Ice and snow measurements in support of the operational evaluation of the Nathaniel B. Palmer in the Antarctic winter environment

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Test Report

TR-1992-14

ICE AND SNOW MEASUREMENTS

in support of the

OPERATIONAL EVALUATION OF THE NATHANIEL B. PALMER IN THE ANTARCTIC WINTER ENVIRONMENT

F.M. Williams, J. Everard and S. Butt

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SUMMARY:

An operational evaluation of the icebreaker Nathaniel B. Palmer in the Antarctic winter environment was carried out in the region of the Weddell Sea in August and September, 1992. This report describes the ice and snow measurements performed by IMD, gives details on the methods, and presents the data from the trials.

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ICE AND SNOW MEASUREMENTS

in support of the OPERATIONAL EVALUATION OF THE NATHANIEL B. PALMER IN THE ANTARCTIC WINTER ENVIRONMENT

§1.0 INTRODUCTION

The Nathaniel B. Palmer is a 6620 tonne Antarctic research ship commissioned in March 1992. The vessel was designed to operate continuously in 1 m level ice, and to penetrate pressure ridges with keels up to 6 m. Figure 1 shows a general view of the ship. Edison Chouest Offshore (ECO) owns and operates the vessel. North American Shipbuilding of Larose, Louisiana, a subsidiary of ECO, built it. The Palmer is chartered to Antarctic Support Associates, who manage it for U. S. National Science Foundation (NSF).

U. S. Coast Guard Naval Engineering Division (USCG) and Ship Structures Committee (SSC), and Canadian Coast Guard Northern (CGN) and Transportation Development Centre (TDC) sponsored an operational evaluation of the Nathaniel B. Palmer in the Antarctic winter environment. in the region of the Weddell Sea in August and September, 1992. Science and Technology Corporation (STC) provided the technical coordination for the project. STC, Fleet Technology Corporation, Melville Shipping Limited, and IMD performed separate tasks which comprised the broad trials project. Table 1 lists performing agency, sponsor, and funding level for each of the tasks.

The Palmer departed Punta Arenas, Chile, on August 22, 1992, and transited the Drake Passage to the Weddell Sea, near the South Orkney Islands. After entering the ice, the ship operated in medium to very heavy pack, including pressured ice, for 6 days. The ship then transferred to the eastern side of King George Island, on the West side of the Antarctic Peninsula, and completed 4 days of testing in level ice. The Palmer returned to Punta Arenas on September 13. Figure 2 is a map of the area of operation, showing daily ship positions.

The IMD task was to lead the ice and snow measurement program and to report on the results. The purpose of the ice and snow measurements was to provide the environmental data required for the interpretation of the ship performance and ice load measurements. IMD planned the program, provided the test equipment, and directed the on-ice activities.

This report describes the ice and snow measurements, and presents the data from the trials. Separate reports by other project participants [1-4] present the ship performance, propulsion, and hull loads results.

§2 SHIP MEASUREMENT PROGRAM

The measurement of ship performance in the Antarctic winter environment was a principal project objective. The performance tests included open water resistance and maneuvering, seakeeping, resistance in broken ice and level ice, ramming in thick ice and ridges, and maneuvering in ice. Table 2 lists the ship performance tests conducted, including test name, time, and location.

Companion project objectives were measurement of ice loads on the hull and the propulsion machinery in the Antarctic winter environment. These parameters were monitored throughout the periods of operation in ice, and the respective data recording system was triggered automatically by preset load levels.

Determination of the effect of ice and snow conditions on ship performance and hull loads requires that the ship parameters be correlated with the properties of the ice and snow in which the performance or loads were experienced. For simplified ice and snow conditions, the measurements required to meet project objectives are listed in Tables 3 to 6, in order of importance to the interpretation of the associated ship parameters. Measurements may appear in more than one table. Table 3 gives measurements which are important for evaluation of performance in level ice. Table 4 concerns broken channel and broken ice fields. Table 5 lists measurements relevant to ship progress in a ridge. Table 6 lists measurements which assist in the interpretation of ice loads on hull and propeller. In each table, the 'ID' column is the measurement identity number, and the '#' column gives the typical number of samples per site.

The ice and snow conditions in which the ship operated were complex. At each site, the objective was to characterize the ice encountered by the ship as completely as possible, within the limitations of personnel safety, ship logistics, and time available on the ice. Measurements which were incomplete or not carried out are indicated by 'NA' or a blank in the tables of results.

§ 3 ICE MEASUREMENT METHODS

§3.1 Thickness (ID 1)

An ice thickness profile is a set of thicknesses at measured distances from the beginning of the test section, along the line of ship travel. For level ice tests, the test section was defined by markers thrown from the bridge, and the ice party measured ice thickness at regular intervals along the edge of the ship track. In heavy floes where the ship would not advance steadily, the ice party measured thickness ahead of the ship in holes augured through the ice.

§3.2 Temperature and salinity profile (ID 3,4)

A 9.68 cm diameter vertical ice core was taken at each site. The internal temperature of the core was measured immediately upon retrieval, at 10 cm intervals. Slices of core were then cut, and stored in airtight bags.

In the ship laboratory, the core samples were melted and warmed to 24°C. The conductivity of the melted samples was measured using a Guildline Instruments Model 8400B Autosal, with a rated precision of ± 0.002 ppt. We calibrated the Autosal using a laboratory standard seawater sample. Guildline provides the following formula to convert the conductivity reading from the Autosal to salinity [5, 6]

$$S = a_0 + a_1 R_T^{.5} + a_2 R_T + a_3 R_T^{1.5} + a_4 R_T^2 + a_5 R_T^{2.5} + (T - 15)^* \{b_0 + b_1 R_T^{.5} + b_2 R_T + b_3 R_T^{1.5} + b_4 R_T^2 + b_5 R_T^{2.5}\} / \{1 + k(T - 15)\} \quad (1)$$

where S is salinity in parts per thousand (‰)
R_T is the conductivity ratio = instrument reading ÷ 2
T is instrument bath temperature, °C

$$\begin{aligned} a_0 &= 0.0080 & b_0 &= 0.0005 \\ a_1 &= -0.1692 & b_1 &= -0.0056 \\ a_2 &= 25.3851 & b_2 &= -0.0066 \\ a_3 &= 14.0914 & b_3 &= -0.0375 \\ a_4 &= -7.0261 & b_4 &= 0.0636 \\ a_5 &= 2.7081 & b_5 &= -0.0144 \\ k &= 0.0162 \end{aligned} \quad (2)$$

In fact, the accuracy of the salinity measurements was limited not by the instrumentation, but by brine drainage and contamination (by snow or seawater) at the time of sampling. The sampling process was accurate to within ± 5% or approximately 0.2 ‰. The spread sheet uses an approximation of the above formula, correct to ± 2% or approximately 0.08 ‰. Both of these variations are less than differences which can exist between different locations in a single floe. In level, uniform first year sea ice, salinity differences up to 2 ‰ can occur between samples from the same level in adjacent cores [7].

§3.3 Density (ID 8)

The bulk density of the ice is a factor in both ice inertia effects and ice buoyancy effects on ship performance. The bulk density measurement was accomplished in-situ, by measuring the thickness and freeboard of a flat, snow-free ice piece.

§3.4 Flexural strength and bending modulus (ID 10,11)

§3.4.1 BILT: Beam in Laboratory Test. The ice party cut large ice blocks from test floes, or from broken pieces at floe margins. Orientation and depth in the floe was marked on the blocks. Some ice pieces were retrieved directly from the water using a cargo basket. We cut uniform beams approximately 1.2 m X 0.1 m X 0.1 m, using chain saws with a chain saw mill. The beams were stored in the science freezer for 24 hours to allow the temperature to stabilize. The temperature of the freezer was set to the average ice temperature for the test area. At test time, we measured the core temperatures of the beams. The test configuration was three point bending, with load and deflection measured. Figure 3 shows the test setup. Appendix F contains the instrumentation set-up and calibration information. Beams were tested with the top, or uppermost, surface of the ice in tension. Flexural strength was calculated from the maximum load, and bending modulus from the slope of the linear portion of the load-deflection curve, using the classical beam expressions

$$\sigma = \frac{3\,P\,l}{2\,b\,h^2} \qquad E = \frac{k\,\Delta P\,l^3}{4\,b\,h^3\,\Delta y} \tag{3}$$

where σ is the flexural strength, E is bending modulus, P is the load,, l, b and h are beam length, width and thickness, y is beam deflection, and k is a geometric factor which depends on the offset of the deflection measurement from the point of load application.

§3.4.2 BIST: Beam In-Situ Test. The global strength and bending characteristics of the floe may be inferred from small beam tests, but direct measurement requires a full thickness, in-situ, test. We did full thickness three point bending tests, with load and deflection measurements, at level ice sites in Maxwell Bay and Admiralty Bay. Figure 4 shows the apparatus. Appendix F contains the instrumentation set-up and calibration information. The ice party cut beams approximately 5h long X 0.8h wide X h, where h is the full thickness, using long bar (up to 48 in), chain saws and a saw guide. A clearance space was cut with the first beam, to allow it to be rolled onto its side for testing. Subsequent beams were cut at either end of the first, and slid into the original hole for testing. Beams were tested with the top, or uppermost, surface of the ice in tension, within 10 minutes of being cut. Flexural strength and bending modulus were determined in the same way as for the BILT test.

§3.5 Hardness (ID 24)

Ice surface hardness, or effective contact pressure over a small area, is an important parameter for contact forces such as hull and propeller loads. We measured hardness on the top, or tension, surface of the broken BILT samples, at the same room temperature, using a 136° pyramid Vicker's Indenter and mechanical advantage to apply the load. Figure 5 shows the apparatus. Hardness is

$$H = \frac{2P}{d^2} \tag{4}$$

where P is the load, and d is the length of the maximum diagonal of the square indentation.

§3.6 Crystal structure (ID 13)

The ice party examined the crystal structure on site in core and beam samples. In the laboratory, we prepared thin sections of the ice from the broken BILT samples and examined them through crossed polaroid filters under low power magnification. A limited number of thin sections were photographed.

§3.7 Fracture toughness (ID 23)

The fracture toughness K_{Ic} is related to the maximum stress through

$$K_{Ic} = \sigma \sqrt{\pi a}\, F(a/h) \qquad (5)$$

where a is the size of the flaw which initiated the failure. For notched three point bend specimens with a = notch depth, l/h > 8 and a/h < 0.6 [8],

$$F(x) = 1.106 - 1.552\, x + 7.71\, x^2 - 13.53\, x^3 + 14.23\, x^4 \qquad (6)$$

Determination of fracture toughness requires measurement of flaw size, or introduction of a flaw of prescribed size. For sites where sufficient beam samples were available, fracture toughness tests were conducted in addition to the strength tests by cutting a sharp-tipped notch, about half the thickness, in beam samples. Where it was not possible, due to time restrictions on the ice, to secure a sufficient number of samples to conduct independent strength and toughness tests, we estimated the fracture toughness from the flexural strength tests using a typical grain diameter, measured on the thin sections, as the flaw size a and the stress intensity in the vicinity of an elliptical crack, given by equation (5) [9] with

$$F(a/h) = 1.122 \qquad (7)$$

Table 7 shows that, with this method, the stress intensity factors from the notched beam specimens, with an average of 167 $kN/m^{3/2}$, are higher than from the unnotched specimens. The value from the notched beam specimens is somewhat high compared with other values obtained for sea ice [10]. Previous studies [10] on the influence of crack size on toughness results suggest that the stress intensities calculated from the unnotched specimens should be as high as the results for the notched specimens. This discrepency indicates that a typical grain diameter does not represent the flaw size. In fact, a flaw size approximately four times the reported grain size would give stress intensity factors in the same range as those from the notched specimens. The photos show that the grain size distribution is quite broad, and grain diameters four times the nominal values reported do occur. This topic requires further study.

§ 4 SNOW MEASUREMENT METHODS

§4.1 Thickness (ID 2)

A snow thickness profile is a set of snow depths at measured distances from the point of first bow contact, along the line of ship travel. In thick floes where the ship would not advance steadily, the ice party measured snow depth at each auger hole. For level ice tests, the snow depths were measured along the edge of the ship track, along with the ice thickness.

§4.2 Temperature profile (ID 5)

Snow temperatures were measured at depth intervals of 10 cm in a fresh vertical cut through the snow cover.

§4.3 Density (ID 6)

The snow density varies with depth. For ship performance, the total mass and buoyant mass of the snow are significant. The global snow density is mass per unit area divided by volume per unit area of cover. We took full thickness snow cores of diameter 10.4 cm, recorded the undisturbed depth, and placed the core in a sealed bag. The weight was determined in the laboratory from the volume of the melted sample.

§4.4 Compactness (ID 12)

Compactness is a measure of the energy required to compress a unit volume of material. It is an indication of the amount of energy the snow cover can absorb while being compressed by the ship hull. We measured compactness at the surface only, using a modified Kinosita hardness gauge. Figure 6 shows the gauge, which allows a known mass, m, to be dropped from a known height, r, and the sinkage s measured. The diameter of the gauge is 11.36 cm. The compactness χ is given by

$$\chi = \frac{m(r+s)g}{As} \tag{8}$$

where A is the contact area. Two different masses, 5.5 kg and 2.2 kg, were available with the gauge. On this trip, because of high snow compactness, we used the 5.5 kg mass most frequently.

§4.5 Grain structure (ID 7)

Snow grains metamorphose readily with change in temperature, humidity, wind, and solar radiation. Therefore we examined snow grain structure in-situ, behind a sun and wind shelter, using low power magnification and a dark background. Size and shape of the surface layer grains were noted in order that the snow category [11] might be determined. The snow category description table from [11] is included in Appendix E.

§5 RESULTS

§5.1 Ice and snow thickness

Appendix A shows ice and snow thicknesses and distance along the ship track for each test site where the ice party completed a thickness profile. The average thickness of ice and of snow for each site is reported in the summary, Table 10.

§5.2 Temperature and salinity profiles

The ice party retrieved and sampled 12 full thickness cores during the project. Appendix B contains a table and a chart of temperature and salinity versus depth for each core. Table 10 shows the average, or bulk, salinity and temperature for each site.

The tables in Appendix B calculate brine volume ν_b at each level in two ways. The columns '$\nu 1$' use the formula from [12]

$$\nu_b = S \times 10^{-3} \left[0.93 - \frac{45.917}{T} \right] \quad (9)$$

More recently, [13] revised the formula as

$$\nu_b = 0.93 \times S \left[-4.732 - 22.45\,T - 0.6397\,T^2 - 0.0107\,T^3 \right] \quad (10)$$

The columns headed '$\nu 2$' use this second formula. The differences between the two formulae are smaller than the range of error of the measurements.

