NWRI Contribution 99-235

BOTTOM-SEDIMENT TYPE AND BATHYMETRY OF EASTERN LAKE ONTARIO FROM ACOUSTIC SURVEYS

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MANAGEMENT PERSPECTIVE

This survey of the bottom sediments of eastern Lake Ontario is part of a study by a consortium of western New York colleges funded by the New York State Nature Conservancy. The objective of the study is to develop an understanding of the processes and evolution of the eastern coast of Lake Ontario so that they can be applied to effective shoreline management.

This report describes an acoustic study of the bottom sediments and morphology of the nearshore zone of eastern Lake Ontario conducted with the seabed-classification system, RoxAnn™. RoxAnn surveys in September 1998 were used to map the bottom types and morphology of the zone. The survey results, although reconnaissance in nature, provide the most detailed description of bottom-sediment characteristics yet available. They will be used in conjunction with the consortium's results from other sampling and remote-sensing procedures to develop the framework required for the shoreline-management plan.

Future work will depend upon the availability of funding from the Nature Conservancy or its affiliates.

ABSTRACT

Sediments of the eastern shore of Lake Ontario's are being investigated by NWRI and a consortium of western New York colleges funded by the Nature Conservancy of New York State. The purpose of the study is to determine the source and dispersal of sediments in support of the development of a shoreline-management plan. Several approaches are being used to collect new data including NWRI's RoxAnn™ seabed-classification system.

RoxAnn surveys of the nearshore zone have been used to map the sediment pattern and the bottom morphology, and data have been analysed by the GIS program, Arc/Info. The RoxAnn data indicate that the coastal-zone sediments consist of an extensive deposit of well-sorted sands bounded on the south by exposed glacial tills and lag deposits and on the north by exposed bedrock. The limited textural data available for the sands indicate that they are very well-sorted to at least the 18-m contour and that a change from sand to silt and clay occurs at depths greater than about 40 m. The areal coverage of the sands within the 30-m contour is about 140 square kilometres. The three major bottom types have characteristic shore-normal depth profiles. Many of the sand profiles show roughness and breaks in slope at the depth intervals 9-19 m and 20-28 m which may be derived from lower lake levels.

1. INTRODUCTION

The eastern coast of Lake Ontario in New York State is a dynamic zone whose sedimentary processes and evolution are poorly understood. The Nature Conservancy of New York State has funded a study by a consortium of colleges in western New York to map the east-coast shoreline and nearshore sediments and to develop the understanding of coastal processes and evolution needed for the setup of a shoreline-management plan.

NWRI was invited to participate in the study and to use its RoxAnn seabed-classification system to map the sediment types and morphology of the nearshore zone. This report describes the results of a three-day survey of the study site in September 1998. The survey, although limited in time, was able to provide the most detailed characterization of sediment distribution and bottom morphology yet available for this shore reach. The mapping was successful in identifying the contacts between the three basic sediment types and in providing an overview of site bathymetry and bottom morphology. Of particular interest are features in the shore-normal depth profiles which may be related to lower lake levels and which will be important in the understanding of the evolution of the water-level curve.

2. STUDY SITE

The study area extends along the east shore of Lake Ontario from Selkirk Shores State Park north to Stony Point and from the shoreline out to about the 30-m contour. Sutton et al (1970, 1974) mapped the area in 1968 and 1969 as part of a study of the nearshore sediments of southern Lake Ontario, and the area was also investigated as part of a lakewide survey of Lake Ontario sediments by Thomas et al (1972a, b). The study by Sutton et al indicated that most of the current study area was covered by a continuous sheet of uniform sand which they suggested was the remnant of older shoreline deposits formed at a lower lake level 5000 years ago (Sutton et al 1972). The shoreline at that time was about 10 m below the current lake level and may be evident as a relict feature in the current offshore bathymetry.

3. SURVEY PROCEDURE

The survey equipment used was RoxAnn, an acoustic sea-bed classification system capable of recording detailed data on water depth and bottom-sediment type (Rukavina and Caddell 1997, Rukavina 1998). RoxAnn connects to an echo sounder and uses the properties of its first and second echoes from the bottom as a measure of its acoustic roughness and hardness. It then combines these parameters to produce an acoustic classification of bottom-sediment type. Independent data on sediment type are needed to convert the acoustic labels to physical sediment types.

RoxAnn surveys were attempted on August 26, 1998 but turned back by bad weather. A second run from September 14-17, 1998 was successful in completing the required coverage. Figure 1 shows the survey area and track lines and Appendix 1 is a log of field activities. All field work was done from the launch Puffin, a 25-foot trailerable aluminum workboat dedicated to RoxAnn surveys. Traverses were run as intersecting zigzag lines from south to north and then north to south in a diamond-shaped pattern. A number of lines normal to the shoreline were also run to record the properties of the nearshore profile. Navigation was by differential GPS with corrections provided by the Youngstown, New York, and Cardinal, Ontario, beacons and the survey datum NAD27 was used to provide consistency with earlier data. Static checks of GPS accuracy at a local benchmark at the start and end of the survey indicated that it was between 4 and 5 m. It is assumed that the dynamic accuracy was in the range of 5-10 m.

The survey sounder was the Atlas Deso 10 hydrographic sounder, a two-transducer system operating at frequencies of 210kHz and 30kHz. The high and low-frequency data were fed to two RoxAnn systems and recorded on notebook computers by the survey program, Microplot. Microplot logs RoxAnn data and associated GPS positions at one-second intervals or at about 2-3 m intervals for the standard survey speeds of 2-3 m/s. Only the high-frequency data were analysed because there were no core data available to calibrate the low-frequency results. The high-frequency data record only surface sediment types because penetration at that frequency is limited. Echo returns represent the response from the top few cm of the sediment surface to a maximum of about 50 cm depending on the texture and porosity of the bed sediment

RoxAnn requires independent data on bottom-sediment type from samples or diver or underwater-television observations to convert its acoustic sediment labels to physical bottom types. The expectation was that these data would be available from other surveys by the study team but, in fact, no sample data were collected. Although time was not available for the sampling needed for proper calibration, a limited number of grab samples was collected offshore from Southwick Beach at the northern end of the area on the final day of the survey. A mini-Shipek grab (Mawhinney and Bisutti 1987) was used to sample the top 5 cm of sediment at 8 sites in water depths ranging from 2.5 to 18.7 m.

