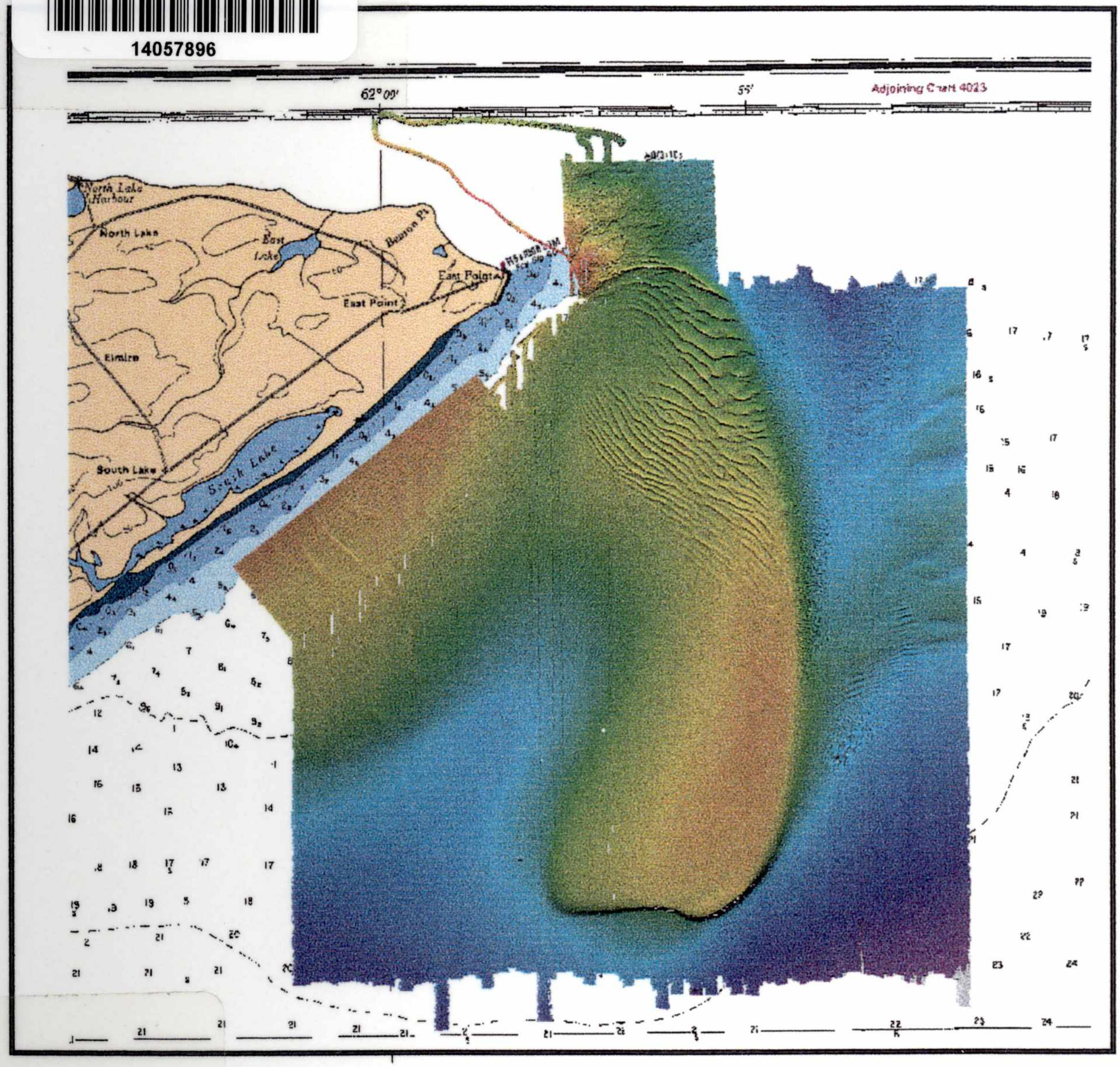
Cruise Report IML 99-037a
CCGS Frederick G. Creed

Multibeam Bathymetric Surveys on Milne Bank and off Northeast Prince Edward Island



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Geological Survey of Canada Atlantic
Dartmouth, Nova Scotia

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B2Y 4A2

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Front Cover: Colour shaded-relief map of the seafloor on Milne Bank and vicinity, PEI. The image is a composite of three sets of multibeam bathymetric surveys completed between 1997 and 1999. The main part of Milne Bank and the waters east and west of it were completed in 1997 (Shaw et al., 1997); the inshore area of South Lake was completed in 1998 (D.L. Forbes, 1999, pers com) and the north end of Milne Bank was completed in 1999 together with a repeat survey of the bedforms.

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CRUISE INFORMATION

Cruise Number	IML 99037a
Vessel	CCGS *Frederick G. Creed*
Dates of Survey	August 12 to 17 (Day 224 to 229), 1999.
Areas of Operation (Fig. 1)	Milne Bank and East Point, Prince Edward Island Offshore of Boughton Bay Basin Head to Little Harbour

Geological Survey of Canada personnel

Robert Taylor (Scientist)
John Shaw (Scientist)
Darrell Beaver (System Specialist)
D. Frobel (System Specialist)
R. Currie (System Specialist)

***F. G. Creed* personnel**

Roger Harvey (Captain)
Philippe Cahn (Chief Officer)
Gilles Beaulieu (Chief Engineer)
Maurice Jean (Chef)

Canadian Hydrographic Service personnel

Charles O 'Reilly (Tidal section)
Glenn King (Tidal Section)
Carmen Reid (Tidal Section)
Dave Blaney (Hydrographer)

OBJECTIVES

Collect digital bathymetry of Milne Bank, and the marine areas adjacent to East Point, Prince Edward Island, to understand modern marine and coastal processes, and late Holocene sea-level history. More specifically, the objectives are:
(1) to complete a repeat survey over the large bedforms on Milne Bank to map their migration patterns and morphological changes since the 1997 bathymetric survey (Shaw et al. 1997) and to resurvey the distal end of Milne Bank to determine if it is building southward.
(2) to extend the 1997 digital bathymetric coverage northward to define the northern extent of the bedforms on Milne Bank.
(3) to determine whether there is presently an active transfer of sediment between the shores west or south of East Point and Milne Bank, or whether Milne Bank is cut off and isolated from onshore sources of sediment.

ACCOMPLISHMENTS AND PRELIMINARY INTERPRETATIONS

Milne Bank

Milne Bank (Figs. 1, 2) is located off East Point at the northeast tip of Prince Edward Island. The bank has been surveyed by Geological Survey of Canada Atlantic (GSCA) on two previous occasions: in 1988 to map the occurrence and distribution of offshore aggregates and minerals (Frobel, 1990) and in 1997 to map the bedforms and to determine whether the bank functions as a sink for sediment eroded along the north coast of PEI (Shaw et al., 1997).

In 1999 a 2.5 km by 3.3 km portion of northern Milne Bank (Fig. 2) was re-mapped using the Simrad EM1000 swath bathymetric system. A total of 51 survey lines extending north to south, at 50 m spacing were completed. Most of the *repeat* grid was completed on Julian Day 227 (August 15) but 9 lines had to be completed on Day 229 (Appendix 1, 2).

A comparison of the navigation and bathymetry collected in 1997 and 1999 suggests that there is very good registration between them and that the repeat survey was extremely successful. Preliminary interpretations of the 1997 and 1999 data revealed the overall pattern and size of bedforms were very similar in both years. The smallest bedforms were mapped just off the northeast slope of Milne Bank in 29 m of water (Fig. 2, 3; Table 1). The bedforms were largest and least regular in form or shape along the northeast slope of the bank, and they decreased in amplitude and wavelength, south and west across the bank, as the water depths decreased (Fig. 2, 3; Table 1). The asymmetry of the features also decreased farther south and west along the area of the repeat survey. The physical dimensions of the bedforms were measured using UNIX computer program *xmgr* which produces a profile between two designated points and allows measurements of individual features (Fig. 3). The larger bedforms surveyed along lines 1 to 3 are called sandwaves (M. Li, pers comm, 1999).

Table 1 Physical Characteristics of bedforms on Milne Bank, PEI from the August 1999 survey.

Location on Milne Bank (Fig. 3)	Water Depth (at trough) (m)	Bedform Characteristics Amplitude (m)	Wavelength (m)	Shape
Line 4	29	0.2 to 0.7	9 to 31	irregular
Line 3	22 to 18	3.0 to 3.9*	230 to 416	asymmetrical
Line 2	19 to 16	4.7 to 2.3	200 to 300	asymmetrical
Line 1	15	1.2 to 2.1	106 to 150	asymmetrical

* most were 3-4 m but some bedforms were smaller at 1.1 m height

Comparison with the 1997 seabed surveys revealed that the bedforms are migrating southward. Measurements of crest position at 45 bedforms along nine lines, including those in Figure 3, show a net southward migration varying from 5 m to 34 m during the two years. In the vicinity of

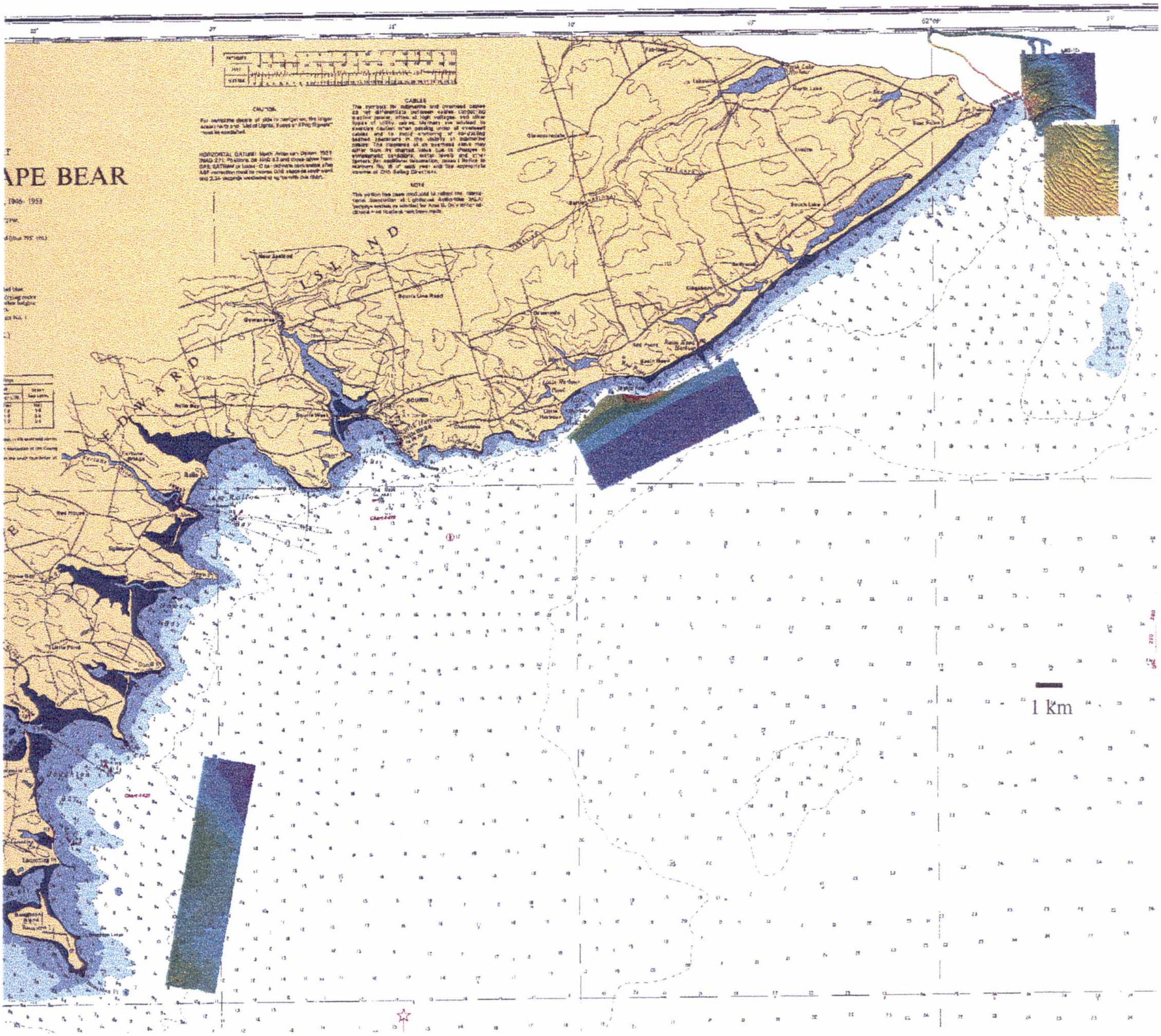


Figure 1. Location of areas surveyed off northeast PEI during August 14 to 17, 1999 using CCGS Frederick G. Creed.

