Appendix I
Great Lakes Sediment Mapping by Sidescan Sonar Analysis

Great Lakes Dry Cargo Sweepings Impact Analysis

Sidescan Sonar Data Acquisition

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FINAL REPORT

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EXECUTIVE SUMMARY

More than 485 miles (781 km) of sidescan sonar data were collected from six survey sites on three Great Lakes to identify, map, and characterize dry bulk cargo “sweeping” deposits on the lakebed. Sidescan sonar data were collected using a L3-Klein System 3000 digital sidescan sonar deployed from USCG Cutters ALDER, MOBILE BAY, and NEAH BAY on Lakes Superior, Michigan, and Erie, respectively, between September 19, 2006 and October 19, 2006. A fourth vessel, the charter vessel REBEL QUEEN was also utilized on Lake Erie. The survey sites were selected based on GIS analyses of shipping data provided by the U.S. Coast Guard that included information on the location and types of sweepings materials being introduced into the Great Lakes by dry bulk carriers.

The dominant sweepings materials under consideration include taconite (iron ore), crushed stone (limestone), and coal. All of these materials have high acoustic impedances, which makes them potentially visible to acoustic survey tools such as sidescan sonar. The results of the surveys in Lakes Superior, Michigan, and Erie clearly demonstrate that sweepings deposits produce acoustic backscatter anomalies that can be detected and mapped by sidescan sonar survey equipment, and that the low-frequency (100 kHz) sonar is particularly effective at detecting these materials.

A major finding of this work is that the low-frequency sonar detects historical (buried) sweepings deposits on the lakebed, while the high-frequency sonar detects more recent deposits that are exposed on the surface of the lakebed. In fact, many of the acoustic anomalies observed on the low-frequency records are not observed on the high-frequency (500 kHz) records. This response typically occurs when deposits are buried under a thin veneer of fine-grained sediment which is not penetrated by the high-frequency sonar. For habitat assessment and sampling purposes, the high-frequency sonar is the tool of choice to find and locate sweepings deposits that are present at, or on, the sediment-water interface. Sediment samples taken at the Duluth Survey site in October 2006 verified the presence of coal and taconite pellets on the lakebed and confirmed the ability of the sidescan sonar equipment to accurately identify and locate sweepings deposits on the lakebed.

Multiple acoustic anomalies were observed on the lakebed that were classified into six major categories based primarily on shape, pattern, orientation, and acoustic response. Amorphous, sub circular ring, linear, patterned (repeating), elongate string, and indistinct/wispy acoustic anomalies were commonly observed on many of sidescan sonar records. A seventh category includes miscellaneous anthropogenic features such as shipwrecks and a downed plane observed on the lakebed. These acoustic anomalies generally exhibit preferred orientations that are parallel or sub-parallel to the designated Lake Carrier Association (LCA) shipping lanes. They vary in size and orientation, and are likely produced by a combination of the type and amount of material released, the method of release, the water depth in which the release occurs, and the direction and speed of ship movement at the time of release.

Another major finding of this work is that sweepings deposits are not confined exclusively to the designated LCA shipping lanes, but are widespread and ubiquitous across all of the areas surveyed in Lakes Superior, Michigan, and Erie. Undisturbed reference sites do exist, but must be selected with care due to the widespread distribution of these materials.

An evaluation of the regional distribution was accomplished by developing a new “linear density” measure that provides a quantitative measure of the number of targets or acoustic events per

survey line kilometer. This linear density is normalized to survey line length and can be used to make direct comparisons with survey data from other regions and other Great Lakes.

Regional Distribution Summary

Survey Location	Acoustic Anomalies by Class (listed in order of occurrence)	Linear Density[1]	Average Spacing[2]	Mean Orientation
Lake Superior - Duluth	Linear, Elongate, Amorphous, Indistinct/Wispy	3.2 /km	312 m	56 ^{o}
Lake Superior - Silver Bay	Linear, Elongate, Patterned (repeating), Sub-Circular Ring, Amorphous, Indistinct/Wispy	15.6 /km	64 m	55 ^{o}
Lake Michigan Primary	Linear, Elongate, Patterned (repeating), Amorphous, Indistinct/Wispy	3.8 /km	263 m	6 ^{o}
Lake Michigan Secondary	n/a	n/a	n/a	n/a
Lake Erie Primary	Linear, Elongate, Amorphous	2.0 /km	500 m	245 ^{o}
Lake Erie Secondary	Sub-Circular Ring, Elongate Sub-Circular, Linear, Amorphous	1.5 /km	667 m	79 ^{o} (53 ^{o})

[1] Number of targets or acoustic events per line kilometer
[2] Average spacing between anomalies

The greatest number and density of acoustic anomalies were observed in Lake Superior at the Silver Bay survey site located east of Silver Bay, Minnesota. Silver Bay has more than five times the number of anomalies per line kilometer when compared to the other survey sites. All of the major feature classes were observed within the Silver Bay survey area, and were oriented sub-parallel to the main LCA shipping lanes. Acoustic anomalies associated with sweepings deposits were also widespread and ubiquitous at the Duluth survey site where coal and to a lesser extent taconite, is the dominant material transported eastward through western Lake Superior. However, the number and density of acoustic anomalies are considerably less than at Silver Bay, and amorphous, elongate string, and linear acoustic anomalies dominate.

In southern Lake Michigan, crushed stone and coal are the primary materials being transported, with the orientation of observed acoustic anomalies trending south to north sub-parallel to the designated LCA shipping lanes. Lakebed sediments are a mixture of silt and fine-grained sands locally colonized by *dressenids* (zebra/quagga mussels*)*. The number and density of acoustic anomalies is considerably less than observed in Silver Bay survey area, but is similar to those observed at the Duluth survey area in Lake Superior. As in Lake Superior, the acoustic anomalies are ubiquitous and widespread, with no clear relationship to the designated LCA shipping lanes.

In the Central Basin of Lake Erie, crushed stone and coal are the primary materials being transported, with the orientation of observed acoustic anomalies trending toward the west southwest parallel and sub-parallel to the designated LCA shipping lanes. The number and density of observed acoustic anomalies is low, with most of the anomalies observed in the central and northern portion of the areas surveyed. Lakebed sediments are predominately silts and clays locally colonized by *dressenids*. Within the Lake Erie primary survey area, amorphous, elongate string, and linear anomalies dominate.

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INTRODUCTION

Prior work clearly demonstrates that sidescan sonar can be used successfully in combination with other tools to map and characterize lakebed habitat and ship-derived debris from vessel sweepings (e.g. Mackey and Liebenthal 2005; Meadows et al. 2005; Ferrini and Flood 2001; Fuller and Foster 1998; Cameron and Lewis 1994; Mayer et al. 1994). Based on the Draft Technical Memorandum entitled: Scientific Plan for Dry Cargo Sweepings Impact Analysis prepared for the U.S. Coast Guard by Volpe National Transportation System Center, Parsons, Brinckerhoff Quade & Douglas, Inc. with CH2M-Hill dated June 13, 2006, field work was initiated on or about September 19, 2006 to acquire sidescan sonar acoustic trackline data at six sites located in three Great Lakes - Lake Superior, Lake Michigan, and Lake Erie.

According to the Scientific Plan – "Detailed bottom profiling of selected tracklines will be made using appropriate technology such as side scan sonar or equivalent techniques to identify areas of intense sweepings deposition. The detailed bottom profiling includes confirmation bottom photographs and material samples to verify and calibrate the electronic scans. Real-time data visualization during the data collection process should be used to note locations for verification photographs, samples, and other potential notable features. Acoustic discontinuities should be noted and minimized using appropriate procedures.

Data interpretation will be conducted to characterize geophysical bottom materials and areas of dry cargo sweepings deposition. All bottom profiling; confirmation photographs, material samples, and any other pertinent information should be georeferenced and made available for the ARC-GIS platform.

The information gathered on the lake bottom from side detailed bottom profiling will define the geophysical characteristics (e.g. dunes, cobbles, boulders, clays, etc.) present at each site. The geophysical characterization will then be used to make qualitative assessments of the potential affects of sweepings deposition.

Bottom profiling data collection will be coordinated with other data collection activities to optimize the identification and locations of the data collection efforts."

This report summarizes field activities and initial analyses using the sidescan sonar data to characterize the type and distribution of sweepings deposits at each of the six survey sites and to identify potential future sampling locations for further analysis.

Technical Note: Metric units of measurement are used throughout this study. English units of measurement are provided where appropriate. Navigation data were collected in latitude - longitude format with distance units in meters. Geospatial data are displayed in a Universal Transverse Mercator (UTM) projection with a datum of WGS84 (meters).

STUDY OBJECTIVES

The objective of this study is to detect, characterize, and map the distribution of sweepings on lakebed sediments, lakebed features, and associated benthic habitats within areas commonly transited by commercial shipping vessels. Specifically, geophysical tools will be used to:

1. Acoustically identify and map the locations and characteristics of potential “sweepings” deposition areas at a reconnaissance level within four to six pre-selected survey sites within three Great Lakes to determine the area, density, pattern, and distribution of ship-derived “sweepings” deposits on the lakebed.

2. Over specific areas of interest, acoustically characterize and map potential “sweepings” deposition areas at high resolution for further sampling and analyses.

3. Identify potential sampling locations within “sweepings” deposition areas and associated undisturbed “reference” areas. Provide a list of potential sampling coordinates for further sampling and investigation.

4. Infer and map general substrate characteristics (texture, composition, sedimentary structures) and associated habitats within these areas using acoustic data, bottom grab samples, and underwater video where appropriate.

GEOPHYSICAL DATA COLLECTION

Equipment

The geophysical data collection and sampling program was standardized and designed to minimize error, maximize reliability, and ensure repeatable results throughout this study. Prior work clearly demonstrates that sidescan sonar can be used successfully in combination with other tools to map and characterize lakebed geologic features and ship-derived debris from vessel sweepings (e.g. Mackey and Liebenthal 2005; Meadows *et al.* 2005; Ferrini and Flood 2001; Fuller and Foster 1998; Cameron and Lewis 1994; Mayer *et al*. 1994).

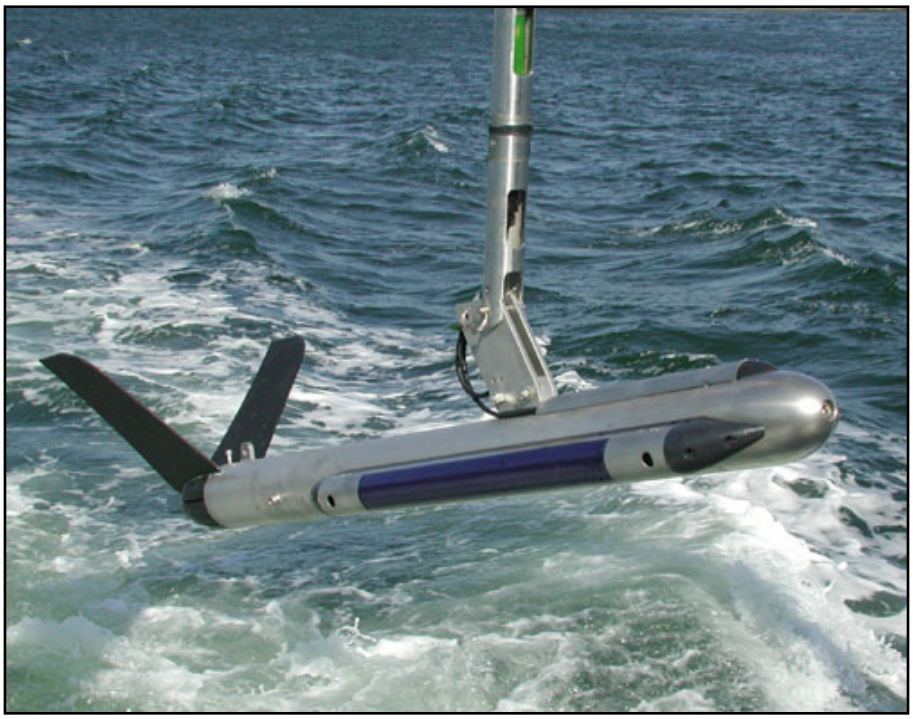


Figure 1. L3-Klein System 3000 Towfish (photo courtesy L3-Klein, Inc.)

Equipment used in this study included a L3-Klein System 3000 Dual Frequency Digital Sidescan Sonar coupled with L3-Klein's Sonar Pro data acquisition software, a Trimble Model DSM 212H Digital Geographic Positioning System (DGPS) operating at a 1 Hz sampling rate, and Chesapeake Technologies SonarWiz.Map data collection/mosaicking software. The L3-Klein System 3000 is an integrated, 100% digital sidescan sonar system consisting of a stainless steel towfish that is towed behind or along side the survey vessel, a Topside Processing Unit (TPU), and a PC running Sonar Pro sidescan sonar data collection software.

Acoustic data are collected digitally by the sidescan sonar towfish and transmitted via coaxial cable to the TPU. The TPU is connected via a standard CAT-5 Local Area Network (LAN) to a Windows-based PC running the Sonar Pro data collection software. The Sonar Pro software integrates acoustic and navigation data and generates a real time center-out waterfall display of the sidescan sonar data as it is being collected (Figure 2). The software provides the capability to identify, capture, locate, and save targets of interest "on-the-fly" as the sidescan sonar data are collected. The software also monitors towfish altitude off the bottom, produces real-time navigation plots, and provides digital readouts of critical data collection parameters as the survey progresses. All data is also saved for later post-processing and analysis.

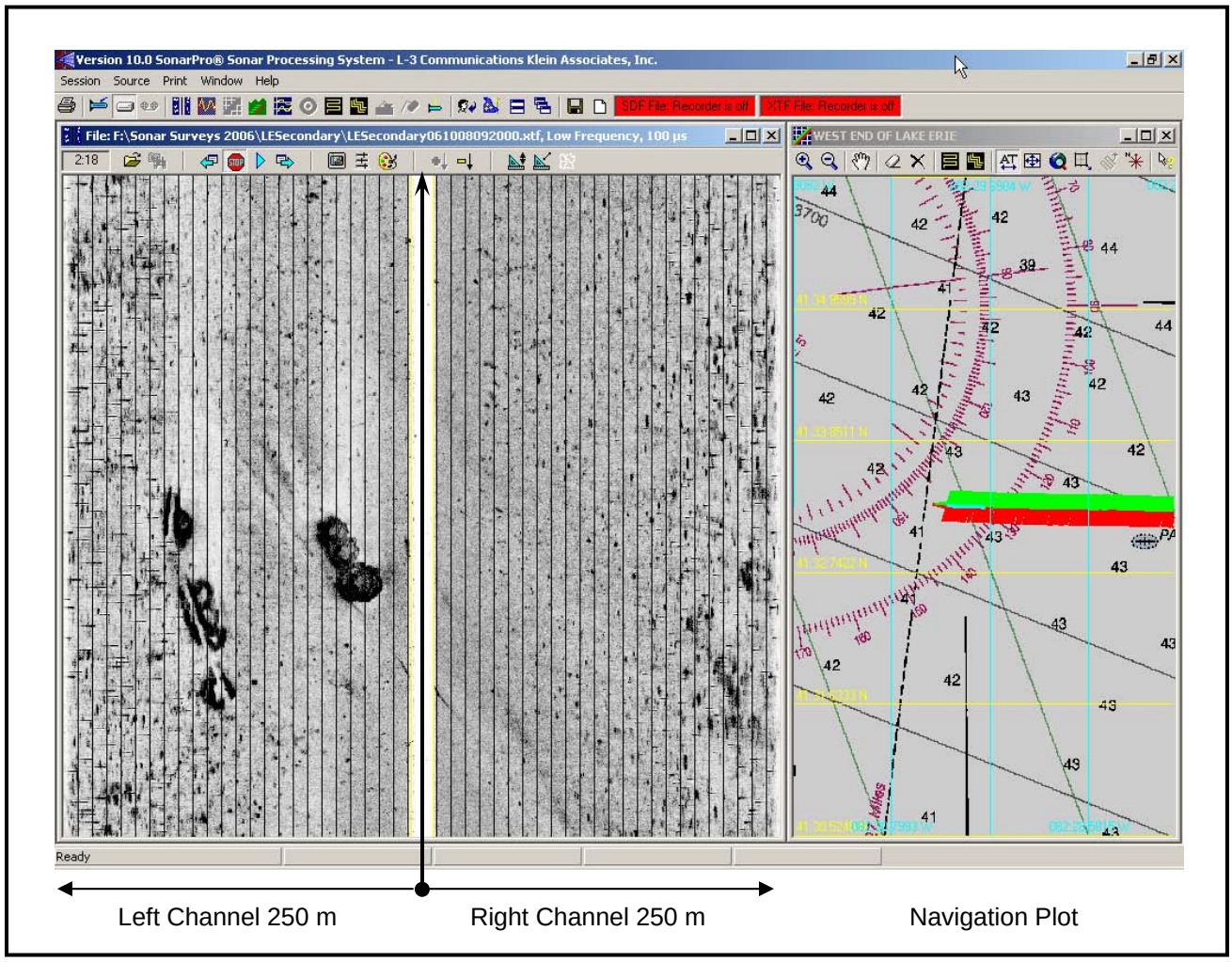


Figure 2. Typical sidescan sonar center-out waterfall display. Sidescan sonar image scrolls downward as a function of vessel speed. Range setting is 250 m yielding a total swath width of 500 m. Range lines are spaced at 10 m intervals measured from the towfish. Arrow indicates direction of vessel movement with current towfish position at the top the waterfall display. White area in the center of the display is the water column below the towfish (in this case ~ 10 m). Dark backscatter areas represent harder materials with higher acoustic reflectivity. Dark circular masses are potential sweeping targets of interest. Navigation chart shows location of vessel, towfish and approximate area surveyed by the sidescan sonar. Red is the left channel, green is the right channel, with vessel moving due west. (Habitat Solutions - Lake Erie Secondary Survey site – October 2006).

The L3-Klein Sidescan Sonar operates and collects data simultaneously at 100 kHz (low-frequency) and at 500 kHz (high-frequency). Low-frequency tools have greater range (i.e. wider effective swath widths) and are therefore capable of covering larger areas quickly - but the images they produce may have a somewhat reduced resolution and one may not be able to resolve fine details or bottom structure. Conversely, high-frequency tools have reduced range (i.e. narrower effective swath widths) – but produce images that can be used to detect and resolve fine-scale bottom details. High-frequency tools may be able to resolve bottom features less than 5 cm under the best of conditions. Generally, features or larger can be commonly detected and resolved with high-frequency sidescan sonar. Low-frequency tools can commonly

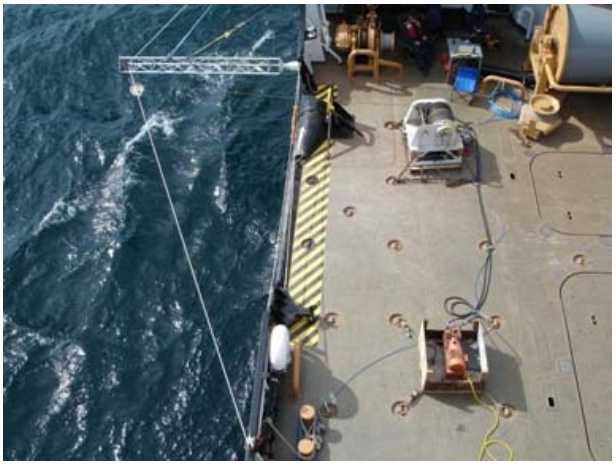
resolve bottom features on the order of 50 to 70 cm or larger. Target precision was estimated to range from 3 to 5 meters Root Mean Square (RMS), with precision decreasing as distance increases from swath centerline (up to 5 meters RMS) or with increasing water depth and towfish layback distance.

A Trimble DSM 212H DGPS receiver operating at a 1 Hz sample rate was used to provide positional data for the sidescan sonar. Differential positioning is less than 1 meter horizontal RMS. Positional data are electronically fed directly from the DGPS receiver into the Klein Sonar Pro data acquisition software to provide instantaneous real-time geo-referencing of the sidescan sonar data.

Sidescan Deployment

The sidescan sonar towfish was deployed from three different U.S. Coast Guard Cutters – the USCG Cutter ALDER (Lake Superior), the USCG Cutter MOBILE BAY (Lake Michigan), and the USCG Cutter NEAH BAY (Lake Erie). The sonar towfish was also deployed from the 30-foot charter vessel REBEL QUEEN (Lake Erie) for shallow-water operations. On Lakes Superior and Michigan, survey water depths ranged from 80 feet (24 m) to more than 600 feet (185 m). Deeper water depths necessitated the use of weighted armored coaxial cable up to 2800 feet (850 m) in length, an oceanographic winch with slip ring, a wireless T-Count cable metering sheave block, and an electrically driven hydraulic power unit (Figure 3a). The oceanographic winch was used to raise and lower the towfish and armored cable. On Lake Erie, survey water depths ranged from 35 feet (10 m) to 80 feet (24 m). Shallow water depths allowed for the use of a lightweight Kevlar-reinforced coaxial cable up to 650 feet (200 m) in length that was fed through the T-Count cable metering sheave block and raised and lowered using the Cutter's aft capstan and secured with a Klein cable grip. For all surveys conducted on USCG vessels, the T-count sheave block measured the amount of cable out between the towfish and the sheave block. Cable out distances were electronically fed to the TPU to calculate towfish layback and position relative to the DGPS antenna.

Deploying Sidescan Sonar



Sidescan Sonar data acquisition

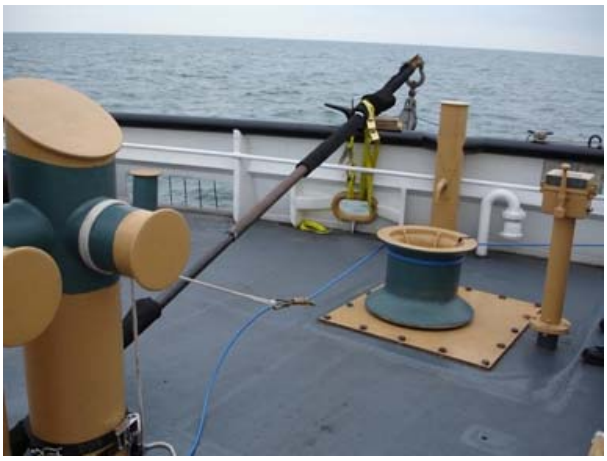
Figure 3a. Sidescan deployment from USCG Cutter ALDER (Lake Superior) using section of Spilled Oil Recovery System (SORS) boom mounted port side forward of buoy deck. Survey water depths necessitated use of an armored coaxial tow cable, oceanographic winch, and hydraulic power unit (HPU) to keep the sidescan sonar towfish at proper depth. Photo to the right shows the fully extended SORS boom, T-Count cable metering sheave block, oceanographic winch, and electrically driven HPU (orange).

Sidescan Sonar deployed from fabricated steel pipe with armored coaxial tow cable

Wireless T-Count cable metering sheave block

Figure 3b. Sidescan deployment from USCG Cutter MOBILE BAY (Lake Michigan) using steel pipe mounted on the port side aft quarter. Survey water depths necessitated use of an armored coaxial tow cable, oceanographic winch, HPU, and T-Count cable metering sheave block.

Sidescan Sonar deployed from fabricated steel pipe with lightweight coaxial tow cable



Coaxial tow cable secured using Klein cable grip and capstan

Figure 3c. Sidescan deployment from USCG Cutter NEAH Bay (Lake Erie) using steel pipe mounted on the port side aft quarter. Shallower water depths allowed for use of lightweight Kevlar reinforced coaxial tow cable, which was run through a T-Count cable metering sheave block. Towfish was deployed and retrieved using the aft capstan. Coaxial cable was secured using a Klein cable grip.

In early October, a 30-foot Sportcraft charter fishing vessel was used to collect sidescan sonar data from shallow waters in Lake Erie over the Secondary Survey site located north of Sandusky and west of Vermillion, Ohio (Figure 4). The charter boat platform was used while the USCGC NEAH BAY was undergoing unscheduled engine repair and maintenance. A portable generator was used to provide AC power to the sidescan sonar TPU and data acquisition computers. Habitat Solutions has considerable experience deploying the side scan sonar towfish from smaller vessels in nearshore and shallow-water areas of the Great Lakes. At the time of the survey, numerous private recreational vessels were present within, or near, the survey area. The smaller vessel platform provided easy maneuverability and as a result, minimized disturbance to the sport fishermen in the area.

30-foot Sportcraft charter fishing vessel REBEL QUEEN

Sidescan Sonar deployed using lightweight coaxial tow cable and Klein cable grip

Figure 4. Sidescan deployment from 30 foot Sportcraft charter fishing vessel REBEL QUEEN (Vermillion, Ohio) using lightweight Kevlar reinforced tow cable secured using a Klein cable grip. Towfish was deployed and retrieved by hand. This vessel was ideal for shallow quiet-water operations in the heavily fished waters off Vermillion and Sandusky.

Methods

While onboard the larger USCG vessels, sidescan sonar data were collected and processed using a Dell 670 Workstation. Navigation data were fed directly into the workstation from the DGPS and integrated with the sidescan data by the Sonar Pro software. As a backup, a separate navigation program was run on a Panasonic CF-72 Toughbook laptop computer where positional data were collected and stored every 30 seconds for the entire period of the survey.

Onboard the smaller charter fishing vessel, sidescan sonar data were collected and processed using the Panasonic CF-72 Toughbook laptop computer. Backup navigation data were collected and stored every 10 seconds using a Panasonic CF-28 Toughbook laptop computer. Sidescan and navigational data were then transferred to the Dell 670 Workstation onshore for post-processing. In all cases, raw digital data were collected, stored, and archived on multiple hard drives and archived on DVD's. Digital data include navigation data (location, bearing, speed) and raw acoustic backscatter data collected by the sidescan sonar in XTF format.

To assist with the identification of potential sampling locations and areas of interest, post-processed sidescan sonar mosaics were generated using Chesapeake Technologies sidescan

sonar mosaicking software. either during or shortly after sonar data collection operations were completed. Post-processed digital data were archived on multiple hard drives and/or DVD's. Archived digital data included: 1) processed navigation and sidescan sonar acoustic backscatter data, 2) screen captures from individual sidescan sonar tracklines and, 3) screen captures of sidescan sonar mosaics.

Initial Survey Site Selection

Survey sites were selected based on geospatial analyses of commercial shipping records provided by the U.S. Coast Guard. The details of these analyses have been described elsewhere (Technical Memorandum "USGS Dry Cargo Sweepings Scientific Investigation: Identification of Sonar Investigation Sites", CH2M HILL, December, 2006). Maps were produced for Lakes Superior, Michigan, and Erie identifying areas with extensive "sweepings activity" and therefore a high potential for sweepings deposits. Designated survey areas were then outlined based on the inferred type and number of sweepings events. Using this information, initial reconnaissance survey lines were located within the designated survey areas based on the density and orientation of expected sweepings deposits. These lines were designed to assess the local and regional distribution of sweepings deposits and to identify potential "reference" or undisturbed areas of the lakebed for comparison.

Typically, several longitudinal survey lines oriented parallel to the long axis of the survey box were run to assess the regional distribution of sweepings deposits. Based on these initial surveys, several perpendicular survey lines would then be run to identify potential "reference" or undisturbed sites and to further assess the regional distribution of sweepings deposits. For all surveys, low-frequency (100 kHz) and high-frequency (500 kHz) data were collected and recorded simultaneously. Records from both the 100 kHz and 500 kHz datasets were used to interpret the sidescan sonar data. Specific locations of interest were then identified for more detailed high-resolution sidescan sonar surveys (typically at a 50 or 100 m range scale) and/or possible lakebed sampling.

Two experimental survey lines were run at the Duluth survey site in Lake Superior to test and calibrate the sidescan sonar equipment. Sidescan sonar range settings were initially set at 150 and 200 m, but after some experimentation, a default reconnaissance range setting of 250 m was used for all subsequent surveys. This yielded a survey swath width of 500 m per reconnaissance survey line. Survey lines were typically spaced 350 to 400 m apart to provide a minimum 25% overlap in order to avoid holes or "windows" in the data. This overlap also allows for layback comparison to test and validate the location of the towfish.

On-Site Field Analyses

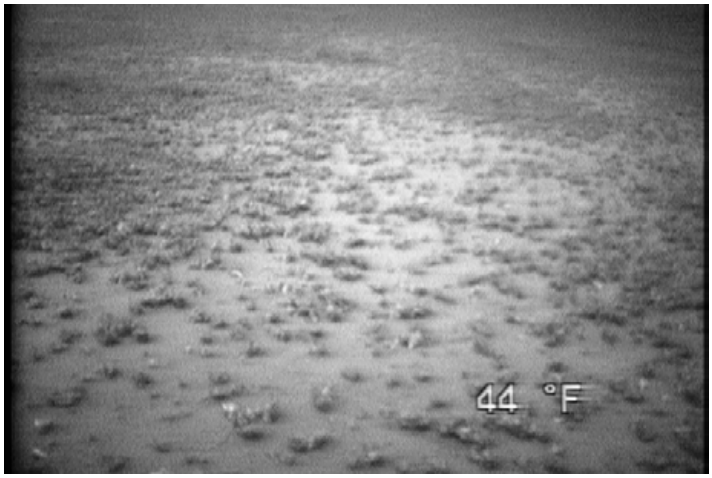
Sidescan sonar measures and records the backscatter characteristics (intensity, texture, pattern, and distribution) of lakebed deposits or other features on the bottom. These data are then interpreted to represent a particular substrate type or feature. Direct sampling (i.e. ground truthing) or visual confirmation is necessary to identify and verify the physical characteristics of the material providing the specific backscatter response. For these surveys, a Petite Ponar grab sampler (Figure 5) was used to obtain samples of the lakebed at selected sites in order to assess grain size and the presence/absence of sweepings materials. An Aqua View underwater video camera (Figure 6) coupled with a digital camcorder were used to obtain digital video images of the lakebed at selected sites where there was sufficient water clarity. The maximum water depth at which samples and/or video could be taken were constrained by cable length (~100 m), sea state conditions, and water clarity.

