Field study of ice characteristics off the West Coast of Newfoundland

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FINAL REPORT

FIELD STUDY OF ICE CHARACTERISTICS OFF THE WEST COAST OF NEWFOUNDLAND

VOLUME 1 PUBLIC DATA

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By
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EXECUTIVE SUMMARY

This report describes the results of a field program carried out off the West Coast of Newfoundland from March 7th to 22nd, 1999. The intent of the field program was to characterize the ice regime in order to improve the design and operating criteria for year-round oil and gas operations.

Due to the mild temperatures and wind patterns, the ice coverage was very limited throughout the immediate area of interest for oil and gas. Drifting sea ice never reached the shoreline in the areas off Cornerbrook or Stephenville, an unusual occurrence. In order to gain dependable access to ice floes of sufficient size and thickness, the team had to move to Plum Point, a community on the Southern end of the Strait of Belle Isle.

In general, the weather conditions for carrying out the field program proved to be quite difficult. Of the 14 days in the field only two days were clear and allowed for easy flying offshore. The other days saw frequent snow showers, high winds, gale force winds, blizzard conditions, and freezing rain. This is unusual for that time of year, which is normally characterized by relatively stable and clear weather. The presence of large amounts of open water due to the early ice-out probably contributed to this exceptionally moist and poor weather.

Despite these conditions a significant amount of information was obtained on general ice properties, site specific comparisons between ice properties, Arctic and Antarctic Institute (AARI) hot point drill profiles, and the bore hole jack strength profiles. Also basic information was collected on the nature of the pack ice and ridges.

Ten first-year pressure ridges were examined, of these, three were grounded ridges, while the other seven were floating. Maximum sail height for floating ridges was 2.6m. Maximum sail height for grounded ridges was 3.8m. For comparison, the one-year return period maximum sail height obtained in simulations of floating ridges for the design of the Confederation Bridge was about 4m. Predicted maximum annual ridge sail height for the West Coast of Newfoundland was 4.7m (Pilkington, 1997). Although some of the keels of the grounded ridges were profiled, no measurements were obtained on ridge keel depths for floating ridges. However, from the measured sail heights a nominal maximum keel depth of about 10 to 14m can be estimated. Noting that this was a very mild year, the 23m design keel depth suggested by Sandwell (1998) may not be unreasonable. However, more statistical data on keel depths will be required to confirm the design ridge.

Consolidated layer thicknesses were measured using mechanical augers, borehole jack and hot point drill. The three methods give similar results, although each method has its own strengths and weaknesses. However, the borehole jack profiles are considered to be the most reliable. Consolidated layer thicknesses in the range of 0.9 to 2m were measured. It is noted that the Freezing Degree Days for the 1998/99 winter were only 365 compared to the mean of 645, therefore the consolidated thicknesses measured should not be considered typical maximums.

Floe diameter distributions were obtained from high oblique photographs. The resulting floe size distributions give significantly larger floe sizes than the distributions used for the design of Confederation Bridge. Part of the difference is attributable to a bias in the analysis of the vertical photographs of ice floes in the Northumberland Strait. This difference in floe sizes is only important for wide structures, if limit force criteria are used. In this case, more data on floe sizes would be needed.

No multi-year floes or icebergs were detected during this project. However, in a normal year they would be expected. Further work on assessing the risks associated with multi-year ice and icebergs is warranted.

Four pull-up tests (measuring the bond between the consolidated layer and the keel) were carried out at Site 3, the data relating to these tests are part of the proprietary volume of this report (Volume 2).

Although this study has provided significantly more information on ice conditions on the West Coast of Newfoundland, it has emphasized the need for further work to define ice conditions well enough for preliminary design of offshore production systems. Some of these recommendations were initially made in Pilkington et al. (1997).

- Upward looking sonar arrays should be placed on the seabed at the locations of interest. These would provide excellent data on the number and size of ridge keels, as well as on ice movement during the winter and current and wave heights during open water periods. This would allow better calculation of ridge loads on potential structures, and provide information on wave loads and currents as well.

- Satellite drift buoys placed on the ice in February would provide ice drift data with good time resolution. This would allow calculation of the number and speed of encounters between ridges and an offshore structure.

- Since 1999 was not a typical year off the West Coast of Newfoundland, at least one more field study should be done under more normal conditions. Such a field study could be designed to coincide with the occurrence of old ice floes (based on AES ice charts) or icebergs, since these may be the design features for some structures.

- Further work on potential extreme ice features such as rubble bergs, grounded rubble fields, multi-year floes and icebergs is warranted.

Before any serious design work is contemplated, a more comprehensive set of ice strength data is required and would include keel strengths, as well as flexural and crushing strengths of the consolidated layer.

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1 INTRODUCTION

1.1 Background to the Project

The development of hydrocarbon resources off the West Coast of Newfoundland will likely require the use of offshore production platforms. Ice may control the environmental loads on these platforms. Depending on the location and the ice conditions, a wide variety of platforms may be used, ranging from multi-leg platforms (if the ice regime is not severe) to caisson type structures in the nearshore areas. Our knowledge of the ice regime in the area, in the context of ice loads on structures, is minimal and there are few direct ice measurements in this region. This project was therefore aimed at obtaining detailed direct measurements of ice conditions in this area.

In 1997 Canatec and Sandwell Inc. carried out a study of the ice regime in the area (Pilkington et al., 1997 and Sandwell,1998). They concluded that there was a serious need for ice data and that a field program should be conducted. Some of their recommendations were to acquire more information on:

- Consolidated layer thickness, temperature and salinity.
- Ridge height and depth, spacing, consolidation, porosity, and block sizes.
- Ice drift.
- Old ice intrusions.

The present field study aimed to collect some of this information.

One of the problems with this project was the relatively low budget when considering the costly transportation component. The project team succeeded in attracting additional funding from Exxon Production Research. Exxon’s main interests were related to calibration of the AARI hot point drill, and to detailed comparisons between borehole jack data, hot point drilling, mechanical drilling and pull-up tests. This information had a direct bearing on the analysis of field data obtained off Sakhalin Island. The additional funding allowed doubling the amount of field time. However, because of the mixture of public and industry funding for the field work, two reports have been issued. Volume 1 (this report) contains all public data. Volume 2 contains the specific data on the work funded by industry as mentioned above. Volume 2 is proprietary until December 31, 2002.

1.2 Overview of Ice Conditions

Ice conditions off the West Coast of Newfoundland are typical of the Gulf of St Lawrence in general. They are similar to the Northumberland Strait, where the Confederation Bridge to Prince Edward Island has been completed. There are three main differences with Northumberland Strait:

- Icebergs, large first-year ridges and multi-year ice can, on rare occasions, reach the West Coast of Newfoundland from the coast of Labrador, via the Strait of Belle Isle.

- The North shore of the Gulf of St Lawrence is relatively cold (Sept-Iles averages 1526 yearly freezing degree-days compared to 740 in Summerside). These colder conditions cause considerably thicker ice, which can drift into the West Coast of Newfoundland.
- The West Coast of Newfoundland is more open to the large fetch of the Gulf of St Lawrence in terms of wind, waves and ice.

General ice conditions, freeze up and break up patterns are described in Pilkington (1997).

1.3 Overview of Ice Issues Relating to Ice Loads

The emphasis of this project was focused on the ice properties which are most important in the context of ice loads on structures. Ice sheet information (such as ice sheet thickness, salinity, temperature, density and microstructure) is important for defining the general ice regime in the area. However, it has been found that, in similar sub-arctic regions, probabilistic ice loads are dominated by interactions with ridges of various kinds.

Ice ridges and rubble features are formed when level ice features are compressed and sheared by environmental driving forces. Depending on the environmental conditions during ridging, such as ice thicknesses, temperature, direction and speed of motion, driving forces, water depth, floes or shoreline configuration etc., many different types of ridges or rubble features may result. Compression ridges, hummock fields, shear ridges, grounded rubble piles, and rafted ice features are some of the types of ice features which can be formed.

Recent work related to the design of the conical piers for the Northumberland Strait focused on the forces exerted by large ridges with keels in excess of 15 m deep. Total load on the piers was a combination of keel failure load and consolidated layer failure load. The possible existence of large cohesive rubble features (sometimes called rubble bergs or stamukha) was also a concern. Probabilistic simulations of ice loads showed that the total load can switch from being dominated by the keel failure load to being dominated by consolidated layer failure, with relatively small changes in assumptions about keel depth distribution, structure properties and consolidated layer thickness distribution. The same is expected to happen for West Newfoundland offshore structures. So both keel and consolidated layer properties are considered to be important.

Recent field measurements off Sakhalin Island Russia, suggested that compacted slush and frazil ice at the base of the refrozen layer can be mistaken for undamaged solid ice, especially using thermal drills but even using augers. It is for this reason that in-situ strength profiles were measured during this project.

1.4 Brief Literature Review (FYI Ridges)

In all sea ice regions of the world, first-year ridged ice is the most frequent ice feature after level ice. Except where multi-year ice and icebergs also exist, it is the first-year ridge or ice rubble feature that will govern the ice load design criteria.

Despite the importance of these features, their mechanical properties are not well known, and ice load models have been somewhat speculative and empirical. To address this uncertainty, a significant amount of research has recently been done on the study of ice loads due to first-year ridge keels. This work has been partly supported by the Canadian Government and is discussed in Croasdale (1999). A number of full-scale ridge keel strength measurements have been made in the last four years (Croasdale & Associates 1996, 1997, 1998 and 1999). Most of the results are still confidential.

A catalogue of sea ice ridges, summarizing all the available information on ridge properties to date, and including 112 individual first-year ridge geometries is given in Burden & Timco (1995). The data is analyzed in terms of sail and keel angles as well as porosity. It includes information on ridge geometry in the Baltic Sea as discussed in Lepparanta & Hakala (1992), and ridge properties off the North coast of Alaska as reported by Tucker et al. (1981).

Despite their importance, design values or distributions for first-year ridge parameters are still difficult to obtain, and they include significant amounts of uncertainty. This situation is due to the following general considerations:

- Most of the ridge volume is underwater and very difficult to access from above or from below.
- Ridge keels are made of large random blocks, and bulk properties measurements require large sample volumes, difficult to achieve under field conditions.
- Ridge formation conditions are an important key to understanding their internal properties (such as inter-block bonding) and they are generally not known.
- Because of the highly random nature of the various parameters defining ridge geometry and properties, a large number of measurements would be required to define their distributions.
- Each ice covered area of the world has its own set of climactic conditions which can give rise to different first-year ice features being formed.

Despite these difficulties, first-year ridges continue to be the subject of significant research efforts (for example Hoyland and Loset, 1999).

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2. PROJECT OBJECTIVES

2.1 General Objective

The objective of this project was to conduct a field study off the West Coast of Newfoundland to provide on site detailed information on regional ice characteristics and ice properties in the context of ice loads on structures.

2.2 Measurement Priorities

The emphasis of this project was on the ice properties which are most important in the context of ice loads on structures. Although ice sheet information (such as the thickness, salinity, temperature, density & microstructure of sheet ice) is important to define the general ice regime in the area, it has been found that, in similar sub-arctic regions, ice loads are dominated by interactions with ridges of various kinds.

First year ridges consist of a sail, a keel and a consolidated layer which is two to three times the ambient ice thickness.

Probabilistic simulations of ice loads on structures subject to first year ridges show that depending on structure shape and size, either large keels or thick consolidated layers potentially dominate the total load on the structure. The possible existence of large, fully cohesive, rubble features is also a concern.

Since we do not know at this point which of these ice characteristics will dominate ice loads on the various possible structure to be designed for different water depths off the West Coast of Newfoundland, all the key ice characteristics must be measured. However experience from similar areas of the world such as the Baltic, PEI, and Sakhalin, has shown that the following are very important in the context of ice loads on structures:

- Ridge keel characteristics
- Ridge consolidated layer characteristics
- Hummock field (Stamukha) characteristics

2.2.1 Ridge Keels

Keel depth is important because ice loads due to keels are roughly proportional to the square of the keel depth. The shape of the depth profile is also important as some keels are triangular in shape while others are more trapezoidal, and this leads to different failure loads.
Keel depth can decrease significantly on either side of the maximum, so that for larger structure widths for example, the effective keel depth can be significantly reduced.
The length of the ridge should also be measured to check if the ridge can fully envelop a structure of a given diameter. The mechanical properties of the keel material are also important. These are outside the scope of this study, but work has already been done in

Northumberland Strait on keel strengths, and the results have some relevance to this region also. (Croasdale & Associates Ltd., 1997, 1998).

2.2.2 Consolidated Layer

Ridge consolidated layer thickness is a key measurement, but experience elsewhere has shown that different drilling techniques can give different results. For example, hot water drilling seems to give consolidated layer thicknesses which are consistently higher than mechanical drilling. The difficulty is to differentiate the refrozen layer which has significant strength from the low porosity material below which has little mechanical strength.

Different ways of identifying the boundary between the two layers exist. Profiling the strength of the consolidated layer using a borehole jack not only provides a good measurement of its thickness, but it also provides an index of its strength which can be compared to other areas of the world.

2.2.3 Hummock Fields

Hummock fields, rubble bergs and other rubble features such as grounded rubble piles are a concern. Under some conditions (cold temperatures, low porosity) rubble features can form into a "solid mass" which could lead to extreme loadings on structures, should they become ungrounded. These conditions can occur at the edge of the landfast ice for example. Part of this field study was dedicated to identifying the possible source areas for such features.

3. General Description of Field Work

3.1 Summary

The central and southern portion of the Western Coast of Newfoundland, from Parson's Pond to Stephenville, are of particular interest to hydrocarbon development. The 1999 field program was initially scheduled to operate from Rocky Harbor, near Cornerbrook. Since the 1998-99 winter was milder than normal, landfast ice did not become established along the central portion of the Western Coast of Newfoundland. Rather, the ice was dispersed throughout the Gulf, as illustrated by the RADARSAT image from 9 March 1999 shown in Figure 3-1. Since it was not feasible to work from the Cornerbrook area, base operations were moved north to Plum Point. From Plum Point, the ice that had accumulated along the Québec shore and the ice entering the Gulf through the Strait of Belle Isle could be accessed.

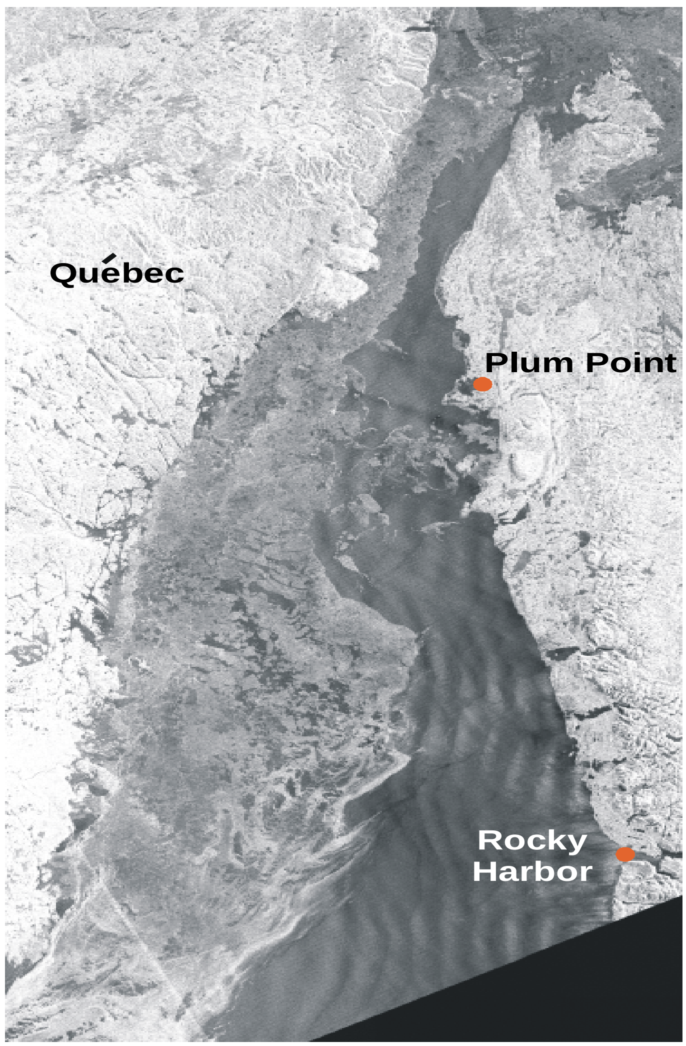

Figure 3-1: 09 March RADARSAT ScanSAR Image of the Ice Conditions Between the Northern Peninsula of Newfoundland and Québec (Courtesy of Canadian Ice Services)

Figure 3-2 shows the Freezing Degree Day (FDD) accumulation for Stephenville for 1998-99. After about March 1, the majority of days have mean temperatures above freezing and the Cumulative Degree Day Index becomes positive.

Inspection of Freezing Degree Days for the region over a 38 year period (Figure 3-3) shows that 1999 was the 2nd warmest year on record. Total Freezing Degree Days for 1998-99 were 365 °C-day. This is compared to the long term statistics which have a mean of 645°C-day and standard deviation of 175 °C-day, maximum of about 1000 °C-day. The low FDD total explains why the ice conditions were very light and needs to be taken into account when using the results of this field program.

During the field project, the weather proved to be quite difficult. The predominant wind direction was offshore, resulting in the accumulation of ice along the Québec coastline. Of the two weeks spent in the field, only two days were clear enough to enable flying by helicopter to the ice offshore. The weather during subsequent days was poor and included frequent snow showers, high winds, blizzard conditions and freezing rain. In spite of the less than favorable conditions, a significant amount of information was obtained on the general ice properties and the nature of the pack ice and first year ice ridges in the Gulf of St. Lawrence.

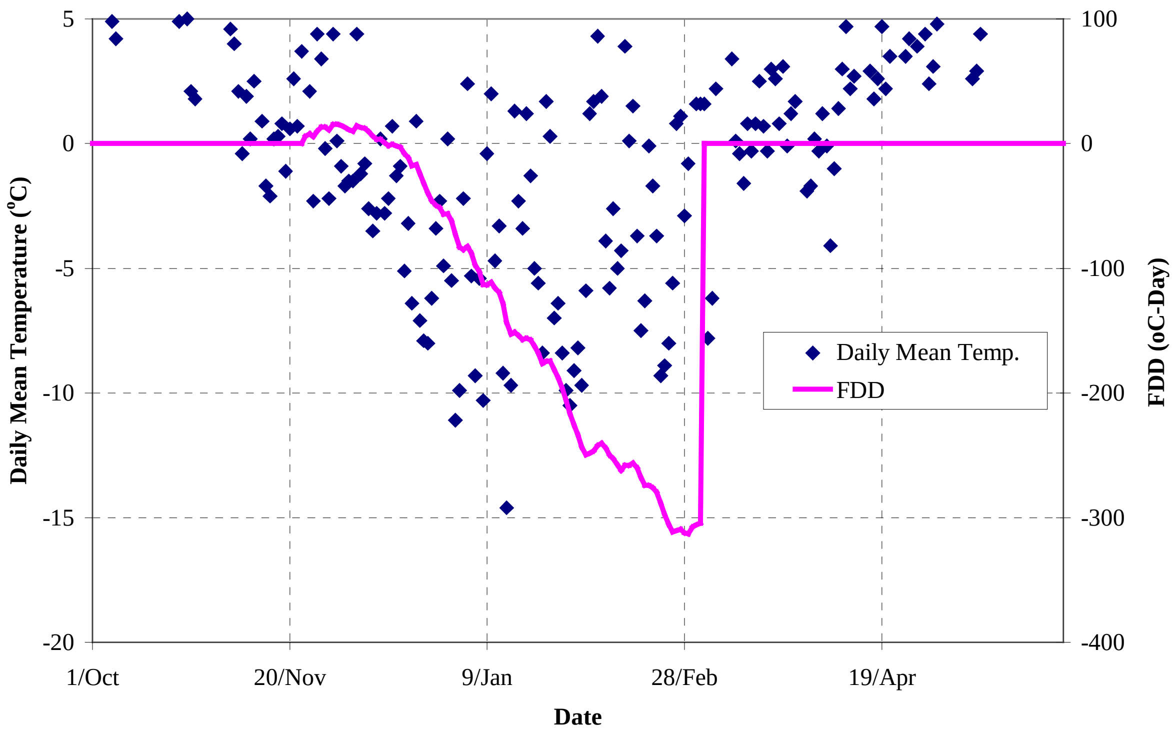

Figure 3-2: Freezing Degree Day Accumulation for Stephenville 1998-1999

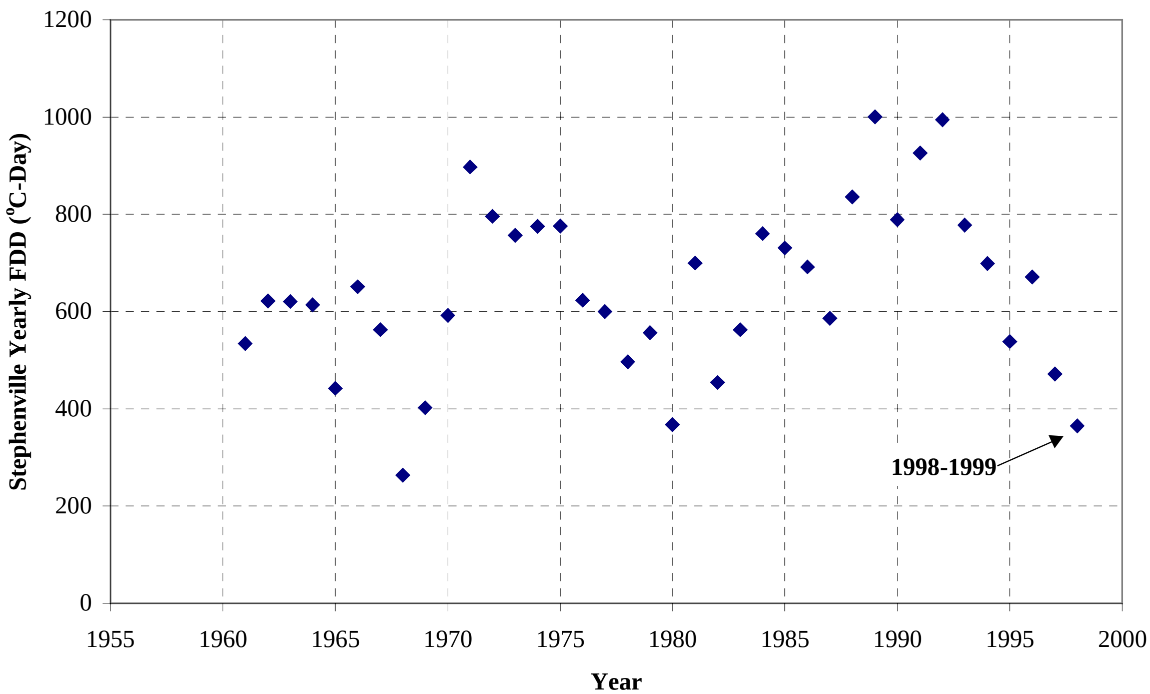

Figure 3-3: Historical Total Freezing Degree Day for Stephenville (1960 – 1999)

3.2 Description of Measurement Methodologies

This section contains short descriptions of the various measurement methods used.

3.2.1 Surveying

When surveying the surface profile of a ridge, survey lines were first established so that the surface topography of the ridge could be characterized fully. This was done by one person with a "thread distance meter". The end of the thread was attached to an ice block by winding it several times around an asperity, and the thread meter was zeroed. Points along a straight line perpendicular to the ridge crest were then marked every five metres, using a paint spray can. If possible, three such lines were established across each ridge, to better define the three dimensional shape of the ridge sail. The distance between lines was around 20 metres, but it varied according to the ridge shape. After ten days of using the thread distance meter, it was realized that some of the thread was winding itself around the helicopter tail rotor. To avoid any possibility of the thread affecting helicopter safety, use of the thread meter was stopped. A trailing rope was used instead, with knots at 5 and 10 metres.

At each point the surveyor recorded snow depth and ice surface level. Ice surface level was measured either by using a hydraulic leveling instrument supplied by NRC, or by using rod and level. The hydraulic leveling instrument consists of a long tube with a pressure transducer at one end of the tube. The difference in pressure between the two ends of the tube is a measure of the difference in vertical level. This was especially useful on windy days when operating a survey level can be difficult. At each location, at least one hole was drilled through the ice to provide a reference water level shot. The freeboard of the ice surface could then be calculated.

Note that throughout the report, specific stations at each site have been named according to the following code: Station S2L1-30 indicates that the station was located at S2= Site 2, on L1= line 1, - 30 at a distance of 30 m from the start of the line.

Figure 3-4: Drilling and Surveying at Site 8

3.2.2 Mechanical Drilling

Mechanical drilling was done using 2 inch (5 cm) augers and a gas power head. Each auger length was 1 meter long, the connections were secured by bolts and lock nuts. By using a stepping stool, two metres of auger could be added each time, reducing the connecting time. When drilling to define the thickness of the consolidated layer, a two meter length was sufficient. This type of drilling could be carried out by one person. When logging deeper holes, two people were necessary for taking notes and making bolt connections. Nut drivers were found to be helpful in speeding up the process.

Notes were made on prepared sheets. The bottom of each layer and the “tip feel” for that layer were recorded. Tip feel could be classified as:

- H = hard: when drill penetration was slow, some pressure often needed to be applied to the drill for good penetration. This indicated solid ice.
- S = soft: when drill penetration was easy without need for pressure. Sometimes the drill had to be supported or drilling was too fast and the clearing of cuttings was inadequate. This would tend to indicate warm and weaker ice but competent ice layers.
- R = ram: when the auger could be pushed down by ramming the drill into the hole. This could indicate either tightly compacted rubble, or high porosity ice.
- P = push: when the auger could be simply pushed through without ramming. This indicates very weak ice or loose rubble.
- V = void: when there is no resistance at all to drill penetration.

When estimating the consolidated layer thickness, it was assumed that the bottom of the consolidated layer was the top of the first void (V), or the first area where the drill could be pushed (P). Small voids above or near the water line were not included in this definition.

Mechanical drilling was usually done some distance away from the ridge sails, and the top of the consolidated layer was level zero, the top of the solid ice surface, unless otherwise noted.

3.2.3 AARI Hot Point Drill

The hot point drill is a drilling system invented at the Arctic and Antarctic Research Institute (AARI) in St Petersburg. It consists of a metal rod with a small shaped head containing an electrical heating element. The rod is plugged into a 220Volts generator through a cable. The cable goes over a wheel that turns when the rod melts down into the ice. The rotation of the wheel is recorded and is a measure of drill penetration distance and speed. This provides a continuous profile through the ridge sail and keel, with excellent resolution (about 3cm).

A hot point drill profile is a plot of penetration velocity versus depth in the ice. An example of such a profile, with explanations of the notations used, is given in Figure 3-6. Drill velocity is related to ice porosity. High porosity ice requires less melting and is penetrated faster. Details on the drill power levels, criteria for selecting voids in terms of penetration velocity, consolidated layer definition, are discussed in Volume 2.

A picture of the AARI hot point drill in operation is shown in Figure 3-5 (note the data acquisition system and the generator in the background).

Figure 3-5: AARI Hot Point Drill

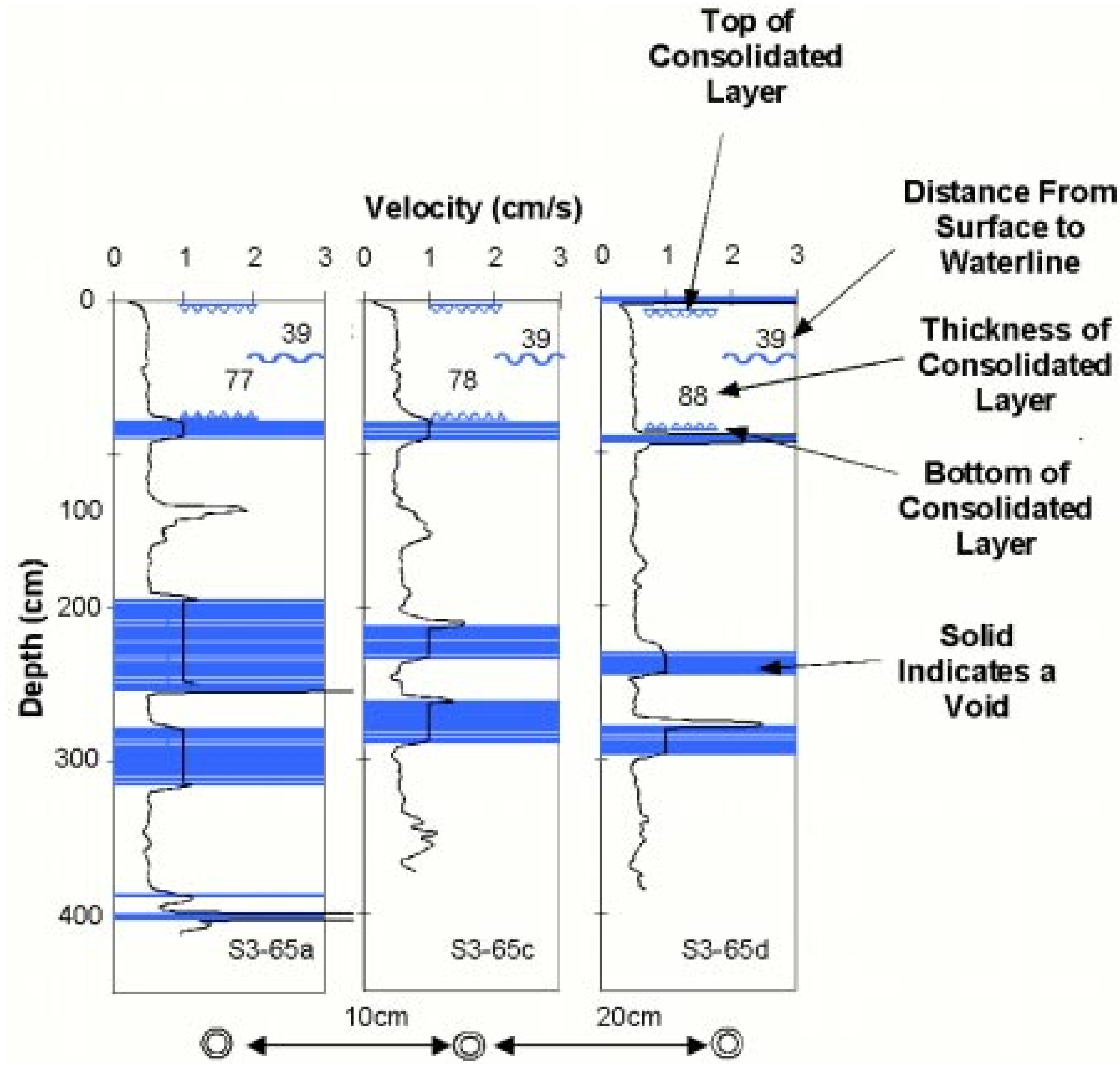

Figure 3-6: Examples of Hot Point Drill Profiles

3.2.4 Coring

Ice coring was done using a 6 inch (15cm) CRREL core barrel, with a gas power head. With it, a 4 inch (10cm) diameter core can be obtained. Extensions are added when necessary. In general, as soon as a core was retrieved, its temperature was measured by introducing a temperature probe into a small hole freshly drilled into the core. Temperatures were measured every 10 or 20 cm. Sections of the core were cut at regular intervals and placed into sealed bags for salinity measurements. Even though care was taken to do this quickly, inevitably (given the warm temperatures) some brine drainage occurred before the sample was bagged. Figure 3-7 shows some photos of this activity. Usually, a second core was retrieved near the first and these samples were shipped back to Ottawa. Analysis of these cores is reported in Johnston (1999). A third core was retrieved when needed for density measurements.

Figure 3-7: Ice Coring and Associated Measurements

3.2.5 Borehole Jack

The borehole jack is a small hydraulic jack made small enough and shaped so that it can fit into a 6 inch (15cm) hole. The jack is usually manually lowered into the hole left by the corer. At regular intervals the jack is expanded by hydraulic pressure using an electrical hydraulic pump plugged into a small gas generator. As the jack expands against the ice, the hydraulic pressure and the jack expansion are recorded. The curve of pressure versus displacement gives information on the strength of the ice at that level. The process is repeated every 25 cm and this provides a vertical strength profile through the ice. Figure 3-8 shows the borehole jack, the hydraulic pump and the data acquisition system.

Normally, comparison of borehole jack test peak strength with laboratory unconfined compression tests yields a ratio of 3 to 4 (Masterson, 1996).

Figure 3-8: Borehole Jack

3.2.6 Density Measurements

Ice density has been found to be an important variable in predicting ridge failure loads and ice strength. The density can be most accurately measured by using the submergence technique (as opposed to determining the density based upon sample dimensions and weight alone). However, submerged density measurements are not easy to perform. Details of the method used are described below:

The density measurement apparatus was set up (in the hurry tent if wind was a problem). The equipment consisted of an electronic scale, a graduated beaker, and calipers for measurement of dimensions. The beaker was half filled with sea water from the core hole. The scale was leveled, then the weight of beaker and water was measured. A sample was prepared by coring or cutting ice from the keel (approx. 0.5 litre in size). The sample was then placed in the water, and the weight of water + ice was measured. The block was then submerged using a thin metal rod. The total vertical force on the scale was measured. The water level with the sample submerged was recorded. The sample was then taken out and the new water level was recorded (as a double check, water level was measured both by reading the graduations and by independently measuring the height of water above the bottom of the beaker with a ruler).

Outside dimensions of the sample were recorded to provide a measure of the bulk volume. Four lengths and four diameters were recorded, to within better than a millimeter (apart from irregular samples for which the dimensions were estimated). The weight of the sample (drained) was again recorded. Water density in the beaker was recorded every 30 minutes, using a hygrometer. It did not vary significantly.

Figure 3-9: Density Measurements at Site 3

3.3 Overall List of Data Collected

(Note that some of this data, for example - all the pull up strength results, are reported in Volume 2)

<u>March 9, Site 1</u>

- One surface level survey line across the center of ridge (using NRC's hydraulic leveling instrument)
- Drilled and document 9 auger holes (2 inch), but only to a maximum depth of 8 m. Points 15m away from sail peaks on both sides were >8m deep keel.
- Recovered 4 cores from 2 holes in consolidated layer and below. Measured 2 temperature and 2 salinity profiles.

<u>March 10, Site 2</u>

- 3 surface profiles about 25m apart
- 13 auger holes on line 1, 5 auger holes on line 2
- 2 (drained) density measurements (bulk density and submerged density methods)
- 2 temperature profiles
- 2 salinity profiles
- 1 core saved for crystallography
- 50 block sizes were measured later

<u>March 11, Site 3</u>

- 2 surface profiles about 20 m apart.
- 2 full cores to about 4 m depth (bottom at these locations), with about 20 salinities and temperatures in each core. Kept some good samples for crystallography.
- 50 ice block sizes
- 12 full penetration hot point holes. Including 4 in one single location to investigate repeatability.
- 4 well documented auger profiles at same locations as hot point holes.
- 3 borehole jack profiles at same locations.
- 36 drained density measurements, providing density profiles for 2 cores (using both the submergence method and the weight volume method).

<u>March 13,</u>

<u>Site 4:</u>

- 3 level survey lines
- block sizes
- 3 auger holes to 2 m deep (for consolidated layer and freeboard only)

<u>Site 5:</u>

- 3 auger holes to 2 m deep (for consolidated layer and freeboard only)
- 100 block sizes.
- 1 surface survey line across peak of ridge, plus ridge crest.

Site 6:

- 2 surface survey lines
- 4 auger holes to 2 m deep (for consolidated layer and freeboard only)100 block sizes
- 100 block sizes.

March 14,return to Site 3

- 4 pull-up tests
- saved samples cut by chain saw from one block for crystallography
- 10 undrained densities in one profile (from waterline to –60cm) by two methods

March 15:

Return to Site 3

- 17 submerged densities on keel blocks (by two methods).
- 20 hot point drill profiles (every meter along the line of pull up blocks)

Site 7:

- 3 surface profiles
- 2 auger holes to 2m depth
- 1 salinity and temperature profile
- 1 core saved for crystallography
- drift velocity measurement

Site 8:

- 3 surface profiles
- 2 auger holes to 2m depth
- 1 salinity and temperature profile
- 1 core saved for crystallography
- drift velocity measurement

Site 9:

- 2 surface profiles
- 1 auger holes to 2m depth
- 1 salinity and temperature profile
- 1 core saved for crystallography
- drift velocity measurement

March 16, return to Site 3

- 8 borehole jack profiles near pull-up blocks

March 17, hotel cold room

- Porosity and power calibrations of hot point drill

March 18, Site 10:

- 6 borehole jack profiles at 12.5 cm vertical spacing
- 20 hot point drill holes. Some for power calibrations, some for comparison with borehole jack
- 6 cores (salinity and temperature profiles)

- 1 undrained submerged density profile.

March 19:

Site 11:

- 10 hot point drill holes
- 3 borehole jack tests profiles very close to hot point drill holes.
- 3 cores, and 1 ice blocks for crystallography
- 4 bulk density measurements

Site 12:

- 3 cores (temperature, salinity and fabric)
- 3 borehole jack profiles.
- 40 blocks sizes
- 1 surface profile

March 20:

Return to Site 12

- 10 hot point drill profiles
- 2 temperature profiles

Hotel cold room

- 3 porosity calibrations of hot point drill with ice cubes of different salinities

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4. AERIAL RECONNAISSANCE AND PHOTOGRAPHY

4.1 Flight Lines

As mentioned earlier, only two days out of the fifteen field days were suitable for helicopter reconnaissance offshore: March 13 and March 15. During the flights, still photographs and video footage were taken to record ice conditions. Table 4-1 provides the location, altitude and speed of the flight lines. Figure 4-1 shows a map of the flight lines and of the 12 sites visited during the project.

	Start	Start. Time	Latitude/ Longitude	End	End Time	Latitude/ Longitude	Alt. (feet)	Speed (mph)	Notes
Mar 10	Plum point	09:35	51 04.6 56 53.0	Site 2	09:55	51 18.75 56 45.47	150	100	along shore
Mar 11	Plum point	09:00	51 04.6 56 53.0	Site 3	09:20	51 18.77 56 45.44	*150*	*100*	along shore, floe sizes 20 to 100m, then 20m ridge spacing 40m then 10m
Mar 13	Plum Point	09:25	51 04.6 56 53.0	Site 2	09:45	51 18.75 56 45.57	150, 120	70	along shore, strong head wind
	Site 2	09:45	51 18.75 56 45.57	Site 4	10:55	51 25.73 56 53.17	*150*	80	bearing 355 magnetic
	Site 4	11:45	51 24.39 56 56.05	pt B	12.03		150	120	bearing 292, end on landfast ice
	pt B	12:03		Site 5	12:12	51 10.29 57 52.30	varies		circles to find Site 5
	Site 5	13:30	51 18.29 57 52.30	Site 6	14:00	51 18.76 57 17.77	1000,	75	bearing 136, after seals altitude 300
	Site 6	15:49	51 18.82 57 19.86	Plum Point	16:10	51 04.6 56 53.0	500	100	no heading, looking for floes
Mar 15	Site 3	09:40	51 18.77 56 45.44	Site 7	10:11	51 07.24 57 23.96	1000	100	down to 100' for pictures of stamukha
	Site 7	12:10	51 07.09 57 24.56	pt C	12:20		500	100	
	pt C	12:20		Site 8	12:50	51 18.98 57 00.76	300	96	
	Site 8	15:05	51 18.98	Site 9	15:33	51 19.62	300	100	
	Site 9	17:08	51 19.62	Plum Point	17:48	51 04.6	300	100	

Table 4-1: Location, Altitude and Speed of Helicopter Flight Lines

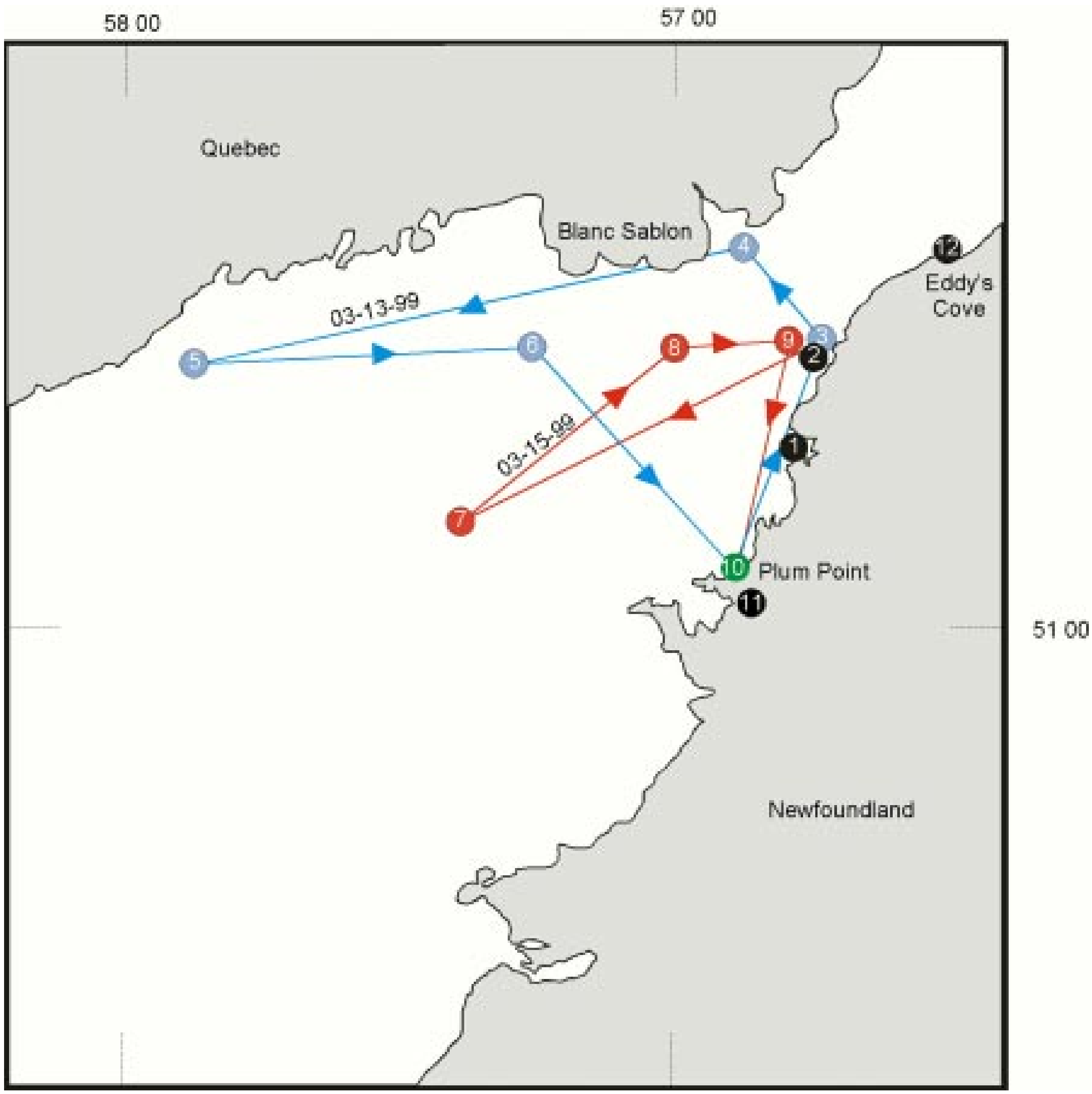

Figure 4-1: Map of the Helicopter Reconnaissance Flight Lines

4.2 Floe Sizes

To estimate floe sizes, "high oblique" photographs (those that include a horizon) were analyzed knowing the altitude of the camera and the focal length of the camera (38mm), using image analysis fundamentals (Estes, 1983). Each picture then provided a floe size distribution for a particular area. Ridge spacing within each floe was estimated when ridges were visible, however individual ridges were often difficult to see, and ridge spacing was generally estimated.

Typical results of this analysis are given in Table 4-2 and Table 4-3. Corresponding photographs are shown in Figure 4-2 and Figure 4-5. The floe count included all identifiable floes larger than about 20 m in the pictures. Their area usually made up more than 50% of the area of the picture. On March 13, overall average floe size was 128m, and average ridge spacing was 81m. The three largest floes ranged from 1500m to 2100m in diameter. On March 15, average floe size was 174m, and ridge spacing was 55m. The three largest floes ranged from 1500 to 2300m. Note that it was sometimes difficult to see if a floe was separate or part of a conglomerate (especially for the floes nearer the horizon).

A total of 17 photos were examined and 425 floes were measured from them. About 100 ridge spacing estimates were done. It is estimated that an identifiable ridge was about 0.5m high.

