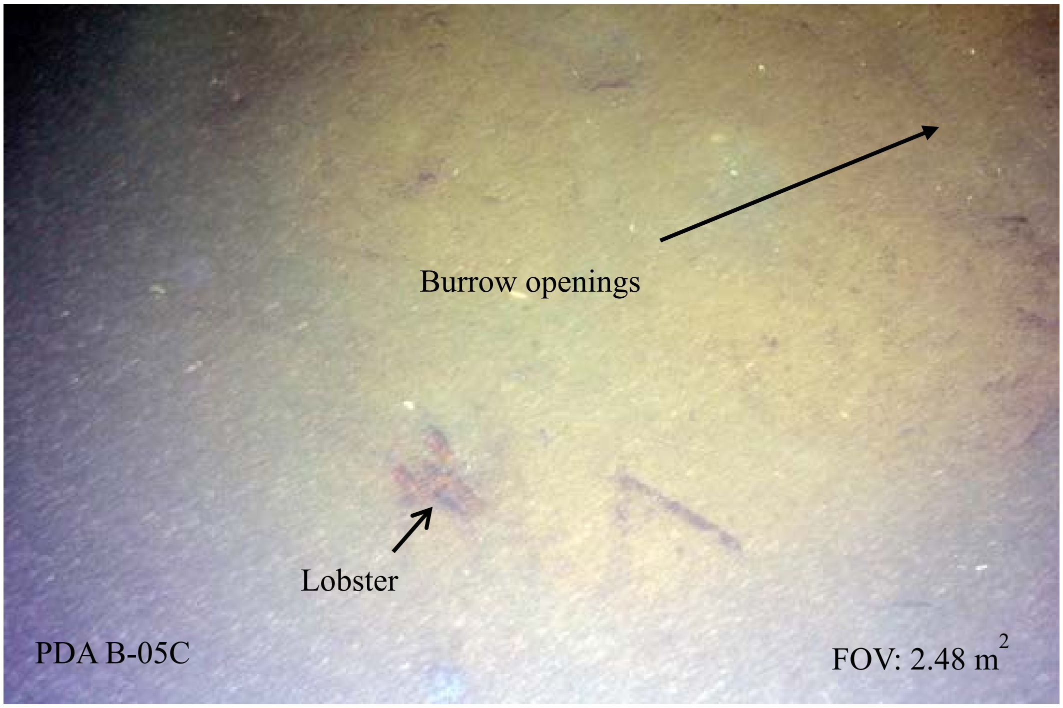


Figure 3-24. Sediment-profile image depicting Stage 1 tubes at the sediment-water interface and worm in shallow burrow indicative of Stage 2 fauna