The tables in Appendix B also contain a calculation of ice flexural strength according to the relationship between strength and brine volume presented by Vaudrey [14]:

$$\sigma = 960 - 1920 \sqrt{\nu_b} \quad (11)$$

where σ is in kPa. These numbers, in column 'Str', are included for reference only. The average of these numbers is reported in Table 10 as 'Vaud'.

§5.3 Ice hardness

Hardness results were sensitive to local ice structure on the scale of the indentation, 10 mm. To increase reliability, multiple measurements were performed on each beam fragment. The data are contained in Appendix C. The average for each small beam fragment is reported, together with the depth in floe and strength results for that site, in Table 7.

§5.4 Ice flexural strength and bending modulus - BILT

The BILT apparatus provided smooth consistent results for both flexural strength and bending modulus. Figure 7 shows a typical test load and deflection time series. Since the beams were 10 cm deep and were identified according to their location in the parent ice sheet, the BILT results make it possible to distinguish properties of granular and congellation ice types. Table 7 presents the results of all the BILT tests, and includes the average hardness at each depth. Table 10 lists the average BILT flexural strength and bending modulus at each site.

§5.5 Ice flexural strength and bending modulus - BIST

In-situ beam tests were carried out at four sites. Multiple beams at a single site provided very consistent results. For one series of four beams, the average strength was 550 kPa, and the standard deviation 30. Certain ice conditions made the tests more difficult to perform. At one site, ice thickness changed from 80 cm to 54 cm over the length of the beam. Here, the ice party trimmed the beam bottom surface to achieve a uniform beam. At another site, parts of the unconsolidated snow-ice top layer flaked off when immersed in water. The ice party trimmed this layer off before testing. Table 8 presents the results of all the BIST tests. Figure 8 shows a typical test load and deflection time series. Table 10 shows the average BIST flexural strength and bending modulus at each site. At three sites, the ice party pulled half of a broken beam out of the test hole and used it for BILT samples. These samples are indicated in Table 7.

§5.6 Ice crystal structure and density

A detailed study of ice crystal structure was beyond the scope of the present project. From the limited number of thin sections examined, it seems that the Weddell floes contained large portions of granular ice, which might be frazil, refrozen rubble, or snow ice. Maxwell Bay ice included similar portions of both granular and columnar ice, but in the level ice in Admiralty Bay, columnar ice was dominant. Appendix D contains photos of thin sections for various test sites.

Freeboard measurements at some sites were uncertain because of uneven ice thickness and persistent snow cover. At the BIST sites, we measured width and freeboard of beam specimens, slices of ice turned on their side, and thus avoided the snow effect. Densities calculated from these data are included in Table 8.

§5.7 Snow properties

Snow was a significant feature of the ship operating environment, particularly in the Weddell Sea, where snow depths reached 0.98 m. Table 9 presents the snow bulk density and temperature, and the average snow compactness for each site.

§5.8 Snow crystal structure

As for the ice, a detailed study of snow crystal structure was beyond the scope of the present project. The ship encountered a wide variety of snow types. Table 9 includes a brief description and a typical size and shape for crystals in the top layer. The snow category based on these characteristics is also recorded.

§6 DISCUSSION

§6.1 Ice strength comparison

Large scale beam tests (BIST), small scale beam tests (BILT), and estimates from temperature and salinity data (T-S) provide three indices of ice strength. Figure 9 shows the BIST and T-S strengths plotted against the BILT strength for the same site. Over the narrow range of strengths encountered on the project, BIST and BILT show the same trend, while T-S strength shows a weak negative correlation with BILT. All strength values fall between 350 and 705 kPa. These values are typical of moderate to cold first year sea ice.

The BIST strength is lower than the corresponding BILT strength, consistent with the common observation that strength decreases as stressed area, or volume, increases. A recent study on the effect of of beam size on flexural strength [15] performed tests on sea ice beams over four orders of magnitude in beam volume. Strength varied as (beam volume)$^{-1/12}$. Hence for the large beam tests, we estimate the corresponding strength of a smaller beam using

$$\sigma_2 = \sigma_1 \left(\frac{V_1}{V_2}\right)^{1/12} \tag{12}$$

where σ_2 is a scaled BIST strength, σ_1 is the measured BIST strength, V_1 is the measured large beam volume, and V_2 is a reference volume, here taken to be that of a beam 1.0 m X 0.1 m X 0.1 m. Figure 9 also shows the scaled BIST strengths plotted against the BILT strength for the same site. The points fall near the 1:1 line, indicating that, with volume scaling, the BIST and BILT tests provide comparable measures of ice strength.

The above ice strength comparisons are supported by a small data set, and measurements over a narrow range of ice conditions. Repeat measurements, and experiments with different ice conditions are necessary to determine whether the results have general applicability.

§6.2 Ice structure and type

Ice salinity varied with depth in an indeterminate manner, and salinity profiles varied from site to site. This lack of pattern is in contrast to Arctic ice, where the characteristic salinity profile reflects ice growth and brine drainage processes. A study on the physical and structural characteristics of Weddell Sea ice edge ice in the summer [16] reports that summer salinities generally fall between 3‰ and 7‰, with an average of 4.5‰ for first year ice and 3.5‰ for multi-year ice, increasing slightly with thickness. Figure 10 shows bulk salinity for Weddell Sea floes and level ice near King George Island, plotted against ice thickness. The distribution matches that reported in [16]. Figure 10 also shows salinity-thickness trends for first year and multi-year Arctic ice [7].

In [16], the authors define Antarctic multi-year ice as "all ice that has survived at least one melt season", and later conclude that "thickness and salinity measurements ... did not reveal ice demonstrably older than two years". In practice, it appears that previous Antarctic studies have used thickness as the means of identifying multiyear ice. Figure 10 indicates that the ice development processes, and in particular the concept of multiyear ice, may be quite different in the Antarctic from the Arctic.

In the pack south of the South Orkney Islands, the ice party tended to study thicker floes, but the ship encountered a wide range of ice thicknesses. The origin of the different ice thicknesses is of practical interest to ship operators, because it may give information on ice mechanical properties and extent of ice hazard. The thickness of undeformed Antarctic ice varies little with latitude, but increases during the winter season to a maximum of around 0.60 m [17]. Further increases in thickness occur through ridging [17] or frazil accumulation [16].

Near the South Orkneys, ridge features were identifiable, but not prominent. Thicknesses variations across individual floes were usually less than 100%, and heavy snow cover obscured surface details. At one site (RM26), ridge blocks about 0.15 m thick added a thickness of approximately 1 m near the edge of a 2 m floe, indicating pile up of a refrozen channel. Ridging may account for ice thickness increases between 0.6 m and 1.5 m, but it does not appear to account for the total volume of ice at the larger ice thicknesses encountered.

For the summer ice edge, [16] reports that in multi-year floes (2.5 m to 5.0 m thick), about 72% of the ice thickness is frazil ice, and in first year floes (0.4 m to 2.5 m thick), about 37% is frazil ice. Most of the remainder is congellation (columnar) ice. The frazil occurs at every level, and in some cases comprises the entire floe. The frazil could account for the larger ice thicknesses in the Weddell, but it in turn poses the question of the origin of a very large volume of frazil ice.

The possibility that flooded snow cover makes up part of the ice thickness in the Weddell was put forward in [17] and confirmed in [18]. If snow cover is on the point of flooding, then the submerged depth is the ice thickness, and

$$\rho_s h_s = h_i (\rho_w - \rho_i) \quad (13)$$

where h_s and h_i are snow and ice thicknesses, and ρ_s, ρ_w, and ρ_i are snow, water and ice densities respectively. Equation (13) also expresses the condition of a floe with newly consolidated snow ice. With values for ρ_w and ρ_i of 1.025 and 0.937 Mg/m^3 respectively, the coefficient of h_i in Equation (13) is 0.088.

Figure 11 shows snow mass per unit area, $h_s\rho_s$, plotted against ice thicknesses for all the sites for which the snow data were obtained. The line in Figure 11 represents equation (13), the condition for the formation of snow ice. The best fit line for the points is

$$\rho_s h_s = 0.002 + 0.080 h_i \quad (14)$$

with a squared correlation coefficient of 0.956. Although there is uncertainty in the result because of the variations in the parameters across a floe, the correspondence between equations (13) and (14) indicates that the floes measured were close to the condition of forming snow ice. In the case of the point which is above the line in Figure 11, the snow was, in fact, flooded.

For undeformed winter ice, [18] found that the increase in thickness due to flooded snow could be 10 to 20 cm in ice 60 cm thick. These figures, together with crystal structure photos and the appearance of "banded frazil" in [16] raise the possibility that some of the ice identified as frazil may have been snow ice, although the $\delta^{18}O$ isotope measurements reported are typical of ice from seawater. Finally, the crystal structure photos and the relationship in Figure 11 indicate that snow ice comprised part of the thick floes documented in this project.

The significance of the snow ice formation is that thick floes may contain a significant portion of new ice, which does not satisfy the 'survived at least one melt season' definition of multiyear ice. Nor do these floes satisfy the two other most common criteria for multiyear ice: flexural strength around 1000 kPa (it was 660 to 700 kPa), and salinity around 1‰ (it was 2.5 to 6.5 ‰). Hence the classification of these floes, from the point of view of ship operations, is ambiguous.

§7 SUMMARY AND CONCLUSIONS

During the project, 12 test sites were documented. Measurements included 12 cores, more than 40 thickness profiles, 60 small beam tests and 11 large beam tests. Ice thicknesses ranged from 0.5 to 4.0 m, and strengths of small beams from 524 to 705 kPa. The snow cover mass increased with ice thickness. Table 10 provides a summary of all the measurements, giving average values for each test site.

Full thickness beam tests provide the most direct measure of ice strength related to ship performance. Laboratory tests on beams 1.0 m X 0.1 m X 0.1 m gave consistent results, and the small beam strengths were related to the large beam strengths by the volume scaling law in equation (12). Hence where full thickness tests are not possible for logistical reasons, the strength of large beams may be estimated from the results of small beam tests.

The substantial data set obtained will enable the ship performance and ice load measurements to be interpreted in the context of the snow and ice conditions. Furthermore, the data set provides valuable information on the actual ice and snow environment for ships operating in the Antarctic region.

The data from this project pertain to a geographic area and a time of the year not previously documented. The results add to the description of Weddell Sea ice presented in previous studies, and at the same time show that important information is missing from the scientific data base. The ice nomenclature developed for Arctic ice types may not be well adapted to the description of Weddell Sea ice from the point of view of ship operations. Further information on the source, the distribution, and the mechanical properties of the various ice types is required in order to determine the risks and limitations for ship operations at various times of year in the Weddell Sea.

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Table 1
PROJECT TASKS, PERFORMERS AND SPONSORS

Task	Performer	Sponsor
Ice loads on hull	STC	SSC, USCG
Ship performance	STC	USCG
Trafficability and operations	STC	NSF
Propulsion performance and loads	Fleet	CGN, TDC
Ice and snow measurements	IMD	CGN, TDC, IMD
Ice drift	STC	USCG
Superstructure icing	STC	USCG
Ice Navigation and piloting	STC, ASA	NSF
Performance of science in ice	Kennedy	NSF
Vessel evacuation and survivability	Melville	CGN, TDC

Table 2: SHIP PERFORMANCE TEST LOCATIONS

A	B	C	D	E	F	G	H
Date	Time	Lat	Long	No. of Tests	Test #s	No. Data Points	Comments
23/8/92	0700-1045	52°56'	70°29'	10	OR1-OR12	40	Two runs each at two directions per test; manual recording of GPS
23/8/92	0700-1045	52°56'	70°29'	10	OM1-OM11	10	One turn each to port and starboard per test; manual recording of GPS; one case with both 30° and 15° rudder
25/8/92	1330-1530	55°10'	57°55'	8	RW1-RW8	8	Head seas and following seas
26/8/92	1205-1630	56°20'	52°14'	15	SK1-SK15	15	One speed, five headings, Beaufort 4; full roll stabilization, one tank stabilization, no stabilization
26/8/92	1315-1330	56°30'	51°46'	1	SK16	1	Beaufort 8 initially; seas subsided to Beaufort 4 during filling of roll stabilization tank, tests cancelled
28/8/92	1610-1740	59°06.9'	44°52.7'	6	IE1-IE6	6	Four speeds; 90% concentration of extremely broad range of FY and MY ice
29/8/92	1614-1622	60°38.6'	43°37.4'	1	RM1	1	Originally identified as LR1 OW approach at 8 kts; ship stopped by floe
30/8/92	1614-1633	60°52.2'	45°02.4'	3	RM2-RM4	3	Originally identified as LR2-LR4 OW approach at 10 kts; ship stopped by floe
31/8/92	1328-1430	60°54.0'	44°50.9'	18	RM5-RM22	17	Impact speeds of 5 to 9 kts in 7.4 ft of ice with 31 in of snow, but variable ice ocnditions

Table 2: SHIP PERFORMANCE TEST LOCATIONS

	A	B	C	D	E	F	G	H
1	Date	Time	Lat	Long	No. of	Test	No. Data	Comments
2					Tests	#s	Points	
3								
33								in the floe, including 16+ ft ridge (keel)
34								
35	31/8/92	2030-2050	60°54.10'	44°49.9'	3	RM23-RM25	3	Ramming in 4.1 ft ice with 16.5 in snow;
36								ram without heeling, turn heeling system on
37								and creep, then ram with heeling system on
38								
39	1/9/92	1505-1615	60°55.2'	44°45.2'	15	RM26-RM40	15	Ramming in 4 to 12 ft ice with 16 to 30 in of
40								snow; refrozen rubble field with rubble piles;
41								heeling system filled but not activated
42								
43	5/9/92	0244-0320	60°40'	54°10'	2	SK22-SK23	2	Data collected on not-to-interfere basis
44								enroute to King George Island; Beaufort 9, Sea
45								State 6
46								
47	5/9/92	1250-1505	61°19'	56°32'	9	SK24-SK32	7	Head seas to following seas at 30° increments;
48								Beaufort 8, Sea State 6; full power on two
49								engines
50								
51	6/9/92	1253-1415	62°13'	58°49'	5	LR5-LR9	5	Ice thickness of 18 inches, 2.4 in snow
52	6/9/92	1811-1814	62°13'	58°49'	2	LR10-LR11	0	Ice of 29.8 in, snow of 5.3 in; cracks to track
53	6/9/92	1920-2037	62°13'	58°49'	6	LR12-LR17	6	Ice of 22.6 in, snow of 3.6 in
54								
55	7/9/92	1244-1355	62°13'	58°52'	6	LR18-LR23	4	Ice thickness of 23.1 in, snow depth of 4.3 in
56	7/9/92	1351-1355	62°13'	58°52'	1	LR24	1	Ice thickness of 47.1 in, snow depth of 10.5 in
57								
58	7/9/92	1601-1605	62°13'	58°52'	1	CC1	1	In channel from tests LR18-LR24
59								
60	8/9/92	1426-1642	62°07'	58°24'	9	LR25-LR33	9	Admiralty Bay, 21.9 in of ice, 3.6 in of snow
61								