Because independent data on sediment type were limited, no pre-calibration of RoxAnn was attempted. The default limits for the 8 bottom categories from previous surveys were used. The categories were mud, muddy sand, sand, coarse sand, gravel, boulders/hard, weeds on soft and weeds on hard.

4. DATA ANALYSIS

4.1 RoxAnn bottom types and bathymetry

The RoxAnn survey tracks were limited to a zig-zap pattern in a northerly direction, an intersecting zig-zag pattern south and a medial line. The low density of the data would not ordinarily warrant GIS mapping and areal analysis but the alongshore consistency of bottom types suggested that it might be more informative to display the results as maps with sediment contacts rather than as line plots. To prepare the RoxAnn file for GIS analysis, all the data were checked, fixes with poor GPS quality were removed, and depths were corrected to IGLD85 using NOAA data from the Oswego gauge. The edited file was then imported into an Arc/Info GIS for voronoi-polygon analysis of the RoxAnn bottom types (Rukavina and Delorme 1992). This type of analysis produces a chloropleth map by first associating with each data point a polygon extending half the distance to surrounding data points and then grouping areas of the same type. The result is a map with georeferenced boundaries and a table of areas of coverage of the data classes.

RoxAnn labels for bottom type were checked against the grain-size data from the small suite of samples offshore from Southwick Beach and also deeper samples collected from 4 sites during the original lakewide survey by Thomas et al in 1968 and an NWRI cruise in June 1998 (Charlton and Reynoldson, NWRI, personal communication). Although the data were limited, it was possible to associate the RoxAnn type muddy sand with well-sorted fine sand and the type mud with sizes ranging from very fine sand to muddy sand. The size classes sandy mud and mud recovered in the offshore samples were beyond the limits of the survey area in depths greater than 40m.

The RoxAnn depth data were also imported into the GIS and contoured to produce a bathymetric map with a contour interval of 5 m. Depth data are approximate because no barcheck records were collected to correct for the dependence of velocity of sound on water temperature. Plots of shore-normal profile lines for the three major bottom types were produced to show their characteristic morphology, and echo-sounder records were examined for changes in slope or bottom type which might be indicative of lower lake levels.

4.2 Sediment samples

Data on the locations, depths and descriptions of grab samples collected during this survey are listed in Appendix 2. The samples were analysed for grain size by sieving in NWRI's Sedimentology Laboratory and size statistics were computed with the laboratory's SIZMERGE program.

5. RESULTS AND DISCUSSION

The GIS map of RoxAnn bottom types is shown in Figure 2 and their areal coverage is listed in Table 2. The legend in Figure 2 lists the default bottom types developed from previous surveys. Some of types have been adjusted to agree with the limited sample data available from Southwick Beach and are labeled "interpreted".

Figure 2 shows an extensive deposit of sand along most of the study reach which is bounded at its north end by bedrock and at its south end by coarse-grained lag deposits and glacial till. Inshore bottom types grade from gravel to coarse sand to sand within the 5-m contour. The shallowest records at 2 m depth show a very hard bottom suggesting either very tightly-packed sand or near-surface bedrock. From about 5 to 15 m, the record type is uniform fine sand and from 15 m to the outer boundary of the survey area at 30 m, the type is very fine sand or muddy sand with patches of coarser sediment. A grab sample collected in one of the sand patches consisted mainly of zebra mussels in a matrix of fine muddy sand and it is possible that the apparent textural changes elsewhere within the area of very fine sand also represent zebra-mussel druses.

Bedrock is exposed at the shoreline in the area of Black Pond and is also visible in shallow water. RoxAnn records it as boulders, hard bottom and gravel. The hard bottom extends offshore to depths of 10 to 15 m and then gives way to the sand deposit.

South of North Pond the inshore sand deposit gives way at about 10 m to a highly-variable lakebed with an irregular topography and with RoxAnn types of gravel, boulders and sand. This is a pattern typical of glacial tills with a veneer of coarse lag deposits. The types boulders, gravel and sand in areas of this type generally represent high to low proportions of lag material relative to exposed till.

GIS areal analysis indicates that more than 90 percent of the survey area consists of sand. Muddy sand and very fine sand are dominant at 50 percent and fine sand and sand account for 25 and 18 percent respectively. The balance of the area consists of gravel or lag deposits (7%), and 1 percent or less of hard and weed bottom.

Table 1. GIS areas of bottom types and depth distribution

RoxAnn bottom type	Area	Percent		Depth Interval, m	Area	Percent
	sq km	area			sq km	area
muddy sand/very fine sand	75.98	49.2		0 - 5	18.22	11.8
fine sand	37.82	24.5		5 - 10	25.39	16.5
sand	27.14	17.6		10 - 15	23.31	15.1
coarse sand	0.63	0.4		15 - 20	23.88	15.5
gravel/lag deposits and till	10.19	6.6		20 - 25	30.28	19.6
boulders/bedrock	0.80	0.5		25 - 30	31.71	20.6
weeds on hard	0.01	0.0		>30	1.47	1.0
weeds on soft	1.54	1.0				
other	0.18	0.1		Total	154.27	100.0
Total	154.27	100.0				

Bottom type is also reflected in the bathymetry (Figure 3) by the changing roughness of the contours and in the shape of shore-normal profiles (Figure 4). Profiles of the sand deposit (Southwick, North Pond) are smooth and convex upward inshore of the 20-m contour and planar with a reduced slope offshore from 20 m. At Black Pond, a steeper bedrock slope inshore gives way to a typical sand profile offshore. The Salmon River and Selkirk profiles are respectively a sand profile interrupted by irregular patches of lag deposits, and a shallower very rugged erosional profile dominated by glacial and lag deposits.

Echo-sounding records occasionally showed breaks in slope and irregular profiles at water depths between 9 and 19 m and 21 and 28 m (Figure 5). Figure 6 shows the sites and depth ranges where the anomalous topography was observed. Profile form at these locations varied. In some cases the rough portion of the profile was depressed below the surrounding profile; in others it was elevated. Offshore slope below the break tended to be lower than above the break. Several of the profiles showed notches or rises at their upper and lower ends. It is possible that these breaks in slope represent remnants of stillstands at the lower lake levels (Dune stage?) inferred in earlier studies by Sutton et al (1972), and that the jagged profiles result from irregular till or bedrock substrate which is still exposed. Zebra mussels were recovered from one of the slope breaks opposite Southwick Beach and it is likely that other sites will also be attractive to mussels because of the combination of moderate depth and hard substrate within an otherwise featureless bottom.