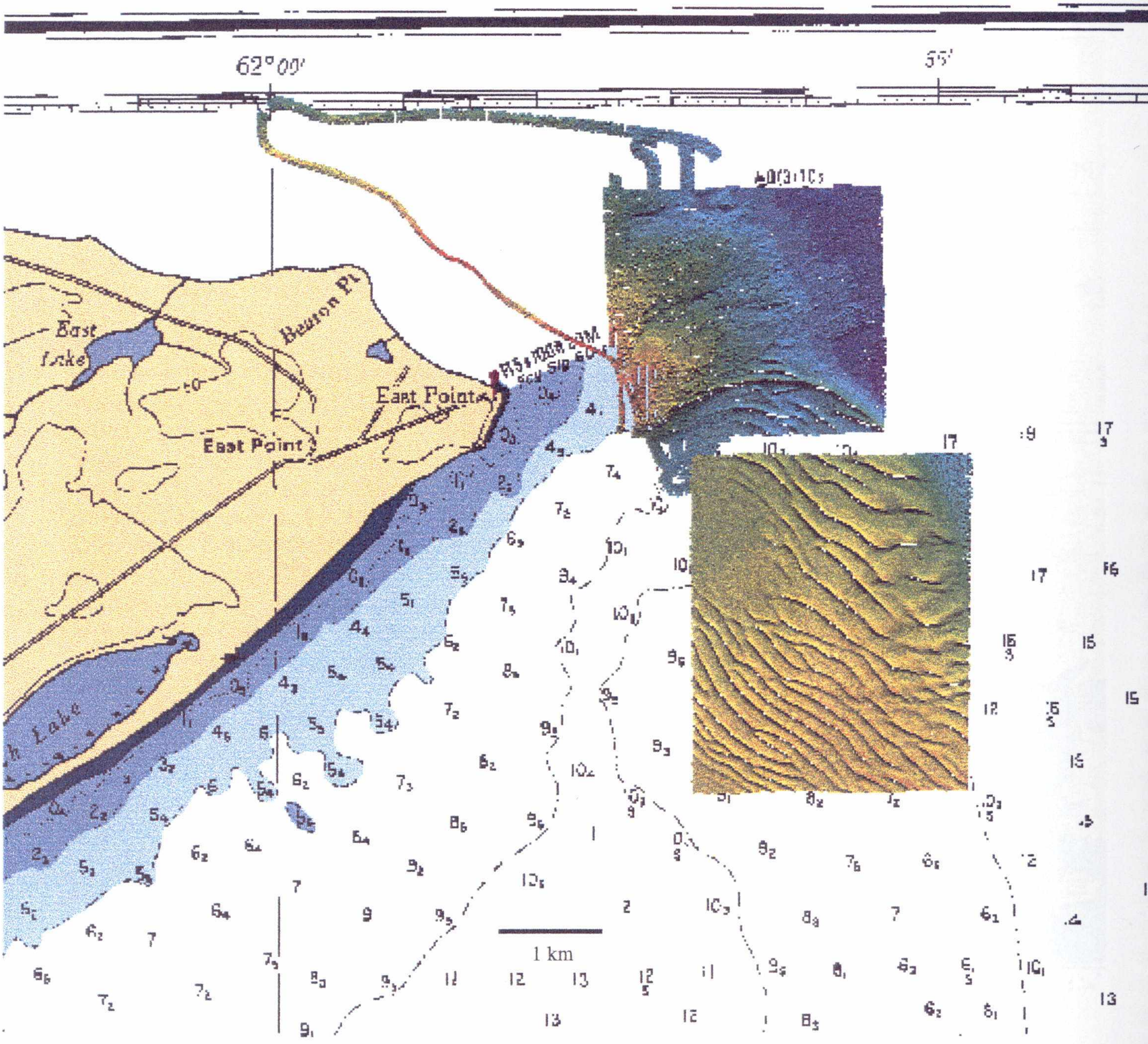


Figure2. Two colour shaded-relief bathymetric images of the northern portion of Milne Bank, PEI. The lower image is the area that was surveyed in 1997 (Shaw et. al. 1997) and resurveyed in this cruise to map bedform migration. The upper image was surveyed in 1999 to map the northern extent of the bedform field and to determine the sediment transport links between the present shoreline and Milne Bank.

lines 2 and 3 (Fig. 3) crest migration varied from 20 to 27 m whereas the bedforms farther south in the vicinity of line 1 showed the greatest lateral variation in migration. To the west of line 1 (Fig. 3) the average crest migration decreased to 5.5 m; it was 32 m at line 1 and to the east of line 1 crest migration averaged 34 m. Crest migration was as high as 40 m on two of the bedforms. Along most of the bedforms the crests had aggraded by 0.2 to 0.9 m; however, slight decreases in crest elevation of 0.2 to 0.3 m were measured near the ends of bedforms where the crest was less well defined on the bathymetric images (inset Fig 3.) The largest growth in crest heights of 0.9 and 0.4 m were observed along lines 2 and 1 respectively (Fig. 3). Differential migration and straightening along several of the bedforms suggests that lateral sediment transport is a very important component in understanding the dynamics of these features. Techniques for measuring the lateral changes along the bedforms will require further development. Figure 4 provides a cross-sectional view of Milne Bank and the location of the sandwave field at its northern end. It appears that as the water depths decrease toward the south, the bedforms are smeared out and disappear. The presence of the bedforms only in the deeper waters at the northern end of the bank suggests that they are dominated by tidal currents.

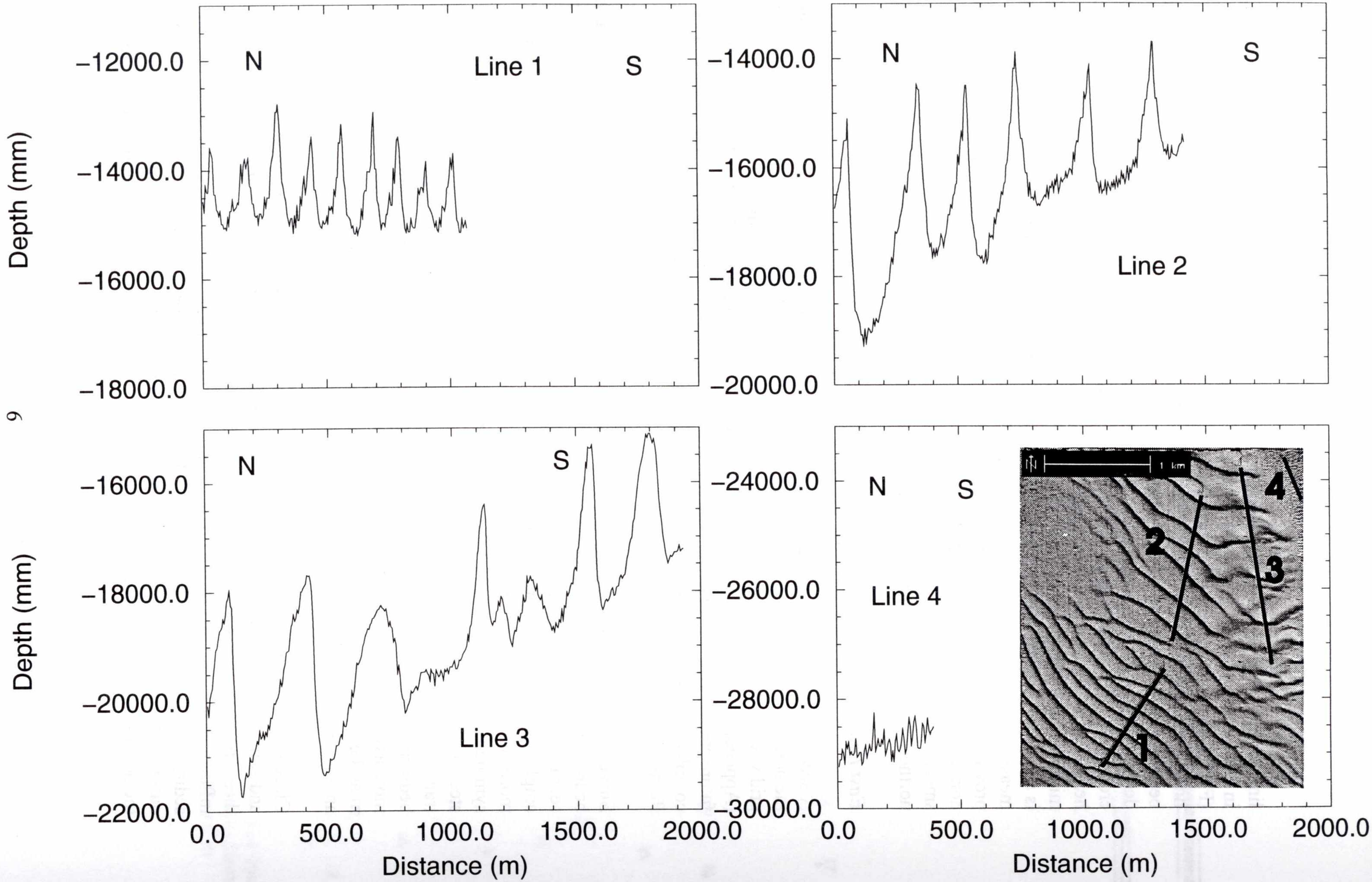
East Point

A second survey grid *east* (Fig. 2, Appendix 2) was completed off East Point in order to delineate the northern extent of the bedform field previously mapped in 1997 on Milne Bank. The survey grid was 2.3 km by 2.5 km in extent. It consisted of 34 north-south lines at 75 m spacing (Appendix 2). In addition two survey lines were extended westward to 62° W to delineate a future survey area where there were few charted depths (Fig. 2). These reconnaissance lines were completed also to see if there were any major sediment bodies or large bedforms west of East Point.

Surveys revealed a large curvilinear bedform that extends seaward from the eastern edge of the bedrock platform off East Point (Fig. 2, 5). The bedform is broken into three and possibly four segments along its length. Closest inshore, in 13 m depth, the bedform is only 1.7 m in amplitude. As water depths increase to 19 and 20 m, the feature increases to 4 m in height and it more closely resembles the larger sandwaves observed on Milne Bank (Fig. 5b). Bedform symmetry increases toward its apex. The feature is steeper on the north side closer inshore and steeper on the south slope farthest offshore, suggesting a reverse in the direction sediment transport /bedform migration. At the apex of the large bedform there are two additional bedforms north of it and the main field of bedforms to the south. The bedforms to the north are more asymmetrical in profile and they progressively increase in amplitude from 2 m to nearly 4 m at the ridge (Fig. 5b). Farther west as the large bedform curls southward it merges with another bedform of similar amplitude (Fig. 5a,b).

Close inshore along the bedrock platform there is a 4 m increase in depth between the northern and southern base of the ridge (Fig. 5b). The difference decreases eastward where there is less than a metre difference in depth. The basin effect along the south side of the ridge probably influences the character of the tidal currents and the ultimate suspension and transport of sediment. Aerial photographs (80442-53, 54) provide evidence of suspended sediment plumes outlining the position of the bedrock off East Point and satellite photos show sea ice moving from the north shore around Milne Bank (Grant, 1994). There are no detailed current measurements in

Figure 3. Examples of the character of bedforms observed within the *repeat* survey area (Appendix 2, Fig. 2) at the northern end of Milne Bank, PEI. Line locations are shown on the shaded-relief bathymetry (inset), and the bedform characteristics are summarized in Table 1.



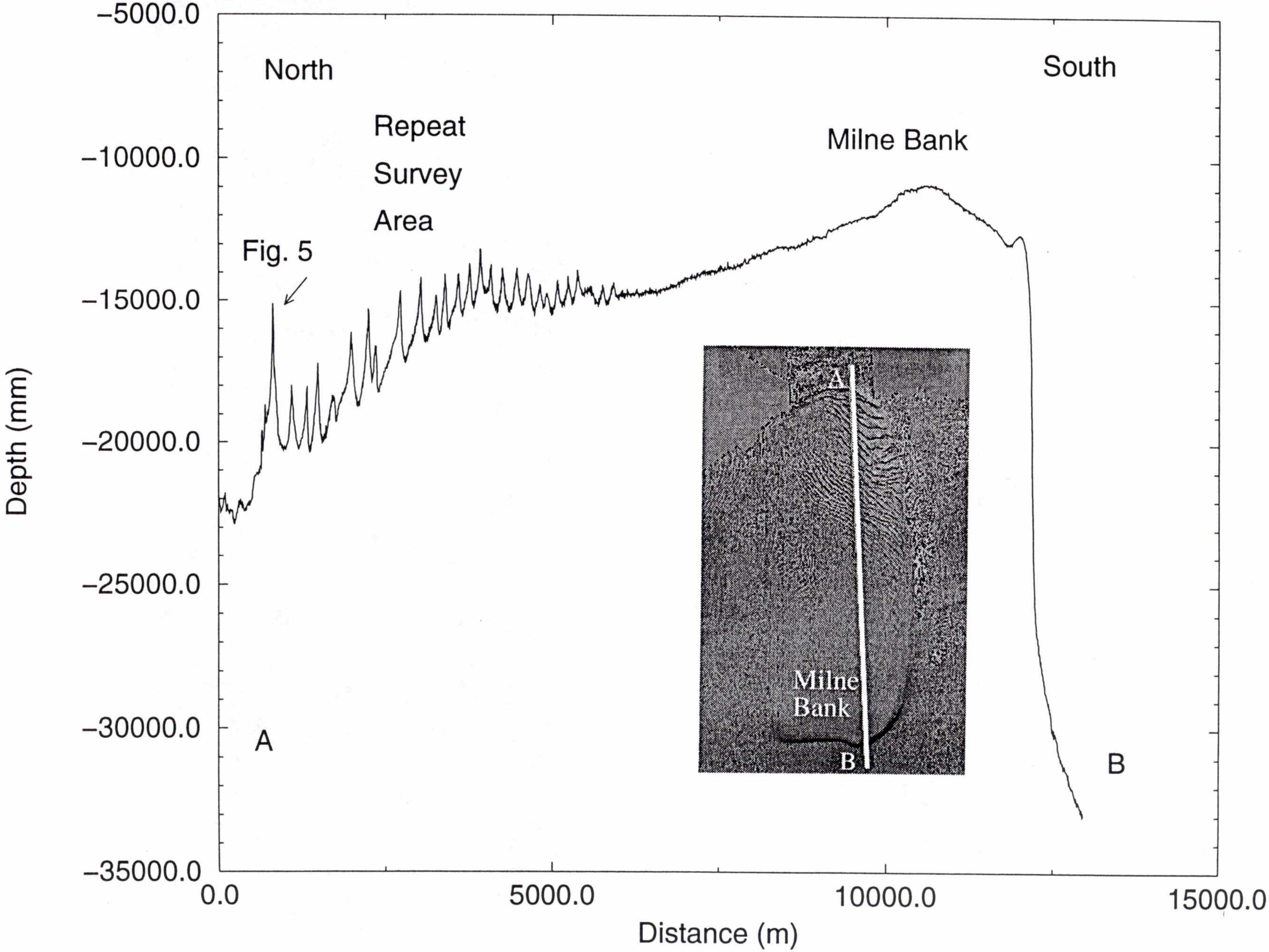


Figure 4. North-south profile across Milne Bank showing the location of the main field of bedforms and the large ridge (detailed in Fig. 5) marking the northern end of the bedforms. The shaded-relief bathymetry (inset) shows the location of the profile.

the immediate area of the bedforms. The only records are from a site (46.573° N, 62.071° W) to the west in 43 m water depth (www.mar.dfo-mpo.gc.ca/science/ocean/ocean _data.html). The measurements were collected over 26 days in October-November 1970. Easterly (85°to 88°) flowing currents with a mean vector velocity of 0.04 to 0.05 m/s and maximum instantaneous velocity of 0.45 m/s were observed.