13-Mar-99		Floe #	Dist. To Horiz. (mm)	Width (mm)	Dist. Between Ridges (mm)	Scale	Floe diameter (m)	Ridge Spacing (m)
Photo #	10	1	65	65	32	3164	206	101
Time =	16:01	2	49	80	40	4197	336	168
Altitude (ft) =	500	3	32	80	80	6427	514	514
Dip Angle (rad) =	0.0064	4	30	34	34	6856	233	233
Dist to Horiz (mm)	34	5	18	130		11426	1485	
Depression angle (rad)	0.7363	6	11	28		18698	524	
		7	36	12		5713	69	
		8	29	24	24	7092	170	170
		9	16	10		12855	129	
		10	61	18		3372	61	
		11	60	18		3428	62	
		12	16	18		12855	231	
		13	15	17		13712	233	
		14	25	13		8227	107	
		15	24	13		8570	111	
		16	29	12		7092	85	
		17	10	19		20567	391	
		18	11	26		18698	486	

Table 4-2: Floe Size Distributions from Photograph 10 (March 13)

15-Mar-99		Floe #	Dist. To Horiz. (mm)	Width (mm)	Dist. Between Ridges (mm)	Scale	Floe diameter (m)	Ridge Spacing (m)
Photo #	3							
Time =	12:18	1	64	27	27	3214	87	87
Altitude (ft) =	500	2	60	38	19	3428	130	65
Dip Angle (radians) =	0.0064	3	51	24		4033	97	
Dist to Horiz (mm)	34	4	45	19	19	4571	87	87
Depression angle (radians)	0.7363	5	70	17	17	2938	50	50
		6	59	18		3486	63	
		7	25	65		8227	535	
		8	22	24		9349	224	
		9	15	60		13712	823	
		10	14	95		14691	1396	
		11	75	12		2742	33	
		12	44	13		4674	61	
		13	54	35		3809	133	
		14	25	19		8227	156	
		15	22	12		9349	112	
		16	19	13		10825	141	
		17	20	9		10284	93	
		18	27	9		7618	69	
		19	26	17		7911	134	
		20	17	13		12099	157	
		21	21	7		9794	69	
		22	20	6		10284	62	
		23	18	10		11426	114	
		24	18	9		11426	103	
		25	21	9		9794	88	
		26	18	7		11426	80	

Table 4-3: Floe Size Distributions from Photograph 3 (March 15)

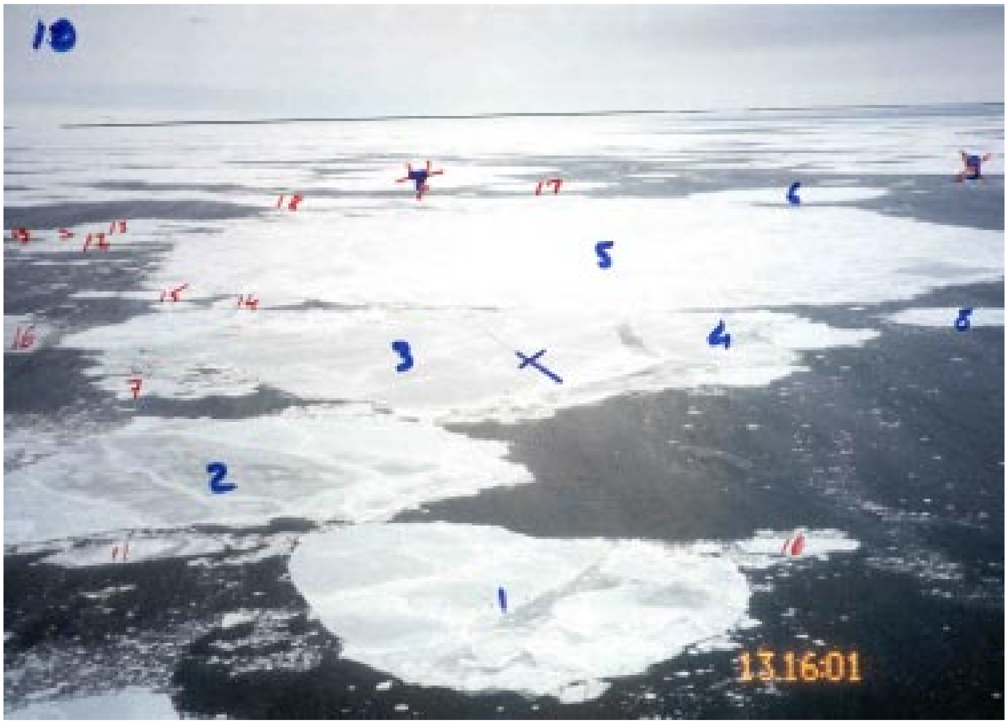

Figure 4-2: Floe Diameters from Oblique Photographs (March 13, Photo 10)

Figure 4-3: Floe Diameters from Oblique Photographs (March 15, Photo 3)

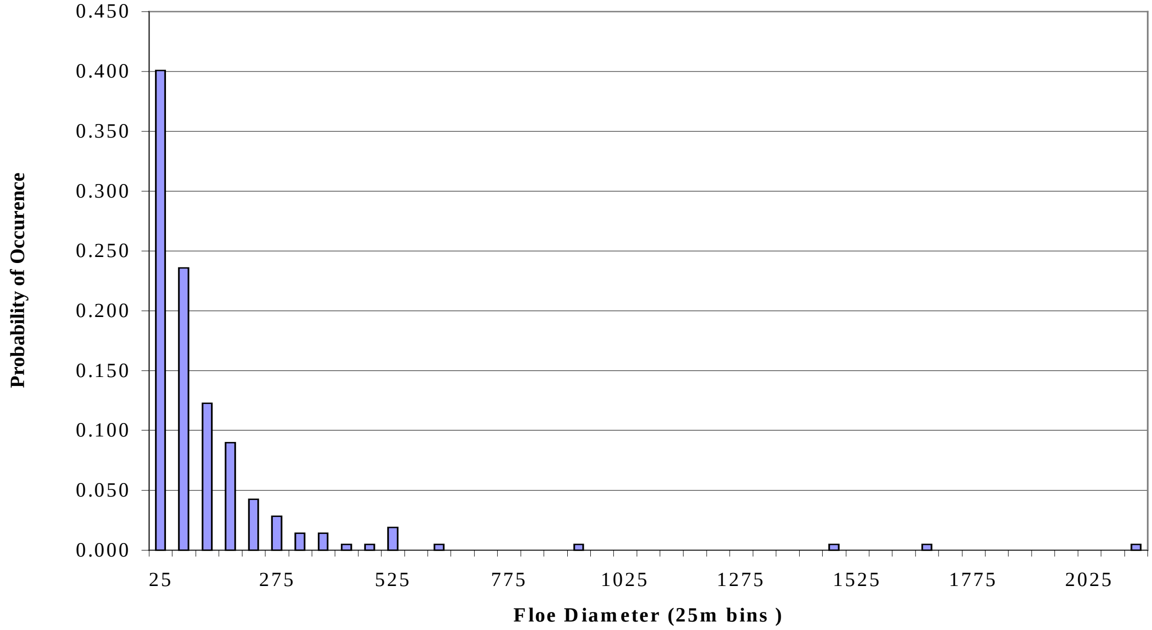

Figure 4-4: Floe Diameter Distribution (March 13)

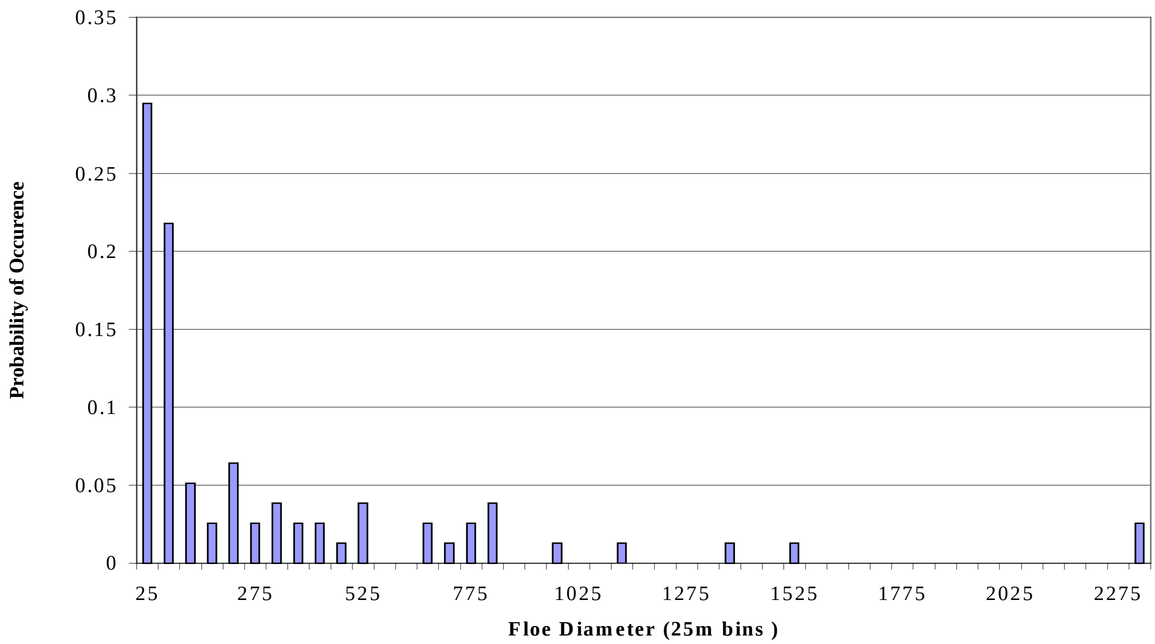

Figure 4-5: Floe Diameter Distribution (March 15)

4.3 Drift Speeds

During the ice reconnaissance of March 13 and March 15, when landing on a floe and taking off, the times and positions were recorded. This allowed calculation of the floe drift speed. Results are shown in Table 4-4. As would be expected, floe drift in this area appeared dominated by tidal currents in the Strait of Belle Isle.

Unfortunately, due to the poor weather conditions, we were not able to acquire sufficient drift speed data to be of much use for design. Also, drift speeds on the South West coast of Newfoundland would be quite different from those near the Strait of Belle Isle.

Date	Site	Landing time	Lat.	Long.	Take-off time	Lat.	Long.	Time diff. (min.).	Distance (nm)	Drift speed (knots)	Direction
13/3/99	4	10:55	51 25.73	56 53.17	11:38	51 24.39	56 56.05	43	2.2	3.07	SW
13/3/99	6	14:00	51 18.76	57 17.77	15:49	51 18.82	57 19.86	109	1.3	0.72	W
15/3/99	7	10:11	51 07.24	57 23.96	12:10	51 07.09	57 24.56	119	0.5	0.25	SW
15/3/99	8	12:50	51 18.98	57 00.76	15:05	51 20.04	56 58.14	135	2.1	0.93	NE
15/3/99	9	15:33	51 19.62	56 48.01	17:08	51 20.46	56 46.53	95	1.7	1.07	NE
									AVG.	1.2	

Table 4-4: Drift Speed Measurements.

4.4 Extreme Ice Features

During aerial surveys, special attention was given to any ice features that might be of concern to offshore structures. However, due to the deteriorated state of the ice cover, and the large amount of open water, these observations may not be representative of normal ice conditions.

Two rubble bergs (solidified mounds of rubble, or stamukha) were seen, but their dimensions were small. Figure 4-6 shows one of these rubble bergs. Its size was estimated at 40m long by 15m wide, with a sail about 3m high.

Many areas of grounded rubble were seen, especially along the Quebec coastline which consists of a lot of shoals and islands. Sites 2, 3 and 5 were some of the grounded rubble areas with the highest ridge sails (3 to 4 m). By chance we were on Site 3 as it was breaking up and floating away (probably due to high tide and waves). In this case, the rubble area broke up under wave action into small pieces (about 20m by 20m, see Figure 4-6). The possibility of lightly grounded rubble areas floating away in larger pieces cannot be ignored.

No icebergs or multi-year ice floes were seen during this Project.

Figure 4-6: Small Rubble Berg, Near Site 7

Figure 4-7: Break-up of Site 3

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5. OBSERVATIONS BY SITE

A total of 12 sites were visited during this field project. Most of the sites were visited only once, but Site 3 (where four pull-up tests were carried out) was visited several times.
The following sections provide all the data obtained at each site. It was decided to include in this report as much of the raw data as possible, in order to allow future readers to re-analyze the raw data in different ways, if they wish.

5.1 Site 1 St. Genevieve Bay (51°09′, 56°52′)

On 9 March 1999, a reconnaissance was performed of the ice along a portion of the coast along the Northern Arm of Newfoundland. For the most part, there was very little landfast ice south of Plum Point. A few small ridges were noted near New Ferolle Point, outside of the bay at Plum Point, but these ridges were not sufficient for detailed analysis. Moving north of Plum Point along the shore, a first year ridge, about 70m long and 2 m high was found and selected as Site 1. A photo of the site is shown in Figure 5-1. The ridge was one of the largest ridges in a large composite floe (about 1.5 km in diameter) apparently attached to the shore near the mouth of St. Genevieve Bay. The next day, high winds from the northeast dislodged this floe and pushed it away offshore. The floe must have been only lightly grounded and not really part of the stable landfast ice. The floe was quite heavily ridged, about half of the area consisting of ridged ice. It is estimated that about 5 other ridges similar to Site 1 could have been found in the floe. The ridge selected was relatively uniform along its length, it did not appear to be grounded, as there were no apparent tidal cracks around it.

The field party landed at Site 1 on the afternoon of March 9, and a survey line was drawn across the center of the ridge. The ice thickness was documented by drilling nine 50 mm auger holes every 5 m along the survey line (Figure 5-2). The profile of the ridge sail was also surveyed at 5 m intervals along Line 1. The results of the ridge survey are shown in Figure 5-3, which shows that the ridge crest was 2.6 m high. The ridge keel was over 8 m thick (the maximum length of auger taken that day) at a distance of 15 m on either side of the ridge crest. Estimated keel depth was about 10m, based on normal sail to keel ratio of 3.96. However, the ridge profile (Figure 5-6) seems to indicate a larger keel depth or a trapezoidal ridge keel shape.

This being a reconnaissance flight, the whole complement of measurement equipment could not be carried, and only some mechanical drilling, surveying and coring were done (no borehole jack or hot point drill).

Figure 5-1: Photograph of Site 1

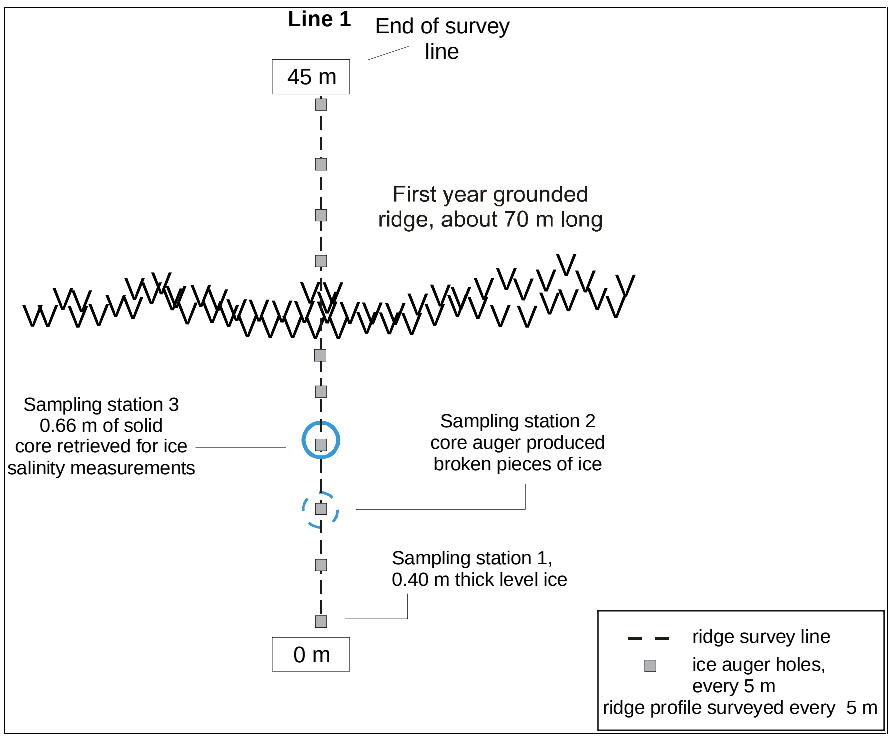


Figure 5-2: Schematic of Site 1

5.1.1 Ridge Surface Profiles

A ridge surface profile perpendicular to the ridge crest, and obtained with the hydraulic survey unit, is shown in Figure 5-3.

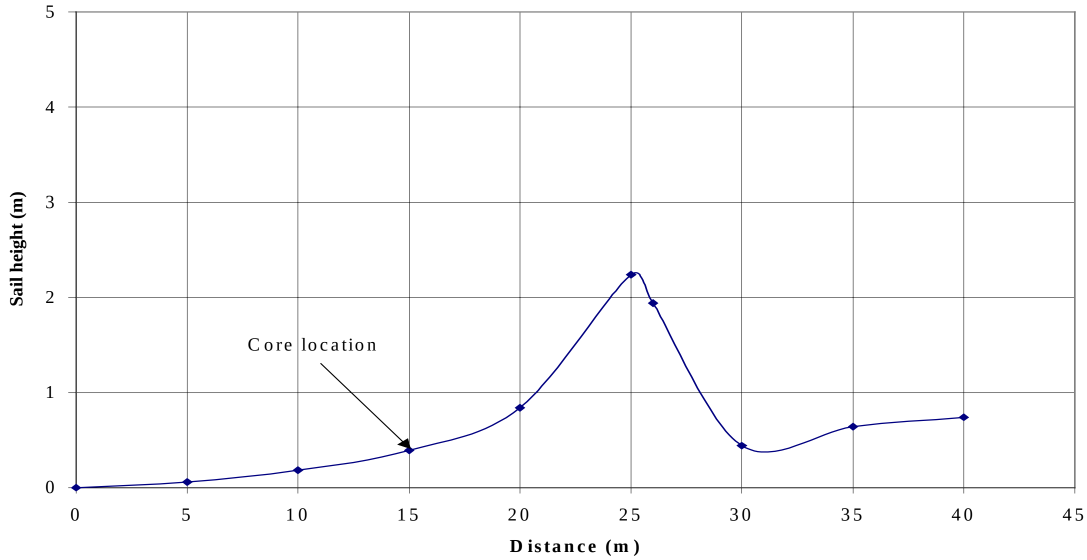


Figure 5-3: Surface Profile of Ridge, Site 1, Line 1

5.1.2 Block Sizes

A total of 27 ice blocks visible at the surface of the ridge sail were measured. These blocks were, quite uniformly, about 0.30 m thick (as shown in Figure 5-4) with some larger tabular ice blocks noted. The length of the blocks was fairly random between 1 and 2m (see Figure 5-5). Details of the ice blocks measurements are given in Table 5-1. The block length averaged 4.9 times the thickness. While the length to width ratio average was 1.57.

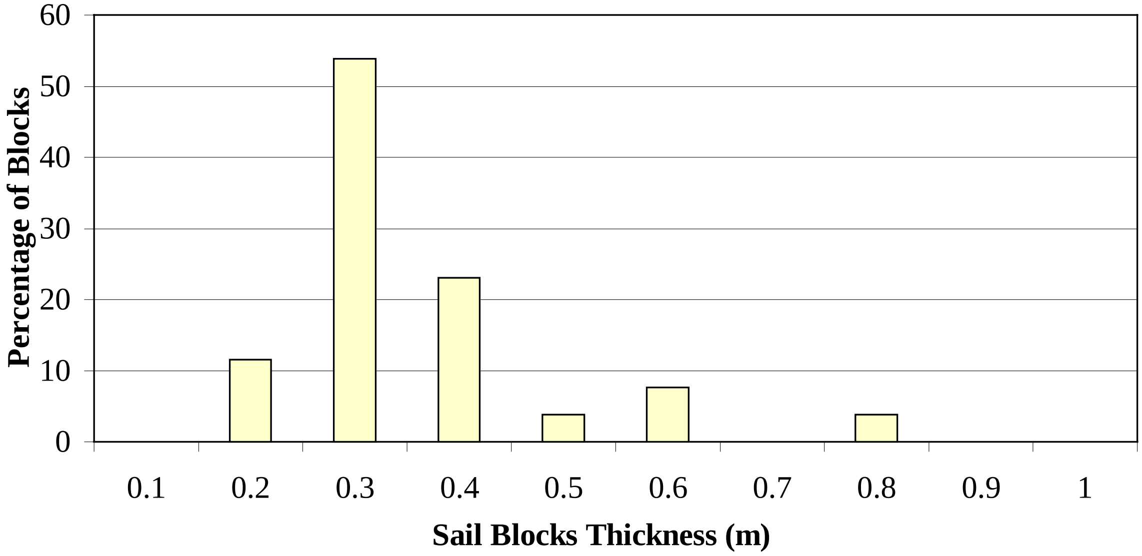


Figure 5-4: Blocks Thickness Distribution, Site 1

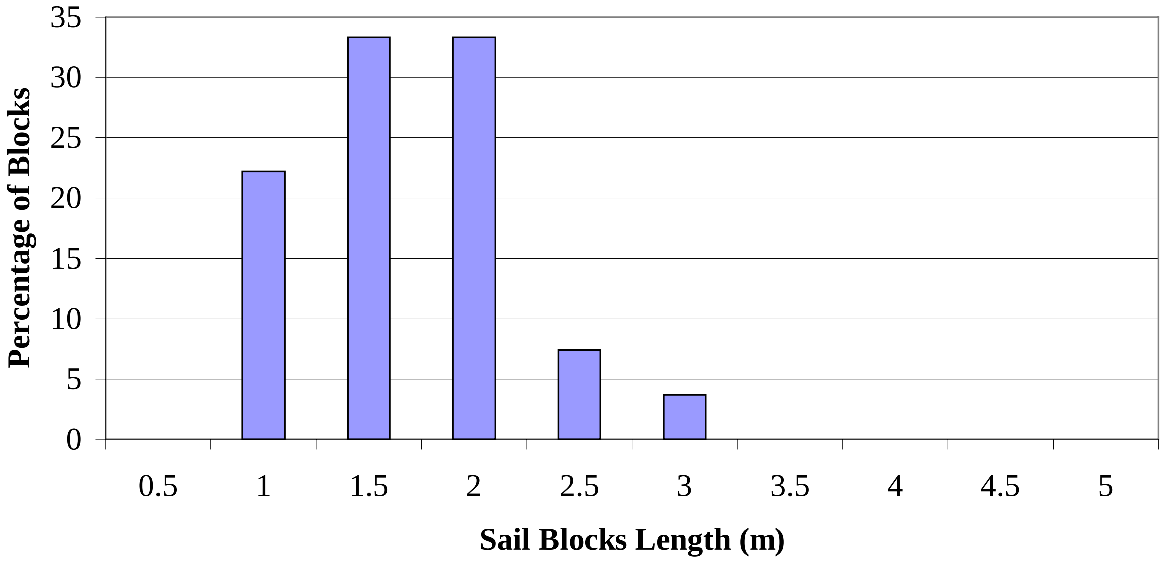


Figure 5-5: Blocks Length Distribution, Site 1

Block #	H (m)	L (m)	W (m)	Block #	H (m)	L (m)	W (m)
1	0.8	2.4	2	16	0.32	1.7	0.85
2	0.64	2.28	1.9	17	0.32	1.38	0.65
3	0.6	1.26	0.96	18	0.32	1.2	1.1
4	0.54	2.03	0.9	19	0.32	1.18	1.0
5	0.4	1.45	1.08	20	0.31	1.53	1.46
6	0.39	1.05	0.82	21	0.3	2.15	1.5
7	0.38	1.84	1	22	0.3	1.88	1.37
8	0.36	2.75	1.64	23	0.3	1.12	1.0
9	0.36	2.0	2.0	24	0.29	2.05	1.53
10	0.35	1.63	1.57	25	0.24	1.33	1.13
11	0.34	1.6	0.53	26	0.23	1.65	0.66
12	0.33	1.93	1.36	27	0.2	1.85	0.58
13	0.33	0.83	0.74	**AVG.**	**0.37**	**1.67**	**1.15**
14	0.33	0.83	0.74		**L/H=**	**4.49**	
15	0.32	2.2	1.08		**L/W=**	**1.57**	

Table 5-1: Sail Blocks Size Measurements, Site 1

5.1.3 Consolidated Layer Data

Mechanical drilling field records are given in Table 5-2 (all data in metres).Note that the drill holes near the ridge sail did not go through the keel, as only 8m of auger were available on this reconnaissance day. In the third hole (S1L1-10), note that no drilling was needed between 2.8 m and 7.5 m, as penetration was by ramming or pushing (the same is true for the last hole S1L1-45). This shows that although there are ice blocks at stations 10 m and 45 m, the blocks are quite porous and weak and can be crushed by the drill tip without drilling. This may indicate that the ridge was in an advanced state of deterioration, due to the warm weather.

Station	**S1L1-0**	**Station**	**S1L1-5**	**Station**	**S1L1-10**	**Station**	**S1L1-15**	**Station**	**S1L1-20**
Snow	0.07	Snow	.03	Snow	.07	Snow	0	Snow	0.04
Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel
.35	H=hard	0.4	H=hard	0.2	H=hard	0.25	H=hard	0.35	H=hard
0.5	V=void	1.0	P=push	0.25	V=void	0.5	S=soft	0.4	S=soft
0.7	H=hard	1.3	V=void	0.6	S=soft	0.7	H=hard	0.5	H=hard
0.7	Bottom	1.8	P=push	0.9	V=void	1.2	V=void	0.8	P=push
		2.5	H=hard	1.0	S=soft	2.0	S=soft	1.0	H=hard
		2.8	V=void	1.5	V=void	No bottom		1.5	S=soft
		3.3	P=push	1.8	H=hard			2.0	S=soft
		3.7	V=void	1.9	V=void			No bottom	
		3.8	P=push	2.4	R=ram				
		3.8	Bottom	2.8	S=soft				
				3.6	P=push				
				4.0	R=ram				
				5.0	R=ram				
				5.2	R=ram				
				5.85	P=push				
				7.5	P=push				
				7.5	Bottom				
Station	**S1L1-30**	**Station**	**S1L1-35**	**Station**	**S1L1-40**	**Station**	**S1L1-45**		
Snow	0	Snow	0	Snow	0	Snow	0		
Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel		
0.8	H=hard	0.4	H=hard	1	H=hard	0.9	H=hard		
1.1	V=void	0.45	V=void	2	P=push	1.2	R=ram		
1.75	H=hard	0.55	H=hard	No bottom		2	P=push		
2	V=void	0.6	V=void			3	R=ram		
No bottom		1	H=hard			8	P=push		
		2	P=push			8	Bottom		
		No bottom							

Table 5-2: Mechanical Drilling Records, Site 1

The resulting estimates of consolidated layer thicknesses (based on the rules set out in 3.2.2) are shown in Table 5-3. The whole data set for the ridge profile at Site 1 is plotted in Figure 5-6.

Horiz. Distance	Sail Height (Ice Surface)	Snow Thickness	Snow Height	Consol. Layer Thickness	Consol. Layer Bottom	Ridge Thickness	Keel Bottom
x (m)	h (m)	s(m)	S (m)	T (m)	C(m)	R (m)	K(m)
0	0.00	0.07	0.07	0.35	-0.35	0.7	-0.70
5	0.06	0.03	0.09	0.4	-0.34	3.8	-3.74
10	0.18	0.07	0.252	0.6	-0.42	7.5	-7.32
15	0.39	0	0.392	0.7	-0.31		
20	0.84	0.04	0.878	0.5	0.34		
25	2.24	0	2.24				
26	1.94	0	1.94				
30	0.44	0	0.44	0.8	-0.36		
35	0.64	0	0.64	0.55	0.09		
40	0.74	0	0.74	1	-0.26		
45	0.74	0	0.74	1.2	-0.46	8	-7.26

Table 5-3: Ridge Profile Data, Site 1

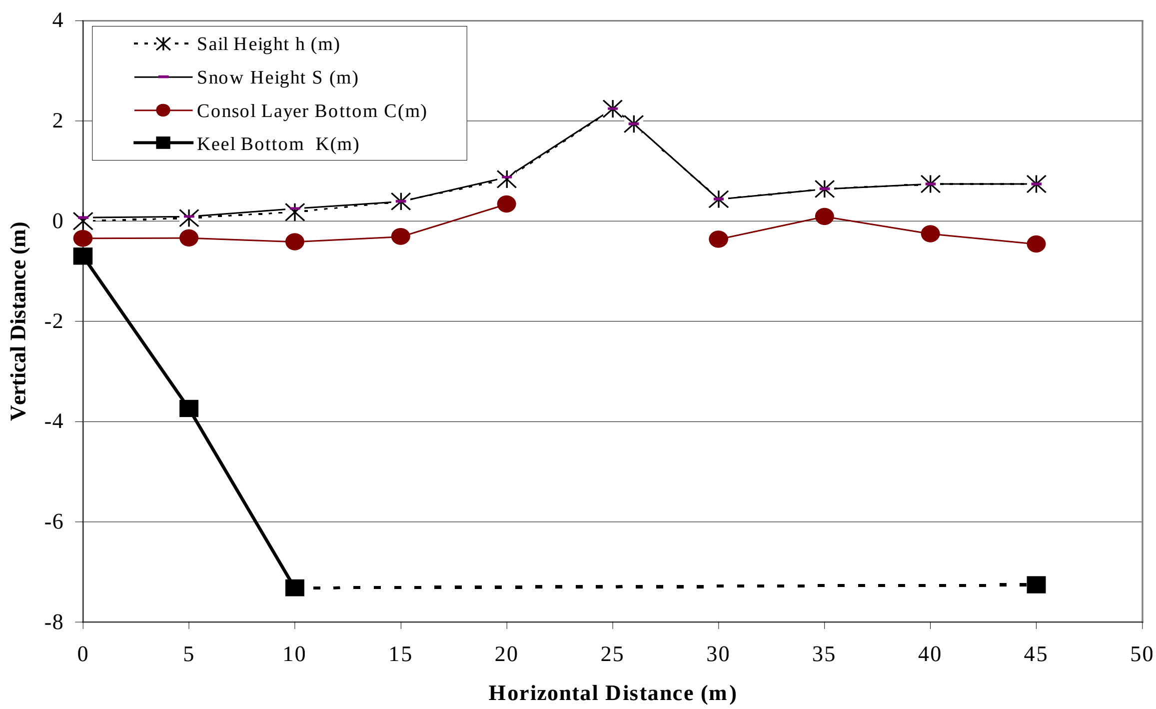


Figure 5-6: Ridge Profile, Site 1

5.1.4 Coring, Temperature and Salinity Profiles

The mechanical core auger was used to extract an ice core 10 m from the start of the survey line, as noted in Figure 5-2. The core that was retrieved from that station consisted of numerous broken pieces of ice. To obtain a less fractured core, a second core was extracted from the 15 m station along the survey line. The second core produced three pieces of ice, with a total length of 0.66 m. The temperature profile of the solid ice fragments (and occasionally slush) was measured. A hand saw was used to section the core fragments into 50 mm sections, which were sealed in individual plastic bags for salinity measurements. The temperature profile and ice sectioning process were performed as quickly as possible to avoid air temperature effects and to minimize brine drainage from the ice. Frequently, the unused portion of the core was returned to the auger hole until it was ready to be sectioned for salinity samples, thereby further minimizing brine drainage. The coring process continued until the full thickness of the ice had been sampled.

After transporting the ice salinity samples from Site 1 to the hotel, the bags were taken from the cooler and the ice was left to melt at room temperature. A calibrated conductivity meter was used to measure the ice salinity. Figure 5-7 shows that the ice salinity of the top 0.66 m of core was between 4 - 5 ppt. The notation of open circles and broken lines used to represent the salinity profile in Figure 5-7 reflects the length of ice core that was melted (for instance 0 - 50 mm, 50 - 100 mm, etc.). Breaks in the line show where the core had fragmented in the core auger.

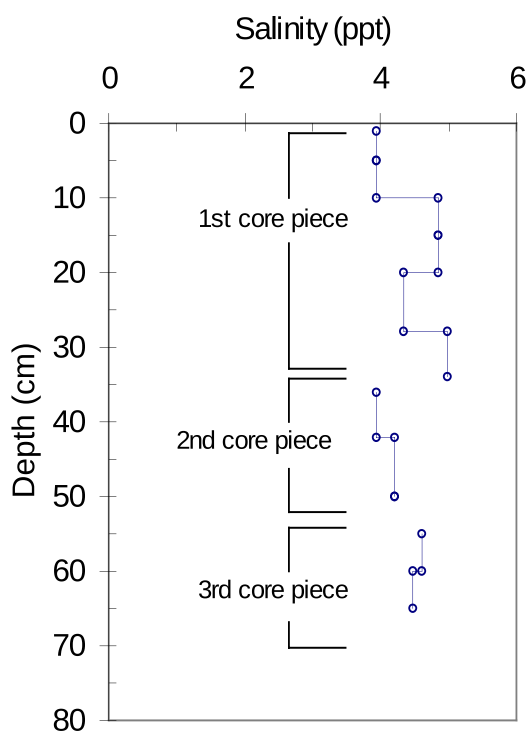


Figure 5-7: Ice Salinity at Site 1

5.2 Site 2 Flowers Cove (51^{o} 18.75, 56^{o} 45.57)

Site 2 was a first year ridge was located in the landfast ice (about 1 km from Anchor Point lighthouse) near Flower's Cove, north of St. Genevieve Bay. The morning of 10 March 1999 was spent sampling the ridge. The weathered appearance of the ridge at Site 2 indicated that it was older than the ridge at Site 1. The ridge topography was measured along three survey lines (Figure 5-8). Although it was not apparent at first sight, the ridge was grounded on a shoal. Water depth at the end of line 1 (S2L1-110) was 1.5m, at a distance of 70m from the ridge crest, and a maximum water depth of 6.8m was measured on the deeper side of the ridge.

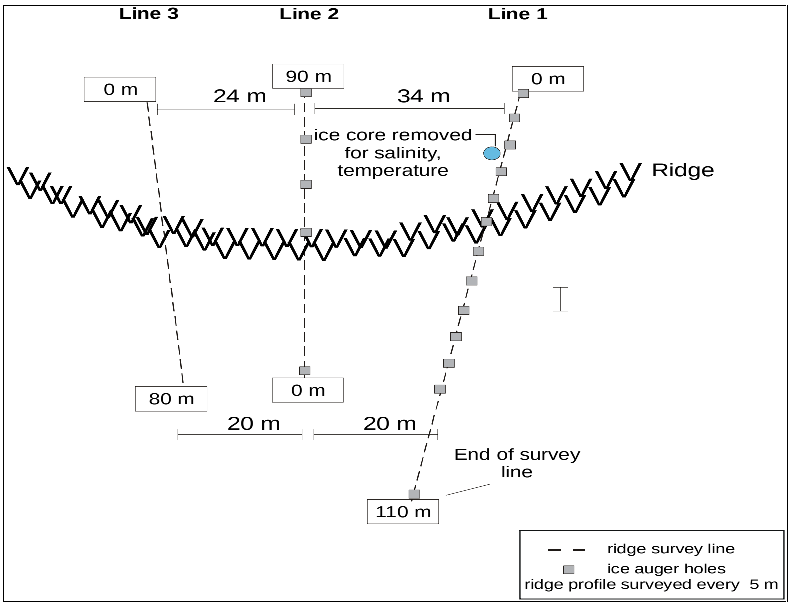


Figure 5-8: Schematic of Site 2

Figure 5-9: Photograph of Site 2

5.2.1 Surface Profiles

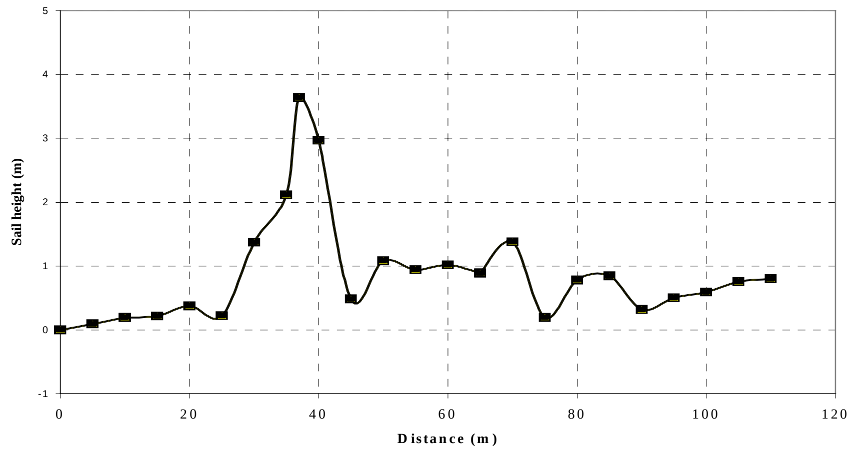


Figure 5-10: Surface Profile of Ridge, Site 2, Line 1

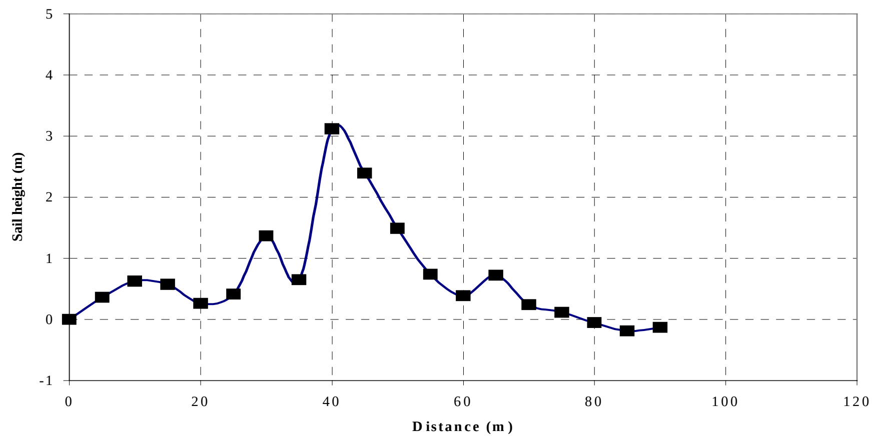


Figure 5-11: Surface Profile of Ridge, Site 2, Line 2

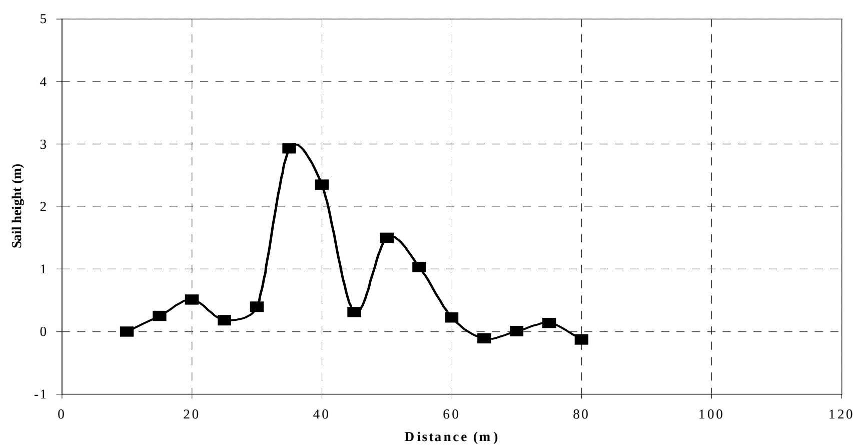


Figure 5-12: Surface Profile of Ridge, Site 2, Line 3

5.2.2 Block Sizes

A total of sixty sail blocks were measured at Site 2. Block size distribution plots are shown in Figure 5-13 and Figure 5-14. Detailed measurements are given in Table 5-4. Blocks are significantly thinner than at Site 1. The size and appearance of the blocks at Site 1 indicate that ridging occurred at the size early in the season (thinner ice blocks) and was followed by rafting of thicker ice later in the season (thicker blocks). The block length distribution has a fairly high peak at 1m, 5 times the block thickness.

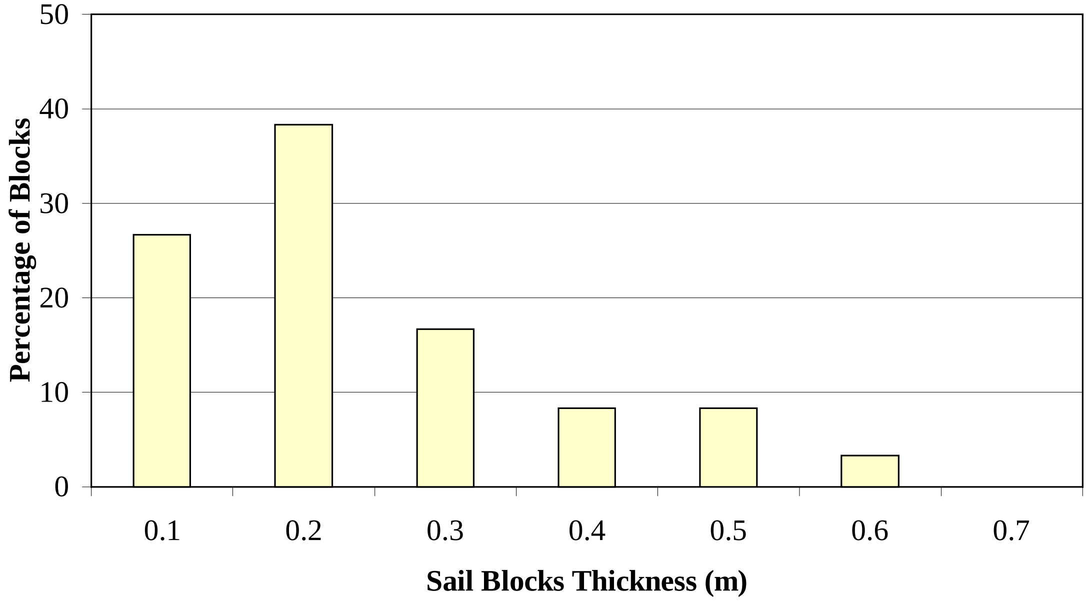


Figure 5-13: Blocks Thickness Distribution, Site 2

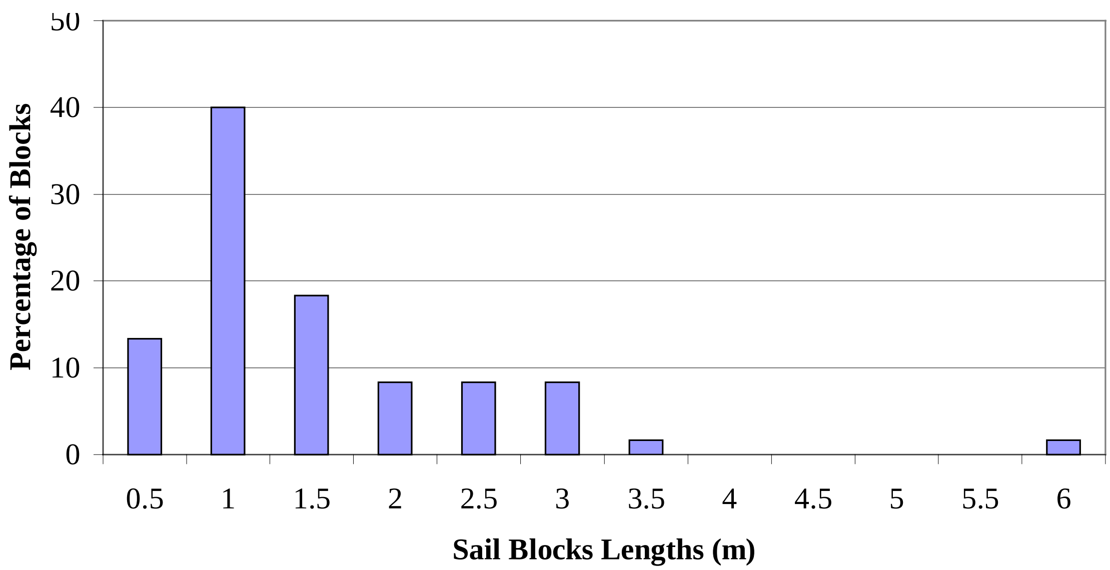


Figure 5-14: Blocks Lengths Distribution, Site 2

Block #	T (m)	L (m)	W (m)	Block #	T (m)	L (m)	W (m)	Block #	T (m)	L (m)	W (m)
1	0.15	0.34	0.33	21	0.15	1	0.8	41	0.19	1.56	1.08
2	0.16	0.56	0.52	22	0.2	1.05	0.82	42	0.34	1.6	1.55
3	0.2	0.56	0.43	23	0.35	1.05	0.95	43	0.2	1.64	1.22
4	0.18	0.57	0.5	24	0.22	1.06	0.82	44	0.43	1.82	1.8
5	0.19	0.66	0.37	25	0.2	1.1	0.38	45	0.52	2	1.28
6	0.1	0.66	0.48	26	0.4	1.1	0.74	46	0.32	2.05	1.64
7	0.16	0.71	0.7	27	0.23	1.1	0.96	47	0.3	2.2	0.75
8	0.05	0.74	0.7	28	0.34	1.17	0.94	48	0.14	2.25	0.72
9	0.09	0.77	0.46	29	0.15	1.2	0.98	49	0.55	2.28	2.15
10	0.29	0.79	0.6	30	0.15	1.23	1.22	50	0.6	2.3	1.28
11	0.23	0.8	0.64	31	0.35	1.23	1.22	51	0.5	2.34	2.2
12	0.19	0.82	0.48	32	0.18	1.25	0.54	52	0.25	2.55	0.8
13	0.18	0.83	0.5	33	0.46	1.26	0.92	53	0.23	2.63	1.64
14	0.15	0.86	0.44	34	0.18	1.3	0.6	54	0.4	2.9	2.5
15	0.16	0.86	0.58	35	0.15	1.36	0.89	55	0.35	2.94	1.4
16	0.09	0.9	0.74	36	0.17	1.4	1.14	56	0.4	3	2.2
17	0.22	0.9	0.64	37	0.1	1.4	1	57	0.61	3.05	2.7
18	0.1	0.95	0.86	38	0.31	1.5	1.17	58	0.14	3.14	1.86
19	0.15	0.96	0.62	39	0.15	1.5	1.43	59	0.46	3.3	2.6
20	0.26	0.96	0.93	40	0.19	1.55	0.97	60	0.43	6.03	4.7
								Avg.	**.25**	**1.53**	**1.10**
								L/T=	**6.7**	**L/W=**	**1.47**

Table 5-4: Sail Blocks Size Measurements, Site 2

5.2.3 Consolidated Layer Data

Field records of auger holes on line 1 are given in Table 5-5. Consolidated layer thickness estimates (where some keel rubble was present) are 0.7m, 0.7m 1.0m, and 1.6m at stations S2L1-10, 15, 20 and 25 respectively. A definite consolidated layer could not be identified for stations S2L1-45 to 110. The resulting data on ridge cross-section is summarized in Figure 5-15.