Data on sediment texture are available only for the series of grab samples collected at Southwick Beach (Appendix 2, Figure 7) and for a few offshore samples from lakewide cruises by NWRI in 1968 and 1998. Modal size for the Southwick samples was 2.5 Phi and silt-clay content was less than 2% for all samples. The Phi scale is a logarithmic scale commonly used by geologists to describe grain size. The Phi range of 1 to 4 corresponds to a range of 0.5 to 0.063 mm on the metric scale. Phi sorting decreased slightly in an offshore direction from 0.28 Phi at 2.5 m to 0.47 Phi at 18 m. In the cruise samples, the transition from sand to silt and clay took place at depths between 40 and 45 m.

6. CONCLUSIONS

Surveys of the nearshore zone of eastern Lake Ontario with a RoxAnn seabed classification system have provided the first comprehensive view of the sediment types and bathymetry of the zone. Most of the area consists of an extremely well-sorted sand sheet which extends to depths of more than 30 m. The sand deposit is bounded on the north by exposed bedrock and on the south by glacial sediments and their coarse lag deposits. Echo-sounding profiles of the three basic substrate types show distinctive features of roughness and slope. Several of the sand profiles show breaks in slope at depths of about 10 and 20 m which may be the result of stillstands at lower lake levels.

GIS analysis of the RoxAnn bottom-type and depth data has been used to produce maps of sediment boundaries and bathymetric contours and to estimate the relative coverage of the bottom types. Muddy sand or very fine sand is the dominant type at 49% followed by fine sand at 25%, sand at 18% and gravel or lag deposits at 7%. Remaining classes account for 1% or less of the area of the zone.

Only limited data are available on the relationship between texture and water depth. Samples from water depths of 2 to 18 m offshore from Southwick Beach are very well-sorted sands to fine sands. Offshore data from earlier NWRI cruises place the boundary between sand and mud at 40 to 45 m.

7. RECOMMENDATIONS FOR FURTHER WORK

RoxAnn coverage was limited by budget and weather to an open-grid reconnaissance survey. Better definition of the contacts with bedrock and till and of the shallow-water sediment types would require a tighter grid in selected areas and followup surveys with underwater television and samples.

Proper calibration of RoxAnn or any other remote-sensing equipment depends upon an adequate supply of samples and bottom observations. This was missing in this case. Any future work should include sufficient sediment sampling and underwater-television or diver observations to support the interpretation of the data from the other surveys.

It was evident from the weather and storm waves encountered during the survey that the eastern coast is a dynamic one. The RoxAnn surveys provide only a snapshot of sediment distribution at the time of the survey. Changes in sediment pattern caused by water-level fluctuations and seasonal storms will require further surveys to determine the seasonal responses in both sediment type and bathymetry. These should be supplemented by detailed measurements of the changing nearshore profile by diver observations or by bottom instrumentation that records sediment movement as well as waves and currents.

Echo-sounding records showed anomalous profiles which may represent stillstands at lower lake levels. More detailed surveying to determine the distribution and consistency of slope breaks would be advisable since this type of data is key to the understanding of the longterm evolution of the coast.

8. ACKNOWLEDGEMENTS

Dave Gilroy of NWRI's Technical Operations group was the coxswain for the survey. Brian Trapp (AERB/NWRI) operated the RoxAnn system. Contractor Marilyn Dunnett assisted in the reduction of the data, and the GIS analysis was contracted to Carolyn Bakelaar. The study was funded by the New York State Nature Conservancy and administered by Donna Senator of the University of Rochester's Research Administration Office. Dr. Donald Woodrow of the Department of Geosciences, Hobart and William Smith College, Geneva, New York, was the principal investigator.