Along the inner shelf off north PEI between East Point and North Lake in water deeper than 10 m the seafloor is dominated by bedrock. There was evidence of some thin deposits of mobile sediment offshore and a progression of short bedforms leading to the large bedform shown in Figure 5a but no large scale deposits of mobile sediment which could presently feed Milne Bank directly from the North Shore of PEI. Repetitive surveys of the main field of bedforms showed there was a net southward migration of these features. For the bedforms to move south a new bedform must form at the northern end of the field. An alternative sediment transport scenario based on the 1999 survey is that sediment from the north coast is transported along the beach or inshore bars, where they exist. Some portion of the sediment moving past East Point, would be transported into the deeper basin just south of the point and then transported northward along the basin where it is incorporated into the bedforms. This raises the question of whether more sediment is derived from the east shore than the north shore of PEI.

Also, if a new bedform develops at the northern end of the bedform field how does it form? No bathymetry was obtained across the large ridge at the north end of the bedforms in 1997(Fig. 5) so its mobility is unknown. However because the ridge appears comprised of several segments, a hypothesis to be examined is that differential lateral migration results in parts of the ridge breaking away and joining the main group of bedforms. The other hypothesis is that the large ridge remains in place and its presence affects the tidal currents to spawn new bedforms in the area immediately south of it.

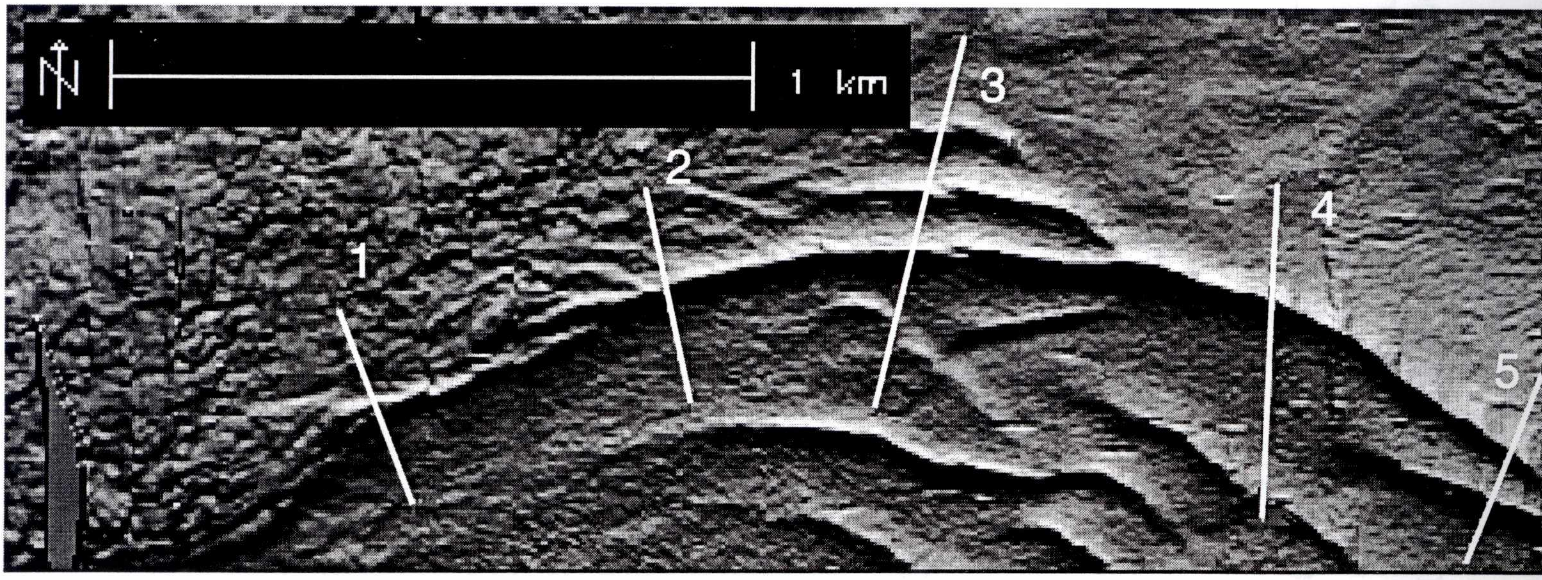


Figure 5a. Location of profiles (shown in Fig. 5b) surveyed across this large bedform at the northern end of Milne Bank, PEI.

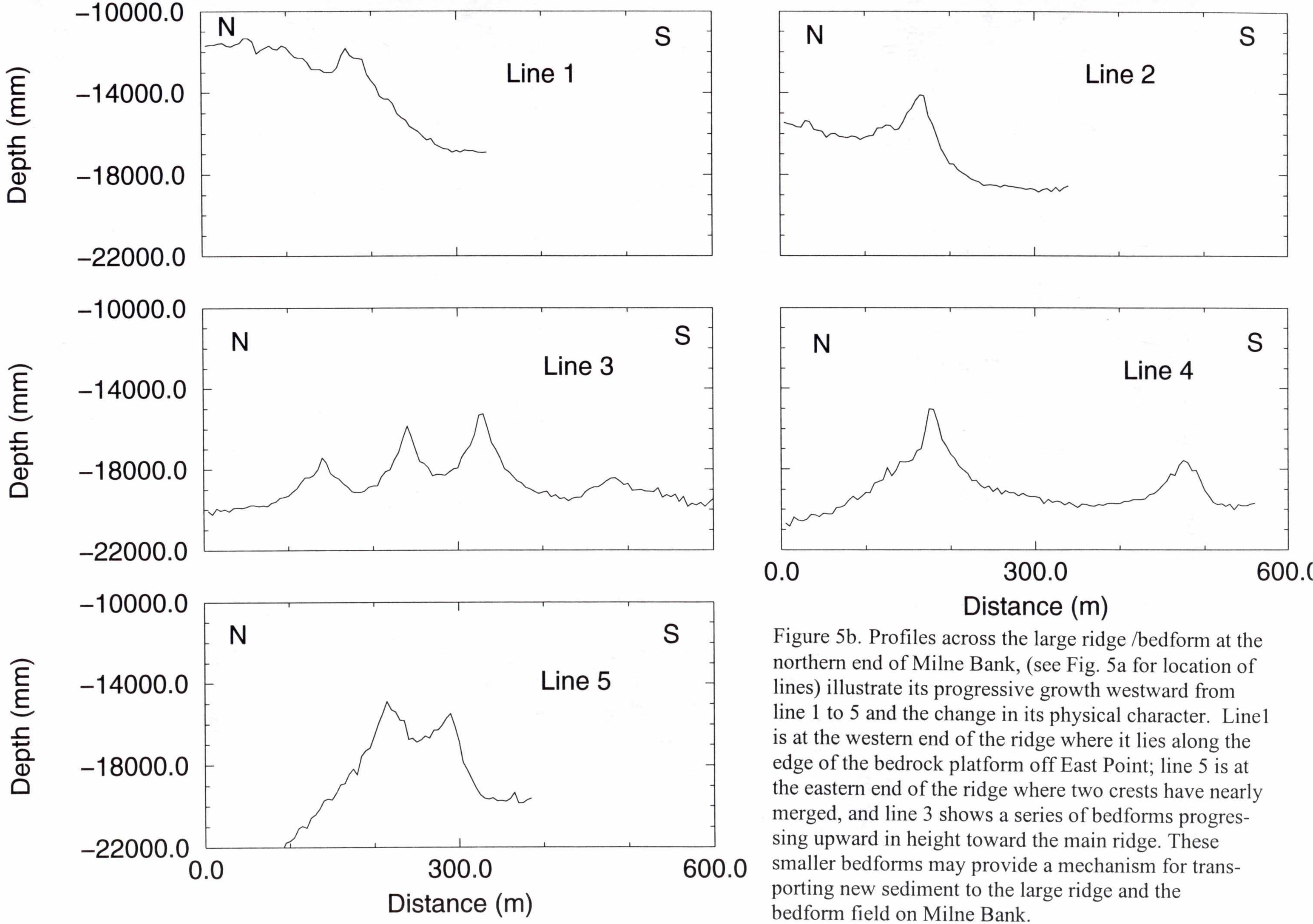


Figure 5b. Profiles across the large ridge /bedform at the northern end of Milne Bank, (see Fig. 5a for location of lines) illustrate its progressive growth westward from line 1 to 5 and the change in its physical character. Line1 is at the western end of the ridge where it lies along the edge of the bedrock platform off East Point; line 5 is at the eastern end of the ridge where two crests have nearly merged, and line 3 shows a series of bedforms progressing upward in height toward the main ridge. These smaller bedforms may provide a mechanism for transporting new sediment to the large ridge and the bedform field on Milne Bank.

Offshore of Boughton Bay and Basin Head-Little Harbour

The surveys off Boughton Bay and Basin Head-Little Harbour (Fig. 1) were alternate sites chosen because bad weather prevented surveying off East Point and Milne Bank. The two alternate survey sites were chosen because of their marked contrast in coastal planform and onshore stability. The coastline in the vicinity of Boughton Bay consists of long, narrow estuaries, fronted by narrow barrier beaches or spits, and separated by cliffed headlands. Along Basin Head-Little Harbour the coastline is a more linear with short, broad embayments, infilled by older beach deposits. The headlands are present but do not protrude beyond the main shoreline because of embayment infilling. The objective was to map the differences in offshore topography and sediment redistribution as a consequence of marine transgression in the two areas. The Launching Bay shores have also been a traditional area of commercial beach sediment mining (Owens, 1980) and it was hoped the survey would provide more information about the availability of sediment offshore for resupply to the beaches.

Offshore of Boughton Bay

A survey grid 1.8 km by 8 km was completed off Boughton Bay between Spry Point and Boughton Point (Fig. 1, 6; Appendix 2). Eighteen lines at 100 m spacing, in water depths ranging from 15 to 28 m, were surveyed parallel to shore.

Within the survey grid, the deeper water is to the northeast. The seabed consists of two broad shallow platforms separated by a shallow depression. Within the depression there are several short meandering troughs 100 to 300 m wide, incised 1.5 m. There is also a series of short, small dendritic drainage patterns of unknown origin cut into the bottom. An initial impression upon seeing the image was that the bottom resembled a drowned kame topography.

The surface morphology of the platform south off Boughton Island consists of irregular scarps of 0.5 to 1.0 m relief. There is a partial cover of sediment but the platform appears to be an extension of the bedrock ledges observed onshore. The platform to the northeast, off Boughton Bay, is a few metres deeper than the one to the south and its surface profile at 18.5 to 19 m depth is more uniform. First impressions were that the surface resembles a relict glacial deposit truncated by the recent marine transgression, but there is no seismic or sample information to confirm that interpretation. Onshore, the surficial sediment is ablation till, overlying bedrock (Prest, 1973).

Within the deeper water off the north end of Boughton Bay there is a well-defined 800 to 900 m wide band of sediment in water depths of 24 to 24.5 m (Fig. 6). The deposit, which accoustically resembles sand, may be fed from, or connected to, the main channel draining the estuary in Boughton Bay. There are also several depressions extending offshore from the platform that resemble sediment infilled channels.

Basin Head to Little Harbour

A survey grid 2.1 km by 6 km in size was completed between Basin Head Harbour and McKinnon Point, the western headland of Little Harbour (Fig. 1, 7; Appendix 2). Within the grid, 21 lines were surveyed at 100 m spacing parallel to shore, in water depths ranging from 20 to 36 m. A series of 12 "fill" lines were used to survey the inner part of Little Harbour.