Station	**S2L1-0**		**S2L1-5**		**S2L1-10**		**S2L1-15**		**S2L1-20**
Snow	0		0		.1		.03		.03
Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel
0.4	Hard	0.5	Hard	0.5	Hard	0.5	Hard	0.4	Soft
Bottom		Bottom		0.7	Soft	0.7	Soft	1.0	Soft
				1.8	Push	1.6	Push	1.75	Push
				2.2	Push	2.0	Hard	1.8	Hard
				3.55	Push	2.5	Hard	2.5	Push
				Bottom		2.6	Void	3.4	Soft
						3.0	Soft	3.9	Push
						4.73	?	Bottom	(toggle)
						Bottom	(toggle)		
Station	**S2L1-25**		**S2L1-45**		**S2L1-55**		**S2L1-65**		**S2L1-110**
Snow	.4		0		0		.1		0
Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel
1.0	Soft	6.2	Hard (with small voids)	4.0	Soft (with small voids)	5.0	Soft	1.5	Hard
1.6	Hard	Ground		6.0	Ram	Ground		Ground	
2.0	Push			Ground					
3.0	Push								
4.0	Ram								
4.5	Push								
Bottom									
Other holes near Station zero		**#1**		**#2**		**#3**			
	Snow	0		0		0			
	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel			
	0.7	Hard	0.9	Hard	0.6	Hard			
	1.5	Push	1.9	Push	2.35	Push			
	Bottom	(toggle	Bottom	(toggle)	Bottom	(toggle			

Table 5-5: Drilling Records, Site 2, Line 1

Field records of auger holes on line 2 are given in Table 5-6.
Note that distances indicated are measured from near the end of line 1.
There was no mechanical drilling on line 3.

Station	S2L2-0		S2L2-90		S2L2-80		S2L2-70		S2L2-60
Snow	0		0		0		0		.15
Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel
1.2	Hard	1.0	Hard	0.6	Hard	0.8	Hard	0.9	Hard
Rock		2.1	Push	Bottom		1.8	Push	5.0	Push
		Bottom		WD=	7.1	Bottom			
		WD=	7.1	FB=	.08	WD=	7.1		
		FB=	.02			Est. FB=	.50		

Table 5-6: Drilling Records, Site 2, Line 2

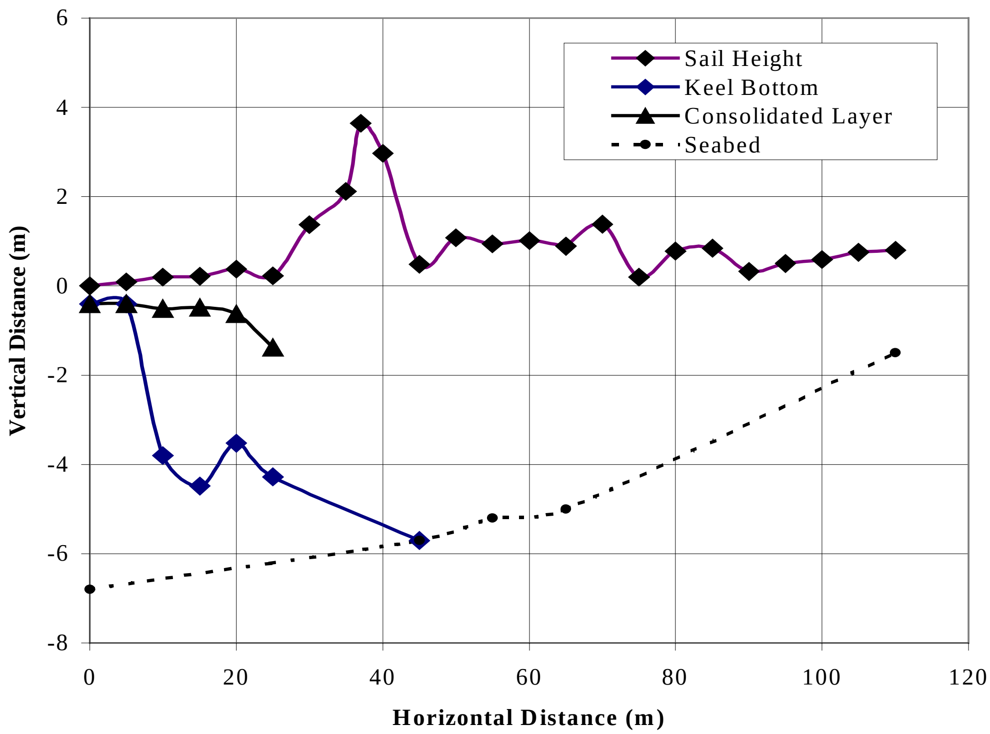


Figure 5-15: Ridge Profile, Site 2, Line 1

5.2.4 Density Measurements

One core sample was taken from the ice for density measurements. This was a first attempt at measuring the ice density and its purpose was to check the methodology. The sample was from near the bottom of a solid ice sheet (-0.5m). The sample was obtained after temperature measurements were made, so that some brine drainage occurred, however the ice appeared quite solid with low porosity, so that brine drainage was probably small.

The results were as follows:
Hygrometer reading: before = 1.028 g/cm^3, after = 1.026 g/cm^3, avg. = 1.027 g/cm^3
Weight water (and beaker) W0=1598 g Volume V0= 1020 cm^3
Weight water + ice core W1=2312 g
Weight core submerged W2 =2395g Volume V2= 1820 cm^3
Core dimensions:
Core diameters D1= 9.56 cm D2 = 9.81cm Davg = 9.685
Core lengths L1=10.55 cm, L2=10.57 cm, L3=10.56 cm, L4=10.57 cm, Lavg=10.56 cm

Densities can be calculated as follows:

1. Core volume
   By submergence V3=1820-1020= 800 cm^3
   By bulk measurement V4= $\pi/4*(9.685^2)*10.5625$= 778 cm^3
2. Density
   By submergence: $\rho_{ice} = \rho_{water}$ -(W2-W1)/(V2-V0) = 1.027 – 83/800 = 0.923 g/cm^3
   By bulk measurements: ρ_{ice} = (W1-W0)/V4= 714/778 = 0.918 g/cm^3

5.2.5 *Temperature and Salinity Profiles*

The core at Site 2 was located near station S2L1-25, near the foot of the ridge sail Ice macrostructure as well as salinity and temperature profiles are shown in Figure 5-16. The relatively high salinity between 0.50 and 0.80 m depth may be due to intrusion of salt water through the tidal cracks.

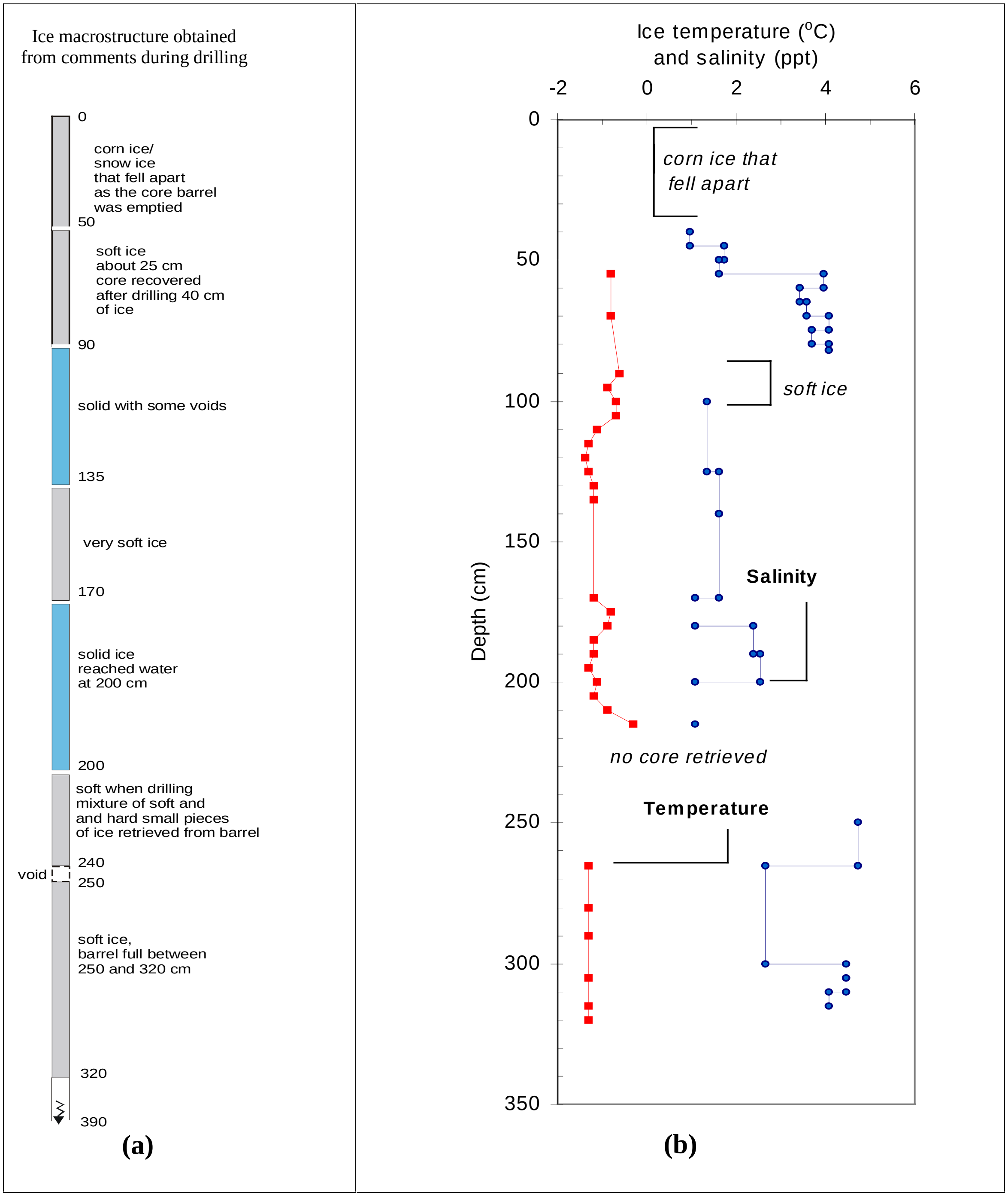


Figure 5-16: Site 2, (a) Ice Macrostructure and (b) Temperature and Salinity Profiles

5.2.6 Hot point Drill Data

Measurements using the AARI hot point drill were carried out on the grounded ice ridge at Site 2 and in the surrounding ice. Figure 5-17 shows a sketch of the Site 2 with hot point hole locations indicated. The tidal cracks appeared to be near station S2L1-30. Seven profiles were obtained, one of which (S2L1-25) is not included because of the large number of noise spikes, which are probably due to tidal cracks. In total, 6 profiles were corrected for glitches, as shown in Figure 5-19. As indicated, these profiles provide cross-sections perpendicular to the sail crest (lateral) and along the sail crest (longitudinal). (Note: refer back to Figure 3.6 for explanation of symbols).

Figure 5-18 shows how the proportion of large voids (as a volume fraction) seems to increase with distance from the ridge peak, while the proportion of small voids is constant. Velocity profiles from the hot point drill indicates that there are fewer voids under the ridge sail, possibly due to the higher compressive stresses in the keel.

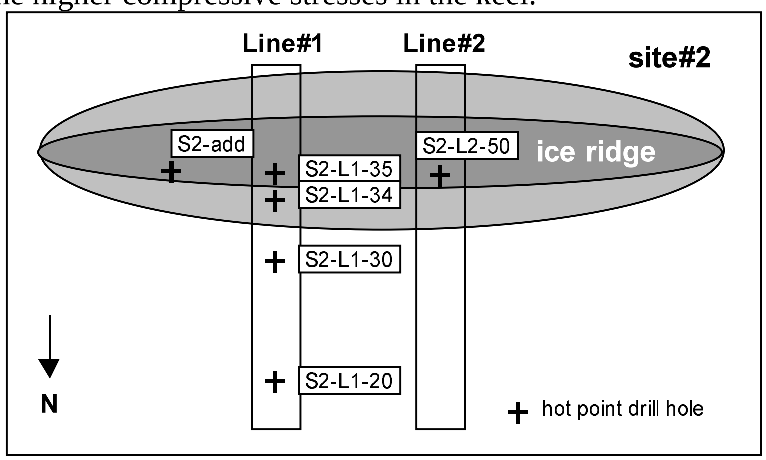


Figure 5-17: Sketch of Hot Point Drill Profile Locations, Site 2

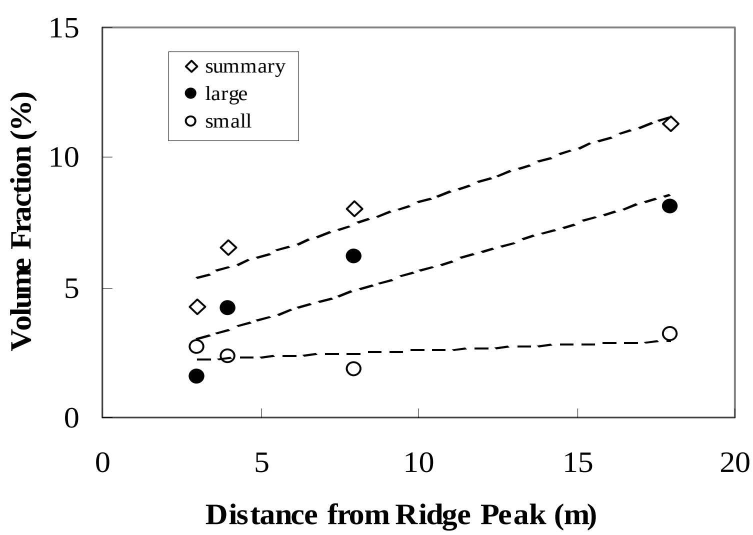


Figure 5-18: Void Ratio vs. Distance from Ridge Peak, Site 2

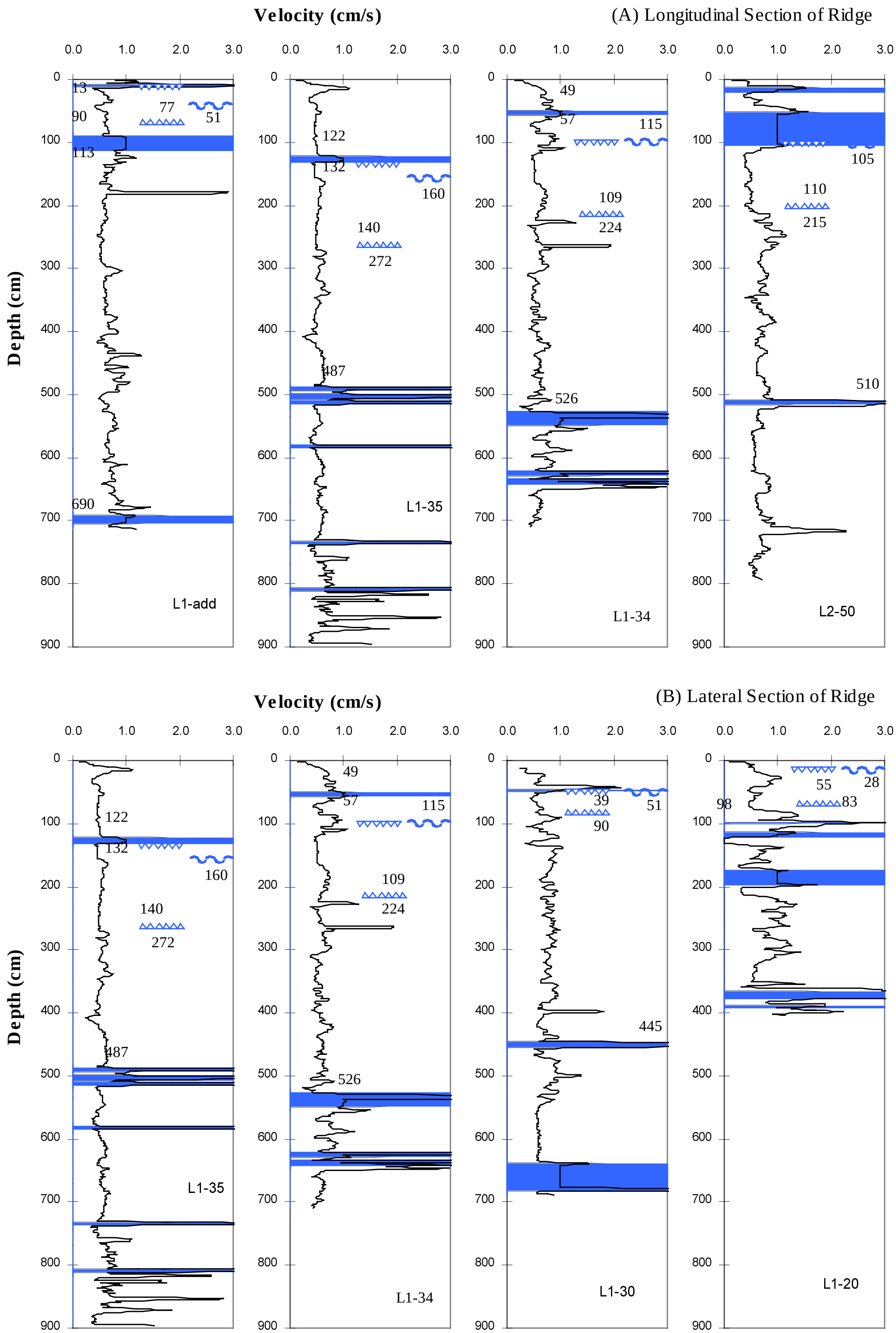


Figure 5-19: Hot Point Drill Profiles, Site 2

From profile S2L1-20, a consolidated layer thickness of about 1m may be estimated, which compares well with auger drilling. The other velocity profiles are near the ridge crest, with larger freeboards. The profiles all have a common characteristic (different from S2L1-20) in that they show a relatively constant drill rate through the whole ridge, with few small cavities, until the very bottom of the profile. This tends to indicate a highly compressed low porosity mass, due to the stresses associated with the formation of a grounded rubble pile. The profile at S2l1-20, away from the sail shows more drill rate variability and higher drill rates corresponding to a less compacted ridge keel.

The measurements of freeboard height were not carried out on this day because of failure of the water level indicator (however freeboard is available from the level survey). By evening the malfunction was repaired, and after that the water level indicator worked well.

Measurements of drill power were recorded during drilling. Figure 5-20 shows a summary of the drill power changes (in percent relative to initial power). Generally during drilling the power changes were less than 2%. The average and standard deviation of the power changes are 0.51% and 1.18% respectively. An increase of power of about 4 % occurs close to the moment of heater failure. A reduction of power by 1% occurred when other equipment was connected to the generator. Note that there is a tendency for drill power to increase with depth. However this increase is not more than 1 percent.

In later hot point drilling, the power measurements were recorded at the start of each profile. These data were written to a field book. Time and date of heater replacements were also recorded.

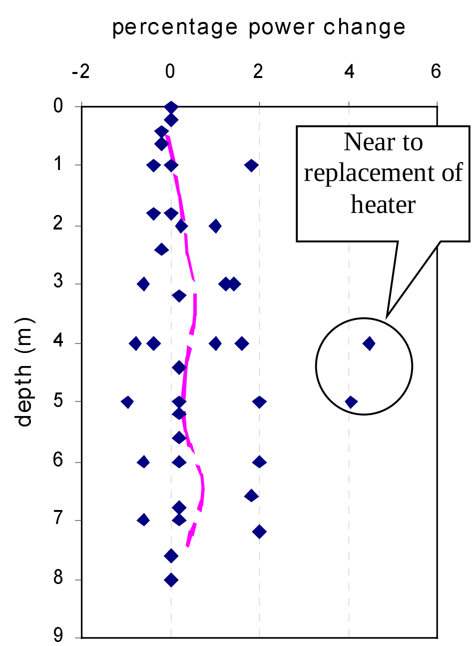


Figure 5-20: Summary Power Change Profile, Site 2

5.3 Site 3 Flower's Cove (51^o 18.77, 56^o 45.44)

A first year ice ridge in Flower's Cove was selected as Site 3 (about 1 km from Site 2). Site 3 had the advantage of being accessible on foot, if flying was not possible. Site 3 was examined on four different days (11, 14, 15 and 16 March), allowing an extensive amount of work to be done on that site. The ridge at Site 3 was grounded on a shoal (in about 5.5 m of water) and had a large (15 m x 15 m) slab of smooth ice to the north (selected for pull-up tests). Figure 5-21 shows Site 3 and the four large ice blocks (about 1 m thick) that were excavated from the ridge. All information related to these pull-up blocks is documented in Volume 2 (a separate volume).

Figure 5-22 presents a schematic of Site 3. Two survey lines were drawn to determine the surface profile of the ridge, as shown in Figure 5-24 and Figure 5-25. Profiles of the keel were obtained from auger holes and hot point drill profiles. The dimensions of 39 ice blocks in the sail were measured. Temperature, salinity (Figure 5-30) and density measurements were made on ice cores from two stations, Station 65 and Station 70 (shown in Figure 5-22). Borehole jack tests were also performed at these two locations.

Figure 5-21: General View of Ridge, Site 3

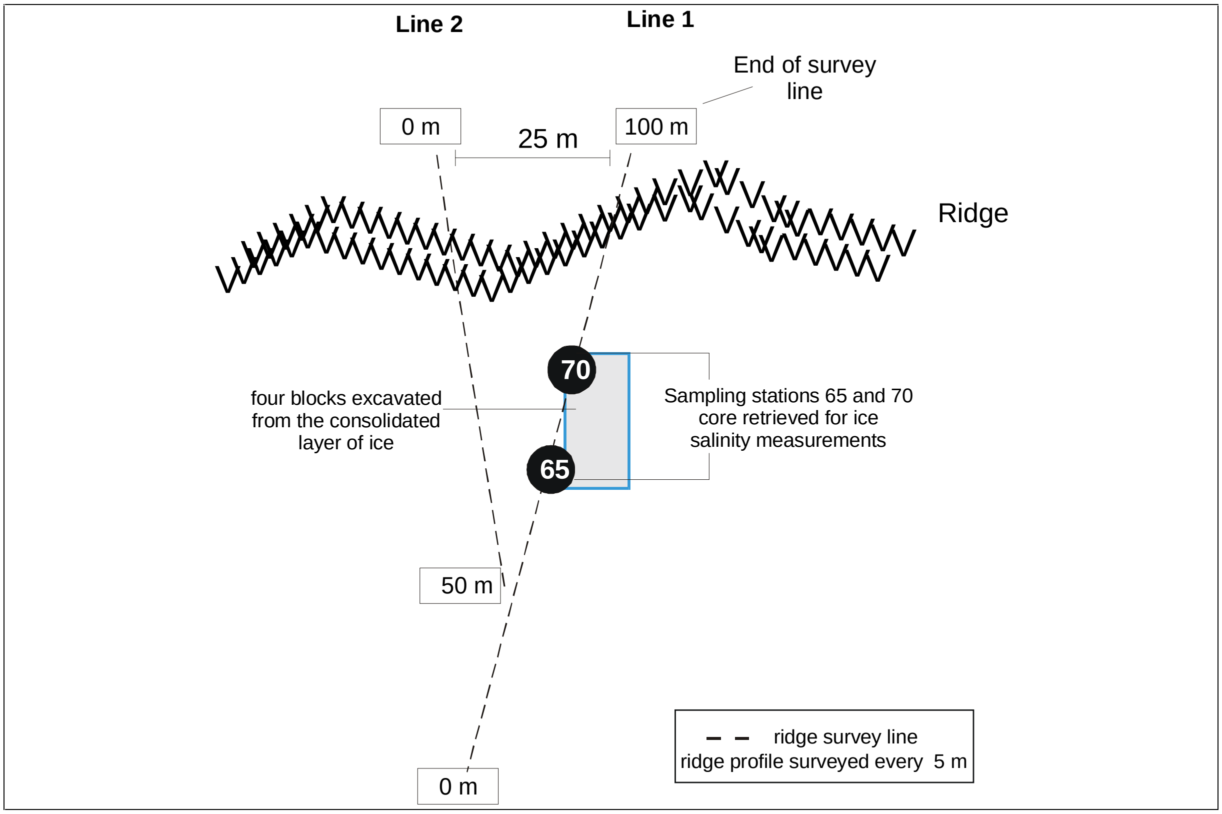


Figure 5-22: Schematic of Site 3

Figure 5-23: View of Hot Point Drill Location Relative to Pull Up Test Line, Site 3

5.3.1 Surface Profiles

Two lines were surveyed at Site 3, as shown in Figure 5-22. Maximum ridge height above sea level was 3.8m.

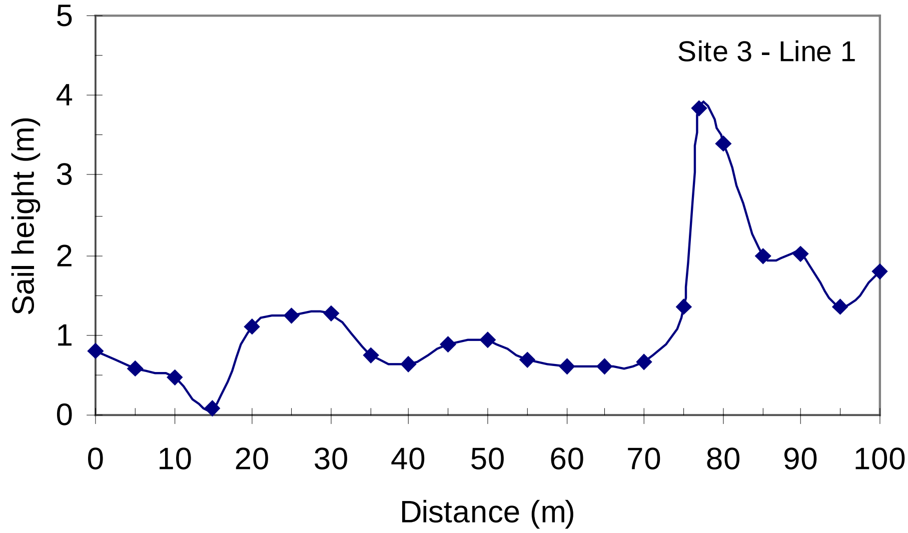


Figure 5-24: Surface Profile, Site 3, Line 1

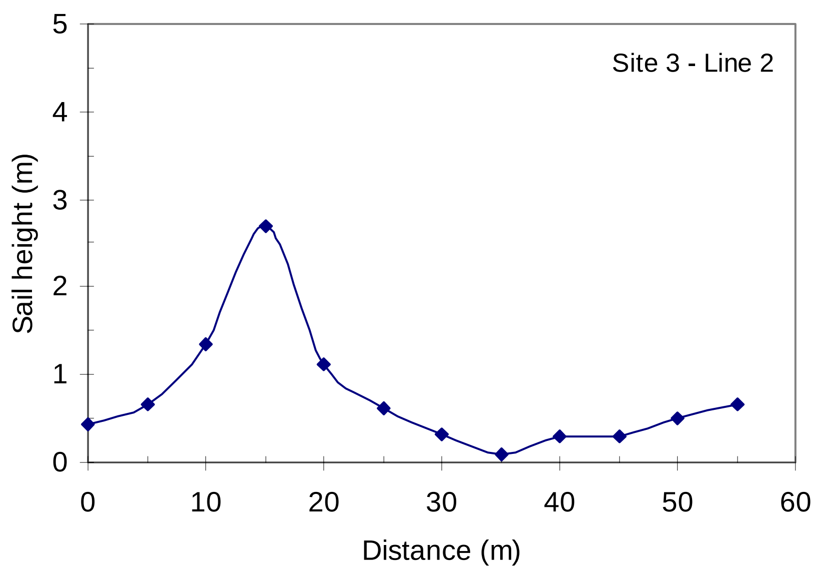


Figure 5-25: Surface Profile, Site 3, Line 2

5.3.2 Block Sizes

A total of 39 blocks were measured at Site 3. Thickness and length distributions are shown in Figure 5-26 and Figure 5-27. Most blocks were close to 0.3m thick, indicating that the ridge most likely formed during one single event with one dominant ice thickness. Typically, block lengths are more randomly distributed than block thicknesses and range from 1m to 2 m. Details of the block measurements are given in Table 5-7.

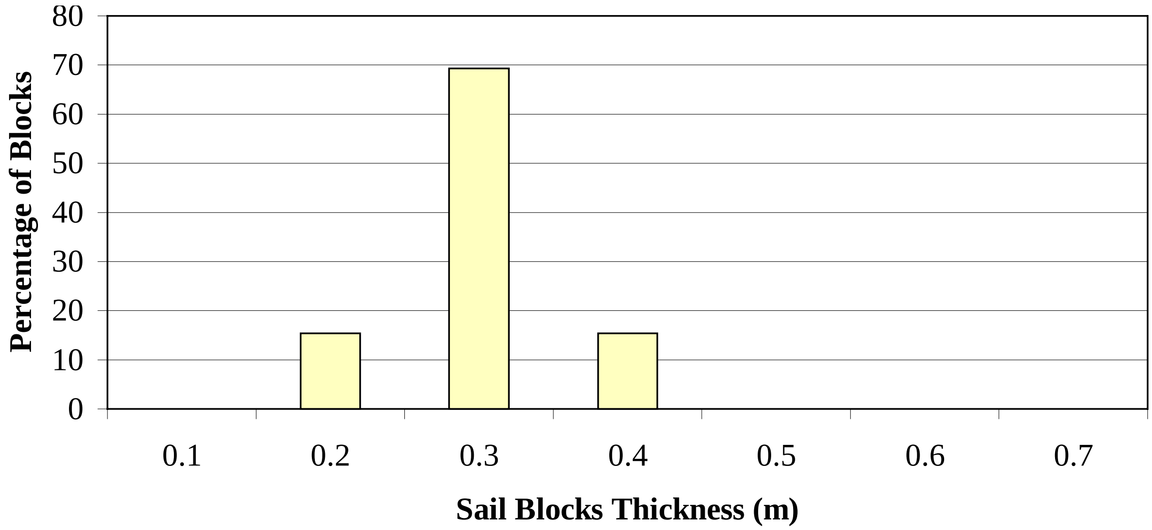


Figure 5-26: Blocks Thickness Distribution, Site 3

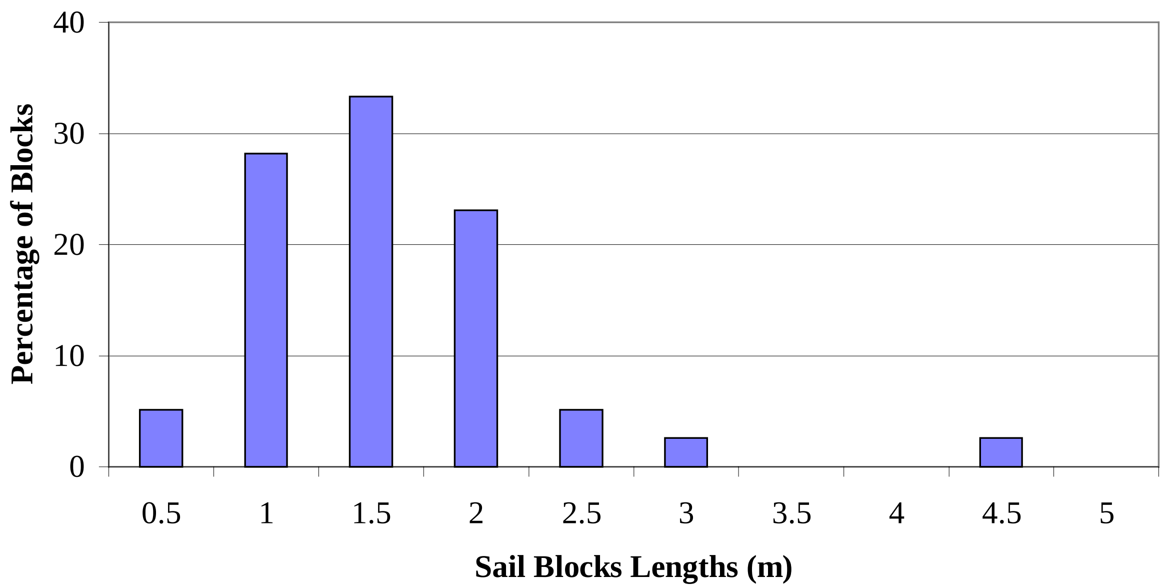


Figure 5-27: Blocks Lengths Distribution, Site 3

Block #	T (m)	L (m)	W (m)	Block #	T (m)	L (m)	W (m)	Block #	T (m)	L (m)	W (m)
1	0.2	1.2	0.7	14	0.3	0.9	0.7	27	0.33	1.5	1.3
2	0.2	0.6	0.3	15	0.3	0.9	0.7	28	0.35	2.0	1.6
3	0.25	1.0	0.6	16	0.3	1.7	1.1	29	0.35	2.0	1.1
4	0.25	0.7	0.5	17	0.3	1.6	1.1	30	0.35	1.9	1.7
5	0.25	1.5	1.2	18	0.3	0.8	0.8	31	0.35	4.5	3.0
6	0.25	1.6	1.4	19	0.3	1.1	0.6	32	0.35	1.4	0.8
7	0.27	0.9	0.6	20	0.3	2	1.5	33	0.35	2.0	1.4
8	0.28	1.1	0.9	21	0.3	1.6	1.8	34	0.37	1.6	1.2
9	0.3	1.4	1.1	22	0.3	1	0.7	35	0.4	2.1	1.4
10	0.3	1.6	1.1	23	0.3	2.9	1.7	36	0.4	2.1	1.6
11	0.3	1.6	0.7	24	0.3	1.4	1	37	0.4	2.1	1.6
12	0.3	1.5	1.1	25	0.3	1.2	0.9	38	0.4	2.2	1.8
13	0.3	1.2	0.6	26	0.3	2.3	1.6	39	0.45	2.5	2.1
								Avg.	**0.31**	**1.62**	**1.17**
								L/T=	**5.12**	**L/W=**	**1.44**

Table 5-7: Sail Blocks Size Measurements, Site 3

5.3.3 Consolidated layer data

Since detailed ridge cross sections were obtained by the hot point drill, mechanical augering was limited to a few holes on line 1, which could be compared with the hot point drill data. Auger holes 70(1) and 70(2) were at a distance of 0.5 and 0.7m respectively from hot point drill profile S3L1-70, to which they should be compared (see Section 6.8). Consolidated layer thickness at these locations is estimated at 1.8m and 0.95. Consolidated layer thickness estimate at S3L1-60 and 65 is 0.9m.

Station	**S3-L1-70 (1)**		**S3-L1-70 (2)**		**S3-L1-65**		**S3-L1-60**
Snow	.30	Snow	.30	Snow	0	Snow	0
Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel
0.9	Hard	0.1	Hard	0.9	Hard	0.9	Hard
1.0	Void	0.15	Void	1.1	Void	1.55	Void
1.8	Hard	0.95	Hard	1.4	Soft	2.0	Soft
2.0	Push	1.25	Void	1.5	Void	2.9	Soft
2.4	Void	1.95	Soft	1.9	Soft	3.2	Void
2.7	Soft	2.10	Void	2.0	Push	3.5	Soft
3.3	Void	2.20	Soft			4.	Void
3.5	Soft	2.6	Void			4.7	Soft
4.9	Soft	3.0	Soft			Bottom	
Bottom		3.3	Void				
		3.4	Soft				
		4.1	Void				
		4.8	Soft				
		5.0	Soft				
		Bottom					
Void ratio	.2		.38		.15		.31

Table 5-8: Mechanical Drilling Data, Site 3

5.3.4 Density Measurements

Densities at Site 3 were measured on three different days. On March 11, 36 density measurements were done on two cores extracted from Station S3L1-70. The density measurements were done on “drained” samples (i.e. samples that had been out of the water for several minutes) which had been used for temperature measurements. Results of these measurements are shown in Table 5-9. It is interesting to note that for the core at station S3L1-70 there is a clear drop in bulk buoyancy at the –1.17m level. This level also corresponds to the bottom of the consolidated layer (based on auger and borehole jack tests). At station S3L1-65, the drop in buoyancy is at the -0.85m level, which also corresponds to the bottom of the consolidated layer based on auger data at that station (0.9m).

sample #	depth (m)	W0 Weight (g)	W1 Weight (g)	W2 Weight (g)	V1 Volume (cm3)	V2 Volume (cm3)	dw Hygro meter	B2 Buoyancy Force (g)	V3, Bulk Volume (cm3)	V, Sample Volume (cm3)	Bulk Density (g/cm3)	Submerged Density (g/cm3)	Bulk Buoyancy (g/cm3)
		Water only	Water + ice	Block under water	Block under water	no ice	Water density	W2-W1	from Length & Diameter	V1-V2	(W1-W0)/V3	dw-B2/V	B2/V3
core at Station S3L1-70													
2	-0.42	1568	2077	2170	1590	930	1.025	93	693	660	0.734	0.884	0.134
3	-0.55	1622	2192	2300	1725	1030	1.025	108	670	695	0.851	0.870	0.161
4	-0.67	1597	2118	2214	1670	1030	1.026	96	592	640	0.880	0.876	0.162
5	-0.89	1585	2100	2202	1625	1000	1.026	102	598	625	0.862	0.863	0.171
6	-1.01	1579	2187	2292	1720	995	1.026	105	705	725	0.863	0.881	0.149
7	-1.17	1569	2008	2080	1517	970	1.026	72	567	547	0.774	0.894	0.127
8	-1.35	1759	2350	2438	1870	1180	1.026	88	782	690	0.755	0.898	0.112
9	-1.5	1754	2123	2174	1600	1380	1.026	51		220		0.794	
10	-1.85	1749	2333	2410	1835	1180	1.026	77	683	655	0.855	0.908	0.113
11	-2	1746	2392	2477	1900	1370	1.026	85	721	530	0.896	0.866	0.118
12	-2.42	1735	2076	2116	1555	1170	1.026	40	412	385	0.828	0.922	0.097
13	-2.5	1721	2346	2451	1890	1140	1.026	105	730	750	0.856	0.886	0.144
14	-2.7	1695	2193	2294	1700	1120	1.026	101		580		0.852	
15	-2.97	1686	2178	2250	1680	1090	1.026	72	563	590	0.874	0.904	0.128
16	-3.36	1654	1841	1869	1300	1080	1.026	28		220		0.899	
17	-3.64	1650	2194	2280	1715	1060	1.026	86	716	655	0.760	0.895	0.120
										avg.	**0.830**	**0.881**	**0.134**
										stdev	**0.054**	**0.030**	**0.022**
core at station S3L1-65													
1	-0.05	1626	2215	2338	1775	1050	1.026	123	704	725	0.837	0.856	0.175
2	-0.25	1612	2209	2328	1775	1030	1.025	119	714	745	0.836	0.865	0.167
3	-0.45	1598	2182	2298	1730	1010	1.025	116	690	720	0.846	0.864	0.168
4	-0.65	1591	2225	2350	1790	1010	1.025	125	757	780	0.838	0.865	0.165
5	-0.85	1594	2156	2230	1675	1000	1.025	74	683	675	0.822	0.915	0.108
6	-1.05	1562	2186	2251	1700	1000	1.024	65	687	700	0.908	0.931	0.095
7	-1.25	1691	2189	2245	1690	1125	1.023	56	561	565	0.887	0.924	0.100
8	-1.45	1687	2277	2342	1790	1120	1.022	65	682	670	0.865	0.925	0.095
9	-1.65	1768	2219	2280	1710	1200	1.022	61	542	510	0.832	0.902	0.113
10	-1.85	1742	2336	2403	1845	1180	1.022	67	678	665	0.876	0.921	0.099
11	-2.05	1734	2338	2407	1850	1175	1.022	69	689	675	0.877	0.920	0.100
12	-2.25	1727	2357	2434	1875	1170	1.022	77	722	705	0.872	0.913	0.107
13	-2.45	1719	2414	2497	1940	1160	1.022	83	788	780	0.882	0.916	0.105
14	-2.65	1709	2373	2441	1890	1150	1.022	68	732	740	0.907	0.930	0.093
15	-2.85	1705	2309	2377	1815	1140	1.022	68	680	675	0.888	0.921	0.100
16	-3.05	1696	2317	2390	1830	1130	1.022	73	709	700	0.876	0.918	0.103
17	-3.25	1745	2348	2428	1870	1175	1.022	80	695	695	0.868	0.907	0.115
18	-3.45	1741	2281	2356	1790	1170	1.022	75		620		0.901	
19	-3.65	1733	2352	2452	1880	1125	1.022	100	775	755	0.799	0.890	0.129
										avg.	**0.862**	**0.904**	**0.119**
										stdev	**0.030**	**0.024**	**0.029**

Table 5-9: Drained Densities at Site 3

On March 14 and 15, 27 density measurements were done on “undrained” samples, taking care to do the measurements without lifting the sample out of the water, or doing it very quickly (less than 1 second) when necessary. Results are shown in Table 5-10.

Note that as expected the drained densities are lower (by 3%) than the undrained densities. There is also a fairly clear tendency for the specific buoyancy of the ice samples to decrease with depth as shown in Figure 5-28. This could also be interpreted as a relatively high buoyancy near the surface and a lower (but fairly constant) buoyancy below.