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Figures

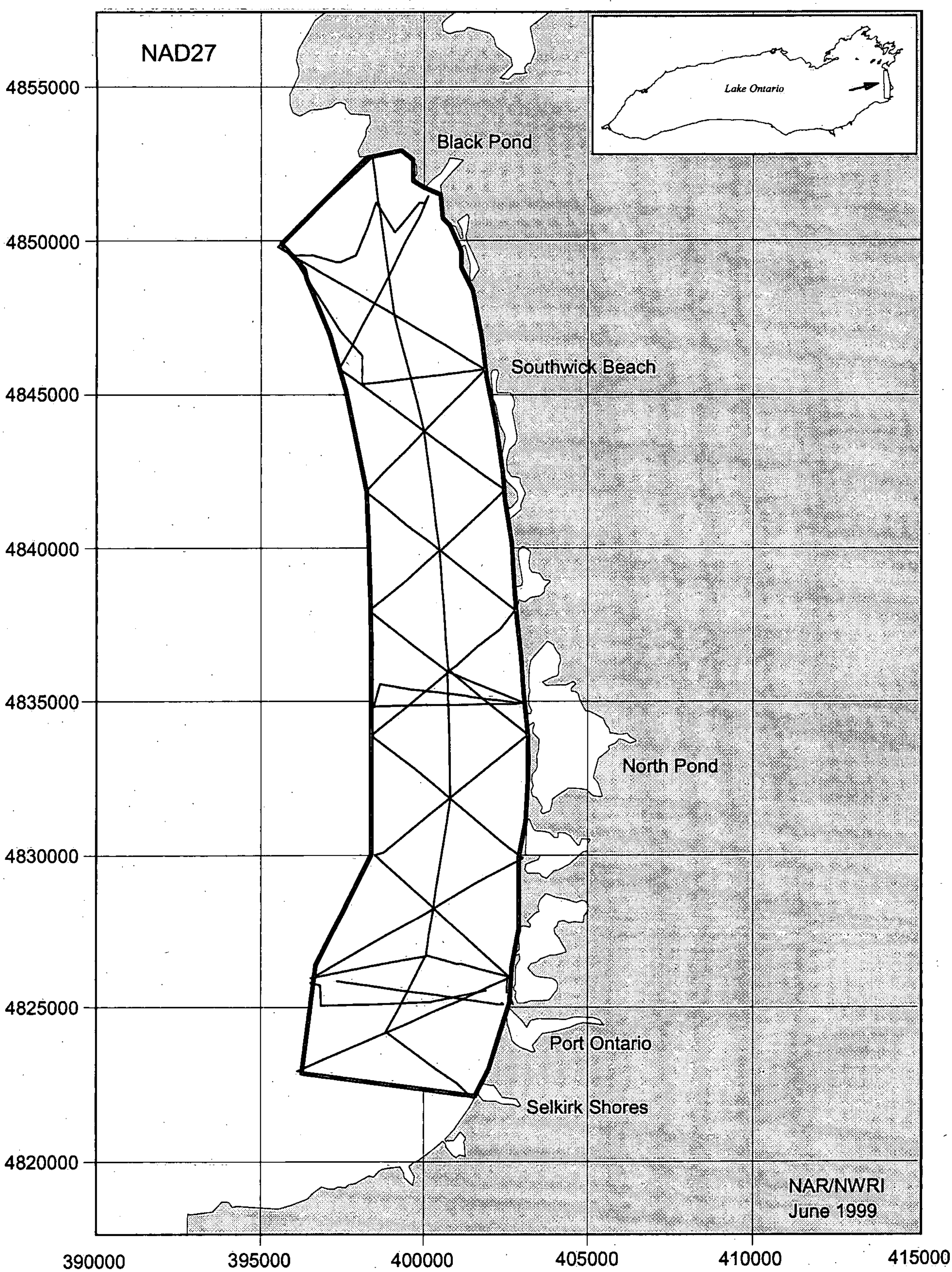

Figure 1. Study area and RoxAnn survey tracks

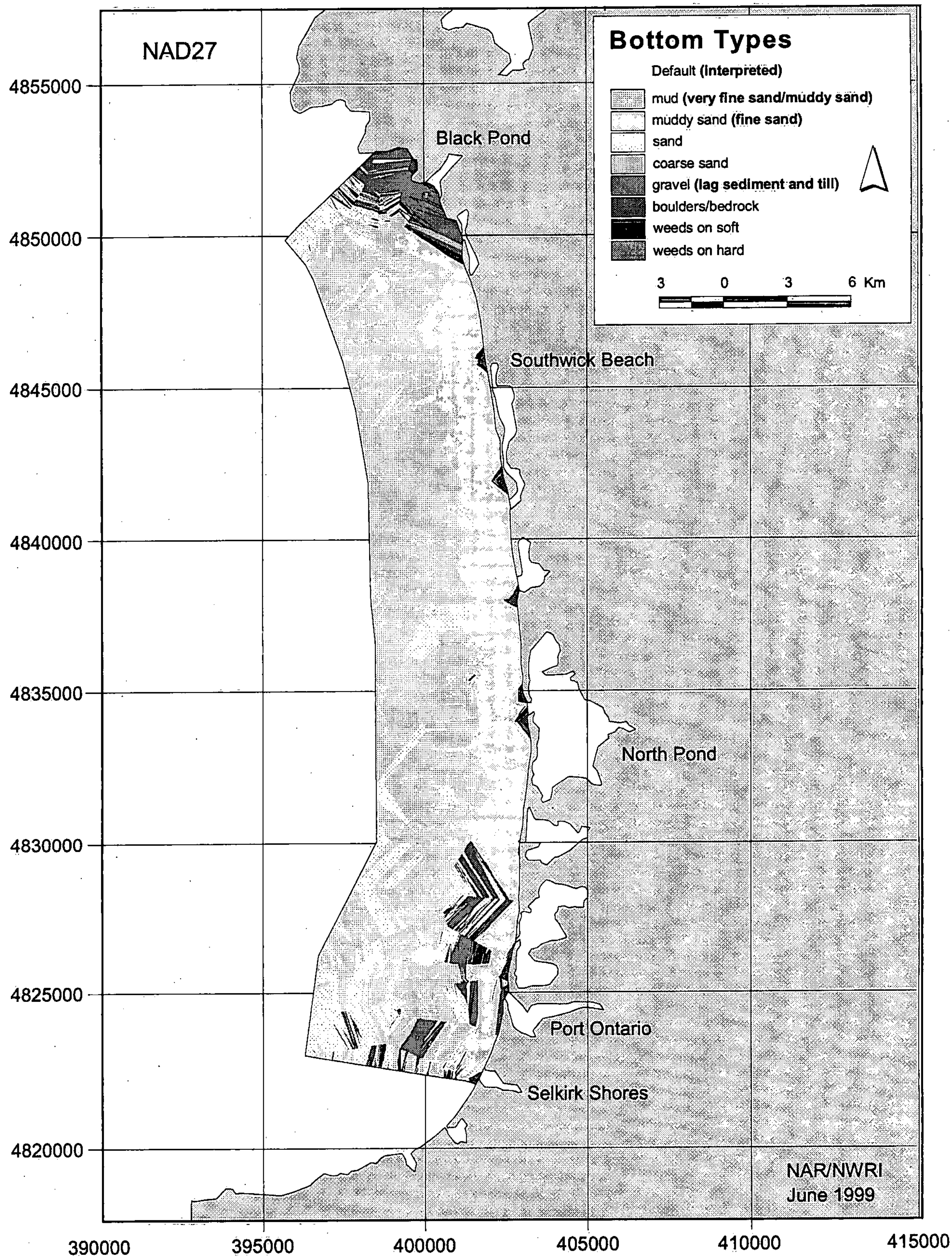