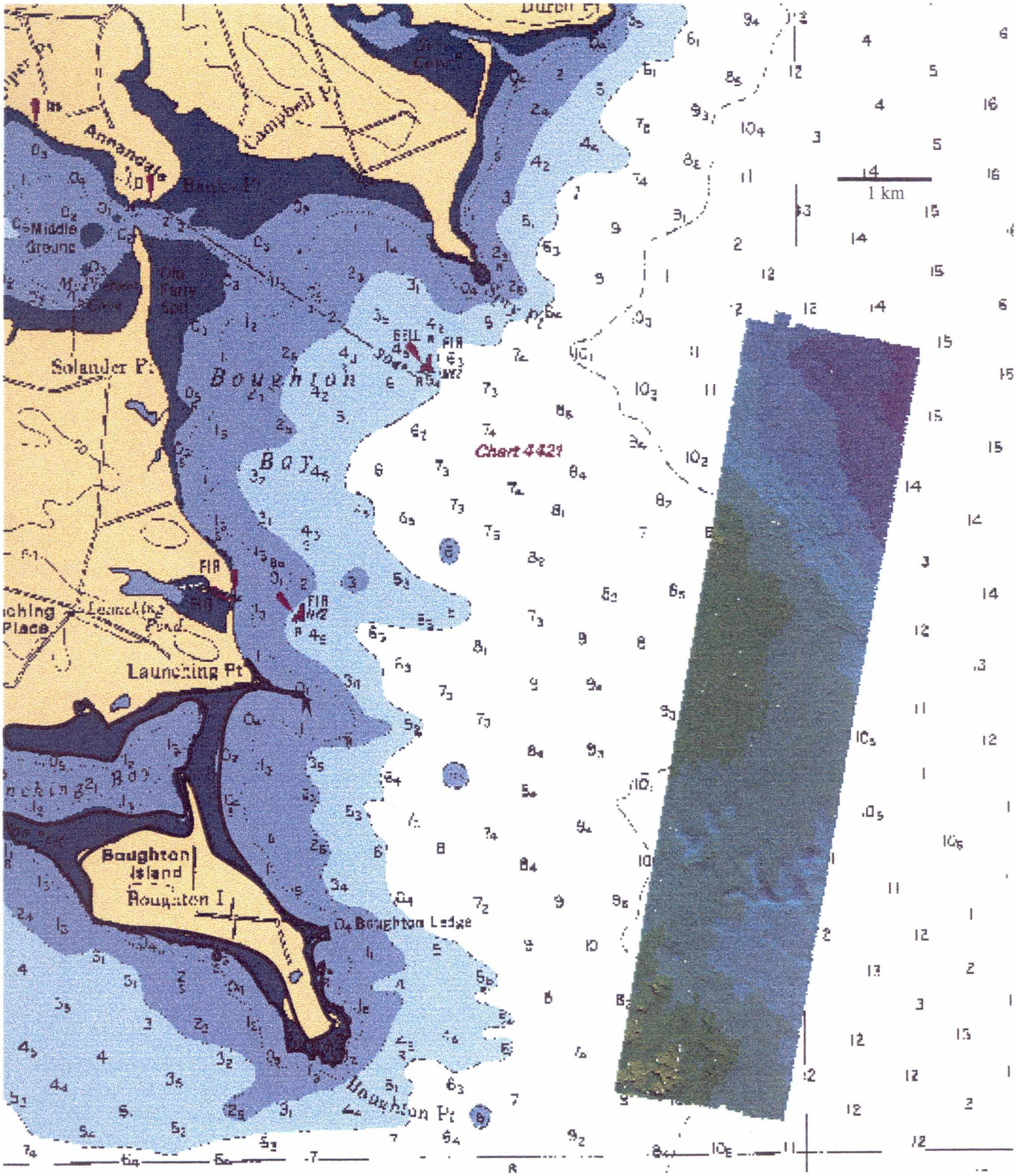


Figure 6. Colour shaded -relief bathymetry of the seafloor off Boughton Bay, PEI.

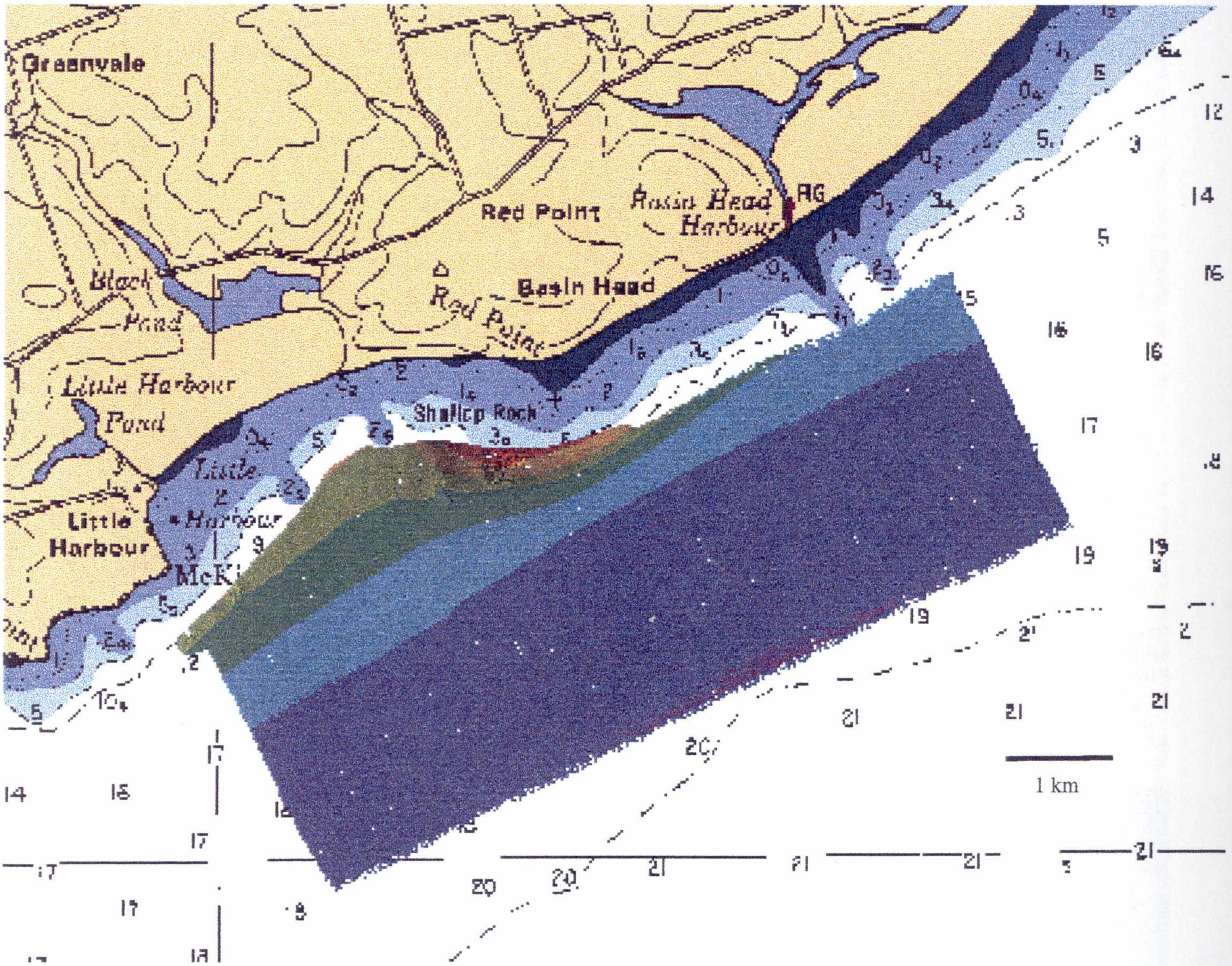


Figure 7. Colour shaded -relief bathymetric image of the seafloor off Little harbour and Basin Head ,PEI.

The sea floor within this area is essentially featureless with only a couple of exposures of bedrock occurring within the shallow parts of Little Harbour. The survey did not extend far enough inshore at Basin Head Harbour to pick up the promontories shown on Hydrographic chart 4403 (CHS, 1985). The seabottom material appears to be mainly sand. Samples collected in1988 from water depths of 29 to 32 m off this area were described as red-brown silty mud (Frobel,1990). Depths are fairly constant parallel to shore but there is a slight rise toward the east and west end of the shallow basin off Little Harbour. Sea floor profiles perpendicular to shore were concave with a marked decrease in slope at 28 to 30 m water depths. Shoreface profiles were just over 0.5°(Tan ϕ =0.012 to 0.013) in water depths of 21 to 28 m and less than 0.5° (Tan ϕ =0.003 to 0.004) in depths of 31 to 33 m. An exception was the bedrock outcrop in Little Harbour which is steeper. The low gradient, smooth concave shoreface of this area contrasts with the irregular shoreface mapped off Boughton Bay.

The low- gradient, sand covered shoreface off Little Harbour provides evidence for the hypothesis that Little Harbour has been gradually infilled with sediment after Basin Head infilled and excess sediment began moving southward past Red Head. Onshore at Little Harbour there is an extensive sand dune complex that appears to be actively building seaward. This situation contrasts with northern PEI where only a thin discontinuous sand sheet with multiple sand bars exist close inshore. The onshore dunes on the north coast in PEI National Park are large, but the dune field is narrower and shows little evidence of building seaward at present. Sand appears to be trapped in the large channels extending offshore of the national park and within the estuaries (Forbes et al., 1999), instead of onshore as at Little Harbour. The continuous sand cover off Little Harbour also contrasts with the isolated sand deposits and the more irregular topography of glacial deposits and bedrock that exist off Boughton Bay.

SUMMARY OF OPERATIONS

Operations are in Atlantic Daylight Saving Time (Z - 3 hours).

Day 224 Thursday 12 August

GSCA staff leave BIO at 11:30 and 12:30 and drive to Souris PEI via the Confederation Bridge.. Two vehicles are used to transport the gear (van and suburban). They arrive in Souris PEI at 16:30 and 17:30 respectively. Weather is overcast with rain for most of the trip.

Day 225 Friday 13 August

GSCA staff check out of Hilltop Motel and drive to *Frederick G. Creed* at 07:30. It is overcast and cool, with a light southerly breeze. Gear is loaded aboard the *Creed.* By 10:00 it is sunny with light southerly breezes and slight seas. At 14:18 *Creed* leaves the wharf. At 15:35 sound velocity profile (SVP) 225.001 is collected using the gasoline powered winch on the quarterdeck. SVP 225.001 is collected in a depth of 40 m at 46°18.9072 N. 61°55.7660 W., south of Milne Bank (Appendix 3). Forty metres was the length of the winch cable, therefore future sampling in deeper water will require the use of a rope. At 16:10 we start Line1 running north up the bank at 12 kts, then return south on Line 2 which is just east of Line 1, so they barely overlap. We then proceeded north on Line 3, on the same track as Line 1, at 6 kts initially then in the interest of time we increased our speed to12 kts, until reaching the steep face of the bank where the speed was reduced to 6 kts. We finish Line 3 at 17:05 and turn for Souris. The vessel is tied up at the wharf in Souris at 18:30.

Mobilization proceeds reasonably smoothly except DI05 can not be brought on line, and DI01 crashes when we first attempt to clean lines. The patch test does not reveal any discrepancies. R. Currie departs for Dartmouth to pick up another workstation to replace DI05.

Day 226 Saturday 14 August

Frederick G. Creed leaves dock at 07:30. An alternate survey area is selected off Boughton Bay (Fig. 1, 6) because of bad weather conditions at Milne Bank. Winds out of SW predicted to pick up to 35 knots by late morning. An SVP was taken in 30 m water depth south of Souris but a second attempt is required. Switch from winch to rope to deploy velicometer. SVP 226.001 collected at 46° 15.76 N. 62° 17.71 W., in 29 m water depth. Survey grid *Prince.sry* was used to input the 2000 series survey lines. Begin running line 2000 at 08:55 running south. Problem with logging navigation on line 2001; it has split into two separate lines, so the southern part of line is renamed 9001. Same thing happens with line 2009, a part is renamed 9009. At 11:11 workstation DI01 crashes when trying to exit HIPS. Complete survey lines 2000 to 2017 at 100 m spacing (Appendix 2).

Winds remain at 23-25 knots out of SW during morning. By 1600 the winds are decreasing to 19 knots from SW but the waves remain at 1 to 2 m all day. End survey offshore of Boughton Bay at 16:26, arriving in Souris at 1700.

Day 227 Sunday 15 August

Overcast light rain and drizzle, winds calm, seas near calm. *Creed* leaves wharf at 07:04. Arrive at first SVP site on east side of Milne Bank at 08:37 but a second SVP is required. SVP 227.001 is collected at 08:51 at 46° 26.32 N. 61° 53.93 W., in 32 m water depth (Appendix 3). *Creed* proceeds to *Repeat* survey grid at 08:54. Lines 1000 to 1046 (excluding lines 39 to 42) were surveyed at 50 m line spacing. Survey ends at 17:03 at the end of line 1038. Winds are from N to NNE all day with the wind increasing from 8 to 14 knots. Maintaining the last couple of lines is more difficult because of oblique wave approach to lines. Forecast is for NE winds increasing to 30 knots by morning. By late afternoon problems are encountered with DI01 – unable to bring in tides due to lack of disc space. Darrell Beaver isolates the problem to temporary files created when the system crashed. They are erased and the problem is corrected. Return to Souris and tie up at the wharf at 18:25. Darrell works on DI01 and completes backups, including one of the GRASS project, until 22:40. Rain falls all evening.

Day 228 Monday 16 August

Overcast, and light rain, winds NNE at 10-15 kts. *Creed* departs wharf at 07:10 sailing toward alternate survey area off Basin Head. The survey grid *Basin.sry* consists of 3000 series lines at 100 m spacing (Fig. 1,7). Each line is about 15 minutes long. Reach 46° 20.3394 N. 62° 07.2032 W., the site for SVP 228.001 at 07:51 (Appendix 3). The water depth is 35 m. The first download of the data does not work so re-entered SVP 228.002. Waves are 1 to 2 m, running oblique to shoreline. Stop the vessel to turn the Simrad system on and off at 09:05 to eliminate a gap in the data which shows up on the grass data. Lower Canadian flag to halfmast at 09:10 to honour Jean Drapeau, the former mayor of Montreal and the champion of EXPO 67. His funeral is today. At 12:30 it is decided not to proceed to Milne Bank as the wind is increasing from the North at 20-25 kts. By 12:30 began to see problems with sounding data along beams 16 and 48. Every second ping appears to be bad. Shut down the Simrad system at 12:39 at end of line 3010. When processing the soundings on lines 3010 & 3018 beams 16 & 48 are filtered out. Shut down the Simrad system at 13:59 to try and correct the poor beams.

Winds by 13:52 are N to NW at 20-25 kts, but it is sunny now. Labrador rescue helicopter flies by at 13:30 looking for the coast guard vessel but they quickly reroute to the Annadale area where it appears there is smoke in the water. After finishing survey offshore to Line 3020 the *Creed* proceeds toward Little Harbour to survey the shallow inshore area. The lines are labelled as the 3100 series. Survey starts at 15:05 but at 15:30 Merlin crashes as we try to adjust it and line 3100 is lost. Merlin is required by the Captain to follow the lines and fill in the survey area. Darrell gets things working again by 15:42 when we resume surveying. Line 3101 is a test line only. Resume survey with line 3102. Survey inner lines at 8 knots and faster along the outer lines. Finish surveying at 17:44 and tied the vessel at wharf in Souris at 18:30. Beautiful, calm evening with spectacular sunset. Too bad we can not continue the survey!