Sample #	Depth m	W0 Weight of water (g)	W1 Weight of water +ice block (g)	W2 Weight (block under water) (g)	V1 volume (block under water) (cm3)	V2 volume (no ice) (cm3)	weight block (+bag)	dw Hygro meter water density	B2 Buoyancy Force (g)	V Volume of ice sample (cm3)	W Weight of ice sample (g)	Ice sample density (g/cm3)	Ice sample density (g/cm3)	Ice sample buoyancy (g/cm3)
									W2-W1	**V1-V2**	**W1-W0**	**W/V**	**dw-B2/V**	**B2/V**
core at SW corner of block 1														
1	0.395	1734	2335		1870	1165	601	1.023		705	601	0.852		
2	0.445	1846	2354		1865	1270	512	1.023		595	508	0.854		
3	0.52	1894	2281	2348	1770	1305	397	1.023	67	465	387	0.832	0.879	0.144
4	0.62	1882	2446	2545	1980	1315	570	1.023	99	665	564	0.848	0.874	0.149
5	0.72	1500	2161	2264	1685	920	662	1.023	103	765	661	0.864	0.888	0.135
6	0.82	1496	2090	2162	1580	920	600	1.023	72	660	594	0.900	0.914	0.109
7	0.895				1985	1105	891	1.023		880				
8	0.945	1481	2434	2560	1970	905	954	1.023	126	1065	953	0.895	0.905	0.118
9	0.995	1909	2548	2603	2025	1400	565	1.023	55	625	639	1.022	0.935	0.088
10	1.045	1886	2502	2561	1980	1305	621		59	675	616	0.913	0.936	0.087
											avg.	**0.887**	**0.904**	**0.119**
											stdev	**0.058**	**0.025**	**0.025**
core at SE corner of block 1														
1	-1.72	2013	2471	2527	1900	1405	467	1.023	56	495	458	0.925	0.910	0.113
2		1847	2394	2458	1820	1230	553	1.023	64	590	547	0.927	0.915	0.108
3		1891	2298	2337	1720	1290	419	1.023	39	430	407	0.947	0.932	0.091
4		1859	2500	2625	1960	1240	643	1.023	125	720	641	0.890	0.849	0.174
5		2003	2476	2525	1940	1400	485	1.023	49	540	473	0.876	0.932	0.091
6	-1.92	1953	2477	2524	1915	1340	534	1.023	47	575	524	0.911	0.941	0.082
7		1955	2114	2127	1510	1345	167	1.023	13	165	159	0.964	0.944	0.079
8	-2.26	1719	2095	2131	1510	1105	382	1.023	36	405	376	0.928	0.934	0.089
9	-2.39	1724	1843	1855	1240	1105	124	1.024	12	135	119	0.881	0.934	0.089
10	1.84	1805	2214	2280	1640	1190	420	1.024	66	450	409	0.909	0.877	0.147
11		1808	2392	2450	1840	1210	591	1.024	58	630	584	0.927	0.932	0.092
12	2.8	1824	2398	2452	1875	1220	583	1.024	54	655	574	0.876	0.942	0.082
13		1846	2416	2491	1880	1245	578	1.024	75	635	570	0.898	0.906	0.118
14		2019	2376	2407	1800	1415	369	1.024	31	385	357	0.927	0.943	0.081
Igor1		1744	1897	1923	1305	1125	161	1.024	26	180	153	0.850	0.880	0.144
Igor 2		1759	1918	1943	1340	1150	167		25	190	159	0.837	0.892	0.132
											avg.	**0.905**	**0.917**	**0.107**
											stdev	**0.039**	**0.027**	**0.027**

Table 5-10: Undrained Densities at Site 3

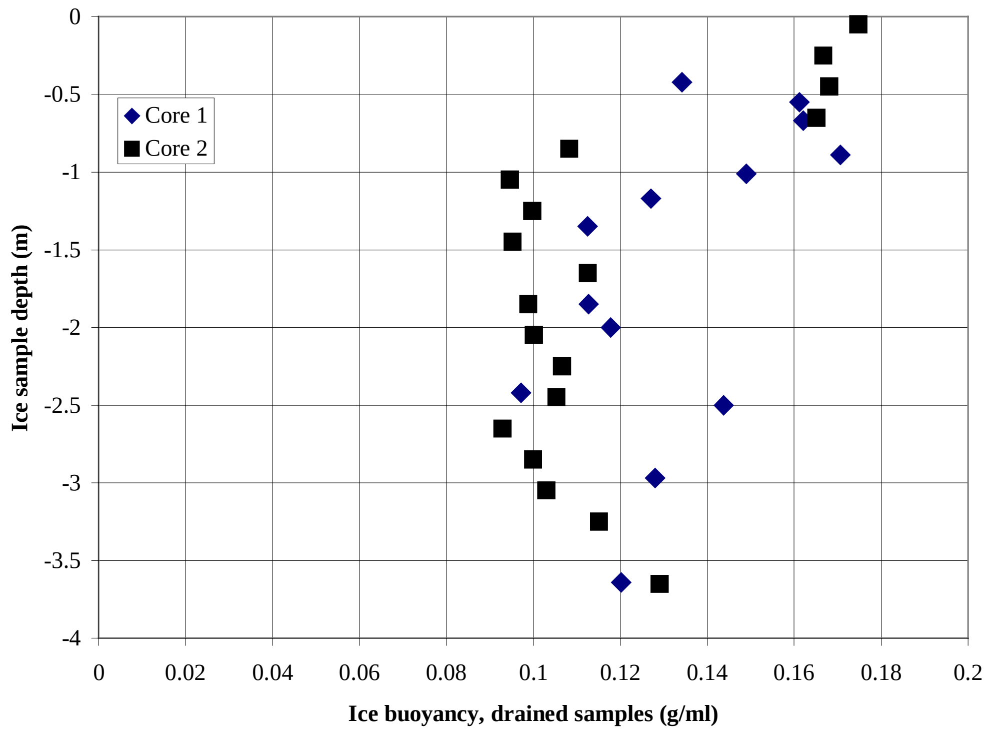


Figure 5-28: Specific Buoyancy, Drained Samples, Site 3, Cores 1 & 2

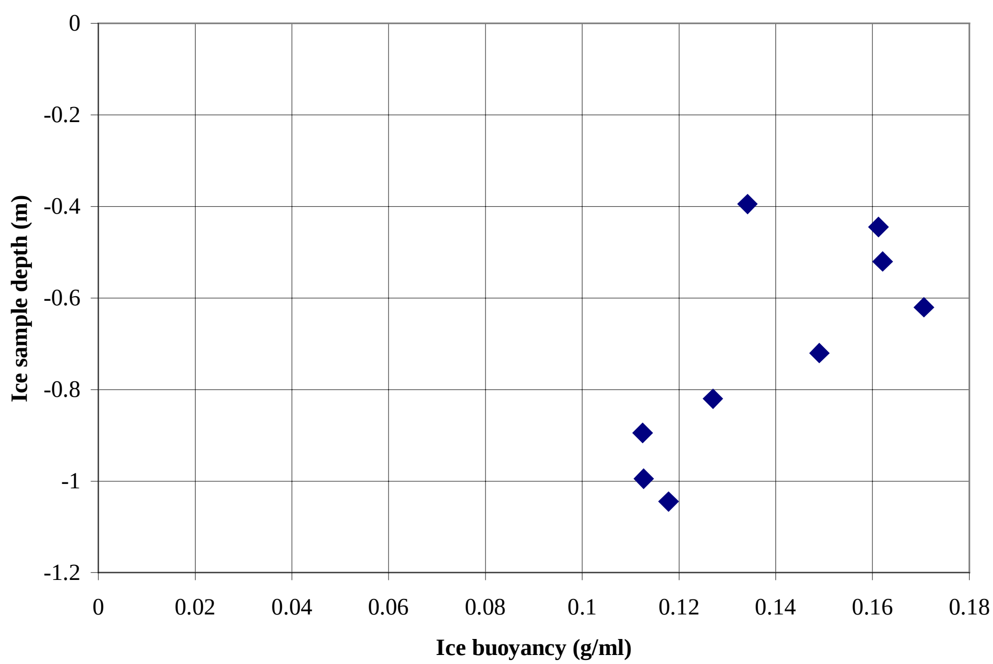
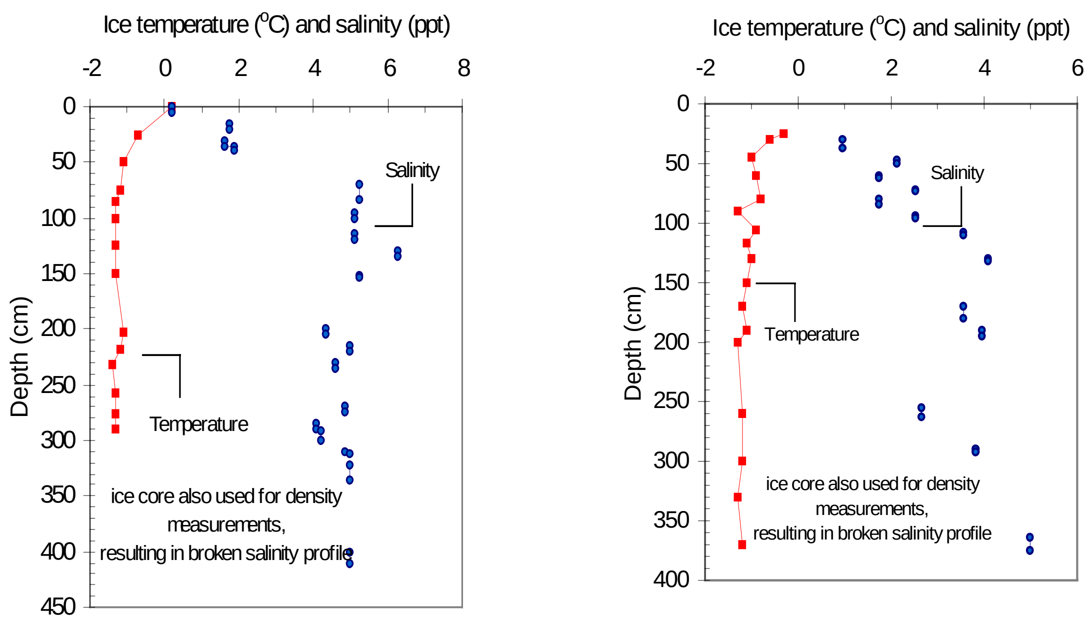


Figure 5-29: Specific Buoyancy, Undrained Samples, Site 3, Core 3

5.3.5 Coring, Temperature and Salinity profiles

Temperature, salinity (Figure 5-30) and density measurements were made on ice cores from two stations, Station 65 and Station 70 (shown in Figure 5-22). Salinity and density measurements were made by using, alternately, 50mm thick sections of ice from the same core, resulting in the broken profile shown in Figure 5-30. The salinity of the seawater at Site 3 was 28 ppt.

Interesting pieces of the cores were saved from Site 3 for crystallographic work. In addition, a solid core (about 1 m thick) was obtained from one of the blocks excavated near stations 65 and 70.



Station 65 Station 70

Figure 5-30: Temperature and Salinity Profiles, Site 3, Line 1,

5.3.6 Borehole Jack Data

The mechanical strength of the ice was tested at 2 stations (0.25 m depth intervals for each hole) using the borehole jack. The *in situ* strength tests indicated that the maximum borehole jack pressure (reached before the jack platens extended 35mm) was 11 MPa. The bore hole has no displacement rate control. The displacement rate depends on the resistance being encountered (ice strength). At high ice strengths, such as the 11MPa, it takes about 60 seconds to extend. Under zero load conditions the ram extends in about 10seconds.

The measured strength is normal for warm first year sea ice or deteriorating fresh water ice (Sinha, 1997, and Prowse et al 1991) and it reflects some deterioration of the ice cover at Site 3. The two profiles done at stations 65 and 70 on line 1 are shown in Figure 5-32 and Figure 5-33. Results, in terms of maximum borehole jack pressure, are shown in Table 5-11. A summary of the results in graphical form is shown in Figure 5-31. The zero pressure values correspond to depths where a cavity prevented us from doing a test.

At a depth of 1m below the ice surface, the maximum borehole jack pressure drops to less than 1MPa. Note that all pressure indicated includes about 0.2 MPa for piston friction under no load. Assuming that a borehole jack pressure of 1MPa indicates the bottom of the consolidated layer consolidated layer thicknesses of 0.9 and 1.1m can be estimated for stations S3L1-65 and S3L1-70 respectively.

Jack pressures at the 1.75, 2.0 and 3.0m depths indicate significant strengths which correspond to weak but competent ice blocks in the keel.

Depth below ice surface (m)	Station S3L1-65	Station S3L1-70
0.25	10.06	3.63
0.50	10.78	6.07
0.75	5.60	6.87
1.00	0.68	1.31
1.25	1.23	0.05
1.50	0.00	0.64
1.75	2.99	0.72
2.00	1.82	0.72
2.25	0.00	0.68
2.50	0.00	1.31
2.75	0.00	0.00
3.00	4.26	0.72
3.25	0.76	0.05
3.50	0.76	0.81
3.75	1.69	0.00

Table 5-11: Maximum Borehole Jack Pressure (MPa) vs. Depth, Site 3

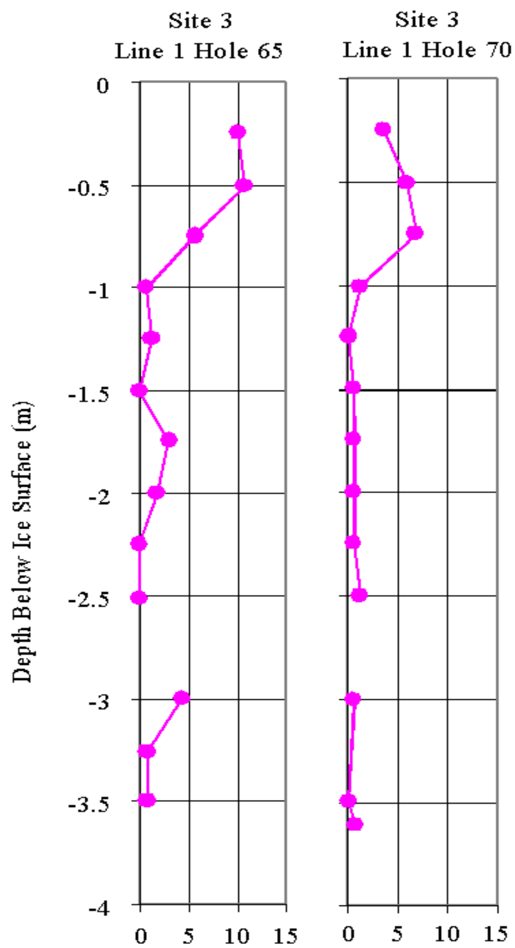
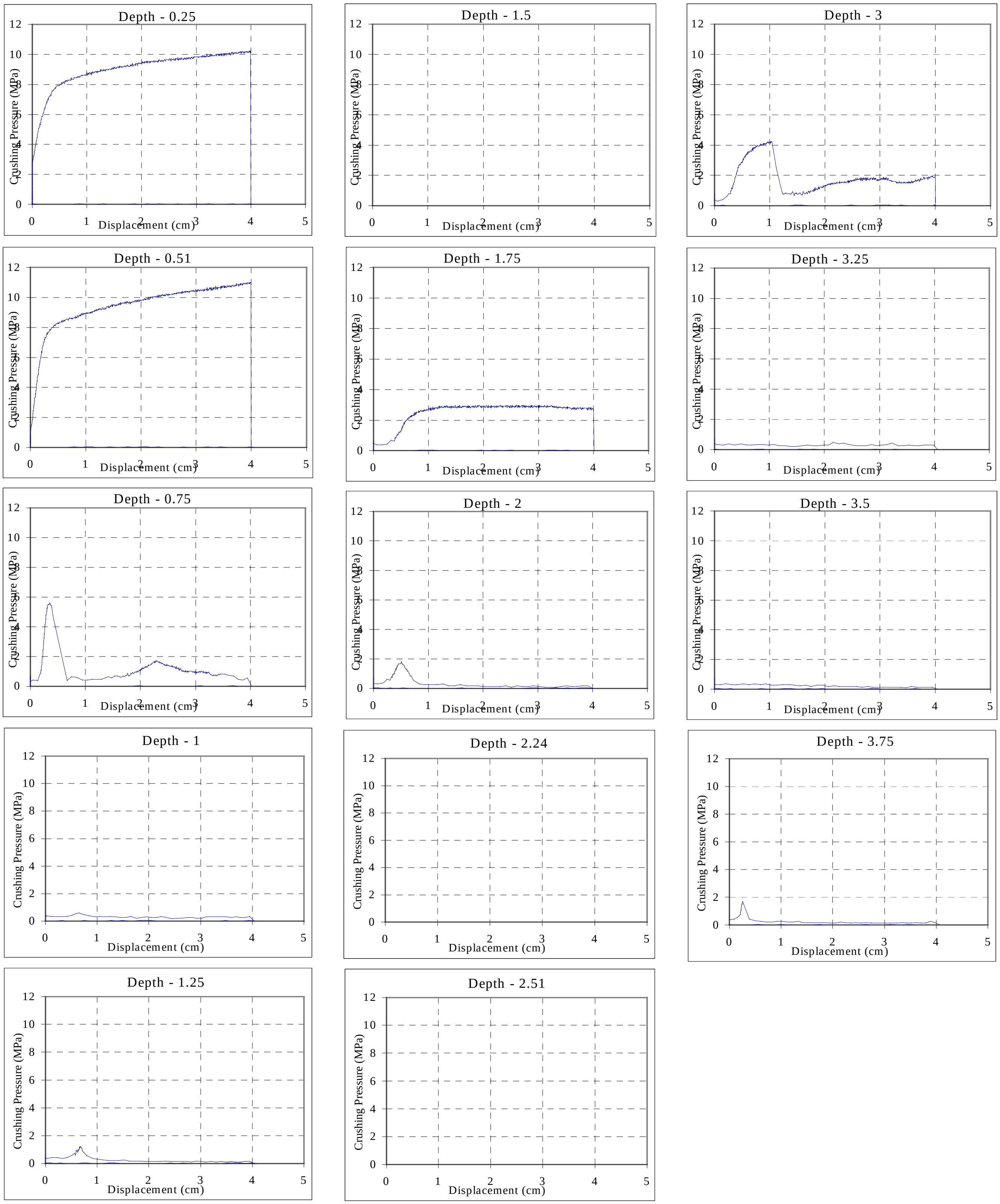
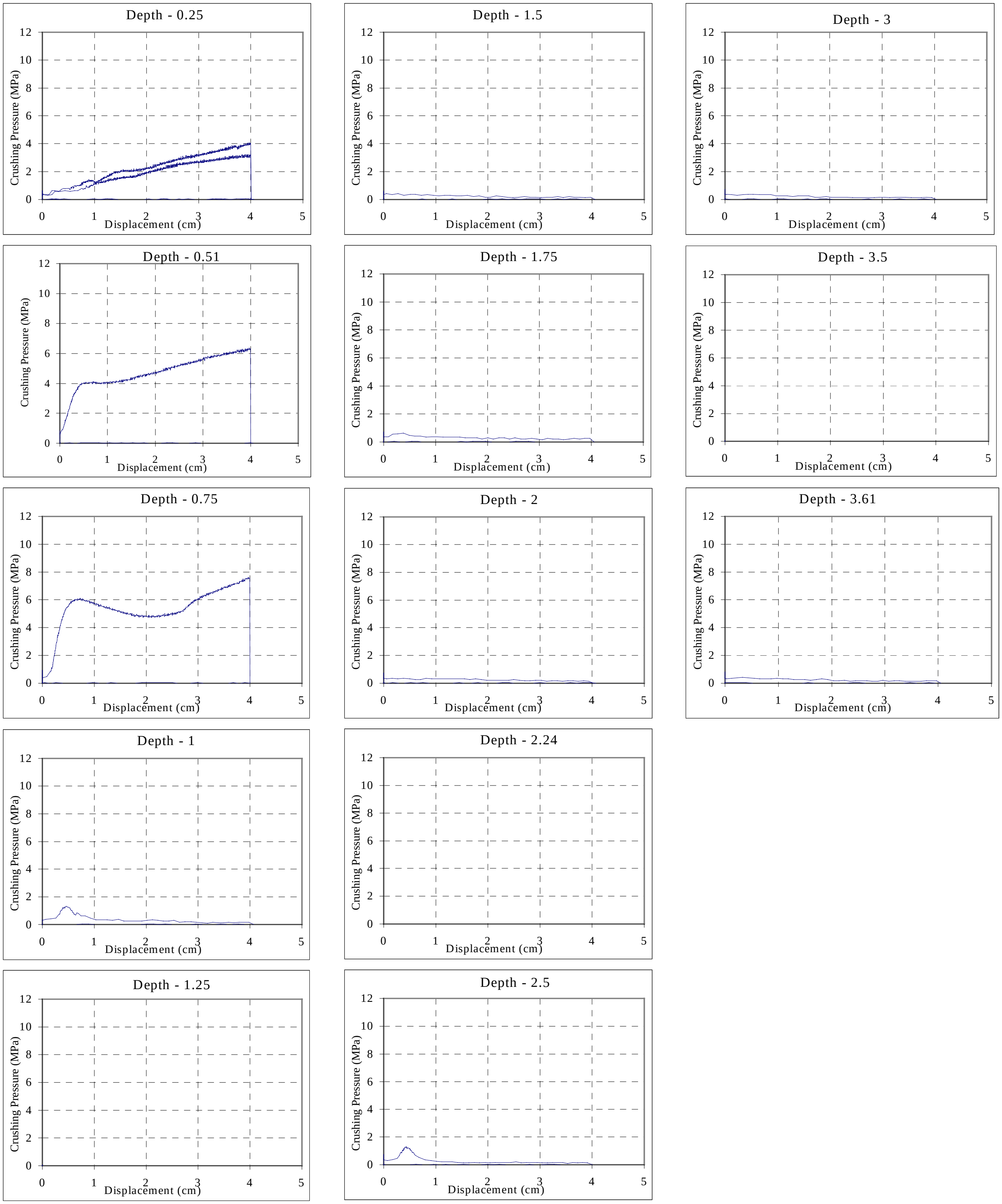


Figure 5-31: Maximum Borehole Jack Pressure (MPa) vs. Depth, Site 3



Site 3 Line 1 Hole 65

Figure 5-32: Borehole Jack Test Results, Site 3, Line 1, Station 65



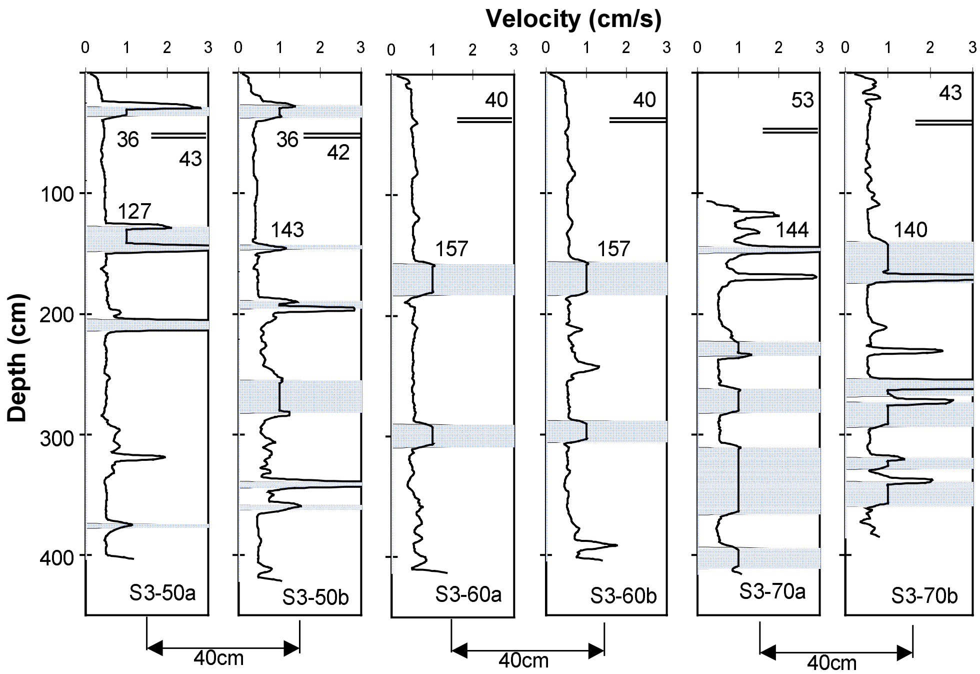
Site 3 Line 1 Hole 70

Figure 5-33: Borehole Jack Test Results, Site 3, Line 1, Station 70

5.3.7 Hot point Drill Data

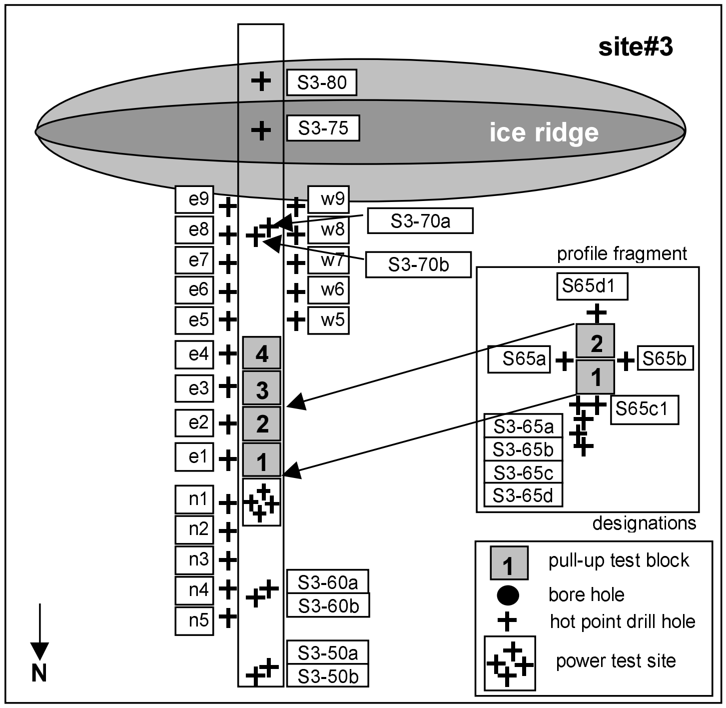
Hot point drill profiles were obtained on the grounded ice ridge at Site 3 or in nearby rubbled (or level?) ice . More than half of all the hot point drill profiles were obtained at this site. Measurements were carried out on three different days (March 12,15,16):

On March 12, 12 holes were drilled along Line 1, at a spacing of about 5 metres. Two points S3-75 and S3-80 are located near the top of the ridge, where the sail height was about 3.5 metres. At points S3L1-50 , S3-60 and S3L1-70 two holes were drilled at a distance of about 0.40 m from each other (see



- Figure 5-36) to check repeatability.
- On March 15 measurements were continued at Site 3. Only 4 holes were drilled (at a spacing of 0.1m to check repeatability), due to failure of the electronic block on the measuring channel.
- On March 16, after replacement of the electronic block, a power calibration of the drill (presented in Volume 2) was carried out, and ice samples were taken for porosity

measurements. A total of 19 profiles were also drilled along line 1, at a spacing of 1



meter (

- Figure 5-34), where pull-up tests were to be done. These profiles were drilled especially for comparison with the pull-up tests and the structures of the blocks that were pulled out. These results are included in Volume 2.

A cross-section of the hot point drill velocity profile for the ridge (corrected for surface elevation) is shown in Figure 5-35.

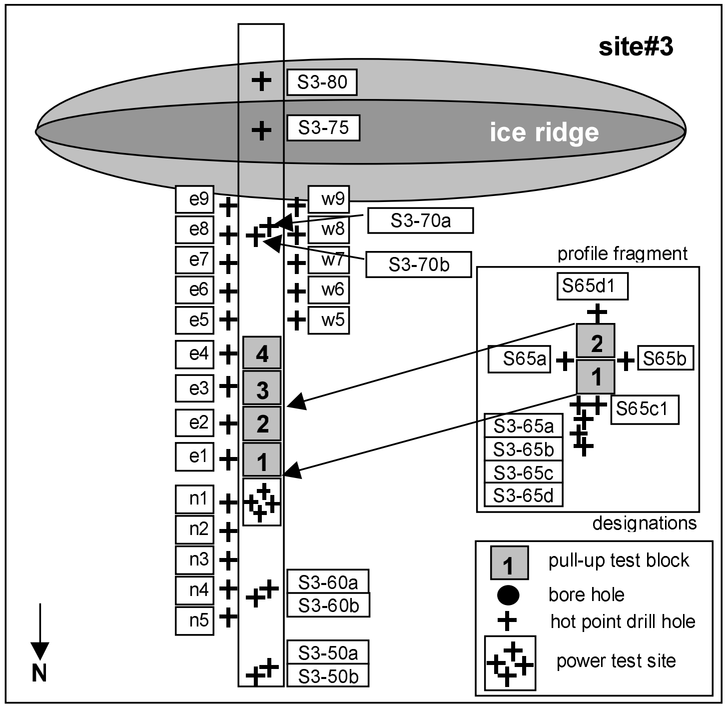


Figure 5-34: Sketch of Hot Point Drill Hole Locations, Site 3

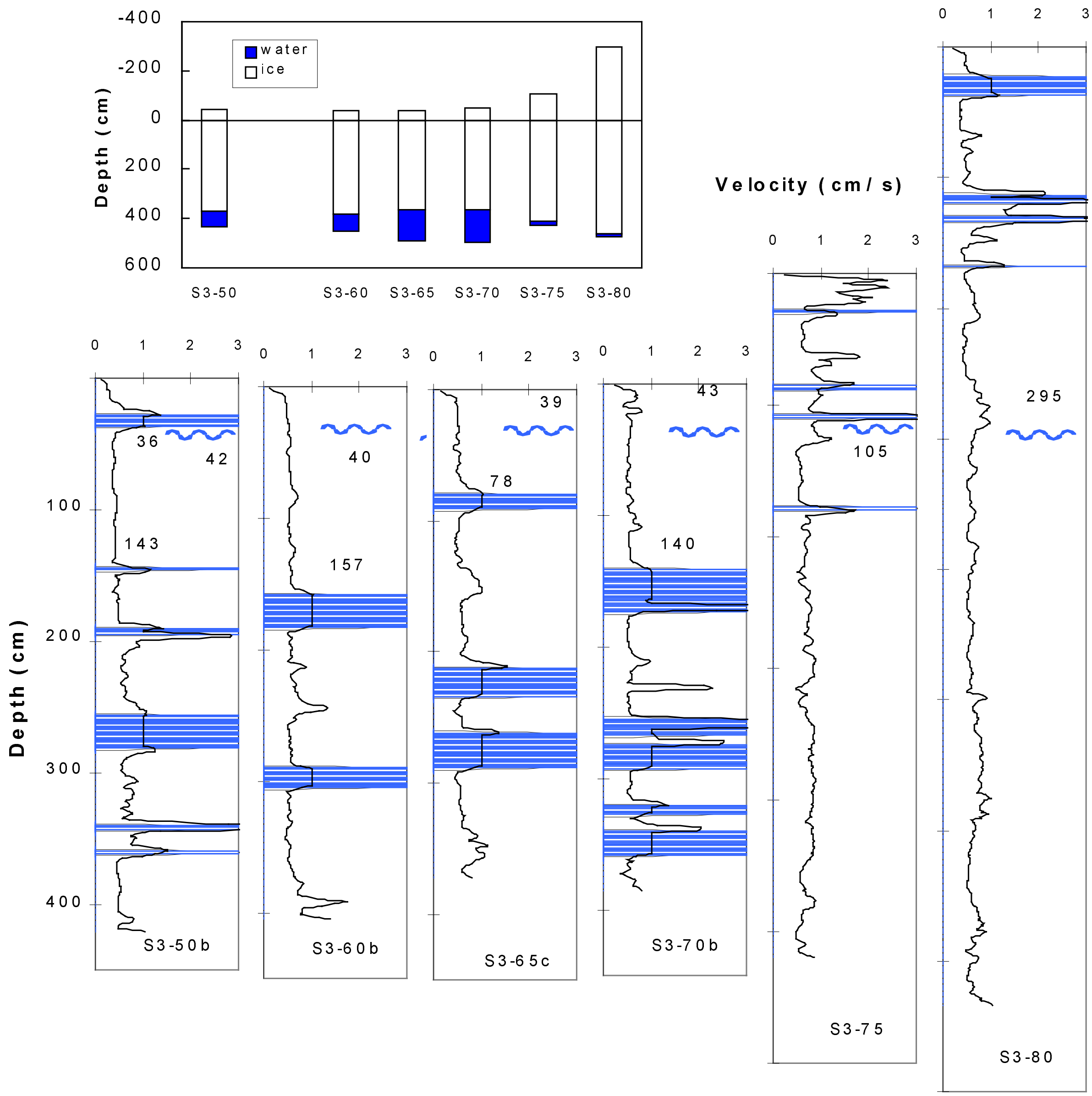


Figure 5-35: Cross-section of Ridge, Site 3

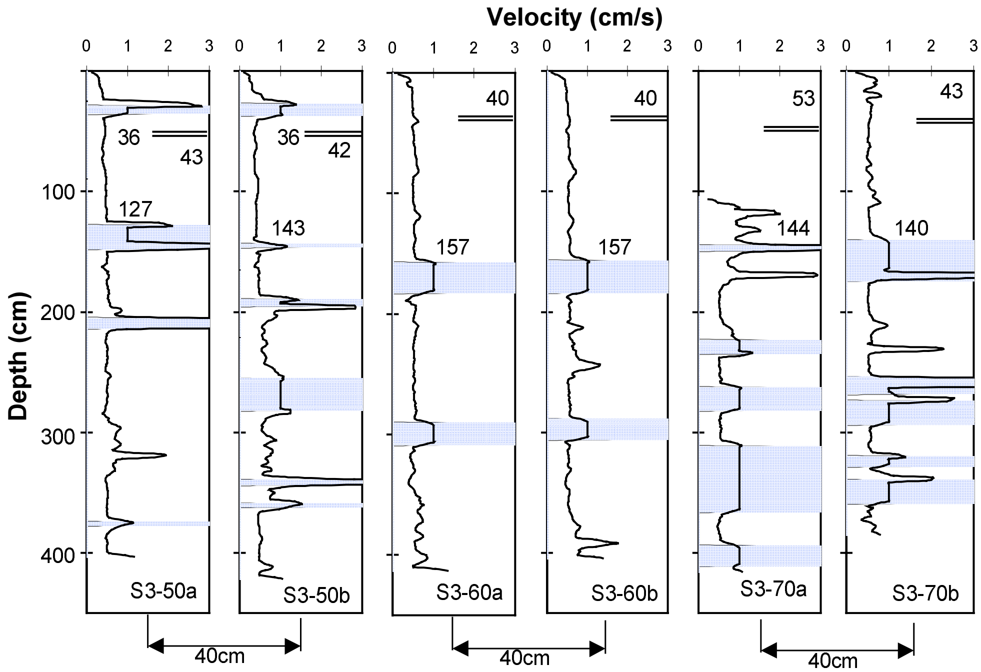


Figure 5-36 and Figure 5-37 show the repeatability of adjacent hot point profiles. Even profiles within 100 m of each other show some significant differences, demonstrating the heterogeneity of the ridge keel.

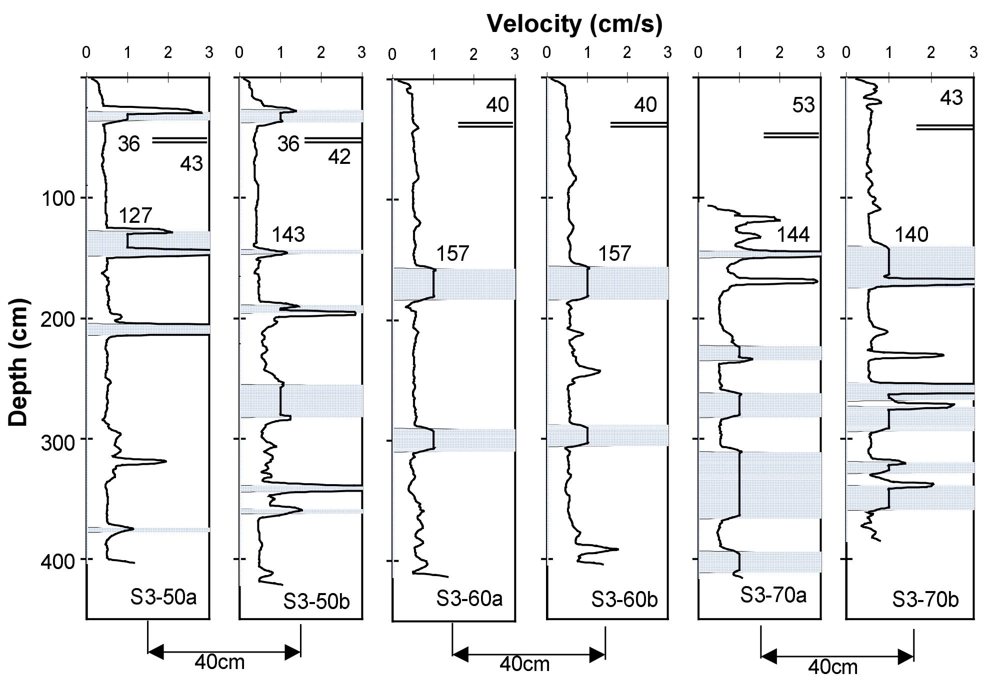


Figure 5-36: Repeated Hot Point Drill Profiles, Site 3

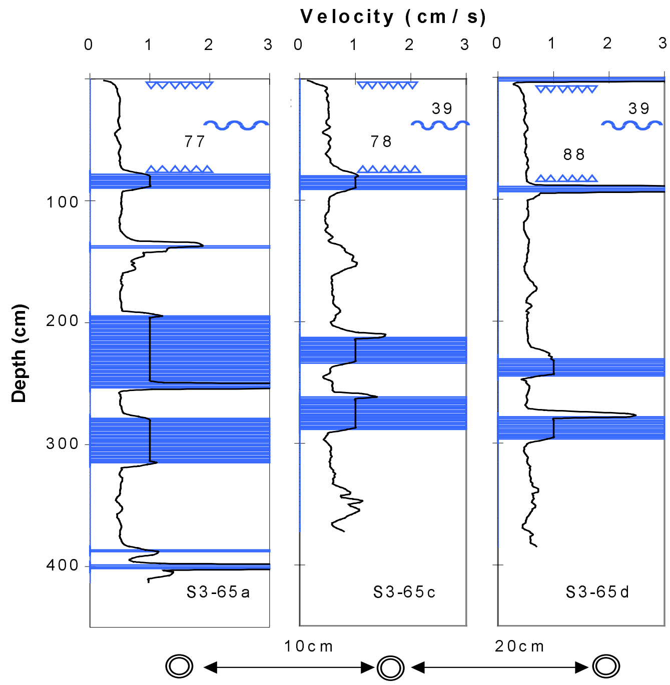


Figure 5-37: Comparison of Adjacent Hot Point Drill Profiles, Site 3

During the drilling on March 16, the change in sea level relative to the ice surface was measured. The measurements were made in the rectangular hole left in the ice after the pull up tests (assuming that the elevation of the grounded ridge itself was constant). Table 5-12 lists these sea level data. Thus, the measurements of March 16 were carried out near around high tide. The full amplitude of the sea level changes was about 60-80 cm.

Local Time	11:30	14:44	16:12	16:28
Freeboard Height (cm)	30	60	55	45

Table 5-12: Sea Level Changes at Site 3

Near the ice ridge peak, the snow cover thickness varied from 20 cm (points S3E8 and S3W7) to 50 cm (points S3W9 and S3E9). The hot point drill depths for these points were measured from the top boundary of the snow.

5.4 Site 4 (51° 25.73, 56° 53.17)

On 13 March the field party examined Sites 4, 5 and 6 during a reconnaissance flight to the Québec shore. Sampling a number of ridges in one day allowed only an examination of the surface topography of the ridge, ice thickness, snow depth and sail block dimensions. Ice cores were not retrieved for salinity, temperature and density measurements or crystallography.

On the way to Québec, it was found that the receding ice had left Sites 2 and 3 on the edge of the landfast ice. The flight over the Gulf of St. Lawrence revealed that the dominant floe size in this region of the Gulf was about 100 m, with some larger floes about 300 m in diameter.

Site 4 (Figure 5-38) was selected as an older, drifting floe that appeared to be weathered by spray or rain, as its surface was shiny and slippery. The morning of 13 March was spent examining the 100 m x 100 m floe. A schematic of Site 4 is shown in Figure 5-39. Three survey lines were drawn over the ridge sail, the results of which are shown in Figure 5-40, Figure 5-41, and Figure 5-42.

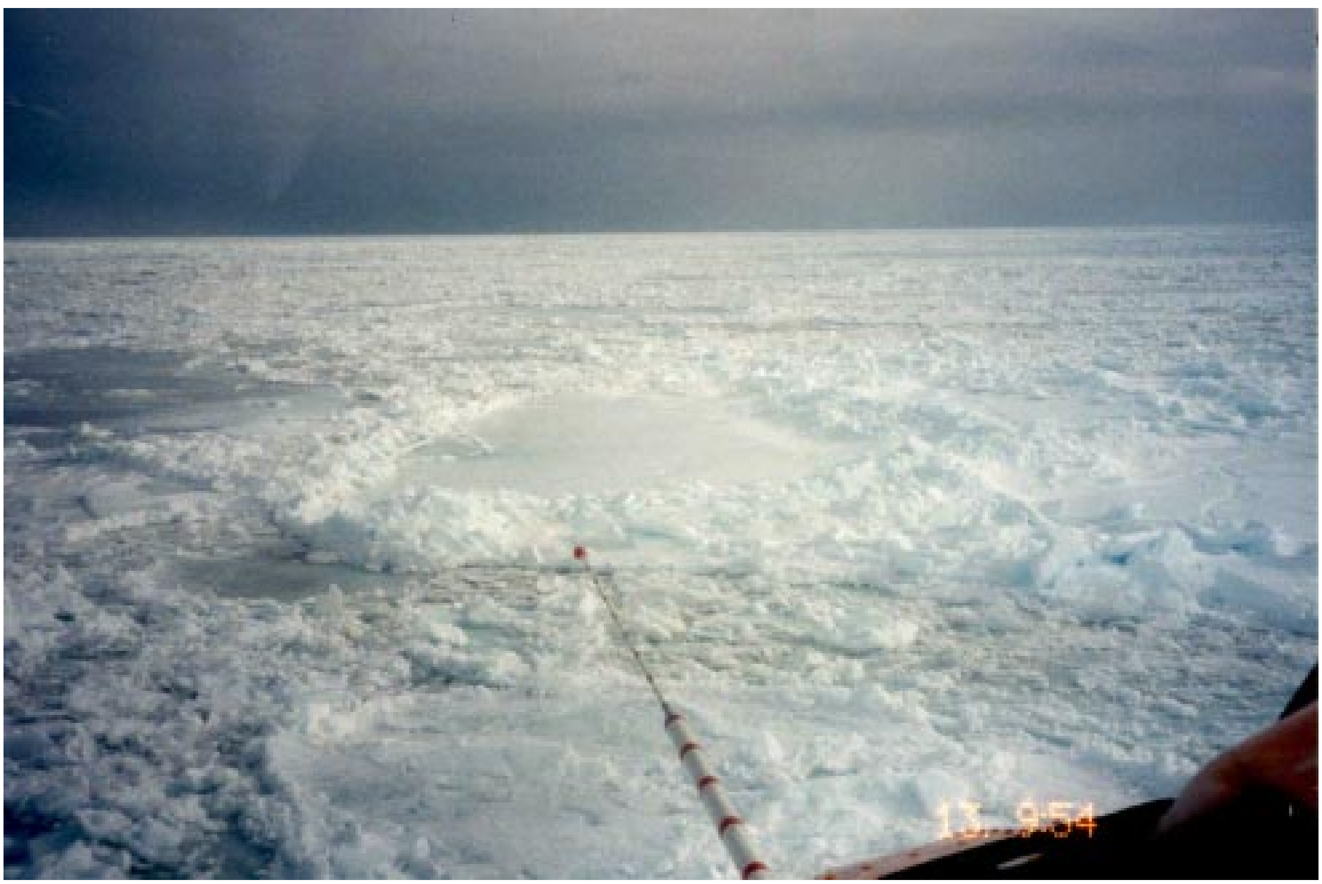


Figure 5-38: Photograph of Site 4

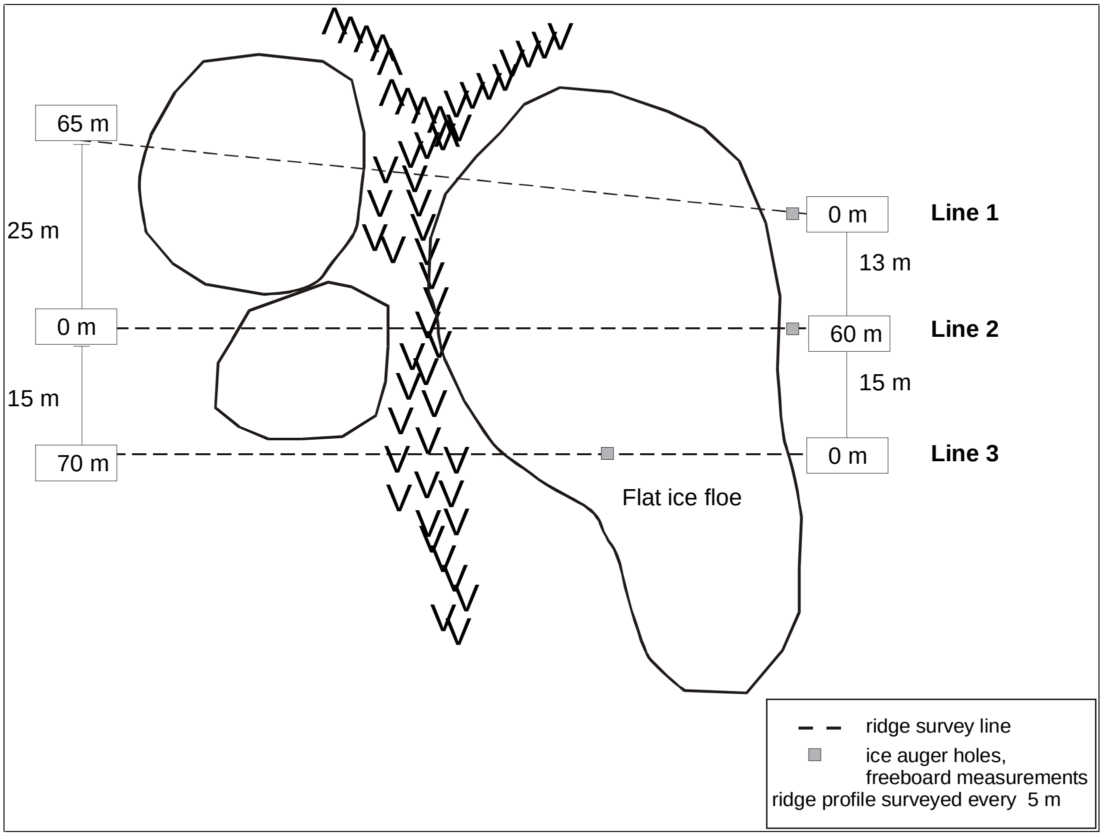


Figure 5-39: Schematic of Site 4

5.4.1 Surface Profiles

Three surface profiles were surveyed at Site 3:

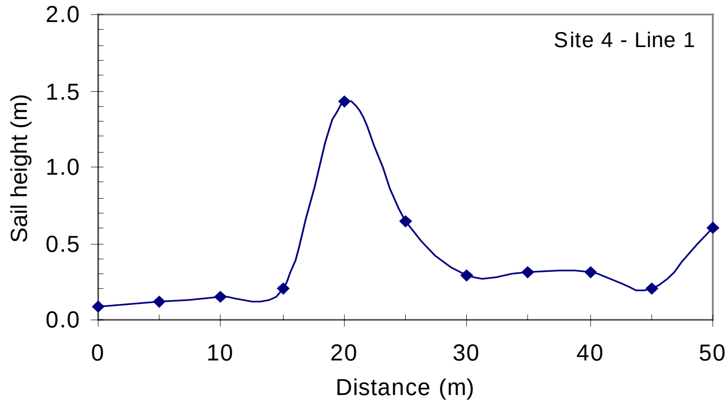


Figure 5-40: Line 1, Site 4

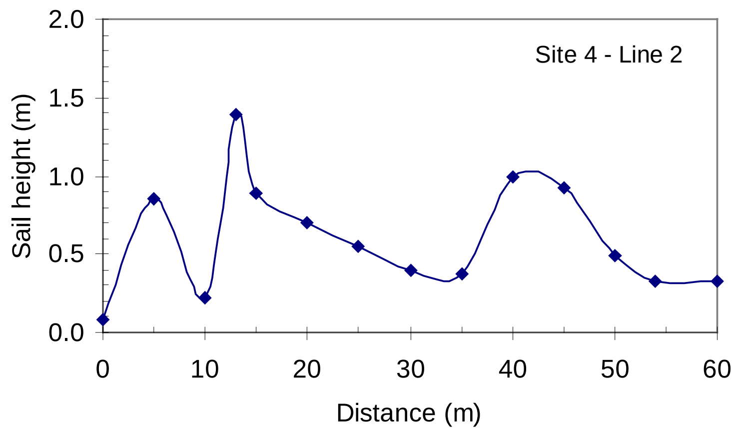


Figure 5-41: Line 2, Site 4

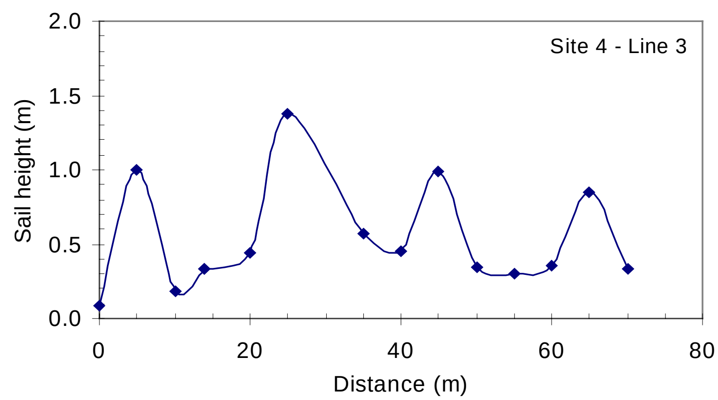


Figure 5-42: Line 3, Site 4

5.4.2 Block Sizes

A total of 31 ridge sail blocks were measured. The block size distributions are shown in Figure 5-43 and Figure 5-44. Detailed block size data is given in Table 5-13. It contains information on the slope of each block relative to vertical (90 degrees is vertical).