Figure 2. RoxAnn bottom types

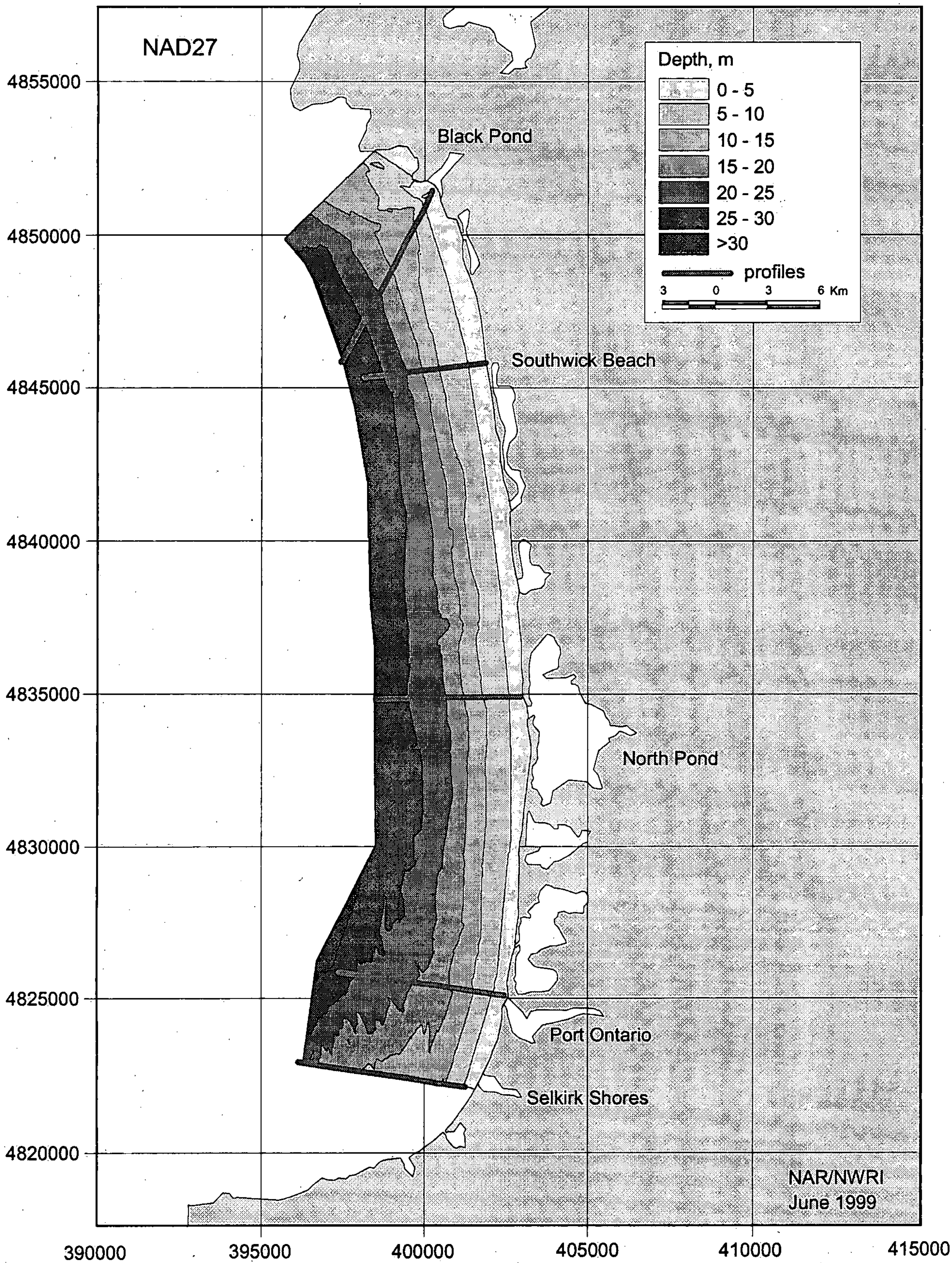

Figure 3. RoxAnn bathymetry

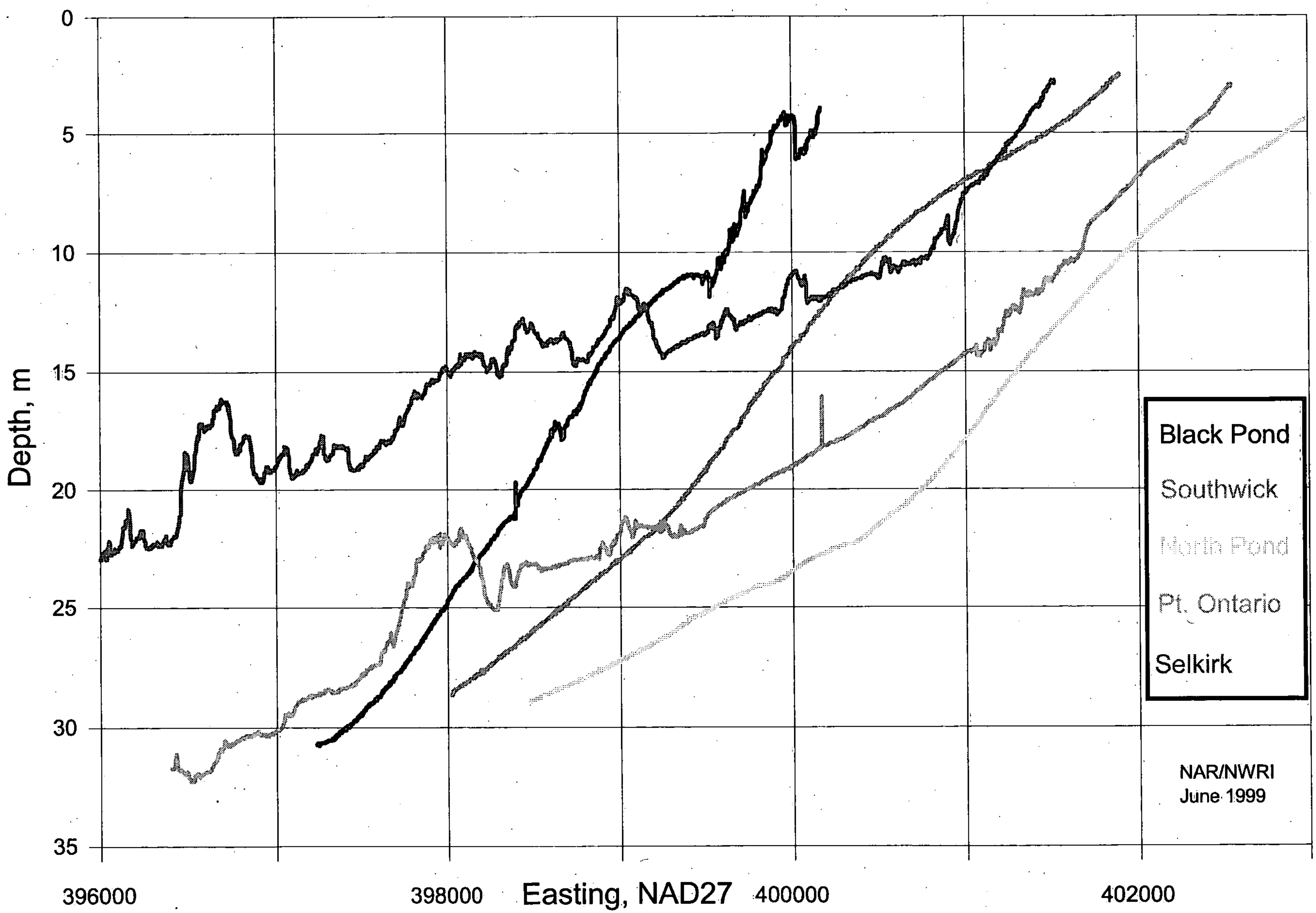

Figure 4. Shore-normal depth profiles

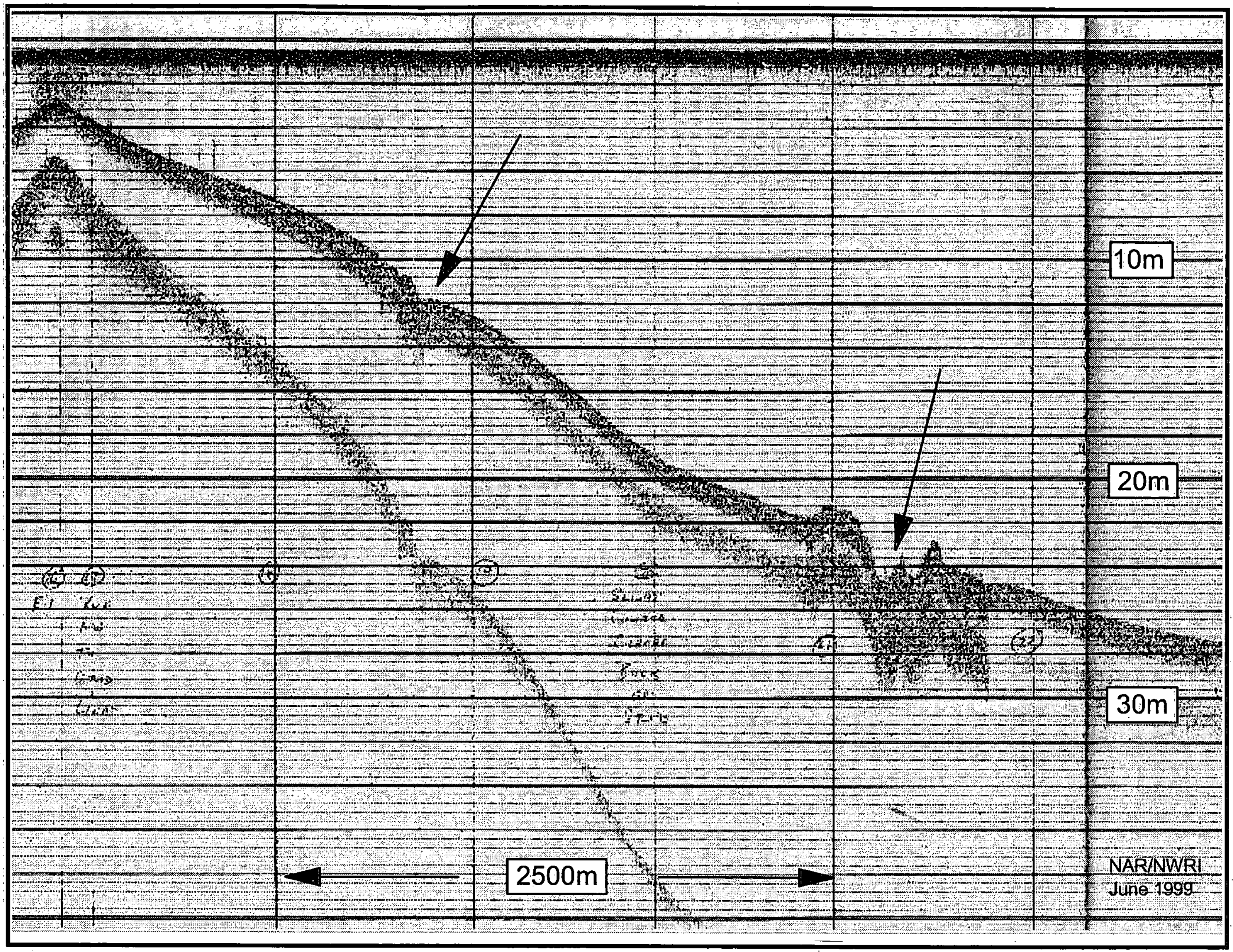