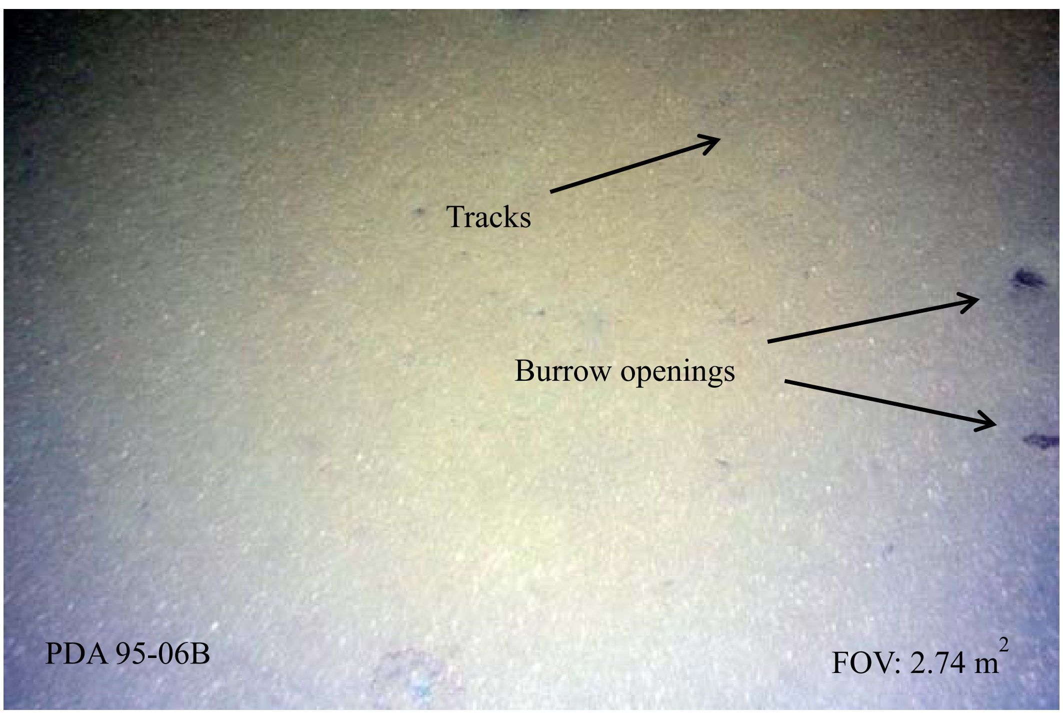


Figure 3-25. Plan-view images depicting burrows and tracks

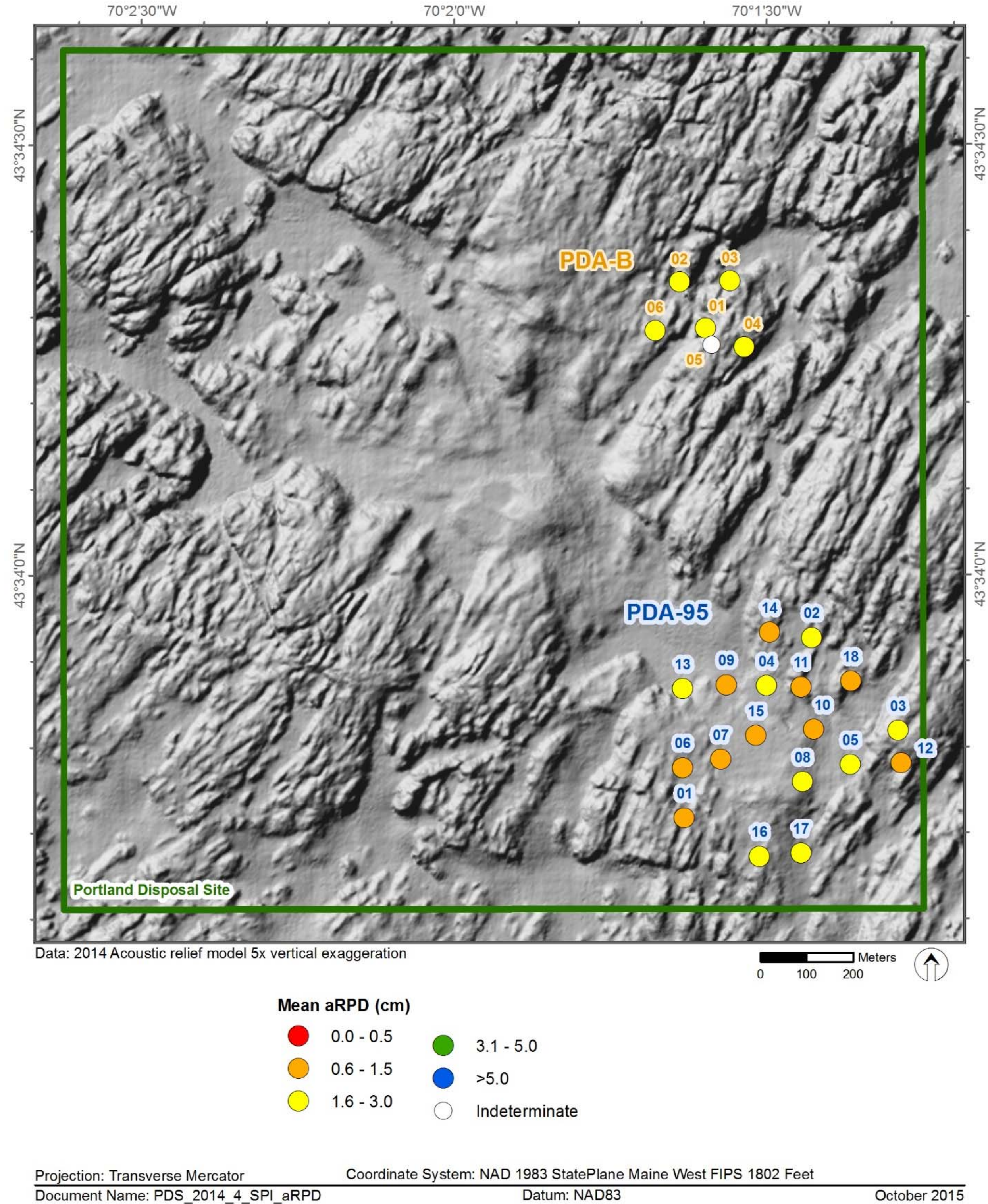


Figure 3-26. Mean station depth of the apparent RPD (cm) at stations sampled at PDS