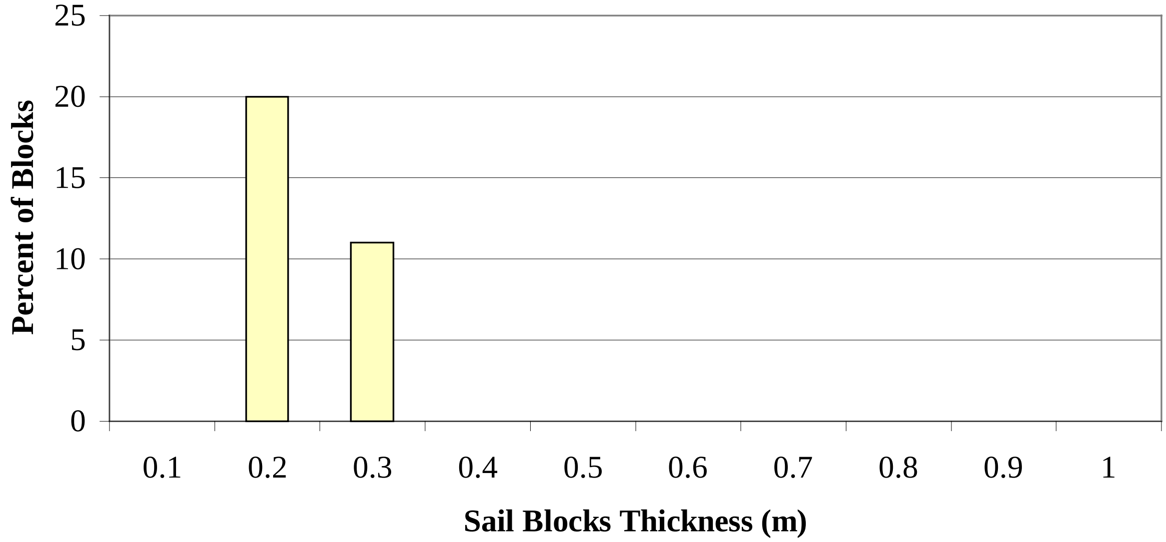


Figure 5-43: Blocks Thickness Distribution, Site 4

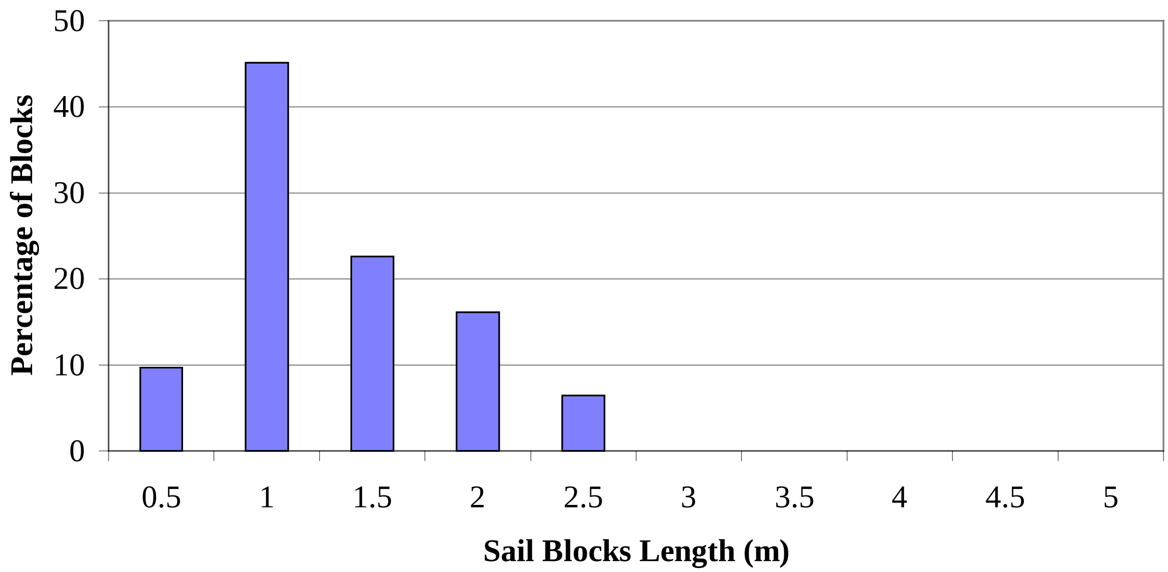


Figure 5-44: Blocks Thickness Distribution, Site 4

Thickness T (m)	Length L(m)	Width W(m)	Slope (degree)	Thickness T(m)	Length L(m)	Width W(m)	Slope (degree)
0.2	1.2	1.0	50	0.3	1.7	1.4	20
0.2	1.3	0.8	80	0.2	1.0	0.6	20
0.2	1.4	1.1	80	0.2	2.0	1.1	20
0.3	2.3	1.7	40	0.2	1.9	1.2	20
0.2	0.9	0.4	50	0.2	1.1	0.9	10
0.2	1.0	0.7	30	0.2	0.9	0.5	10
0.35	1.7	1.7	30	0.2	1.2	0.9	20
0.3	1.8	1	30	0.2	1.0	0.7	50
0.3	2.7	2.3	40	0.2	1.4	0.9	20
0.3	1.0	0.7	20	0.2	0.9	0.7	30
0.3	1.9	1.4	0	0.2	0.9	0.7	30
0.3	1.1	0.8	0	0.2	0.9	0.7	30
0.3	1.7	1.5	0	0.2	0.7	0.5	0
0.3	1.4	1.2	10	0.2	0.7	0.5	10
0.3	2.2	2.2	10	0.2	1.1	0.9	0
0.2	0.7	0.5	0				
			Average	**.24**	**1.35**	**1.0**	**24.5**
				L/T=	**5.65**	**L/W=**	**1.4**

Table 5-13: Sail Blocks Size Measurements, Site 4

5.4.3 Consolidated Layer Data

This being a reconnaissance flight, ice drilling was kept to a minimum. The main purpose of drilling was to determine consolidated layer thickness, and to provide some freeboard readings for the surface profile surveys. One hole was drilled on each survey line, as shown in Table 5-14.

Consolidated layer thicknesses were 1.1, 1.2, and 1.6 metres (average 1.3m).

	S4-L1-05		**S4-L2-60**		**S4-L3-15**
Freeboard	0.3		0.16		0.40
Snow	0.0		0.0		0
Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel
0.5	Hard	0.4	Hard	0.7	Hard
1.1	Soft	1.2	Soft	1.6	Soft
1.8	Push	1.9	Push	1.7	Push
2.0	Soft	2.00	Soft	2.0	Soft

Table 5-14: Drilling Data, Site 4

5.5 Site 5 (51° 18.29, 57° 52.30)

Site 5, was part of a large hummock field that was grounded on a shoal, just off the Iles Aux Chiens on the Quebec shore. Attached to this 4 m high rubble pile was a rubbled area about 2 km long and 0.5 km wide. Figure 5-45 shows the heavily rubbled surface with no flat areas. The site was examined between 12:00 and 14:00 on March13. Figure 5-46 shows a schematic of Site 5. The rubble pile had a crest that was about 35 m long and was grounded in about 8.5 water depth.

Figure 5-45: Photograph of Site 5

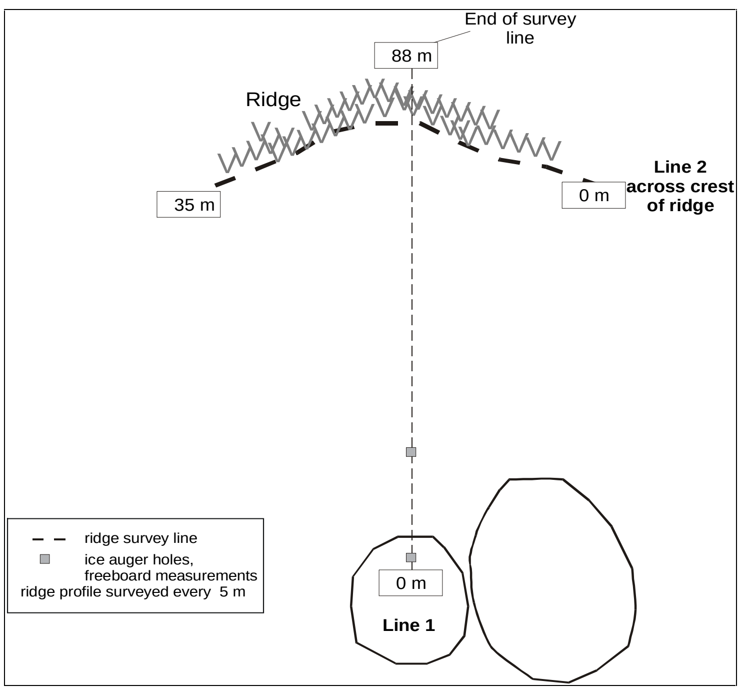


Figure 5-46: Schematic of Site 5

5.5.1 Surface Profiles

Ridge profiles were obtained by surveying one line perpendicular to the crest of the ridge and another line parallel to the crest (Figure 5-47 and Figure 5-48). As progress through this rubble was particularly difficult, and the area was large, only one line was surveyed across the ridge. A survey of the ridge crest was also made.

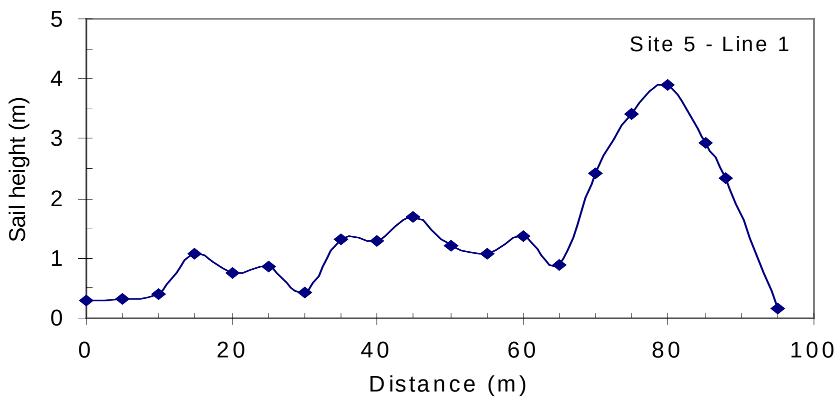


Figure 5-47: Line 1, Site 5

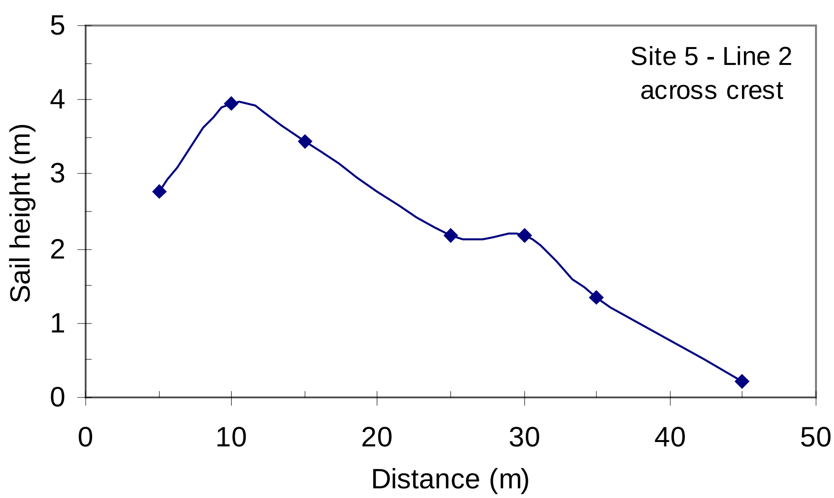


Figure 5-48: Line 2, Along Ridge Crest at Site 5

5.5.2 Block sizes

Block thickness and length distributions are given in Figure 5-49 and Figure 5-50. Details of the block size measurements are shown in Table 5-15. The sail blocks at Site 5 are significantly thicker than the sail blocks at previous sites.

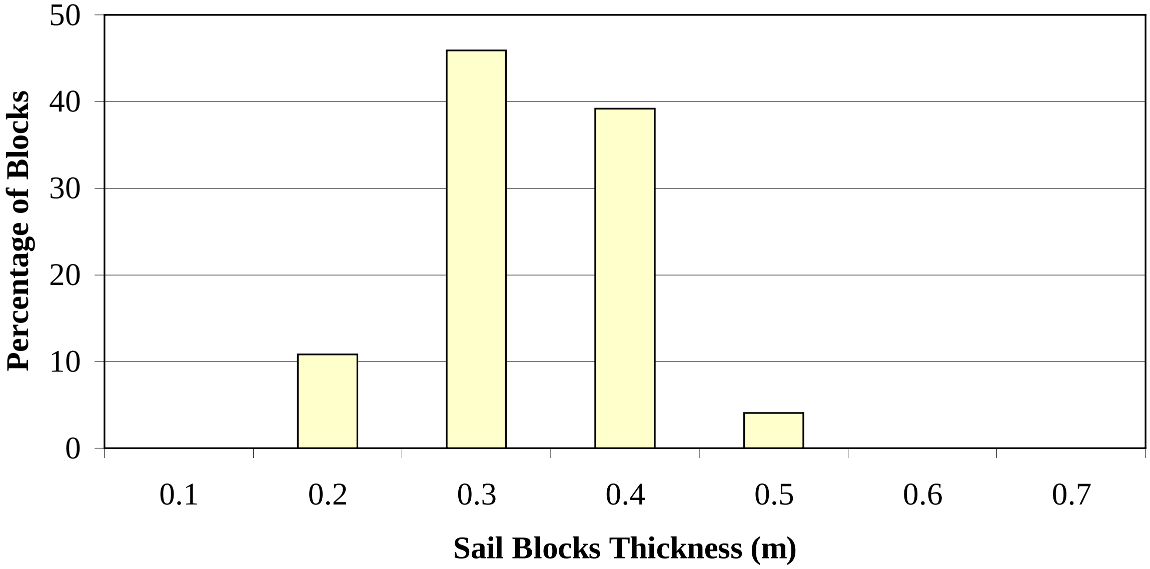


Figure 5-49: Block Thickness Distribution, Site 5

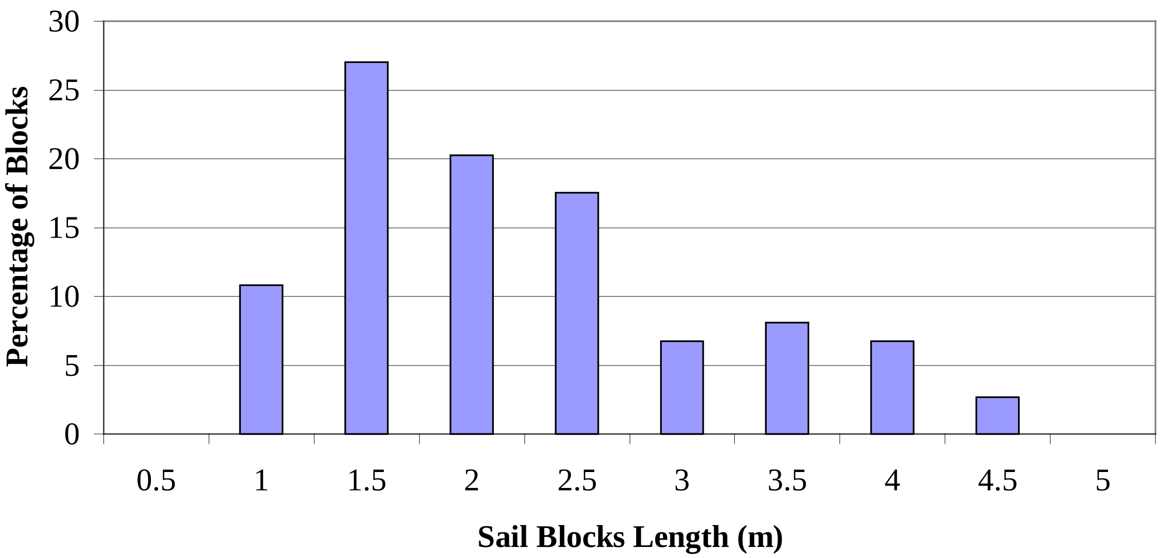


Figure 5-50: Block Length Distribution, Site 5

Thickness T (m)	Length L(m)	Width W(m)	Slope (degree)	Thickness T(m)	Length L(m)	Width W(m)	Slope (degree)
0.2	1.3	0.6	40	0.35	4.3	3	20
0.2	0.9	0.8	20	0.35	3.3	1.3	30
0.2	1.9	0.9	30	0.35	2.0	2.0	10
0.25	1.9	1.6	70	0.4	1.8	1.1	20
0.25	2.3	1.6	20	0.4	4	2.3	20
0.25	2.1	1.6	50	0.4	2.1	1.9	20
0.25	1.1	0.9	40	0.4	2.3	1.7	20
0.25	1.7	1.3	30	0.4	1.5	1.1	0
0.3	1.9	1.3	0	0.4	1.4	0.8	10
0.3	1.3	0.6	10	0.4	2.1	1.6	10
0.3	2.1	1.3	70	0.4	1.6	1.2	10
0.3	2.4	2.0	80	0.4	2.2	1.5	10
0.3	2.7	2.1	40	0.4	1.7	1.4	20
0.3	2.0	1.2	90	0.4	2.6	1.6	40
0.3	2.8	2.4	30	0.4	2.7	1.6	10
0.3	2.7	1.8	30	0.4	1.2	1.1	30
0.3	3.1	2.3	30	0.4	1.3	0.7	10
0.3	1.4	0.8	10	0.4	1.3	1	80
0.3	1.1	0.6	10	0.4	2.1	1.2	70
0.3	2.2	2.0	20	0.4	2	1	60
0.3	1.3	0.9	90	0.4	1.7	0.8	20
0.3	3.0	2.4	30	0.4	1.7	1.3	30
0.3	1.5	1.1	20	0.4	2.3	1.2	20
0.3	1.1	1.0	30	0.4	3.5	2.2	70
0.3	2.3	1.8	40	0.4	4	2.2	80
0.3	2.3	0.1	40	0.4	3.3	2.3	30
0.3	1.4	0.7	50	0.4	4.0	3.0	10
0.3	1.1	1.0	30	0.4	3.9	1.9	20
0.3	3.1	2.1	20	0.4	3.5	1.8	10
0.3	1.1	1.1	30	0.4	4.7	4.1	10
0.3	1.3	0.8	40	0.4	3.5	2.1	10
0.3	1.7	1.2	10	0.4	2.5	1.2	20
0.3	2.3	1.8	40	0.5	2.4	1.6	20
0.3	1.5	1.0	50	0.5	3.1	2.0	10
0.3	1.6	1.2	20	0.5	1.8	1.1	10
0.35	1.5	1.3	70				
0.35	1.1	0.7	60				
0.35	3.7	2.3	70				
0.35	4.0	2.5	70	T	L	W	A
			Averages	**0.34**	**2.23**	**1.49**	**32**
				L/H=	**6.54**	**L/W=**	**1.81**

Table 5-15: Sail Blocks Size Measurements, Site 5

5.5.3 Consolidated Layer Data

As previously mentioned, the flight on 13 March was a reconnaissance flight. As such, ice drilling was used to determine consolidated layer thickness, and to provide some freeboard readings for the surface profile surveys. The data is shown in Table 5-16.

In all auger holes, a small void was encountered at a depth of 0.5m. This could be interpreted as a rafted layer. If this small void is ignored, consolidated layer thicknesses were 0.8m, 1.3m, and 1.5m (average 1.2m).

	S5-L1-05		**S5-L1-10**		**Flat ice**
Freeboard	0.29		0.36		0.15
Snow	0		0		0
Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel
0.5	Hard	0.5	Hard	0.5	Hard
0.6	Void	0.6	Void	0.9	Void
0.8	Soft	1.3	Soft	1.5	Soft
0.9	Void	2.0	Push	2.0	Void
1.4	Soft				
2.0	Push				

Table 5-16: Drilling Data, Site 5

5.6 Site 6 (51° 18.76, 57° 17.77)

Site 6 was examined on 13 March, between 14:00 and 15:00 hours. Site 6 was a very hummocked floe (see Figure 5-52) about 200 m in diameter that had a recently formed ridge on one side. Figure 5-51 shows a schematic of Site 6. Two lines were surveyed across the ridge, the results of which are shown in Figure 5-53 and Figure 5-54. Maximum sail height was 1.9m, but freeboard was consistently high, with some sections averaging over 1m freeboard.

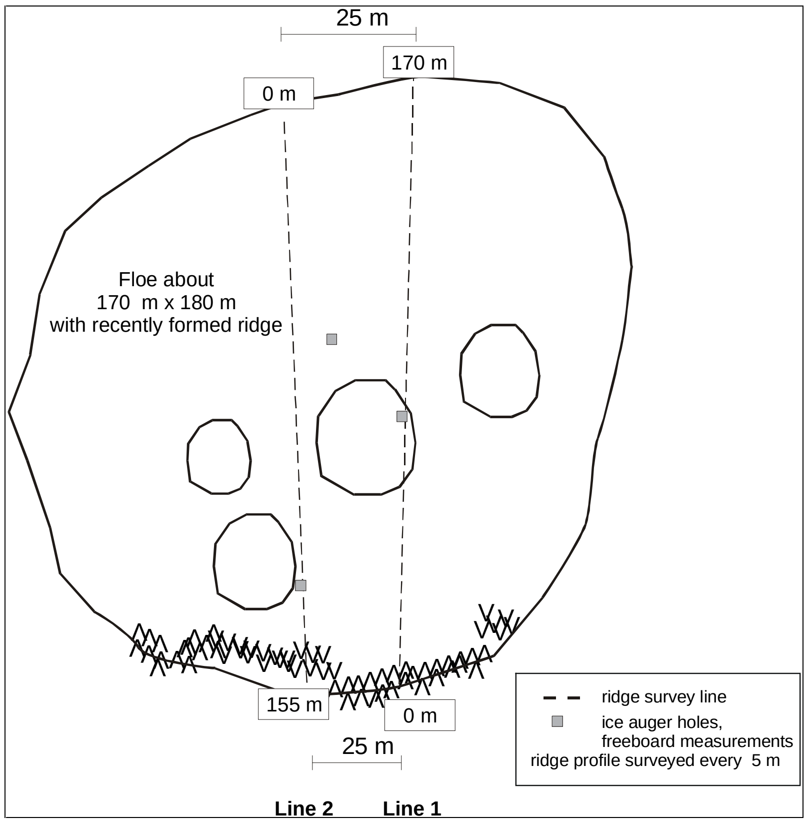


Figure 5-51: Schematic of Site 6

Figure 5-52: Photographs of Site 6

5.6.1 Surface profiles

Two surface profiles were measured at Site 6:

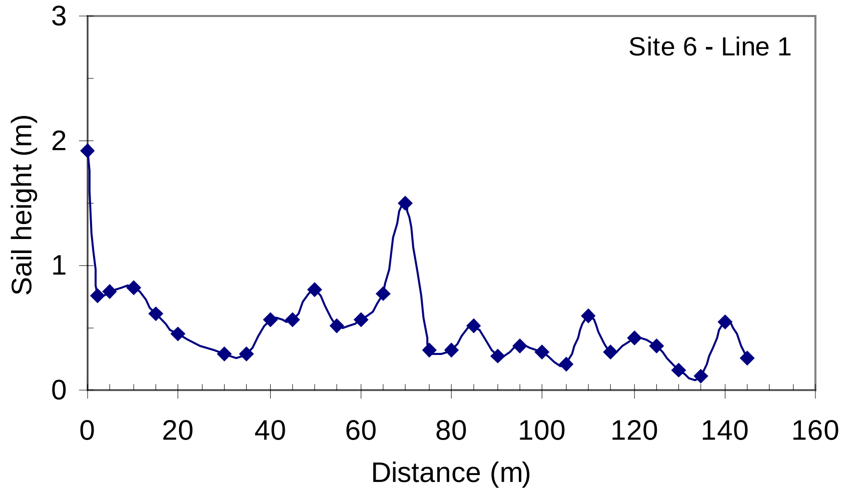


Figure 5-53: Line 1, Site 6

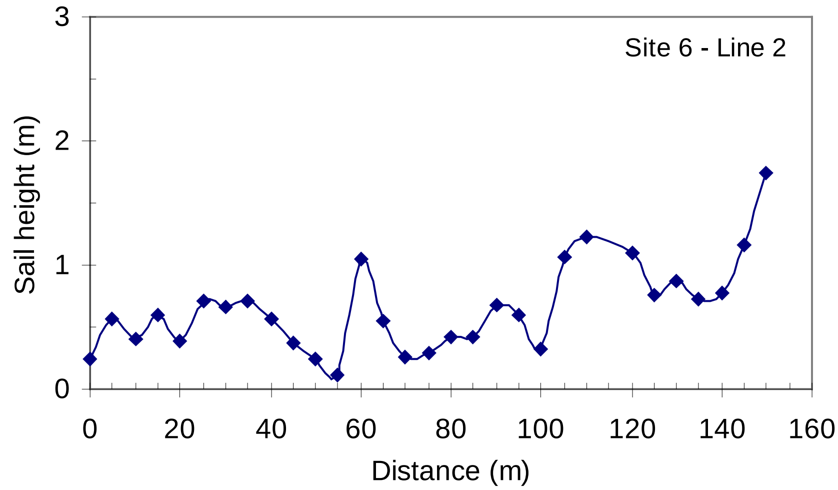


Figure 5-54: Line 2, Site 6

5.6.2 Block Sizes

A total of 62 sail block sizes were measured at Site 6, most of which were near the edge of the floe where the new ridge had formed. Block size distributions are shown in Figure 5-55 and Figure 5-56, with the block size data given in Table 5-17. Sail blocks were generally thicker than in other sites, most of them being 0.4m or thicker.

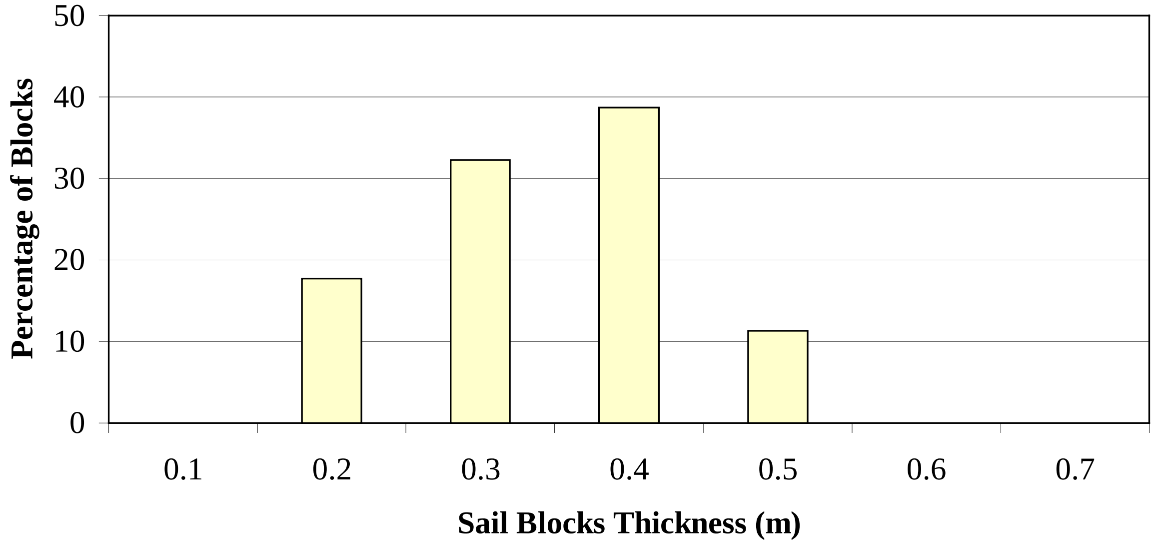


Figure 5-55: Block Thickness Distribution, Site 6

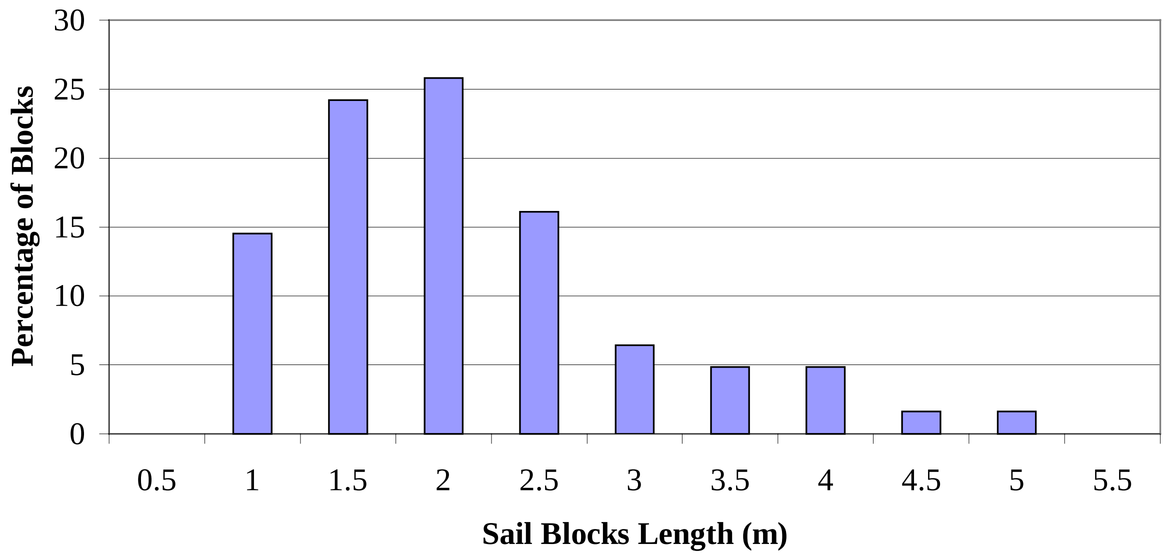


Figure 5-56: Block Length Distribution, Site 6

Thickness	Length	Width	Slope	Thickness	Length	Width	Slope
T (m)	**L(m)**	**W(m)**	**(degree)**	**T(m)**	**L(m)**	**W(m)**	**(degree)**
0.2	1.0	0.9	60	0.3	2.1	1.2	80
0.3	1.0	1.0	20	0.3	2.1	1.4	30
0.2	1.1	0.9	70	0.3	2.1	1.5	10
0.3	1.1	0.8	70	0.4	2.1	1.7	40
0.3	1.1	0.8	10	0.4	2.1	1.4	40
0.3	1.1	0.7	20	0.4	2.2	1.2	30
0.4	1.2	0.6	20	0.3	2.3	2.0	20
0.4	1.2	0.9	80	0.4	2.3	1.5	90
0.5	1.2	1.1	20	0.3	2.4	1.5	80
0.3	1.3	1.2	10	0.4	2.5	1.2	20
0.4	1.3	1.0	10	0.4	2.5	1.4	10
0.2	1.4	1.2	80	0.5	2.5	1.8	20
0.2	1.4	1.1	90	0.2	2.7	0.4	30
0.2	1.4	1.1	70	0.3	2.7	1.9	10
0.4	1.4	0.9	20	0.4	2.7	2.5	70
0.2	1.5	1.3	20	0.5	2.7	1.9	20
0.3	1.5	1.2	10	0.2	2.8	2.1	20
0.3	1.6	1.3	80	0.4	2.8	1.7	70
0.3	1.6	1.3	40	0.4	3.0	1.8	10
0.3	1.6	0.9	20	0.4	3.1	2.7	20
0.3	1.6	1.4	50	0.2	3.3	3.2	40
0.3	1.6	1.6	40	0.4	3.3	2.2	20
0.3	1.7	1.4	20	0.4	3.7	1.6	20
0.4	1.7	0.8	80	0.4	3.8	2.3	40
0.2	1.8	1.2	20	0.5	4.1	2.8	50
0.2	1.8	0.8	70	0.5	4.11	3.2	20
0.3	1.8	1.4	70	0.5	4.3	4	10
0.4	1.8	1.2	40	0.5	5.0	2.7	20
0.3	1.9	1.4	30				
0.4	2.0	1.3	20				
0.4	2.0	1.7	20				
0.4	2.0	1.4	50				
0.4	2.0	1.4	10				
0.4	2.0	1.6	0	**T**	**L**	**W**	**A**
			Average	**0.34**	**2.15**	**1.51**	**37**
				L/H=	**6.44**	**L/W=**	**1.52**

Table 5-17: Sail Blocks Size Measurements, Site 6

5.6.3 Consolidated Layer Data

Freeboard readings for Site 6 are shown in Table 5-18. Consolidated layer thickness estimates are 0.5m, 0.9m, 0.5m, and 0.8m. Comparison of the consolidated thickness to the block thickness indicates that the Site 6 was a recently formed ridge, in that the ridge had relatively little time to enable development of a consolidated layer.

	S6L1-60		**S6L2-125**		**S6L2-100**		**Flat ice**
Freeboard	0.22		0.23		0.65		0.12
Snow	0		0		0		0
Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel
0.5	Hard	0.9	Hard	0.5	Hard	0.8	Hard
0.8	Push	1.0	Void	0.6	Void	0.9	Void
1.2	Soft	1.5	Soft	1.0	Soft	1.1	Push
2.0	Push	2.0	Push	1.1	Void	bottom	
				1.6	Soft		
				2.0	Push		

Table 5-18: Drilling Data, Site 6

5.7 Site 7 (51° 07.24, 57° 23.96)

On 15 March, clear weather permitted the field party to fly offshore. Since it was difficult to find sizeable ridges on large floes, large ridges on floes that were less than 100 m in diameter were decided upon. On 15 March, Sites 7, 8 and 9 were sampled.

Site 7, examined from 10:00 to 12:00 on 15 March, included a noticeable shear ridge (Figure 5-58). Site 7 was used to determine if a shear ridge could have different keel or consolidated layer characteristics than other ridges. The results show no significant difference in the keel depth and consolidated layer thickness of compression ridges and shear ridges. A schematic of Site 7 is illustrated in Figure 5-57, which shows the three lines used to characterize the sail profile (Figure 5-59, Figure 5-60 and Figure 5-61). Maximum sail height was 1.6m. The ice thickness was determined from two auger holes.

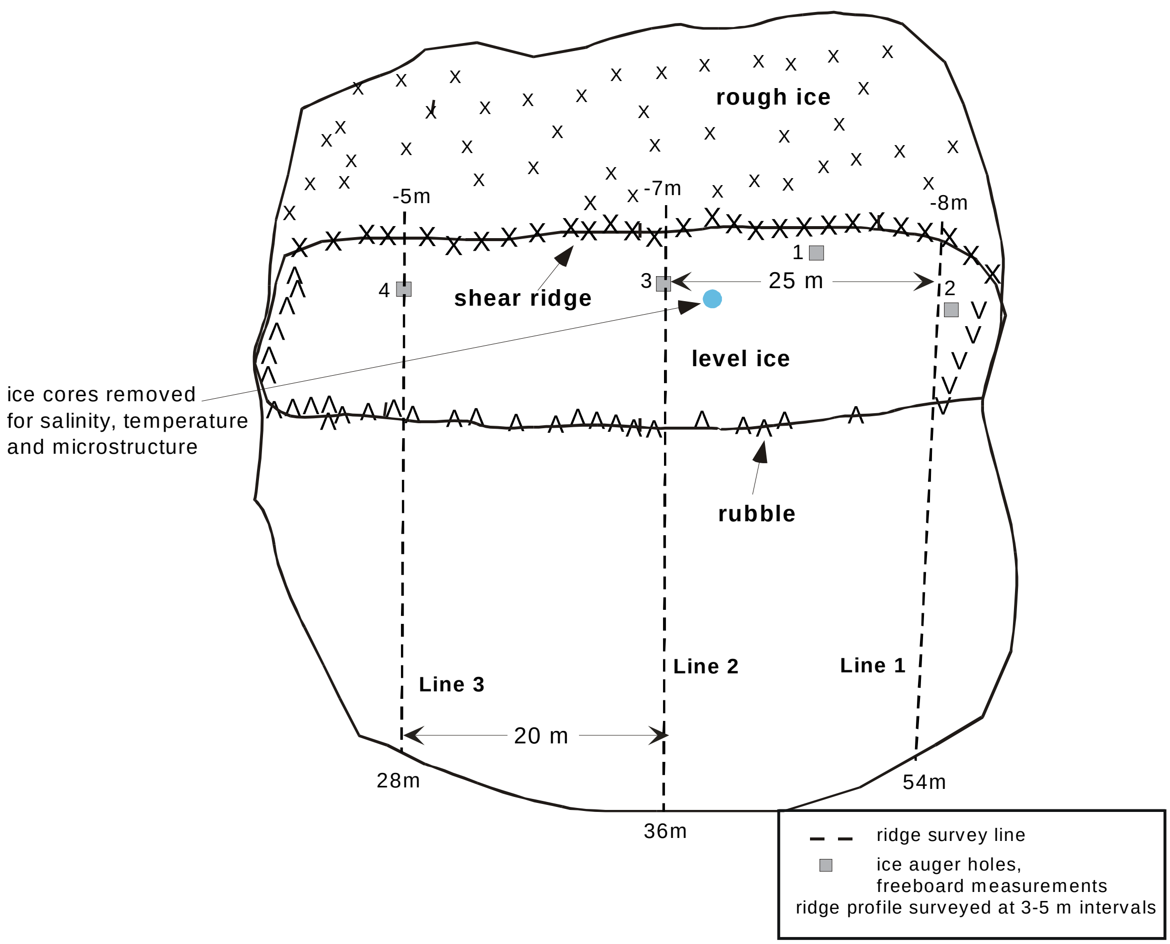


Figure 5-57: Schematic of Site 7

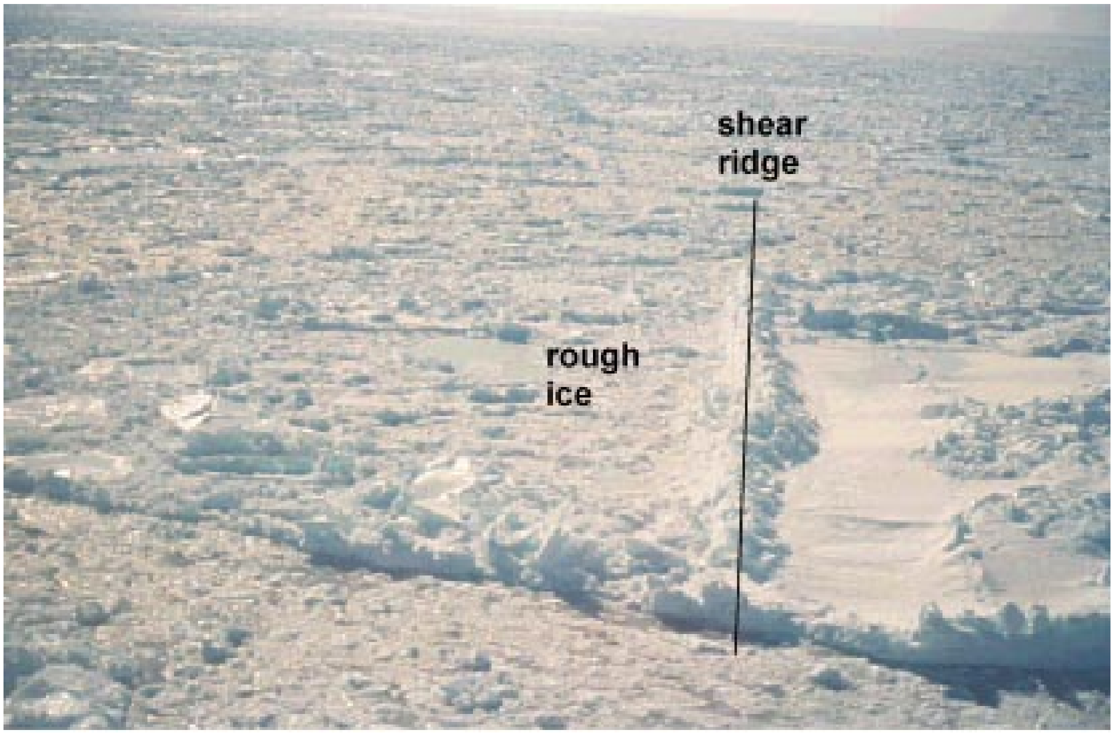


Figure 5-58: Photographs of Shear Ridge at Site 7

5.7.1 Surface profiles

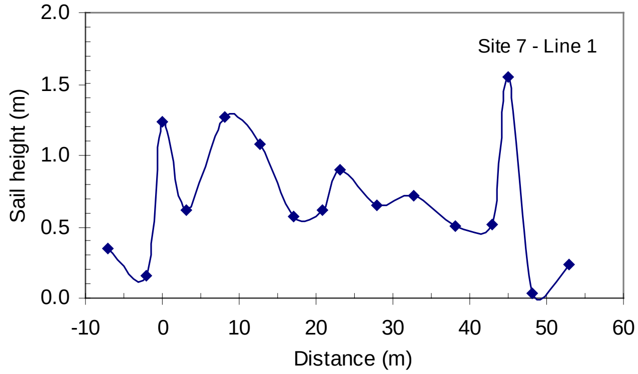


Figure 5-59: Site 7, Line 1

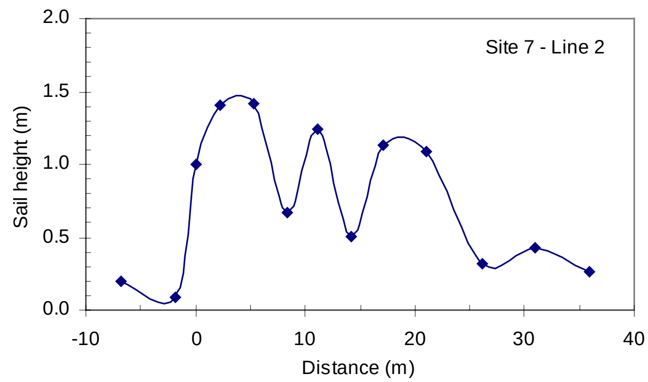


Figure 5-60: Site 7, Line 2

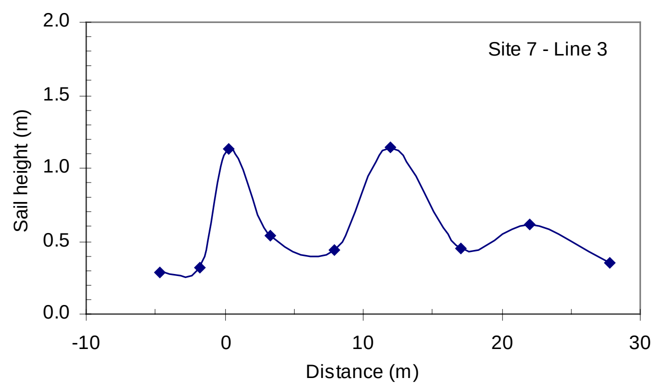


Figure 5-61: Site 7, Line 3

5.7.2 Block Sizes

A total of 26 sail blocks were measured at Site 7. The block size distributions are shown in Figure 5-62 and Figure 5-63. Detailed block size measurement data is given in Table 5-19. Blocks are relatively thin, 30% of them being between 0 and 0.15m. Block lengths are small, 38% of them being less than 0.75m. Potentially, thin and short sail blocks could be characteristic of shear ridges.