Figure 5. Sample of breaks in profile

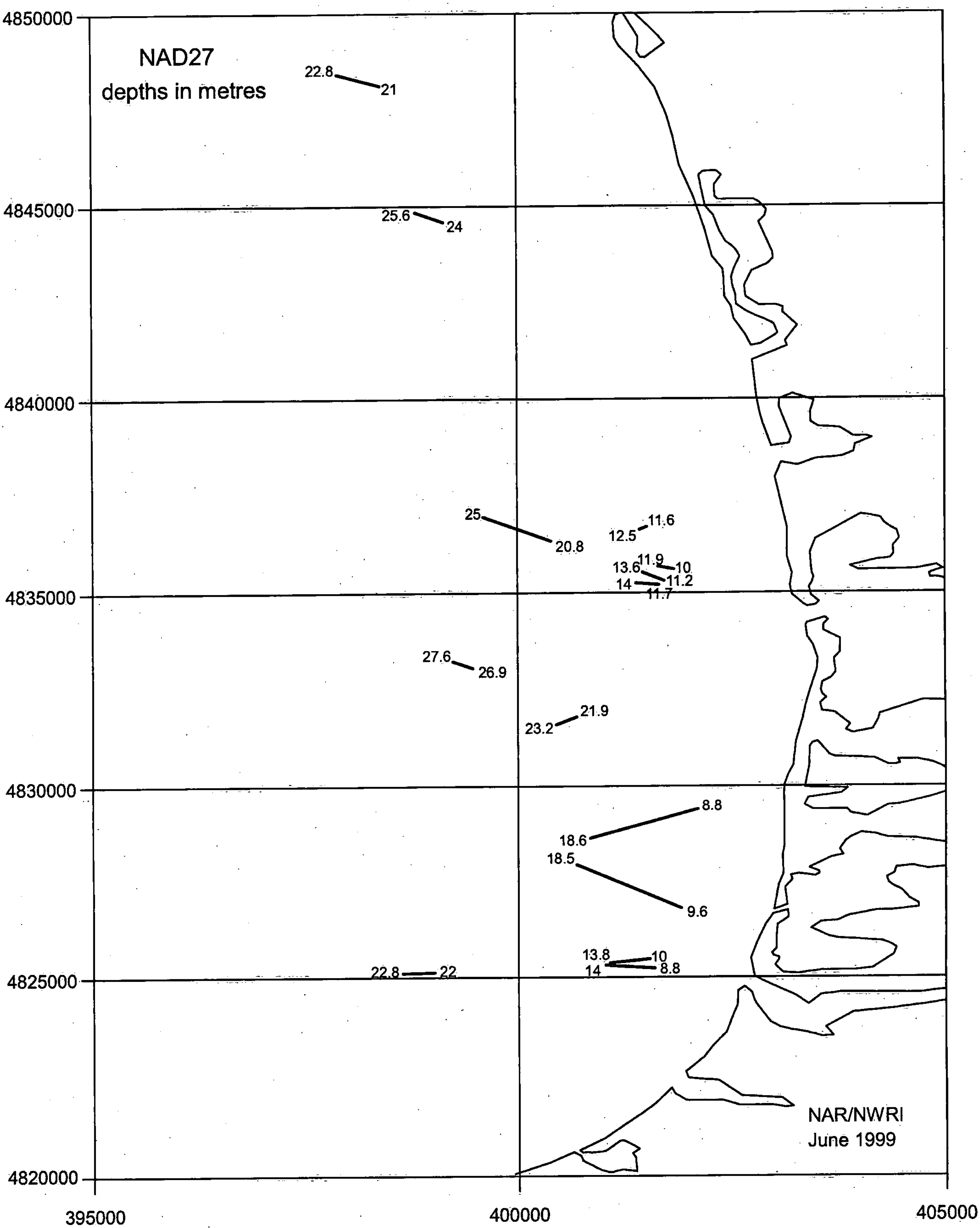

Figure 6. Locations and depths of profiles with slope breaks

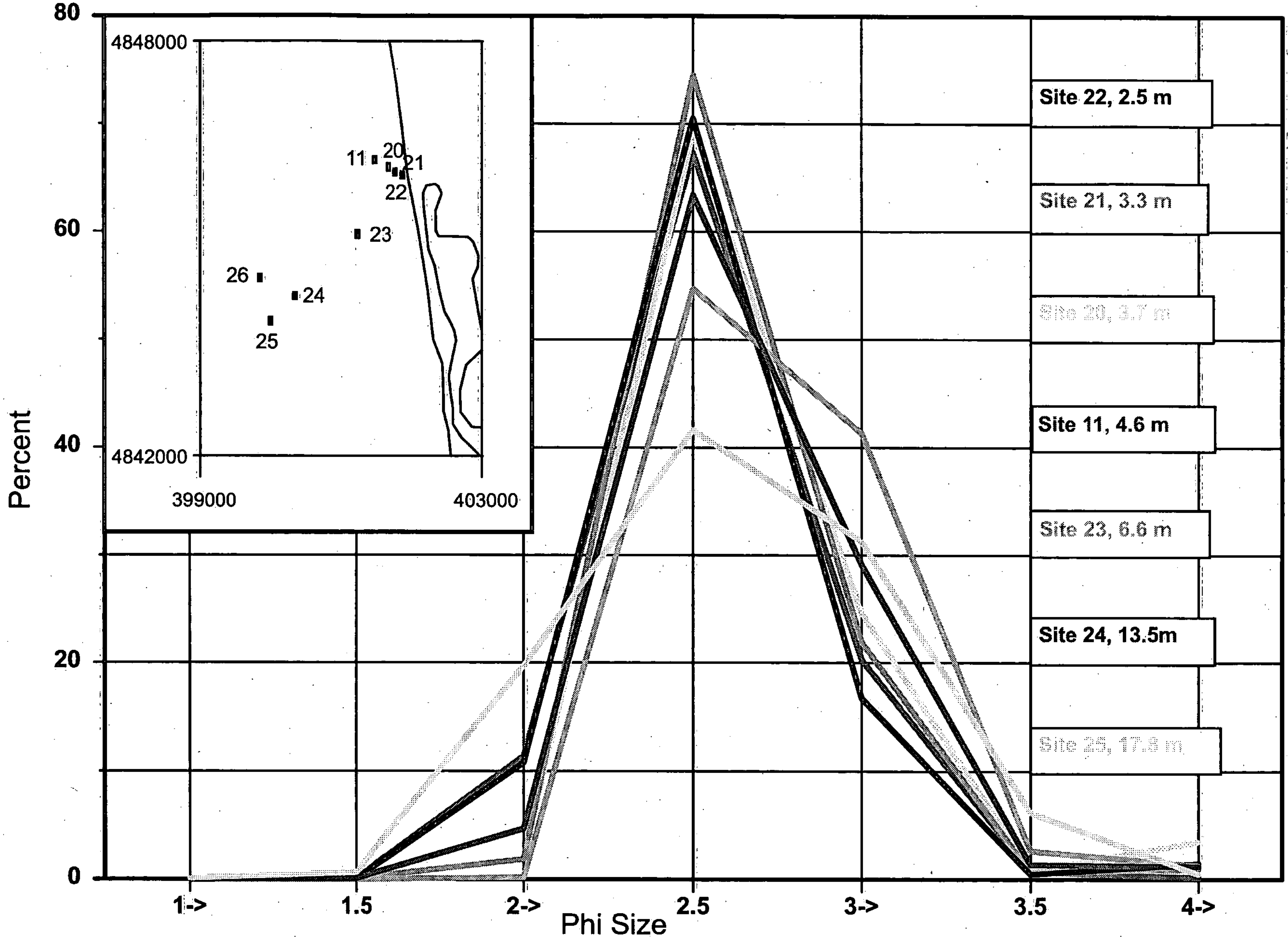

Figure 7. Sediment texture offshore from Southwick Beach

Appendix 1

Survey log

Tuesday, August 25, 1998

- left CCIW at 1515, arrived Port Ontario at 2110
- met with Don Woodrow and discussed work priorities for tomorrow