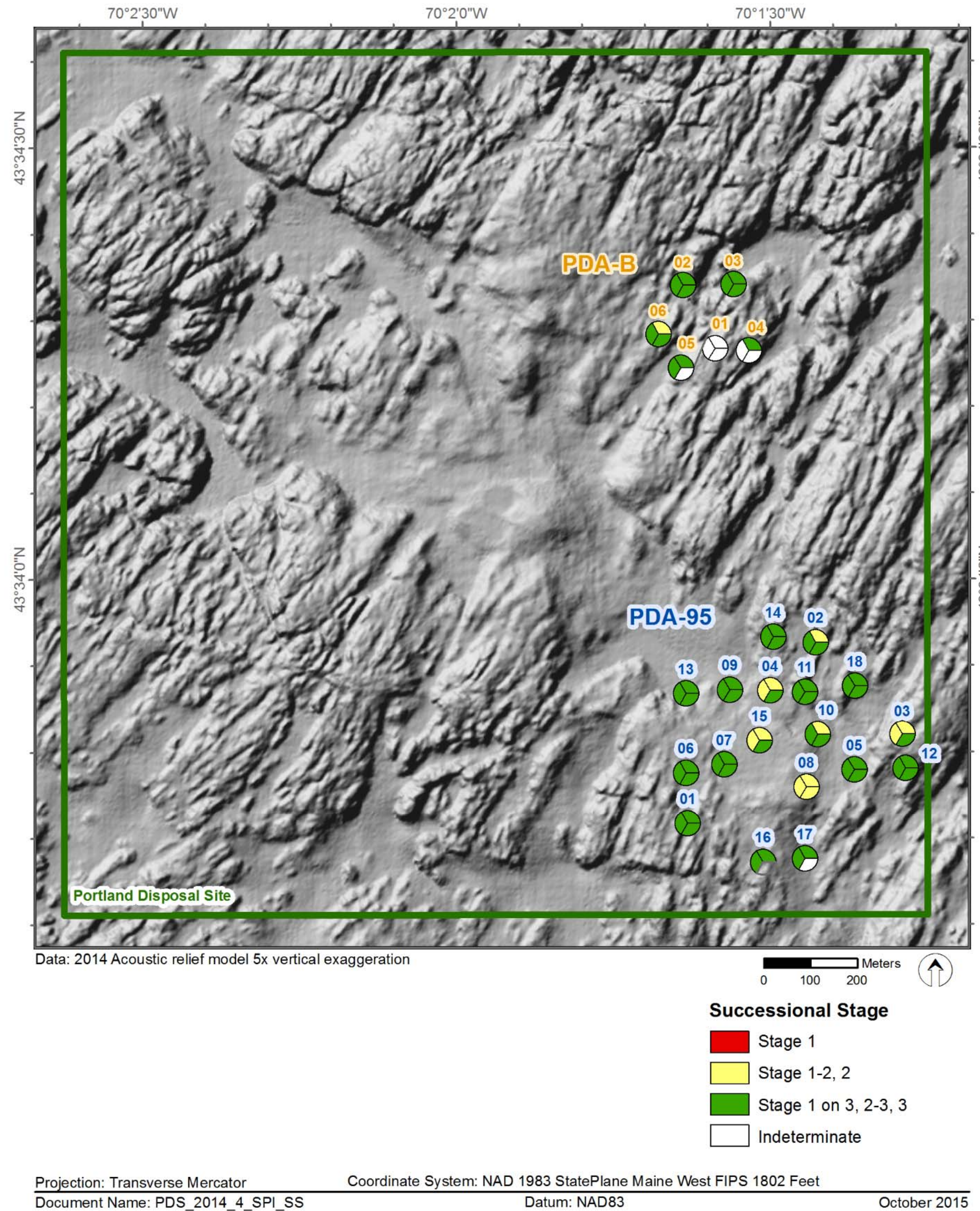


Figure 3-27. Infaunal successional stages at stations sampled at PDS

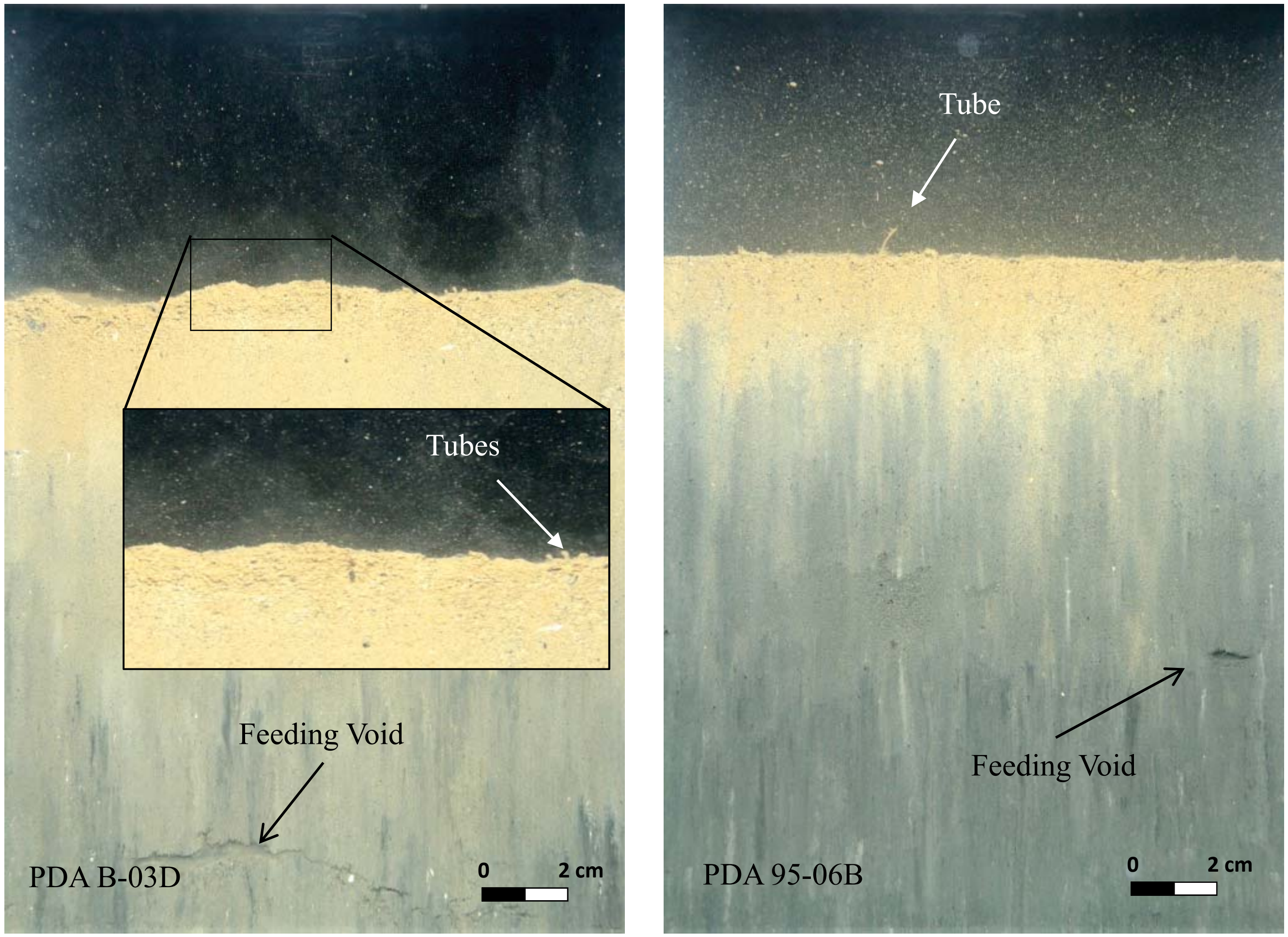


Figure 3-28. Sediment-profile images depicting Stage 1 tubes at the sediment surface over Stage 3 feeding voids at depth