Petite Ponar grab sampler

Petite Ponar deployment and recovery - USCGC ALDER

Figure 5. Petite Ponar grab sampler used to obtain sediment samples from the lakebed. Screens and rubber backflow flappers have been removed to show Lake Superior sediment inside sampler. A power winch and fairlead block were used to retrieve the sampler after reaching the bottom.

Underwater drop video camera and 100 m cable



Still image captured from underwater video - Lake Michigan Primary Site

Figure 6. Aqua View underwater drop video camera was used to capture and digitally record digital video images of the lakebed. Underwater video can provide images that can be used to evaluate surface features, texture, and heterogeneity of the lakebed. These images can also provide insight into the biological organisms and communities that utilize lakebed habitats. Still image shows invasive *dressenids* (zebra/quagga mussels) and *chladophora* (algae) distributed across a soft silt substrate (Lake Michigan Primary – Sample Location 1). At this location, sweepings deposits resting on the lakebed surface would likely be colonized by *dressenids*.

Sidescan sonar records were reviewed to identify areas and locations of inferred sweepings deposits. Preliminary sidescan mosaics were generated to identify regional trends and patterns within the survey area. Sampling coordinates were determined from sidescan sonar mosaics and where appropriate, compared with individual targets previously identified on the waterfall display during initial sidescan sonar data acquisition.

Sampling considerations included the estimated size (or area) of the deposit, its orientation and lateral continuity, and the strength of the acoustic backscatter response. Within the areas surveyed, there are numerous small targets that could be interpreted as discreet sweepings deposits. Limitations in positional accuracy, water depth, and difficulty in maintaining position over survey sites severely limited the ability to sample small targets. Thus, to increase the probability that samples were indeed derived from an appropriate acoustic reflector, locations with multiple targets and/or larger-sized targets were selected for sampling.

It should be noted that during the Lake Superior surveys, the dynamic positioning capabilities of the USCGC ALDER were used to maintain a fixed position for extended periods of time over selected sample sites. This increased the probability that samples acquired during the Lake Superior surveys were representative of the acoustic anomalies detected by the sidescan sonar. The USCGC MOBILE BAY, USCGC NEAH BAY, and the charter vessel REBEL QUEEN did not have dynamic positioning capabilities. However, these vessels were positioned updrift of the target locations and allowed to drift slowly across the sampling site. The Petit Ponar and/or underwater video were deployed when DGPS data indicated that the vessel was directly over the designated sampling site.

Bow thrusters used to keep vessel over sampling site in Lake Superior - USCGC ALDER

Figure 7. Dynamic positioning capabilities of the USCGC ALDER were put to good use during sampling phase of the Lake Superior survey work.

Additional sampling considerations included the need to obtain representative samples from all major acoustic reflectors observed within the survey area, even though these reflectors may not be associated with sweepings deposits. However, time constraints and weather limited the ability to sample many of these acoustic reflectors. In general, 5 to 8 sediment samples were obtained from each major survey site.

Sediment samples were described, photographed, and transferred into gallon-size zip-lock bags for further analyses. Detailed grain size analyses were not performed, as additional sediment sampling is planned for the spring of 2007. However, all samples were sieved using a 75 µm mesh sieve to separate and characterize any sweepings deposits found within the sample. In many cases, coal, crushed stone, taconite, and shell material were found in the samples. The Appendix contains a summary of sample locations and analyses performed on the sediment samples.

SIDESCAN SONAR SURVEYS - Lake Superior

Based on an analysis of historical sweepings data, two survey sites were identified in western Lake Superior (Figure 8). The southern site is located near Duluth and is focused primarily on coal and iron (taconite) sweepings deposits. The northern site is located east of Silver Bay and is primarily an iron (taconite) site.

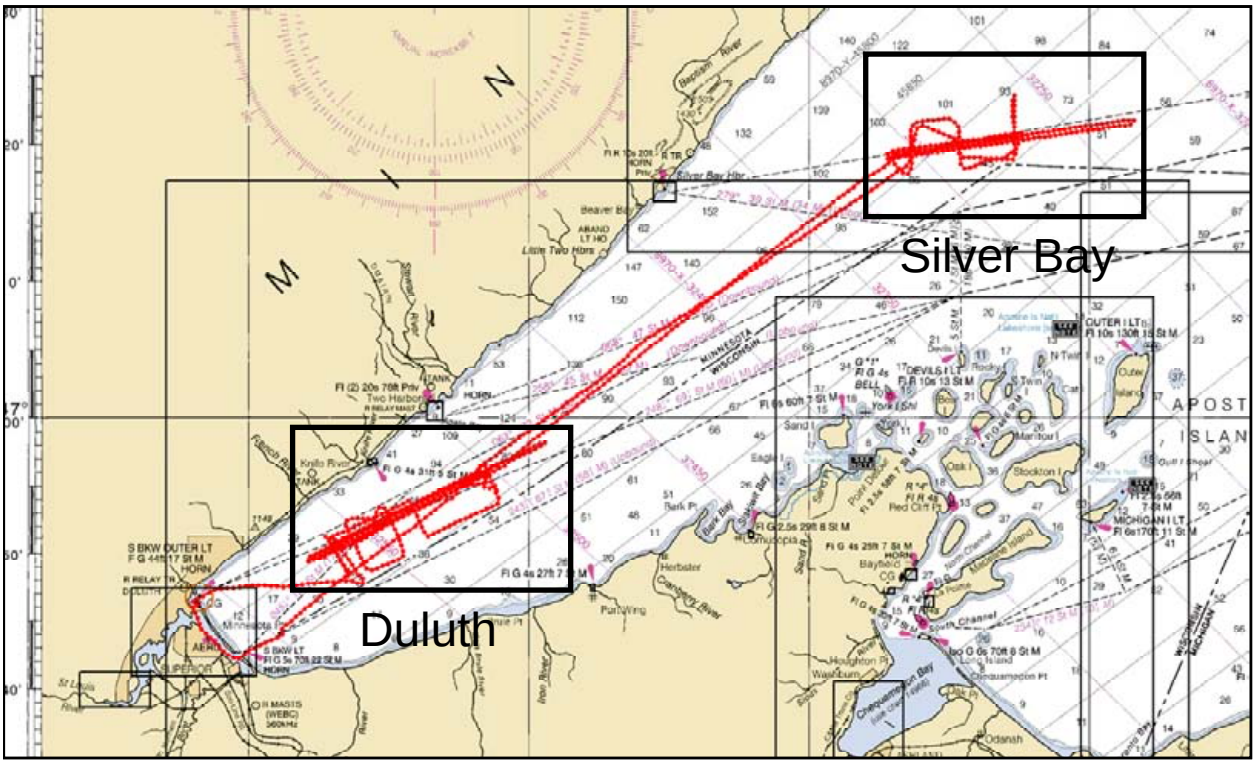


Figure 8 Navigation plot showing location of Lake Superior survey sites. The Duluth survey site is located northeast of Duluth, and the Silver Bay survey site is located east of Silver Bay.

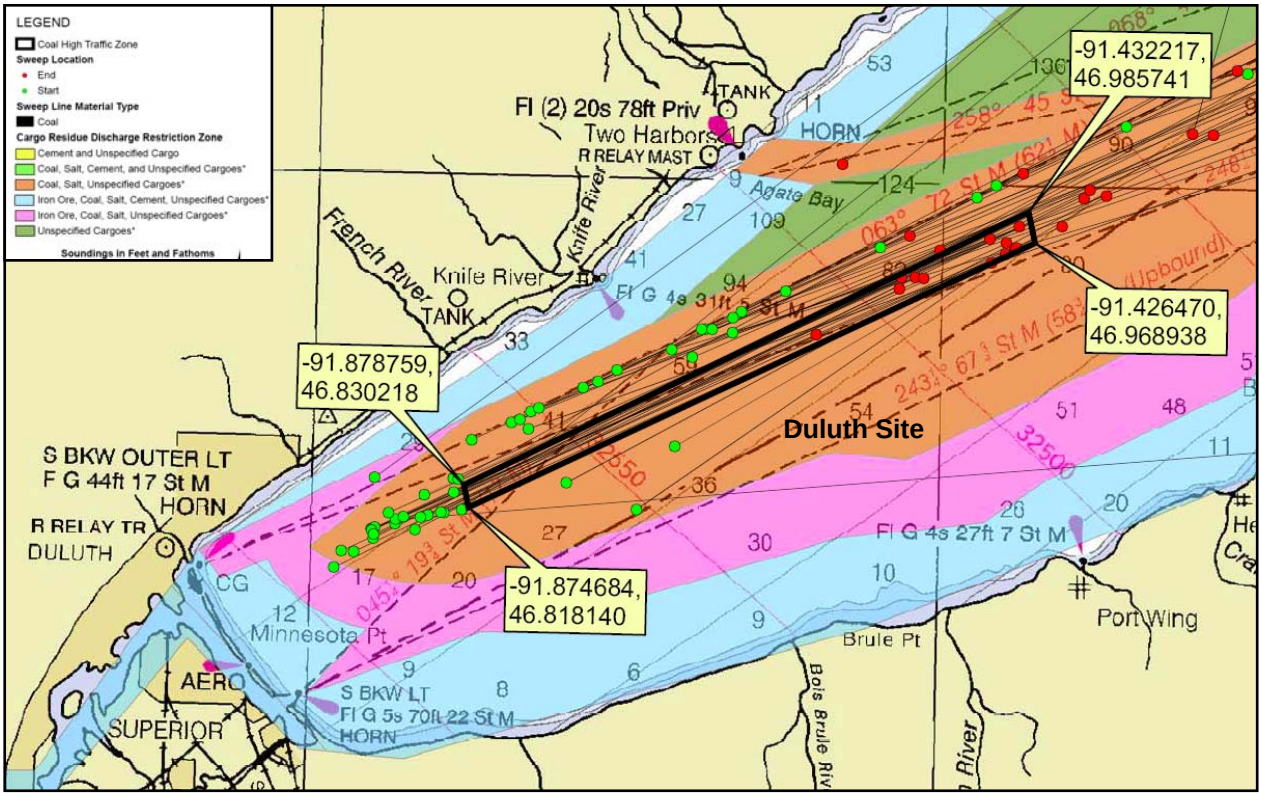


Figure 9a. Outline of Duluth survey site in Western Lake Superior showing sweepings activities and coverage densities.

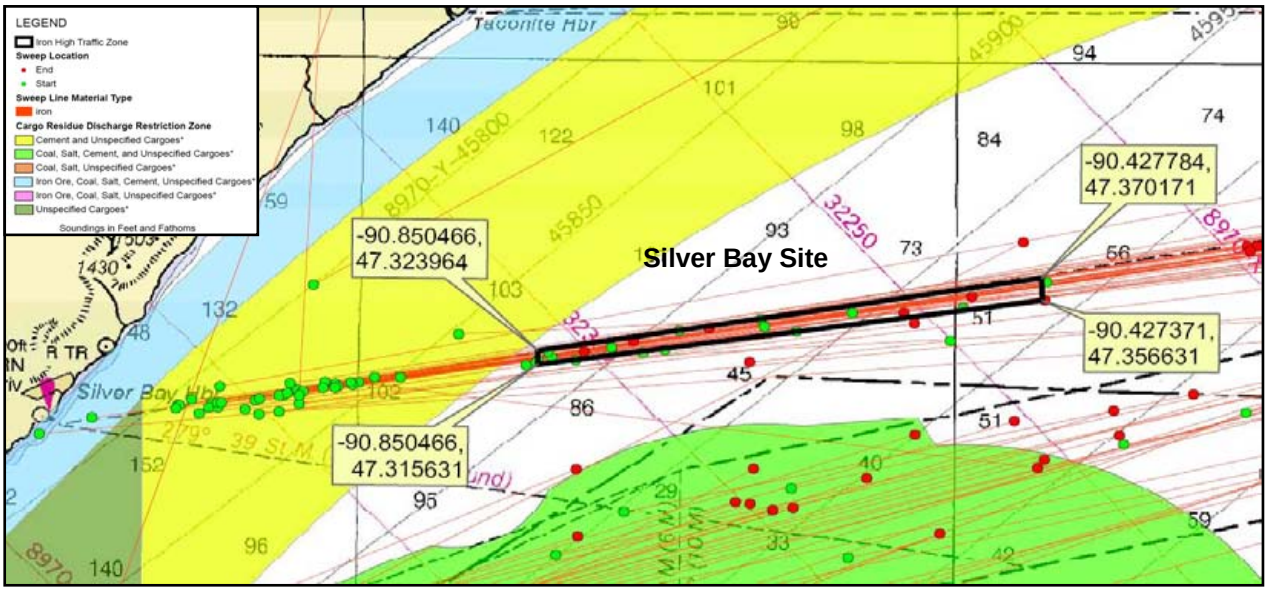


Figure 9b. Outline of Silver Bay survey site in Western Lake Superior showing sweepings activities and coverage densities..

Duluth Survey Site

A total of 81 nautical line miles (161 km) of sidescan sonar line data were acquired at this survey site. Approximately 31 square miles of lakebed were scanned. Sidescan data were acquired over approximately 65% of the designated survey area.

Multiple sidescan survey lines were run longitudinally within the designated Duluth survey site (Figure 10). Survey efforts focused in the western and central portions of the survey area where water depths were somewhat shallower and historical sweepings data suggested a higher concentration of sweepings deposits. Perpendicular survey lines were run to evaluate the regional distribution of sweepings deposits and identify potential reference sites (scale in meters).

Quality of the sidescan data from this site ranged from fair to good with multiple targets identified as possible sweepings deposits. Surface-water returns and surface wave effects degraded data quality in some areas. An initial comparison of low and high-frequency sidescan data revealed that many acoustic features do not show up on the high-frequency records. Most of the acoustic lakebed signatures were found in the low frequency 100 kHz records. Low frequency acoustic pulses have more energy, may penetrate further into the lakebed, and are less attenuated by the water column. Target densities (targets per line km) were low to moderate at this survey site.

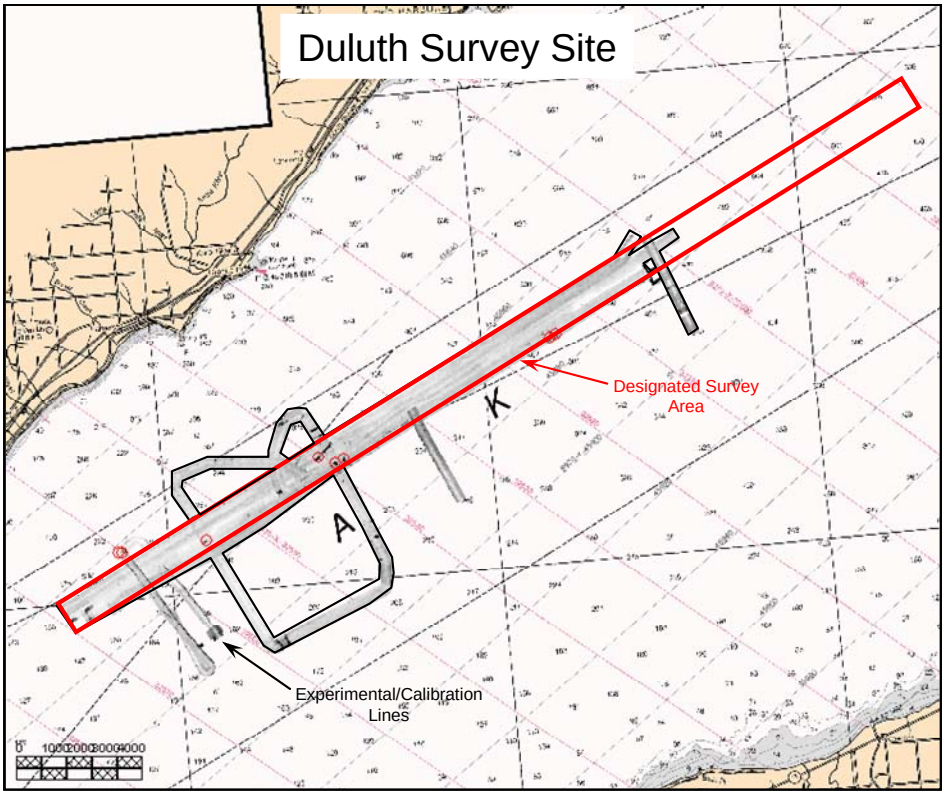


Figure 10. Sidescan sonar coverage within the Duluth survey area (scale in meters). The area outlined in red is the designated survey area. Approximately 65% of the total designated survey area was scanned. At the beginning of the field program, several experimental lines were run to test and calibrate the sidescan sonar and navigation equipment. Small red circles mark the location of areas sampled during the survey to assist with sidescan sonar data interpretation.

Silver Bay Survey Site

A total of 77 nautical line miles (143 km) of sidescan sonar data were acquired at this survey site. Approximately 27 square miles of lakebed were scanned. Sidescan data were acquired over approximately 90% of the designated survey area.

Multiple sidescan survey lines were run longitudinally within the designated Silver Bay survey area (Figure 11). After completing the first two longitudinal lines, a decision was made to concentrate our efforts in the western half of the survey area. Geological complexities in the eastern half of the survey area severely limited the ability to acoustically detect potential sweepings deposits. However, it is highly probable that sweepings deposits do exist in that area. Further investigation of the unusual geological features within the eastern half of the survey area may be of academic interest in the future.

Quality of the sidescan data from this site ranges from fair to good, as a strong surface-water return and surface wave effects significantly reduced the quality of the sidescan data, especially near the outer edge of the records. A large number of targets were identified as possible sweepings deposits. Complex repeating patterns were observed on the records and multiple targets were present throughout the entire western portion of the survey area. Most of the acoustic lakebed signatures observed in the western portion of the survey area were found in the 100 kHz records. Acoustic anomalies and target densities (targets per line km) were very high in the western portion of the survey area.

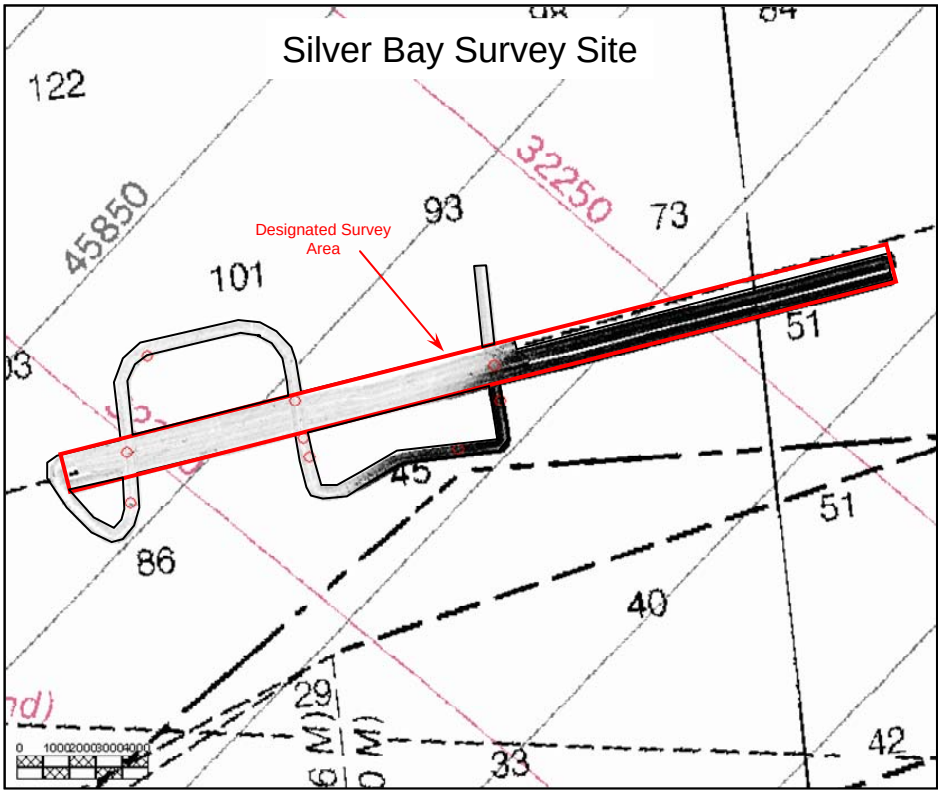


Figure 11. Sidescan sonar coverage within the Silver Bay survey area (scale in meters). Lakebed substrates (dark areas) to the east are geologically complex and sweepings deposits can not be detected or resolved in that area. The area outlined in red is the designated survey area. Approximately 90% of the total designated survey area was scanned.

SIDESCAN SONAR SURVEYS - Lake Michigan

Based on analysis of USCG sweepings data, two survey sites were selected in southern Lake Michigan. The Lake Michigan Primary site is located in south central Lake Michigan well north of the Indiana ship channel. The Lake Michigan Secondary site is located in shallow waters immediately north of the Indiana ship channel and breakwall.

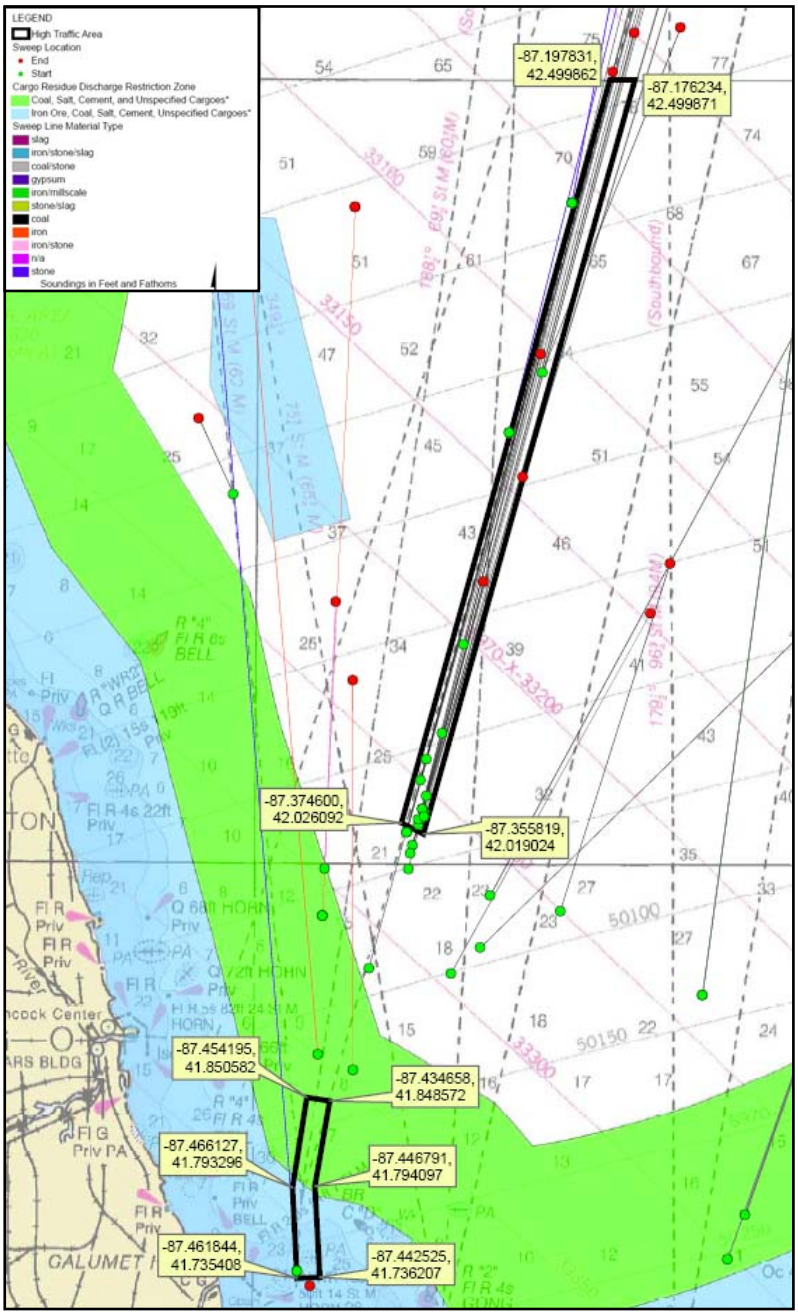


Figure 12. Outline of Lake Michigan Primary and Secondary survey sites showing locations along with historical sweepings activities and coverage densities.

Lake Michigan Primary Survey Site

A total of 107 nautical line miles (200 km) of sidescan sonar line data were acquired at this survey site. Approximately 38 square miles of lakebed were scanned. Sidescan data were acquired over approximately 60% of the designated survey area.

A single reconnaissance survey line was run longitudinally north to south down the center of the designated survey area (Figure 13). Based on observed lakebed characteristics and the distribution of potential sweepings deposits in this reconnaissance line, additional sidescan data were collected in the southern third of the survey area. Perpendicular survey lines were run to assess potential changes in sweepings distribution relative to the Lake Carrier Association (LCA) shipping lanes.

Quality of the sidescan data is good, even though surface-wave effects locally reduce the quality of the sidescan data, especially near the outer edge of the records. Complex repeating patterns were observed locally and multiple targets were present within the main area surveyed. Acoustic anomalies and target densities (targets per line km) are low to moderate in the southern portion of the survey area. Lakebed substrates in the extreme southern edge of the survey area are geologically complex (dark area, Figure 13), and acoustic anomalies associated with sweepings deposits were not detected or resolved in those areas.

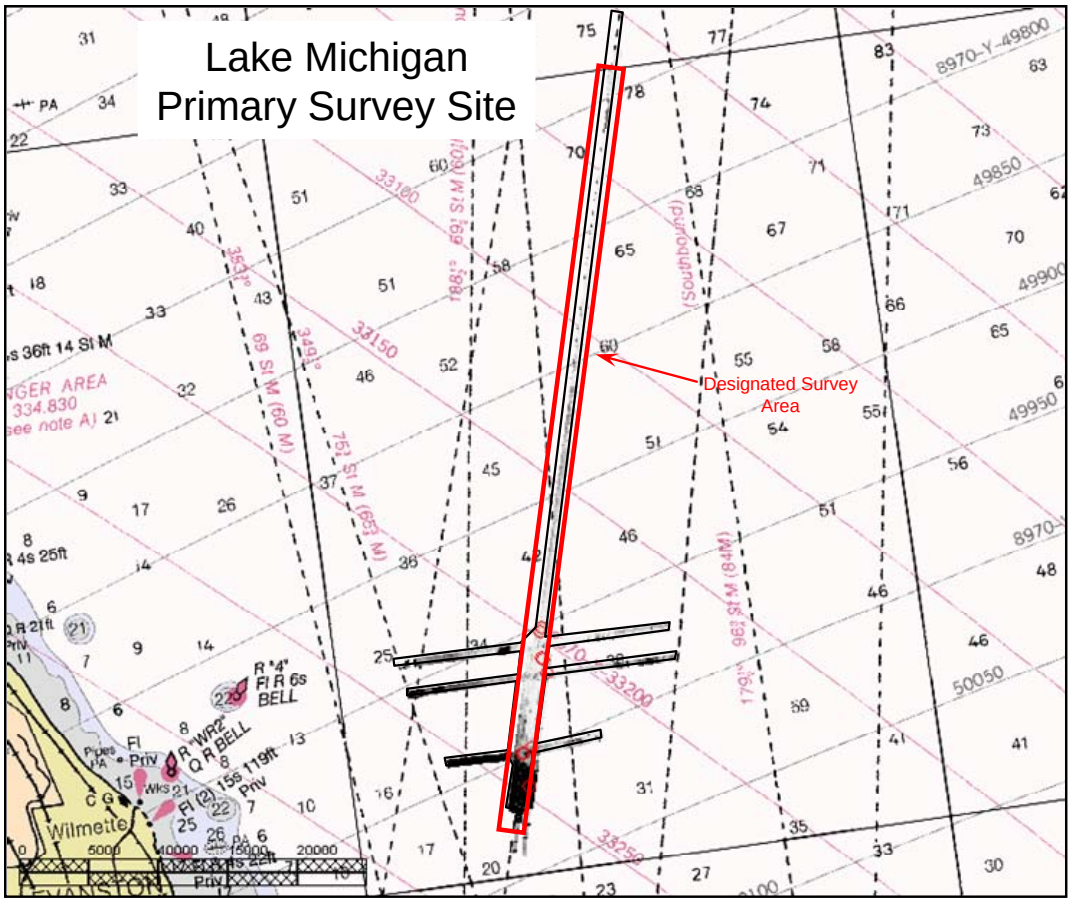


Figure 13. Sidescan sonar coverage within the Lake Michigan Primary survey area (scale in meters). The area outlined in red is the designated survey area. Approximately 60% of the total designated survey area was scanned.