Table 2: SHIP PERFORMANCE TEST LOCATIONS

	A	B	C	D	E	F	G	H
1	Date	Time	Lat	Long	No. of	Test	No. Data	Comments
2					Tests	#s	Points	
3								
62	8/9/92	1851-1858	62°07'	58°24'	3	CC2-CC4	3	In channel from tests LR25-LR33
63								
64	8/9/92	2011-2032	62°07'	58°24'	4	LR34-LR37	4	Icebreaking with two engines in 18.9 in of ice,
65								4.6 in of snow
66								
67	9/9/92	1405-1420	62°06'	58°24'	4	LR38-LR41	4	Ice thickness of 22.6 in, snow depth of 1.9 in,
68								one partial turn
69								
70	10/9/92	1616-1755	61°32'	57°33'	7	SK33-SK39	7	Head seas to following seas in 30° increments;
71								initially Beaufort 8, moderating to 5;
72								full roll stabilization; spray data collection
73								
74	10/9/92	1930-2058	61°32'	57°33'	7	SK40-SK46	7	Head seas to following seas in 30° increments;
75								initially Beaufort 5, moderating to 3;
76								no roll stabilization

Table 3
ICE AND SNOW MEASUREMENTS
for ship performance in level ice
(listed in order of priority)

ID	measurement	#	method
1	ice thickness	10	every 10 sec. along ship track
2	snow thickness	10	every 10 sec. along ship track
3	ice temperature profile	3	in core immediately on retrieval
4	ice salinity profile	3	melted samples from core
5	snow temperature profile	3	in situ depth profile
6	snow density	3	full depth snow sample
7	snow grain size	3	in situ crystal photo
8	ice density	3	in samples from core
9	water salinity	1	sample from ship track
10	ice flexural strength	3	in situ 3 point beam test
11	ice bending modulus	3	in situ 3 point beam test
12	snow compactness	3	modified Kinosita gauge
13	ice crystal structure	3	thin section photos
25	hull roughness survey	1	roughness gauge

Table 4
ICE AND SNOW MEASUREMENTS
for ship performance in broken ice
(listed in order of priority)

ID	measurement	#	method
1	ice thickness	10	in ship track
2	snow thickness	10	in ship track
14	ice concentration	1	visual estimate, photo
15	channel width	5	direct or photo
16	ice piece size	1	photo
3	ice temperature profile	1	core in adjacent floe
4	ice salinity profile	1	melted samples from core
8	ice density	1	in samples from core
6	snow density	3	full depth snow sample
9	water salinity	1	sample from ship track

Table 5
ICE AND SNOW MEASUREMENTS
for ship performance in ice ridge
(listed in order of priority)

ID	measurement	#	method
17	ridge sail geometry	1	survey
18	ridge keel geometry	12	auger holes
19	distance to major cracks	4	video, direct
20	ridge consolidation profile	4	temperature in core (limited depth)
1	thickness adjacent ice	4	channel edges, both sides of ridge
15	broken channel width	3	in ridge: video, direct
21	channel profiles in ridge	2	reference lines painted on ridge, video
22	ice block size	5	direct
2	snow thickness	12	at auger holes
10	ice flexural strength	3	small (3 point) beam from ridge block
11	ice bending modulus	3	small (3 point) beam from ridge block
6	snow density	3	full depth snow sample
7	snow grain size	3	in situ crystal photo

Table 6
ICE AND SNOW MEASUREMENTS
for ice loads on hull and propeller
(listed in order of priority)

ID	measurement	#	method
1	ice thickness	10	in ship track
16	ice piece size	5	photo, direct
10	ice flexural strength	3	3 point beam in block from channel
11	ice bending modulus	3	3 point beam in block from channel
23	ice fracture toughness	3	sample block from channel
3	ice temperature	3	sample block from channel
24	ice hardness	5	Vickers' indenter
13	ice crystal structure	3	thin section photos
8	ice density	3	in samples from core
9	water salinity	1	sample from ship track

Table 7: BEAM IN LABORATORY DATA

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	SITE	TIME	l	b	h	a	T1	P1	D1	T2	P2	D2	∂e/∂t
2			(m)	(m)	(m)	(m)	(sec)	(N)	(mm)	(sec)	(N)	(mm)	/10^3sec
3													
4	IE1_27/8/92	921	0.7	0.100	0.105	0.006	3.480	-265.4	0.275	3.704	-472.6	0.373	0.125
5	IE1_27/8/92	930	0.7	0.099	0.102	0.006	3.364	-53.6	-0.248	4.044	-471.2	-0.124	0.147
6	IE1_27/8/92	949	0.7	0.098	0.098	0.006	5.580	-132.9	-0.314	6.460	-386.1	0.131	0.461
7	IE1_27/8/92	956	0.7	0.097	0.100	0.006	2.976	-80.9	-0.503	3.960	-776.1	-0.235	0.293
8	IE1_27/8/92	average											
9													
10	RM1_29/8/92	2050	1	0.105	0.104	0.004	3.988	-77.0	-3.419	4.760	-534.7	-3.203	0.106
11	RM1_29/8/92												
12	RM1_29/8/92	2057	1	0.094	0.101	0.003	3.164	-109.2	0.915	4.200	-520.9	1.137	0.088
13	RM1_29/8/92												
14	RM1_29/8/92	2104	1	0.106	0.108	0.002	4.092	-147.3	-2.628	4.676	-461.7	-2.510	0.065
15	RM1_29/8/92												
16	RM1_29/8/92	2110	1	0.095	0.112	0.002	4.216	-103.3	-2.713	5.040	-515.6	-2.517	0.107
17	RM1_29/8/92	2117	1	0.096	0.104	0.003	4.780	-99.3	-0.863	5.332	-455.8	-0.667	0.088
18	RM1_29/8/92	2127	1	0.101	0.105	0.004	2.728	-107.2	0.157	3.576	-600.5	0.464	0.147
19	RM1_29/8/92	average											
20													
24	RM23_31/8/92	1945	1	0.110	0.082	0.001	3.048	-48.0	0.438	3.488	-296.0	0.713	0.071
31	RM23_31/8/92	1954	1	0.113	0.080	0.001	3.712	-91.4	0.275	4.180	-380.2	0.503	0.055
32	RM23_31/8/92	average											
33													
37	RM26_1/9/92	1204	1	0.100	0.105	0.002	3.764	-121.7	0.242	4.160	-397.9	0.379	0.065
41	RM26_1/9/92	1215	1	0.101	0.100	0.003	3.100	-28.3	-0.366	4.132	-261.8	-0.320	NA
45	RM26_1/9/92	1222	1	0.101	0.101	0.002	4.464	-92.1	0.379	5.336	-244.0	0.333	NA
49	RM26_1/9/92	1230	1	0.106	0.094	0.002	4.540	-53.9	-0.510	5.024	-357.1	-0.268	0.090
53	RM26_1/9/92	1238	1	0.100	0.100	0.003	3.100	-116.4	1.183	3.588	-386.7	1.360	0.073
57	RM26_1/9/92	1246	1	0.093	0.100	0.003	3.156	-78.9	-0.804	3.772	-328.2	-0.634	0.065
61	RM26_1/9/92	1301	1	0.114	0.099	0.002	1.356	-111.8	-0.510	1.952	-626.8	-0.190	0.146
65	RM26_1/9/92	1309	1	0.100	0.096	0.002	3.880	-181.5	1.098	4.320	-515.6	1.347	0.091

Table 7: BEAM IN LABORATORY DATA

	N	O	P	Q	R	S	T	U	V	W	X
1	σ	E	a/h	F(a/h)	KI	ind d	ind P	hard	core T	notes	
2	(kPa)	(MPa)			(kPa√m)	(m)	(N)	(MPa)	(°C)		
3											
4	654.7	1660.9	0.0574	1.1220	100.9	0.0071	51	11.5	-10.4	piece picked by crane	
5	680.5	2835.2	0.0587	1.1220	104.8	0.0101	145	16.0	-10.3	-1.4°C at harvest	
6	440.3	549.6	0.0611	1.1220	67.8	0.0110	201	18.7	-10.8		
7	859.0	2375.8	0.0598	1.1220	132.3				-10.8		
8	658.6	1855.4			101.5			15.4	-10.6		
9											
10	706.2	4313.1	0.0385	1.1220	88.8	0.0075	100	20.1	-4.7	0-10cm depth	
11						0.0113	152	13.4	-4.7	0-10cm depth	
12	824.7	4684.1	0.0299	1.1220	89.8	0.0085	101	15.8	-3.6	10-20cm depth	
13						0.0088	152	22.1	-3.6	10-20cm depth	
14	564.3	4854.6	0.0186	1.1220	50.2	0.0062	102	29.9	-3.7	20-30cm depth	
15						0.0097	151	18.1	-3.7	20-30cm depth	
16	654.1	3835.8	0.0179	1.1220	58.2	0.0103	203	21.6	-3.9	20-30cm depth	
17	657.8	4042.5	0.0288	1.1220	71.6	0.0115	211	18.0	-3.7	10-20cm depth	
18	819.9	3362.4	0.0383	1.1220	103.1	0.0145	216	11.6	-4.4	0-10cm depth	
19	704.5	4182.1			77.0			19.0	-4.0	cut from pit in floe	
20											
24	592.3	3514.7	0.0121	1.1220	37.3		average	22.1	-4.7	10-20cm depth	
31	785.8	5225.6	0.0125	1.1220	49.4		average	27.6	-4.8	0-10cm depth	
32	689.1	4370.1			43.3			24.9	-4.8	broken piece at margin	
33											
37	548.7	4257.6	0.0191	1.1220	48.8		average	23.3	-4.2	20-30 cm depth	
41	390.7	NA	0.0300	1.1220	42.6		average	23.5	-4.1	10-20 cm depth	
45	355.2	NA	0.0198	1.1220	31.6		average	34.4	-4.4	0-10 cm depth	
49	567.1	3378.6	0.0212	1.1220	50.4		average	19.9	-4.6	20-30 cm depth	
53	585.9	3726.6	0.0302	1.1220	63.8		average	20.4	-4.1	10-20 cm depth	
57	535.3	3851.8	0.0302	1.1220	58.3		average	13.3	-4.6	10-20 cm depth	
61	844.9	3515.5	0.0202	1.1220	75.1		average	38.7	-4.8	0-10 cm depth	
65	845.2	3675.4	0.0209	1.1220	75.2		average	23.6	-5.0	0-10 cm depth	

Table 7: BEAM IN LABORATORY DATA

	A	B	C	D	E	F	G	H	I	J	K	L	M
66	RM26_1/9/92	average											
67													
68	LR5_6/9/92	109	1	0.099	0.100	0.002	3.148	-116.4	-1.072	3.548	-296.6	-0.804	0.110
69	LR5_6/9/92	115	1	0.099	0.094	0.001	7.820	-180.2	0.052	8.216	-328.9	0.360	0.106
70	LR5_6/9/92	120	1	0.096	0.097	0.001	3.596	-107.9	-4.327	4.560	-407.8	-4.053	0.099
71	LR5_6/9/92	124	1	0.096	0.097	0.001	3.560	-253.9	-1.255	3.720	-374.9	-1.124	0.047
72	LR5_6/9/92	128	1	0.102	0.102	0.004	2.892	-152.6	-3.798	3.280	-398.6	-3.569	0.102
73	LR5_6/9/92	132	1	0.106	0.100	0.004	2.160	-100.6	-3.072	2.604	-439.3	-2.955	0.052
74	LR5_6/9/92	136	1	0.097	0.101	0.004	2.040	-66.4	-3.569	2.360	-349.9	-3.406	0.067
75	LR5_6/9/92	142	1	0.101	0.100	0.003	2.480	-101.9	-3.576	2.744	-299.9	-3.497	0.033
76	LR5_6/9/92	148	1	0.110	0.101	0.003	2.976	-151.9	-3.517	3.200	-373.6	-3.406	0.051
77	LR5_6/9/92	152	1	0.099	0.101	0.003	2.408	-79.6	-3.020	2.764	-215.7	-2.994	0.011
78	LR5_6/9/92	158	1	0.102	0.100	0.002	1.488	-50.6	-2.647	2.344	-249.9	-2.523	0.052
79	LR5_6/9/92	203	1	0.098	0.099	0.002	2.804	-123.6	-2.360	3.060	-272.9	-2.183	0.070
80	LR5_6/9/92	207	1	0.088	0.096	0.001			NG	3.172	-377.5	NG	
81	LR5_6/9/92	average	1										
82													
83	LR16_6/9/92	52	1	0.098	0.101	0.005	0.620	-64.5	-0.033	2.992	-390.7	0.072	0.044
84	LR16_6/9/92	126	1	0.093	0.101	0.006	1.240	-61.8	0.458	5.000	-374.9	0.523	0.026
85	LR16_6/9/92	129	1	0.097	0.099	0.003	1.000		3.896	3.232	-265.7	3.836	NA
86	LR16_6/9/92	131	1	0.099	0.097	0.003					-334.8		NA
87	LR16_6/9/92	134	1	0.102	0.095	0.006	0.124		-0.392	1.296	-428.2	-0.209	0.067
88	LR16_6/9/92	138	1	0.101	0.097	0.006	0.620	-0.9		1.900	-427.5	-0.739	NA
89	LR16_6/9/92	144	1	0.102	0.098	0.006	0.620		0.732	4.116	-287.4	0.811	0.031
90	LR16_6/9/92	149	1	0.101	0.096	0.002	0.620		-0.052	2.916	-367.0	0.072	0.046
91	LR16_6/9/92	152	1	0.100	0.094	0.002	1.488		0.275	2.644	-412.4	0.458	0.063
92	LR16_6/9/92	155	1	0.101	0.094	0.005	0.620		-0.869	2.264	-362.4	-0.752	0.041
93	LR16_6/9/92	207	1	0.101	0.096	0.040					-88.1		NA
94	LR16_6/9/92	213	1	0.101	0.097	0.037					-99.3		NA
95	LR16_6/9/92	218	1	0.101	0.095	0.044					-47.4		NA
96	LR16_6/9/92												
97	LR16_6/9/92	223	1	0.099	0.097	0.049					-42.8		NA