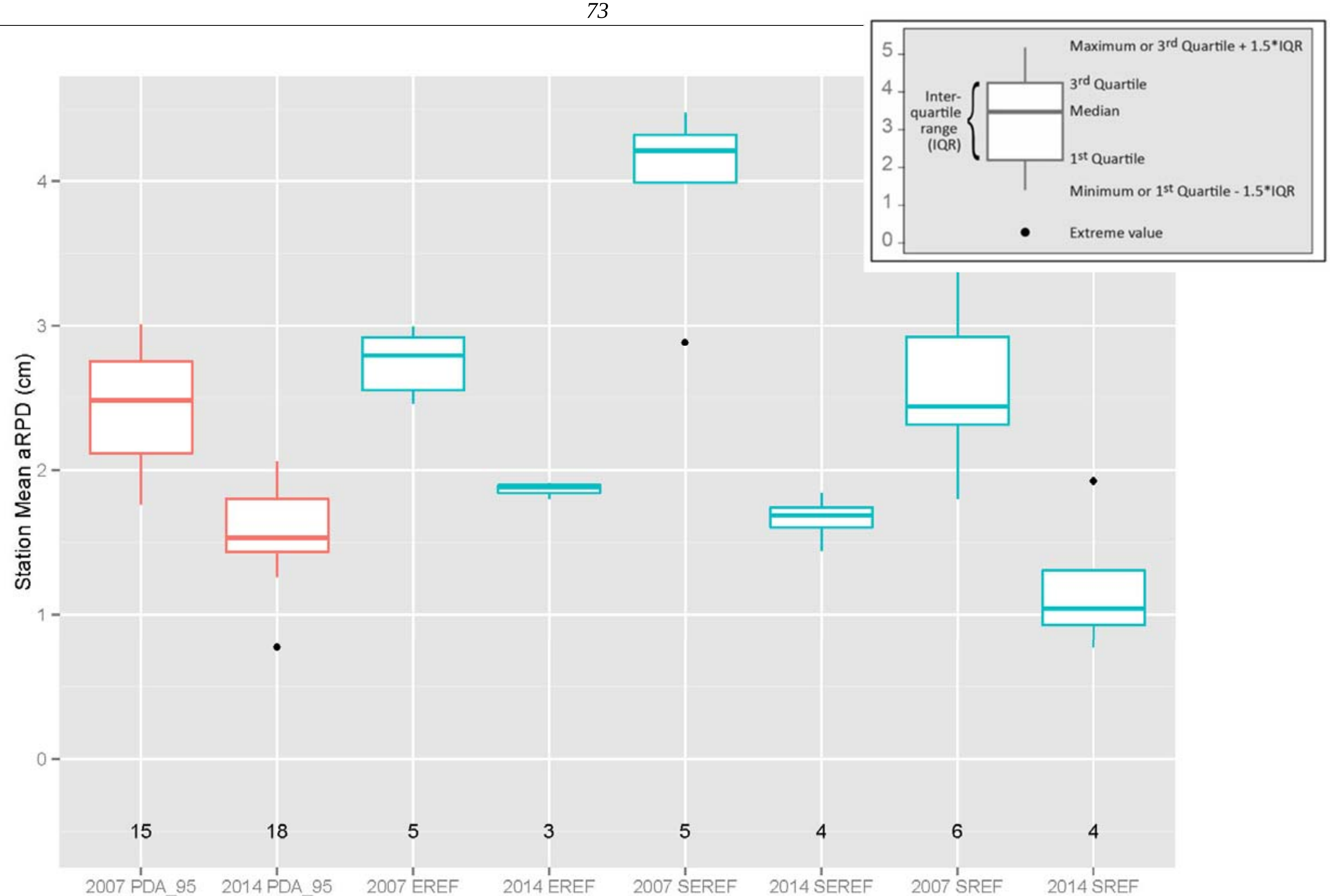


Figure 3-29. Boxplots showing the distribution of mean aRPD depths measured at the disposal site and reference area stations in the 2007 and 2014 surveys