Lake Michigan Secondary Survey Site

A total of 31 nautical line miles (58 km) of sidescan sonar line data were acquired at this survey site. Approximately 11 square miles of lakebed were scanned. Sidescan data were acquired over approximately 80% of the designated survey area.

Four shallow-water reconnaissance survey lines were run longitudinally down the center of the Lake Michigan Secondary survey area (Figure 14). No apparent sweepings deposits were observed. Complex lakebed geology and mobile substrates make detection of sweepings deposits difficult. It is likely that sweepings materials (if present) were incorporated into the large mobile sand sheets that blanket this area.

Quality of the sidescan data is good, even though surface wave effects locally reduce the quality of the sidescan data. The last two lines were abandoned in favor of acquiring additional ground-truth data from the Lake Michigan Primary survey site.

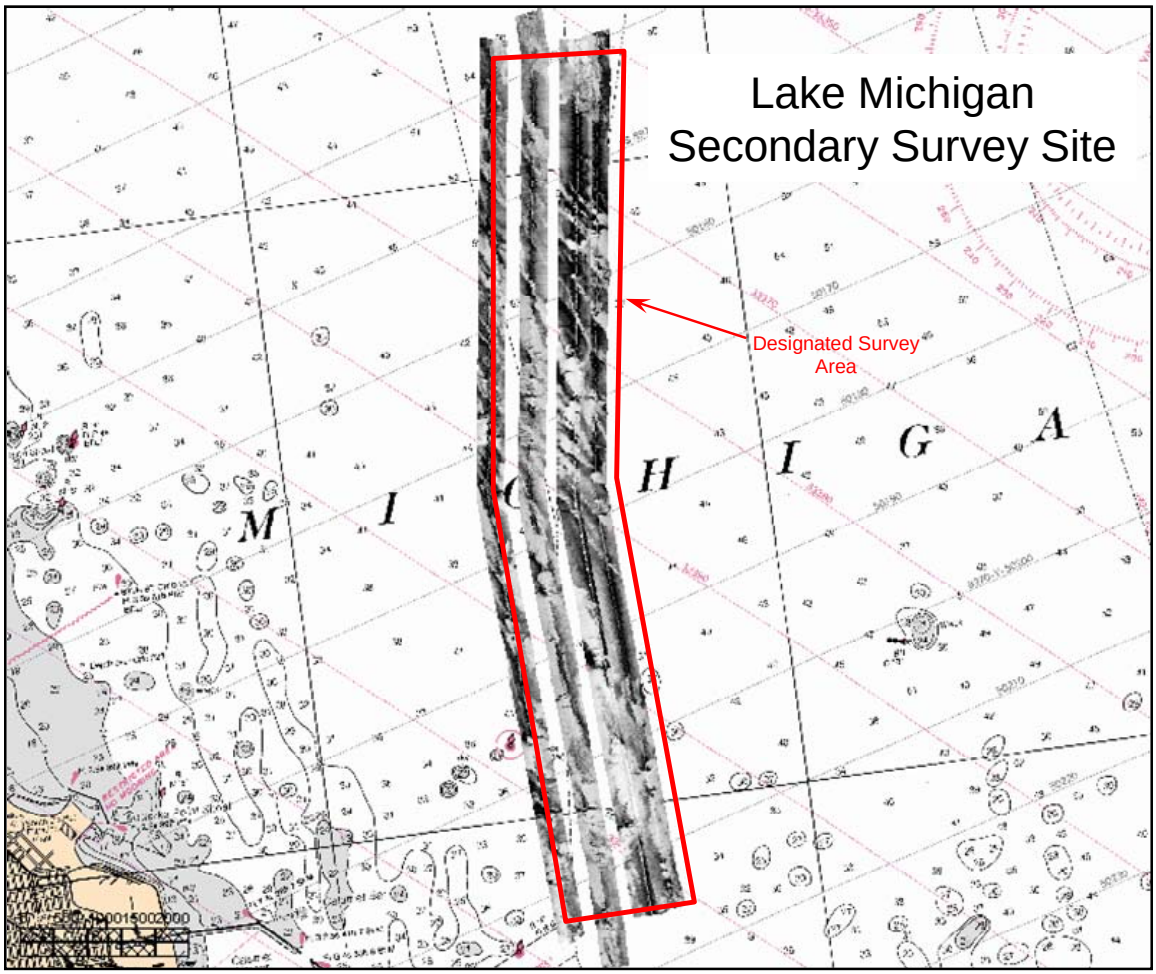


Figure 14. Sidescan sonar coverage within the Lake Michigan Secondary area (scale in meters). The area outlined in red is the designated survey area. Approximately 80% of the total designated survey area was scanned.

SIDESCAN SONAR SURVEYS - Lake Erie

Based on analysis of USCG sweepings data, two survey sites were selected in the western portion of the Central Basin of Lake Erie. The Lake Erie Primary site is located directly north of Cleveland, Ohio. The Lake Erie Secondary site is located northeast of Sandusky and northwest of Vermillion (Figure 15). A third site was located to the east of the primary site, but was not sampled due to time and weather constraints. Shallow water depths and the Lake Erie Islands constrain how and where large commercial ships transit the western and central basins of Lake Erie.

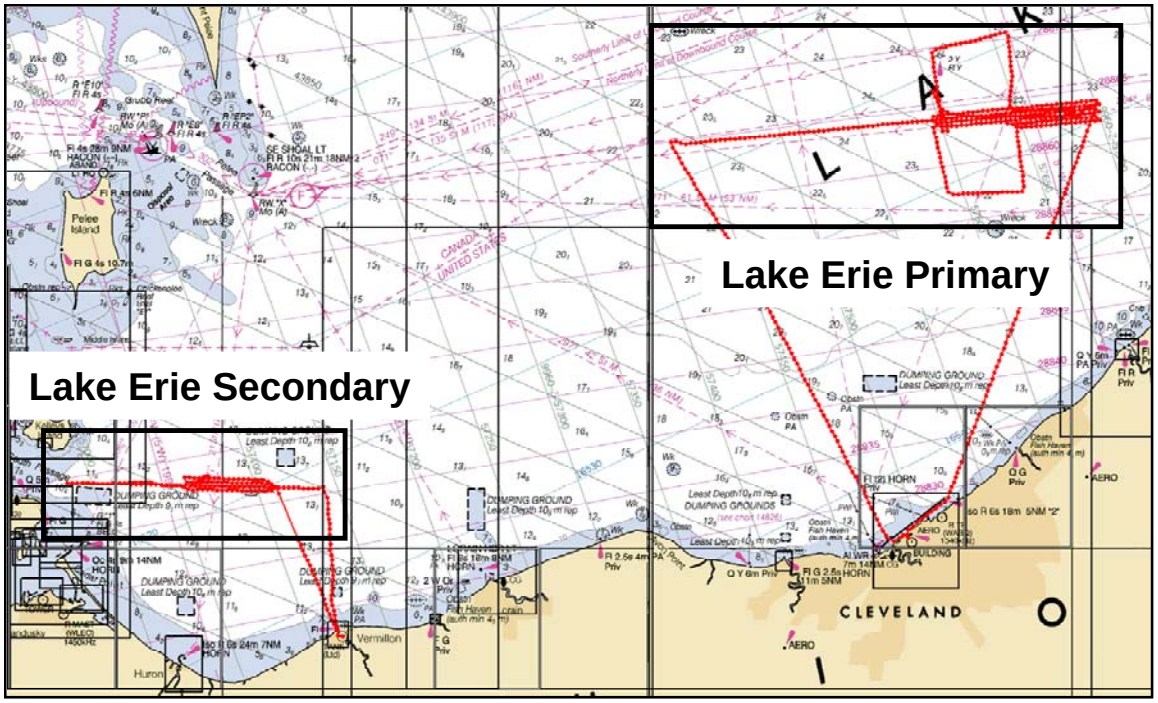
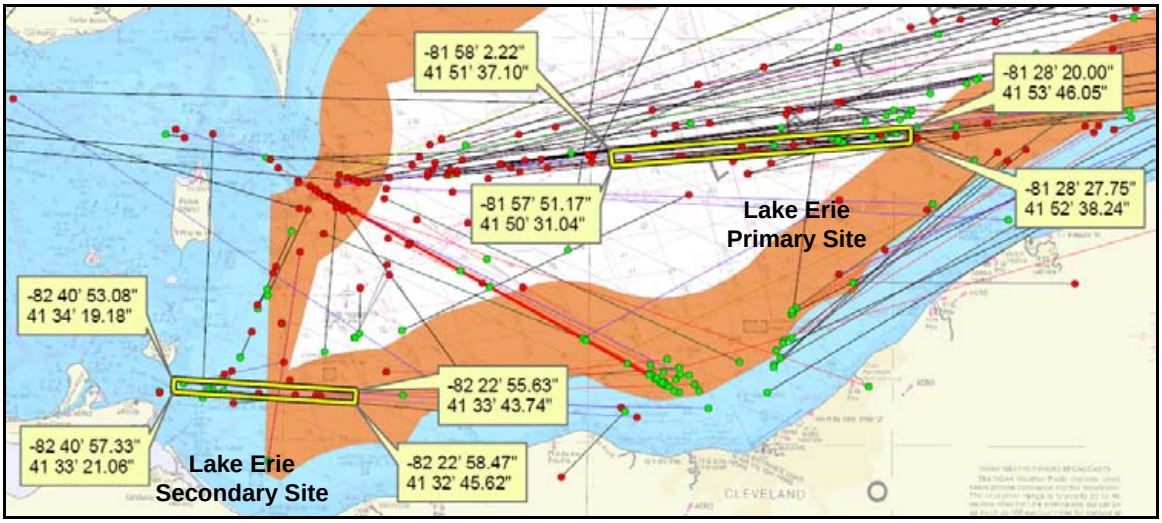


Figure 15. Navigation plot showing location of Lake Erie survey sites.



Cleveland

Figure 16. Outline of Lake Erie Primary and Secondary survey sites showing locations along with historical sweepings activities and coverage densities.

Lake Erie Primary Survey Site

A total of 82 nautical line miles (152 km) of sidescan sonar line data were acquired at this survey site. Approximately 29 square miles of lakebed were scanned. Sidescan data were acquired over approximately 60% of the designated survey area.

A single reconnaissance survey line was run longitudinally west to east down the center of the Lake Erie Primary survey area (Figure 17). Based on observed lakebed characteristics and distribution of sweepings deposits, additional sidescan data were collected in the eastern portion of the survey area.

Quality of the sidescan data is fair to poor due to severe surface wave effects that affect data quality. Several acoustic anomalies and targets were identified as possible sweepings deposits, and they were widely distributed across the eastern portion of the survey area. The acoustic response is similar to Lake Superior, where most of the acoustic lakebed signatures are found in the 100 kHz records. Acoustic anomalies and target densities (targets per line km) are moderate to low throughout most of the survey area.

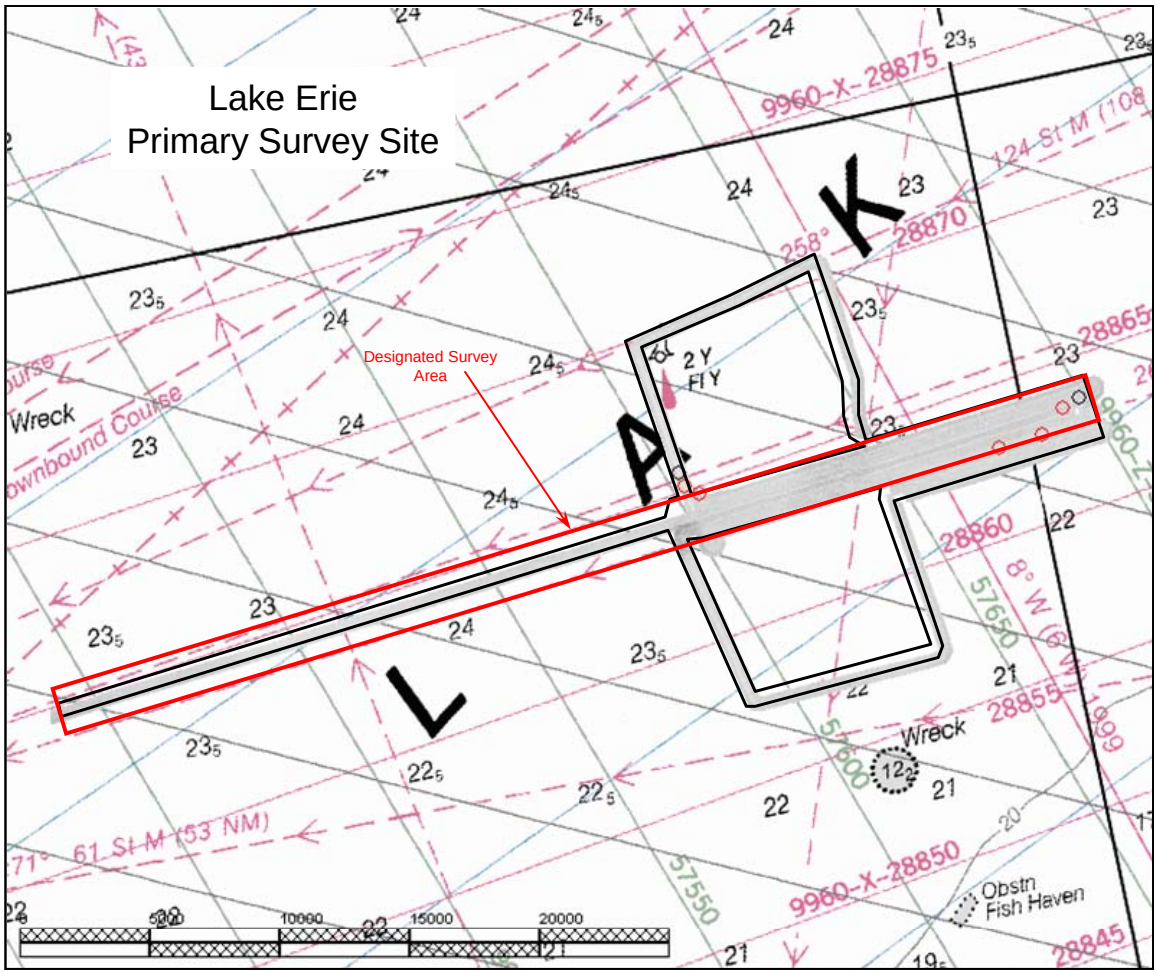


Figure 17. Sidescan sonar coverage within the Lake Erie Primary survey area (scale in meters). The area outlined in red is the designated survey area. Approximately 60% of the total designated survey area was scanned.

Lake Erie Secondary Site

A total of 37 nautical line miles (69 km) of sidescan sonar line data were acquired at this survey site. Approximately 13 square miles of lakebed were scanned. Sidescan data were acquired over approximately 50% of the designated survey area.

A single reconnaissance survey line was run longitudinally east to west down the center of the Lake Erie Secondary survey area (Figure 18). Based on observed lakebed characteristics and distribution of sweepings deposits, additional sidescan data were collected in the eastern and central portions of the survey area.

The sidescan data are of good to excellent quality. A significant number of targets were identified as possible sweepings deposits. Complex repeating patterns were observed in the records and multiple targets are present throughout the central and eastern portions of the survey area. Target densities (targets per line km) range from moderate to high in the central and eastern portions of the survey area.

This site may also contain hopper-dredge deposits that are similar in character to smaller dry-bulk cargo sweepings deposits. Some of the semi-circular deposits extend several 10's of meters across suggesting deposition of a significant volume of material. These deposits may be hopper-dredge deposits rather than dry bulk cargo sweepings deposits. Additional sampling and historical analyses may be required to determine the origin of these materials.

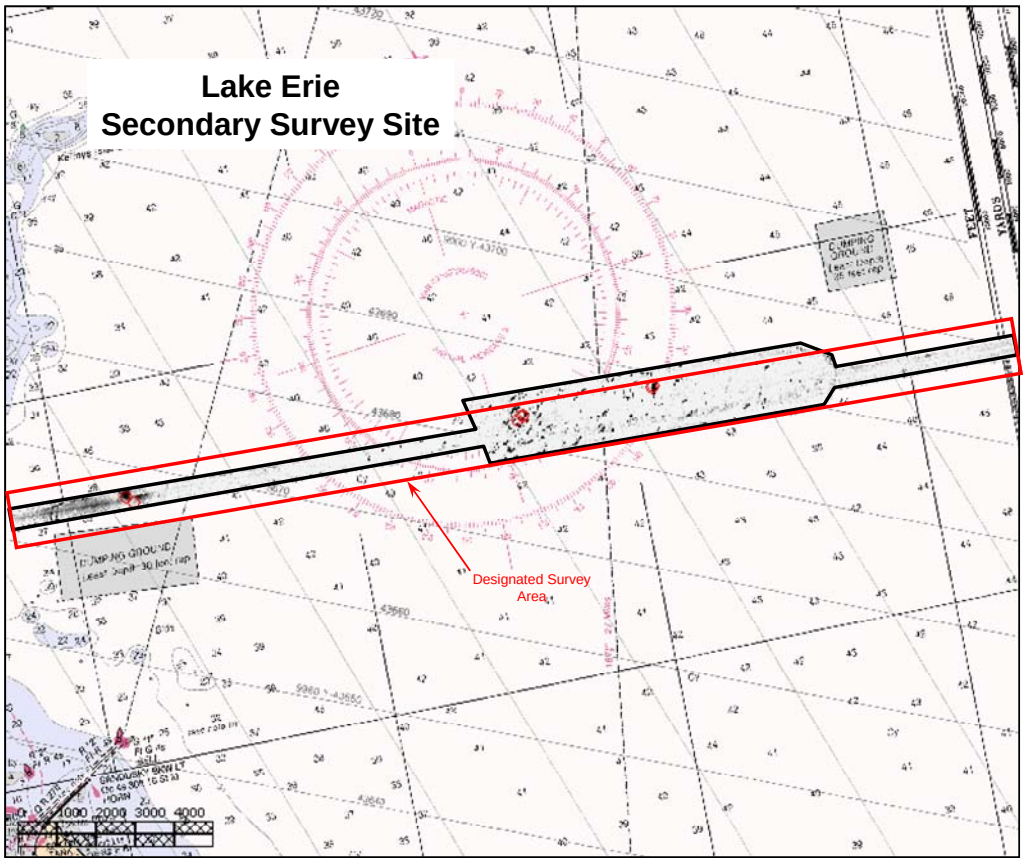


Figure 18. Sidescan sonar coverage within the Lake Erie Secondary survey area (scale in meters).

INTERPRETATION AND ANALYSES

Acoustic Signatures of Sweepings Deposits

Previous researchers have used sidescan sonar to identity and map acoustic backscatter anomalies associated with deposits derived from cargo sweeping operations of dry bulk cargo carriers on the Great Lakes (see summaries by Ferrini and Flood 2001; Cameron and Lewis 1994; Mayer *et al*. 1994). Ferrini and Flood described a range of acoustical shapes, sizes, and patterns associated with sweepings deposits; ranging from long, narrow, linear features extending more than 1500 m on the lakebed; irregularly shaped (wispy) features with diffuse edges; large semi-circular features up to 30 m in diameter; and elongate features made up of distinct semi-circular deposits up to 10 to 15 m in diameter.

For comparison purposes, the sidescan sonar data collected for this study are presented using a grey-scale pallet similar to that used by earlier investigators where a dark or black signature represents an acoustically hard backscatter response. Published images and descriptions of these backscatter anomalies show many of the same features observed in the sidescan sonar data collected during the recent surveys on Lakes Superior, Michigan, and Erie (for example, see Figure 19 below)

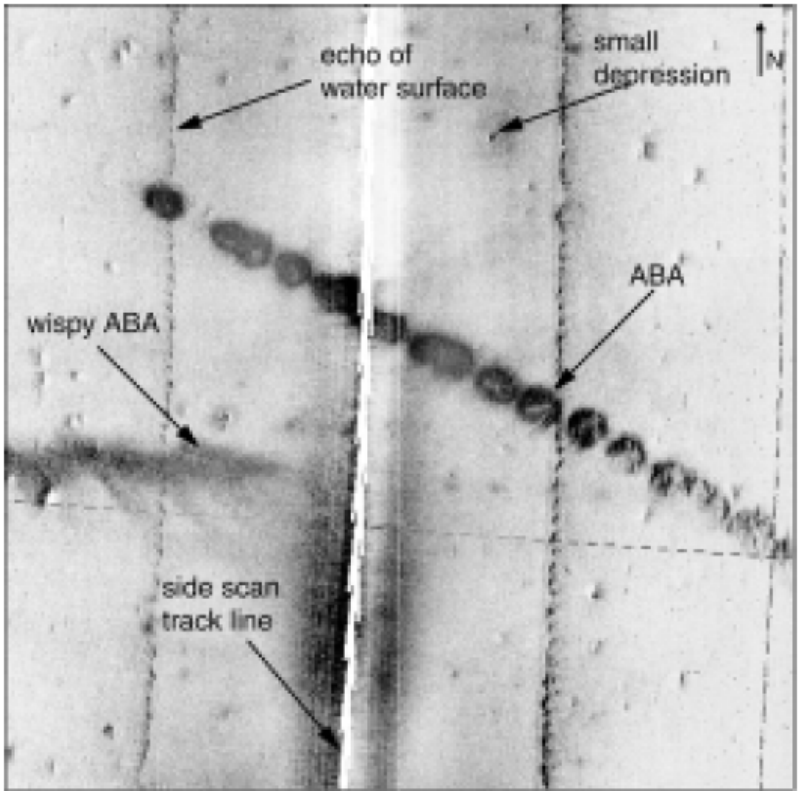


Figure 19. Example of published acoustic backscatter anomalies (ABA) from the bed of Lake Ontario. These features were identified as sweepings deposits based on sample data acquired using a Remotely Operated Vehicle (ROV) and underwater photography. Water depth is 51 m. The main acoustic feature trending from the northwest to the southeast is approximately 175 m long and 10 m wide. Each of the sub-circular features is approximately 10 m in diameter. (from Figure 2, Ferrini and Flood 2001).

Acoustic Classification

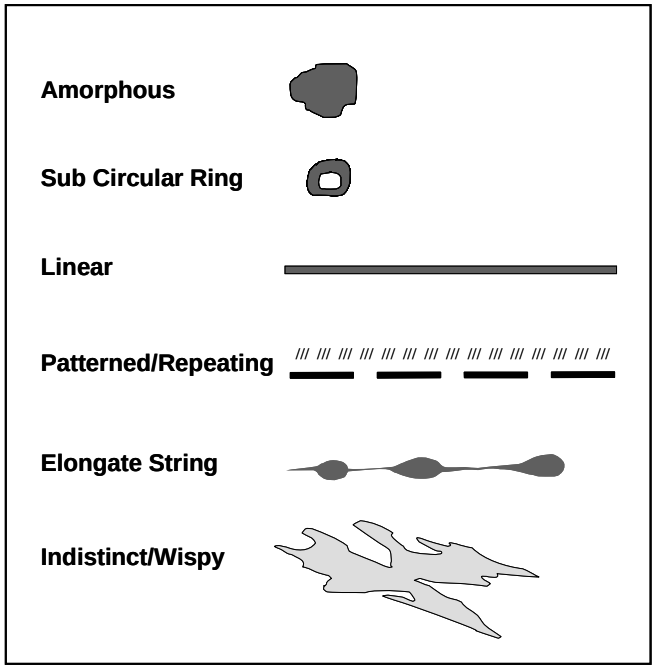
Based on an analysis of the acoustic anomalies observed in this study, a preliminary classification of acoustic backscatter patterns has been developed. This classification is based primarily on the shape, pattern, orientation, and strength of the acoustic backscatter response (Table 1).

Table 1. Acoustic Backscatter Classification Elements and Attributes

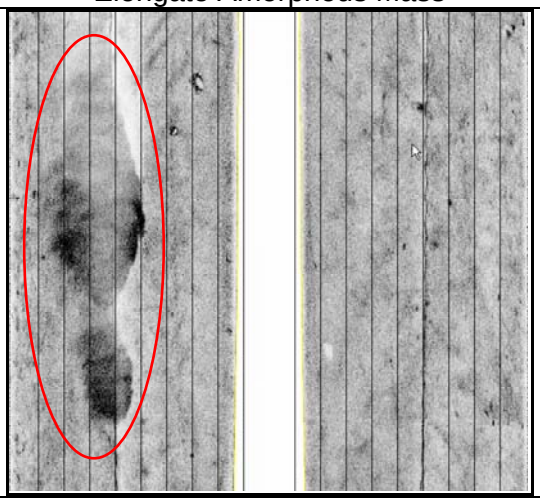
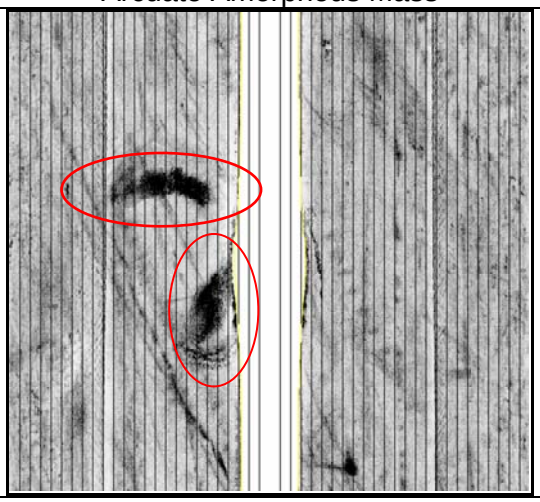
	Attributes		
Classification Elements	*Density (number)*	*Distribution*	*Dimensions (width or diameter)*
Shape	Individual or Group	Isolated or Connected	Small (< 5 m), Medium (5 to 20 m) Large (>20 m)
Pattern	Individual or Group	Random or Repeating	Uniform or Variable
Orientation	Individual or Group	Random or Parallel	Uniform or Variable
Acoustic Response	Strong or Weak	Uniform or Patchy	n/a

Using these classification elements, backscatter acoustic anomalies related to sweepings deposits can be grouped into at least six different types or feature classes based primarily on shape and pattern (Table 2). Acoustic anomalies vary in size and orientation, and it can be can reasonably be assumed that the shape and pattern of these anomalies are controlled by a combination of the type and amount of material released, the method of release, the water depth in which the release occurs, and the direction and speed of vessel movement. In other words, the shape and pattern of these anomalies has the potential to provide some insight into the processes and mechanics of release. Examples of each class or pattern are presented in the scale-corrected waterfall displays below.

Table 2. Basic Shapes of Potential Sweepings Deposits

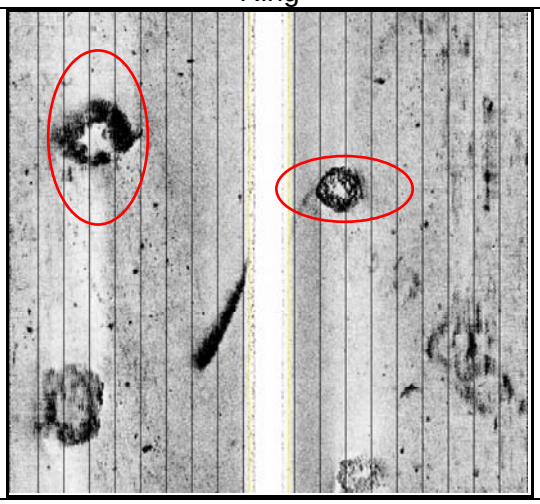
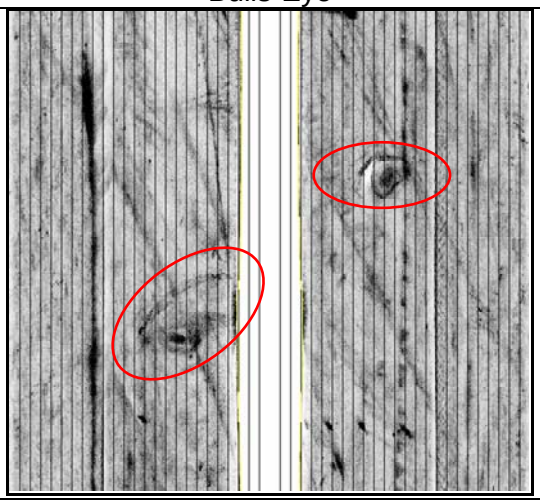


1. Amorphous Mass

Elongate Amorphous Mass	Arcuate Amorphous Mass
	
Lake Michigan Primary Site (200 m)	Silver Bay Site (500 m)

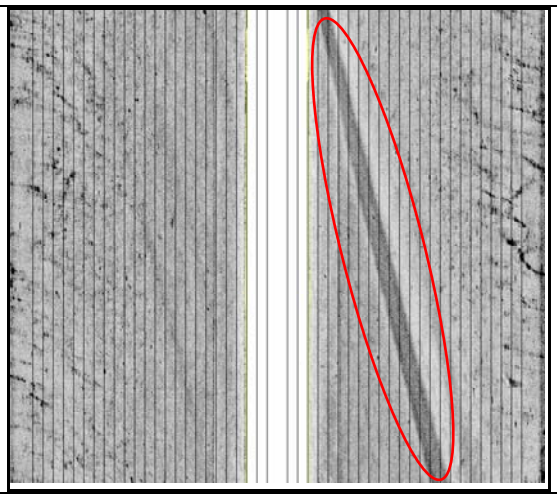
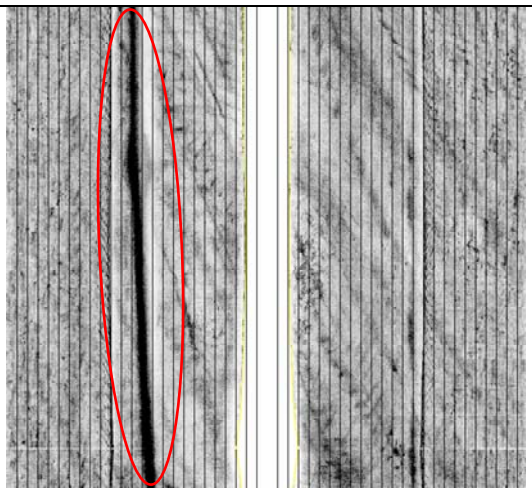
Amorphous masses may be circular, elongate, tear drop, arcuate, or irregular in shape. They are found within a broad range of water depths and substrates, and may exhibit a uniform or patchy acoustic backscatter signature. These features were observed at all of the sites surveyed, except at the Lake Michigan Secondary site where few sweepings deposits were observed.