Day 229 Tuesday 17 August
Clear sky, sunny, winds SW at 7 kts. Depart wharf at 07:05 for East Point to finish the *Repeat* survey and begin *east.sry* survey grid , the 4000 series lines at 75 m spacing (Fig. 1, 2, Appendix 2). At 08:23 complete SVP 229.001 (46° 26.4358 N 61° 54.6859 W) just north of Milne Bank in water depths of 28 m (Appendix 3). Begin *repeat* survey at 08:43 and run lines 1039 to1042 and 1047 to 1051. Complete the *repeat* survey by 10:16 and move north to *east* survey grid. Start line 4000 at 10:20. Grass project labelled as *Eastpoint.ave.* At 13:46 we break off from the grid lines to sail west to 62°west longitude and make an inshore boundary for future survey lines. Lines 4500 and 4501 are used for this exercise. Surveying was resumed in the *east* grid at line 4020 at 14:35. The mermaid/merlin system crashes at 15:37 while surveying line 4024 so have to restart line (new line labelled 9024). Complete a quick test line 9999, before starting line 9024. Complete the survey at the end of line 4031 at 17:11 and head toward Souris. Arrive at wharf in Souris at 18:28. The winds remain out of the SW to SSW all day varying from 11 to 15 knots. The waves are estimated at 0.5 m height.

TECHNICAL OPERATIONS

The Vessel
The ship *Frederick G. Creed* is a twin-hulled vessel of the SWATH type (Small Waterplane Area Twin Hull) with a length of 20.42 m and accommodation for up to five crew and four scientific staff. Typical survey speed was 12 knots.

Digital Bathymetry System
The vessel is equipped with a hull-mounted Simrad EM-1000 swath bathymetric system that receives depth and backscatter information from 60 beams (30 either side). To use the system the transducer depth and a sound velocity profile are required to be manually input each day. The transducer depth is input into the INSTALLATION menu in the EM-1000 TRANSDUCER submenu. It is calculated by obtaining the ship's draft (in feet) fore and aft, immediately before departure, calculating a mean draft (in feet), converting it to metres and subtracting 0.57 m. The SVP is usually collected after the vessel reaches the survey area (see section below on sound velocity measurements).

The transducer arrays (receive and transmit transducers) which are mounted on the starboard pod feed depth signals into the EM-1000. Sounding acquisition is stopped and started and file numbers allocated at the Simrad operators console on the bridge. Usually the file is stopped at the end of each line, and started at the commencement of the next. Backscatter data and swath bathymetry are displayed on a Mermaid Sun workstation on the bridge. The console of the Simrad Quality Control System is used to display a map of simplified bathymetry.

Navigation and Planning of Survey Lines
A Communication Systems International Inc. MBX-2 radio beacon located on the bridge of the ship receives corrected GPS signals from Canadian Coast Guard stations. In east PEI, the signal is from Port aux Basque, Newfoundland. These corrections are fed into the Novatel Global Positioning System (GPS) receiver located in the hull with the POSMV. The corrected differential GPS signal is fed into the POSMV system which uses a motion sensor - a gyro accelerometer package - to provide sub-metre accuracy positions to the Simrad sounder.

The planned survey lines are drawn up using survey builder in GRASS and are plotted on an image of the Hydrographic chart and converted to survey files and AGCNAV files. A disk with the navigation files is inserted into the AGCNAV computer on the bridge. There are two consoles on the bridge and two in the laboratory. One displays the electronic charts and the other AGCNAV.

Seawater Sound Velocity Measurements
An Applied Microsystems Ltd sound velocity profiler Model SVP-16 -3129 is used in conjunction with Soft-16 SVP software in a PC computer. The velocity profiler measures pressure, salinity and speed of sound at 1 m sampling intervals. The profiler is connected to a PC computer with a RS232 2400 baud rate and it is activated by connecting a power plug or shorting plug which completes the circuit.

Before the start of surveys in an area, a sound velocity profile (SVP) is collected from a site just slightly deeper than the area to be surveyed. The location of the SVPs and the recorded data are provided in Appendix 3. The instrument is lowered over the port side quarterdeck using a boom.

Initially it was raised and lowered using a small gasoline-powered winch and 40 m wire cable, but this method was slow and unreliable. After the first day, we manually lowered and raised the profiler using rope. When it was stormy, the profiler was immersed in a container of seawater for about 5 minutes before being lowered over the side of the ship. The procedure reduced the time required to leave the instrument over the side of the ship before lowering it and reduced the risk of damaging the instrument against the ship. Alternatively the instrument was left in the water for 5 minutes and then lowered to the bottom. The delay in lowering the instrument is to prevent thermal drifting in the sensors (the variation of sensor readings at different temperatures).

Upon recovery from the sea, the profiler is washed with fresh water and then connected to the computer; the velocity profile is downloaded onto a labtop computer. Spikes in the data and duplicate data points caused by ships motion are eliminated. The data file is then input to the bridge laptop computer where the values are transferred using PROCOMM to the Simrad EM1000 swath system.

Water Level Measurements

A digital Sutron 8210 gauge with an SDI encoder was used to record water levels in Souris Harbour. The gauge used a float and counterweight system in a 10 inch stilling well. The well was established along the northeast inner end of the government (Coast Guard) wharf, in Souris, PEI (see sketch -Appendix 4). The gauge was established by Carmen Reid and Dave Blaney (CHS) on August 12, 1999 (Day 224) and it was removed on August 30, 1999 (Day 242). A vertical staff gauge was also mounted on the wharf near the Sutron gauge to allow visual recordings of the tide. Water level was recorded every 15 minutes starting at 21:30 (GMT), August 12, 1999 and continued until 19:45 (GMT), August 30, 1999.

The gauge and staff were surveyed into benchmarks (BM) 89P9151; 89P9150 and a new BM 99P9000 which was established in the concrete footing of the second bollard from the inner northeast corner of the wharf. Form 502 (Appendix 4) lists the Hydrographic data relevant to the establishment of the gauge. At sea, predicted water levels for August 1999 at Souris PEI were used for the processing of the multibeam data. After the cruise, the predicted and observed water levels were compared. The differences were significant enough that the Simrad EM1000 data was re-merged using the observed water levels for Souris PEI (Appendix 4).

A second digital Sutron tide gauge with a pressure sensor was established in Covehead Bay along the north shore of PEI but the data from this gauge was not used in this phase of the *Creed* survey.

Data Management

Bathymetry and navigation data from the EM-1000 system were fed via an Ethernet link to HP workstation DI01 (IP address 142.2.4.19) in the laboratory. The bathymetry and navigation files were purified using HIPS (Hydrographic Information Processing System). With the navigation files, the processing was looking for 3 knot speed jumps between points on the line and rejected with interpretation. The processed data was transferred using an NFS (Network File Service) link to DI05 (IP address 142.2.4.23) where it was gridded, given artificial illumination, and displayed using GRASS. Every evening raw data and processed (HDCS) data were backed up on CDROM and Exabyte tapes (Appendices 1, 2). Upon returning to the office the data were merged with the observed tides and new grass files were generated. A "1" was added to the end of the name of each grass file to differentiate it from those merged with the predicted tides. For example on Day 229 the original grass project using predicted tides was *Eastpoint.ave*; the new file using observed tides was called *Eastpoint1.ave.*

ACKNOWLEDGMENTS

The authors wish to thank the crew of *CCGS Frederick G. Creed* for their superb support, seamanship and hospitality. We thank the Canadian Hydrographic Service (Dartmouth, Nova Scotia) for support in collecting water levels during the cruise. In particular thanks are extended to Glenn King for providing the predicted tides for Souris, PEI and to Charles O'Reilly for analysing the tidal records collected during August 1999 from the gauges established in Souris Harbour and Stanhope by Carmen Reid and Dave Blaney of CHS. We also thank Lisa St. Pierre (IML, Rimouski P.Q.) for logistics support with *CCGS Creed.* Russell Parrott provided Unix support during the re-merging of the data; Bob Courtney provided invaluable guidance for using UNIX computer program *xmgr;* and Michael Li provided a critical review of the document,

particularly on the discussion of bedform characteristics and terminology.

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APPENDIX 1

Survey Data Archived
at
Geological Survey of Canada Atlantic
Dartmouth, Nova Scotia

1) General Cruise Log Book : Days 225 to 229 1999 Frederick G. Creed 99-037a

2) Compact Disks:

CD Number	Julian Day (1999)	Contents	Directory
99037a-01	225	HDCS_DATA	hipsdata/HDCS_DATA/99037a/Creed99
99037a-02	226	HDCS_DATA	hipsdata/HDCS_DATA/99037a/Creed99
99037a-03	227	HDCS_DATA	hipsdata/HDCS_DATA/99037a/Creed99
99037a-04	228	HDCS_DATA	hipsdata/HDCS_DATA/99037a/Creed99
99037a-05	229	HDCS_DATA	hipsdata/HDCS_DATA/99037a/Creed99

3) Exabyte Tapes:

Tape Number	Julian Day	Contents	Directory
99037a-01	225/226	raw data backup	/raw/99037a
99037a-02	225/226	HDCS_DATA	/hipsdata
99037a-03	227	raw data	/raw/99037a
99037a-04	227	HDCS_DATA	/hipsdata
99037a-05	228	raw data	/raw/99037a
99037a-06	228	HDCS_DATA	/hipsdata
99037a-07	229	raw data	/raw/99037a Corrupt disc
99037a-08	229	HDCS_DATA	/hipsdata
99037a-09	229	HDCS_DATA	/hipsdata
99037a-10	229	raw data	/raw/99037a
99037a-11		PEI Grass Project	Shaw Di05
99037a-12	total	SUN PROCDATA	/proc/99037a
99037a-13	total	SUNRAWDATA	/raw/99037a

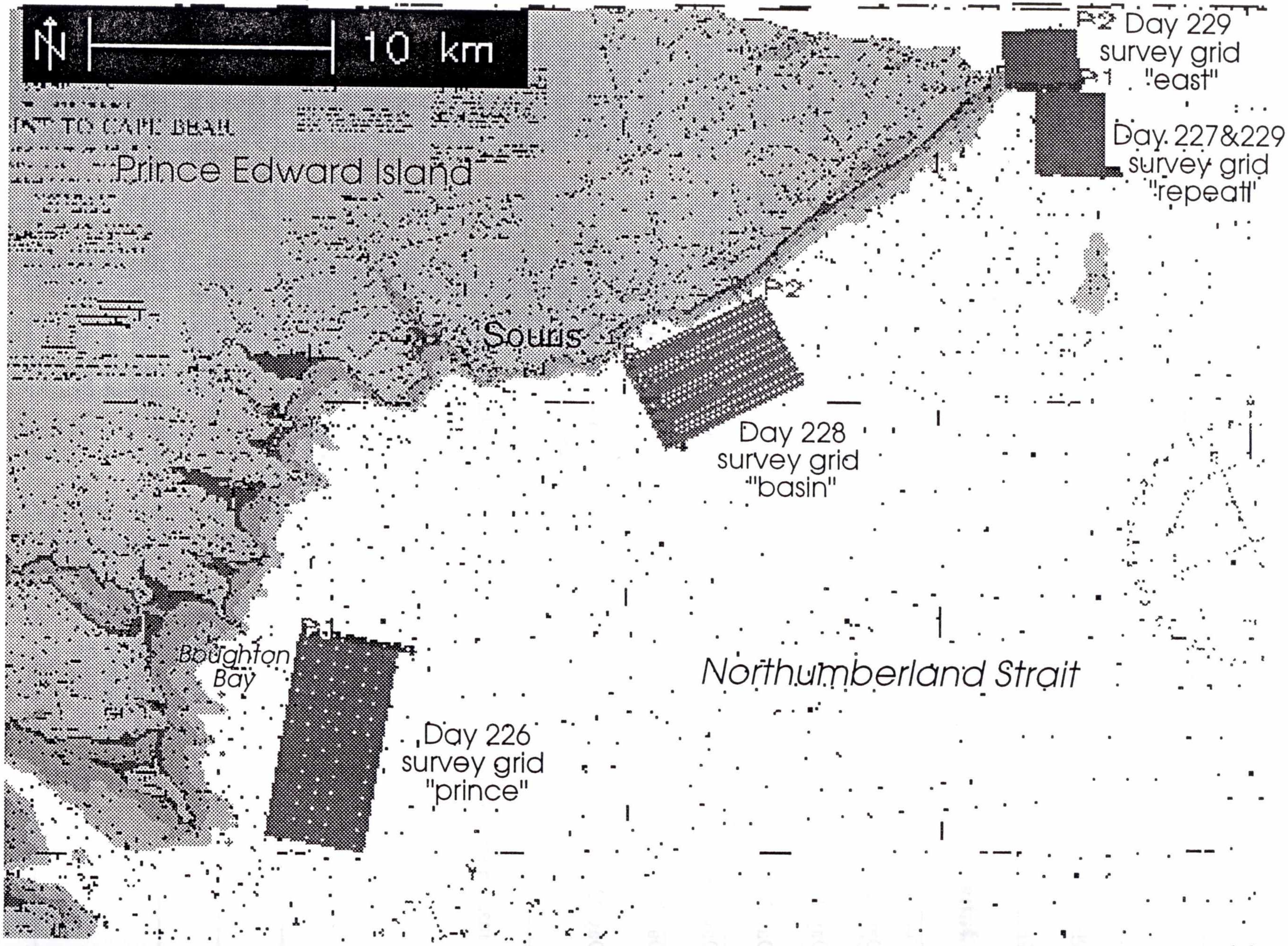
4) Floppy Discs:

Disc Number	Julian Day	Contents
99-037a-01	225 to 227	raw AGC navigation files
99-037a-02	228 and 229	raw AGC navigation files
99-037a-03	225 to 229	SVP files and AGC waypoint files