Table 7: BEAM IN LABORATORY DATA

	N	O	P	Q	R	S	T	U	V	W	X
66	584.1	3734.2			55.7			24.8	-4.5	broken piece at margin	
67											
68	451.2	1642.5	0.0200	1.1220	40.1	0.0107	101	10.0	-6.7	10-20cm	elsner&wms
69	561.7	1409.3	0.0106	1.1220	35.3	0.0094	100	12.8	-6.5	0-10	
70	681.4	3024.8	0.0103	1.1220	42.9	0.0128	150	10.3	-6.8	0to10	
71	631.7	2584.5	0.0104	1.1220	39.7	0.0149	202	10.3	-7.3	0to10	
72	568.4	2413.9	0.0393	1.1220	71.5	0.0057	105	36.5	-7.2	20-30	
73	618.5	6505.2	0.0398	1.1220	77.8	0.0093	162	21.1	-7.2	20to30	
74	535.7	4245.8	0.0398	1.1220	67.4	0.0093	202	26.3	-7.2	20-30	
75	447.6	6000.9	0.0250	1.1220	44.5	0.0072	105	22.8	-7.4	30-40	
76	505.8	4311.7	0.0249	1.1220	50.3	0.0074	164	33.8	-7.4	30-40	
77	322.9	NA	0.0249	1.1220	32.1	0.0089	202	28.8	-7.2	30-40	
78	370.1	3833.2	0.0201	1.1220	32.9	0.0107	151	14.9	-7.9	10to20	
79	427.9	2145.3	0.0202	1.1220	38.1	0.0124	200	14.7	-7.8	10to20	
80	695.0	NA	0.0104	1.1220	43.7				-7.8	0-10	
81	524.5	3465.2			47.4			20.2	-7.3	from BIST site	
82											
83	586.3	7413.2	0.0494	1.1220	82.4	0.0080	100	17.6	-7.1	30to40cm	
84	588.0	11896	0.0592	1.1220	90.6	0.0073	100	21.2	-7.6	20to30cm	
85	419.2	NG	0.0304	1.1220	45.7	0.0074	100	20.6	-8.0	0to10cm	
86	541.9	NG	0.0310	1.1220	59.0	0.0138	150	8.9	-7.8	0to10cm	
87	695.4	6390.0	0.0630	1.1220	107.1	0.0112	203	18.3	-7.9	20to30cm	
88	674.8	NG	0.0619	1.1220	104.0	0.0090	150	20.9	-8.3	20to30cm	
89	444.6	9310.7	0.0615	1.1220	68.5	0.0075	100	20.1	-8.1	10to20cm	
90	594.5	8007.5	0.0209	1.1220	52.9	0.0063	110	31.3	-8.4	40to50cm	
91	705.4	6595.9	0.0214	1.1220	62.7	0.0110	150	14.0	-8.4	40to50cm	
92	610.6	8872.8	0.0534	1.1220	85.9	0.0085	150	23.4	-8.3	30to40cm	
93	423.4	NA	0.4184	1.2515	187.8	0.0137	205	12.3	-8.3	30to40cm	
94	406.3	NA	0.3799	1.1837	164.0	0.0110	210	19.6	-8.4	40to50cm	
95	263.6	NA	0.4574	1.3373	130.3	0.0136	150	9.1	-8.3	10to20cm	
96						0.0164	202	8.5		10to20cm	
97	278.2	NA	0.5036	1.4670	160.1	0.0155	203	9.5	-8.2	0to10cm	

Table 7: BEAM IN LABORATORY DATA

	A	B	C	D	E	F	G	H	I	J	K	L	M
98	LR16_6/9/92	average	1										
99													
100	LR32_8/9/92	2120	1	0.096	0.099	0.003	0.620		0.288	2.816	-397.3	0.530	0.093
101	LR32_8/9/92	2124	1	0.095	0.100	0.003	2.108		-1.935	2.764	-581.4	-1.608	0.129
102	LR32_8/9/92	2126	1	0.093	0.101	0.003	0.620		0.863	3.088	-474.2	1.144	0.111
103	LR32_8/9/92	2128	1	0.099	0.100	0.002	0.620		-2.438	3.068	-379.5	-2.177	0.108
104	LR32_8/9/92	2130	1	0.092	0.101	0.002	0.620		-1.484	3.904	-406.5	-1.248	0.092
105	LR32_8/9/92	2133	1	0.090	0.101	0.003	0.620		-0.373	3.020	-307.1	-0.183	0.073
106	LR32_8/9/92	2135	1	0.099	0.101	0.003	0.620		-2.098	2.448	-516.3	-1.935	0.069
107	LR32_8/9/92	2137	1	0.092	0.102	0.003	0.620		-0.994	3.280	-407.8	-0.660	0.134
108	LR32_8/9/92	2139	1	0.098	0.102	0.003	0.620		0.177	3.596	-599.2	0.439	0.112
109	LR32_8/9/92	2143	1	0.094	0.101	0.002	0.620		-0.889	3.916	-447.9	-0.588	0.122
110	LR32_8/9/92	12	1	0.095	0.101	0.040			NG		-67.7		NA
111	LR32_8/9/92												
112	LR32_8/9/92	18	1	0.095	0.102	0.039			NG		-112.5		NA
113	LR32_8/9/92	22	1	0.096	0.100	0.043			NG		-95.4		NA
114	LR32_8/9/92	average	1										
115													
119	glacier	average											
120													
121													
122													

Table 7: BEAM IN LABORATORY DATA

	N	O	P	Q	R	S	T	U	V	W	X
98	586.1	8355.2			100.1			17.0		from BIST site	
99											
100	637.9	4285.8	0.0304	1.1220	69.5	0.0052	106	44.2	-7.4	0to10cm	
101	919.7	4516.5	0.0301	1.1220	100.2	0.0062	162	47.5	-7.5	0to10cm	
102	756.0	4274.3	0.0298	1.1220	82.3	0.0080	200	35.3	-7.6	0to10cm	
103	575.6	3527.3	0.0150	1.1220	44.3	0.0066	116	30.0	-8.0	20to30cm	
104	653.4	4414.5	0.0149	1.1220	50.3	0.0097	152	18.2	-8.0	20to30cm	
105	502.5	4217.9	0.0298	1.1220	54.7	0.0082	100	16.8	-8.0	30to40cm	
106	766.9	7457.8	0.0267	1.1220	79.2	0.0056	105	37.8	-8.6	10to20cm	
107	642.0	3037.4	0.0266	1.1220	66.3	0.0070	152	35.0	-8.4	10to20cm	
108	893.0	5366.2	0.0266	1.1220	92.3	0.0114	203	17.6	-8.2	10to20cm	
109	697.9	3675.2	0.0148	1.1220	53.8	0.0132	202	13.1	-8.1	20to30cm	
110	289.0	NA	0.3964	1.2109	124.1	0.0100	152	17.1	-8.4	30to40cm	
111						0.0105	216	22.1		30to40cm	
112	453.8	NA	0.3842	1.1906	189.1				-8.8	10to20cm	
113	450.9	NA	0.4283	1.2714	210.7				-8.8	0to10cm	
114	704.5	4477.3			93.6			27.9	-8.1	from BIST site	
115											
119							average	24.2	-7.3	beam samples broke	
120											
121											
122											

Table 8: BEAM IN-SITU TEST DATA

SITE	TIME	l (m)	b (m)	h (m)	T1 (sec)	P1 (N)	D1 (mm)	T2 (sec)	P2 (N)	D2 (mm)	∂e/∂t (/sec)
LR5_6/9/92	1512	2.00	0.40	0.50	4.736	-3541	-2.350	14.944	-12220	-13.870	0.279
LR5_6/9/92	1607	2.00	0.40	0.51	6.400	-4653	-5.158	12.720	-14970	-11.240	0.161
LR5_6/9/92	1622	2.00	0.40	0.52	2.480	-1112	-2.360	9.728	-12570	4.738	NA
LR5_6/9/92	average										
LR16_7/9/92	412	1.98	0.40	0.40	9.920	-1680	-5.815	14.720	-3348	-13.390	0.101
LR16_7/9/92	415	1.98	0.40	0.40				4.888	-7735	-2.468	NA
LR16_7/9/92	437	1.98	0.40	0.40			NG		-3094	NA	NA
LR16_7/9/92	average										
LR23_7/9/92	1440	2.51	0.48	0.57	12.048	-2369	9.910	15.104	-14390	-0.893	0.241
LR32_8/9/92	1406	2.05	0.45	0.53	2.600	-2321	-11.420	9.400	-21630	-14.960	
LR32_8/9/92	1408	2.05	0.45	0.53					-17330		
LR32_8/9/92	estimate										
LR40_9/9/92	1349	2.51	0.44	0.58					-20454		
LR40_9/9/92	1401	2.51	0.43	0.58	2.752		6.012	13.280	-21769	-3.373	
LR40_9/9/92	1433	2.51	0.44	0.58			0.879		-20600	-9.437	
LR40_9/9/92	1457	2.51	0.44	0.59					-23717		
LR40_9/9/92	average										
LR40_9/9/92	st. dev										

Table 8: BEAM IN-SITU TEST DATA

σ (kPa)	E (MPa)	ρ (Mgm/m^3)	NOTE	SITE
374	31			LR5_6/9/92
432	64	0.542	<thickness	LR5_6/9/92
355	NA	0.051	<freeboard	LR5_6/9/92
387	47	0.937	good data	LR5_6/9/92
	17		{two runs on	LR16_7/9/92
358	NA		{the same beam	LR16_7/9/92
NA	NA		beam tipped, broke assym	LR16_7/9/92
358	17		top layer delaminating	LR16_7/9/92
350	50		uneven beam trimmed	LR23_7/9/92
526	175	0.530	loaded then backed off	LR32_8/9/92
422		0.050	same beam, missed peak	LR32_8/9/92
526	175	0.937	high wind whiteout	LR32_8/9/92
520	NA		lvdt slipped	LR40_9/9/92
567	109		load peak only	LR40_9/9/92
530	87	0.580	<thickness	LR40_9/9/92
583	NA	0.070	<freeboard	LR40_9/9/92
550		0.915	good data	LR40_9/9/92
30				LR40_9/9/92

Table 9: SNOW MECHANICAL PROPERTIES

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	site	time	depth	T	height	mass	ρ	mass	drop	sink	compac	class	
2		(GMT)	(cm)	(°C)	(m)	(kg)	Mg/m^3	(kg)	(m)	(m)	(kPa)	(#)	
3	IE6_28/8	1830	0	-0.7	0.980	2.550	0.325	5.5	0.700	0.182	25.9	freeze bonding between	
4			10	-0.7				5.5	0.620	0.114	34.5	xls, angular, sharp	
5			20	-0.2				5.5	0.860	0.248	23.9	0.6mm - 1mm	
6			30	-0.1				5.5	0.730	0.122	37.4	light upper crust	
7			40	0.0								25 mm crust under	
8			50	-0.3								1 m snow	
9			60	-1.1									
10			70	-1.6									
11	IE6_28/8	1830	average	-0.4			0.325				30.4	5	
12													
13	RM1_29,	1700	7	-2.9	0.210	0.560	0.333	5.5	0.740	0.020	202.9	0.1mm to 0.2mm grains	
14			17	-3.4				5.5	0.842	0.073	66.9	very sharp grains	
15			27	-3.9				5.5	0.820	0.041	112.1	three or more ice-crust	
16								5.5	0.843	0.046	103.2	layers 25mm thick	
17								5.5	0.768	0.049	89.0		
18	RM1_29,	1700	average	-3.4			0.333				114.8	6	
19													
20	RM5_30	1200	0					5.5	0.825	0.060	78.8	lots refrozen xls	
21			20	-16.8				5.5	0.855	0.040	119.5	rounded grains	
22			40	-14.8				5.5	0.850	0.025	186.9	2mm crust	
23								5.5	0.845	0.054	88.9	1mm xls	
24								5.5	0.835	0.340	18.5		
25	RM5_30	1200	average	-15.8							98.5	4	
26													
27	RM23_3	1850	5	-10.5	0.210	1.200	0.394	5.5	0.810	0.065	71.9	as above	
28			15	-8.9	0.170			5.5	0.805	0.430	15.3		
29			25	-6.9				5.5	0.840	0.050	95.1		
30								5.5	0.910	0.041	123.9		
31								5.5	0.825	0.082	59.1		
32	RM23_3	1850	average	-8.8			0.394				73.0	4	

Table 9: SNOW MECHANICAL PROPERTIES

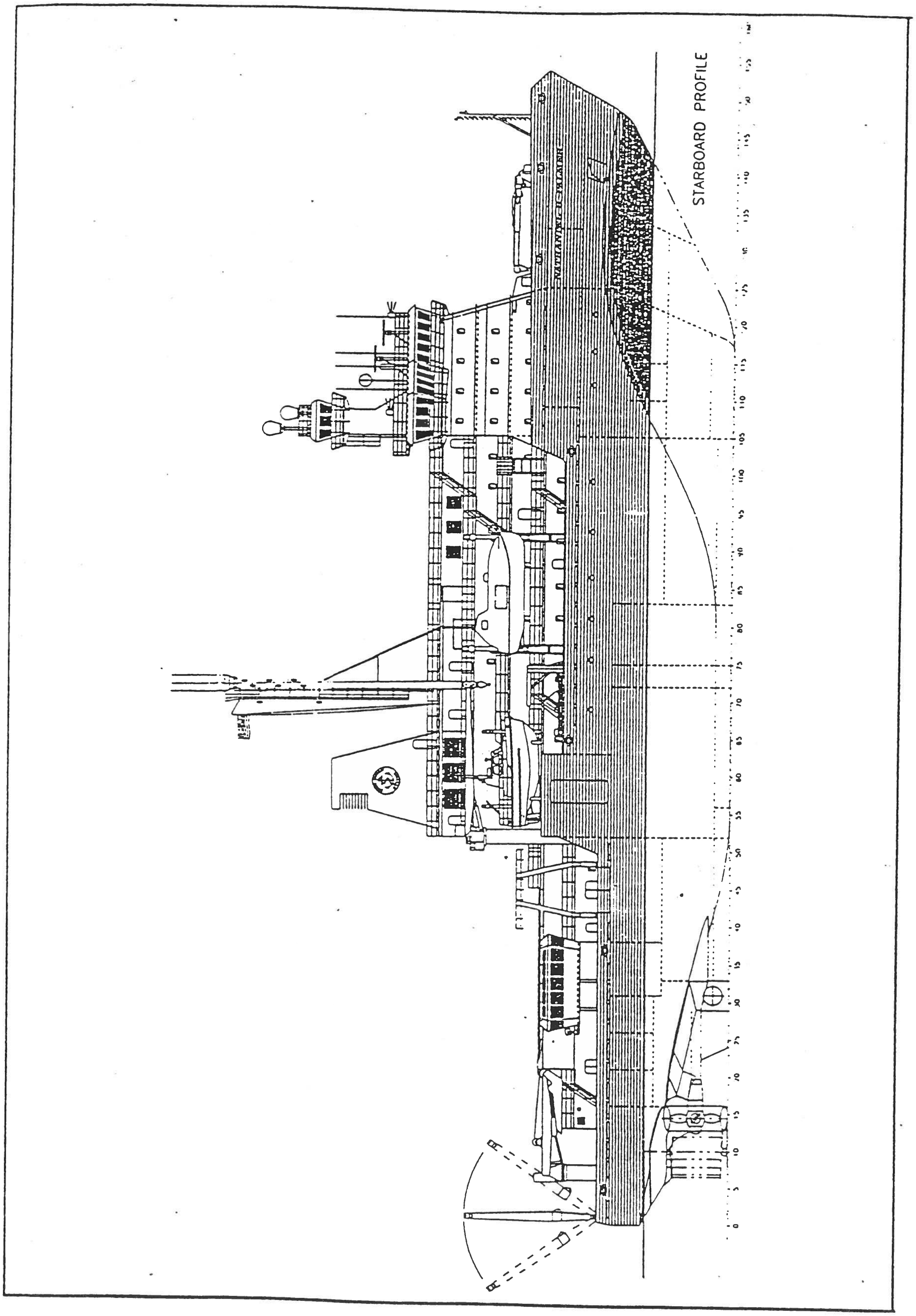
	A	B	C	D	E	F	G	H	I	J	K	L	M
33													
34	RM26_1	1235	6	-5.0	0.490	1.210	0.355	5.5	0.850	0.092	54.7	4 layers	
35			10	-5.7	-0.065			5.5	0.788	0.062	73.2	of ice	
36			15	-6.6				5.5	0.820	0.042	109.6	each 5 mm thick	
37			19	-6.2				5.5	0.800	0.068	68.2	round old grains	
38			25	-6.6				5.5	0.808	0.089	53.8	0.6 mm	
39			30	-6.0				5.5	0.782	0.086	53.9		
40			40	-5.1									
41	RM26_1	1235	average	-5.9			0.355				68.9	3	
42													
43	LR5_6/9	1250	5	-5.1	0.105	0.290	0.345	5.5	0.400	0.018	124.0	thin layer	
44			5	-5.2	0.102	0.287	0.351	5.5	0.400	0.018	124.0	one type	
45			5	-5.0				5.5	0.400	0.021	107.1	wind blown	
46								5.5	0.400	0.026	87.5	hexagonal	
47								5.5	0.400	0.026	87.5	small, sharp	
48	LR5_6/9	1250	average	-5.1			0.348				106.0	5	
49	LR32_8/	1200	3	-1.5	0.070	0.210	0.374	wet driven snow		on old crust		3	
50	LR40_9/	1400	2	-1.5	0.020	0.070	0.437	5.5	0.850	0.026	179.9	layer new wet	
51								5.5	0.850	0.020	232.3	round 1mm xls	
52								5.5	0.840	0.030	154.9	on very hard	
53								5.5	0.840	0.024	192.2	old crust	
54	LR40_9/	average		-1.5			0.437				189.8	3	