2. Sub Circular Rings (Ferrini and Flood 2001)

Ring	Bulls-Eye
	
Lake Erie Secondary Site (200 m)	Silver Bay Site (500 m)

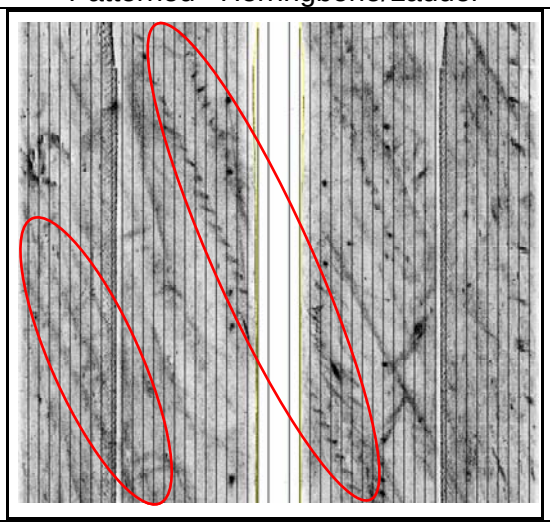
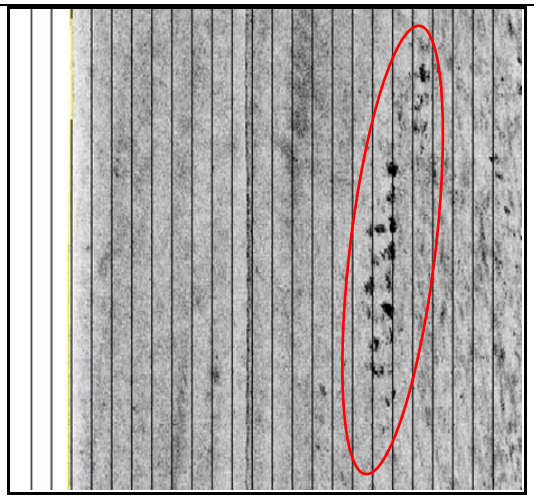
Sub-circular ring anomalies may have characteristics that are analogous to impact craters, and may have several concentric or asymmetric rings associated with the main feature. These features typically exhibit some relief with the outer edge of the ring typically elevated relative to the lakebed. Bulls-eye structures are typically elongate and may be asymmetric. Sub-circular ring shaped acoustic anomalies were observed at the Silver Bay, Lake Michigan Primary, and Lake Erie Secondary sites.

3. Linear

Linear - Uniform	Linear - Uniform
	
Duluth Site (500 m)	Silver Bay Site (500 m)

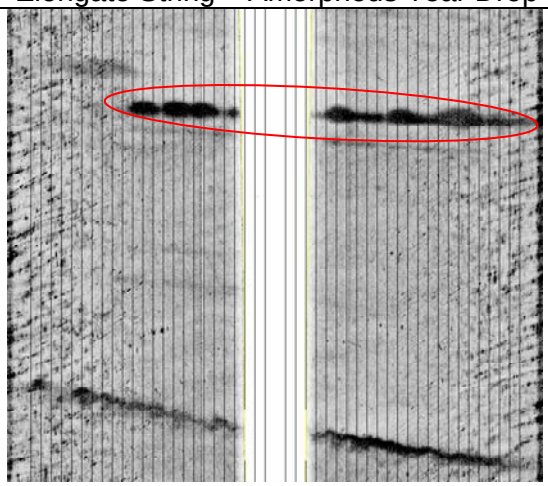
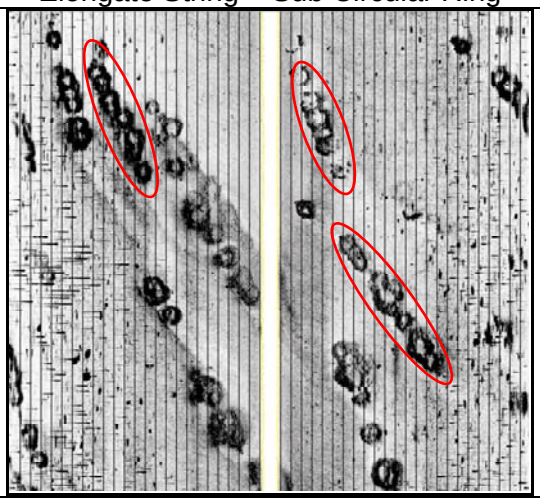
Linear anomalies were observed at all of the sites surveyed, except at the Lake Michigan Secondary site where few sweepings deposits were observed. These features may extend only a few 10's of meters in length to more than 1500 meters on the lakebed. Width is typically 10 to 20 m and may be uniform or vary along the length of the anomaly.

4. Patterned/Repeating

Patterned –Herringbone/Ladder	Patterned – Curvilinear Dot
	
Silver Bay Site (500 m)	Lake Erie Secondary Site (250 m)

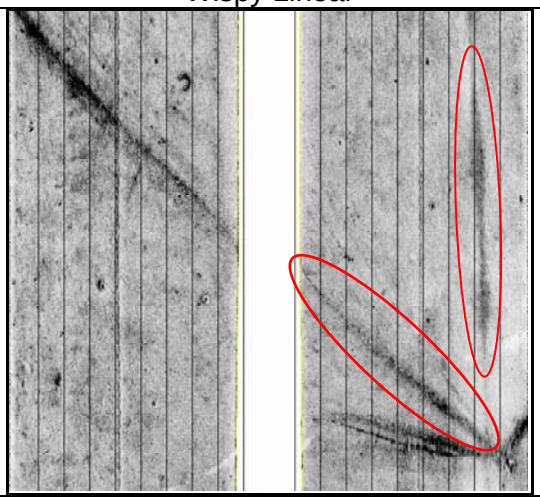
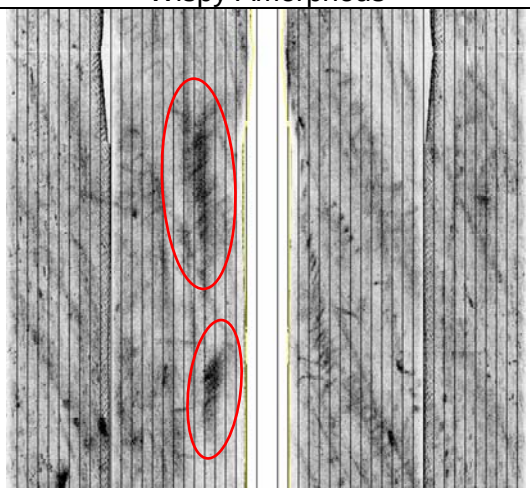
Patterned features typically consist of small acoustic anomalies that are spatially repeated along a preferred path on the lakebed. The spacing and pattern are likely controlled by the mechanism and frequency of release, type and amount of material released, vessel size and speed, and water depth. The orientation of the individual anomalies may vary but the path along which those anomalies occur will likely be the same as the vessel that produced it.

5. Elongate String (Ferrini and Flood 2001)

Elongate String – Amorphous Tear Drop	Elongate String – Sub Circular Ring
	
Duluth Site (500 m)	Lake Erie Secondary Site (500 m)

Elongate acoustic backscatter anomalies were observed at all of the sites surveyed, except at the Lake Michigan Secondary site where few sweepings deposits were observed. These features typically contain multiple individual acoustic anomalies that overlap one another and/or are linked together to form a larger interconnected acoustic feature.

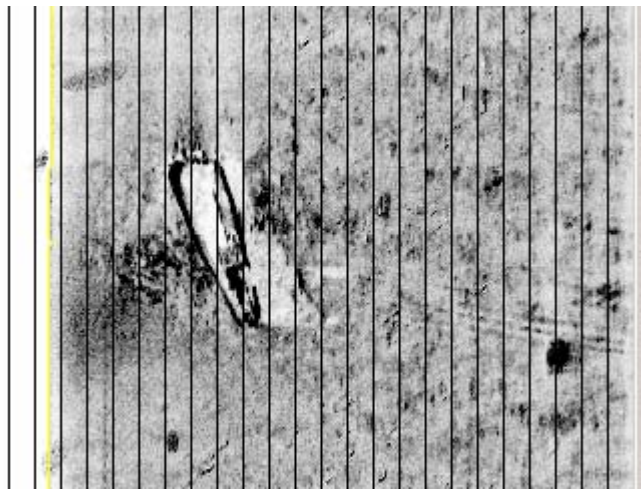
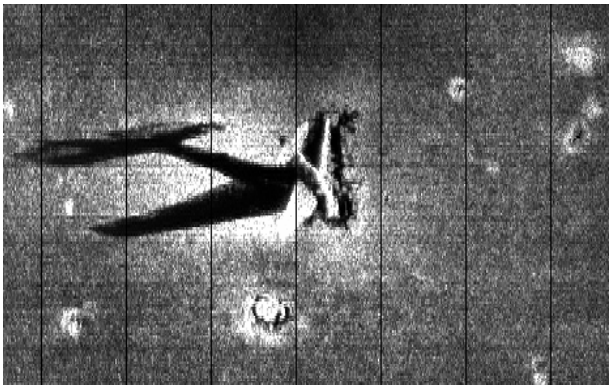
6. Indistinct/Wispy

Wispy Linear	Wispy Amorphous
	
Duluth Site (100 m)	Silver Bay Site (500 m)

Even though many acoustic anomalies found on the lakebed are of the types described above, there are acoustic patterns that do not fit easily into a classification scheme. These features are acoustically complex and may contain multiple acoustic elements. Sweepings materials may be deposited over a wide area yielding very low densities (per square meter) on the lakebed. These low-density deposits may produce a detectable, but weak, backscatter response that would be described as “indistinct” or “wispy” when interpreted on the sidescan sonar data

record. Moreover, these materials may have been deposited many decades ago, and subsequent sedimentation may have buried these deposits under a veneer of fine-grained lacustrine sediments. As burial depth increases, the ability of the sidescan tool to detect a backscatter response diminishes rapidly resulting in a weak acoustic response.

7. Anthropogenic

Shipwreck	Airplane
	
Duluth Survey Site	Lake Michigan Primary Site

Anthropogenic materials were also detected on the lakebed. At the Duluth survey site, a shipwreck on the bed of Lake Superior was imaged in one of the perpendicular survey lines. While collecting high-resolution data, an airplane was imaged sticking straight out of the bottom in 240 feet of water on the bed of Lake Michigan. The dark area is the acoustic shadow cast by the fuselage and tail of the plane

Frequency and Burial Depth

It is also clear from the literature that dual frequency sidescan sonar may be of use when evaluating the age of the anomaly. Ferrini and Flood (2001) described how their Klein 595 dual frequency sidescan sonar was able to detect not only surface deposits, but near-surface and sub-surface deposits as well. Surface deposits are exposed and visible on the lakebed. Near-surface deposits are materials that are within the upper 3 to 5 cm of the lakebed; and sub-surface deposits are generally deeper than 5 cm.

Experimental work in Lake Ontario by Ferrini and Flood (2001) suggests that both low- and high-frequency sidescan sonar signals will penetrate fine-grained sediments, albeit to differing depths. Their calculations suggest that a 100 kHz sidescan sonar towfish <u>may</u> be able to detect subsurface deposits at depths greater than 20 cm below the sediment-water interface. A 500 kHz towfish <u>may</u> be able to detect deposits as much as 5 to 18 cm below the sediment-water interface. Analysis of the sidescan data collected at the Duluth survey Site and the western portion of the Silver Bay survey site shows that the high-frequency signal does not readily penetrate the lakebed and that features that do show up on the high-frequency records are probably at the surface and/or in the near-surface (Figure 20).

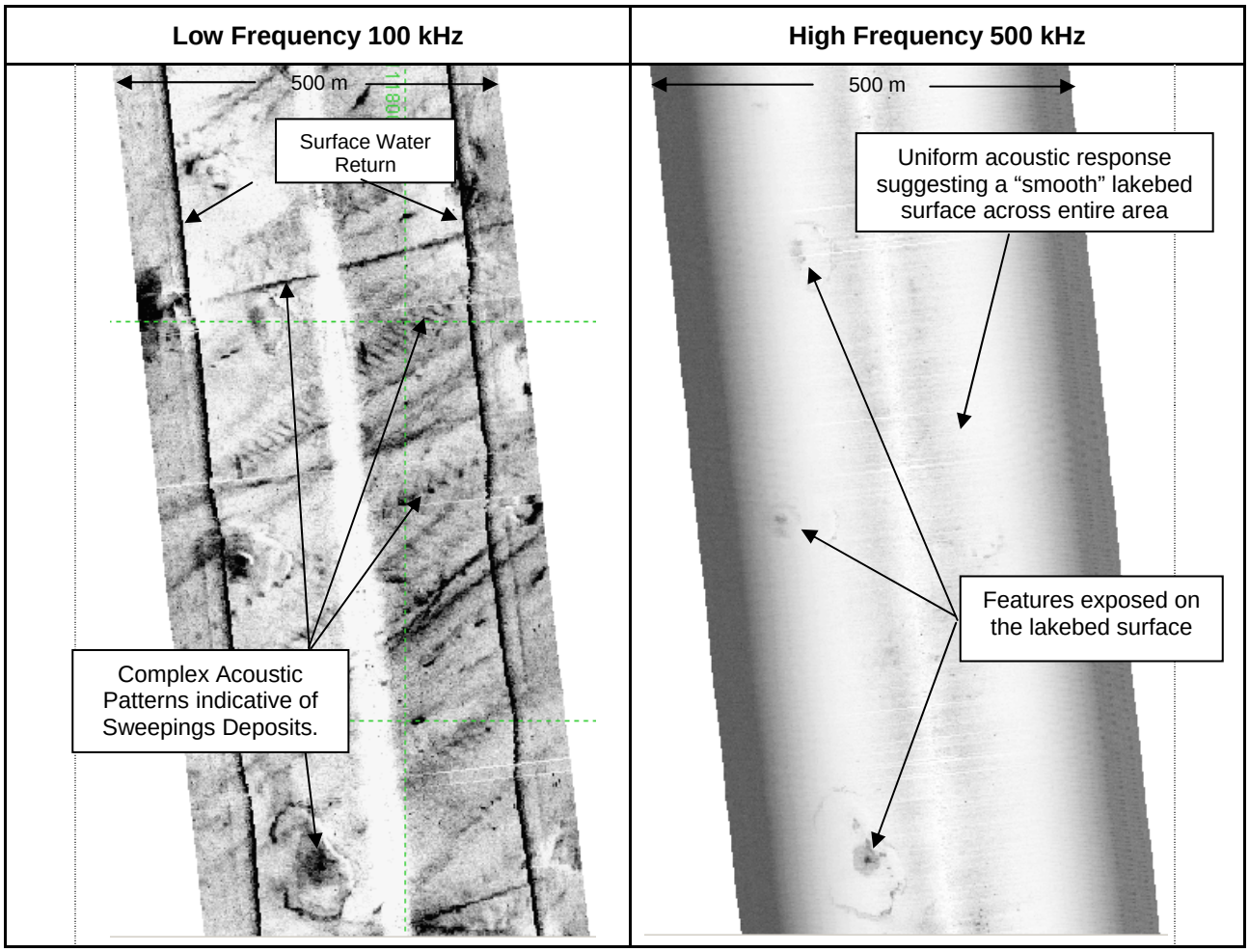


Figure 20. Example comparison of 100 kHz (left) and 500 kHz (right) mosaicked sidescan sonar data records from the Silver Bay Survey site. Note numerous linear backscatter anomalies and targets on the 100 kHz record and uniform acoustic response over the same area on the 500 kHz record. These data (and associated Petite Ponar grab samples) imply that the numerous complex patterns observed in the 100 kHz record are derived from predominately historical sweepings deposits that may be buried by a thin veneer of fine-grained sediment.

These differences in observed acoustic signatures for different sonar frequencies can be explained by the fact that over time, the sweepings deposits are buried by accumulating soft sediment. The low frequency acoustic signal penetrates this thin veneer of sediment and detects the underlying sweepings deposits. The high frequency acoustic signal does not penetrate this thin veneer of sediment and can detect only surface or near-surface features exposed on the lakebed (Figure 21).

In areas where numerous complex patterns are observed in the 100 kHz record, it is likely that the acoustic backscatter response is derived from predominately "historical" sweepings deposits that may be buried by at least 5 to 10 cm of fine-grained sediment. However, the actual depth of these deposits can not be determined from the sidescan sonar records, and additional sampling would be required to evaluate the threshold depth at which the high frequency signal no longer generates an acoustic backscatter response. Ideally, a sampling device capable of retrieving sediment cores would be required to perform this analysis.

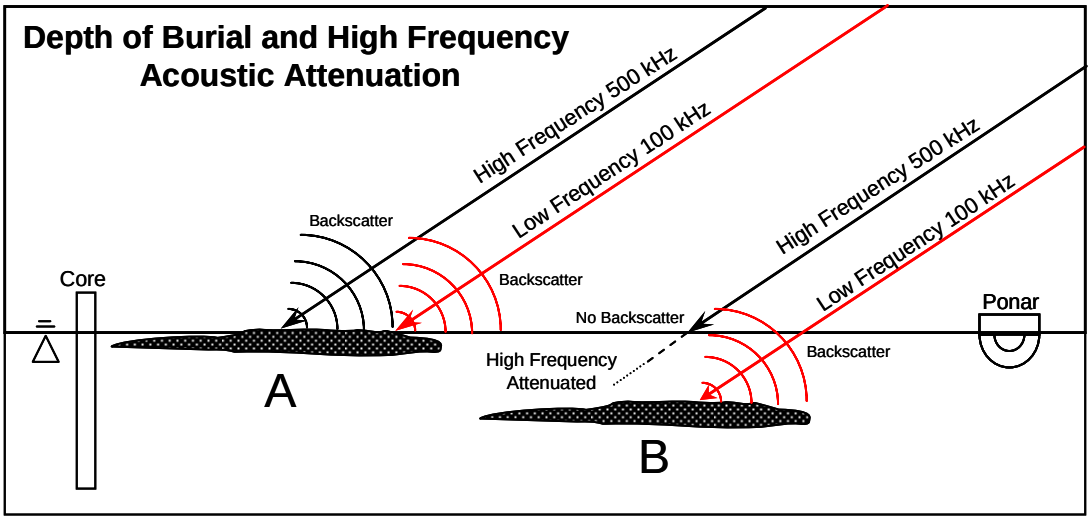


Figure 21. Fine-grained sediments attenuate high-frequency backscatter 5 to 10 cm below the sediment water interface (e.g. Ferrini and Flood 2001). Surface or near-surface sweepings deposits will generate acoustic backscatter anomalies in both the low and high-frequency records. Sub-surface (buried) deposits may only be seen in the low-frequency records.

The distribution and burial of sweepings deposits may have important implications for sediment sampling and the identification of reference or "natural" lakebed deposits.

Based on the information obtained during this study, future sampling locations can be selected with a high degree of confidence by using the high-frequency sidescan records to identify areas where sweepings deposits are present on the surface of the lakebed. The presence of more extensive acoustic backscatter anomalies in the low-frequency sidescan sonar records <u>at the same location</u> provides additional support for the presence of sweepings deposits at depth.

This approach was tested on October 2006 in Lake Superior. Sediment samples taken during water quality testing at four locations at the Duluth survey site confirm the validity of this approach. Three of these sites are located in areas with strong acoustic anomalies present in both the 100 and 500 kHz records. For example, sites 3 and 4 were sampled using a shallow coring device to confirm the presence of sweepings deposits (Figure 22). Core samples taken from these locations yielded abundant near-surface taconite and coal deposits (Figure 23). Samples from a nearby "reference" area that is devoid of acoustic anomalies did not contain any sweepings materials.

Moreover, comparison of low and high-frequency sidescan sonar records can be used to identify areas where sediment deposition rates are higher and/or historical sweepings deposits are buried at depth. Determining the age of these deposits is problematic, as direct sampling (core data) is required to accurately establish depth of burial. Age of the deposits can then be calculated if sedimentation rates are known (e.g. Evans et al. 1981; Kemp et al. 1978).

Duluth Water Quality Sampling Sites

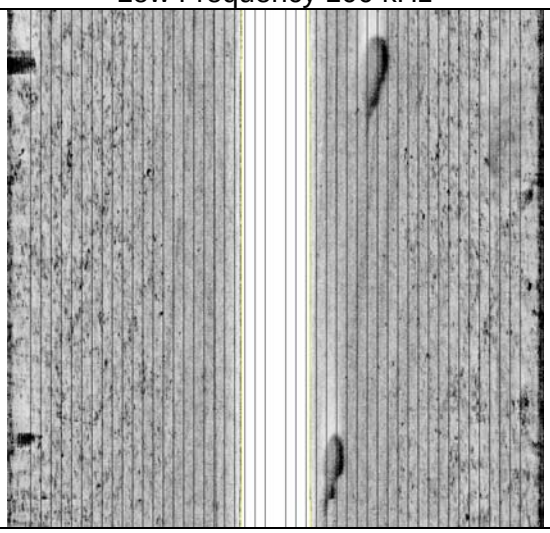
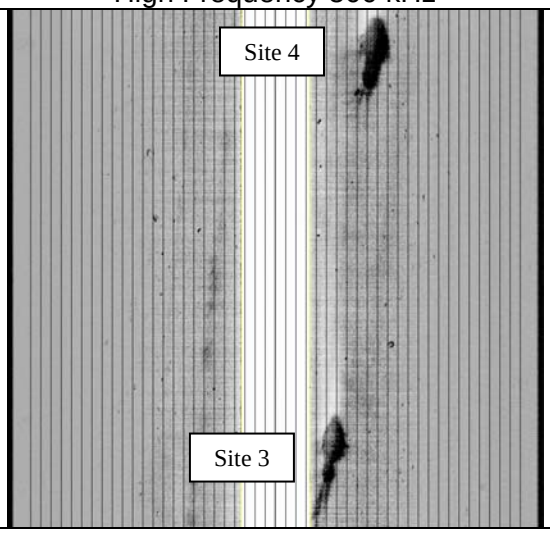
Low Frequency 100 kHz	High Frequency 500 kHz
	
Duluth Survey Site (500 m)	Duluth Survey Site (500 m)

Figure 22. Site 3 and 4 acoustic backscatter anomalies are present in both the low and high-frequency sidescan sonar data records. Sweepings deposits (taconite pellets and coal) were recovered from both of these sites during water-quality sampling in October 2006.

Duluth Survey Site	Duluth Survey Site
Taconite Pellets	Coal and Taconite Pellets

Figure 23a,b. Shallow core samples from Duluth water quality sampling sites yielded taconite pellets and coal with taconite pellets, respectively. Sweepings materials were not present in a similar core taken at a nearby “reference” site.

Ground-Truth Sampling

The sidescan sonar produces records that display acoustic backscatter characteristics of lakebed materials. In many cases, the acoustic response mimics natural patterns and features that can then be used to identify and interpret features on the lakebed. Examples would include certain types of sedimentary structures such as ripples and dunes that are formed by currents and/or waves acting on sand deposits. The presence of ripples or dunes provides direct measure of the sediment and substrate type present at that location on the lakebed.

However, the acoustic backscatter characteristics of many materials are not unique, and additional information is required in order to accurately interpret the sidescan data. During this study, provision was made to collect shallow grab samples using a Petite Ponar grab sampler from locations of interest in order to verify and validate the sidescan sonar interpretation. Samples were processed to determine the composition of coarse-grained materials (>75 µm) in order to assess the presence or absence of sweepings materials at that location. The Petite Ponar sampler can recover sediments down to a depth of 12 cm. Sub-surface sweepings deposits at depths greater than 12 cm would not be recovered using this sampling technique.

A total of 36 separate bottom grab samples were obtained using the Petite Ponar sampler. A summary of the results is given in Table 3 below, and more detailed information and photographs are available in the Appendix.

Table 3 - Ground Truth Summary

Lake/Site	No. Samples	No. Underwater Video Transects	Water Quality	Dominant Substrate
Lake Superior				
Duluth	4	1	1	Silt (ML) with trace of clay Trace fine sand, coal
Silver Bay (Western)	8	n/a		Silt (ML) with trace of clay Trace coal
Silver Bay (Central)	2	n/a		Sandy silt w/gravel, cobbles, coal
Lake Michigan				
Lake Michigan Primary	8	6		Silty clay (CL) with fine sand. Trace gravel, shells, and coal. One site with taconite.
Lake Michigan Secondary	n/a	n/a		n/a
Lake Erie				
Lake Erie Primary	7	n/a		Silty clay (CL) with shell frags Trace coal, shells. One site with taconite.
Lake Erie Secondary	9	2	1	Silty clay (CL) with abundant shell frags. Four sites with gravel, rock frags, coal.

With the exception of two samples taken at the Silver Bay Survey site, lakebed sediments were generally soft, fine-grained silts and clays typically found in deeper-waters of the Great Lakes. In southern Lake Michigan, thin isolated sheets of fine to very fine-grained rippled sand rest on top of these silts and clays.

In Lakes Michigan and Erie, *dressenids* (zebra/quagga mussels) have colonized portions of the lakebed and shell material was recovered in sediment samples taken during this study. Underwater video from Lake Michigan also shows extensive *dressenids* colonization of the lakebed, especially in shallow-water areas in the southern portion of the survey area. The presence of shell material alters the acoustic response by increasing roughness and texture of the lakebed surface. Typically, soft-sediment areas colonized by *dressenids* will generate a mottled or textured appearance on the sidescan sonar records. Moreover, in areas where dressenids are widespread, strong acoustic anomalies indicative of sweepings deposits are still present on the sidescan sonar records. This suggests that the acoustic response associated with sweepings deposits will not be significantly affected by *dressenids*. In fact, *dressenid* shell material generates a considerably different acoustic backscatter response when compared to sweepings deposits, and it is not anticipated that the presence of *dressenids* on the lakebed will compromise the ability to detect or map sweepings deposits during this study.

Underwater Video

In areas with good water clarity, the underwater video provides invaluable information as to the detailed structure and surface texture of the lakebed, and the types of organisms that are actively using lakebed habitat. This information is extremely useful when interpreting sidescan sonar records as the acoustic backscatter response is not only influenced by the grain size and hardness of the material, but the surface texture and distribution of materials on the lakebed as well.

Underwater video equipment was deployed at three of the six survey sites. Typically, the underwater video camera was deployed as the vessel drifted over the sample site. Once on location, the Petite Ponar sampler was lowered over the side to obtain lakebed sediment samples. Water depth limitations, weather, and/or poor water clarity were the primary reasons why underwater video was not deployed at the remaining three sites. Moreover, poor water clarity due to storm-derived resuspension of fine-grained sediments severely limited the resolution and usefulness of the underwater video at the Duluth and Lake Erie Secondary sampling sites.

The underwater video images were recorded on a SONY Digital 8 Camcorder. Video data were then downloaded through the DV port using video capture software onto a PC. The data were then archived to DVD video disks. The video files are stored in AVI format and can be played using standard off-the-shelf DVD software. Frames of particular interest were captured as single digital images in .jpg or .png format for use in presentations and/or written reports. Following are examples of representative lakebed bottom types that were encountered at several sampling sites in the Lake Michigan Primary survey area.

Lake Michigan Primary

Lake Michigan Primary sample site 1	Lake Michigan Primary sample site 2
Dressenids colonizing silt and fine sand	Undisturbed lakebed

Figure 24. Background/reference sites sampled this fall. Lake Michigan sample site 1. *Dressenids* have colonized large areas of the lakebed in this area. *Dressenids* give the bottom a rough or coarse acoustic texture. Lake Michigan sample site 2. Relatively smooth lakebed surface composed of silt and rippled find sands.