4.0 DISCUSSION

The objectives of the August 2014 survey of PDS were to characterize seafloor topography and surficial features, define the physical characteristics of surface sediment, and to evaluate the biological recovery of the benthic community following placement of dredged material. The bathymetric surveys conducted during the 2014 were designed to aid in management of material placement and assessment of long term stability. Since the most recent DAMOS survey in August 2007, approximately 666,600 m^3 of material has been deposited at PDS. Survey tools included multibeam bathymetry, sediment-profile imaging (SPI), and plan-view imaging.

4.1 Management of Placement

Since August 2007, approximately 666,600 m^3 of material has been deposited at PDS, and the most recent disposal activity (2013-2014) was centered on the PDA 95 Mound (Figure 1-3). Placement activity from 2008 through 2010 totaled 38,000 m^3 (50,000 yd^3) and was located at the PDA A mound. From 2012 to 2013 a small amount of material (2,783 m^3) was placed at PDA B (Figure 1-3).

In the early years of PDS disposal site operations, placement was managed by a taut-wire moored target "DG" buoy. Dredging contractors focused on getting close to the target buoy, but not so close as to risk entanglement with the mooring line. This resulted in a potentially greater spread of material around the target location during a given season. The advancements in electronic positioning coupled with the Corps' Dredging Quality Management System (DQM) for logging the track of each scow and its release point allowed for implementation of an electronic target location for managing placement of the dredged material with potentially less spread of material.

The seafloor contours recorded at PDS were predominantly bedrock outcrops with troughs or channels traversing these bottom features. This topography was consistent at all of the disposal locations, and at two of the three reference areas; the SEREF area differed topographically from the predominant seafloor type in PDS (Figure 2-3). The trough or channel areas had relatively soft sediment while the bedrock outcrops had only a thin drape of sediment on rock. High resolution bathymetric survey results provide clear support for targeting placement of dredged material in the soft-sediment troughs where it can be contained by the rock walls.

Stations closest to the disposal mound at PDA 95 exhibited dredged material but those stations furthest away were not documented to have dredged material (Appendix D). This distribution indicated that material placed at this location formed a discrete mound and was constrained by the outcrops surrounding the placement location (Figure 4-1). Dredged material was present at all of the PDA B stations, though at most stations the dredged material had been covered by a layer of ambient sediment a few centimeters thick. Bathymetric observations of the PDA B area found the disposal mound to be indiscernible from the surrounding topography indicating that only thin, widespread layers resulted from the placement of the small volume of dredged material (Figure 4-1).

4.2 Long Term Stability

PDS has received approximately 1.8 million m^3 of dredged material since the beginning of tracking at this site in 1982. Historically, the largest projects were in 1996-1997 and 1998-1999 and placed at the PDA 95 and PDA 98 mounds respectively. The most recent placement was at PDA 95 with 625,866 m^3 placed between 2013-2014.

Recent dredged material placement at PDA 95 was focused on a depression between rock outcrops (Figure 1-3). Bathymetric observations of the PDA 95 mound found a disposal mound within that depression with thin layers extending to the northwest and northeast (Figure 4-1). Stations located outside of the depression (Stations 1, 2, 3, 12, 14, 16, 17, and 18) were found to have no dredged material, while those inside had fresh dredged material evident (Stations 4-11, 13, 15; Figure 4-1). This suggests that there was little spatial transport of the dredged material to surrounding areas after the initial placement.

4.3 Biological Recovery of the Benthic Community

The results of the 2014 SPI survey indicate a relatively high degree of benthic recolonization at the disposal sites at the time of the survey. Recovery of the benthic community at PDS was evident in the aRPD depths and successional stage status observations from SPI and plan-view images.

Almost all of the replicate images from across the disposal site showed abundant evidence of mature, deposit-feeding benthic taxa. The PV images reinforced the SPI results in showing numerous burrow openings, tubes, and tracks on the sediment surface at almost all of the stations. Stage 3 taxa were equally abundant at each of the three reference areas, with evidence of mature, deposit-feeding fauna observed in every replicate image. Similar to the disposal site stations, there were extensive organism tracks, pits, and burrow openings visible in the plan-view images from the reference area stations.