Table 10: ICE AND SNOW SUMMARY

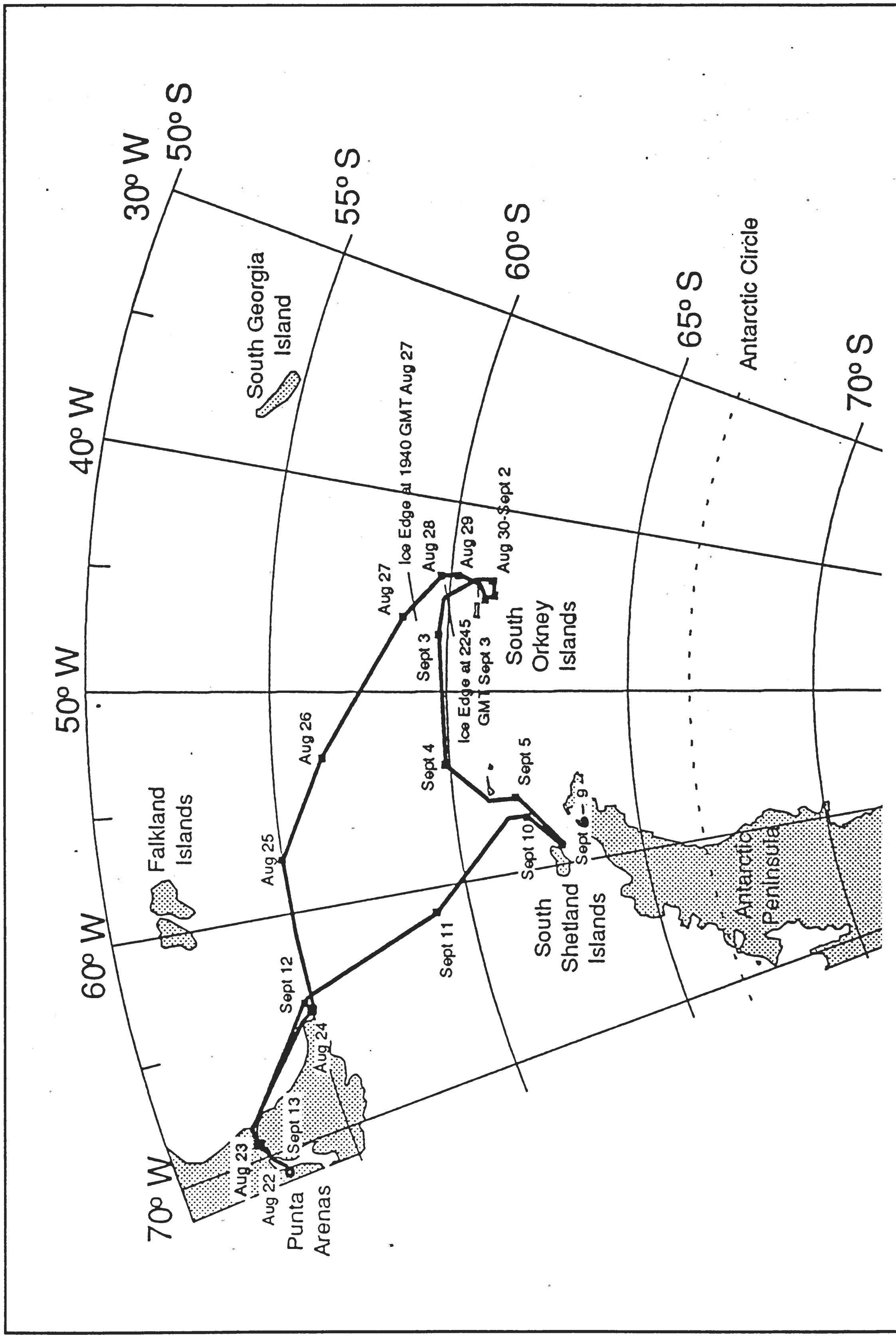
DATE	TEST #	ICE thick (m)	ICE Temp (°C)	ICE Sal (ppt)	ICE STRENGTH BILT (kPa)	ICE STRENGTH BIST (kPa)	ICE STRENGTH Vaud (kPa)	ICE STRENGTH hardn. (MPa)	SNOW thick (m)	SNOW Temp (°C)	SNOW comp (KPa)	SNOW ρ Mg/m^3	SNOW Sn (#)	AIR Temp (°C)
27-Aug	IE1	NA	-1.8	6.52	659			15	NA	NA	NA	NA	NA	3.1
28-Aug	IE6	4.05	-3.0	2.53	NA		569	NA	0.98	-0.44	30.4	0.325	5	-2.4
29-Aug	RM1	1.32	-3.2	3.31	705		527	19	0.27	-3.4	114.8	0.333	5	-1.0
31-Aug	RM5	2.25	-6.6	3.89	NA		627	NA	0.72	-15.8	98.5		4	-21.1
31-Aug	RM23	1.26	-3.3	4.59	689		374	25	0.38	-8.8	73	0.394	4	-14.4
1-Sep	RM26	2.15	-3.6	3.33	584		542	25	0.52	-5.9	68.9	0.355	3	-3.2
6-Sep	LR5	0.46	-4.1	3.47	525	387	570	20	0.07	-5.1	106	0.348	5	-7.2
6-Sep	LR9	0.48	-4.0	3.00			596		0.11	NA	NA	NA	NA	-6.0
6-Sep	LR16	0.52	-4.5	4.27	586	358	540	17	0.10	NA	NA	NA	NA	-7.4
7-Sep	LR23	0.57	-4.0	5.30		350	470		0.08	NA	NA	NA	NA	-5.7
8-Sep	LR32	0.61	-1.7	1.69	705	526	564	28	0.06	-1.5	NA	0.374	3	-8.8
9-Sep	LR40	0.57	-2.9	3.03	705	550	511	28	0.11	-1.5	189.8	0.437	3	0.5
5-Sep	icing		-2.0	13.23										
9-Sep	glacier		-0.4	0				24						

Table 10: ICE AND SNOW SUMMARY

DATE	TEST #	ICE thick (ft)	ICE Temp (°F)	ICE Sal (ppt)	ICE STRENGTH BILT (psi)	ICE STRENGTH BIST (psi)	ICE STRENGTH Vaud (psi)	ICE STRENGTH hardn. (psi)	SNOW thick (ft)	SNOW Temp (°F)	SNOW comp (psi)	SNOW density (lb/ft^3)	SNOW Sn (#)	AIR Temp (°F)
27-Aug	IE1		28.8	6.52	96			2175					NA	37.6
28-Aug	IE6	13.29	26.6	2.53	NA		83	NA	3.22	31.2	4	20.28	5	27.7
29-Aug	RM1	4.33	26.2	3.31	102		76	2755	0.87	25.9	17	20.78	5	30.2
31-Aug	RM5	7.38	20.1	3.89	NA		91	NA	2.36	3.6	14		4	-6.0
31-Aug	RM23	4.13	26.1	4.59	100		54	3625	1.25	16.2	11	24.59	4	6.1
1-Sep	RM26	7.05	25.5	3.33	85		79	3625	1.71	21.4	10	22.15	3	26.2
6-Sep	LR5	1.51	24.6	3.47	76	56	83	2900	0.23	22.8	15	21.72	5	19.0
6-Sep	LR9	1.57	24.8	3.00			86		0.36	NA	NA	NA	NA	21.2
6-Sep	LR16	1.71	23.9	4.27	85	52	78	2465	0.33	NA	NA	NA	NA	18.7
7-Sep	LR23	1.87	24.8	5.30		51	68		0.26	NA	NA	NA	NA	21.7
8-Sep	LR32	2.00	28.9	1.69	102	76	82	4060	0.20	29.3	NA	23.34	3	16.2
9-Sep	LR40	1.87	26.8	3.03	102	80	74	4060	0.36	29.3	28	27.27	3	32.9
5-Sep	icing		28.4	13.23										
9-Sep	glacier		31.3	0				3480						