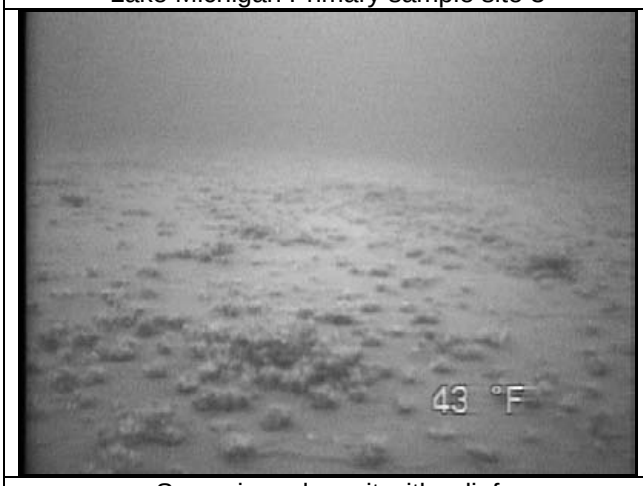
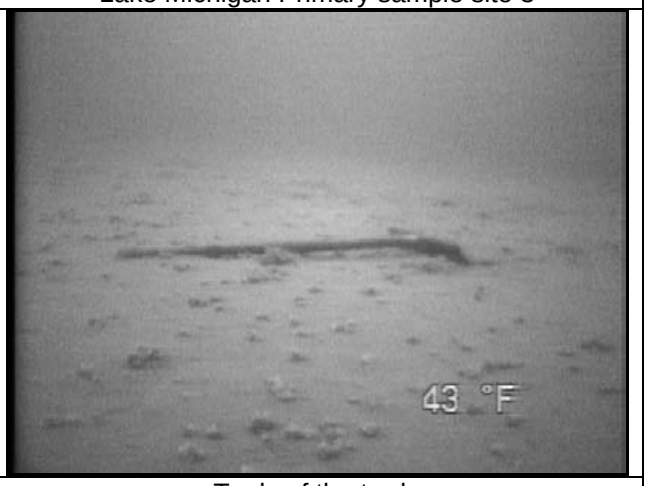
Lake Michigan Primary sample site 3	Lake Michigan Primary sample site 3
	
Sweepings deposit with relief	Tools of the trade

Figure 25. Lake Michigan primary sample site 3. Sweepings deposit with minor surface relief. Coarse-grained sweepings deposits resting on the lakebed surface will likely be colonized by *Dresseinids* and/or *Chladophora*. Tools of the trade - shovel resting on the lakebed approximately 10 m from the sweepings deposit.

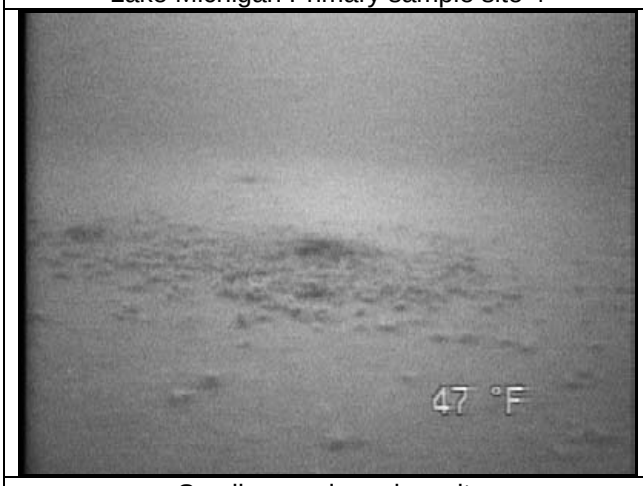
Lake Michigan Primary sample site 4	Lake Michigan Primary sample site 4
	
Small sweepings deposit.	Undisturbed lakebed

Figure 26. Lake Michigan sample site 4. Small sweepings deposit (~ 1.5 m diameter). Relatively smooth lakebed surface composed of silt and rippled find sands is “normal” for this area.

REGIONAL DISTRIBUTION

The distribution of acoustic anomalies on the lakebed was evaluated using the SonarWiz.Map mosaicking software that integrates individual sidescan sonar lines into a single geo-referenced mosaic. At each survey site, a comprehensive examination of the mosaicked sidescan sonar data provides a way to assess and measure the number and orientation of major acoustic anomalies within a survey area.

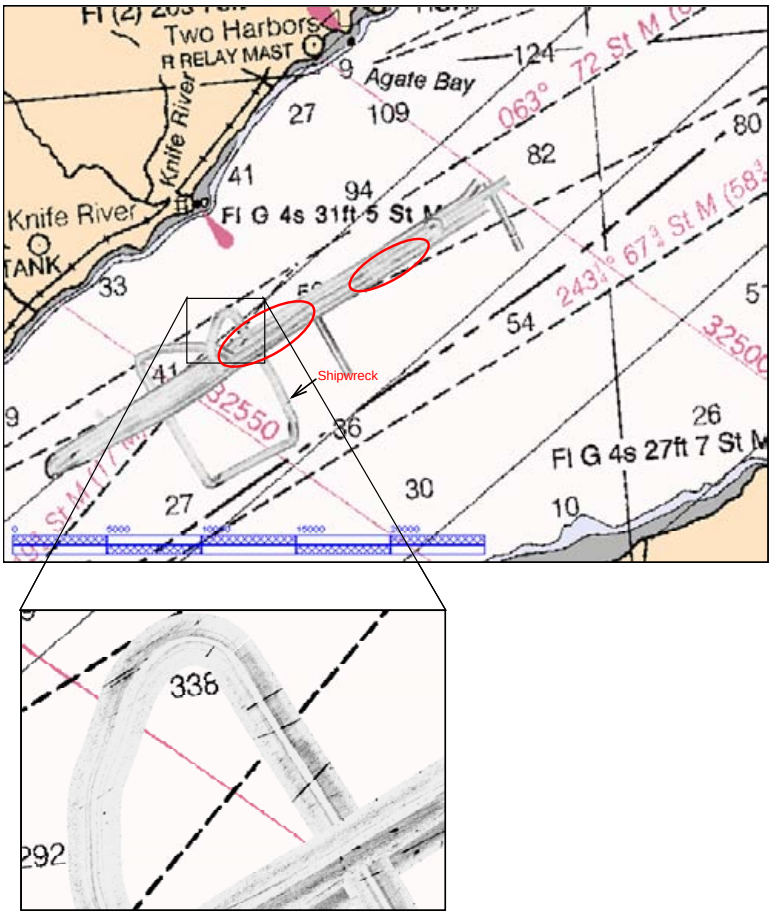
Specifically, the orientation of acoustic anomalies with shapes and/or patterns that lend themselves to directional analyses were measured and recorded at each survey site. Typically, survey lines perpendicular to the LCA shipping lane and/or the longitudinal axis of the main survey area were used for this analysis, as it maximizes the potential for survey line crossings. At the same time, non-linear acoustic anomalies and other features located within the central portion (generally 2/3 of the total swath width) of a “reference” sidescan survey line were evaluated to provide an estimate of the distribution and number of anomalies along each line. These data were then normalized by the length of the survey line in order to provide a common measure of “linear” density that could then be used for a general comparison between survey sites.

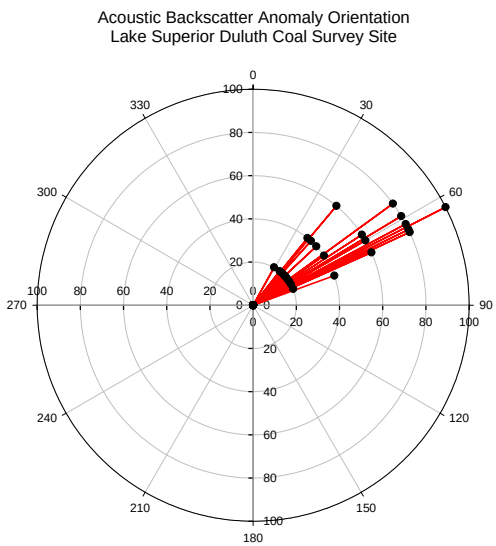
Directional data were grouped, sorted, and a histogram plot generated to assess the range and distribution of directional values. These data were then used to construct normalized polar plots where the magnitude of the polar plot is proportional to frequency. In other words, the longer the line, the more values there are in that direction.

Even though these data can be used to provide rough estimate of the total number of anomalies within a survey area, many smaller acoustic anomalies were not evaluated, especially in the Silver Bay study area. For the purposes of this reconnaissance study, the data generated should be adequate to determine regional distribution patterns and potential sampling sites for additional chemical and biological analyses.

Lake Superior- Duluth

Acoustic features are widespread at the Duluth survey site where coal and to a lesser extent taconite, are the dominant material transported eastward through western Lake Superior. Amorphous, elongate string, and linear acoustic features dominate. Lakebed sediments are soft fine-grained silts and clays that are uniformly distributed across the entire survey area. As described earlier, many of the acoustic anomalies observed in the low-frequency (100 kHz) records are buried under a thin veneer (5 to 15 cm) of fine-grained silts and clay. Moreover, the density distribution of acoustic features is not uniform across the survey area, with more numerous and larger acoustic features found in the central and east central portions of the survey area (see Figure 27). The widespread nature of acoustic features is also illustrated in the perpendicular survey line where several distinct linear acoustic features are located north of the main survey area. Similar but smaller features are also commonly observed in the other survey lines as well, even though densities appear to decrease in the southern portion of the survey area. The average linear density is 3.2 targets per line kilometer and acoustic anomalies are generally oriented towards the northeast (Figure 27).





Orientation plot of acoustic anomalies at the Duluth survey site. Average orientation is east-northeast with a 56° bearing (true). N=56. Polar plot of orientation where radius is normalized frequency.

Figure 27. Distribution and orientation of acoustic anomalies within the Duluth survey site. Within the main survey area, areas circled in red have higher densities of acoustic features per line km than other areas within the survey site. Average linear density is 3.2 targets per line km.

Lake Superior – Silver Bay

The eastern half of the Silver Bay survey area is geologically complex with acoustic characteristics that mask the presence of sweepings deposits on the lakebed (Figure 28). Coarse-grained sediments and a complex network of grooves and/channels are present on the lakebed in this area which are associated with a bathymetric high in central-western Lake Superior. The western half of the survey area is in somewhat deeper water and is underlain by acoustically “soft” fine-grained clays and silts, which provide a marked acoustic contrast to the acoustically “hard” taconite pellets. The greatest number and density of acoustic features were observed in Lake Superior at the Silver Bay survey site. Acoustic anomalies overlap one-another and are widespread and ubiquitous across the lakebed (Figure 29). Linear densities were 15.6 targets per line kilometer which is 5 times greater than the other survey sites.

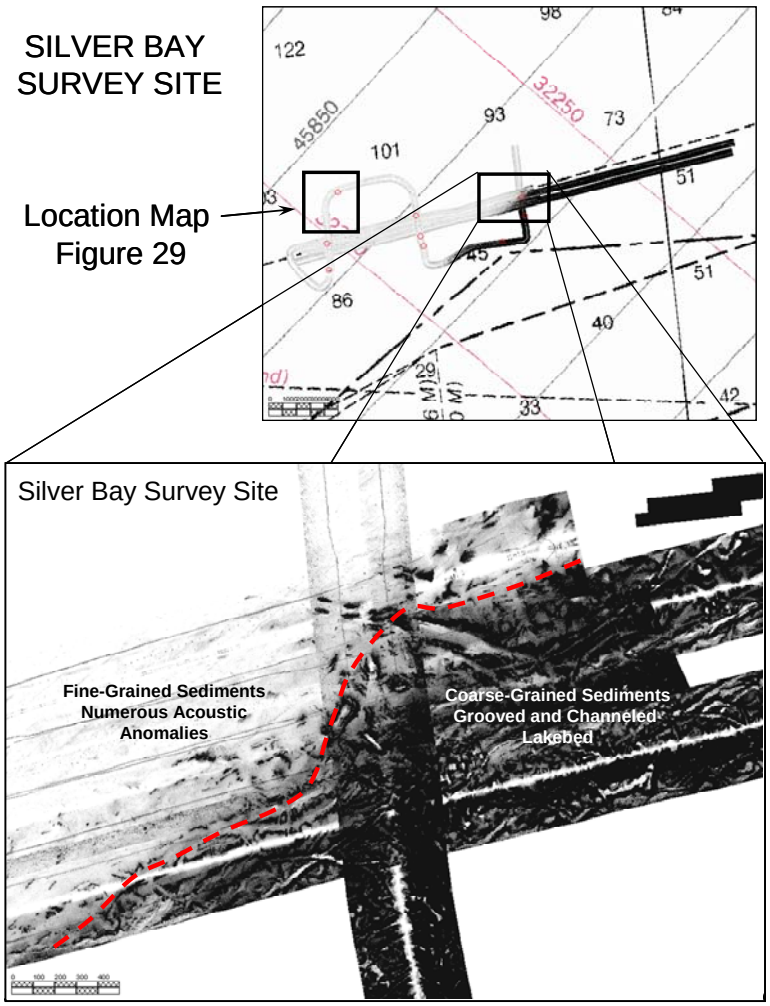


Figure 28. Geologic contact at the Silver Bay Survey site. Soft silts and clays are present on the lakebed to the west and hard sands, gravels and cobble deposits are present on the lakebed to the East. Acoustic anomalies caused by sweepings deposits are masked by the complex geology in the eastern portion of the designated survey area.

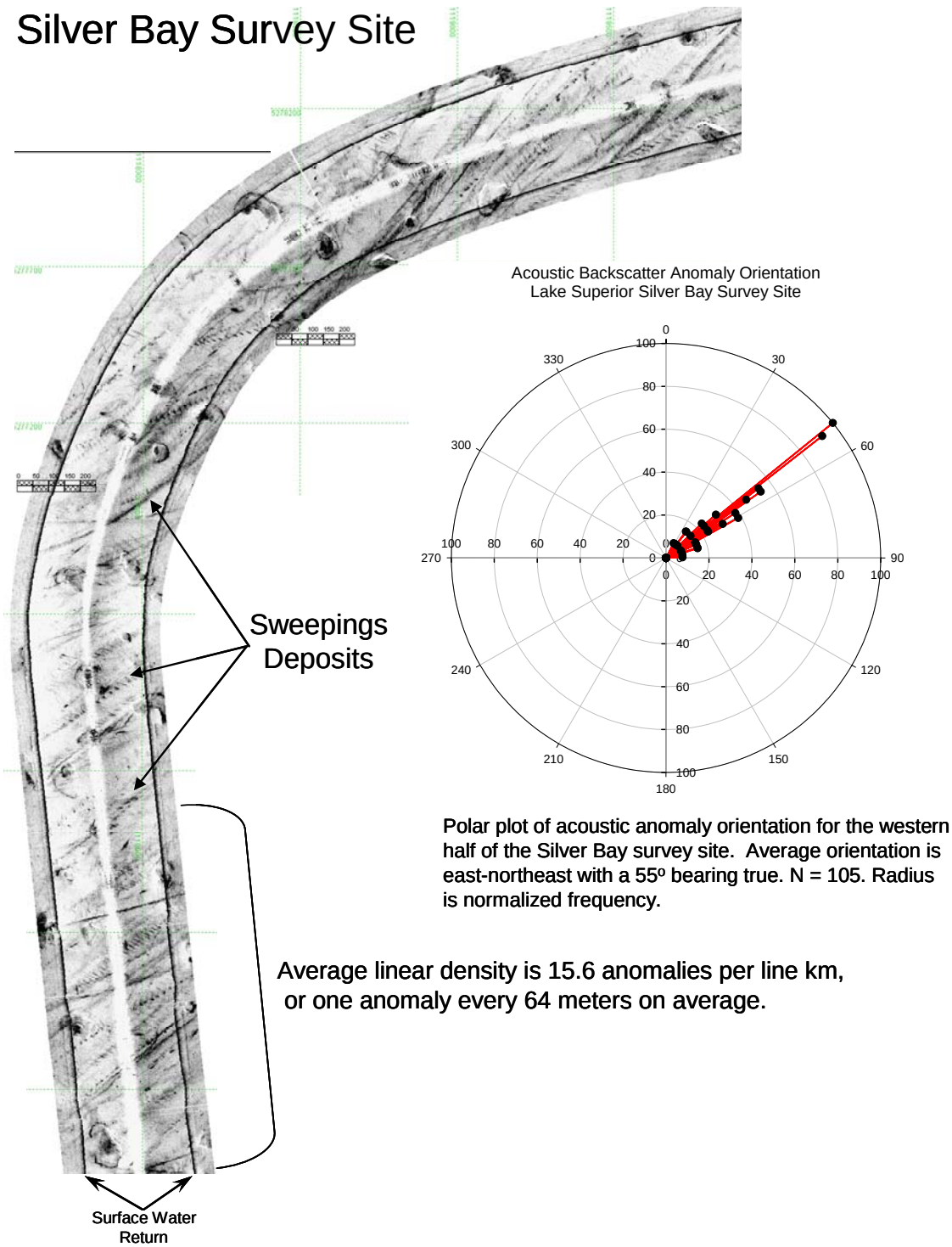
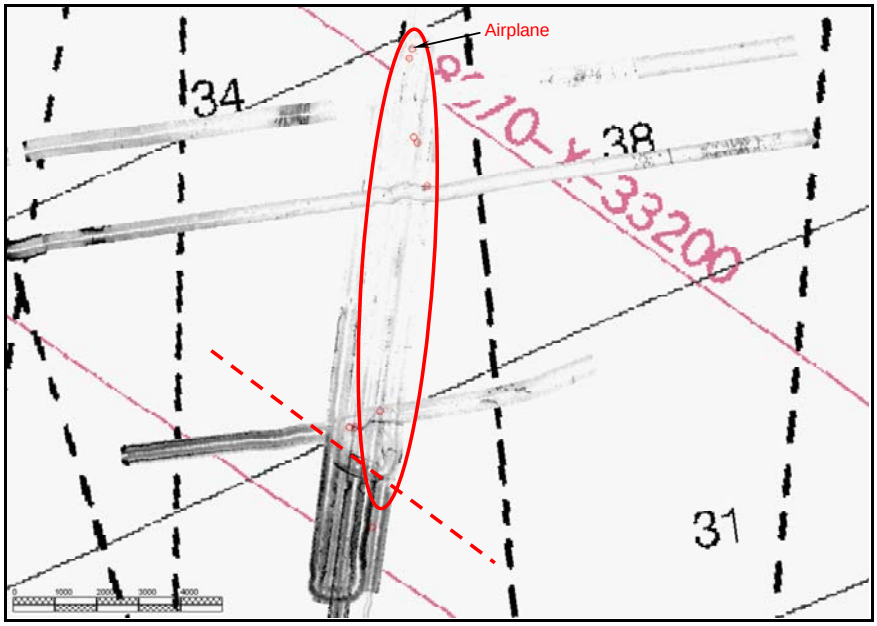


Figure 29. Sidescan Sonar survey line illustrating the complexity and type, density, and orientation of acoustic anomalies within the Silver Bay survey site. The number of anomalies per km is approximately 5 times higher than at any of the other survey sites. Acoustic anomalies are widespread and ubiquitous with 100% of the area impacted by historical sweepings deposits. The directional polar plot is normalized to frequency. Average orientation is 55 ^{o} true.

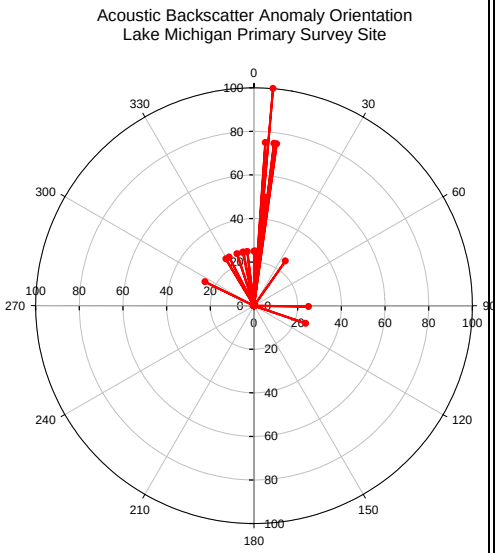
Lake Michigan – Primary Survey site

In southern Lake Michigan, crushed stone and coal are the primary materials being transported, with the orientation of observed acoustic features trending south to north parallel and sub-parallel to the designated LCA shipping lanes Figure 30. The number and density of acoustic features (3.8 targets per line kilometer) is considerably less than observed in Silver Bay survey area, but is similar to those observed at the Duluth survey area in Lake Superior. Amorphous, elongate string, and linear acoustic features dominate. As in Lake Superior, the features are ubiquitous and widespread, with no clear relationship to the designated LCA shipping lanes (Figure 30). However the convergence of LCA shipping lanes no doubt increases the probability of sweepings deposit within the survey area. Lakebed sediments are a mixture of silt and fine-grained sands locally colonized by *dressenids* (zebra/quagga mussels*)*.

Lake Michigan – Primary Survey Site



Red dashed line represents possible geological contact between somewhat harder sediments to the south and softer silts and clays to the north.



Orientation plot of acoustic anomalies at the Lake Michigan Primary survey site. Average orientation is due north with a 6° bearing (true). N=28. Polar plot of orientation where radius is normalized frequency.

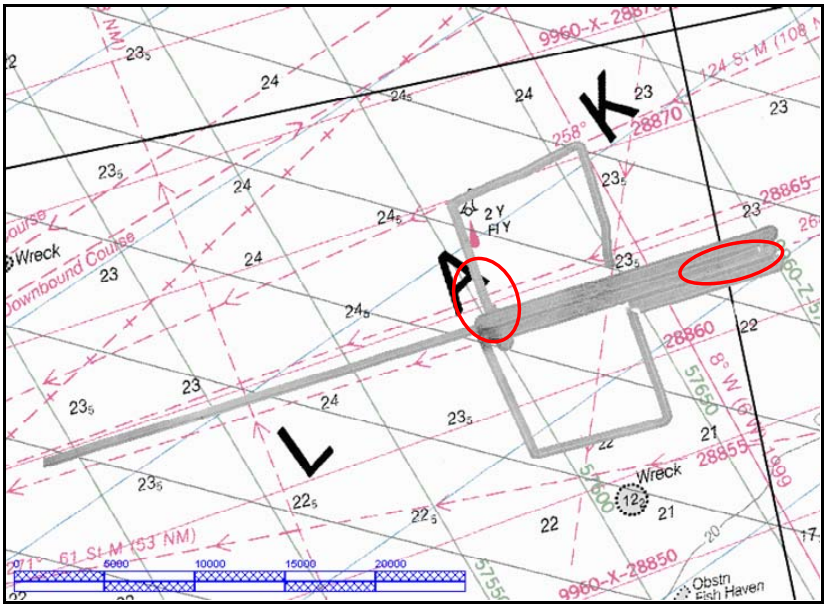
Figure 30. Distribution of acoustic anomalies within the Lake Michigan Primary survey site. Within the main survey area, the area circled in red have slightly higher densities of acoustic anomalies per line km than other areas surveyed within the site. However, acoustic anomalies are ubiquitous and widespread through out the survey area as evidenced by multiple south-north linear acoustic anomalies in the survey lines oriented normal to the main survey area.

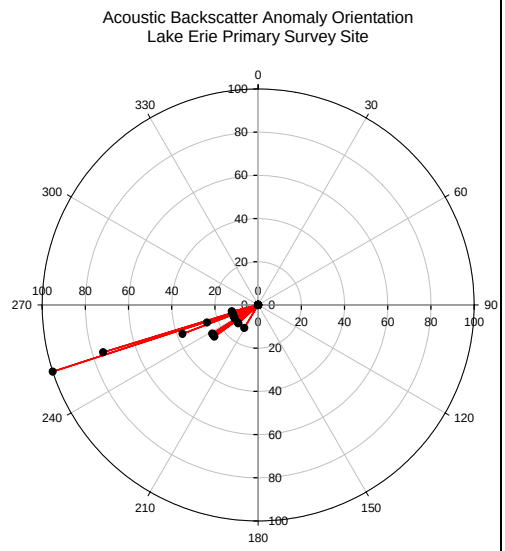
In the southern portion of the Lake Michigan Primary site, water depths are shallower and there is a change in lakebed composition from thin sands overlying silt and clay to predominately silt and clay in the central and northern portions of the survey area. This change occurs along the dashed line which may represent a geological contact. *Dressenid* colonization is also restricted to the southern portion of the survey area where water depths are shallower. Sweepings

deposits were not observed within the Lake Michigan Secondary survey site. This site is located in a dynamic shallow-water area with considerable geological complexity. A hard armored substrate is overlain by mobile sand sheets. If historically present, it is likely sweepings deposits were rapidly re-worked and incorporated into the mobile sand sheets as they transited the area. The Secondary survey site is now a sweepings exclusion area.

Lake Erie – Primary Survey Site

In the Central Basin of Lake Erie, crushed stone and coal are the primary materials being transported. The number and density of observed acoustic anomalies is low (2 targets per line kilometer), with most of the anomalies observed in the central and northern portion of the areas surveyed (Figure 31). Within the Lake Erie primary survey area, amorphous, elongate string, and linear anomalies dominate. Data quality ranges from fair to poor due to surface wave interference, making it likely that smaller acoustic anomalies were not detected. The orientation of observed acoustic anomalies trends generally east to west parallel and sub-parallel to the designated LCA shipping lanes (Figure 31). Lakebed sediments are predominately silts and clays locally colonized by *dressenids*, even though portions of the survey are potentially within the Central Basin anoxic zone. *Dressenids* have the ability to shut down during short periods of adverse water quality and can survive periodic exposure to anoxic waters.



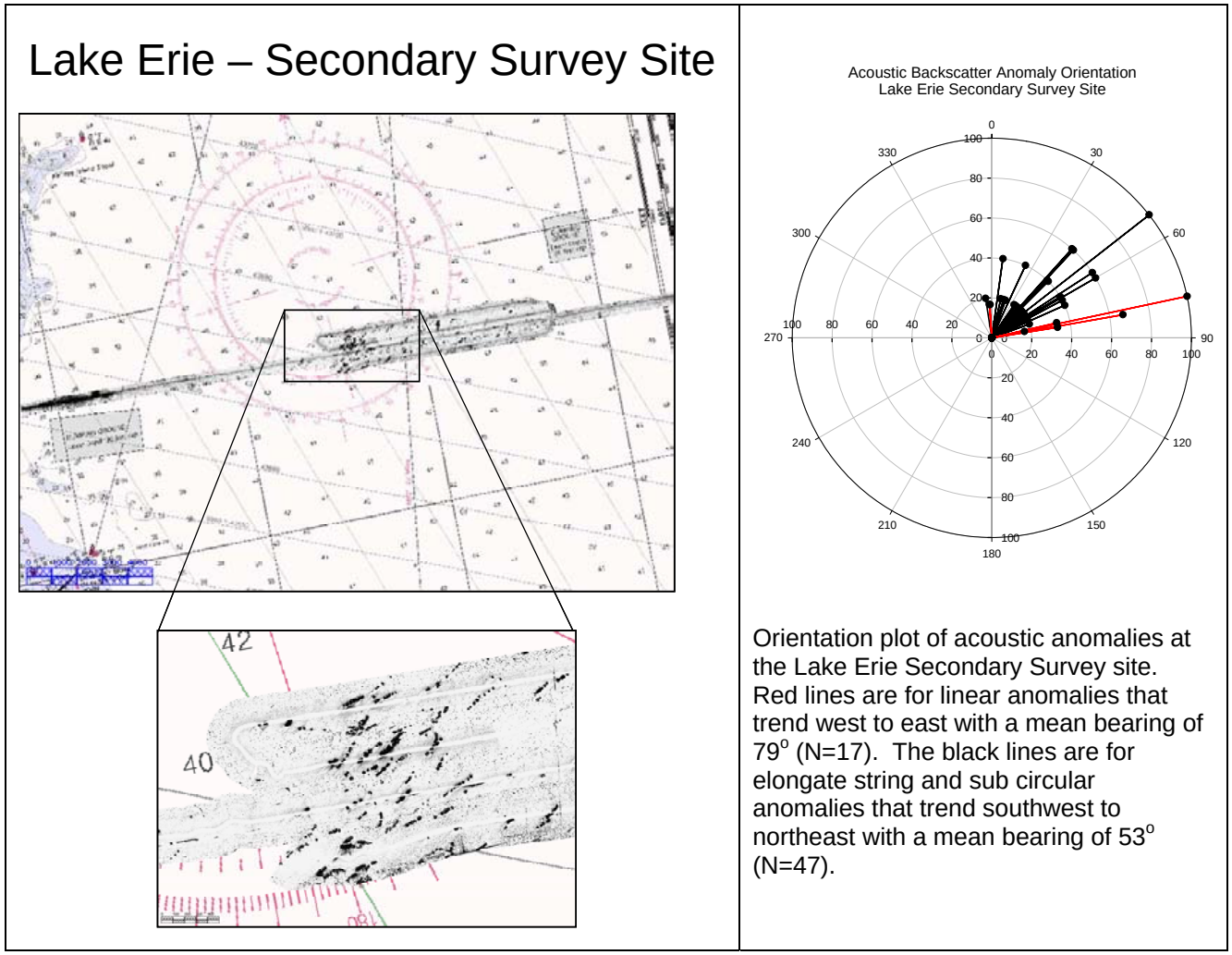


Orientation plot of acoustic anomalies at the Lake Erie Primary survey site. Average orientation is to the southwest with a 245° bearing (true). N=35. Polar plot of orientation where radius is normalized frequency.

Figure 31. Distribution of acoustic anomalies within the Lake Erie Primary survey site. Within the main survey area, areas circled in red have slightly higher densities of acoustic anomalies per line km than other areas surveyed within the site. However, acoustic anomalies are present through out the survey area as evidenced by multiple west - east linear acoustic anomalies in the survey lines oriented normal to the main survey area.