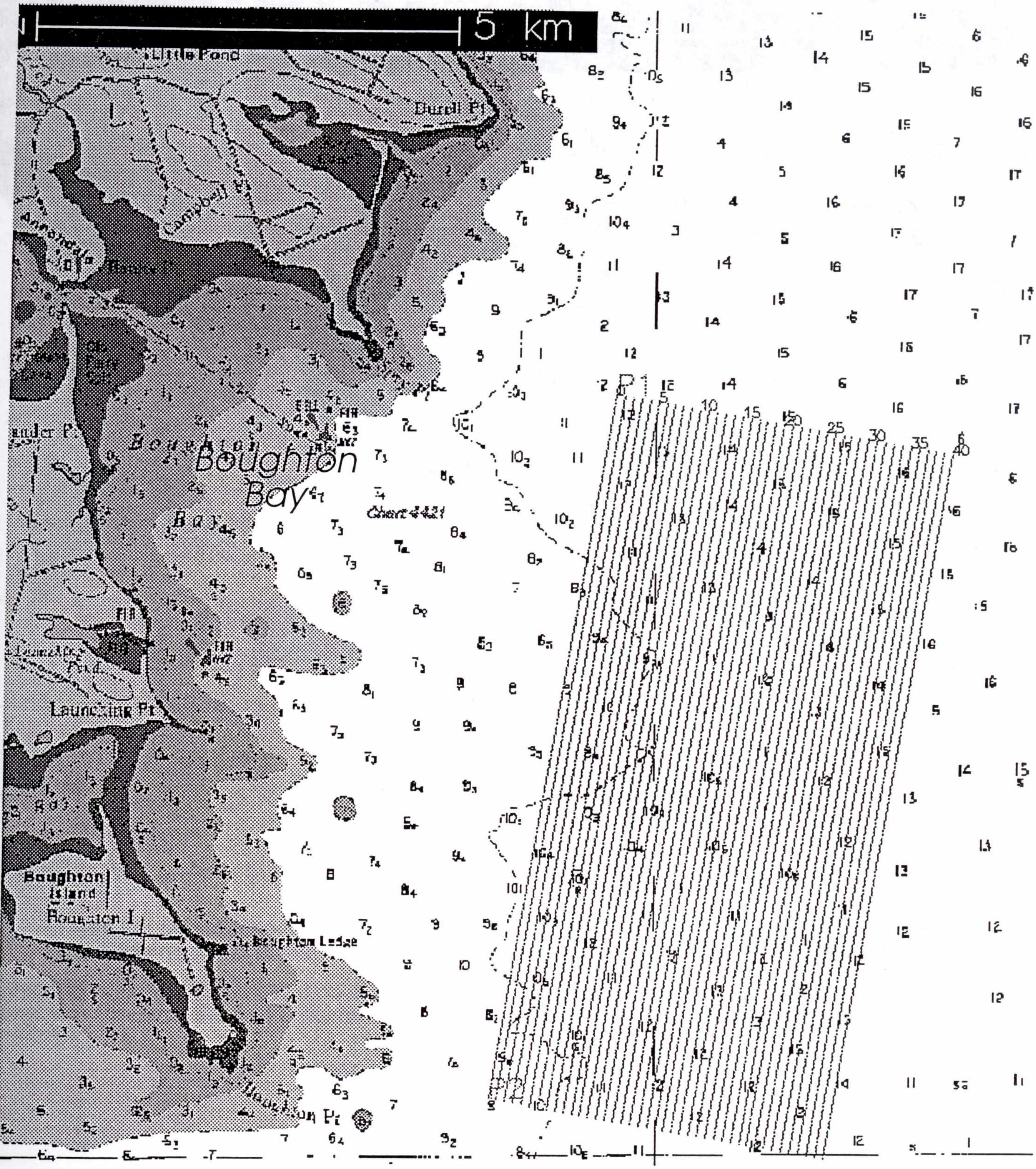
APPENDIX 2
Survey Grids and Line Numbers

Julian	Date Calender	Grid Reference	Survey Line Numbers	Line Spacing
Day 225	Fri. 13 August	*PATCH*	1, 2, 3 (Patch test)	
Day 226	Sat. 14 August	*prince.sry*	2000 to 2017; 9001, 9009	100 m
Day 227	Sun. 15 August	*repeat.sry*	1000 to 1038; 1043 to 1046; 9015	50 m
Day 228	Mon. 16 August	*basin.sry*	3000 to 3020; 3100 to 3111	*100 m
Day 229	Tues. 17 August	*repeat.sry*	1039 to1042; 1047 to 1051	50 m
Day 229	Tues. 17 August	*east.sry*	4000 to 4034; 4500, 4501; 9024, 9999 (test line)	*75 m

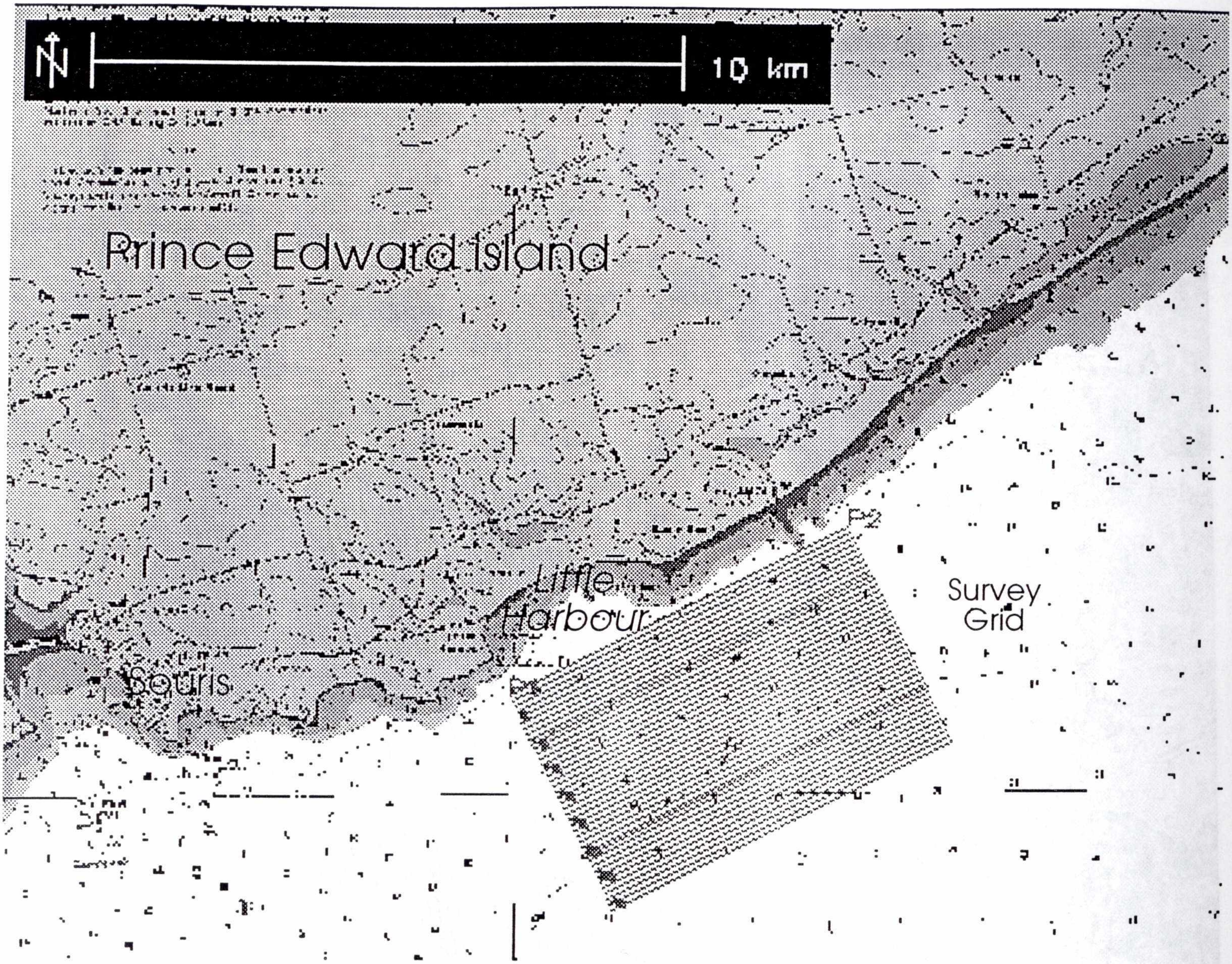
* inshore areas were surveyed using "fill" lines at irregular spacing.



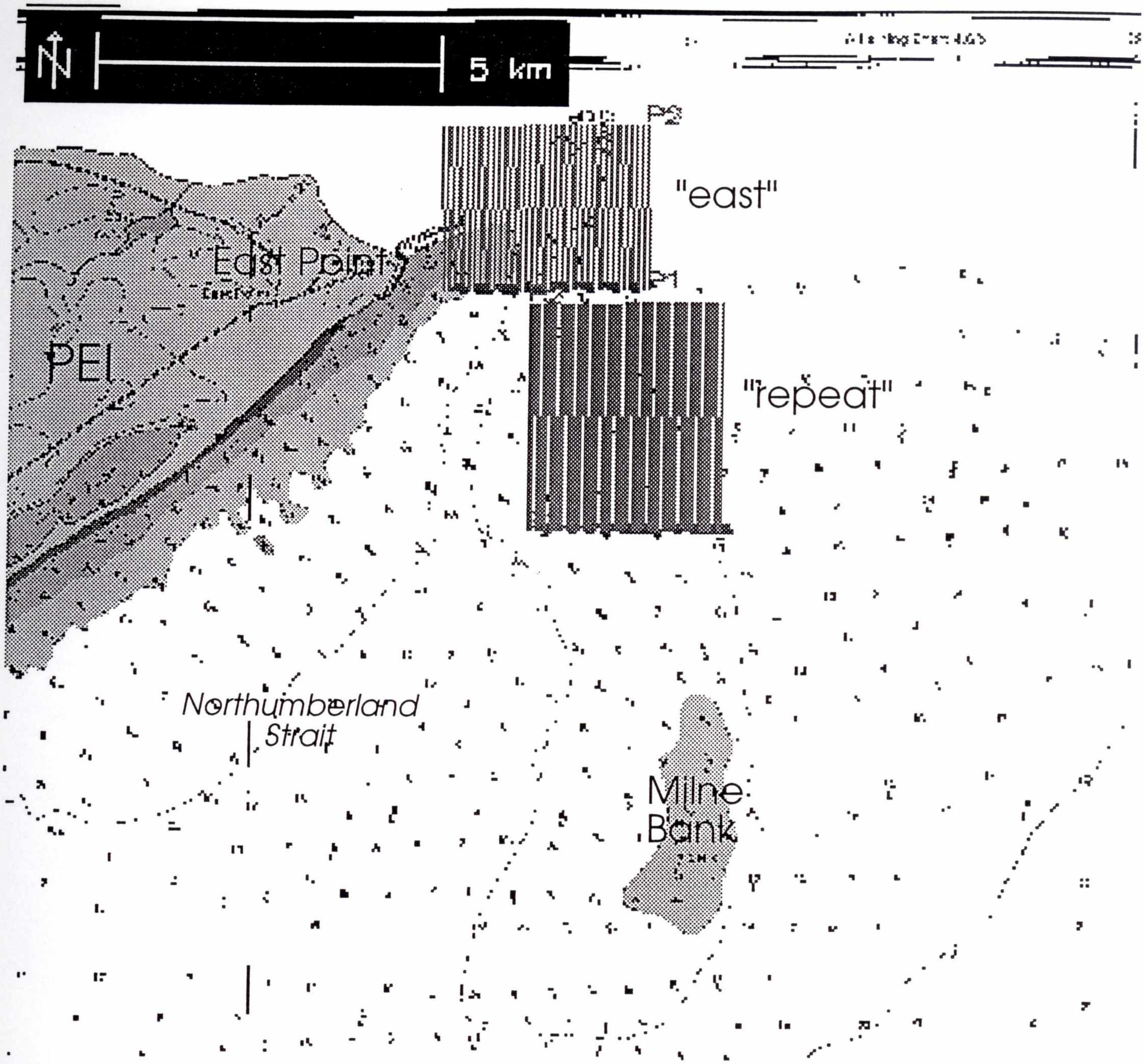
Planned survey grids for cruise Fredrick G. Creed 99-037a



Day 226,1999 Location of survey grid "prince" used to map the seabed offshore Boughton Bay,PEI.



Day 228, 1999. Location of survey grid "basin" which was used to map the seabed offshore of Little Harbour. The shallower parts of the harbour were surveyed using a "fill" technique between completed lines.



Days 227 and 229,1999. Location of survey grids "repeat" and "east" which were used to complete a repetitive survey of the bedforms on Milne Bank and to extend our mapping along the northern extent of the bank.