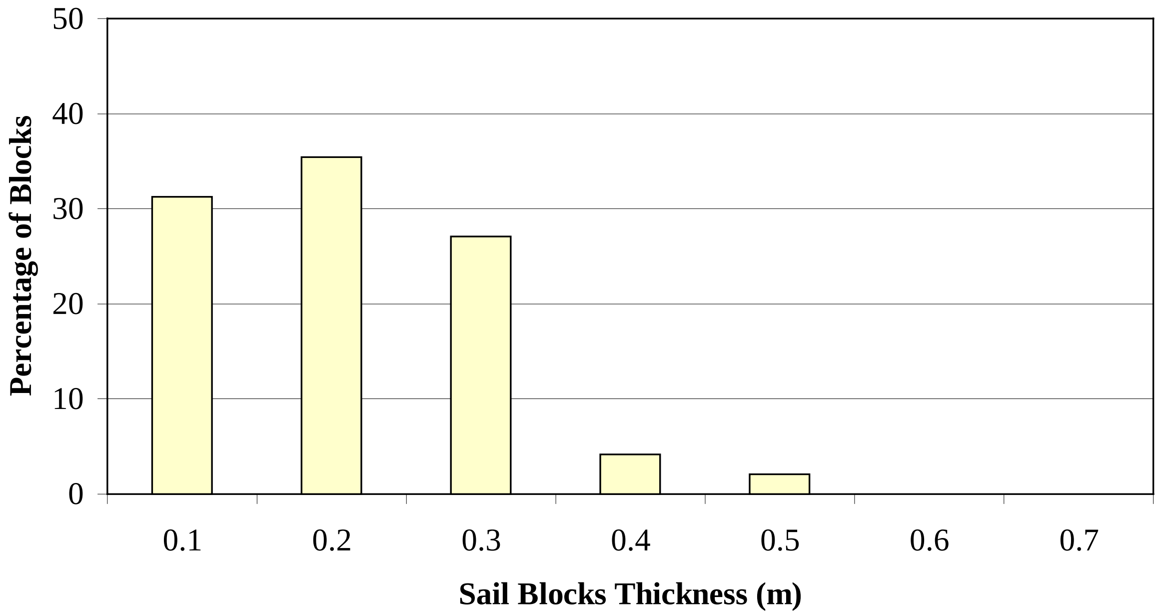


Figure 5-62: Sail Blocks Thickness Distribution, Site 7

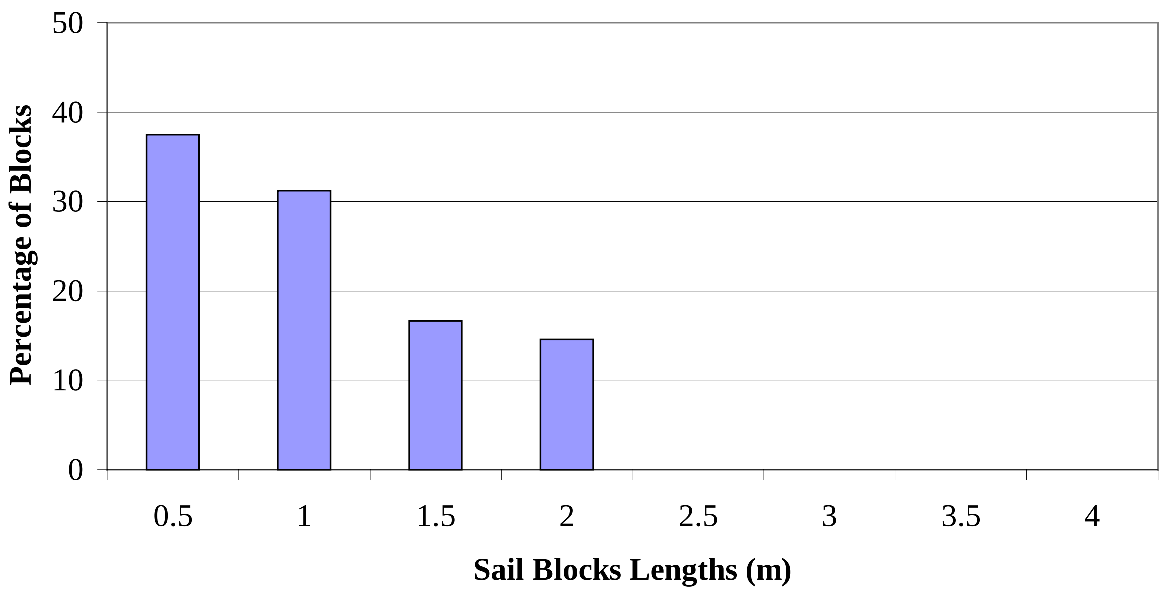


Figure 5-63: Sail Blocks Length Distribution, Site 7

Block	Thickness	Length	Width	Block	Thickness	Length	Width	Block	Thickness	Length	Width
#	**T (m)**	**L(m)**	**W(m)**	**#**	**T (m)**	**L(m)**	**W(m)**	**#**	**T (m)**	**L(m)**	**W(m)**
1	0.17	0.45	0.42	18	0.21	0.72	0.58	35	0.16	1.25	0.65
2	0.12	0.46	0.43	19	0.12	0.78	0.65	36	0.34	1.25	1.06
3	0.13	0.49	0.26	20	0.12	0.78	0.56	37	0.45	1.36	1.7
4	0.15	0.5	0.38	21	0.1	0.8	0.78	38	0.17	1.4	0.85
5	0.14	0.52	0.5	22	0.15	0.82	0.36	39	0.33	1.46	1.12
6	0.08	0.53	0.44	23	0.29	0.85	0.6	40	0.31	1.53	1.44
7	0.17	0.53	0.31	24	0.15	0.89	0.6	41	0.32	1.66	0.99
8	0.2	0.54	0.35	25	0.32	0.91	0.8	42	0.18	1.8	1.48
9	0.11	0.55	0.39	26	0.23	0.96	0.55	43	0.21	1.8	0.86
10	0.17	0.56	0.24	27	0.3	0.96	0.77	44	0.34	1.8	1.48
11	0.2	0.56	0.32	28	0.12	0.98	0.52	45	0.38	1.9	1.53
12	0.11	0.59	0.36	29	0.18	0.98	0.54	46	0.13	2	1.5
13	0.25	0.63	0.5	30	0.13	1.12	0.8	47	0.32	2.03	0.99
14	0.13	0.64	0.31	31	0.24	1.13	0.56	48	0.31	2.17	1.3
15	0.14	0.65	0.5	32	0.3	1.13	1.07	**AVG**	**.21**	**1.03**	**.73**
16	0.2	0.65	0.49	33	0.35	1.24	0.9		**L/T**	**5.31**	
17	0.26	0.7	0.56	34	0.1	1.25	0.76		**L/W**	**1.48**	

Table 5-19: Sail Blocks Size Measurements, Site 7

5.7.3 Consolidated Layer Data

Consolidated layer thickness measurements at Site 7 were 0.6m, 2.0m, 1.0m and 0.7m, with and average of 1.08m. The consolidated layer thicknesses do not take into account the small void at 0.5m in hole 4 (S7L3-3). The notation "ram hard" indicates that drill progression could be maintained by ramming the auger down several times and forcefully. It indicates that the ice being penetrated is still competent but weak and with high porosity, such that the skeleton of ice around the small voids can be destroyed by ramming.

Hole 2	**S7L1-24**	**Hole 3**	**S7L2-30**	**Hole 4**	**S7L3-3**	**Hole 1**	**Flat ice**
Freeboard	0.60		0.49		0.61		.3
Snow	0		0		0		0
Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel	Layer Bottom	Tip Feel
0.3	Snow	0.6	Hard	0.5	Hard	0.5	Hard
0.9	Hard	2.0	Soft	0.7	Void	0.7	Soft
1.8	Ram hard	2.7	Ram hard	1.0	Soft	2.0	Push
2.0	Soft	3.0	Push	1.2	Push		
				1.5	Soft		
				2.0	Push		
				3.0	Ram hard		

Table 5-20: Drilling Data, Site 7

5.7.4 Cores, Temperature and Salinity Profiles

A core was extracted from the ice to determine its vertical macrostructure. As the latter core was being retrieved, the "feel" of the auger was documented, the core barrel was emptied and the dimensions and consistency of the core were noted. The core fragments were then physically pieced together, the appearance of the full core was sketched and the core was sealed in a core-bag. Figure 5-64(a) shows the length of actual core that was taken from Site 7. The consolidated layer of ice was about 1.6 m, however only the uppermost 1.0 m of ice produced solid core. Below about 1.0 m, the ice consisted of soft, highly porous ice. A second core was extracted for temperature and salinity measurements, which are presented in Figure 5-64(b).

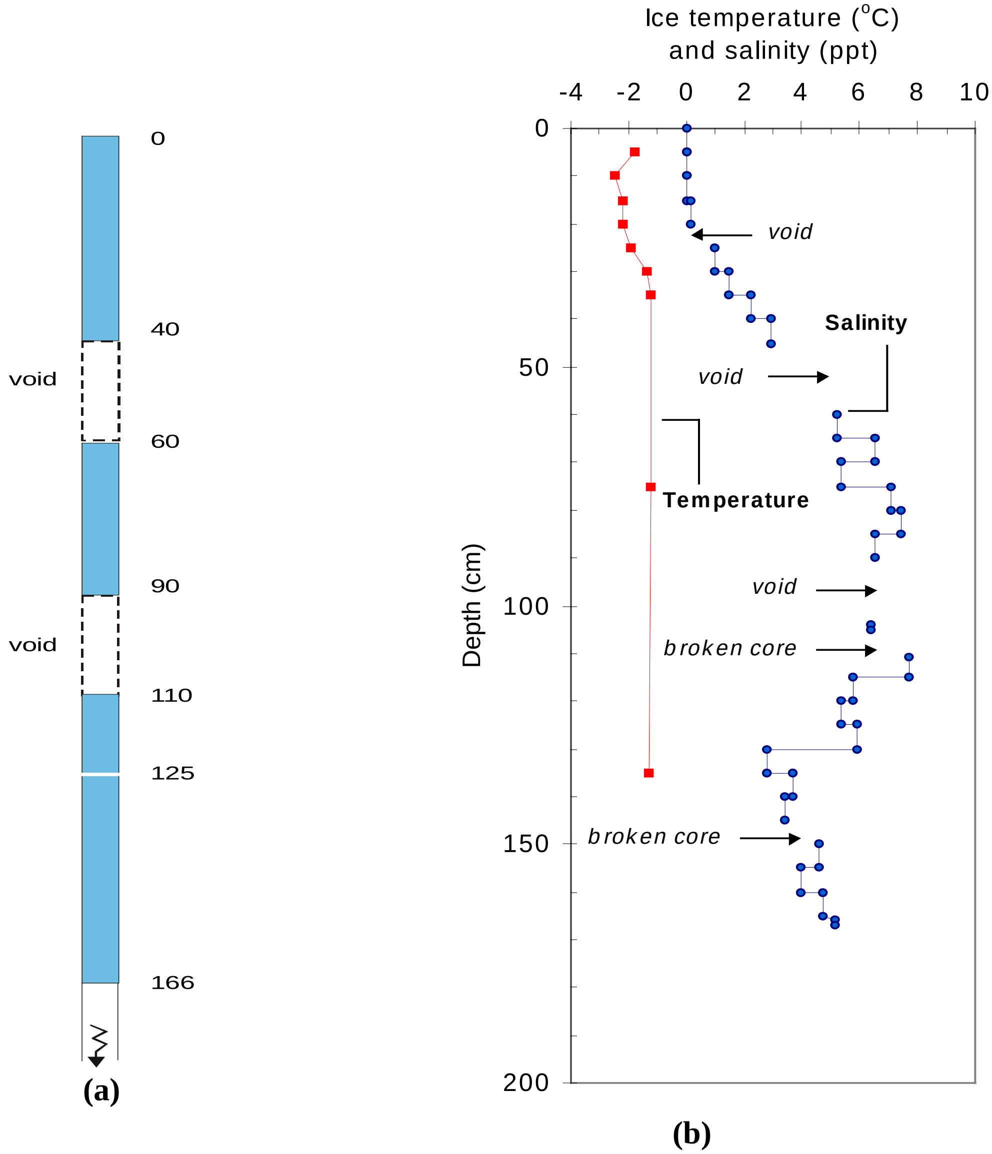


Figure 5-64: Site 7, (a) Ice Macrostructure and (b) Temperature and Salinity Profiles

5.8 Site 8 (51 18.98, 57 00.76)

On 15 March, the field party sampled a small, ridged floe (shown schematically in Figure 5-65) that was selected at Site 8. Three lines were surveyed to characterize the sail profile of Site 8, the results of which are presented in Figure 5-67, Figure 5-68 and Figure 5-69. Maximum height of the ridge was about 2.6m. The ice thickness was measured from two auger holes. The initial and final drift positions of the floe were recorded and later used to determine the drift speed of the floe. One core was extracted for measurements of ice temperature and salinity (Figure 5-73). Another core was extracted to determine the vertical profile of ice macrostructure and was retained for future crystallographic studies. The consolidated layer of ice from Site 8 (shown in Figure 5-72) consisted of broken pieces of solid core interspersed with soft, porous ice and voids.

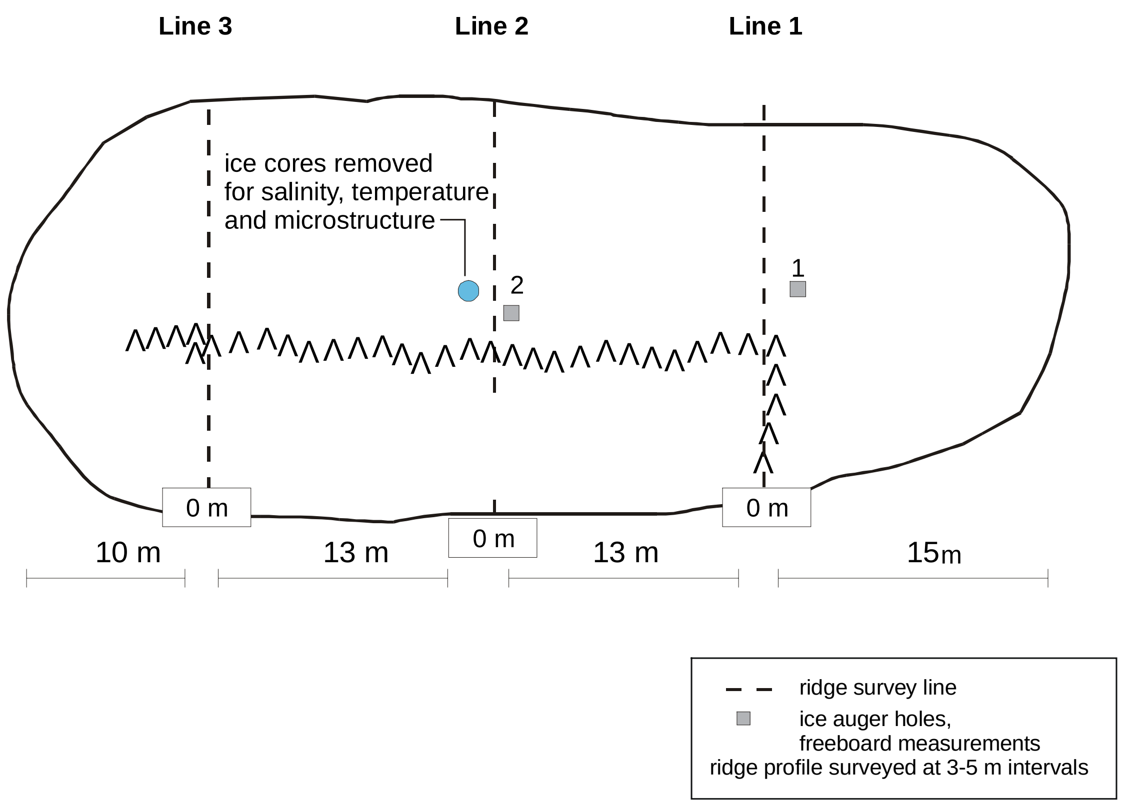


Figure 5-65: Schematic of Site 8

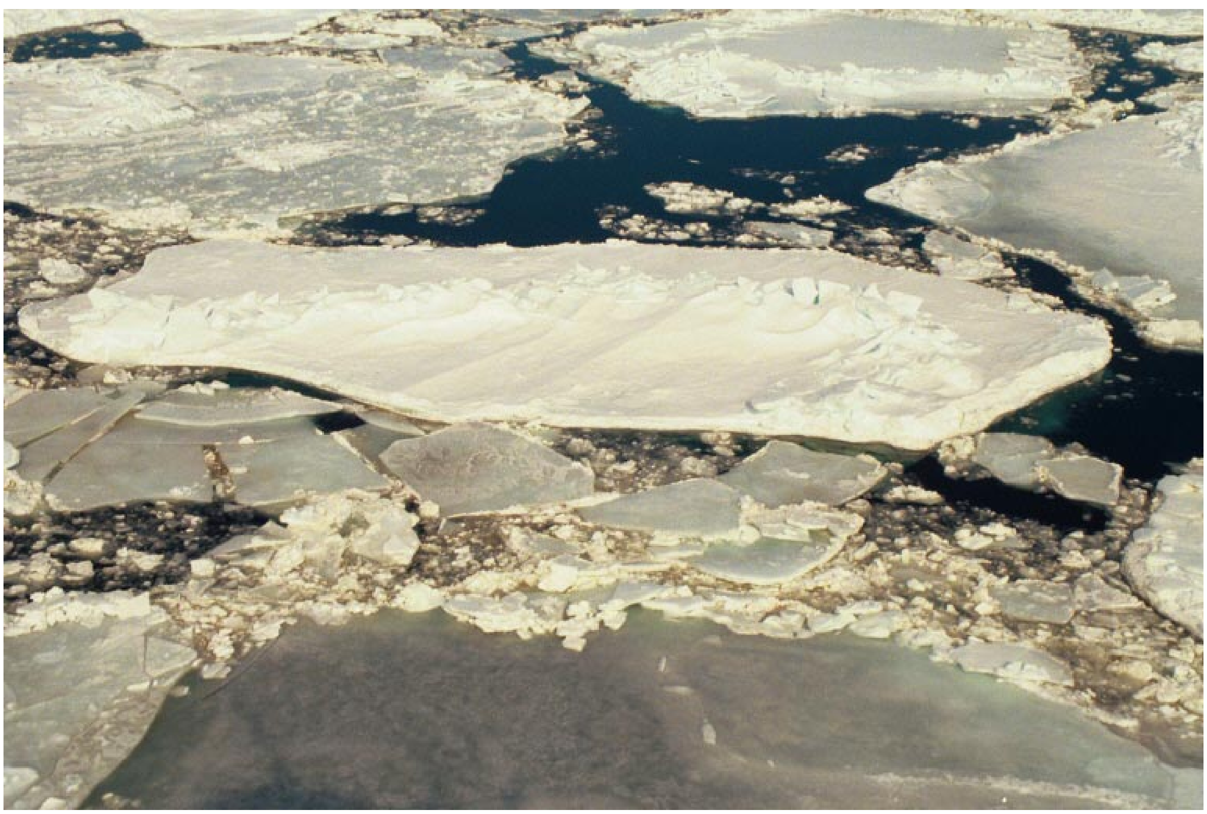


Figure 5-66: Photographs of Site 8

5.8.1 Surface profiles

Three lines were surveyed on Site 8, as shown in Figure 5-65.

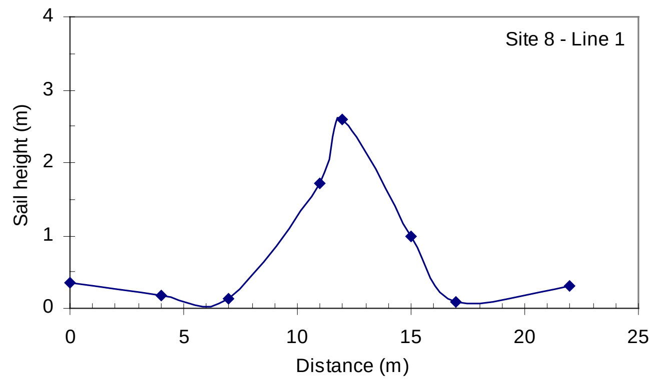


Figure 5-67: Line 1, Site 8

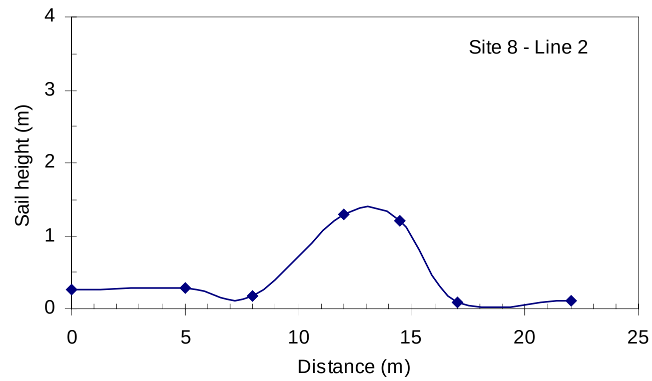


Figure 5-68: Line 2, Site 8

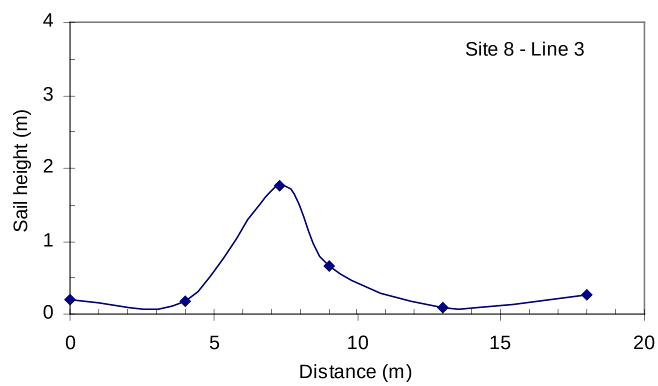


Figure 5-69: Line 3, Site 8

5.8.2 Sail Blocks Sizes

A total of 26 sail blocks were measured at Site 8. The block size distributions are shown in Figure 5-70 and Figure 5-71. Details of the block size measurements are given in Table 5-21 Blocks thickness at Site 8 was relatively uniform with 62% of the blocks between 0.25 and 0.35m.

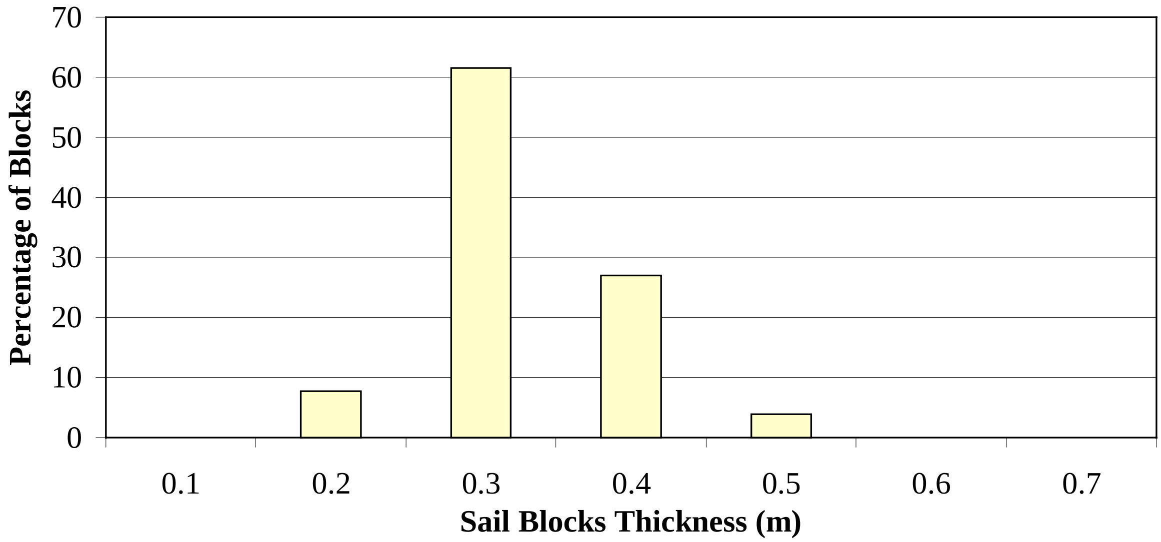


Figure 5-70: Sail Blocks Thickness Distribution, Site 8

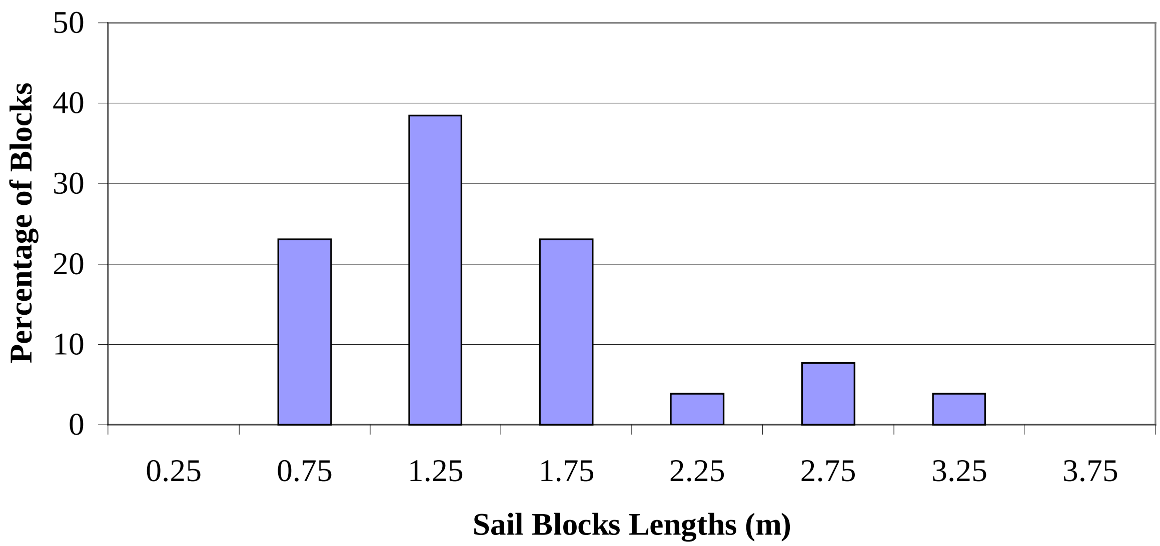


Figure 5-71: Sail Blocks Length Distribution, Site 8

Block	Thickness	Length	Width	Block	Thickness	Length	Width
#	**T (m)**	**L(m)**	**W(m)**	**#**	**T (m)**	**L(m)**	**W(m)**
1	0.26	0.68	0.45	15	0.4	1.42	0.92
2	0.25	0.81	0.55	16	0.35	1.45	1.16
3	0.25	0.87	0.78	17	0.26	1.55	1.18
4	0.38	0.88	0.6	18	0.32	1.66	0.69
5	0.25	0.9	0.74	19	0.23	1.67	0.8
6	0.36	0.98	0.88	20	0.34	1.7	1.42
7	0.32	1.02	0.94	21	0.19	1.83	1.32
8	0.31	1.03	0.74	22	0.41	1.91	1.4
9	0.26	1.15	0.7	23	0.4	2.45	2.16
10	0.30	1.2	0.87	24	0.28	2.62	1.52
11	0.26	1.22	1.14	25	0.53	2.71	1.8
12	0.38	1.24	1.2	26	0.32	3.3	1.57
13	0.30	1.26	1.1	**AVG.**	**0.31**	**1.50**	**1.06**
14	0.26	1.39	0.97	**L/T=**	**4.87**	**L/W=**	**1.43**

Table 5-21: Sail Blocks Size Measurements, Site 8

5.8.3 Consolidated Layer Data

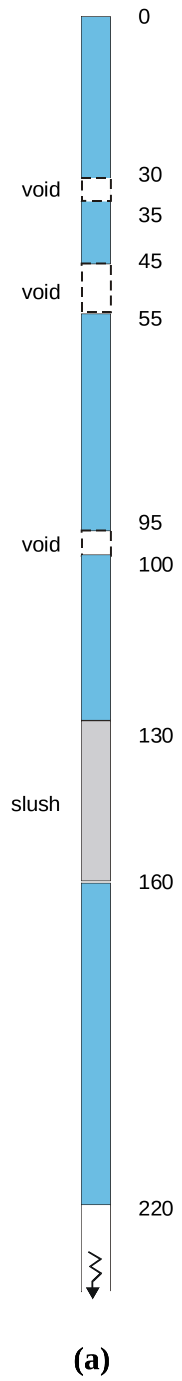
Consolidated layer thickness estimates based on drilling were 1.5m and 1.1m including the hard snow layer (actually this "snow" layer was more like a rotten ice layer, and as such, it has been included in the consolidated layer).

	S8L1		**S8L2**
Freeboard			
Snow	0.25		
Layer Bottom	Tip Feel	Layer Bottom	Tip Feel
0.25	Snow	0.25	Snow
1.0	Hard	1.1	Hard
1.5	Soft	1.8	Push hard
1.8	Push	2.2	Soft
		3.00	Ram

Table 5-22: Drilling Data, Site 8

Figure 5-72: Core of Consolidated Layer Retained for Crystallography, Site 8

5.8.4 Cores, Temperature and Salinity Profiles



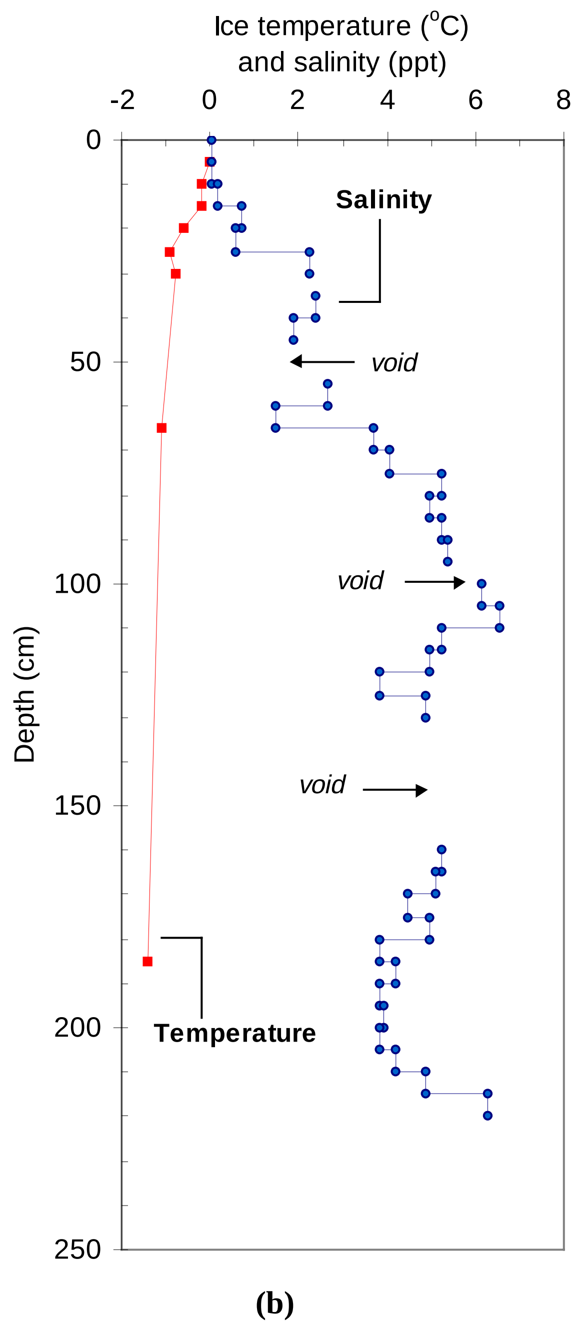


Figure 5-73: Site 8, (a) Ice Macrostructure and (b) Temperature and Salinity Profiles

5.9 Site 9 (51° 19.62, 56° 48.01)

Site 9 was sampled between 15:30 and 17:30 on 15 March. Figure 5-74 shows a schematic of Site 9. Three lines were surveyed across the ridge, the profiles of which are shown in Figure 5-75, Figure 5-76 and Figure 5-77. Maximum sail height was 1.5m. The ice thickness was measured from one auger hole and the initial and final drift positions of the floe were recorded. Again, two cores were extracted, one for temperature and salinity (Figure 5-80) and the other for inspection of the ice macrostructure and future crystallographic work (by NRC).

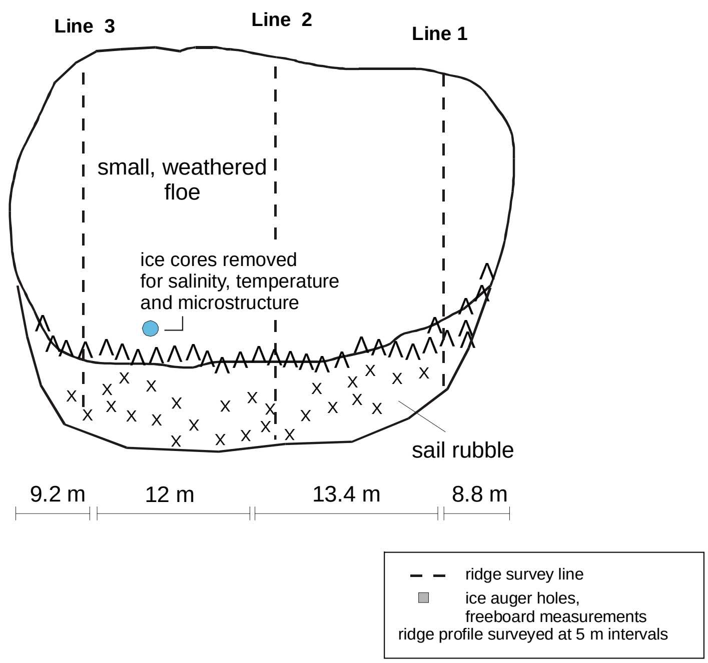


Figure 5-74: Schematic of Site 9

5.9.1 Surface profiles

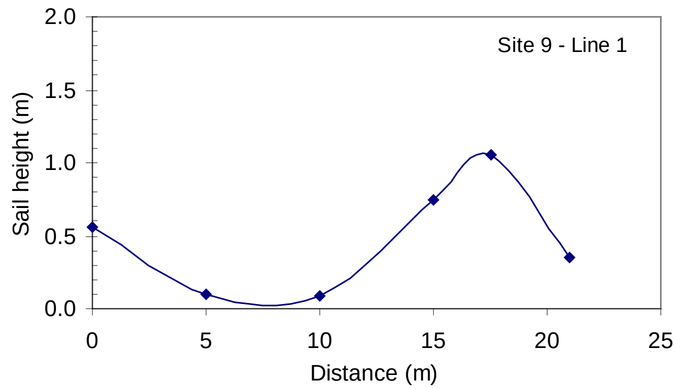


Figure 5-75: Site 9, Line 1

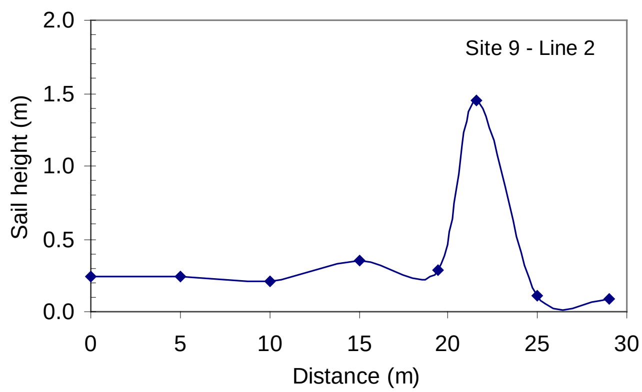


Figure 5-76: Site 9, Line 2

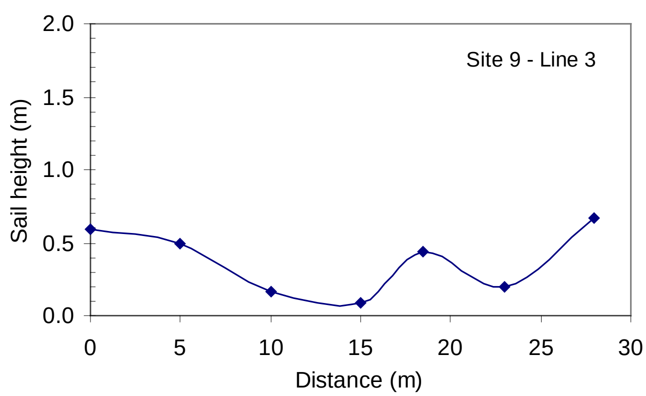


Figure 5-77: Site 9, Line 3

5.9.2 Consolidated Layer Data

An estimate of consolidated layer thickness based on drilling was 1.7m.

	S9L1
Freeboard	
Snow	0
Layer Bottom	Tip Feel
1.0	Hard
1.7	Soft
2.5	Push
3.0	Push

Table 5-23: Drilling Data, Site 9

5.9.3 Block Sizes

A total of 41 sail blocks were measured. The block size distributions are shown in Figure 5-78 and Figure 5-79. Average block thickness was 0.2m with very few blocks of different thicknesses. Block length over thickness ratio averaged 5.5.

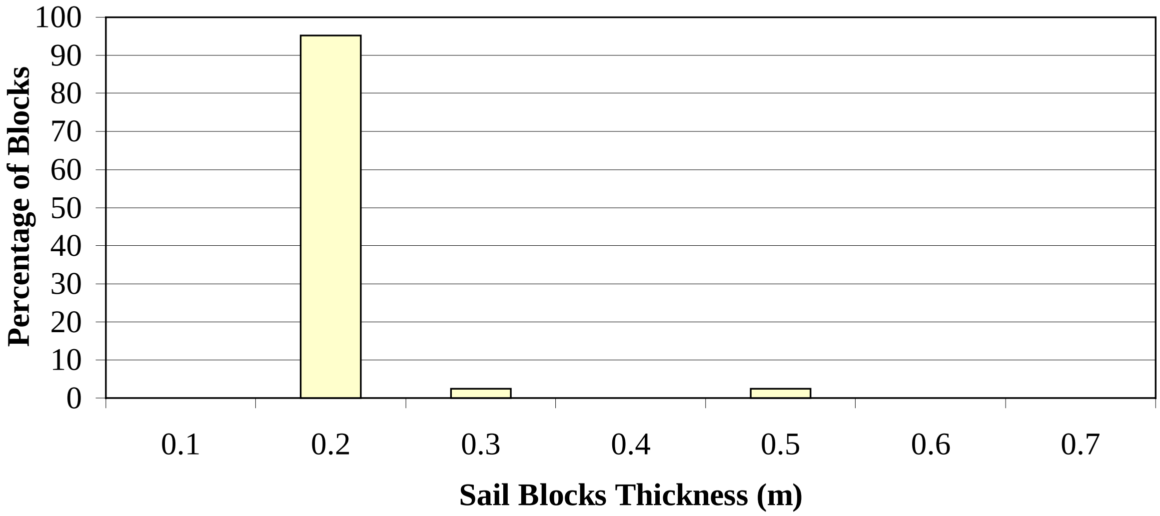


Figure 5-78: Sail Blocks Thickness Distribution, Site 9

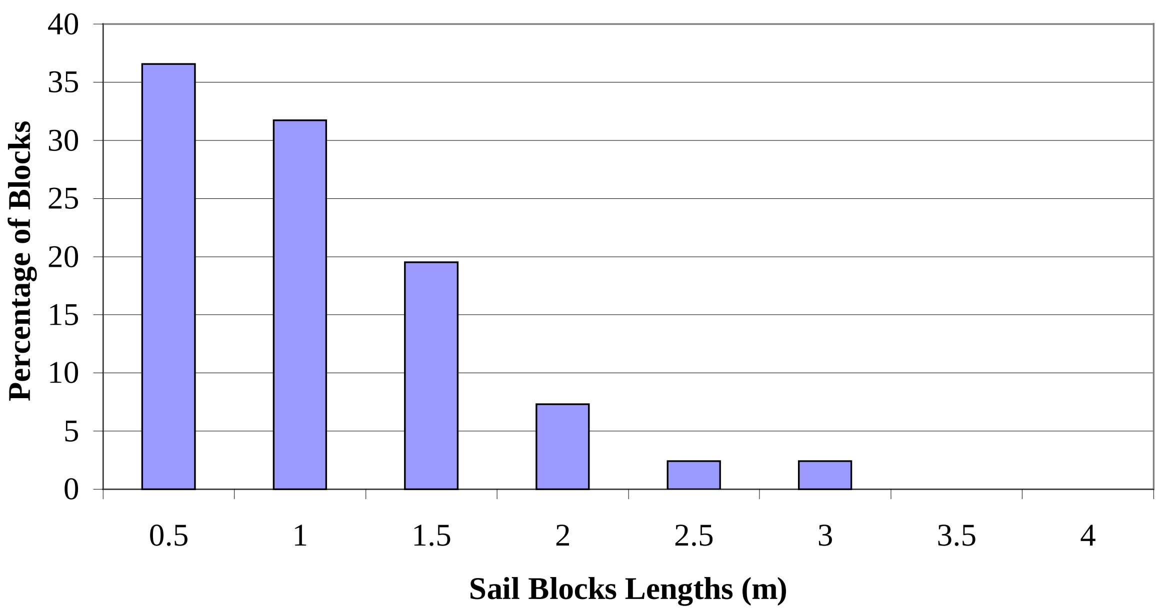


Figure 5-79: Sail Blocks Length Distribution, Site 9

Block	Thickness	Length	Width	Block	Thickness	Length	Width
#	**T (m)**	**L(m)**	**W(m)**	**#**	**T (m)**	**L(m)**	**W(m)**
1	0.20	0.30	0.52	23	0.23	0.99	1.24
2	0.18	0.40	1.2	24	0.17	1.0	0.8
3	0.18	0.45	0.4	25	0.2	1.1	1.06
4	0.18	0.5	0.75	26	0.2	1.1	1.2
5	0.16	0.52	0.3	27	0.18	1.2	1.55
6	0.19	0.56	1.12	28	0.18	1.2	1.1
7	0.17	0.60	1	29	0.19	1.28	0.95
8	0.18	0.60	0.58	30	0.18	1.3	1.8
9	0.20	0.63	0.81	31	0.20	1.4	1.1
10	0.17	0.64	1.2	32	0.18	1.48	1.1
11	0.18	0.67	0.95	33	0.17	1.5	1.1
12	0.18	0.69	0.9	34	0.22	1.6	1
13	0.17	0.7	1.2	35	0.18	1.7	1.15
14	0.18	0.7	1.1	36	0.46	1.7	1.25
15	0.21	0.7	1.35	37	0.17	1.8	0.78
16	0.17	0.8	2.2	38	0.2	1.88	1.17
17	0.18	0.8	0.7	39	0.2	1.9	1.24
18	0.2	0.8	0.6	40	0.22	2.7	1.1
19	0.18	0.83	1.09	41	0.25	2.9	2.4
20	0.22	0.86	1.87				
21	0.22	0.86	0.62	**AVG.**	**0.20**	**1.32**	**0.87**
22	0.18	0.9	1.8	**L/T=**	**6.77**	**L/W=**	**1.57**

Table 5-24: Sail Blocks Size Measurements, Site 9

5.9.4 Cores, Temperature and Salinity Profiles

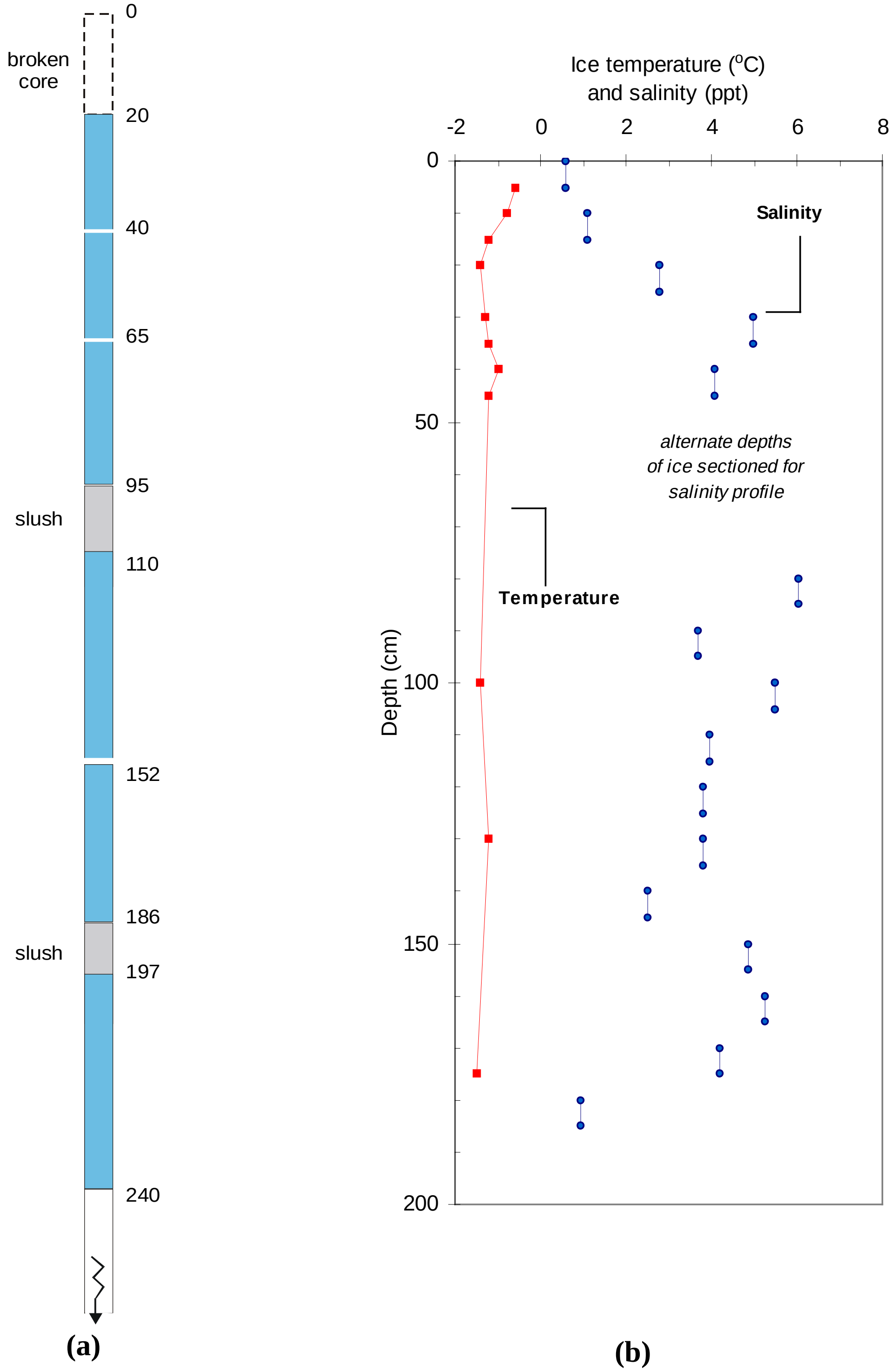


Figure 5-80: Site 8, (a) Ice Macrostructure and (b) Temperature and Salinity Profiles

5.10 Site 10 (51°04, 56°53)

Due to the deteriorating weather, the field party was unable to fly offshore after 15 March. As a result, equipment was tested in the level bay ice (about 200 m offshore) at Plum Point. Level ice in the bay was 0.71 m thick, from which one core was extracted for temperature and salinity measurements (Figure 5-81) and another core was retained for ice crystallography. The *in situ* measurements of ice strength indicated that the maximum crushing strength of the level bay ice was about 11 MPa.