Lake Erie – Secondary Survey Site

In southern Lake Erie within the Lake Erie secondary site, crushed stone and coal are the primary materials being transported. Numerous sub circular ring and elongate string acoustic anomalies with a northeast orientation were observed on the lakebed, especially within the central portion of the survey area (Figure 30). These anomalies have characteristics that are similar to impact craters – they commonly exhibit a circular ridge that is elevated above the lakebed with a depression in the center of the feature. This is the shallowest area surveyed with observable acoustic anomalies. The diameter of these features ranges from 2 -3 m to more than 30 m in size. The large anomalies may be hopper-dredge deposits rather than dry bulk cargo sweepings deposits. It is difficult to reconcile the apparent large volumes of material needed to create these features on the lakebed. Lakebed sediments are predominately silts and clays locally colonized by *dressenids.* Several west to east trending linear anomalies were also observed, but these are a minor component of the acoustic anomalies observed at this site (Figure 31). Linear densities are low and average 1.5 targets per line kilometer at this survey site.



Orientation plot of acoustic anomalies at the Lake Erie Secondary Survey site. Red lines are for linear anomalies that trend west to east with a mean bearing of 79° (N=17). The black lines are for elongate string and sub circular anomalies that trend southwest to northeast with a mean bearing of 53° (N=47).

Figure 32. Map illustrating the distribution of acoustic anomalies within the Lake Erie Secondary survey site. Within the main survey area, the area outlined in the rectangle has higher areal densities of acoustic anomalies per line km than other areas surveyed within the site. Several small linear acoustic anomalies also occur in the eastern half of the survey area.

SUMMARY

The dominant sweepings materials under consideration include taconite (iron ore), crushed stone (limestone), and coal. All of these materials have high acoustic impedances, which makes them potentially visible to acoustic survey tools such as sidescan sonar. The results of the surveys in Lakes Superior, Michigan, and Erie clearly demonstrate that sweepings deposits produce acoustic backscatter anomalies that can be detected and mapped by sidescan sonar survey equipment, and that the low-frequency (100 kHz) sonar is particularly effective detecting these materials. Moreover, many of the acoustic anomalies observed on the low-frequency records are not observed on the high-frequency (500 kHz) records. This response typically occurs when deposits are buried under a thin veneer of fine-grained sediment which is not penetrated by the high-frequency sonar. A major finding of this work is that the low-frequency sonar is detecting historical (buried) sweepings deposits on the lakebed, while the high-frequency sonar is detecting more recent deposits that are exposed on the surface of the lakebed. For habitat assessment and sampling purposes, the high-frequency sonar is the tool of choice to find and locate sweepings deposits that are present at, or on, the sediment-water interface.

Multiple acoustic anomalies were observed on the lakebed that were classified into seven major categories based primarily on shape and distribution: amorphous, sub circular, linear, patterned (repeating), elongate string, and indistinct/wispy. The seventh category includes miscellaneous anthropogenic features such as shipwrecks and a downed plane observed on the lakebed. These acoustic anomalies generally exhibit preferred orientations that trend parallel or sub-parallel to the designated Lake Carrier Association (LCA) shipping lanes. These anomalies vary in size and orientation, and are likely produced by a combination of the type and amount of material released, the method of release, the water depth in which the release occurs, and direction of ship movement at the time of release. In most cases, lakebed alterations such as depressions or ridges associated with the anomalies were not detected, even though it is likely subtle changes in lakebed elevation do occur when these materials are deposited initially. The only exceptions are the numerous circular/ring anomalies found in southern Lake Erie where there is clear evidence for elevated ridges associated with these anomalies.

Another major finding of this work is that sweepings deposits are not confined exclusively to the designated LCA shipping lanes, but are widespread and ubiquitous across all of the areas surveyed in Lakes Superior, Michigan, and Erie. Undisturbed reference sites do exist, but must be selected with care due to the widespread distribution of these materials.

An evaluation of the regional distribution was accomplished by developing a new “linear density” measure that provides a quantitative measure of the number of targets or acoustic events per survey line kilometer. This linear density is normalized to survey line length and can be used to make direct comparisons with survey data from other regions and other Great Lakes.

The greatest number and density of acoustic anomalies observed in Lake Superior was at the Silver Bay survey site located east of Silver Bay, Minnesota (Table 4). All of the major feature categories were observed within the Silver Bay survey site. The dominant material transported through this area is taconite pellets, which are easily detected by the sidescan sonar. The western half of the survey area consists of acoustically “soft” fine clays and silts which provide a marked acoustic contrast to the acoustically “hard” taconite pellets. Acoustic anomalies overlap one-another and are widespread and ubiquitous across the lakebed. The eastern half of the Silver Bay survey area is geologically complex with acoustic characteristics that mask the presence of sweepings deposits on the lakebed. Acoustic anomalies associated with

sweepings deposits were also widespread and ubiquitous at the Duluth survey site where coal and to a lesser extent taconite, is the dominant material transported eastward through western Lake Superior. However, the number and density of acoustic anomalies are considerably less than at Silver Bay, and amorphous, elongate string, and linear acoustic anomalies dominate.

Table 4. Regional Distribution Summary

Survey Location	Acoustic Anomalies by Class (listed in order of occurrence)	Linear Density[1]	Average Spacing[2]	Mean Orientation
Lake Superior - Duluth	Linear, Elongate, Amorphous, Indistinct/Wispy	3.2 /km	312 m	56 ^{o}
Lake Superior - Silver Bay	Linear, Elongate, Patterned (repeating), Sub-Circular, Amorphous, Indistinct/Wispy	15.6 /km	64 m	55 ^{o}
Lake Michigan Primary	Linear, Elongate, Patterned (repeating), Amorphous, Indistinct/Wispy	3.8 /km	263 m	6 ^{o}
Lake Michigan Secondary	n/a	n/a	n/a	n/a
Lake Erie Primary	Linear, Elongate, Amorphous	2.0 /km	500 m	245 ^{o}
Lake Erie Secondary	Sub-Circular, Elongate Sub-Circular, Linear, Amorphous	1.5 /km	667 m	79 ^{o} (53 ^{o})

[1] Number of targets per line kilometer
[2] Average spacing between anomalies

In southern Lake Michigan, crushed stone and coal are the primary materials being transported, with the orientation of observed acoustic anomalies trending south to north sub-parallel to the designated LCA shipping lanes. Lakebed sediments are a mixture of silt and fine-grained sands locally colonized by *dressenids* (zebra/quagga mussels*)*. The number and density of acoustic anomalies is considerably less than observed in the Silver Bay survey area, but is similar to those observed at the Duluth survey area in Lake Superior. As in Lake Superior, the anomalies are ubiquitous and widespread, with no clear relationship to the designated LCA shipping lanes. In southern Lake Michigan; amorphous, elongate string, and linear acoustic anomalies dominate. Sweepings deposits were not observed within the Lake Michigan Secondary survey site. This site is located in a dynamic shallow-water area with considerable geological complexity. A hard armored substrate is overlain by mobile sand sheets. It is likely sweepings deposits would be rapidly re-worked and incorporated into the mobile sand sheets as they transited the area.

In the Central Basin of Lake Erie, crushed stone and coal are the primary materials being transported, with the orientation of observed acoustic anomalies trending toward the west southwest parallel and sub-parallel to the designated LCA shipping lanes. The number and density of observed acoustic anomalies is low, with most of the anomalies observed in the central and northern portion of the areas surveyed. Lakebed sediments are predominately silts and clays locally colonized by *dressenids*. Within the Lake Erie primary survey area, amorphous, elongate string, and linear anomalies dominate. Data quality ranges from fair to poor due to surface wave interference, so it is likely that smaller acoustic anomalies were not detected.

In southern Lake Erie within the Lake Erie secondary site, crushed stone and coal are the primary materials being transported. Numerous sub circular and elongate string acoustic anomalies with a southwest to northeast orientation were observed on the lakebed, especially within the central portion of the survey area. These anomalies have characteristics that are similar to impact craters – they commonly exhibit a circular ridge that is elevated above the lakebed with a depression in the center of the anomaly. The diameter of these anomalies ranges from 2 -3 m to more than 30 m in size. Several west to east trending linear anomalies were also observed, but these are a minor component of the acoustic anomalies observed at this site.

Based on the data collected during the 2006 sidescan sonar surveys, locations of potential sampling sites for future field work are provided in Appendix II attached to this document. Within each survey area, several potential sampling locations were identified using both low and high-frequency sidescan sonar records to select areas where sweepings deposits are likely to be exposed on the surface of the lakebed. The acoustic anomalies associated with these deposits are of several different types and are large enough to be sampled without too much difficulty. Mosaic images for each of the locations are provided in the Appendix for comparison purposes.

ACKNOWLEDGEMENTS

The author would like to thank the U.S. Coast Guard Ninth District and especially the Officers and Crew of the USCGC ALDER, USCGC MOBILE BAY, and USCGC NEAH BAY for their professionalism and extraordinary logistical and field support under adverse conditions. The charter vessel REBEL QUEEN and her captain Bob Hanmer performed admirably under short notice and allowed the project to move forward while repairs were being made to the engines of the NEAH BAY. I would especially like to thank members of the field team, including Mr. Brent Brown, Mr. Mark Mittag, and Mr. Ryan Loveridge with CH2M HILL, and Mr. Ryan Cummings with the USDOT Volpe Transportation Research Center for their long hours and endless good humor while in the field. I would also like to give special thanks to Ms. Marie Gunnerson at Parsons Brinkerhoff who facilitated the administrative and financial aspects of this project and to Ms. Jennifer Byrd at CH2M HILL who processed numerous samples of lakebed sediment.

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APPENDIX I - SUMMARY

Sediment samples provide valuable information about the lakebed, including grain size, composition, sedimentary structures, surface texture (roughness), and evidence for biological activity (feeding or trace burrows, organic materials, or the organisms themselves) that are present on at the location sampled. This information is used to guide and confirm the environmental interpretation of the sidescan sonar data and in the case of this study, to verify that acoustical anomalies are indeed sweepings deposits.

The presence of dry cargo sweepings materials in sediment grab samples is strong evidence that the acoustic anomalies detected by the side scan sonar are indeed generated by historic dry cargo sweepings deposits. While the sweepings sites where sediment grab samples were taken were generally larger sites (10 meters wide or greater), the ability to collect a sediment sample precisely on top of the sweeping site is based upon the ability of the ship to hold a precise position over the sampling location. The dynamic positioning capabilities of the USCGC ALDER and the RV BLUE HERON (water quality samples) maximized the probability that the samples recovered were indeed from the acoustic anomaly being investigated.

The absence of sweepings deposits in the samples does not necessarily mean that the acoustic interpretation is incorrect. The Petite Ponar sampler recovers only the top 12 to 15 cm of the lakebed and it is possible that the acoustic anomaly being investigated is generated by sweepings deposits buried at a slightly greater depth within the lakebed. Moreover, without dynamic positioning capabilities, the area actually sampled may not be directly over the sweepings deposit.

With the exception of two samples taken in the eastern area of the Silver Bay Survey site, sampled lakebed sediments were generally soft, fine-grained silts and clays typically found in deeper-waters of the Great Lakes. In southern Lake Michigan, thin isolated sheets of fine to very fine-grained rippled sand rest on top of these silts and clays.

In Lakes Michigan and Erie, *dressenids* (zebra/quagga mussels) have colonized portions of the lakebed and shell material was recovered in sediment samples taken during this study. Underwater video from Lake Michigan also shows extensive *dressenids* colonization of the lakebed, especially in shallow-water areas in the southern portion of the survey area. The presence of shell material alters the acoustic response by increasing roughness and texture of the lakebed surface. Typically, soft-sediment areas colonized by *dressenids* will generate a mottled or textured appearance on the sidescan sonar records.

In areas where *dressenids* are widespread, strong acoustic anomalies indicative of sweepings deposits are still present on the sidescan sonar records. This suggests that the acoustic response associated with sweepings deposits will <u>not</u> be significantly affected *dressenids*. In fact, *dressenid* shell material generates a considerably different acoustic backscatter response when compared to sweepings deposits, and it is not anticipated that the presence of *dressenids* on the lakebed will compromise the ability to detect or map sweepings deposits during this study.

Finding evidence of dry cargo sweepings in sediment grab samples taken over suspected sweepings sites provides additional evidence that the acoustic anomalies detected by the side scan sonar are indeed historical dry cargo sweepings. Final confirmation will come this next spring when these deposits are sampled more extensively for water quality, geochemical, and biological/habitat parameters.

LAKE SUPERIOR SAMPLING DATA

Duluth Survey Site

Table A1-1. Summary of Samples taken at the Duluth Survey Site

ID	Location		Target	General Description
S-1	46:51.012	91:51.427	Amorph	Silt (ML) with trace clay
S-2	46:51.006	91:51.526	Amorph	Silt (ML) with trace clay
D-1	46:54.663	91:37.884	Amorph	Silt (ML) with trace clay
D-6	46:54.728	91:37.662	Amorph	Silt (ML) with trace clay
WQ-1	46:52.6056	91:45.2340	Linear	n/a
WQ-2	46:51.1024	91:48.8595	Amorph	Laminated Silt (ML) with trace clay
WQ-3	46:52.4466	91:44.7593	Amorph	Laminated Silt (ML) with trace clay
WQ-4	46:52.5157	91:44.4803	Amorph	Laminated Silt (ML) with trace clay
WQ-5	46:52.599	91:44.793	Ref	Laminated Silt (ML) with trace clay

Four petite Ponar grab samples were taken at the Duluth Survey site during the sidescan sonar surveys in September 2006. Five additional sediment samples using a short gravity core were taken while sampling for water quality in October 2006. Sample locations are plotted in Figure A2-1. More detailed descriptions follow:

Table A1-2 Duluth Sample Descriptions

ID	Description	Coarse Material >75µ	Photograph Coarse Material	Sample Photograph
S-1	Silt (ML) with trace clay	Trace Fine Sand	n/a	n/a
S-2	Silt (ML) with trace clay	Possible trace coal		
D-1	Silt (ML) with trace clay	Possible trace coal		

D-6	Silt (ML) with trace clay	Possible trace coal		
WQ-1	Laminated Silt (ML) with trace clay	**Multiple taconite pellets**	n/a	n/a
WQ-2	Laminated Silt (ML) with trace clay	**Rock, Multiple large coal pieces and several taconite pellets**		
WQ-3	Laminated Silt (ML) with trace clay	**Multiple taconite pellets**		n/a
WQ-4	Laminated Silt (ML) with trace clay	**Multiple taconite pellets**		
WQ-5	Laminated Silt (ML) with trace clay	None	No material retained	n/a

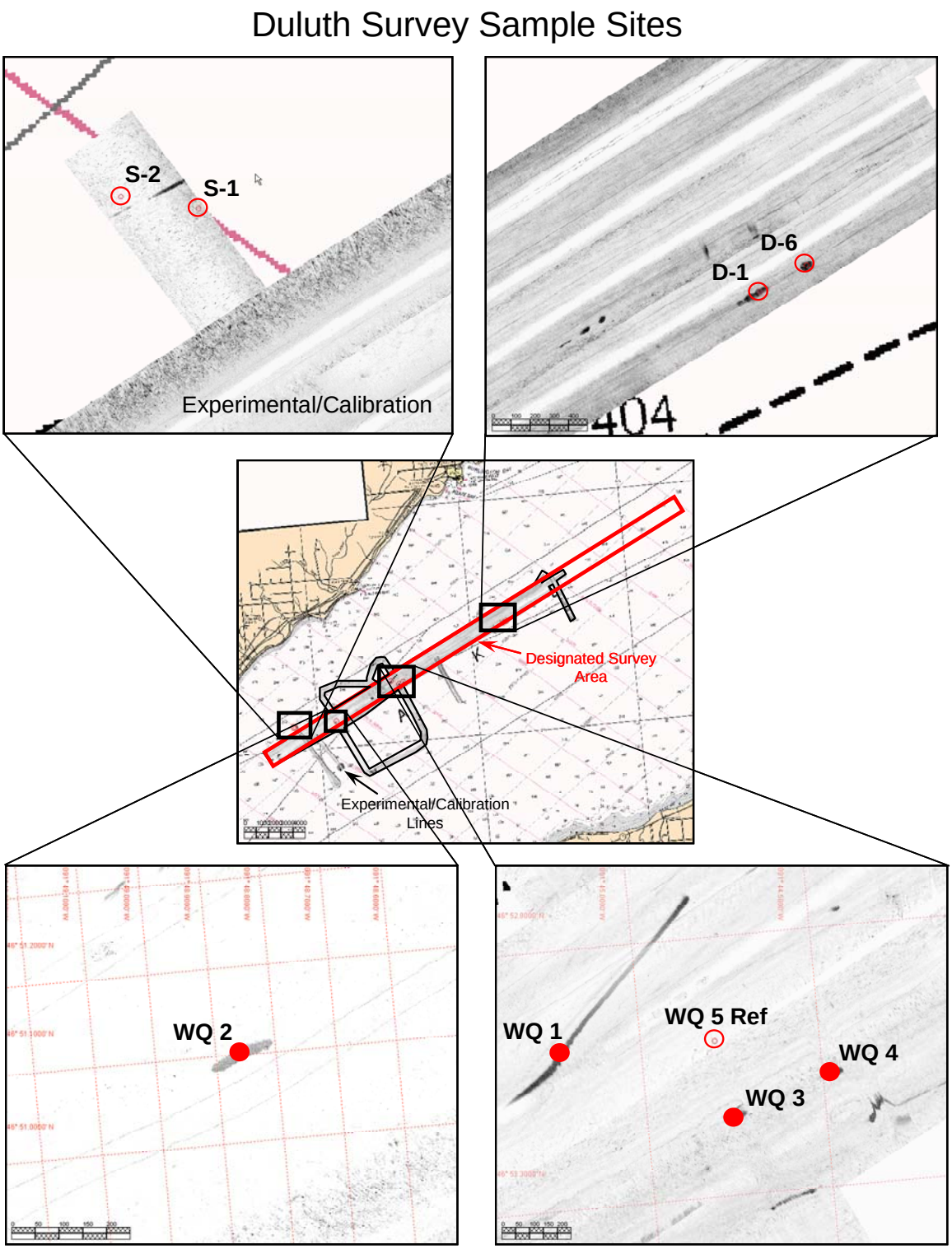


Figure A1-1. 2006 Ground truth sample locations for Duluth Survey site. Solid red circles are 2006 sampling sites where sweepings materials were sampled - coal, limestone, or taconite. Open red circles are sampling sites where no or trace amounts of sweepings deposits were found.

Silver Bay Survey Site

Table A1-3. Summary of Samples taken at the Silver Bay Survey Site

ID	Location		Type	Description
CS1-1	47:19.630	90:49.140	Amorph	Silt with trace clay
CS1-2	47:18.606	90:49.206	Amorph	Silt with trace clay
CS1-3	47:21.545	90:48.228	Ref	Silt with trace clay
CS2-1	47:19.119	90:43.714	Ref	Silt with trace clay
CS2-2	47:19.531	90:43.851	Ref	Silt with trace clay
CS2-3	47:20.313	90:43.975	Ref	Silt with trace clay
CS3-1	47:19.988	90:39.292	Ref	Silt with trace clay, Gravel, Sand
CS3-2	47:19.859	90:37.835	Ref	Silt with trace clay, Medium to Coarse Sand, Gravel, Cobble
CS3-3	47:20.595	90:37.891	Ref	No Recovery

Nine Petite Ponar grab samples were taken at the Silver Bay Survey site during sidescan sonar data collection in September 2006. Sediments were recovered from eight of the sites. Samples were not recovered from the CS3-3 site due to mechanical problems with the sampler. Sample locations are plotted in Figure A -2. More detailed descriptions follow:

Table A1-4 Silver Bay Sample Descriptions

ID	Description	Coarse Material >75µ	Photograph Coarse Material	Sample Photograph
CS1-1	Silt (ML) with trace clay	Trace **coal**		
CS1-2	Silt (ML) with trace clay	No material retained	No material retained	n/a
CS1-3	Silt (ML) with trace clay	No material retained	No material retained	

CS2-1	Silt (ML) with trace clay	No material retained	No material retained	
CS2-2	Silt (ML) with trace clay	No material retained	No material retained	
CS2-3	Silt (ML) with trace clay	Trace **coal**		
CS3-1	Fine Sandy Silt, with trace medium to coarse sand and trace fine to coarse gravel.	Sand with gravel and **coal.**		
CS3-2	Cobble, Gravel, Sand, Silt (ML) with trace clay	Sand, gravel, possible trace coal (cobbles not included in analysis)		

Samples CS3-1 and CS3-2 are located at the western edge of a bathymetric high that generates a strong acoustic response on the sidescan sonar records. A complex network of grooves and/or channels are evident on the lakebed at this location. The acoustic response is indicative of a hard substrate with a coarse surface texture. These samples confirm that the materials present on the lakebed in the eastern portion of the survey area are sand, gravel, and cobble-size materials. These materials appear to form a lag deposit over finer-grained cohesive silts and clays that may be of glacial and/or lacustrine origin.

The complex geology in the eastern portion of the survey area makes it very difficult to detect, identify, and evaluate sweepings deposits using sidescan sonar or other acoustic methods. Given the high density of sweepings deposits in the western portion of the survey area, it is likely that extensive sweepings deposits are present in the eastern portion of the survey area as well.

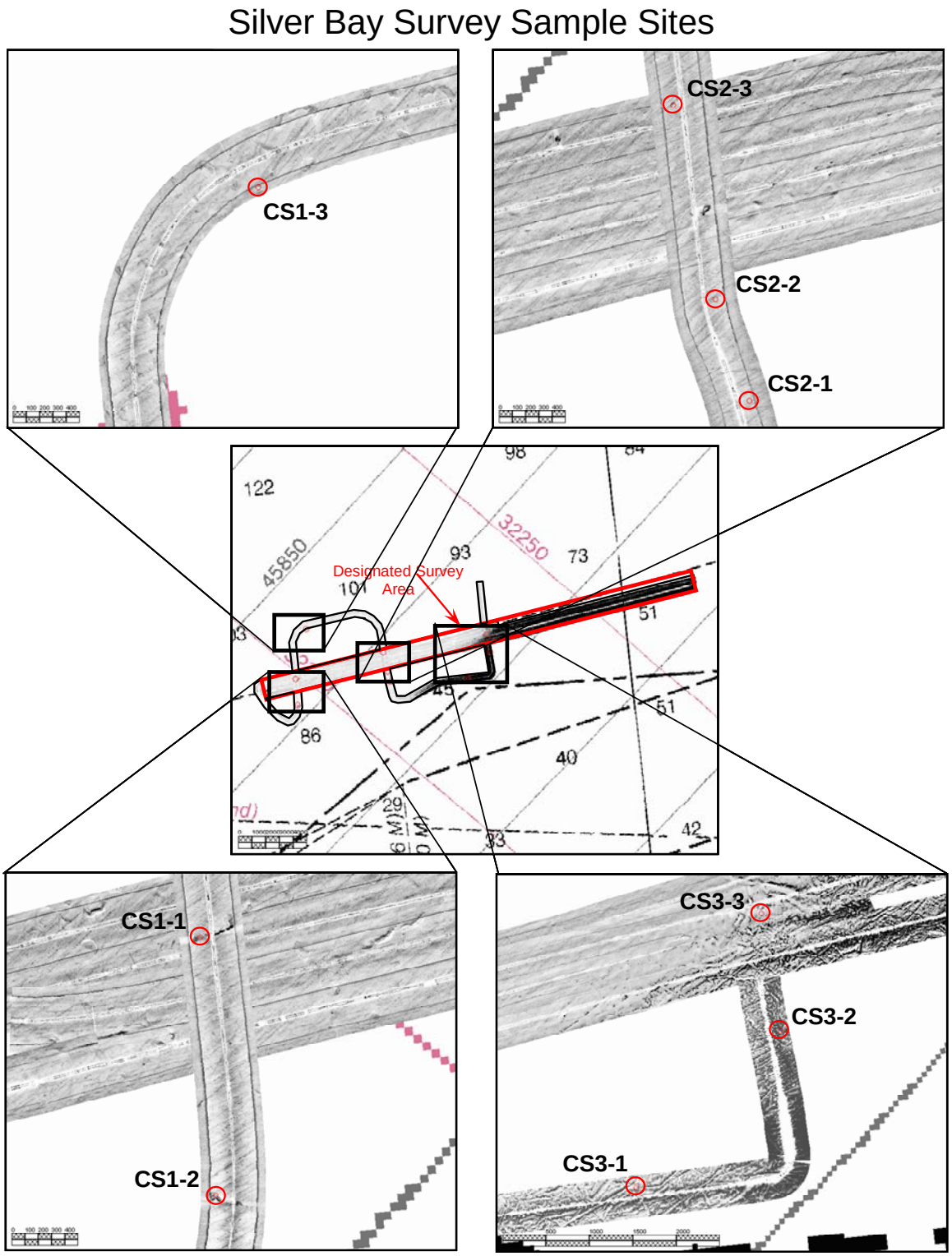


Figure A1-2. 2006 Ground truth sample locations for Silver Bay Survey site.

LAKE MICHIGAN Sampling Data

Lake Michigan Primary

Table A1-5. Summary of Samples taken at the Lake Michigan Primary Survey Site

ID	Location		Type	Description
M-1	42:03.2296	087:20.6263	Ref	Silty clay with fine sand, trace gravel, trace *dress* shells, trace coal
M-2	42:04.5480	087:20.7788	Ref	Silty clay with fine sand, sand w/*dress* shells and coal
M-3	42:04.5067	087:20.6938	Linear	Silty clay with fine sand, gravel w/trace coal
M-4	42:04.7113	087:20.1764	Pattern/ Repeating	Silty clay with fine sand, trace gravel, *dress* shells, trace coal
M-5	42:07.4370	087:18.8100	Amorph	Silty clay with fine sand, trace gravel, trace coal
M-6	42:08.0668	087:19.0077	Ref	Silty clay with fine sand, sand w/trace coal
M-7	42:07.9783	087:18.9439	Elong	Silty clay with fine sand, sand w/trace coal
M-8	42:09.0580	087:18.8971	Amorph	Silty clay with fine sand, sand w/taconite

A total of eight Petite Ponar grab samples were taken during the sidescan sonar surveys in October 2006. Sediments were recovered from eight sites. Sample locations are plotted in Figure A-3. More detailed descriptions follow:

Table A1-6 Lake Michigan Primary Sample Descriptions

ID	Description	Coarse Material >75µ	Photograph Coarse Material	Sample Photograph
M-1	Silty clay (CL) with fine sand	Sand with trace gravel, *dress* shells and trace coal		
M-2	Silty clay (CL) with fine sand	Sand with trace gravel, *dress* shells and trace coal		

M-3	Silty clay (CL) with fine sand	Gravel with potential fine coal traces		
M-4	Silty clay (CL) with fine sand	Sand with trace gravel, *dress* shells and **coal**		
M-5	Silty clay (CL) with fine sand	Sand with trace gravel and potential fine coal	n/a	
M-6	Silty clay (CL) with fine sand	Sand with potential coal traces		
M-7	Silty clay (CL) with fine sand	Sand with trace coal		
M-8	Silty clay (CL) with fine sand	Sand with **taconite**		

The southern portion of the survey area is somewhat shallower and coarser-grained than the deeper-water areas to the north. Silty clay is interbedded with fine sand and gravels in the southern portion of the survey area. *Dressenids* have colonized extensive portions of the lakebed as seen in the underwater video footage and also by the shell material reported in the samples. The mottled acoustic texture observed on the sidescan sonar records can be explained by a combination of *dressenid* shell material and thins sand deposits distributed across a generally fine-grained lakebed. Coal fragments and traces of coal were found in most of the samples indicating that as in Lake Superior, sweepings deposits are widespread and ubiquitous in southern Lake Michigan.