APPENDIX 3
Seawater
Sound Velocity Profiles (SVPs)

Appendix 3
Offshore Sound Velocity Profiles

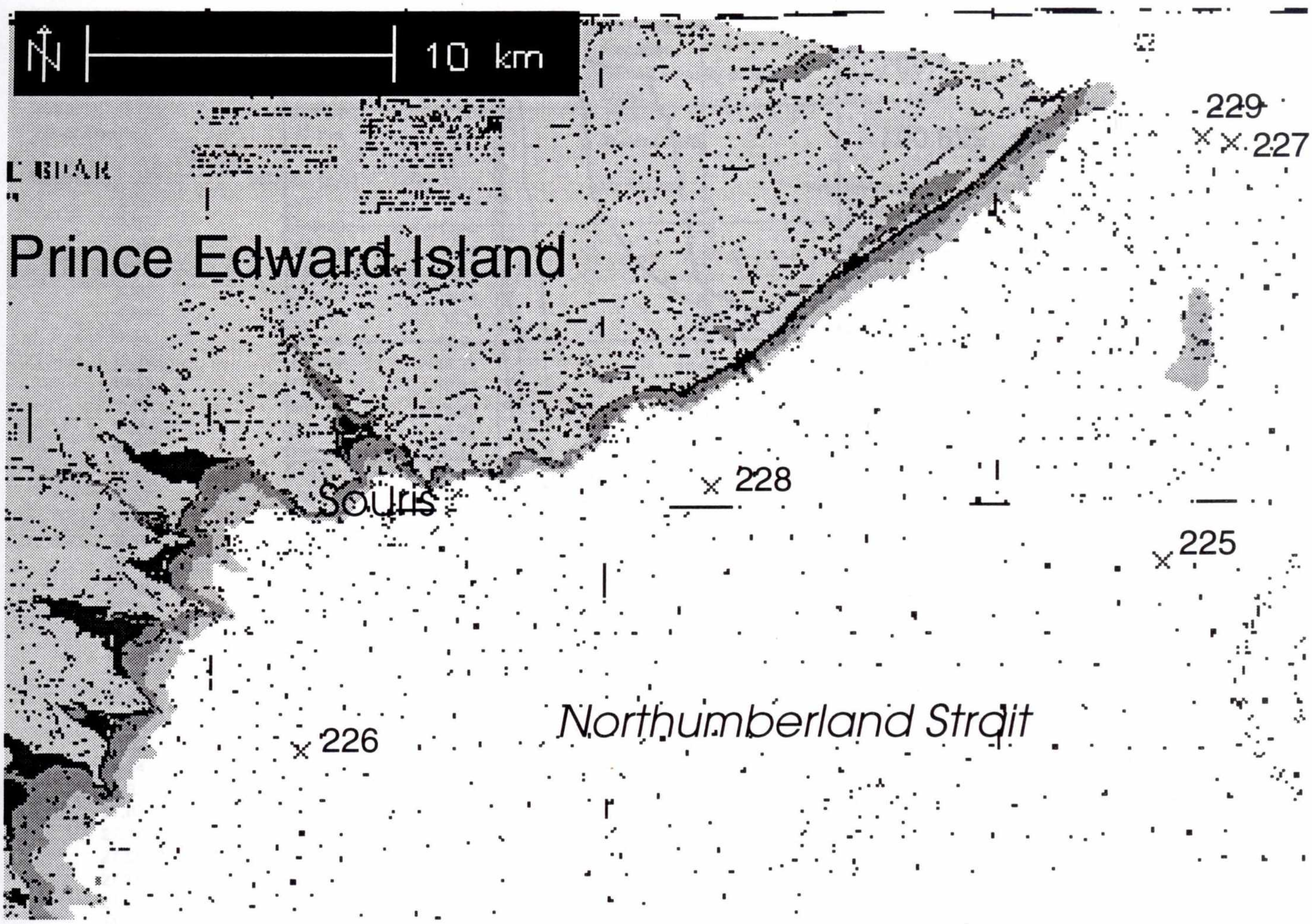


Figure 3-1. Location of sound velocity profiles (SVP) collected on Julian Days 225 to 229, 1999, Frederick G. Creed 99-037a.

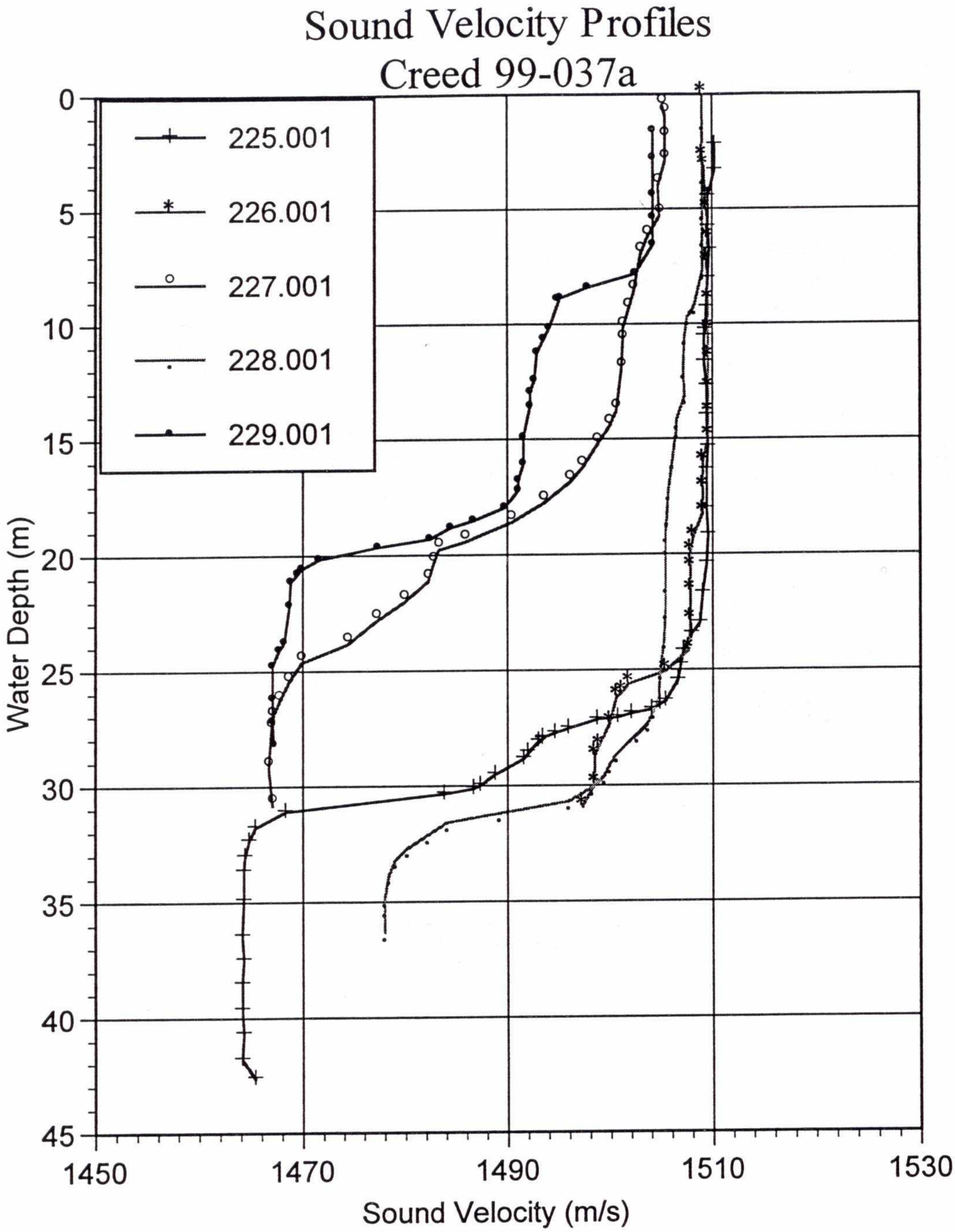


Figure 3-2. Sound velocity profiles of the water column collected between days 225 and 229 at the locations shown in figure 3-1. The largest contrast in profile occurs between the waters adjacent to Milne Bank, ie. 227 and 229, and those farther away, ie. samples 225, 226, 228 where the denser water is deeper. The appearance of a second inversion or plateau in the graph on day 229 versus day 227 may reflect the change in the winds from northerly on the 227 and southwesterly on day 229, and the difference in tidal stage which was slightly higher on day 227.

Appendix 3
Sound Velocity Profiles

SVP 225.001

Location:	46 18.9072 N	61 55.7660 W
Sound velocity profiler:	S/N 03129	
Date:	August 13, 1999	
Time:	18:35 UTC	
Water Depth:	40.1 m	

Depth (m)	Velocity (m/s)	Temp (C)
2.25	1510.25	18.82
3.35	1510.25	18.62
4.49	1509.57	18.38
5.81	1509.57	18.35
6.80	1509.71	18.34
8.03	1509.57	18.3
9.30	1509.44	18.24
10.29	1509.31	18.23
10.57	1509.17	18.22
11.69	1509.17	18.22
12.75	1509.44	18.22
14.02	1509.44	18.21
15.37	1509.57	18.21
16.37	1509.44	18.2
18.06	1509.44	18.19
19.19	1509.57	18.19
20.42	1509.44	18.16
21.69	1509.04	18.13
22.98	1508.77	17.98
23.45	1507.96	17.6
24.22	1507.15	17.36
24.81	1506.88	17.32
25.49	1506.61	17.27
26.39	1505.4	16.76
26.52	1504.87	16.6
26.74	1504.06	16.36
26.92	1502.05	15.85
27.08	1500.72	15.15
27.17	1498.72	14.03
27.55	1495.93	13.59
27.76	1494.61	13.13
27.95	1493.42	12.85
28.01	1493.42	12.94
28.58	1491.97	12.57
28.11	1493.02	12.85
28.86	1491.57	12.43
29.54	1488.81	11.62
30.01	1487.37	11.22
30.14	1486.71	11
30.36	1483.84	10.06
31.11	1468.35	6.32
31.80	1465.42	5.29
32.37	1464.79	5.09
33.03	1464.41	4.96
33.66	1464.28	4.96
34.92	1464.28	4.92
36.44	1464.15	4.86
37.48	1464.28	4.81
38.53	1464.15	4.81
39.64	1464.15	4.8
40.69	1464.28	4.78
41.81	1464.15	4.76
42.64	1465.42	4.75

SVP 226.001

Location:	46 15.76 N	62 17.71 W
Sound velocity profiler:	S/N 03129	
Date:	August 14, 1999	
Time:	11:38 UTC	
Water Depth:	29 m	

Depth (m)	Velocity (m/s)	Temp (C)
0.00	1509.00	18.21
2.76	1509.04	18.21
3.17	1509.17	18.22
5.06	1509.44	18.18
6.32	1509.57	18.17
7.31	1509.44	18.16
9.03	1509.57	18.17
10.29	1509.57	18.16
11.53	1509.57	18.15
12.87	1509.57	18.15
13.93	1509.57	18.15
14.94	1509.57	18.13
16.04	1509.04	18.00
17.17	1509.04	17.98
18.24	1509.04	17.94
19.31	1508.09	17.65
19.93	1507.82	17.60
20.61	1507.82	17.59
21.62	1507.82	17.59
22.89	1507.82	17.53
24.19	1507.69	17.44
25.09	1505.40	16.53
25.62	1501.79	15.45
26.02	1501.12	15.32
26.18	1500.59	15.19
27.36	1499.92	14.94
28.36	1498.85	14.56
28.76	1498.46	14.49
29.98	1498.46	14.48
30.95	1497.26	14.48

Appendix 3 continued

SVP 227.001

Location:	46 26.32 N	61 53.93 W
Sound velocity profiler:	S/N 03129	
Date:	August 15, 1999	
Time:	11:51 UTC	
Water Depth:	32 m	

Depth (m)	Velocity (m/s)	Temp (C)
0.55	1505.13	16.81
0.94	1505.4	16.81
1.98	1505.4	16.83
2.96	1505.4	16.81
4.01	1504.73	16.63
5.33	1504.87	16.6
6.26	1503.66	16.32
6.98	1502.99	16.07
8.63	1502.32	15.77
9.42	1501.79	15.62
10.23	1501.25	15.43
10.81	1501.25	15.39
12.02	1501.12	15.34
13.81	1500.59	15.13
14.48	1499.92	14.85
15.27	1498.72	14.59
16.28	1497.26	14.04
16.89	1496.07	13.53
17.78	1493.55	12.85
18.61	1490.39	11.87
19.44	1485.93	10.45
19.78	1483.32	9.93
20.39	1482.8	9.77
21.13	1482.28	9.49
22.02	1479.94	8.79
22.83	1477.22	8.15
23.85	1474.38	7.08
24.65	1469.89	6.2
25.55	1468.61	5.94
26.36	1467.72	5.76
27.05	1467.08	5.57
27.55	1466.95	5.54
29.23	1466.7	5.53
30.83	1467.08	5.54

SVP 228.001

Location:	46 20.3394 N	62 07.2032 W
Sound velocity profiler:	S/N 03129	
Date:	August 16, 1999	
Time:	10:51 UTC	
Water Depth:	35 m	

Depth (m)	Velocity (m/s)	Temp (C)
1.21	1509.04	18.13
2.46	1509.04	18.14
3.59	1509.04	18.14
5.15	1509.04	18.14
6.29	1509.04	18.13
7.73	1509.04	18.08
9.24	1508.23	17.73
9.72	1507.55	17.55
10.57	1507.28	17.54
12.05	1507.15	17.5
13.17	1507.28	17.4
14.24	1506.48	17.17
14.63	1506.48	17.14
15.98	1506.07	16.99
17.32	1505.67	16.91
18.46	1505.54	16.9
19.13	1505.4	16.86
19.68	1505.4	16.85
21.32	1505.4	16.82
22.46	1505.4	16.8
23.76	1505.27	16.7
25.09	1504.87	16.6
26.27	1504.73	16.48
26.8	1504.2	16.41
27.36	1503.66	16.02
27.83	1502.59	15.67
28.67	1500.59	15.03
29.14	1499.92	14.87
29.61	1499.39	14.52
30.11	1498.19	14.23
30.7	1495.93	13.23
31.21	1489.2	10.92
31.61	1484.1	9.81
32.15	1482.15	9.26
32.71	1480.2	8.87
33.18	1479.03	8.62
33.88	1478.38	8.5
34.86	1477.99	8.39
35.27	1477.99	8.36
36.31	1477.99	8.35