5.10.1 Temperature and Salinity Profiles

Two cores were used for temperature and salinity profiles. Salinities were generally low, but the higher salinities seem to correspond to the higher densities.

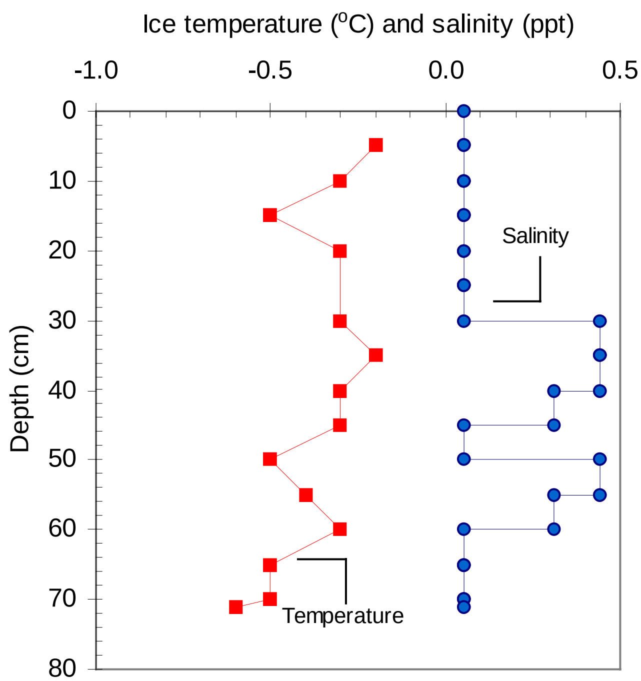


Figure 5-81: Ice Temperature and Salinity from Site 10

5.10.2 Density Measurements

Four density measurements were made at Site 10, for comparison with hot point drill data. Water density was close to that of fresh water. Note that the upper part of the core was snow ice and had a lower density.

Sample #	Depth (m)	Weight water (g)	Weight water + Ice (g)	Weight block under water	WL, block under (ml)	WL, no ice (ml)	Hygrom reading	Avg. length (cm)	Avg. diam. (cm)	Bulk volume (cm3)	Bulk density (g/ml)	Submerged density (g/ml)	Bulk buoyancy (g/ml)
2	-0.19	1401	2447	2580	2050	803	1.001	15.4	9.9	1179	0.887	0.894	0.113
3	-0.33	1470	2333	2408	1890	925	1.001	11.6	10.2	942	0.916	0.923	0.080
4	-0.45	1449	2397	2483	1970	900	1.001	13.1	10.1	1046	0.907	0.921	0.082
5	-0.66	1391	1858	1897	1360	825	1.001	7.1	9.5	505	0.925	0.928	0.077

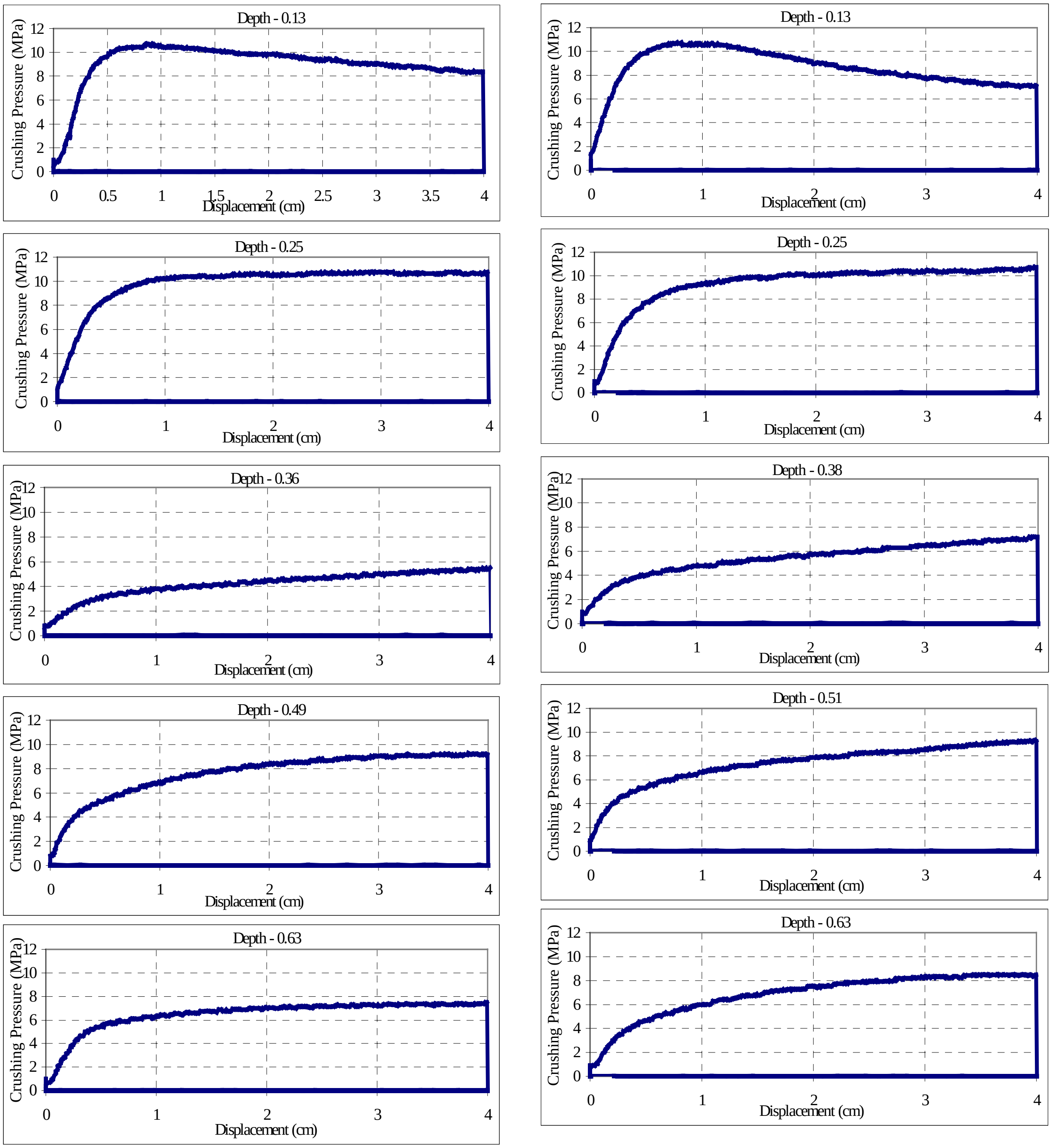
Table 5-25: Density Measurements, Site 10

5.10.3 Borehole Jack Data

Six borehole jack profiles were conducted at Site 10, the results of which are shown in Figure 5-82, Figure 5-83, and Figure 5-84.. The pressures indicated in Table 5-26 are the maximum pressures reached by the borehole jack before an extension of 35mm. The six profiles are quite similar, showing good test repeatability. The minimum strength at the -0.39 level is related to the higher ice salinity.

	Ice Crushing Pressure (MPa)						
Depth Below Ice Surface (m)	Hole 1	Hole 2	Hole 3	Hole 4	Hole 5	Hole 6	Average
-0.13	10.7	10.7	9.5	10.6	10.3	11.1	10.5
-0.26	10.8	10.4	9.9	10.9	10.6	9	10.3
-0.39	5.3	6.8	8.8	8.9	9.8	9.8	8.2
-0.52	9.2	9	9.1	9.6	8.9	8.2	9.0
-0.65	7.4	8.5	8.4	5.9	7.2	6.4	7.3

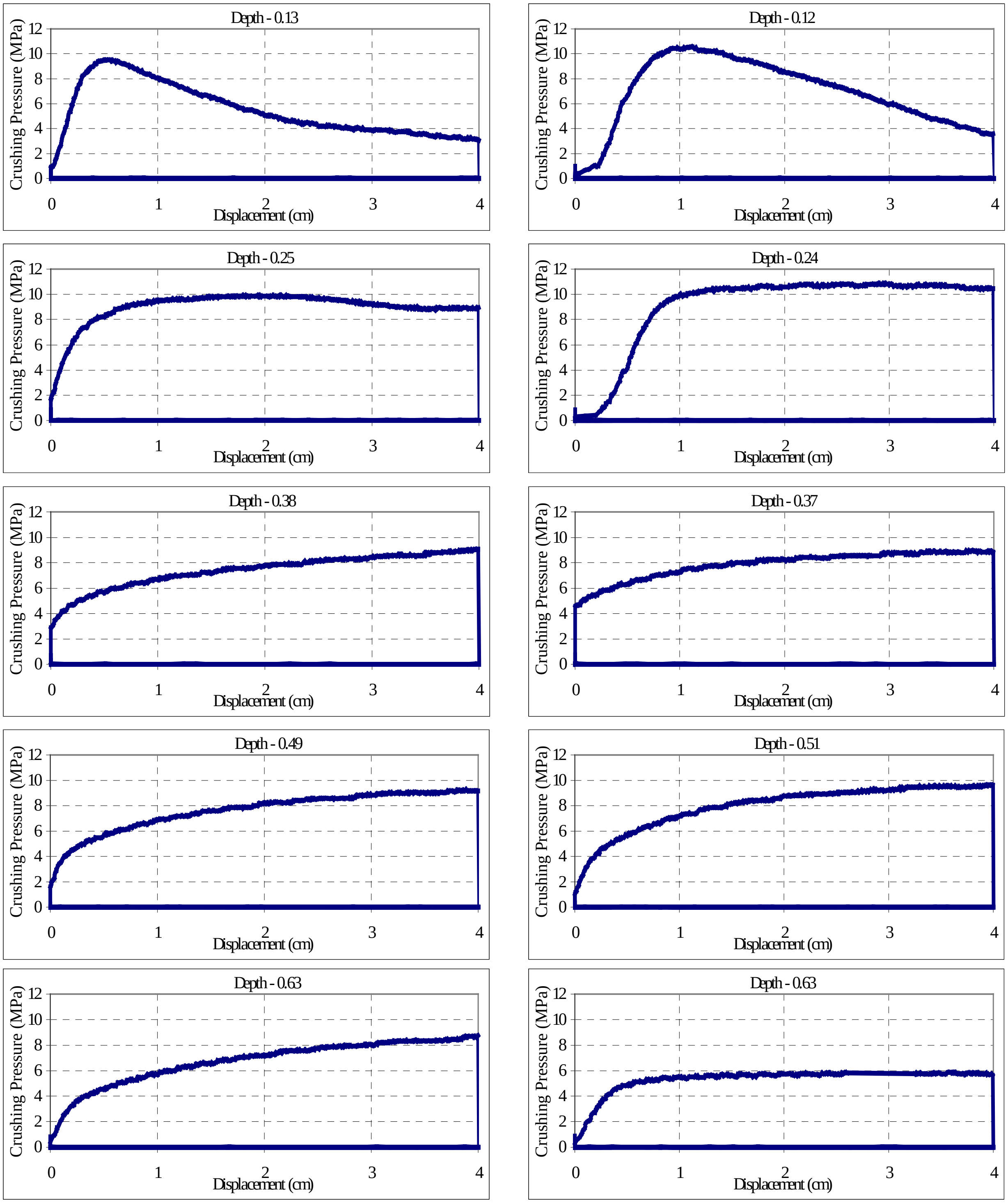
Table 5-26: Summary of Borehole Jack Data, Site 10



Site 10 - Hole 1

Site 10 - Hole 2

Figure 5-82: Borehole Jack Test Results, Site 10, Hole 1 & 2



Site 10 - Hole 3

Site 10 - Hole 4

Figure 5-83: Borehole Jack Test Results, Site 10, Holes 3 & 4

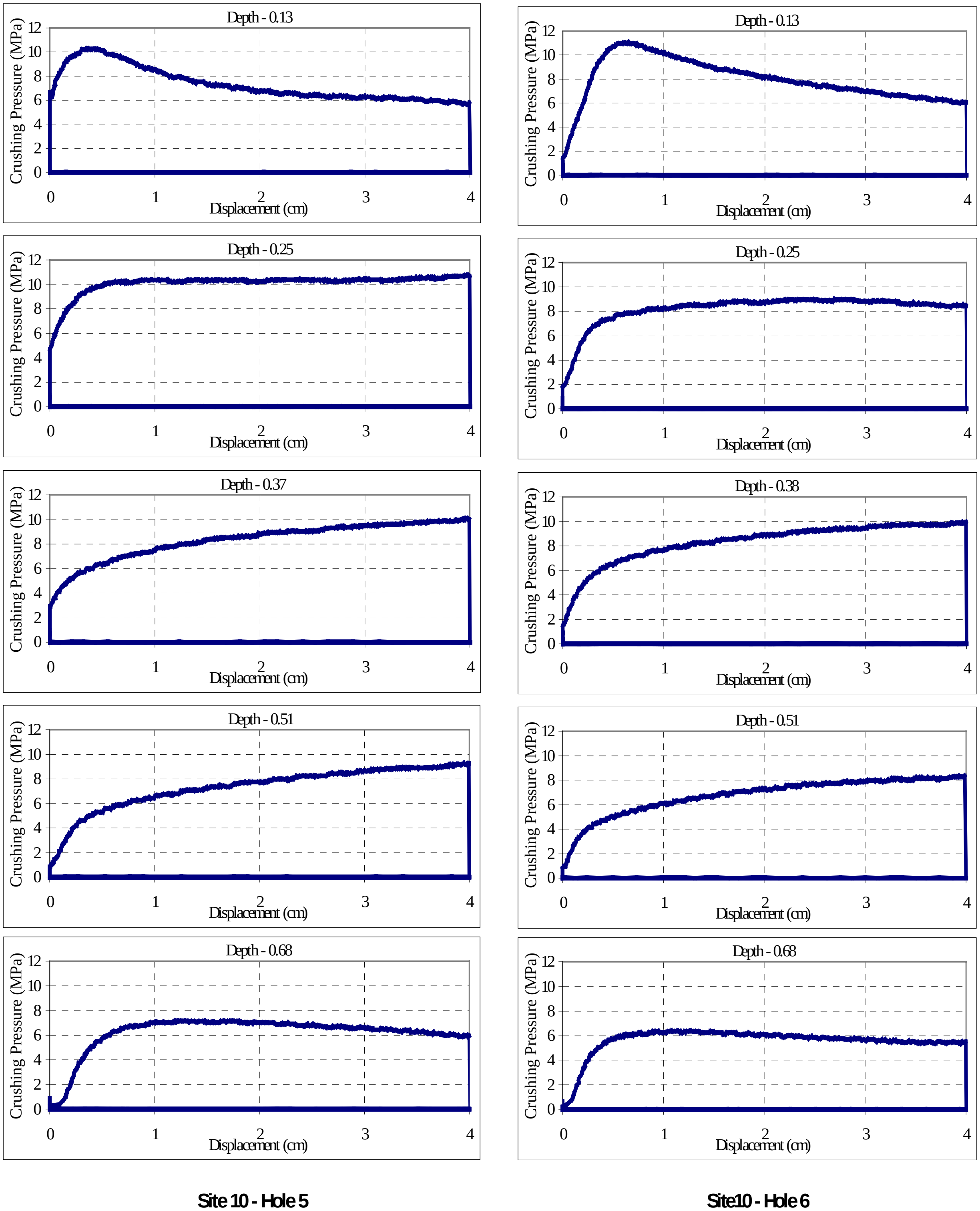


Figure 5-84: Borehole Jack Test Results, Site 10, Holes 5 & 6

5.10.4 Hot Point Drill Data

Hot point drill measurements were carried out on the level ice in Plum Point Bay, as well as in the active zone near a pier on the shore of Plum Point Bay. On the level ice, 9 profiles adjacent to borehole jack tests were obtained, as well as two power tests. Profile pp6 (Figure 5-85) is shown here as it is representative of the ice in the area. The other profiles 8 are included in Volume 2, as they are related to hot point drill porosity calibrations. Note that there appears to a similarity between hot point drill profile and the salinity profile, with the higher salinity sections corresponding to higher drill velocities.

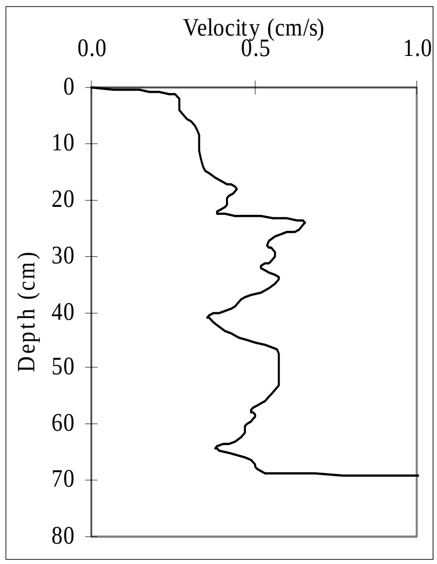


Figure 5-85: Hot Point Drill Profile PP6, Site 10

5.11 Site 11 Otter Pond (51^o04, 56^o53)

Inclement weather on 19 March did not allow access to the ice offshore. The field party moved to Otter Pond, a small lake near Plum Point (accessible from the road), for continued testing of the equipment. Borehole jack profiles of the ice were performed at 6 holes (depth intervals of 0.13m, 0.25m, 0.49m and 0.63 m). The maximum *in situ* ice failure stress was 11 MPa at a depth of 0.13 m (displacement of 10 mm).

Figure 5-86: Photograph of Site 11 (Otter Pond)

5.11.1 Density Measurements

Five density measurements were obtained at Site 11, for comparison with hot point drill data Only bulk density was measured, based on sample size and weight. The data are presented in Table 5-27. Note that the ice near the surface had many air bubbles (see Figure 5-87), resulting in a relatively low ice density.

	sample	depth	weight	Avg.	Avg.	Bulk	Bulk
		m	of sample	length	diameter	volume	density
hole 3	a	-0.105	1349	20.848	9.77	1563	0.863
	b	-0.26	689	10.628	9.825	806	0.855
hole 2	a	-0.07	909	14.498	9.7975	1093	0.832
	b	-0.3	855	13.178	9.745	983	0.870
hole 1	a	-0.06	833	12.635	9.775	948	0.878
						Average	0.86

Table 5-27: Density Measurements, Site 11

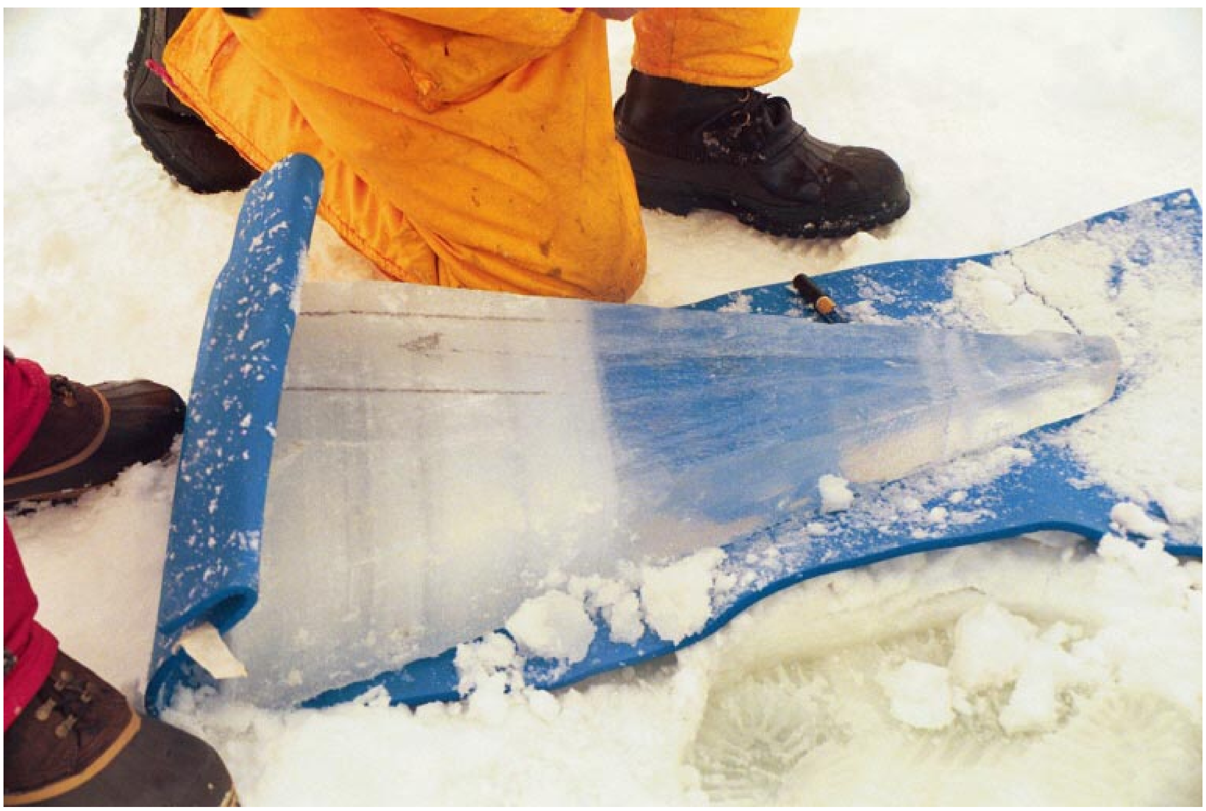


Figure 5-87: Vertical Cross-section of Ice Cover, Site 11

5.11.2 Borehole Jack Data

Three borehole jack profiles were done at Site 11, as shown in Table 5-28. . The pressures indicated in Table 5-28 are the maximum pressures reached by the borehole jack before the maximum platen extension of 35mm. The three strength profiles are quite similar, showing good test repeatability. The low strength at the -0.13 level is a result of flaking at the surface.

	Ice Crushing Pressure (MPa)		
Depth Below Ice Surface(m)	Site 11 Hole 1	Site 11 Hole 2	Site 11 Hole 3
-0.13	3.58	3.71	7.37
-0.26	12.13	11.41	11.96
-0.39	18.65	13.68	13.10
-0.52	17.60	22.86	19.79
-0.65	18.99	5.90	9.10

Table 5-28: Borehole Jack Data Summary, Site 11

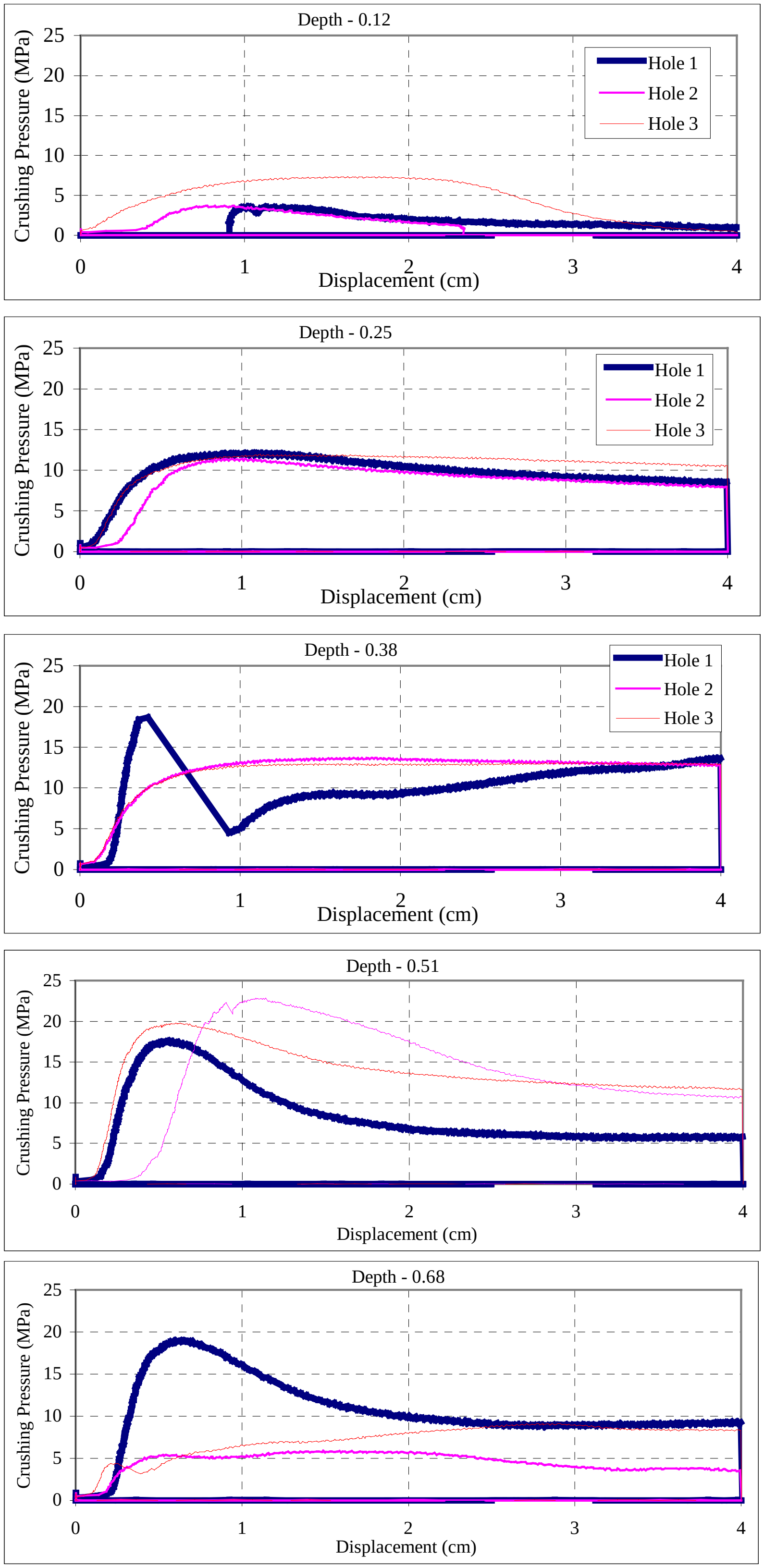


Figure 5-88: Borehole Jack Test Results, Site 11, Holes 1, 2 & 3

5.11.3 Hot Point Drill Data

Hot point drill measurements were carried out on level lake ice with a thickness of about 0.80 m. Four profiles were done near each borehole jack test hole, as well as 4 profiles near the saw cuts where full thickness ice samples were extracted for inspection.

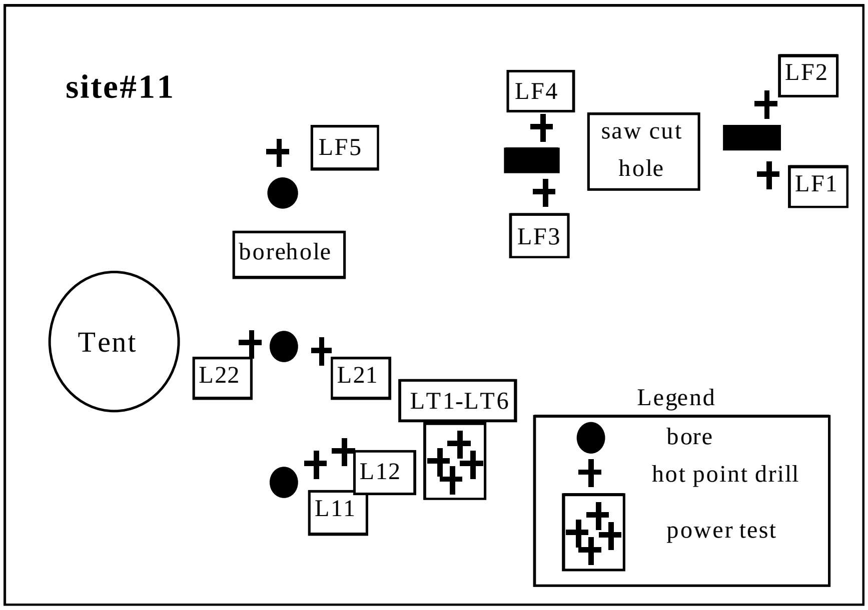


Figure 5-89: Hot Point Drill Profile Locations, Site 11

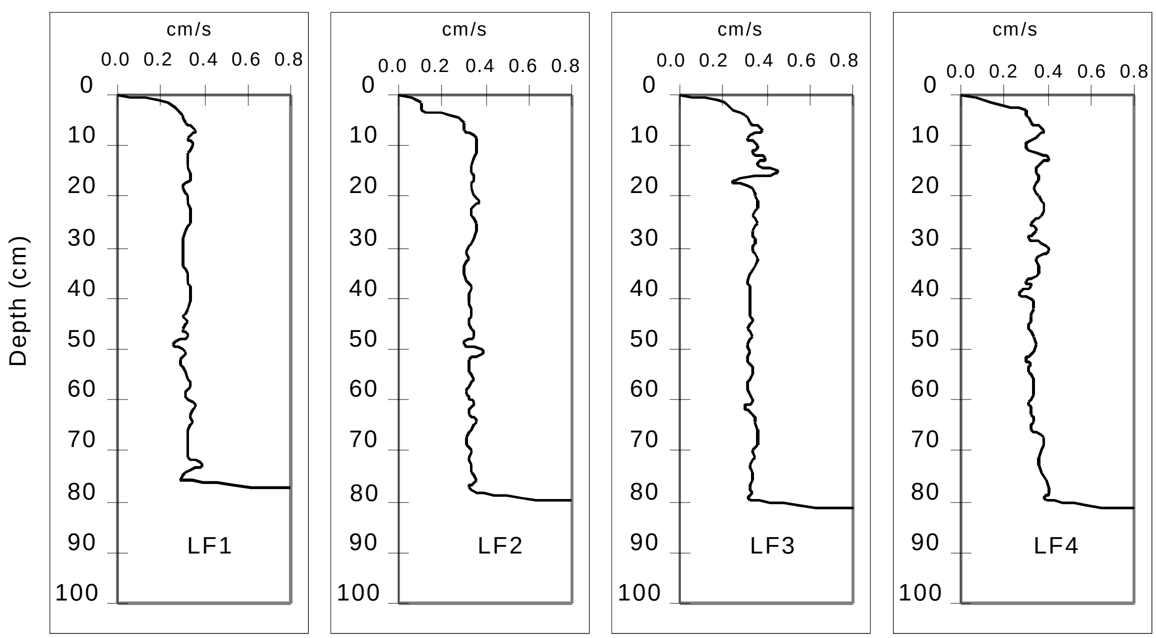


Figure 5-90: Hot Point Drill Profiles Near Ice Sample Locations, Site 11

5.12 Site 12 Eddy's Cove (51°25, 56°27)

The late afternoon of 19 March and the morning of 20 March were spent examining Site 12, which was accessible from the road (Figure 5-92). Site 12 was a landfast, first year ridge (Figure 5-92) that was located near the community of Eddy's Cove. The ridge was about 2.5 m high and was grounded in 5 m of water (see Figure 5-93). Ice cores were extracted for temperature and salinity measurements (Figure 5-98) and future crystallographic work. The *in situ* ice failure strength was tested, yielding a maximum borehole jack strength of about 10 MPa.

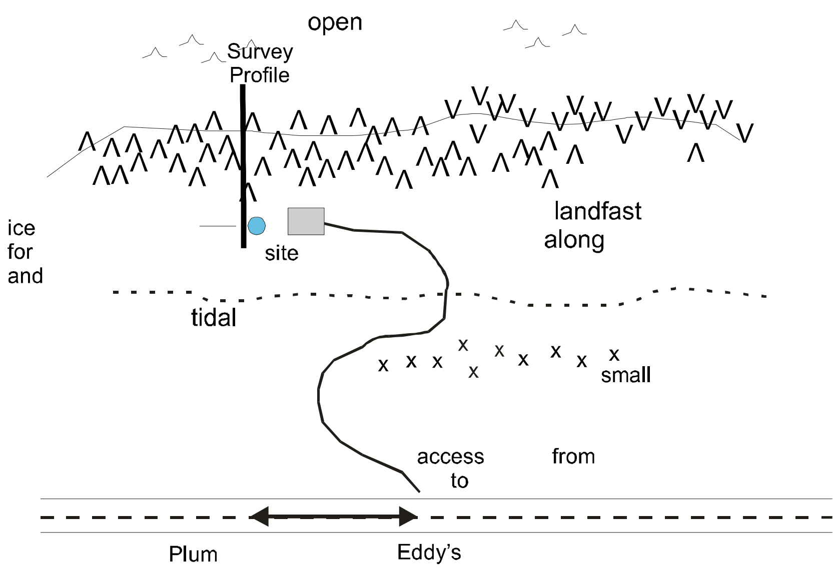


Figure 5-91: Schematic of Site 12

Figure 5-92: Measurements on the Landfast Ridge of Site 12

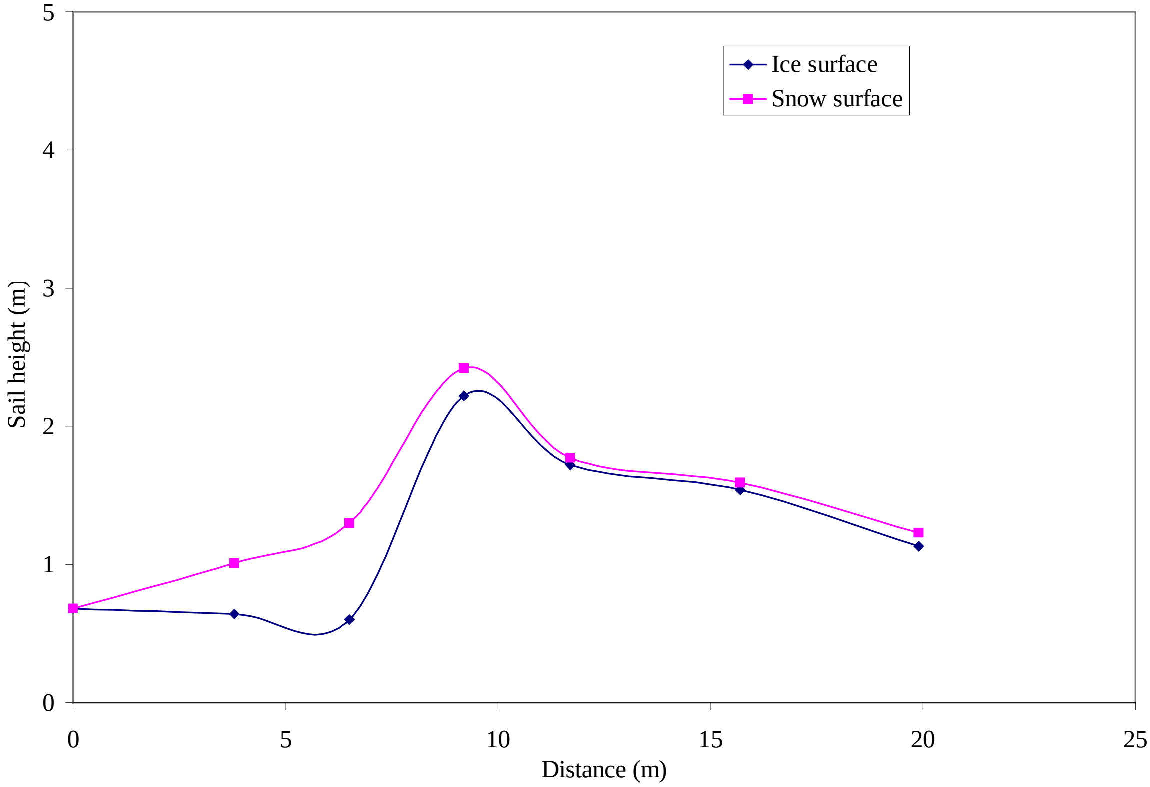


Figure 5-93: Surface Profile, Site 12

5.12.1 Ridge profiles & block sizes

A total of 32 sail blocks were measured. Block size data is presented in Figure 5-94. The thickness and length distributions of the sail blocks are shown in Figure 5-94 and Figure 5-95.

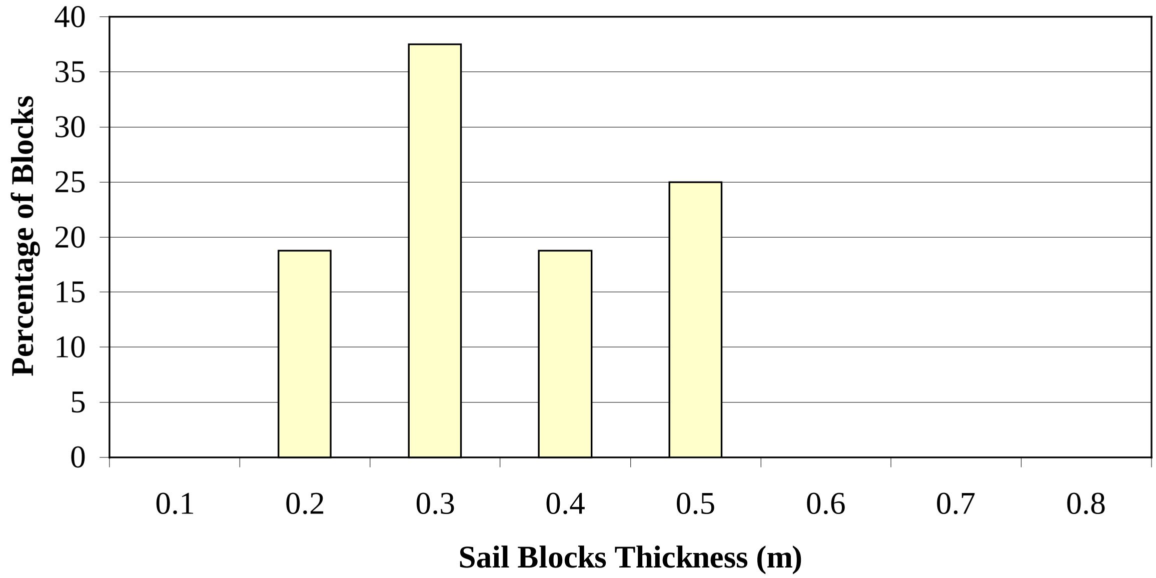


Figure 5-94: Sail Blocks Thickness Distribution, Site 12

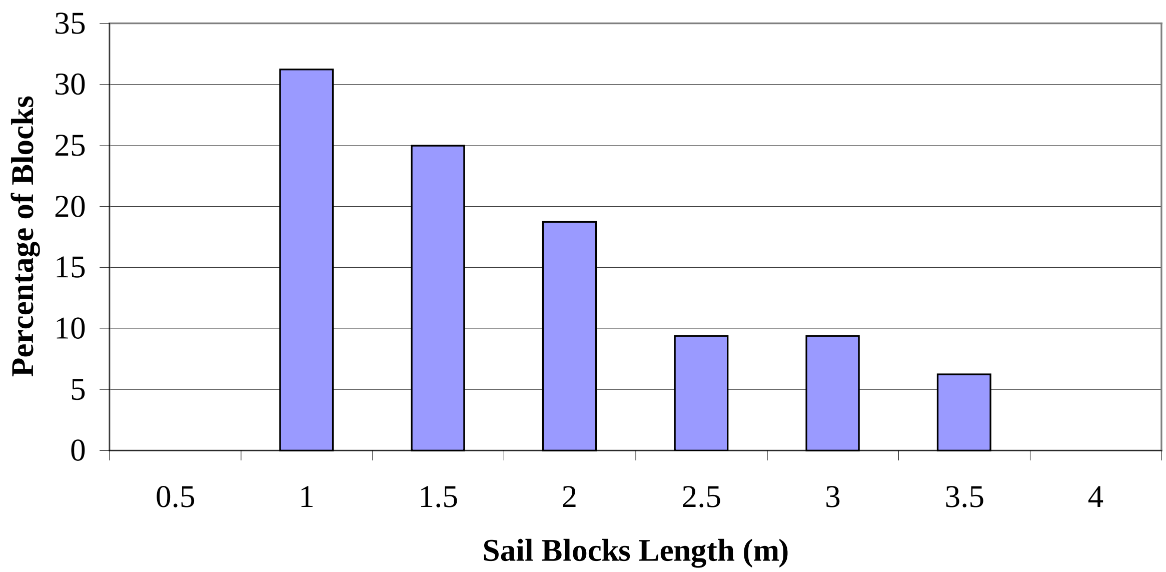


Figure 5-95: Sail Blocks Length Distribution, Site 12

Block #	H (m)	L (m)	W (m)	Block #	H (m)	L (m)	W (m)
1	0.3	0.9	0.6	18	0.3	1.7	1.3
2	0.27	1.1	0.7	19	0.4	1.8	1.3
3	0.30	1.1	1.0	20	0.2	2.0	1.2
4	0.35	1.1	0.9	21	0.35	2.0	1.2
5	0.20	1.2	0.8	22	0.5	2.0	1.5
6	0.22	1.2	1.0	23	0.2	2.1	1.3
7	0.30	1.2	0.8	24	0.4	2.2	1.6
8	0.33	1.2	1.2	25	0.4	2.3	1.4
9	0.40	1.2	1.1	26	0.5	2.5	2.4
10	0.50	1.2	0.9	27	0.5	2.5	1.5
11	0.20	1.5	1.2	28	0.2	2.8	1.7
12	0.26	1.6	1.3	29	0.5	2.8	1.4
13	0.27	1.6	1.1	30	0.4	3	1.7
14	0.30	1.6	1.3	31	0.5	3.5	2.8
15	0.35	1.6	1.3	32	0.5	3.5	2.7
16	0.40	1.6	1.0	**Average**	**.35**	**1.85**	**1.32**
17	0.50	1.6	1.0	**L/H=**	**5.24**	**L/W=**	**1.4**

Table 5-29: Sail Blocks Size Measurements, Site 12

5.12.2 Hot Point Drill Data

The hot point drill measurements were carried out on a grounded ice ridge formed in a shear zone, about 100 metres from the coast. A total of 5 hot point drill profile holes were obtained. Three profiles were in area of the tidal cracks near to the borehole jack test, and 2 profiles were done near the ridge peak. During the last profile, the heater failed at a depth of about 5 metres. Drilling continued after its replacement.