Lake Michigan Primary Survey Sample Sites

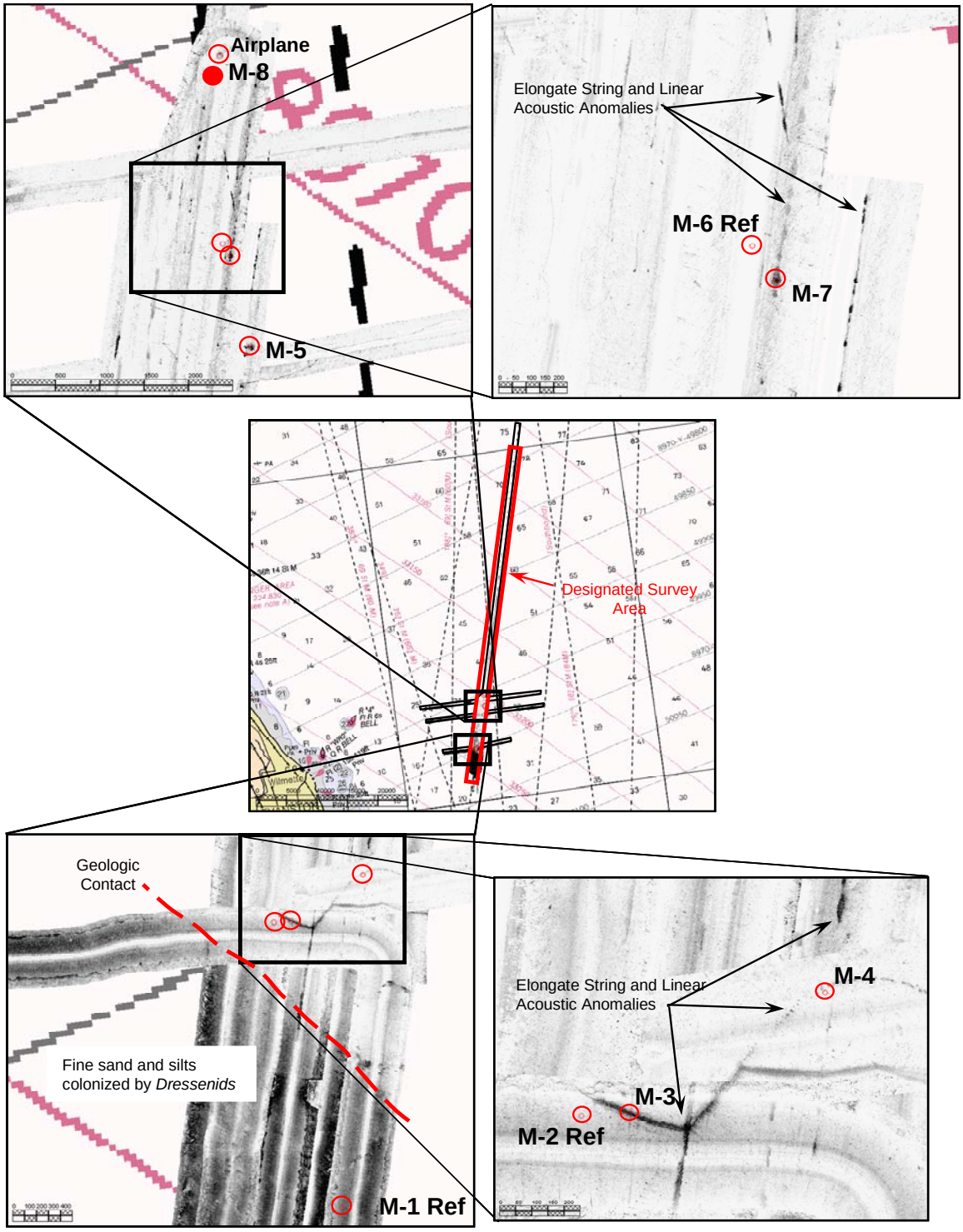


Figure A1-3. 2006 Ground truth sample locations for Lake Michigan Primary Survey site. Solid red circles are 2006 sampling sites where sweepings materials were sampled - coal, limestone, or taconite. Open red circles are sampling sites where no or trace amounts of sweepings deposits were found.

LAKE ERIE

Lake Erie Primary

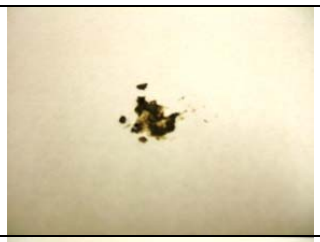
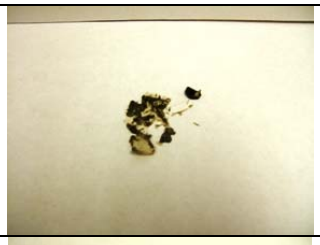
Table A1-7. Summary of Samples taken at the Lake Erie Primary Survey Site

ID	Location		Type	Description
E1-1	41:53.6957	81:39.4895	Amorph	Silty clay (CL) w/ *dress* shells, coal, and a taconite pellet
E1-2	41:53.4050	81:39.3802	Amorph	Silty clay (CL) w/ *dress* shells, coal
E1-3	41:53.1775	81:39.0273	Ref	Silty clay (CL) w/ *dress* shells
E1-4	41:52.8710	81.30.8522	Linear	Silty clay (CL) w/ *dress* shells
E1-5	41:52.9529	81:29.6484	Ref	Silty clay (CL)
E1-6	41:53.3798	81:28.9369	Amorph	Silty clay (CL) w/ *dress* shells, coal
E1-7	41.53.5165	81:28.4450	Elongate	Silty clay (CL) w/ *dress* shells

A total of seven Petite Ponar grab samples were taken during the sidescan sonar surveys in October 2006. Sediments were recovered from seven sites. Sample locations are plotted in Figure A-4. More detailed descriptions follow:

Table A1-8 Lake Erie Primary Sample Descriptions

ID	Description	Coarse Material >75µ	Photograph Coarse Material	Sample Photograph
E1--1	Silty clay (CL)	Large number of *dressenid* shells with **multiple coal pieces (0.4" - 0.6" size range) and taconite pellet.**		
E1-2	Silty clay (CL)	Trace *dress* shells with a **0.1" coal piece.**		

E1-3	Silty clay (CL)	Trace *dress* shells with potential coal particles (<0.1" in size).		
E1-4	Silty clay (CL)	Trace *dress* shells with potential coal particles (<0.1" in size).		
E1-5	Silty clay (CL)	No material retained.	No material Retained	
E1-6	Silty clay (CL)	Trace *dress* shells with **a 0.25" coal piece.**		
E1-7	Silty clay (CL)	Trace *dress* shells.		

Lake Erie Primary Survey Sample Sites

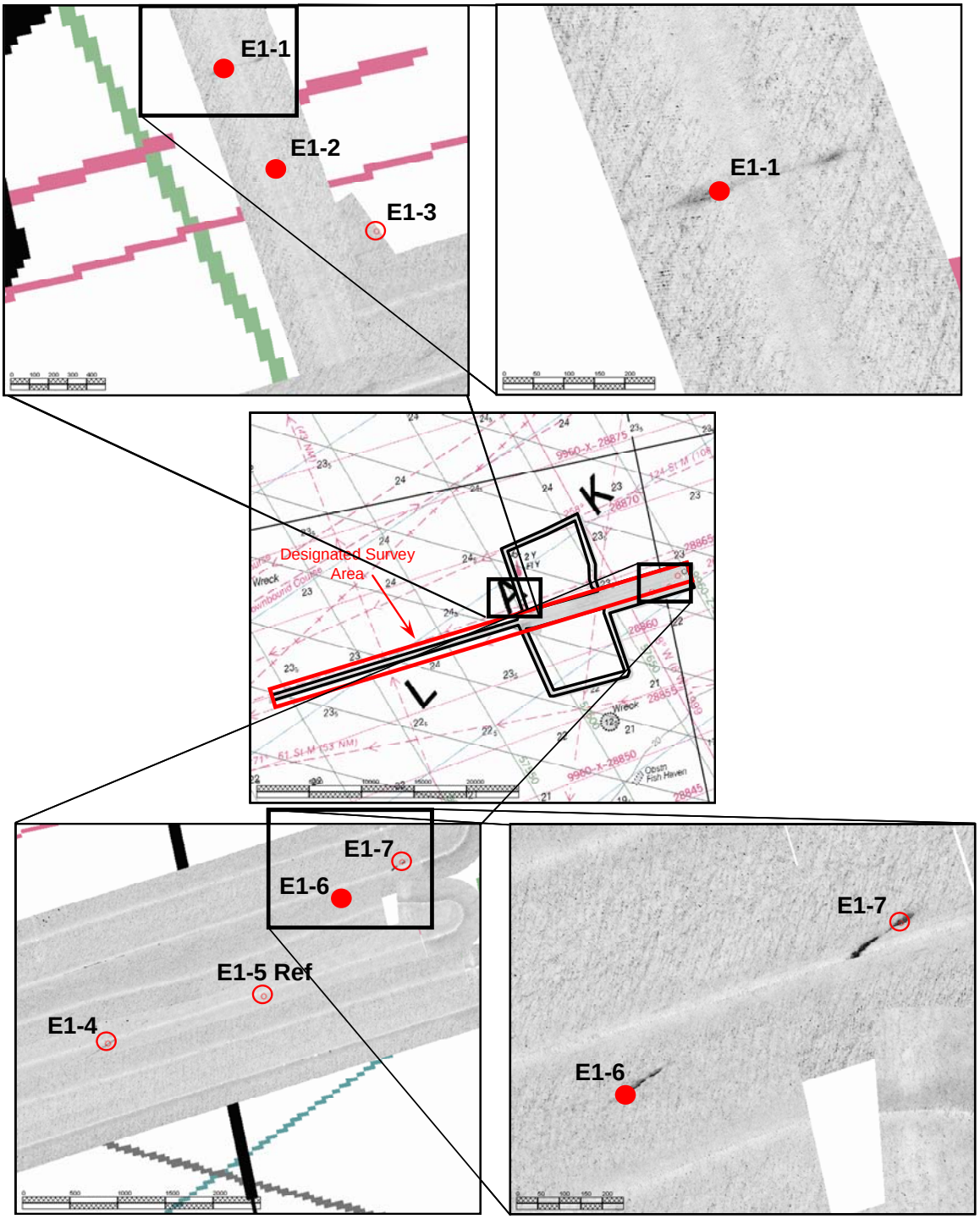


Figure A1-4. 2006 Ground truth sample locations for Lake Erie Primary Survey site. Solid red circles are 2006 sampling sites where sweepings materials were sampled - coal, limestone, or taconite. Open red circles are sampling sites where no or trace amounts of sweepings deposits were found.

Lake Erie Secondary

Table A1-9. Summary of Samples taken at the Lake Erie Secondary Survey Site

ID	Location		Type	Description
E2-1	41:33.4131	82:38.8169	Amorph	Soft brown-grey mud/silt
E2-2	41:33.5012	82:38.9436	Ref	Hard grey silt/clay; rock frags; *Dress* shell frags
E2-3	41:33.5432	82:31.8208	Sub Circ	Two rocks/stone; Ls/dolo
E2-4	41:33.5127	82:31.9307	Sub Circ	*Dress* shell frags
E2-5	41:33.602	82:29.509	WQ	Soft mud/silt
E2-6	41:33.600	82:29.469	WQ	Soft mud/silt; *Dress* shell frags
E2-7	41:33.602	82:29.471	WQ	Soft mud/silt; *Dress* shell frags
E2-8	41.33.562	82:31.828	WQ	Soft mud/silt; *Dress* shell frags
E2-9	41:33.575	82:31.820	WQ	Soft mud/silt; *Dress* shell frags

Table A1-10 Lake Erie Secondary Sample Descriptions

ID	Description	Coarse Material >75µ	Photograph Coarse Material	Sample Photograph
E2-1	Silty clay (CL)	Trace *dress* shells.		
E2-2	Silty clay (CL)	Multiple *dress* shells and rocks (LS/Dolo)		
E2-3	Silty clay (CL)	Rocks (LS/Dolo)		n/a
E2-4	Silty clay (CL)	Multiple *dress* shells		n/a

E2-5	Silty clay (CL)	Multiple *dress* shells **w/ 0.3" coal**		
E2-6	Silty clay (CL)	Multiple *dress* shells with gravel and **small coal pieces**		
E2-7	Silty clay (CL)	Multiple *dress* shells		
E2-8	Silty clay (CL)	Multiple *dress* shells w/gravel and rock		
E2-9	Silty clay (CL)	Multiple *dress* shells.		n/a

Lake Erie Secondary Survey Sample Sites

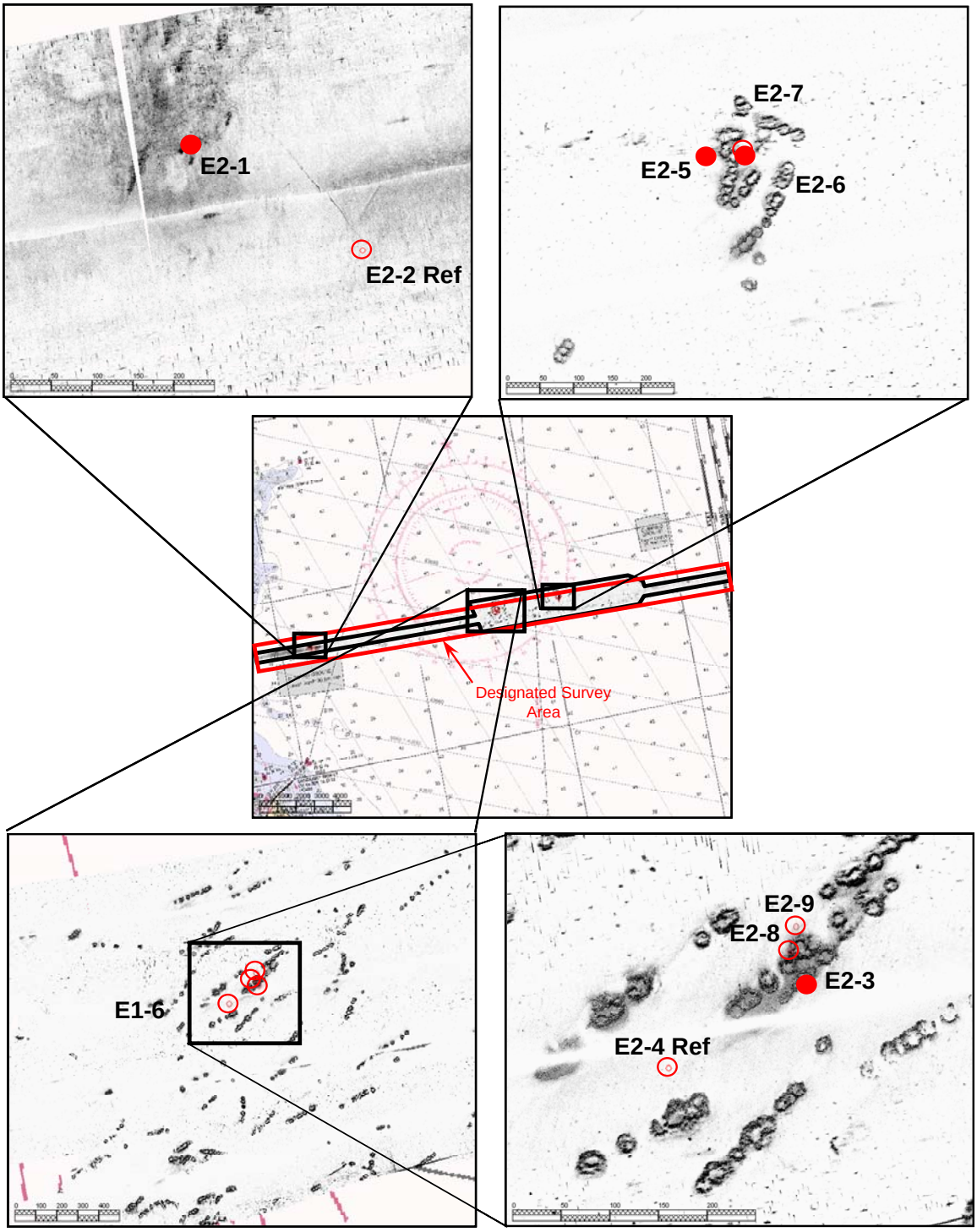


Figure A1-5. 2006 Ground truth sample locations for Lake Erie Secondary Survey site. Solid red circles are 2006 sampling sites where sweepings materials were sampled - coal, limestone, or taconite. Open red circles are sampling sites where no or trace amounts of sweepings deposits were found.

APPENDIX II - POTENTIAL SPRING 2007 SAMPLING LOCATIONS

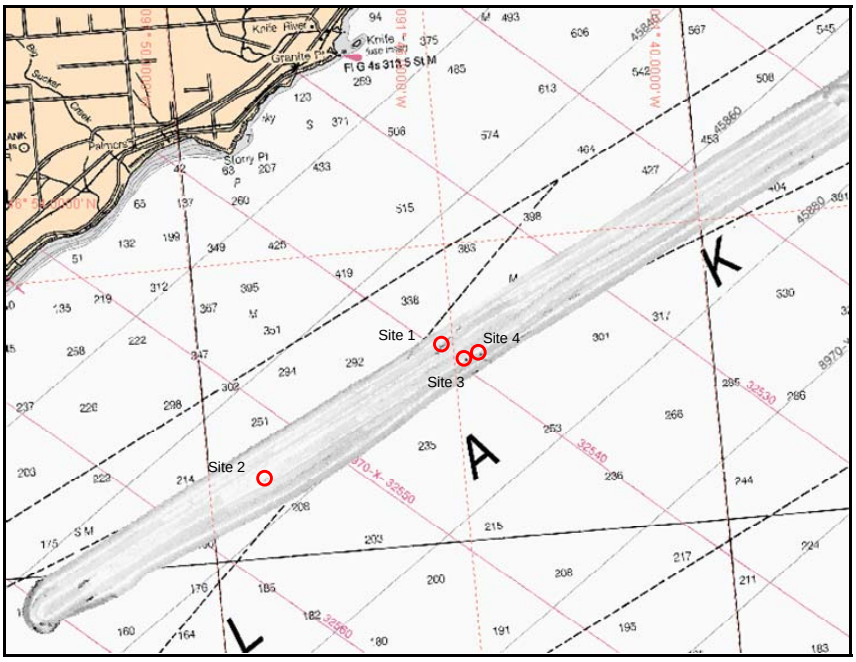


Figure A2-1. Lake Superior – Duluth potential 2007 sampling sites.

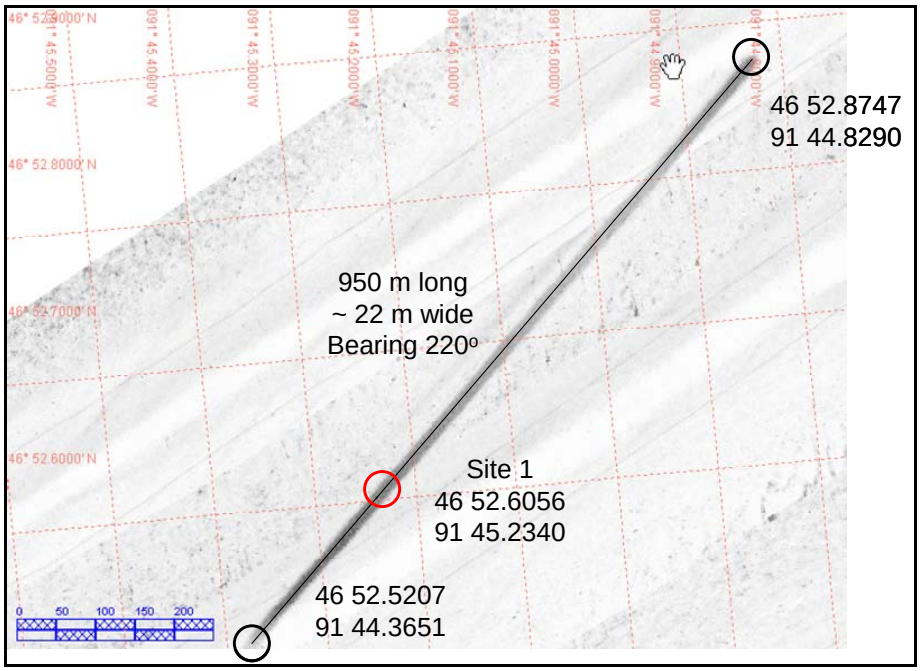


Figure A2-2. Lake Superior – Duluth proposed 2007 sample location 1.
(confirmed sweepings deposit - 2006 WQ sample)

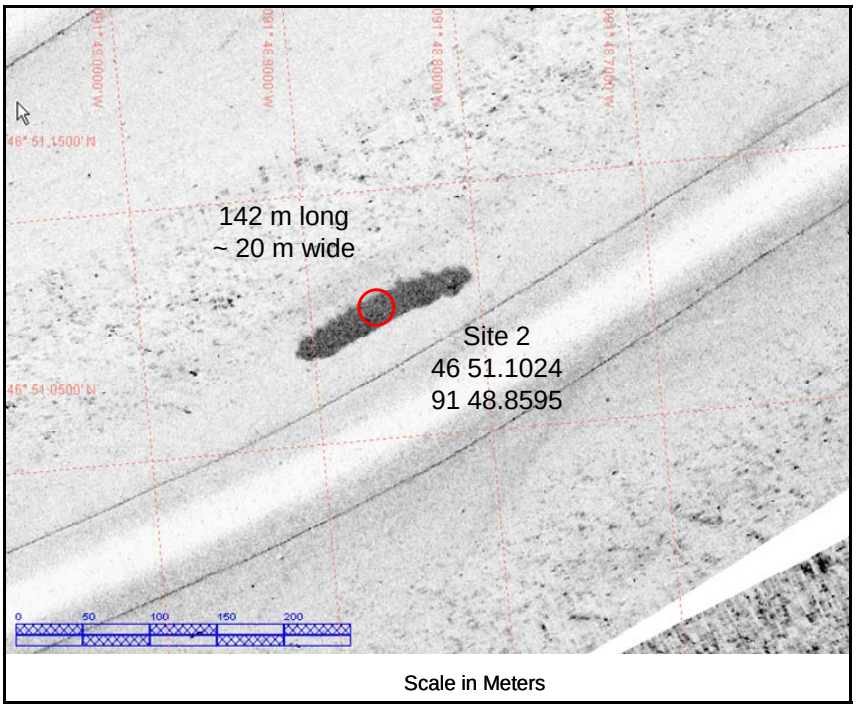


Figure A2-3. Lake Superior – Duluth proposed 2007 sample location 2.
(confirmed sweepings deposit - 2006 WQ sample)

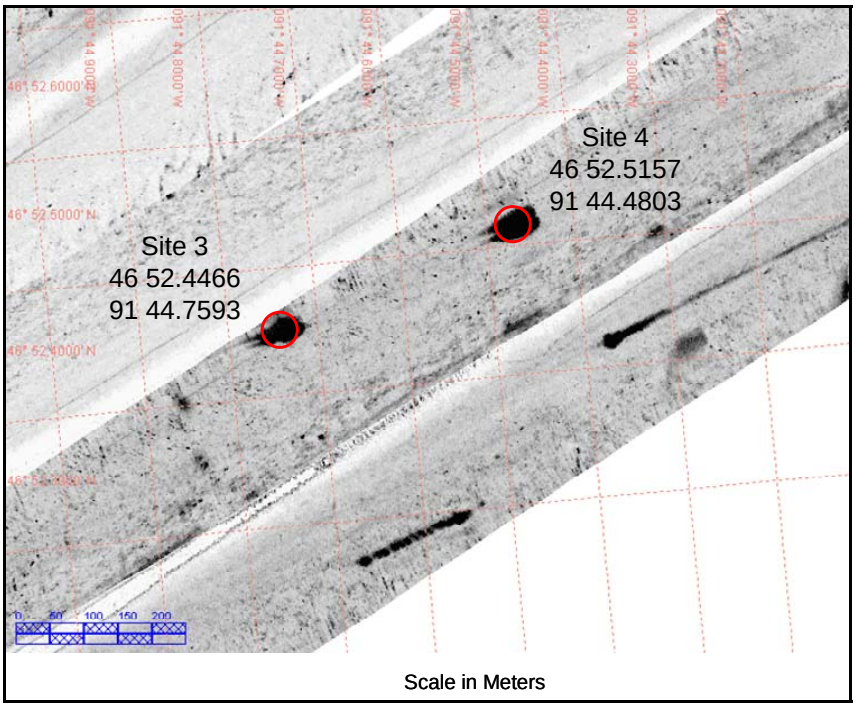


Figure A2-4. Lake Superior – Duluth proposed 2007 sample locations 3 and 4.
(confirmed sweepings deposits - 2006 WQ samples)

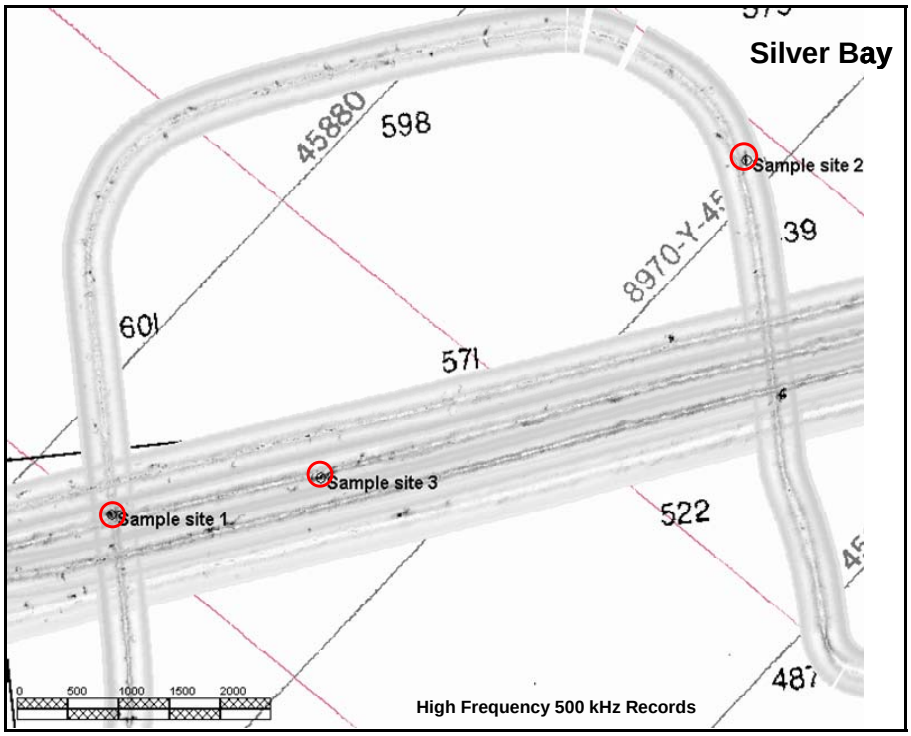


Figure A2-5. Lake Superior – Silver Bay potential 2007 sampling sites (500 kHz).

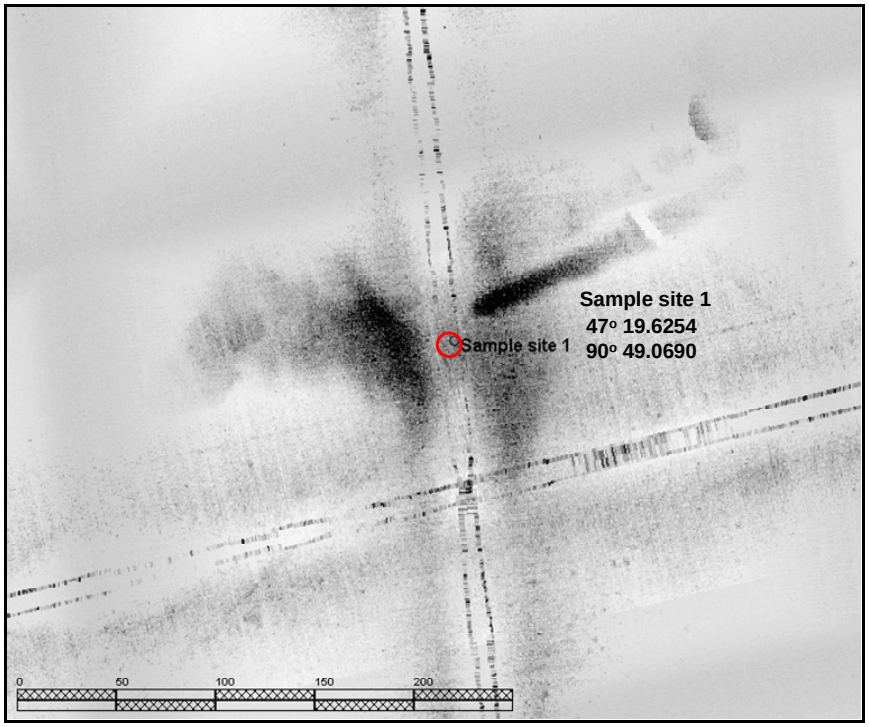


Figure A2-6 Lake Superior – Silver Bay proposed 2007 sample location 1 (500 kHz).

Figure A2-7 Lake Superior – Silver Bay proposed 2007 sample location 2 (500 kHz).

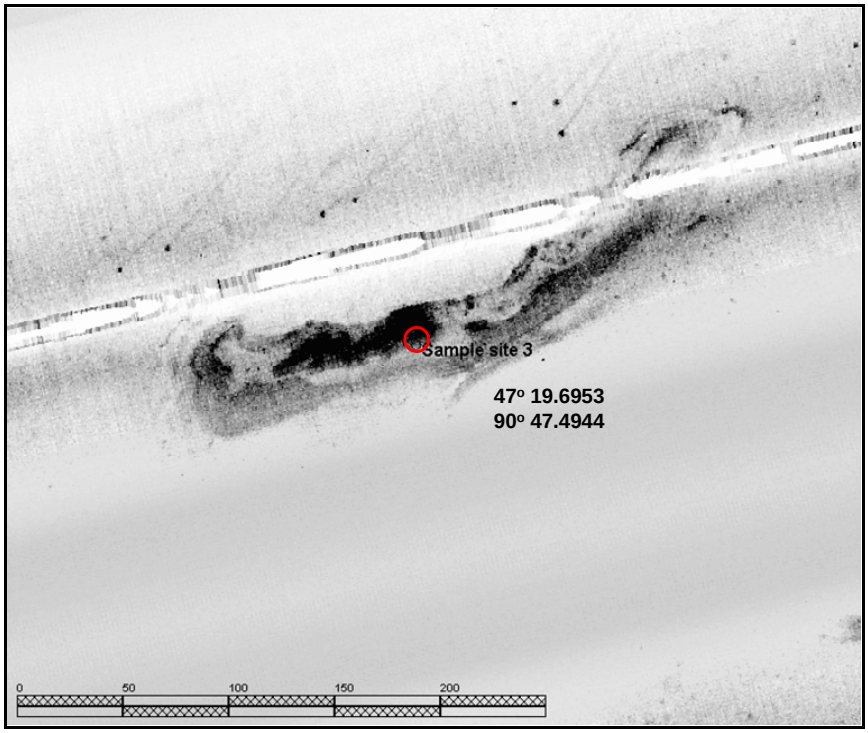


Figure A2-8 Lake Superior – Silver Bay proposed 2007 sample location 3 (500 kHz).