Starboard Profile of the Nathaniel B. Palmer



NATHANIEL B. PALMER Winter Ice Tests, Noon Position

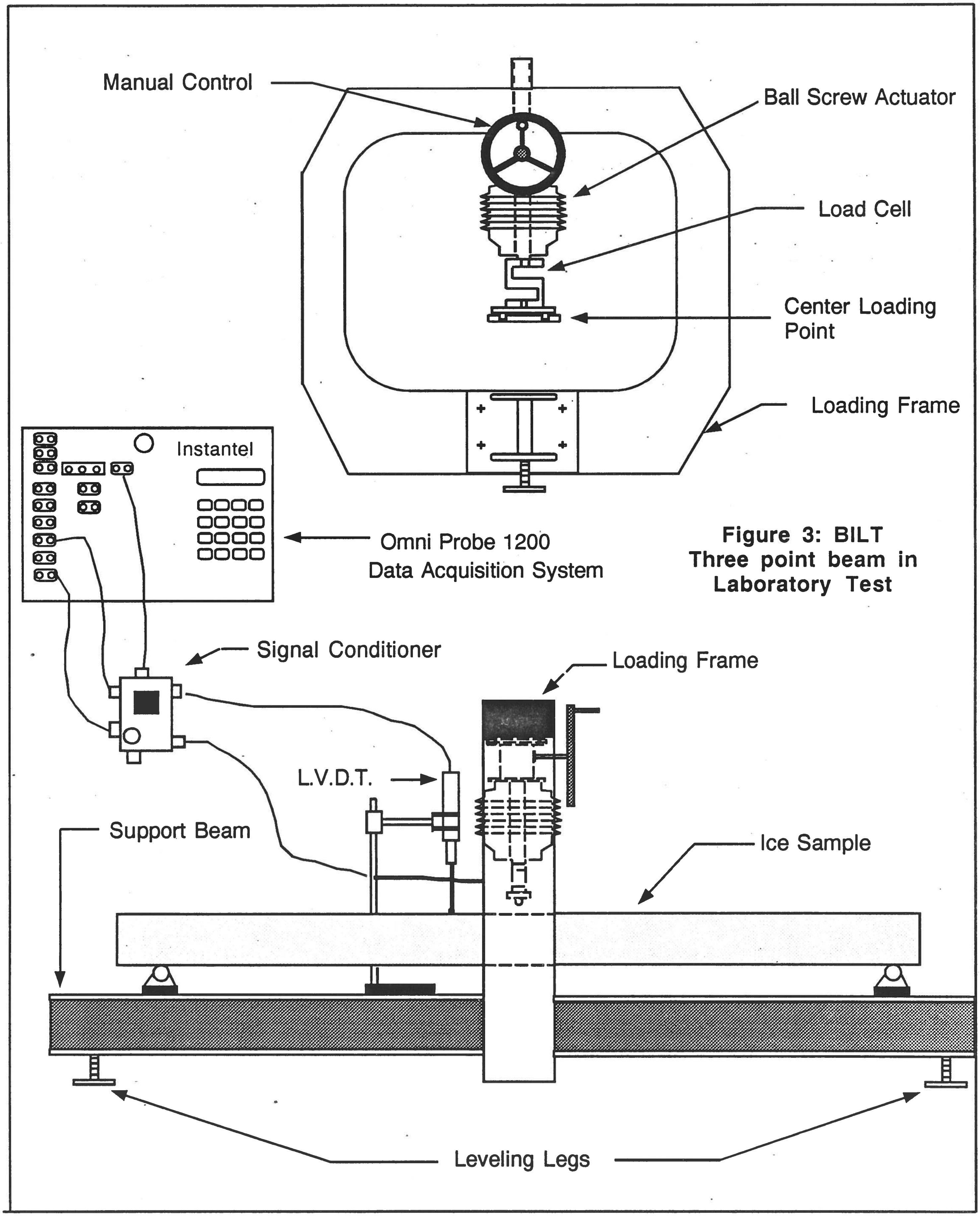


Figure 3: BILT Three point beam in Laboratory Test

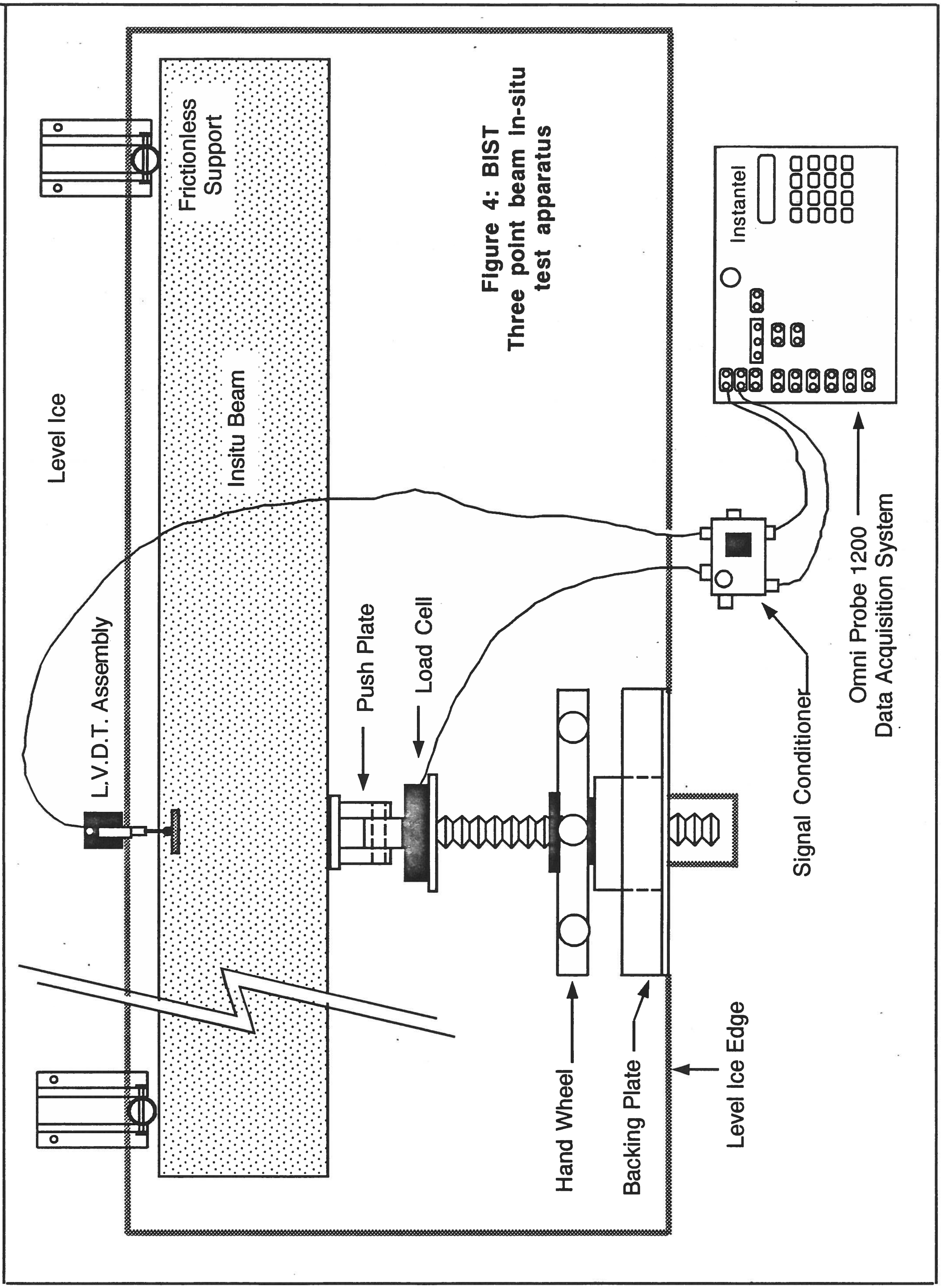


Figure 4: BIST
Three point beam in-situ test apparatus

Figure 5: Vickers indenter and hardness test setup

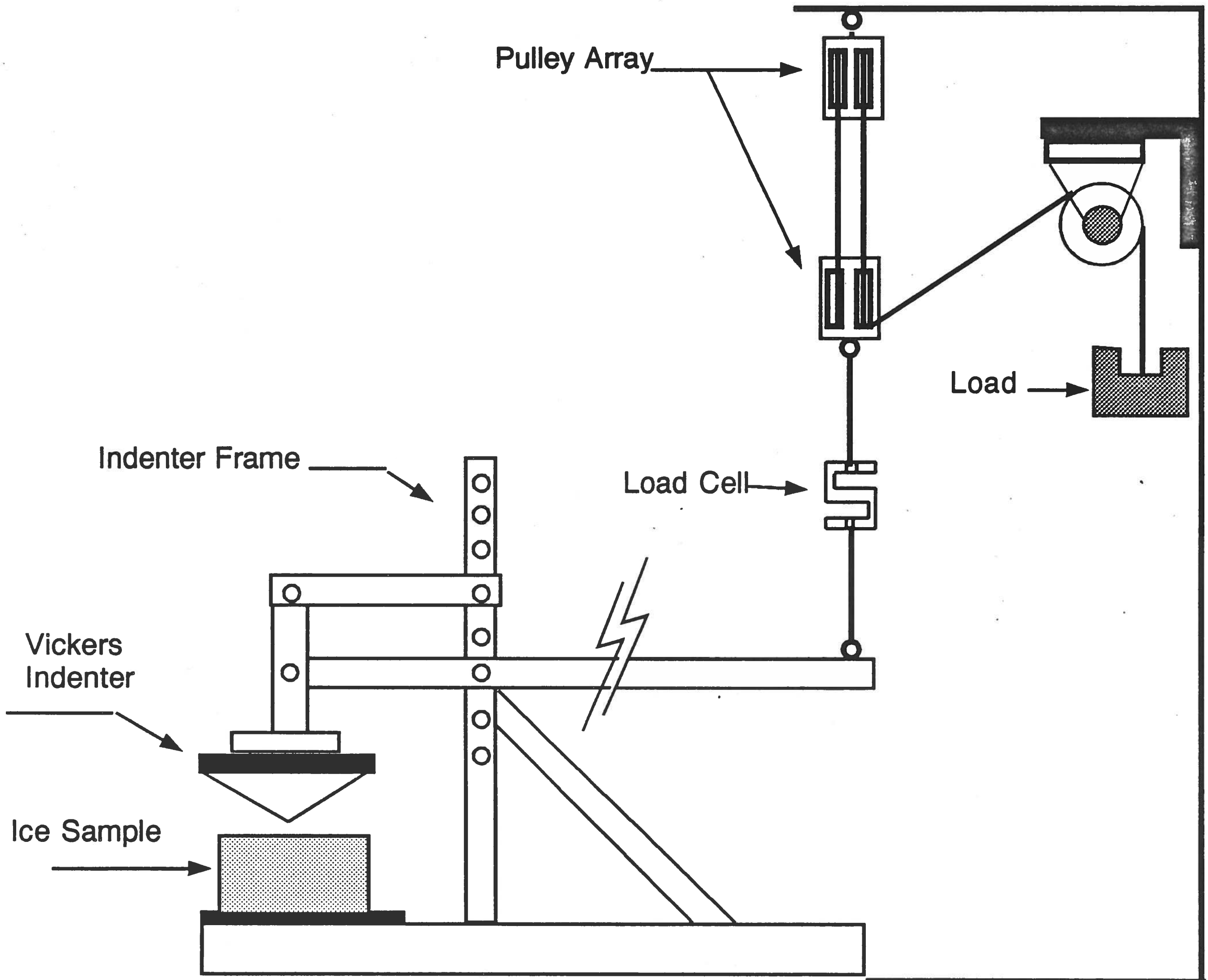


Figure 6: Snow compactness gauge

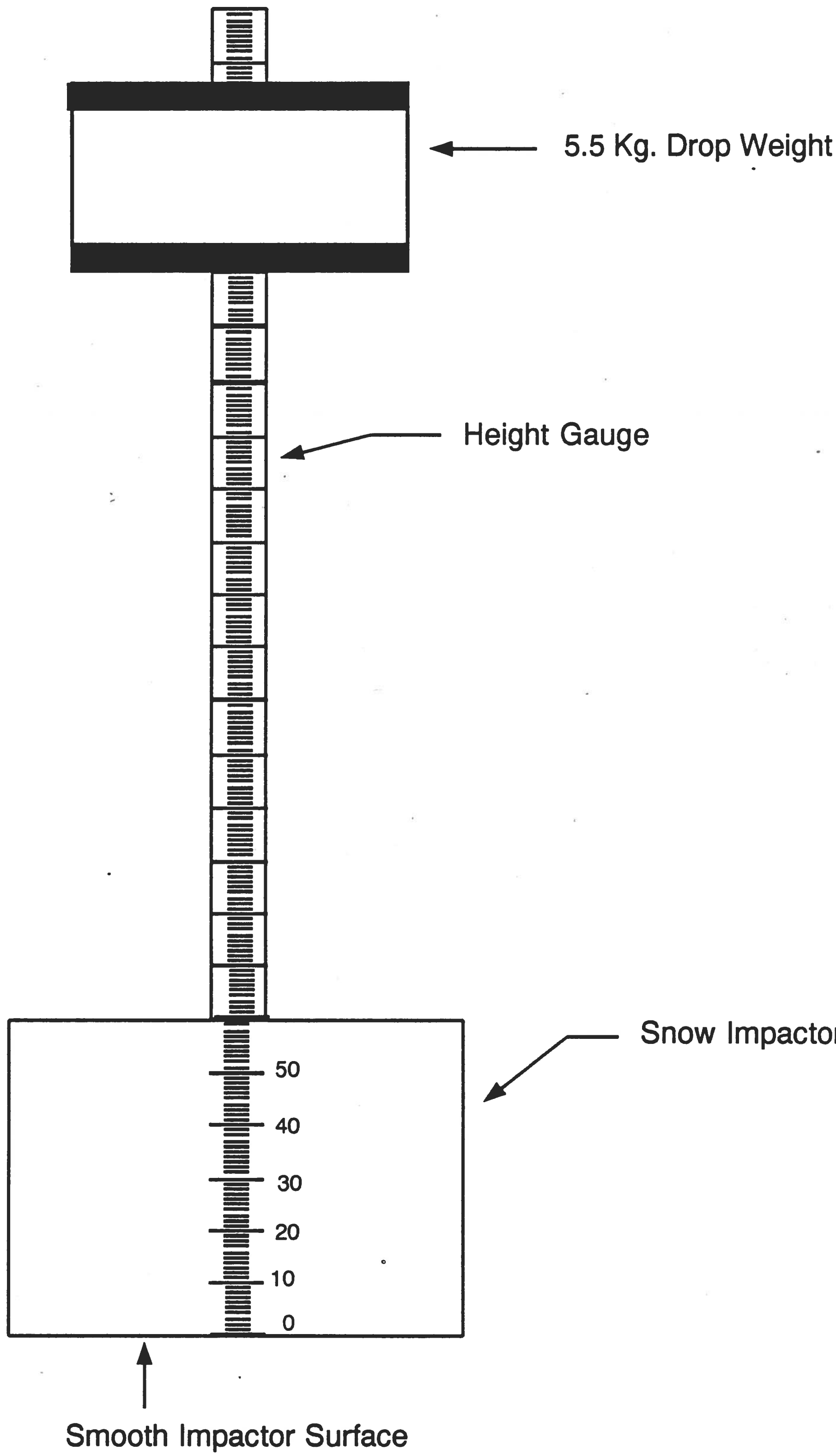


Figure 7: BILT Force and deflection from LR5

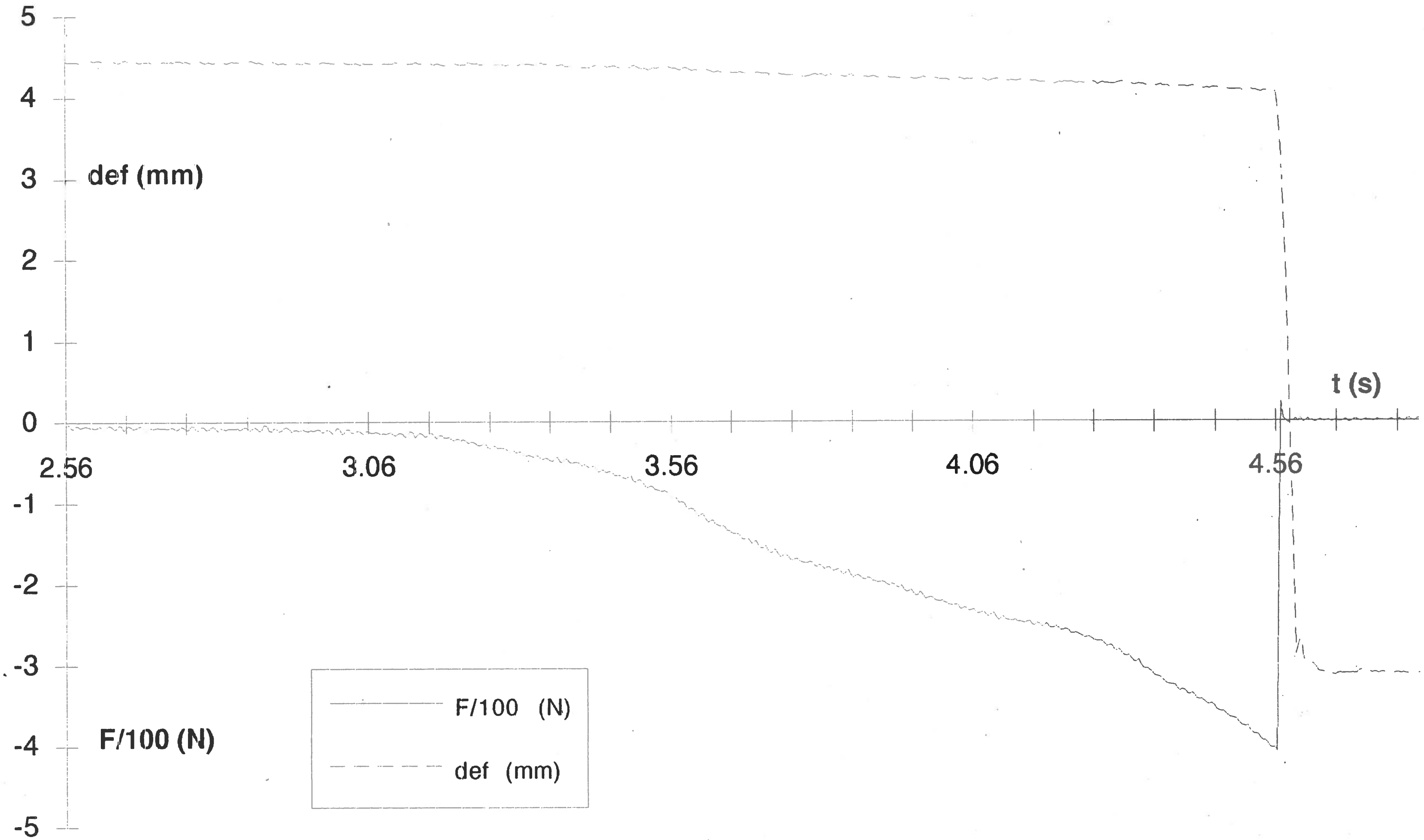


Figure 8: BIST force and deflection from LR5

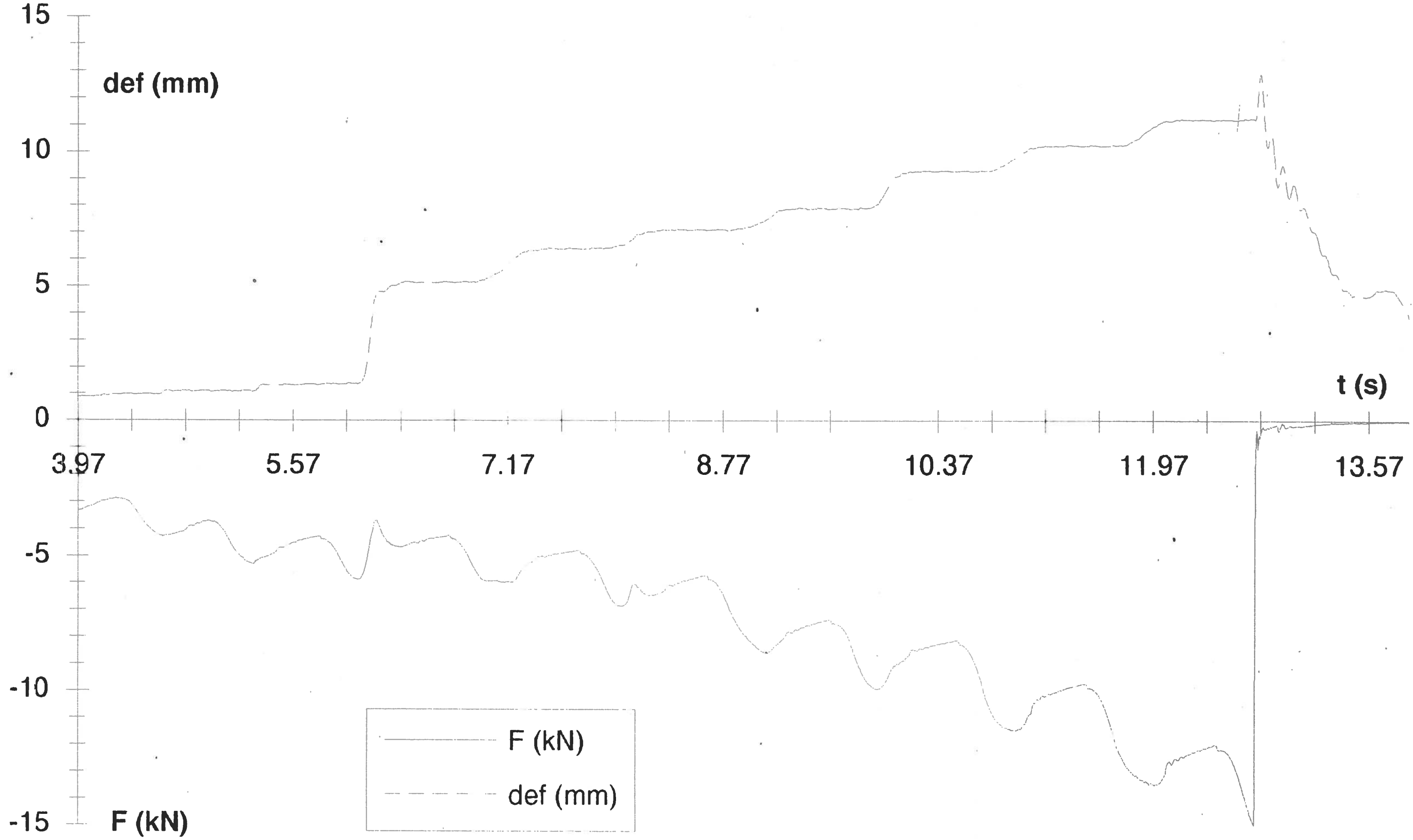


Figure 9: comparison of ice strength measurements

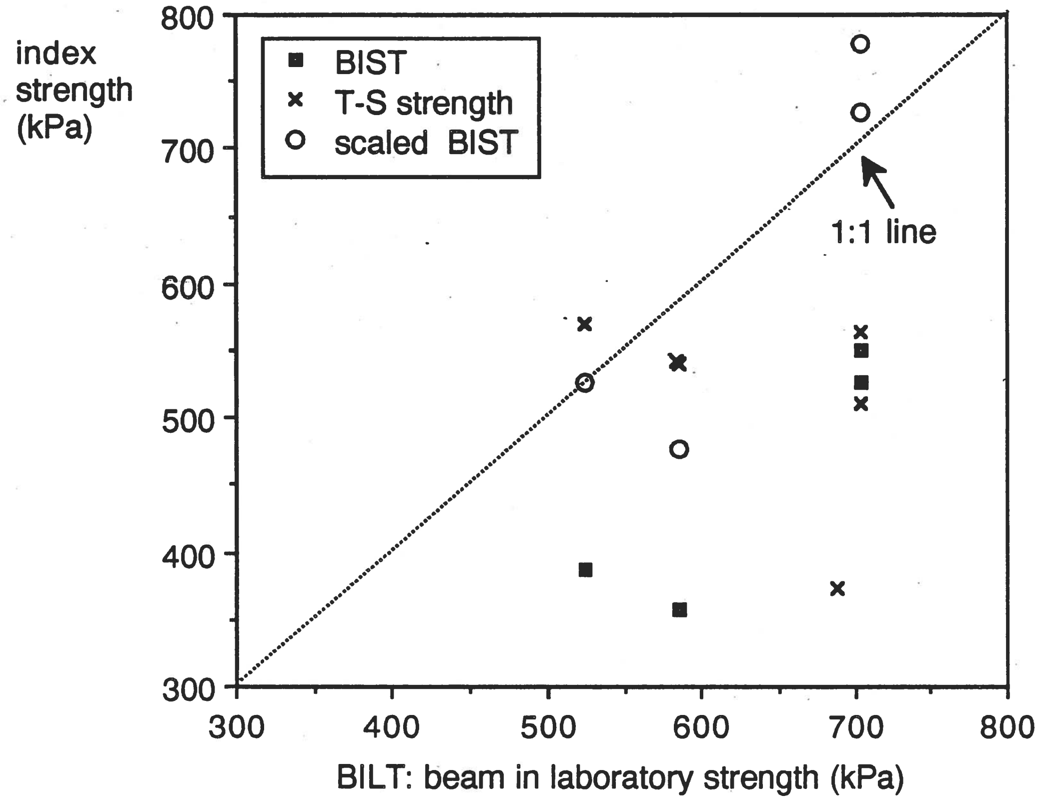


Figure 10: Salinity thickness relationship compared with trend lines for Arctic first year and multi year ice (Cox and Weeks)

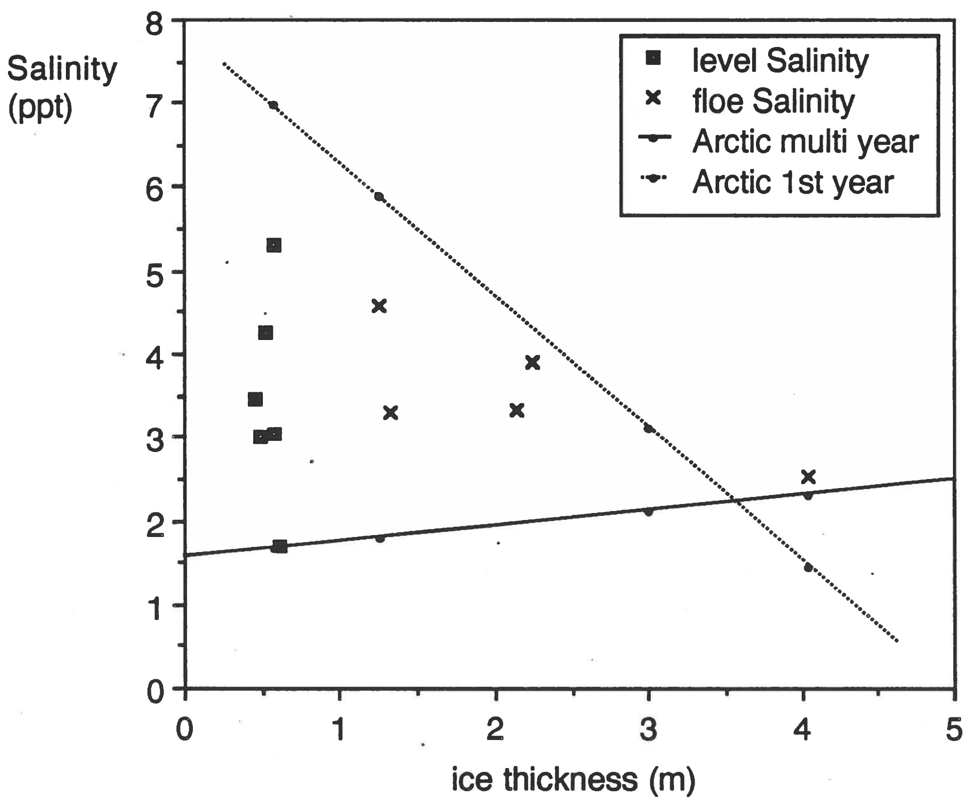
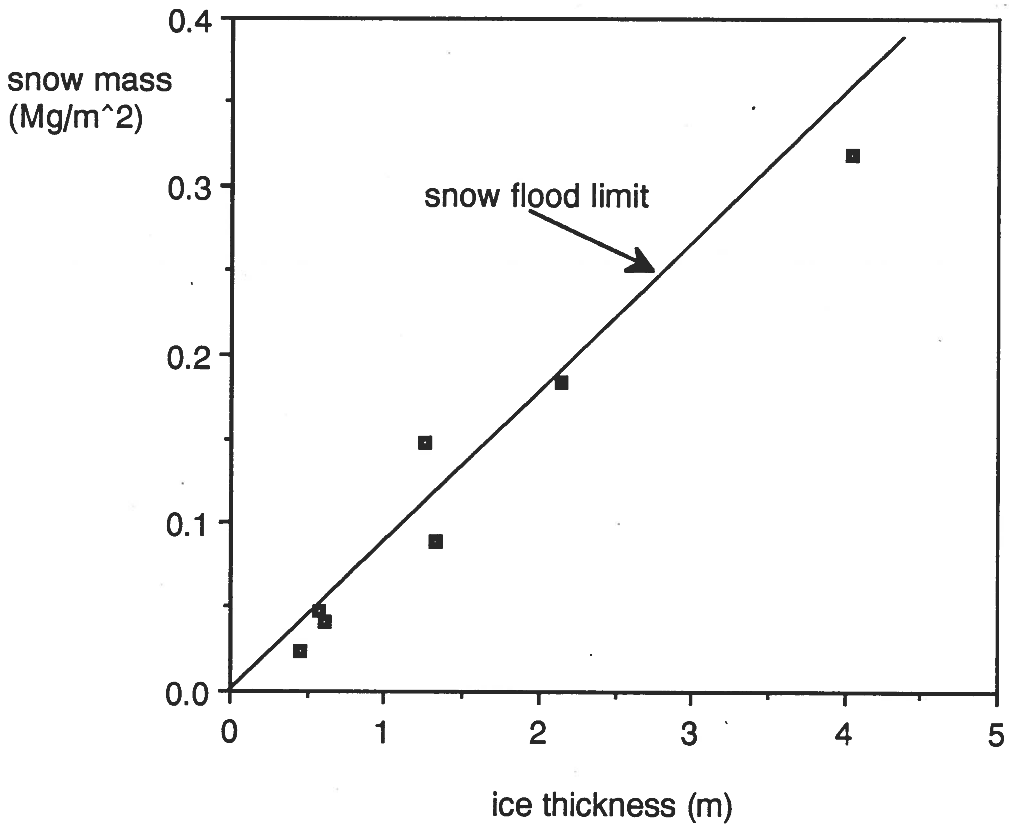


Figure 11: Snow load per unit area as a function of ice thickness, data points and snow flood line.



APPENDIX A

Snow and Ice Thickness Profiles

RM4 to RM23: ICE AND SNOW

site and description	time (GMT)	distance from bow (m)	snow thick (m)	ice thick (m)
RM4 to RM22	1250	30	0.63	2.31
part of		60	0.78	2.35
compound floe		90	0.66	2.14
with ridge				
	1328	average	0.72	2.25
RM23	1846	25	0.44	1.6
uniform floe	1856	50	0.46	1.2
	1904	75	0.36	1.42
	1915	100	0.4	1.17
	1925	125	0.48	1.25
		150	0.52	1
		175	0.4	1.26