Wednesday, August 26, 1998

- launched Puffin at 800 at Lighthouse Marina and started setup
- problems with GPS setup required reprogramming, resolved by 1030
- westerly winds, waves 2-4 feet
- ran two RoxAnn lines and then driven in by 4-6 foot waves
- received differential corrections for GPS from both Youngstown and Cardinal until 1145 and then no longer available
- weather forecast for increasing winds and waves
- returned to the marina at 1235, reserved a slip for the week of September 14
- packed the Puffin
- left for CCIW at 1420, arrived 1915

Monday, September 14, 1998

- left CCIW for Port Ontario at 905, arrived 1400
- launched Puffin at 1420, setup complete by 1515
- GPS check at the lighthouse benchmark
- entered waypoints and completed RoxAnn calibration by 1615
- started survey at 1630, light to no wind, waves less than half a foot
- completed a third of the southern lines by 2030 and ran back in the dark
- completed calibration by 2040
- checked the logged coordinates against the benchmark and found them to be within a few metres

Tuesday, September 15, 1998

- rainy spells, winds light
- Puffin setup and calibration complete by 900

- fast run to North Pond at 910 and ran shore-normal RoxAnn line and then lines south to the marina
- marina at 1335, RoxAnn calibration complete by 1400
- waves building from the southeast, too rough to run north end of survey
- drove to Black Bay to check out the launch ramp and marina, too shallow for Puffin
- worked in motel on editing of new trk files

Wednesday, September 16, 1998

- marina at 730 and run out to check lake conditions, strong north winds and waves too large to run north
- back to the motel to wait out the weather, further work on RoxAnn files
- called Don Woodrow re sample data for RoxAnn calibration from other surveys, none available, new samples required
- check of sea state at north end of the area at 1240, still too rough to work
- replaced the east Ontario shoreline in the survey program with a higher-resolution shoreline available from the NOAA website

Thursday, September 17, 1998

- leave marina at 730
- winds light and offshore, calm at marina but 1-1.5 foot waves at north end of area
- RoxAnn calibration enroute to north end of area, completed at 810
- started RoxAnn survey at 820, completed the north end of the area by 1400 including a shore-normal line at Southwick Beach park
- back to the marina for gas at 1530
- out to resurvey August lines at the south end of area at 1630, waves now 1-1.5 ft
- survey complete at 1840, stopped offshore for calibration, docked at 1855
- checked the sounding records, picked 14 underwater-television sites

Friday, September 18, 1998

- checked out of Port Lodge motel at 645, marina at 730

- sunny, light winds at marina
- setup for underwater television complete by 820
- final GPS check at the lighthouse benchmark
- started run north at 900
- waves 1-1.5 ft at marina increasing to 3 ft at Black Pond at the north end of the area
- underwater tv monitor connections flooded by rough run, survey not possible
- substituted mini-Shipek sampling offshore from Southwick Beach Park and collected 8 samples before weather too rough to continue
- back to marina at 1225, packed by 1315
- left for CCIW at 1425, arrived 1915

Appendix 2

Sample field and grain-size data

Field Data

Site #	Time	UTM NAD27		Depth, m	Samples	Notes
		Northing	Easting	uncorr.		Collection date: 1998-09-18, mini-Shipek sampler
11	10:32:43	4846286	401489	4.6	2 vials	½ bucket well-sorted fine sand
20-1	10:38:33	4846179	401685	3.7		minor fine sand
20-2	10:39:49	4846185	401685	3.7	2 vials	½ bucket well-sorted fine sand
21-1	10:48:03	4846129	401757	3.3		
21-2	10:49:05	4846115	401782	3.2		
21-3	10:49:13	4846114	401783	3.2		
22-1	10:54:17	4846068	401892	2.5		minor fine sand
22-2	10:56:09	4846055	401885	2.5	2 vials	½ bucket well-sorted fine sand
23-1	11:05:11	4845205	401236	6.6	1 vial	½ bucket well-sorted fine sand
23-2	11:09:53	4845220	401234	6.6	2 vials	½ bucket fine sand, surficial organic detritus
24	11:19:23	4844318	400348	13.5	2 vials	½ bucket fine sand, rusty surface
25	11:28:05	4843963	399997	17.8	2 vials	1/3 bucket muddy sand with zebra mussels (1 vial) , shrimp, white shell fragments
26	11:36:53	4844578	399848	18.7	1 vial	2/3 bucket of zebra mussels, minor mud, photograph

Size Data

Site #	Moment Measures (Phi)				Size Fractions (%)			Percentiles							Shepard	Folk Label
Label	Mean	Sort	Skew	Kurt	Grav	Sand	Slt+Cly	50th	5th	16th	25th	75th	84th	95th	Label	Sand/Silt/Clay
11	2.8	0.3	0.0	0.9	0.0	99.8	0.2	2.8	2.2	2.5	2.6	3.0	3.1	3.4	SAND	SAND
20	2.9	0.3	0.3	1.7	0.0	96.5	3.5	2.8	2.5	2.6	2.7	3.1	3.3	3.5	SAND	SAND
21	2.9	0.2	0.4	1.9	0.0	99.0	1.0	2.8	2.5	2.6	2.7	3.0	3.2	3.4	SAND	SAND
22	2.8	0.3	0.1	1.0	0.0	98.5	1.5	2.8	2.2	2.5	2.6	3.0	3.1	3.4	SAND	SAND
23	3.0	0.3	0.3	-0.6	0.0	98.7	1.3	3.0	2.5	2.6	2.7	3.2	3.4	3.5	SAND	SAND
24	2.9	0.3	0.1	0.6	0.0	98.8	1.2	2.9	2.5	2.6	2.7	3.1	3.3	3.5	SAND	SAND
25	2.9	0.4	0.0	-0.4	0.0	99.5	0.5	2.9	2.1	2.4	2.6	3.2	3.4	3.6	SAND	SAND

2557 3