Mean aRPD depths were statistically equivalent at the disposal sites compared to the reference locations despite shallower depths for PDA95 and the reference areas between 2007 and 2014. All but one of the disposal stations exhibited at least one replicate with Stage 3 taxa, suggesting that these stations have transitioned to a well-defined, mature infaunal community. Overall, the results support the conclusion that surface sediments at PDS have been colonized by a mature benthic community that was comparable to that in nearby reference areas but that both disposal sites and the reference areas may be recovering from some disturbance that has resulted in relatively shallow aRPDs.

When compared to SPI results from the 2007 survey, the 2014 aRPD values at the reference sites and PDA 95 were shallower. This followed a similar trend in other biological data, e.g., successional stage, number of feeding voids, that were much lower in 2014 at PDA 95 in contrast to values in 2007. With both reference areas and PDA95 exhibiting shallow aRPDs, it is possible that a seasonal or periodic disturbance, e.g., a storm, might have influenced the benthic habitat and all sites are experiencing a degree of recovery. Despite these differences, the 2014 SPI survey indicates that dredged material deposited at the site is being rapidly recolonized to a mature, Stage 3 infaunal community.

4.4 Management Considerations

The patterns of dredged material on the seafloor at PDS are detectable with calculation of elevation differences between years of placement and traces visible in backscatter and side-scan sonar. These patterns indicate that containment of dredged material is supported by placement in the deepest areas of the site with soft sediments surrounded by rock outcrops (Figure 4-1).

There was no identification of dredged material at any of the reference locations, hence on this basis, those areas are still considered valid for comparison with disposal site conditions. However, SEREF differed in many respects from the other reference locations and the disposal site.

The SEREF area was much deeper than the other reference areas, and the layered appearance of the SPI images at SEREF was consistent with an area that receives turbidity deposits or slumps of mud from the margin of the rock platform (Figure 3-14). Substantial variation in the seafloor topography can be expressed in the physical and biological characteristics of a site, and SEREF had much deeper prism penetration depths compared with the other reference locations; indicating this was an area with finer grain sediments, or sediments that were less compact.

Additionally, slumping occurs episodically at unpredictable intervals and to an unpredictable extent but the disturbance from the resulting turbidity current deposits will undoubtedly influence the successional stages of the infauna community. As discussed previously, an area that is regularly disturbed displays successional Stages of 1 and sometimes 2 (if recovery is taking place). Depending on when the SEREF area was sampled (before or after a turbidite event), the observations and results would contrast substantially. The episodic nature of slumping margins suggest that the physical and biological conditions documented at the SEREF area will be equally as random, and this location is not an ideal location to serve as a representation of stability and control, i.e., this is not a good reference area. Although all the reference areas had statistically inequivalent aRPDs between 2007 and 2014, the difference at SEREF was greatest (Figure 3-29).