Appendix 3 Continued

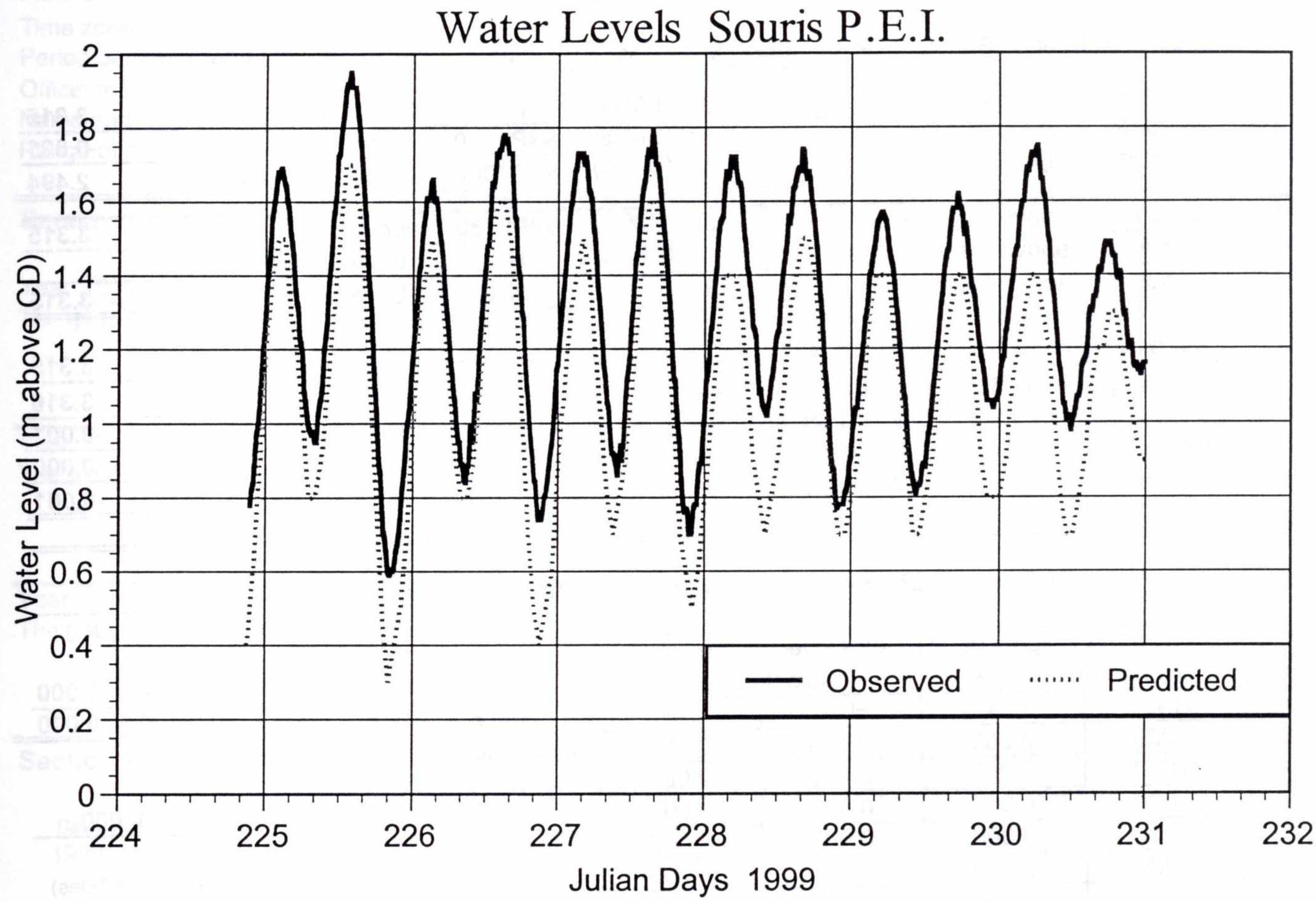
SVP 229.001

Location:	46 26.4358 N	61 54. 6859 W
Sound velocity profiler:	S/N 03129	
Date:	August 17, 1999	
Time:	11:23 UTC	
Water Depth:	28 m	

Depth (m)	Velocity (m/s)	Temp (C)
1.62	1504.2	16.49
2.82	1504.2	16.5
4.4	1504.2	16.49
5.39	1504.2	16.5
6.56	1504.2	16.42
7.82	1502.46	15.64
8.42	1497.79	14.09
8.93	1494.87	13.51
8.87	1495.14	13.48
10.2	1494.08	13.24
10.66	1493.55	13.07
11.26	1492.89	12.83
12.47	1492.63	12.73
12.99	1492.23	12.68
13.6	1492.23	12.65
14.94	1491.57	12.47
16.07	1491.57	12.47
16.8	1491.05	12.24
17.23	1491.05	12.21
17.96	1489.73	11.51
18.52	1486.71	10.79
18.82	1484.49	10.03
19.31	1482.41	9.02
19.65	1477.35	7.67
20.18	1471.55	6.66
20.58	1469.89	6.34
20.79	1469.5	6.28
21.13	1468.86	6.14
22.15	1468.74	6.07
23.76	1468.23	5.84
24.1	1467.72	5.78
24.78	1467.08	5.66
26.21	1467.08	5.64
27.2	1467.08	5.61
28.2	1467.21	5.6

APPENDIX 4

Observed and Predicted Tides, Souris, PEI


Water Levels Souris P.E.I.
Water Level (m above CD)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
224
225
226
227
228
229
230
231
232
Julian Days 1999
Observed
Predicted

TEMPORARY GAUGE DATA — **METRIC** Form TWL-502 — **Canadian Hydrographic Service**

Section 1. Datum Computations and levelling Summary

Place **Souris, PEI**
No. **1650**
Date **12-Aug-99**

Section 1A. By Recovery of Previously Established Chart Datum

Fundamental or Reference Bench Mark **89P9150** is **3.315** m. above chart datum.

BM (a)	89P9150	above chart datum	3.315	BM (a)	89P9150	above chart datum	3.315
BM (b)	89P9151	above /below BM (a)	0.886	BM (b)	99P9000	above /below BM (a)	-0.821
BM (b)	89P9151	above chart datum	4.201	BM (b)	99P9000	above chart datum	2.494
BM (a)	89P9150	above chart datum	3.315	BM (a)	89P9150	above chart datum	3.315
BM (b)	NA	above /below BM (a)		BM (b)	NA	above /below BM (a)	
BM (b)	NA	above chart datum	3.315	BM (b)	NA	above chart datum	3.315

BM 89P9150 above chart datum	+	3.315
Zero of Staff Gauge below BM (enter positive value)	-	3.316
Zero of Staff Gauge + above / - below Chart Datum		-0.001
Zero of Automatic Gauge + above / - below zero of Staff Gauge (use appropriate sign)		0.000
Zero of Automatic Gauge + above / - below Chart Datum (enter on form TWL 501)		-0.001

Section 1B. By Transfer of a Previously Established Chart Datum at (Z) xxx

Month mmm / Day	Observed Heights at Temporary Gauge H.W.	L.W.	Observed or predicted heights at (Z) H.W.	L.W.
dd	0.000	0.000	0.000	0.000
dd	0.000	0.000	0.000	0.000
dd	0.000	0.000	0.000	0.000
dd	0.000	0.000	0.000	0.000
dd	0.000	0.000	0.000	0.000
dd	0.000	0.000	0.000	0.001
Sum	0.000	0.000	0.000	0.001
Mean	0.000	0.000	0.000	0.000
	(1)	(2)	(3)	(4)

(1) - (2)= **r** = 0.000 (2) + (r/2) = **m** = 0.000

(3) - (4)= **R** = 0.000 (4) + (R/2) = **M** = 0.000

Datum for soundings referred to zero of automatic gauge =(Mr / R) - m = **d** 0.000

Datum for Heights is Higher High Water (Large Tides)
HHWLT at Z = 0.00 x r 0.000 /R 0.000

Datum for Heights is 0.00 above Sounding Datum.

Zero of automatic gauge + above / - below sounding datum (d)	0.000
Zero of staff gauge + above / - below zero of automatic gauge (use appropriate sign)	
Zero of staff gauge + above / - below sounding datum (**e**)	0.000

BM (a) xxx above zero of staff gauge	
Zero of staff gauge + above / - below sounding datum (e)	0.000
BM (a) xxx above sounding datum	0.000

BM (a)	xxx	above chart datum	0.000	BM (a)	xxx	above chart datum	0.000
BM (b)	xxx	above /below BM (a)		BM (b)	xxx	above /below BM (a)	
BM (b)	xxx	above chart datum	0.000	BM (b)	xxx	above chart datum	0.000
BM (a)	xxx	above chart datum	0.000	BM (a)	xxx	above chart datum	0.000
BM (b)	xxx	above /below BM (a)		BM (b)	xxx	above /below BM (a)	
BM (b)	xxx	above chart datum	0.000	BM (b)	xxx	above chart datum	0.000

TEMPORARY GAUGE DATA **METRIC** Form TWL-502 **Canadian Hydrographic Service**

Section 2. General Information Date 12-Aug-99

Site Name Government Wharf Vicinity Souris station # 1650
General Locality PEI Lat. N 46-20.7 Long. W 62-15.0
Field Sheets Affected na
Time zone of Obsevations + 0.0 hr.s or GMT
Period gauge in operation: From 12 Aug 1999 To 30 Aug 1999
Officer in Charge: Blaney/Reid Survey Establishment PWLN
Name and type of gauge: Sutron (digital) Sensor Type: Float & encoder
Range of gauge:

Section 3. Type of Record Obtained and Location of Gauging Site

Year 1999 Type of record ☑ Continuou or staff gauge readings: ☐ Hourl or ____ times daily
The gauge was locatec on the Government wharf (former CN wharf) in Souris. A stilling well was installed near the northeastern inner end of the wharf. The gauge was set to read the water level every 15 minutes.

Year ____ Type of record ☐ Continuou or staff gauge readings: ☐ Hourl or ____ times daily
The gauge was locatec

Year ____ Type of record ☐ Continuou or staff gauge readings: ☐ Hourl or ____ times daily
The gauge was locatec

Section 4. Method By Which Bench Mark Elevations Were Originally Established And Were Maintained During The Periods Of Operation Of The Gauge Site.

Date	Description
1999	A level circuit was run from BM 89P9150 to 89P9151 and return. A new benchmark 99P9000 was established near the gauge site with a level circuit run to 89P9150. The tide staff was also levelled from 89P9150. BM 1-1958-TS has been destroyed since 1989. BM 1916-TS was not inspected.

Date	Description

Date	Description

Section 5. Tabulation Of Observed Bench Mark Elevations.

Date	OIC	Establishment	BM No. 89P9150	BM No. 89P9151	BM No. 99P9000	BM No. 1-1958 TS	BM No. 1916-TS	Datum used
1989	G Henderson	Smith Survey	3.315	4.212	na	5.77	15.246	CD
12-Aug-99	D.Blaney	PWLN	3.315	4.201	2.494	destroyed	na	CD

Section 6. Datum for Heights ________ above Sounding Datum, or ________ above Chart Datum

TEMPORARY GAUGE DATA | **METRIC** Form TWL-502 | **Canadian Hydrographic Service**

Section No. 7 Bench Mark Descriptions

Date 12-Aug-99

B.M. No. 99P9000 a CHS (agency) bronze tablet stamped 99P9000 set vertically into the concrete pad of a concrete/steel bollard. The concrete pad, measuring 2 x 2 metres,is level with the asphalt surface of the wharf. The bollard is the second from the inner northeast corner of the government wharf (former CNR wharf).The BM is located between the bollard and the north wharf face, (0.55m from the bollard and 1.00m from the outer face of the wharf). The BM is 9.85m west of a 0.6m jog in the face of the wharf.

Sounding datum ________ m. below.
Chart datum 2.494 m. below.
G.S.C. elevation ________
IGLD (1955) elev. ________
BM condition ________

☑ Correct ☐ Amended

B.M. No. 1-1958 TS est a CHS (agency) bronze tablet stamped ________ set This benchmark was not recovered in 1999. It is supected that the benchmark was destroyed during reconstruction and modification of the wharf approach road.

Sounding datum ________ m. below.
Chart datum ________ m. below.
G.S.C. elevation ________
IGLD (1955) elev. ________
BM condition Destroyed 1999

☐ Correct ☑ Amended

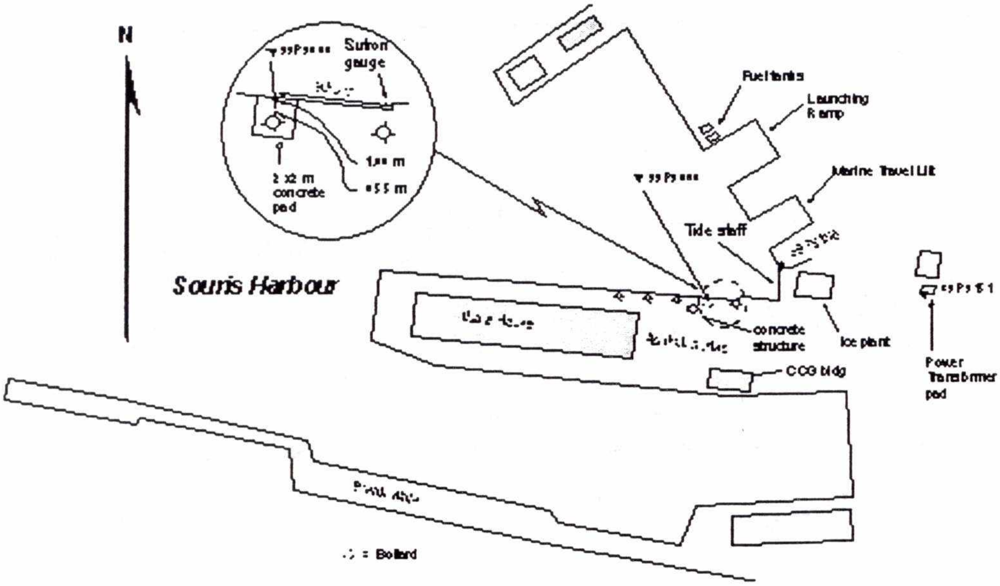
B.M. No. ________ a ________ (agency) bronze tablet stamped ________ set

Sounding datum ________ m. below.
Chart datum ________ m. below.
G.S.C. elevation ________
IGLD (1955) elev. ________
BM condition ________

☐ Correct ☐ Amended

Section No. 8 Sketch ☐ Correc ☑ Amended

Souris, PEI 12 Aug. 1999 Temporary gauging site



Place Souris, PEI File No. 1650

NOTES