		200	0.4	1.26
		225	0.35	1.4
	1944	250	0.39	1.18
		275	0.27	1.05
		300	0.56	1.35
	2025	average	0.42	1.26

RM26: ICE AND SNOW

site and description	marker	distance from bow (m)	snow thick (m)	ice thick (m)	notes
RM26	1	0	0.42	1.5	
1235 GMT	2	25	0.53	2.17	
in ridge	3	50			
across floe,	4	75			
blocks of ice	5	100	0.57	1.57	
under old snow	6	125			
pressure field	7	150			
on far side	8	175	0.43	2.68	pieces underneath
	9	200			
	10	225			
	11	250	0.75	2.3	
	12	275			
	13	300	0.42	1.71	
	14	325			
	15	350			
	16	375	0.54	3.67	
	17	400			
	18	425	0.72	2.65	more underneath
	19	450			
	20	475			
	21	500	0.61	2.68	
	22	525			
	23	550	0.18	0.58	
		average	0.517	2.151	

LR5 ICE AND SNOW

site and description	marker	distance from last (m)	snow thick (m)	ice thick (m)	notes
LR5	1	0.00	0.17	0.26	
Maxwell Bay	2	10.73	0.27	0.30	
Level ice	3	11.35	0.03	0.53	
	4	8.90	0.08	0.46	
	5	12.87	0.05	0.47	
	6	9.25	0.08	0.50	
	7	11.84	0.06	0.46	
	8	10.67	0.06	0.46	
	9	11.57	0.03	0.41	
	10	15.80	0.06	0.45	
	11	21.10	0.06	0.45	
	12	8.23	0.08	0.43	
	13	11.33	0.01	0.41	
	14	11.42	0.05	0.47	
	15	11.00	0.03	0.50	
	16	10.83	0.05	0.45	
	17	12.10	0.08	0.50	
	18	11.32	0.04	0.48	
	19	10.44	0.03	0.45	
	20	15.25	0.07	0.42	
LR5 average		11.89	0.07	0.44	
LR6	1	0	0.02	0.42	
Maxwell Bay	2	30	0.01	0.45	
Level ice	3	30	0.03	0.34	
	4	30	0.07	0.46	
	5	30	0.09	0.45	
	6	30	0.04	0.46	
	7	30	0.11	0.49	
	8	30	0.03	0.47	
	9	30	0.12	0.52	
	10	30	0.05	0.48	
	11	35	0.11	0.51	
LR6 average			0.06	0.46	