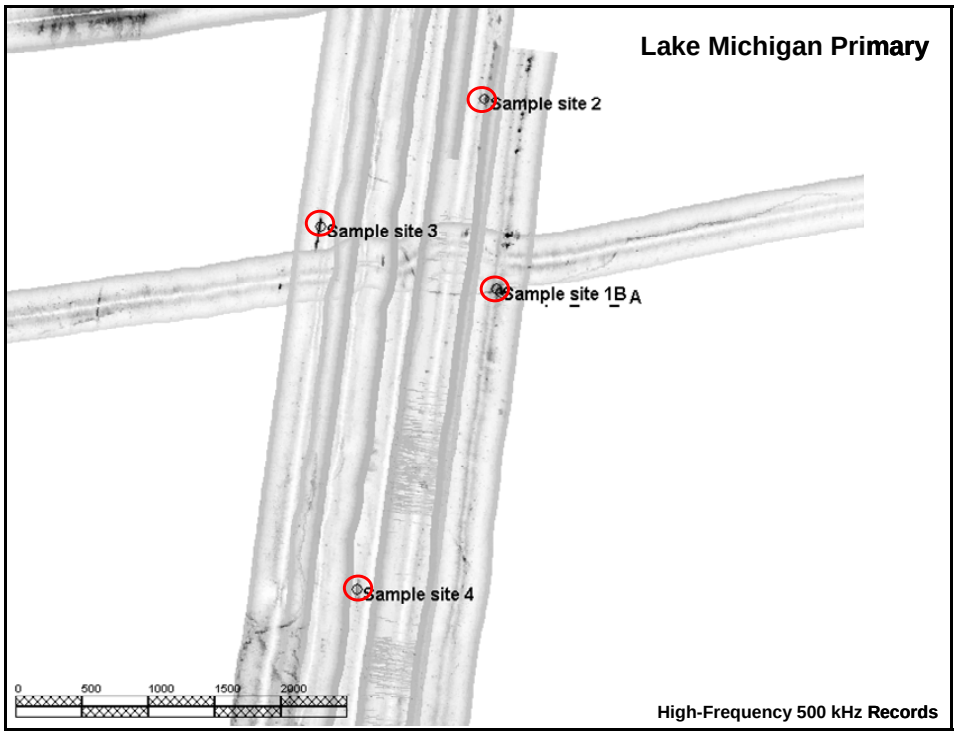


Figure A2-9. Lake Michigan – Lake Michigan Primary potential 2007 sampling sites (500 kHz).

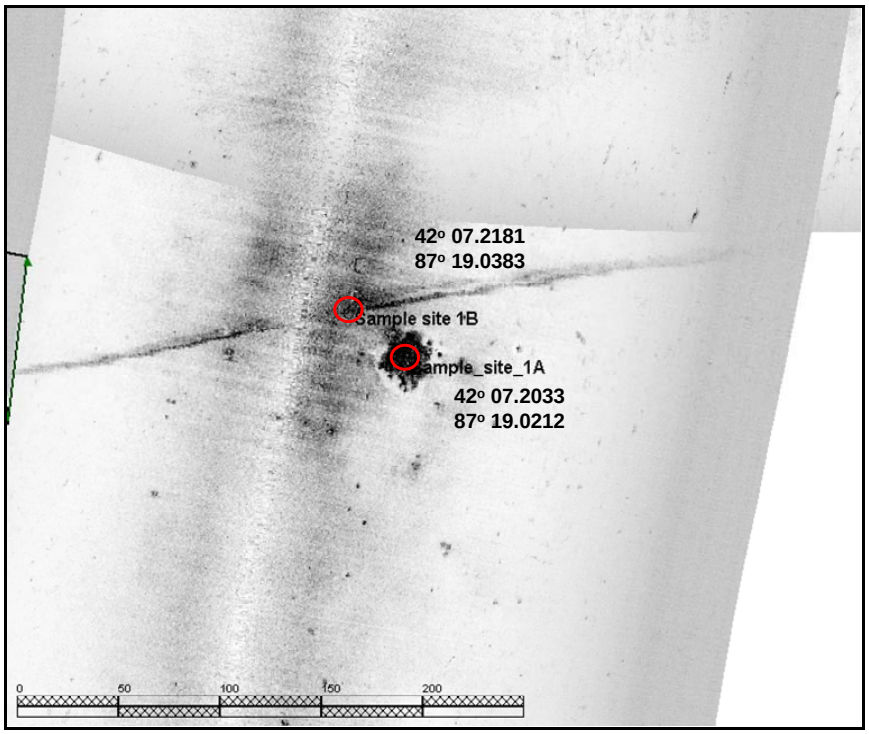


Figure A2-10 Lake Michigan – Lake Michigan Primary proposed 2007 sample locations 1a and 1b (500 kHz).

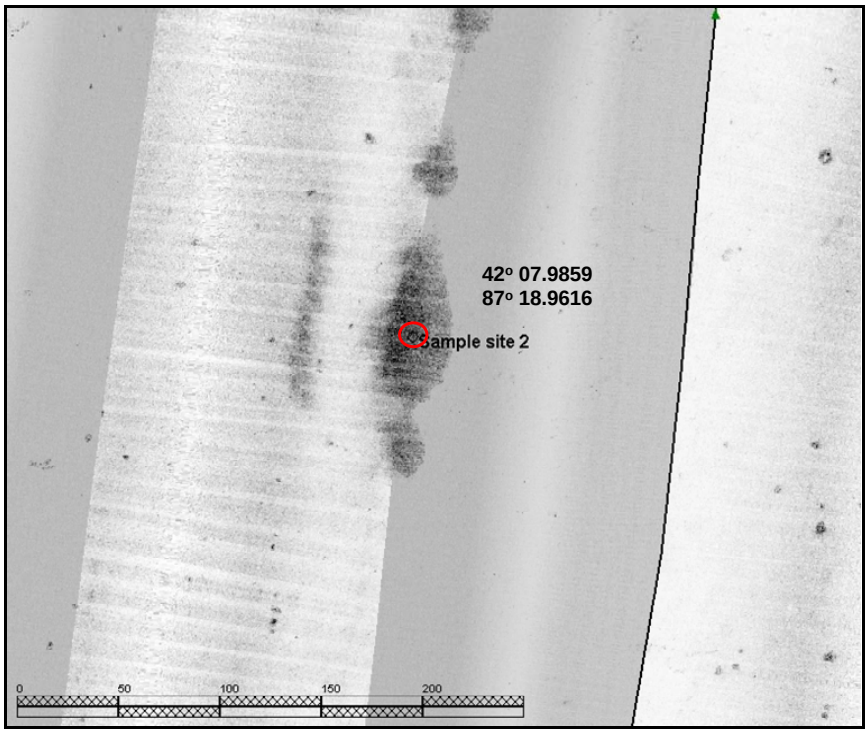


Figure A2-11 Lake Michigan – Lake Michigan Primary proposed 2007 sample location 2 (500 kHz)

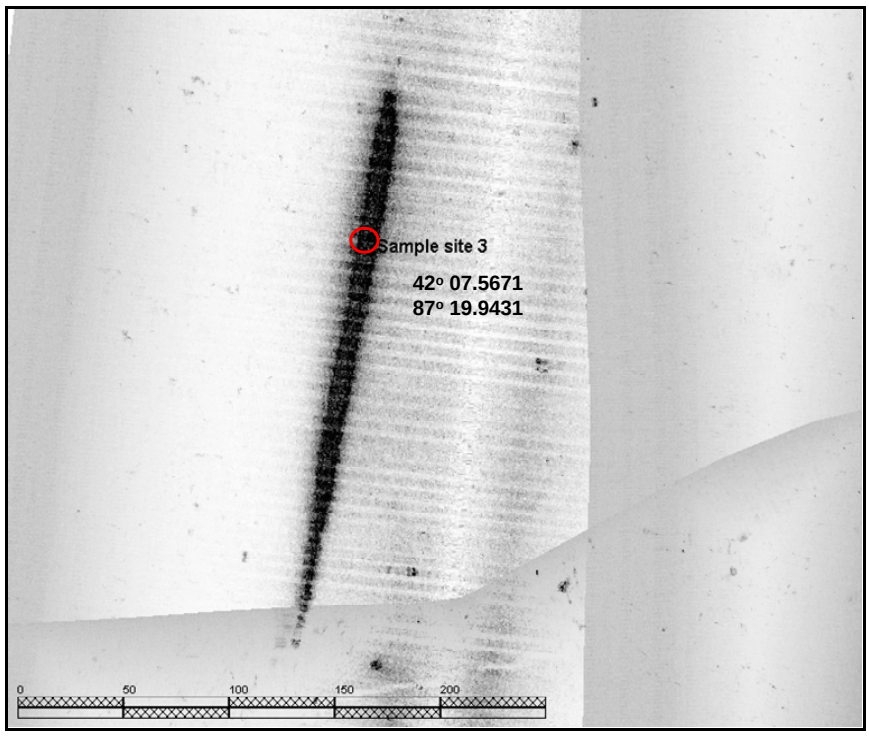


Figure A2-12 Lake Michigan – Lake Michigan Primary proposed 2007 sample location 3 (500 kHz)

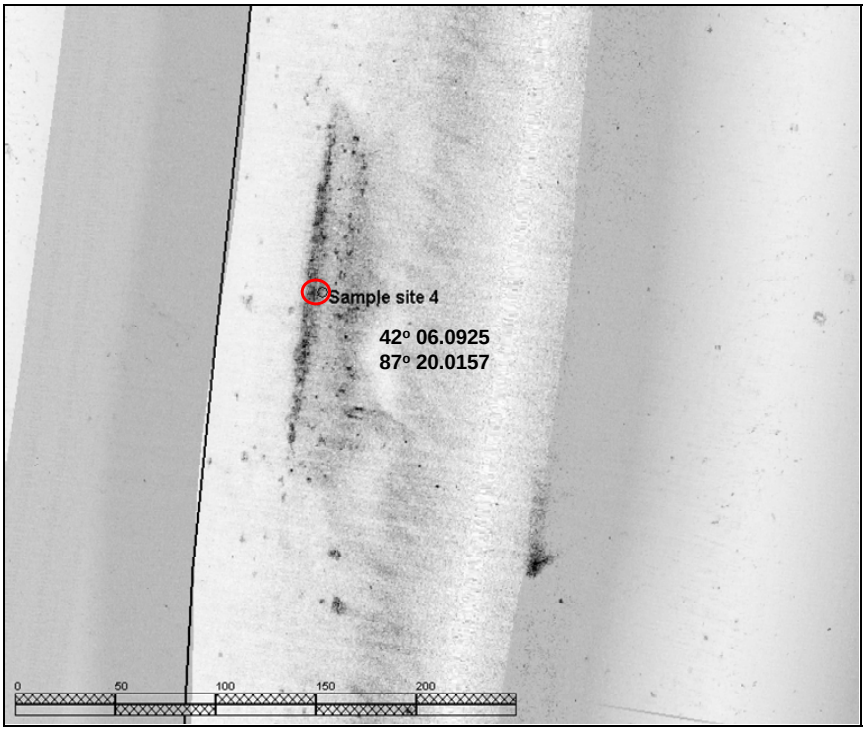


Figure A2-13 Lake Michigan – Lake Michigan Primary proposed 2007 sample location 4 (500 kHz)

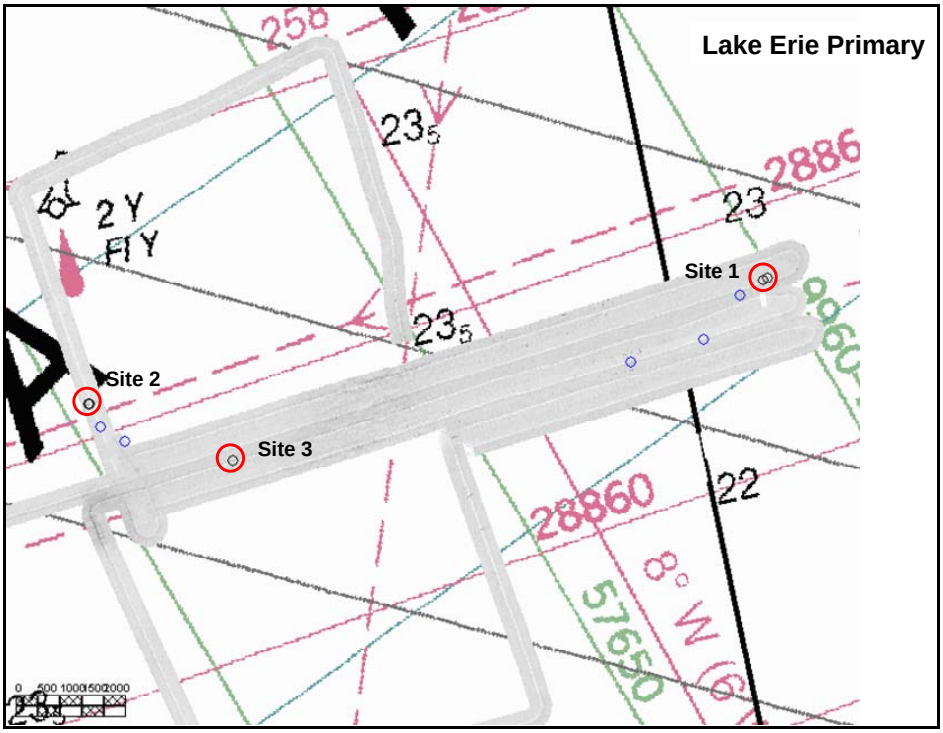


Figure A2-14. Lake Erie – Lake Erie Primary potential 2007 sampling sites.

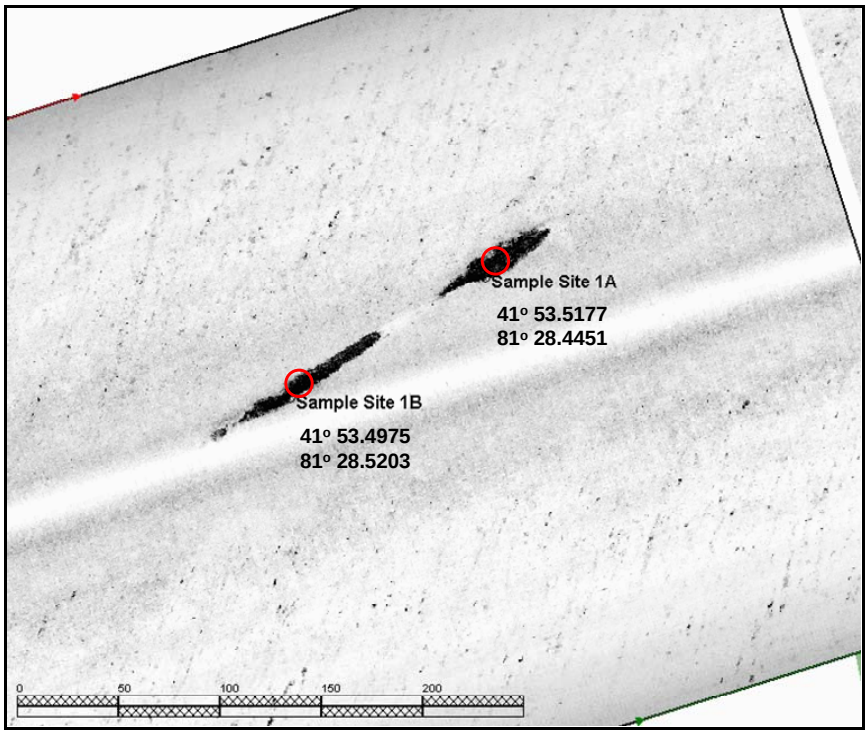


Figure A2-15. Lake Erie – Lake Erie Primary proposed 2007 sample locations 1A and 1B.

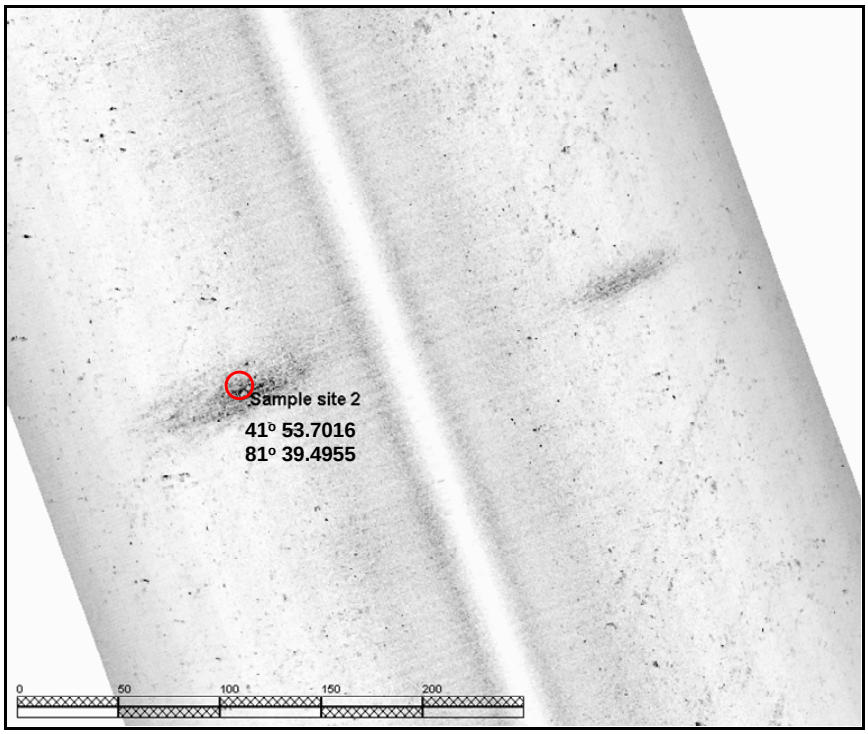


Figure A2-16. Lake Erie – Lake Erie Primary proposed 2007 sample location 2. (confirmed sweepings deposit 2006 sample)

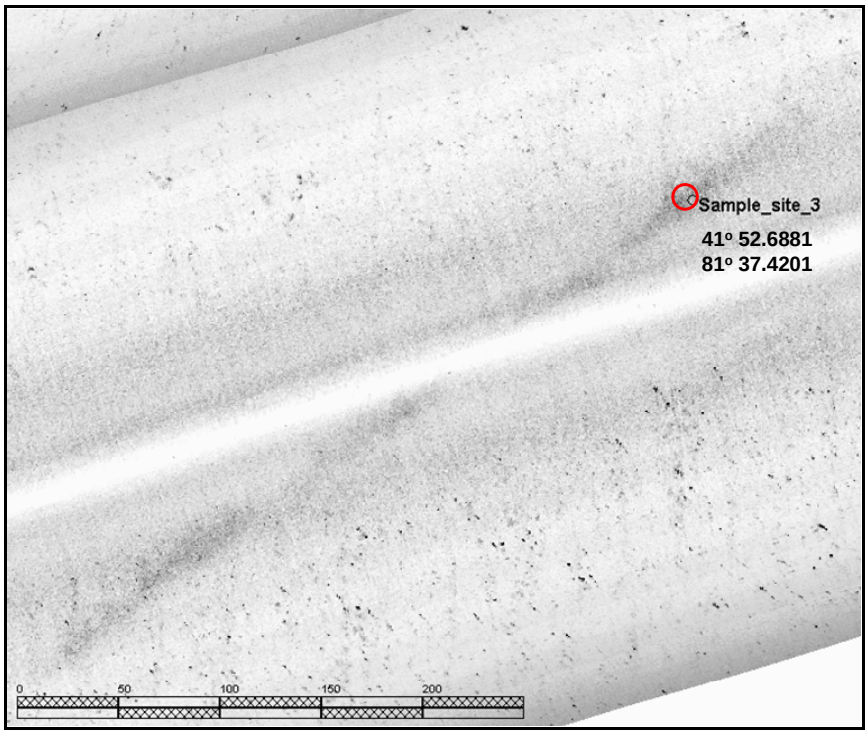


Figure A2-17. Lake Erie – Lake Erie Primary proposed 2007 sample location 3.

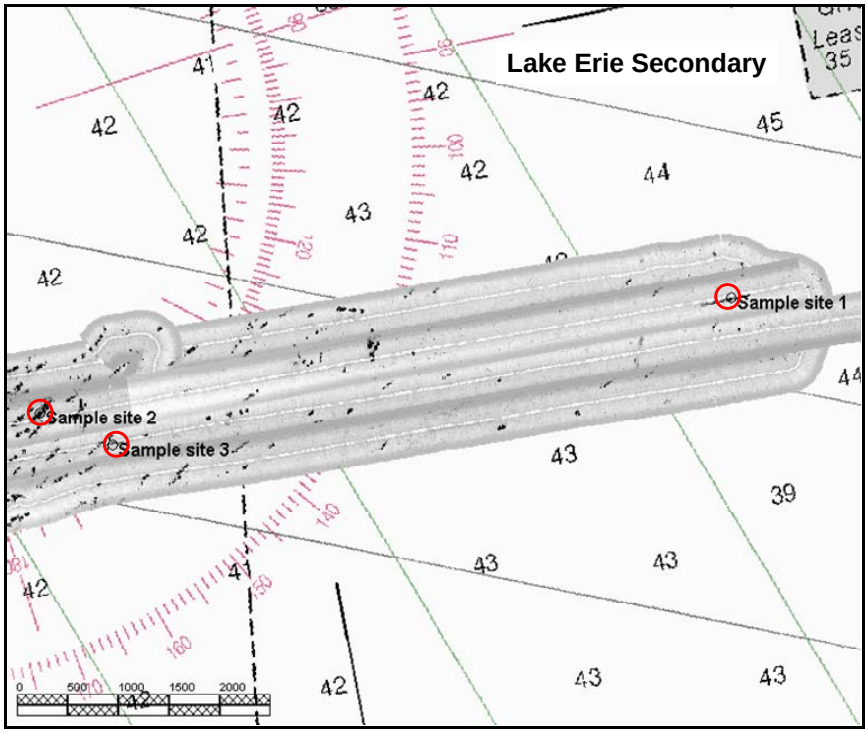


Figure A2-18. Lake Erie – Lake Erie Secondary potential 2007 sampling sites.

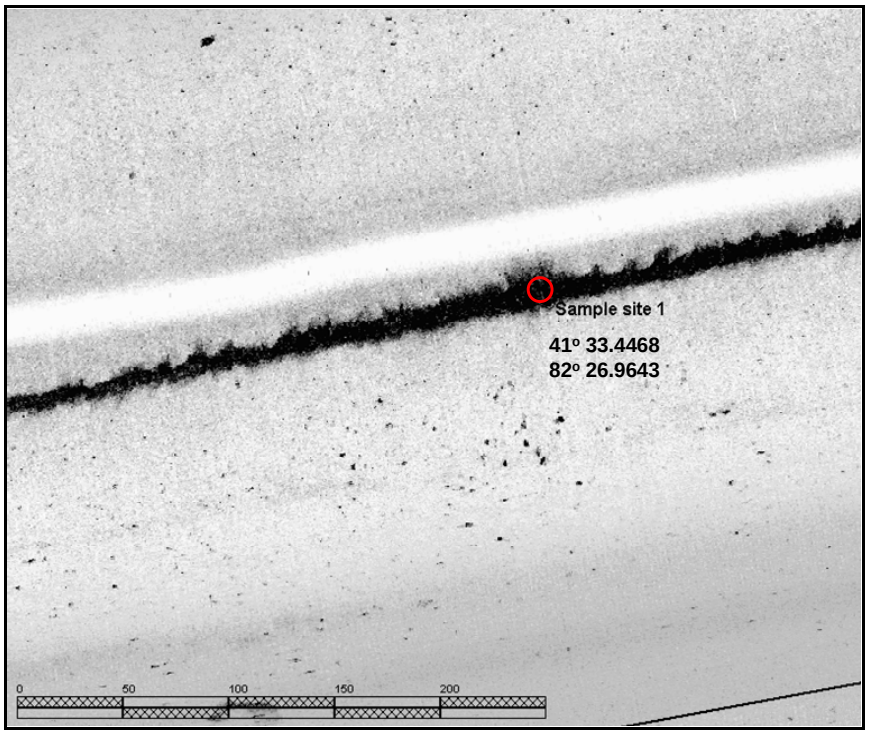


Figure A2-19. Lake Erie – Lake Erie Secondary proposed 2007 sample location 1.

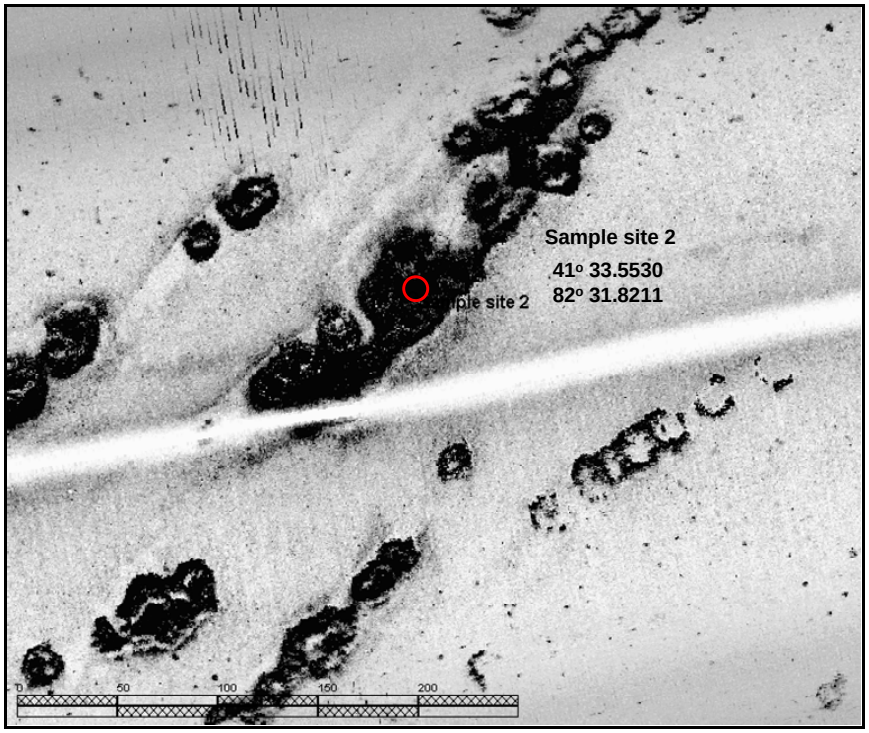


Figure A2-20. Lake Erie – Lake Erie Secondary proposed 2007 sample location 2.

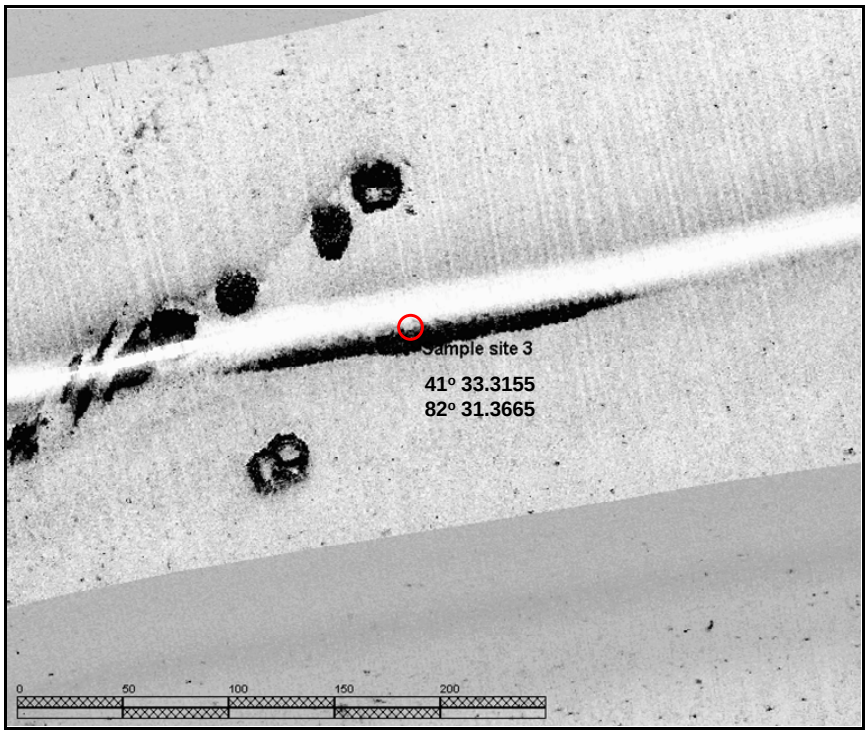


Figure A2-21. Lake Erie – Lake Erie Secondary proposed 2007 sample location 3.

Technical Note: For all of the survey areas, reference or undisturbed locations have not been provided. These are "self evident" from the mosaics and upon finalizing the 2007 sampling program, locations for potential reference sampling sites can be provided upon request.