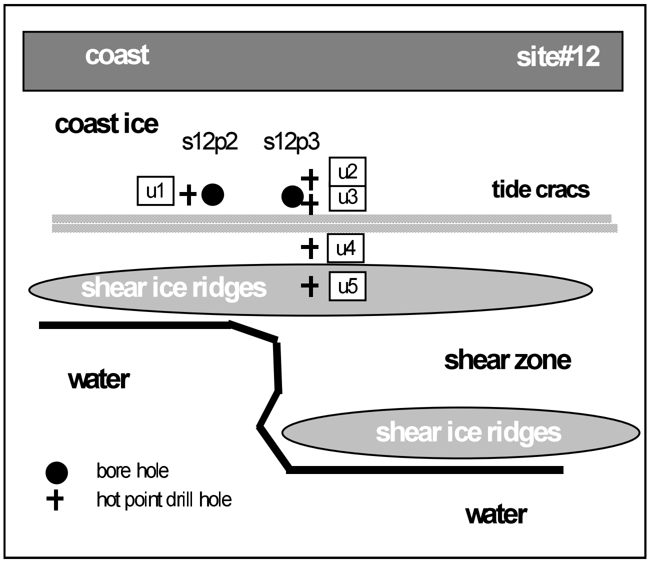


Figure 5-96: Hot Point Drill Hole Locations, Site 12

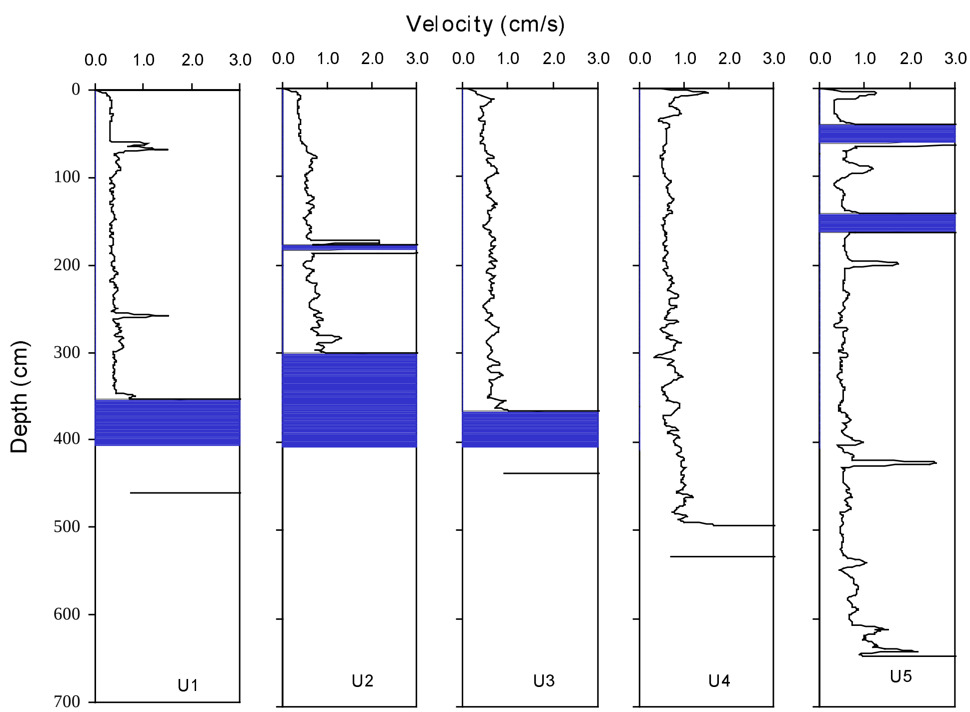


Figure 5-97: Hot Point Drill Profiles, Site 12

5.12.3 Cores, Temperature and Salinity profiles

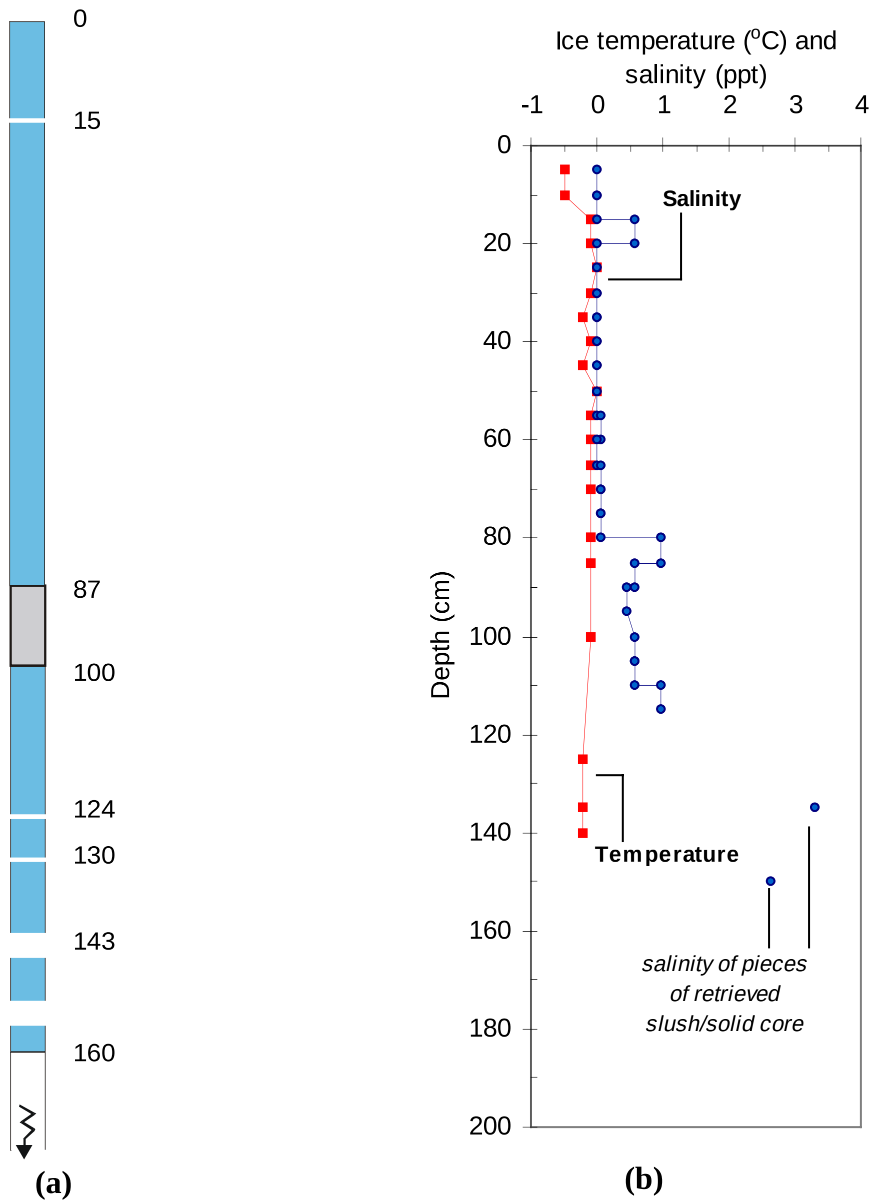


Figure 5-98: Site 12, (a) Ice Macrostructure and (b) Temperature and Salinity Profiles

5.12.4 Borehole Jack Data

Three borehole jack profiles were done at Site 12. The results are shown in Figure 5-99, Figure 5-100, and Figure 5-101. A summary of the results is shown in Table 5-30 The maximum borehole jack pressure reached was 10.6 MPa near the ice surface, which is typical for deteriorating first-year or fresh water ice. The pressures indicated in Table 5-30 are the maximum pressures reached by the borehole jack before the maximum platen extension of 35mm. Note that a pressure of 0.2 MPa is required to move the piston at no load.

The data can be interpreted in terms of consolidated layer thickness. Assuming that a maximum pressure of 1MPa indicates the bottom of the consolidated layer, the estimated thicknesses would be 1.9m, 2.1m and 1.7m for holes 1, 2 and 3 respectively. In hole 3, the low pressure obtained at –1.25m might not be taken into account, as the pressure obtained at the next level down was quite high. This is a judgement call.

	Crushing Pressure (MPa)		
Depth Below Ice Surface (m)	Site 12 Hole 1	Site 12 Hole 2	Site 12 Hole 3
-0.25	10.40	10.06	9.69
-0.50	10.40	9.64	10.28
-0.75	4.51	2.07	2.66
-1.00	2.11	3.37	2.49
-1.25	1.94	2.70	0.76
-1.50	1.94	3.37	3.63
-1.75	1.98	2.91	0.76
-2.00	0.89	1.56	0.93
-2.25	0.97	0.05	1.23
-2.50	0.89	0.00	1.31
-2.75	1.10	0.81	0.89
-3.00	0.81	0.05	0.89

Table 5-30: Borehole Jack Data Summary, Site 12

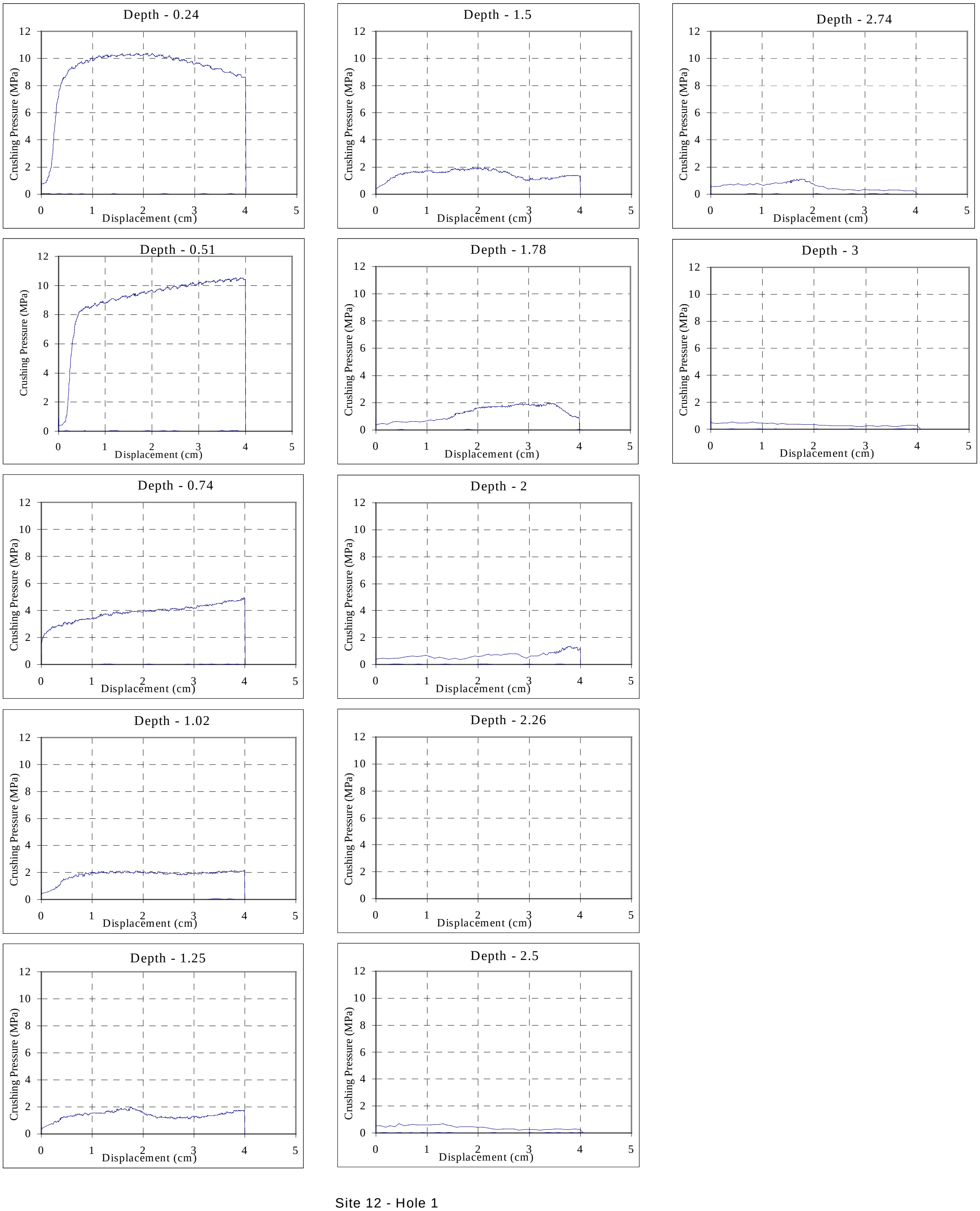
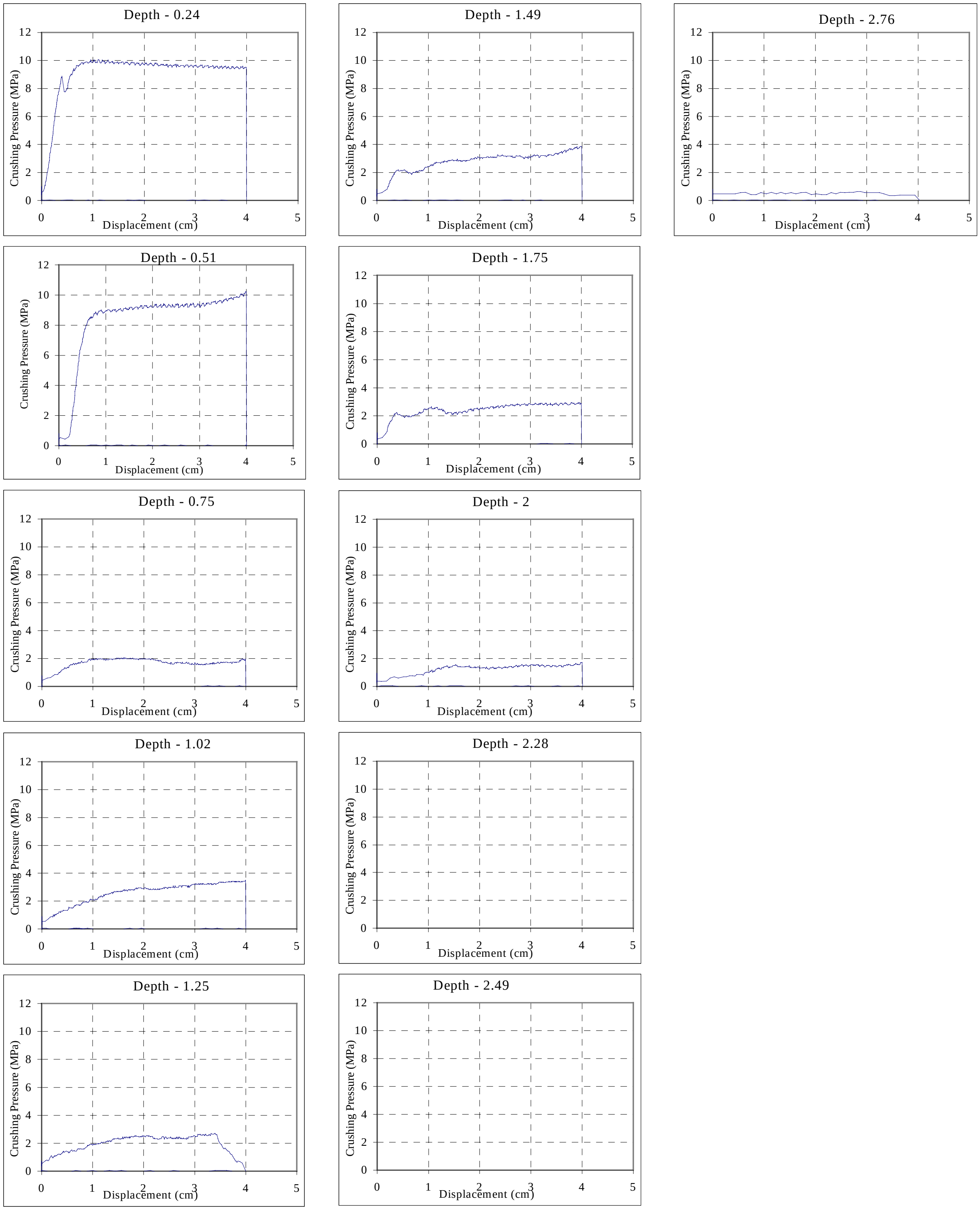


Figure 5-99: Borehole Jack Test Results, Site 12, Hole 1



Site 12 - Hole 2

Figure 5-100: Borehole Jack Test Results, Site 12, Hole 2

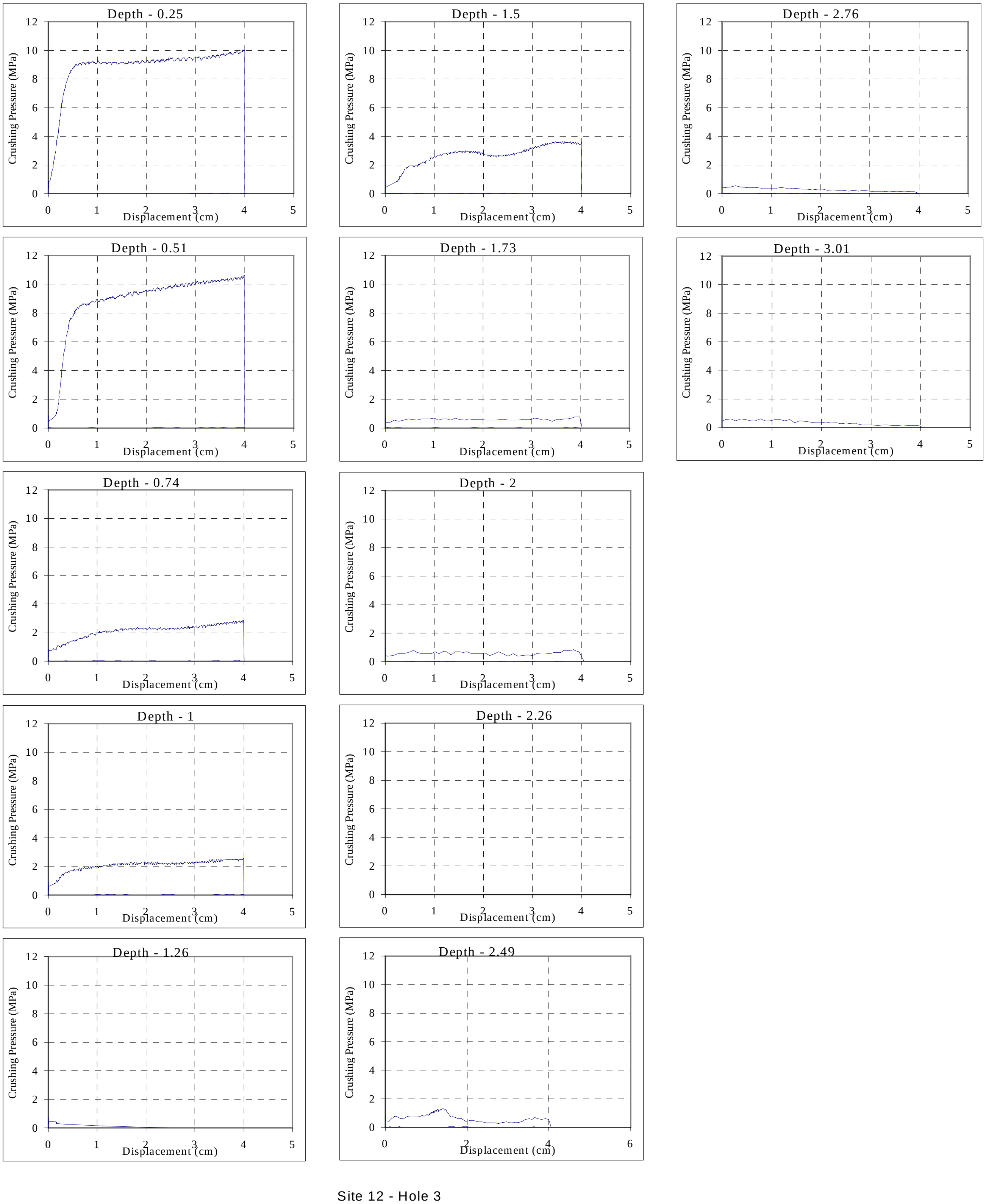


Figure 5-101: Borehole Jack Test Results, Site 12, Hole 3

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6. DISCUSSION

6.1 Information from Cores

Ten first year ice ridges were sampled during the West Coast Newfoundland field program, six of which were floating; the remaining four were grounded ridges in coastal areas. The height of the ridge crest ranged from 1.5 m to 4.0 m. Cores retrieved from the first year ridges revealed that the consolidated layer of ice was inhomogeneous. Frequently, the consolidated layer was comprised of snow ice, solid core, and consolidated slush with small voids interspersed within and/or between the different layers of ice.

One set of ice cores was retrieved for temperature, salinity and density measurements while another set of cores (taken in close proximity to the first core) was retained for future crystallographic work. This is reported in separately by Johnston and Barker (1999). Visual inspection of the ice cores revealed that the ice macrostructure and bulk physical properties of ridged ice exhibit spatial variability.

The full thickness temperature profiles of the ice showed that the ice was between 0^{o}C and -2^{o}C. Furthermore, all sites showed a "reverse" gradient in that the ice was generally warmer at its surface than at its base. Such a gradient is indicative of a period of time with the average air temperature above freezing as shown in Figure 3-2

The salinity of the examined ridges varied from 0 ppt to 7 ppt, with the top 0.30 m of ice typically having a salinity of 0 ppt. Ice salinity profiles for the consolidated layer were quite irregular. The salinity profile of the ridged ice is in contrast to the uniform "C" shaped salinity profile that generally characterizes level, first year sea ice (Nakawo and Sinha, 1981). These differences are to be expected in an ice conglomerate created from the refreezing of ice rubble formed from level ice.

6.2 Floe Diameters and Ridge Spacing

Figure 6-1 shows plots of the floe size distributions for March 13 and March 15, as compared to the floe size data used in design calculations for the Confederation Bridge in Northumberland Strait. The present data give significantly larger floes than data from Northumberland Strait. More importantly, there is a large difference in the probability of occurrence of floe sizes greater than 500m. For Northumberland Strait, the probability of occurrence of floes greater than 500m is 0.00112, while it is 0.042 for the West Coast Newfoundland ice regime observed on March 13, and 0.075 for the ice regime observed on March 15. Thus, the probability of encountering floes greater than 500 m is significantly greater (38 - 70 times) off West Coast Newfoundland than in the Northumberland Strait.

Considering that the floes off Newfoundland tend enter into the Gulf of St. Lawrence through the Strait of Belle Isle (from Labrador), there is some genuine difference in the floe size distributions for the two locations. However a large part of the difference may be an artifact that is introduced by the different measurement techniques. In the case of West Newfoundland field studies, floe size was determined from oblique photos, whereas floe size in the Northumberland Strait is obtained from vertical photographs. A large floe may not be totally encompassed within the frame of vertical photographs, thus its diameter can not be determined. As such the diameter of the floe would not be included in the floe size distribution, resulting in a biased distribution. In addition, most of the large diameter floes that were observed in the present analysis appeared to be relatively thin. The turbulent conditions of the Northumberland Strait would result in the floes breaking up, thereby affecting the floe size distribution.

The present data set is extracted from oblique pictures. In oblique pictures it can be difficult to see floe edges clearly, especially near the horizon. For this reason, the present analysis did not include floes in close proximity to the horizon. . There is probably a slight tendency for some floe edges to be missed, which would result in larger floe diameters. These factors were taken into account in the present analysis and, as such, do not present complications.

Floe size considerations can be important if “limit force” criteria (Croasdale, 1984) are used in the design of structures. “Limit force” refers to the idea that the pack ice force pushing on a floe can be limited by floe size and can therefore limit the total force on a structure. Limit force criteria were not very important for the design of the Confederation Bridge but they could be more important for larger structures, such as offshore platforms. In this case, careful floe size distribution measurements will be necessary. The present study would not be sufficient. It is recommended that these floe size measurements be done from high resolution satellite pictures, or high altitude photographs, so that the problems discussed above are eliminated.

Average ridge spacing in the present data was 68m. This compares well with the ridge spacing used for the Confederation bridge (66m), and with AES profilometer data given in

Pilkington (1997) for the Northern part of the coast. However the present data is limited since ridges are difficult to see in oblique photographs, near the horizon.

Using an average ridge spacing of 68m in design calculations may be misleading. In fact, most of the ridges counted in the ridge spacing work were small ridges less than 1m in height. The spacing for significant ridges is much greater. In fact, it could be said that only six significant ridges were found during the two days of reconnaissance, over a total distance of about 100 nautical miles, and with a swath width of about 0.5km. This number could be increased by a factor of 5 to 10 to account for similar ridges present in the pack ice but not selected for investigation. This still gives a rather large spacing for "significant ridges" with sail heights over about 1.5m. However it must also be remembered that the ice conditions were not typical. It may be more effective in the future to use upward looking sonar to record ridge keel spacings over a whole season, as the ice drifts over the location of interest.

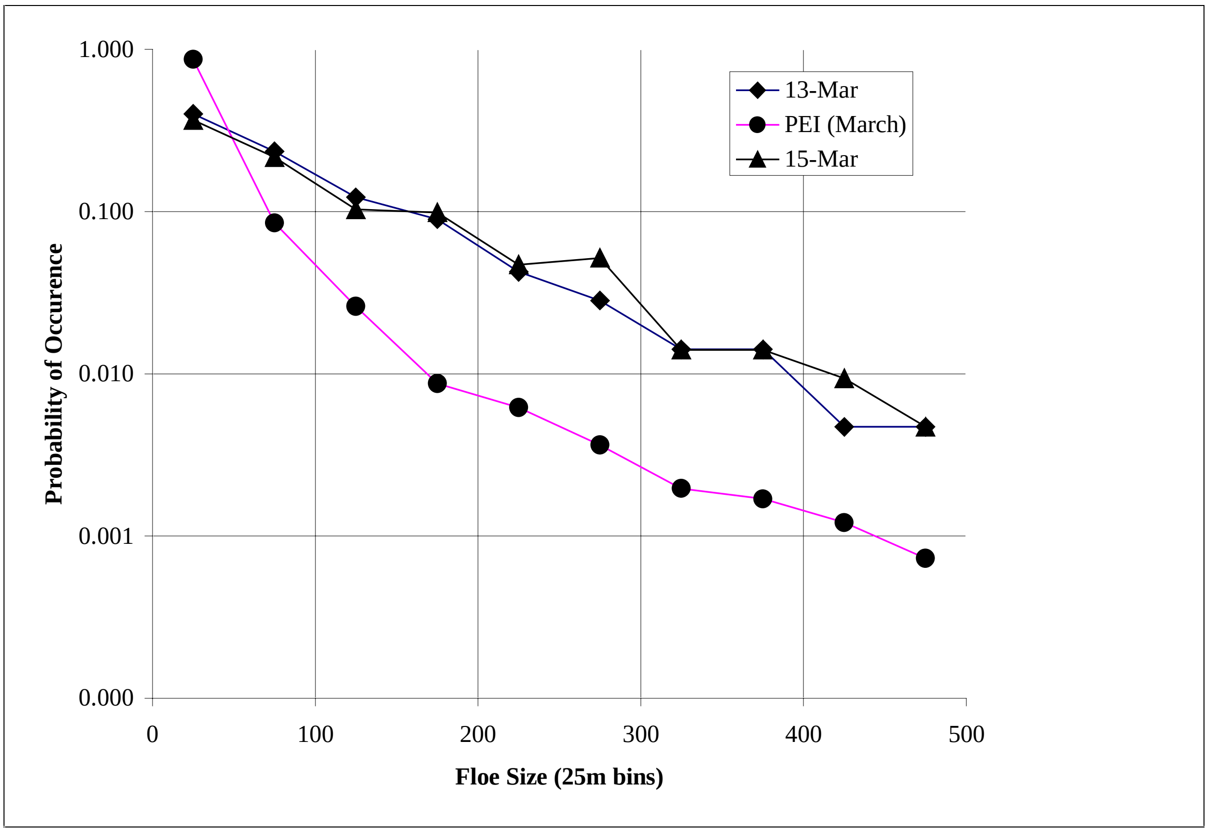

Figure 6-1: Floe Size Distributions (Mar13 & 15) Compared to PEI

6.3 Sail Blocks Sizes

Table 6-1 provides a summary of all the block size measurements carried out during this project. A comparison of block thickness to consolidated layer thickness can provide an estimate of ridge age. This is useful when modeling ridge formation and evolution.

The length over thickness ratios are typical for ice of this thickness (see for example Lepparanta & Hakala, 1992).The average ice block thicknesses recorded were similar, indicating that all the ridges investigated were formed with relatively thin ice about 0.3m thick.

Site	Number of Blocks	Average Thickness	Average Length	Average Width	Length / Thickness	Length / width
		H	L	W	L/H	L/W
1	27	0.37	1.67	1.15	4.89	1.57
2	60	0.25	1.53	1.10	6.70	1.47
3	39	0.31	1.62	1.17	5.12	1.44
4	31	0.24	1.35	1.01	5.65	1.40
5	74	0.34	2.23	1.49	6.54	1.81
6	62	0.34	2.15	1.51	6.44	1.52
7	48	0.21	1.03	0.73	5.31	1.48
8	26	0.31	1.50	1.06	4.87	1.43
9	41	0.20	1.32	0.87	6.77	1.57
12	32	0.35	1.85	1.32	5.24	1.40
AVG.		**0.29**	**1.62**	**1.14**	**5.75**	**1.51**
STDEV.		**0.06**	**0.37**	**0.25**	**0.78**	**0.12**

Table 6-1: Summary of Block Size Measurements (m)

6.4 Ridge Sizes

Ridge size statistics are needed for the design of offshore facilities in this region. At the outset of this study it was recognized that a field program has limited ability to provide statistics on ridge sizes. This is better done using both laser profiles and upward looking sonars. However, a field program has the advantage that large ridges can be sought out and measured. During this program, poor weather and sparse ice limited activities on floating ridges. Nevertheless some data were obtained on surface profiles and sail heights.

A summary of sail heights are given in Table 6-2.

Site Number	Profile Number	Sail Height (m)	Comment	Nominal Keel Depth – floating ridges (m)
1	1	2.24	Grounded	NA
2	1	3.6	Grounded	NA
2	2	3.1	Grounded	NA
2	3	3.0	Grounded	NA
3	1	3.8	Grounded	NA
3	2	2.7	Grounded	NA
4	1	1.4	Floating	5.6
4	2	1.4	Floating	5.6
4	3	1.4	Floating	5.6
5	1	4.0	Grounded	NA
5	2	4.0	Grounded	NA
6	2	1.9	Floating	7.6
6	2	1.6	Floating	6.4
7	1	1.6	Floating	4.8
7	2	1.5	Floating	4.5
7	3	1.2	Floating	3.6
8	1	2.6	Floating	10.4
8	2	1.5	Floating	4.5
8	3	1.8	Floating	5.4
9	1	1.2	Floating	3.6
9	2	1.5	Floating	4.5
9	3	0.7	Floating	2.1
12	1	2.5	Grounded	NA

Table 6-2: Maximum Sail Heights and Estimated Nominal Keel Depths

6.5 Consolidated Layer Thickness

Most of the consolidated layer thickness estimates in this project, were based on drilling with a mechanical auger, since this method is fastest and requires little equipment. The results are somewhat subjective as they relate to the "tip feel" of the auger, which can be affected by the auger head sharpness. This is a disadvantage that can be minimized by experience. However, the mechanical auger gives the operator a good feel for the strength of the ice below, especially if "pushing" and "ramming" are attempted. During this project it was clear that ice that can be penetrated by ramming or pushing is too weak to be part of the consolidated layer. The AARI hot point drill, although it gives a more detailed keel profile, cannot generally differentiate between weak and strong ice.

If all the measurements (based on auger holes) of consolidated layer thickness for Site 1 Site to 9 are grouped, a probability of exceedence curve can be plotted, see Figure 6-2. It should be remembered that the source data for this curve contains only 33 measurements, and that some measurement errors can happen when estimating consolidated layer thickness based on drilling auger holes. However the curve obtained is coherent with similar curves used for the design of the Confederation Bridge, when considering that the present thicknesses are measured on the most severe ridges that were located during the project. It should also be noted that the Freezing Degree Days for the 1998/99 winter were only 365 compared to the mean of 645.

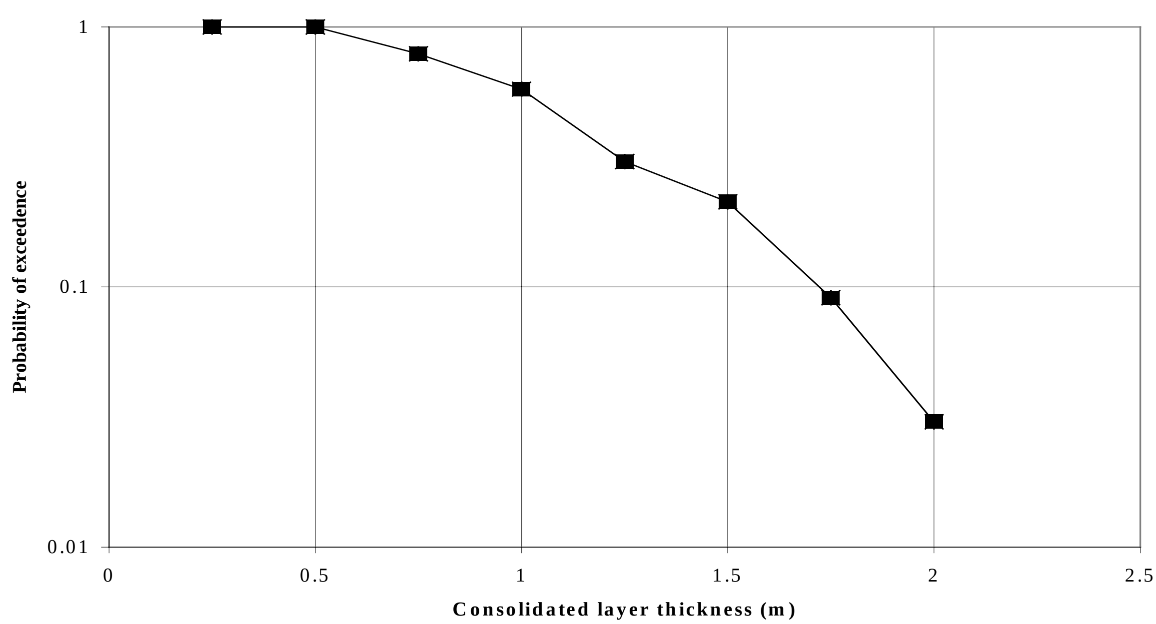

Figure 6-2: Probability of Exceedence Curve for Consolidated Layer Thickness

6.6 Density Measurements

Table 6-3 provides a summary of the density measurements carried out during this project. Undrained submerged keel density is important in keel failure load calculations. It represents the in-situ density and allows calculation of the overall buoyancy of a ridge keel. In general, it should be noted that small differences in *in-situ* keel density make a big difference to the buoyancy of the keels and, therefore, to keel failure loads.

Direct specific buoyancy measurements can also provide a good basis for keel failure load calculations, and are less sensitive to measurement errors. Improvement of these measurements requires a more accurate method of measuring buoyancy when the ice block is submerged. The density measurements conducted in this analysis involved submerging the sample by hand, which introduces variation in the measured buoyancy..

Table 6-3 shows that there is a systematic difference (averaging about 0.03 Mg/m^3) between average densities obtained by bulk measurements and by the submergence method. This may be due to the fact that bulk volume measurements tend to include cavities at the surface of the samples; cavities that are filled with water during submergence. For samples with few cavities, this is not a problem but for very porous samples the submergence method becomes more inaccurate.

The density measurement method using a hygrometer and submergence of the samples to measure buoyancy proved to be carried out easily in the field and provided good specific buoyancy results which can be used in ridge failure load calculations.

Core location		Average Density		Buoyancy
		Bulk	Submergence	Bulk
		Mg/m^3	Mg/m^3	Mg/m^3
S2- 1	Drained	0.918	0.923	
S3L1-70 (16 samples)	Drained	0.830	0.881	0.134
S3L1-65 (19 samples)	Drained	0.862	0.904	0.119
S3L1-E1 (10 samples)	Undrained	0.887	0.919	0.119
S3L1 E1 (16 samples)	Undrained	0.905	0.917	0.107
Site 11 (4 samples)	Fresh water	0.860		
Site 10 (4 samples)	Bay	0.909	0.917	0.088

Table 6-3: Density Measurements Summary

As shown in Figure 5-28 and Figure 5-29, and as expected, there is a large difference in specific buoyancy between samples above water (average about .16 g/ml) and samples below water (average about 0.11 g/ml). Cavities in the above water samples have had time to drain, creating small air bubbles in the ice which increase the specific buoyancy.

Table 6-4 (based on Timco, 1994) provides a comparison of the present density measurements with those of previous investigations "in which brine drainage was minimized". The 26 undrained density measurements carried out during this investigation add to the small body of knowledge on the undrained density of sea ice.

Investigator	Density (above water line)	Density (below water line)
	Mg/m^3	Mg/m^3
This investigation	0.83 to 0.87	0.88 to 0.93
Malmgren (1927)	0.857	0.914 to 0.924
Kovacs & Mellor (1971)	0.84 to 0.88	0.9 to 0.94
Sinha (1986)	0.90 to 0.91	0.90 to 0.91
Timco & Frederking (1983)		0.904

Table 6-4: Density Measurements Comparisons

6.7 Borehole Jack Strength

Borehole jack profiles through the consolidated layer provide a measure of what part of the consolidated layer is characterized by significant strength and, as such, defines the effective thickness of the consolidated layer. As shown in Figure 6-3, there is general agreement between consolidated layer estimates based on borehole jack tests and auger or hot point holes. However, only the borehole jack can show, unequivocally, that the strength of the ice below the consolidated layer is low , and should not be included in the consolidated layer failure load calculation.

The maximum *in situ* crushing strength of the ice was 10 MPa for sea ice from two grounded ridges and 11 MPa for the level bay ice near Plum Point (nearly fresh ice). Sinha (1997) measured the *in situ* failure stress for 0.63 m thick, low salinity (0 - 1.0 ppt) first-year sea ice in Botwood Bay Newfoundland, and reported an ice failure stress of 10 - 23 MPa for an ice surface temperature of -7^{o}C and average stress rates between 0.02 and 2 MPa/s. Temperatures in the Plum Point area were warmer, near zero.

The freshwater ice from Otter Pond had an *in situ* crushing strength between 10 and 23 MPa. Sinha (1990) measured the *in situ* strength of columnar grained, freshwater lake ice at the onset of spring thaw, in March. The author reported an ice failure stress from 15 - 25 MPa for ice surface temperatures between -9.2^{o}C and -6.3^{o}C (at stress rates 0.02 - 3 MPa/s).

6.8 Comparison Between Hot Point Drill, Auger Holes and Borehole Jack Data

One of the objectives of this field study was to obtain information on the consolidated layer thickness in large pressure ridges. Consolidated layer thickness is a major factor in estimating ice forces. The three methods used for the determination consolidated layer thickness were obtained by using auger holes, hot point drill and borehole jack. Each of these methods has its strengths and weaknesses. Auger holes are quick and easy to drill, but tend to have poor vertical resolution and to be subjective, depending upon the person doing the drilling. Hot point drill profiles have excellent vertical resolution but the difference between rubble that is mechanically competent and weak (but tightly packed) is not always clear. It takes the same amount of energy to melt these two types of ice. Borehole jack profiles provide a good quantitative measure of the ice strength, but the vertical resolution is limited to about 0.25m.

Figure 6-3 shows a comparison between hot point drill and auger results at station S3L1-70. The auger hole results have been plotted by assigning numbers to each auger tip feel: 4 for Hard, 3 for Soft, 2 for Ram, 1 for push and 0 for void. The hot point drill profile is shifted by 30cm, because of the 30cm hard packed snow cover. There is a fairly good fit between the three profiles. The distances of 0.5m and 0.7m between the hot point and auger holes may explain some of the differences in profiles. The borehole jack profile shows that although there is ice below the 1m level, it has very little strength, hence is not included in the consolidated layer thickness.

The borehole jack can distinguish between compacted slush/frazil and solid ice, whereas the hot point drill may not. This is illustrated in the profiles obtained at Site 12. The hot point drill data, Figure 5-97 shows in some cases, several metres of constant velocity suggesting several metres of solid ice (up to 5m). However, the borehole jack results indicate consolidated thicknesses of only 1.7 to 2m.

It is further noted that the hot point drill gives the approximately same velocity (hence porosity) in solid ice whether this ice is part of the refrozen layer or is in the form of keel blocks. Thus there is always a potential difficulty of deciding whether the first void is an isolated void in the refrozen layer or whether it is the true base of the refrozen layer. In contrast, the borehole jack shows lower (but distinct) strength for the ice in the keel blocks. Therefore, a borehole jack profile provides a good indication of the consolidated layer thickness as well as the presence of competent blocks in the keel.

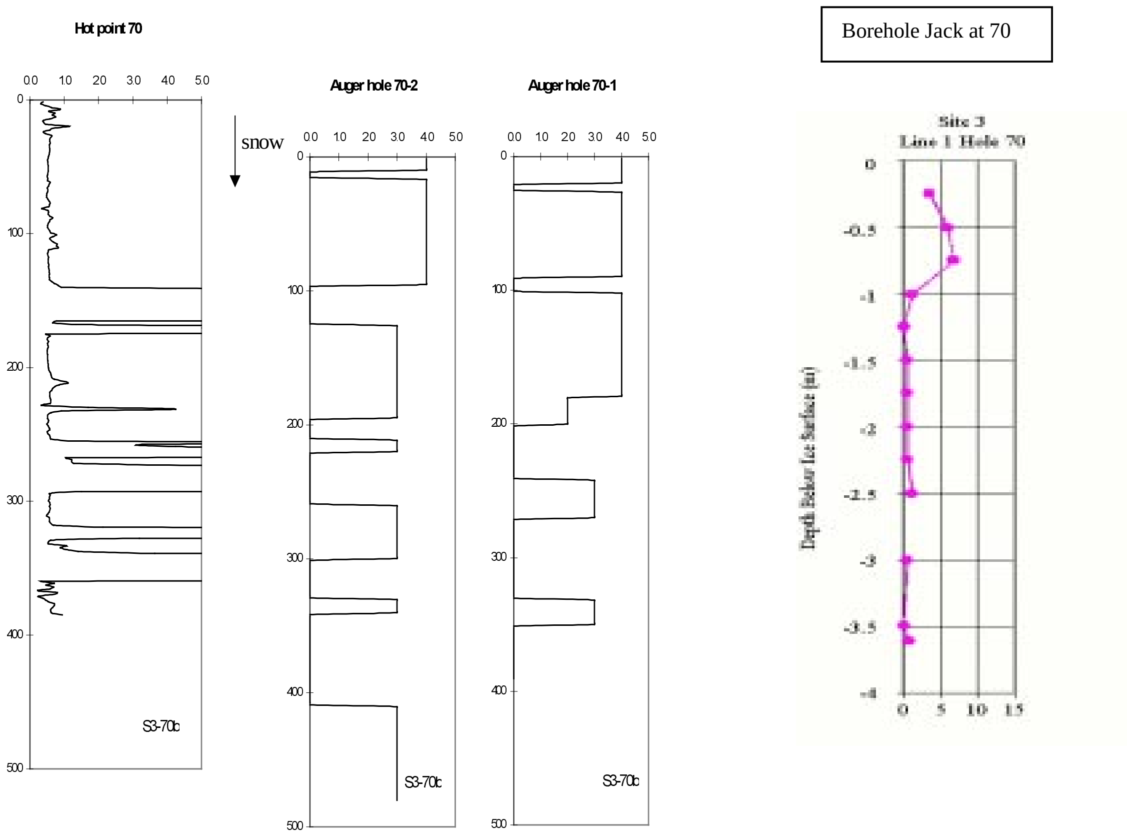

Figure 6-3: Comparison Between Hot Point Drill, Borehole Jack and Auger at Station S3L1-70

6.9 Comments on Extreme Ice Features.

Two floating rubble bergs and many grounded rubble fields were seen during the West Coast Newfoundland field program. The rubble bergs were relatively small, measuring less than 50m in length. The breakup of the grounded ridge-rubble field at Site 3 demonstrates that when ridges become ungrounded, they tend to break-up. There is a concern that some of the large rubble fields in bays off the coast of Quebec might not break up as they float away, particularly if they are grounded in relatively deep water (such as the hummock field at Site 5).

No multi-year ice floes were observed within the ice regime during this visit. It is logical, however, to think that some of the multi-year floes present off the coast of Labrador would drift into the Strait of Belle Isle. Multi-year floes such as these are difficult to identify from the air and may have escaped detection during this program.

Although, historically, icebergs have been seen in the area, no icebergs were seen during this visit. Local knowledge seems to indicate more iceberg sightings than is evident in the historical records. This is also apparent from the literature, i.e. the Strait of Belle Isle Transportation Study carried out by Memorial University in 1973 mentions as many as 200 bergs per year, while AES data indicates only an average of 12 icebergs detected per year. This may be a problem of human perception, but it might also be an indication of a possible problem with the historical data. Possible problems could be the difficulty in detecting, from the air, small icebergs in tightly packed ice and the limited number of flights covering the area. It is recommended that the iceberg issue receive further detailed attention.

7. CONCLUSIONS

Ten first-year ice ridges were examined off the Western Coast of Newfoundland, during 7 - 22 March 1999. Four of these ridges were grounded in coastal areas and six of the ridges were floating in the dynamic pack ice. As such, the data set provides a good representation of both floating and grounded ridges. The ice regime off West Coast Newfoundland was characterized by measuring the floe size, ridge spacing and drift velocity of the floes. The surface topography of the ridges was determined by conventional surveying techniques.

Information on consolidated layer thickness and ridge keel profiles was obtained by mechanical drilling and using the “hot point drill” developed at the Arctic and Antarctic Institute. A borehole jack was also used to measure the compressive strength profile through the consolidated layer, and to better define the consolidated layer thickness, thereby contributing to one of the main recommendations by Sandwell (1998). A comparison between the three different techniques for estimation of the consolidated layer thickness showed reasonable agreement. However, the borehole jack profiles are the most reliable. Each technique has its strengths and weaknesses. Consolidated layer thicknesses up to 2m were measured, but they were not spatially continuous. Also, it is noted that the Freezing Degree Days for the 1998/99 winter were only 365 compared to the mean of 645, therefore the consolidated thicknesses measured should not be considered typical maximums.

Cores were retrieved and analyzed to provide salinity, temperature and density measurements. The consolidated layer was also characterized by noting the amount of retrieved core and correlating this with a description of the ice (solid ice, voids, soft ice) while drilling. Ice cores were taken back to Ottawa where they were analyzed, the result of which are presented in Johnston and Barker, 1999.

Profiles of ice density through the consolidated layer into the keel were measured. This provided a significant amount of new data on ridge keel buoyancy, which is useful for ridge keel failure calculations.

Although some of the keels of the grounded ridges were profiled, no data was obtained on ridge keel depths for floating ridges. The sails of the floating ridges were in the range of 1 to 2.6 m. This suggests a nominal maximum keel depth of about 10 to 14m. Again, noting that this was a very mild year, the 23m design keel depth suggested by Sandwell (1998) may not be unreasonable. However, more statistical data on keel depths will be required to confirm the design ridge.

No multi-year floes or icebergs were detected during this project. Further work in this area of detection is warranted.

Four pull-up tests (measuring the bond between the consolidated layer and the keel) were carried out at Site 3, the data relating to these tests are part of the proprietary volume of this report (Volume 2).

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8. Recommendations

Although this study has provided significantly more information on ice conditions on the West Coast of Newfoundland, it has emphasized the need for further work to define ice conditions well enough for preliminary design of drilling systems. Some of these recommendations were initially made in Pilkington et al. (1997).

- Upward looking sonar arrays should be placed on the seabed at the locations of interest. These would provide excellent data on the number and size of ridge keels, as well as on ice movement during the winter and current and wave heights during open water periods. This would allow better calculation of ridge loads on potential structures, and provide information on wave loads and currents as well.

- Satellite drift buoys placed on the ice in February would provide ice drift data with good time resolution. This would allow calculation of the number and speed of encounters between ridges and an offshore structure.

- Since 1999 was not a typical year off the West Coast of Newfoundland, at least one more field study should be done under more normal conditions. Such a field study could be designed to coincide with the occurrence of old ice floes (based on AES ice charts) or icebergs, since these may be the design features for some structures.

- Further work on potential extreme ice features such as rubble bergs, grounded rubble fields, multi-year floes and icebergs is warranted.

- Before any serious design work is contemplated, a more comprehensive set of ice strength data is required and would include keel strengths, as well as flexural and crushing strengths of the consolidated layer.

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