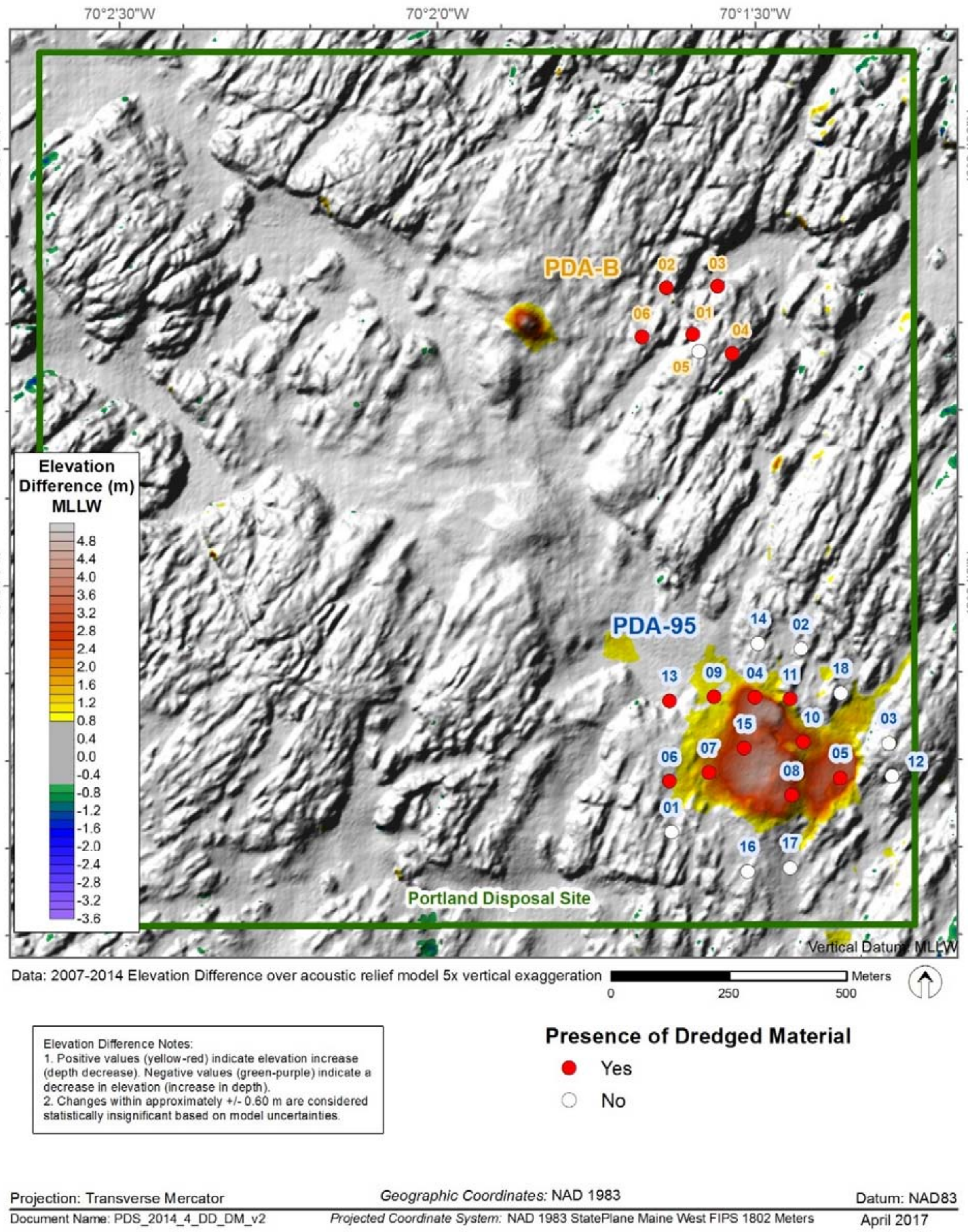


Figure 4-1. Dredged material presence shown on 2007-2014 elevation difference map

5.0 CONCLUSIONS AND RECOMMENDATIONS

The August 2014 survey at PDS was conducted to collect bathymetric data over the entire site and to collect SPI and plan-view imaging at two disposal sites and three reference areas. The survey was designed to assess changes at the site after placement of approximately 666,600 m^3 of dredged material since the previous surveys. The 2014 SPI and bathymetric surveys successfully characterized the seafloor topography and defined the physical characteristics and assesses benthic recovery with the following results:

- The benthic community at the disposal sites was recovering according to the expected recovery paradigm, with full recovery expected within one year of completion of dredged material placement. Mature benthic communities have developed at the most recently used disposal sites but there was also some evidence of recent disturbance (PDA 95 and PDA B).
- Dredged material placed at PDA 95 in the deepest and flattest portion of the site was constrained to a discrete mound.
- SEREF reference area is in a different bottom topography to that of the other reference areas, but more importantly the disposal areas. This reference area is in a location with bottom conditions occasionally disturbed by slumping of fine material from nearby bedrock outcrops, and it is just as likely that benthic conditions could mirror those of a disturbed system if sampling of this area closely follows a slumping event.

The results of the 2014 survey identified the following recommendations:

R1: Direct placement of dredged material to deeper, soft-bottom areas of the site to support containment of material;

R2: Discontinue use of SEREF. Two reference areas are more than sufficient to serve as a control characterization if SEREF is removed from monitoring.

R3: Additional monitoring of PDS is only recommended if significant additional dredged material placement occurs at the site.

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