LR7 ICE AND SNOW

site and description	marker	distance from last (m)	snow thick (m)	ice thick (m)	notes
LR7	1	0	0.11	0.48	
Maxwell Bay	2	30	0.12	0.51	
Level ice	3	30	0.10	0.50	
	4	30	0.10	0.53	
	5	28.5	0.04	0.50	
LR7 average			0.09	0.50	
LR8	1	0	0.07	0.57	
Maxwell Bay	2	30	0.10	0.56	
Level ice	3	30	0.09	0.50	
	4	30	0.12	0.65	
	5	30	0.10	0.56	
	6	30	0.14	0.48	
	7	30	0.06	0.53	
	8	30	0.07	0.48	
LR8 average			0.09	0.54	
LR9	1	30	0.13	0.45	
Maxwell Bay	2	30	0.15	0.48	
Level ice	3	30	0.08	0.48	
	4	20.5	0.06	0.48	
LR9 average			0.11	0.47	
LR10 LR11	1	30	0.16	0.74	
Maxwell Bay	2	30	0.12	0.88	
Level ice	3	30	0.14	0.77	
	4	30	0.12	0.72	
	5	30	0.12	0.78	
	6	30	0.16	0.78	
	7	30	0.12	0.62	
LR10-11 average			0.13	0.76	

LR12-LR17: ICE AND SNOW

site and description	marker	distance from mark (m)	snow thick (m)	ice thick (m)	notes
LR12-LR17	1	0	0.07	0.54	
level ice	2	50	0.07	0.55	
Maxwell Bay	3	50	0.07	0.53	
	4	50	0.06	0.54	
	5	40.1	0.12	0.50	nut
	6	38.6	0.07	0.46	nut
	7	25.1	0.15	0.42	nut
	8	14.6	0.06	0.57	nut
	9	17.4	0.10	0.52	nut
	10	16.5	0.05	0.57	nut
	11	10.8	0.13	0.58	nut
	12	100	0.10	0.48	other side of turn
	13	50	0.08	0.63	
	14	50	0.08	0.66	
	15	26.5	0.10	0.66	lug
	16	50	0.07	0.69	
	17	50	0.09	0.70	
	18	50	0.07	0.71	
	19	50	0.13	0.76	
	20	50	0.14	0.60	
	21	50	0.06	0.63	
	22	32	0.12	0.61	lug
	23	100	0.08	0.56	
	24	50	0.15	0.58	
	25	50	0.15	0.54	
	26	50	0.08	0.59	
	27	50	0.05	0.50	
	28	50	0.12	0.58	
	29	50	0.13	0.58	
	30	50	0.07	0.54	
	31	50	0.11	0.60	
	32	53	0.04	0.50	3 nuts
	33	50	0.07	0.57	
	34	50	0.07	0.57	
	35	50	0.08	0.49	stern
	36	100	0.12	0.58	bow
average			0.09	0.57	

LR18-LR24: ICE AND SNOW

site and description	marker	distance from mark (m)	snow thick (m)	ice thick (m)	notes
LR18 - LR23	1	0	0.14	0.54	
Maxwell Bay	2	100	0.08	0.56	
level ice	3	100	0.06	0.63	
	4	100	0.05	0.57	
	5	50	0.12	0.61	
	6	10	0.08	0.60	
	7	25	0.09	0.62	
	8	25	0.12	0.58	
	9	25	0.11	0.64	
	10	25	0.11	0.59	
	11	25	0.13	0.59	
	12	25	0.08	0.61	
	13	25	0.07	0.64	
	14	25	0.14	0.58	
	15	25	0.11	0.59	
	16	25	0.07	0.53	
	17	25	0.10	0.56	
	18	25	0.10	0.60	
	19	25	0.23	0.56	bow
	20	50	0.11	0.55	midship
	21	50	0.21	0.58	stern
average			0.11	0.59	
LR24	1	0	0.35	1	
Maxwell Bay	2	50	0.24	1.2	
level ice	3	50	0.28	1.1	
	4	50	0.18	1.3	
	5	50	0.3	1.25	
	6	50	0.21	1.25	
	7	50	0.3	1.27	bow

LR25 - LR33: ICE AND SNOW

site and description	marker	distance from mark (m)	snow thick (m)	ice thick (m)	notes
LR25 - LR33	1	0	0.10	0.54	
level ice	2	100	0.06	0.57	+10 flag
Admiralty Bay	3	100	0.07	0.57	
	4	100	0.10	0.57	
	5	100	0.11	0.39	-10 flag
	6	100	0.07	0.52	
	7	100	0.08	0.48	
	8	100	0.10	0.45	flag
	9	100	0.13	0.37	
	10	100	0.09	0.55	
	11	50			flag
	12	50	0.09	0.54	
	13	100	0.06	0.50	
	14	100	0.09	0.57	flag
	15	100	0.12	0.43	
	16	100	0.14	0.50	
	17	100	0.13	0.42	
	18	100	0.10	0.57	
	19	100	0.12	0.49	
	20	100	0.10	0.48	
	21	100	0.11	0.59	
	22	100	0.07	0.53	
	23	100	0.09	0.58	start turn
	24	100	0.09	0.61	
	25	100	0.09	0.60	
	26	100	0.10	0.53	
	27	100	0.10	0.70	
	28	100	0.06	0.62	
	29	100	0.06	0.61	
	30	100	0.06	0.61	
	31	100	0.07	0.59	
	32	100	0.08	0.60	stern
average			0.09	0.54	

LR34 - LR37: ICE AND SNOW

site and description	marker	distance from mark (m)	snow thick (m)	ice thick (m)	ice&snow thick (in)	notes
LR34 - LR37	1	0	0.08	0.35	17.0	
level ice	2	100	0.10	0.64	29.0	
Admiralty Bay	3	100	0.14	0.56	27.5	
	4	100	0.15	0.54	27.0	
	5	100	0.13	0.61	29.0	
	6	100	0.06	0.65	28.0	rafting
	7	100	0.10	0.59	27.0	2 nut markers
	8	100	0.15	0.35	19.5	
	9	100	0.15	0.46	24.0	
	10	100	0.27	0.24	20.0	
	11	100	0.13	0.28	16.0	
	12	100	0.07	0.43	19.5	
		50				2 silver nuts
	13	50	0.09	0.34	17.0	rafting
	14	100	0.07	0.39	18.0	
	15	100	0.07	0.33	15.5	
	16	100	0.11	0.46	22.5	nut
	17	100	0.13	0.59	28.5	
	18	100	0.10	0.64	29.0	
	19	100	0.10	0.61	28.0	
	20	100	0.13	0.58	28.0	stern
			0.12	0.48	23.50	

LR38-LR41: ICE AND SNOW

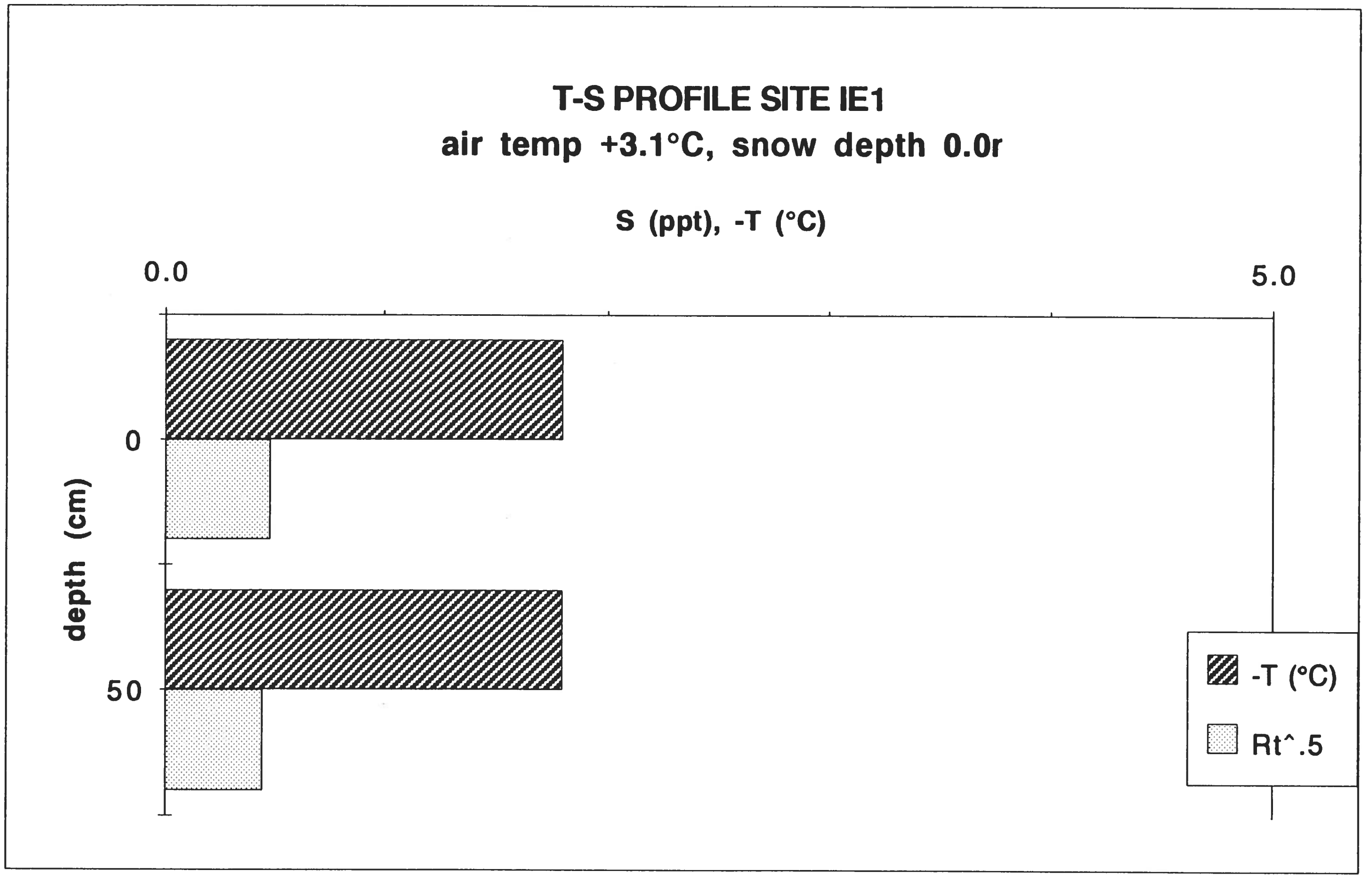
site and description	marker	distance from mark (m)	snow thick (m)	ice thick (m)	notes
LR38	1	0	0.12	0.58	flag (steady state)
level ice	2	50	0.15	0.55	
Admiralty Bay	3	50	0.22	0.61	
	4	50	0.17	0.50	
	5	50	0.15	0.54	
	6	50	0.17	0.59	
	7	50	0.12	0.53	
	8	50	0.15	0.58	
	9	50	0.11	0.62	
	10	37	0.11	0.57	
LR38 average			0.15	0.57	
LR39	11	50	0.13	0.60	flag (steady state)
level ice	12	50	0.16	0.56	
Admiralty Bay	13	50	0.12	0.58	
	14	50	0.14	0.64	
	15	50	0.11	0.55	
	16	50	0.13	0.55	
	17	50	0.13	0.57	
	18	50	0.09	0.65	
	19	50	0.10	0.57	
LR39 average			0.12	0.59	
LR40	20	50	0.12	0.57	flag (start turn)
LR41	21	73	0.07	0.57	flag

APPENDIX B

Temperature and Salinity Profiles

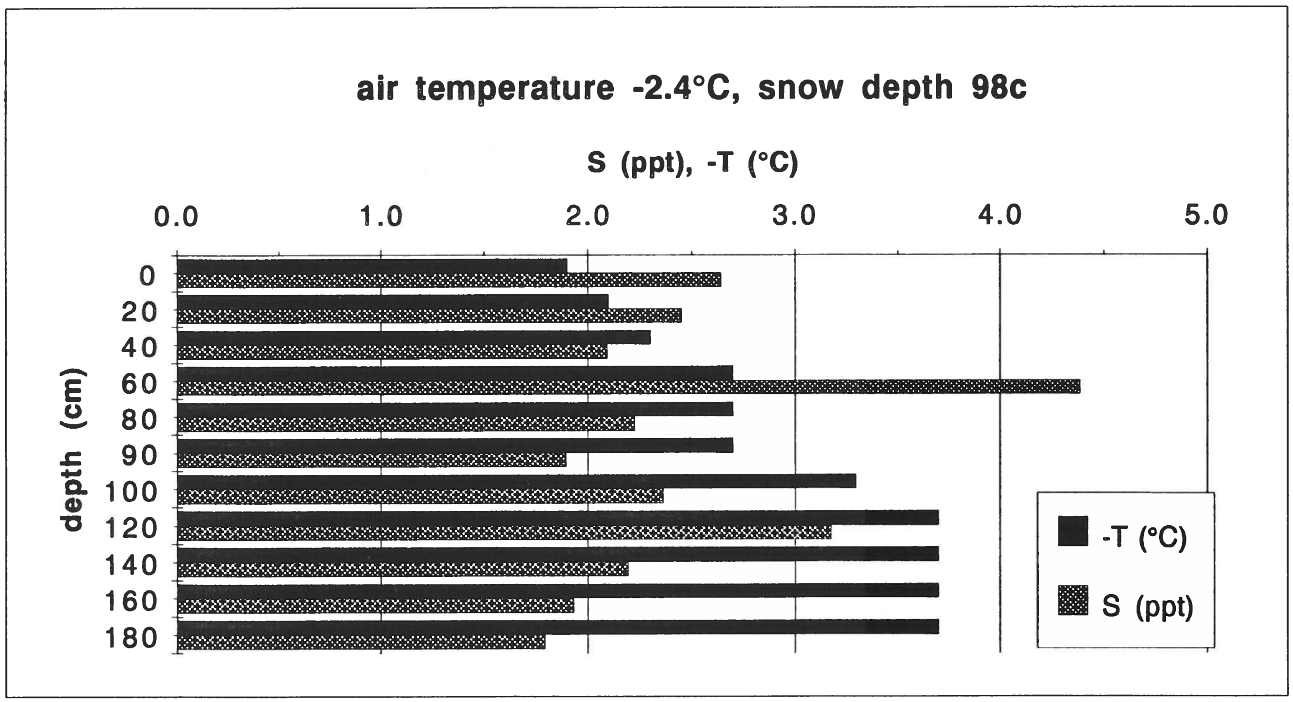
T-S site IE1

depth (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	ν1	ν2	Str (kPa)
0	0.46288	1.8	-1.8	0.48	7.06	0.190	0.195	123
50	0.39860	1.8	-1.8	0.45	6.01	0.162	0.166	187
average					average	0.176	0.181	155
st. dev					st. dev	0.020	0.021	45.8



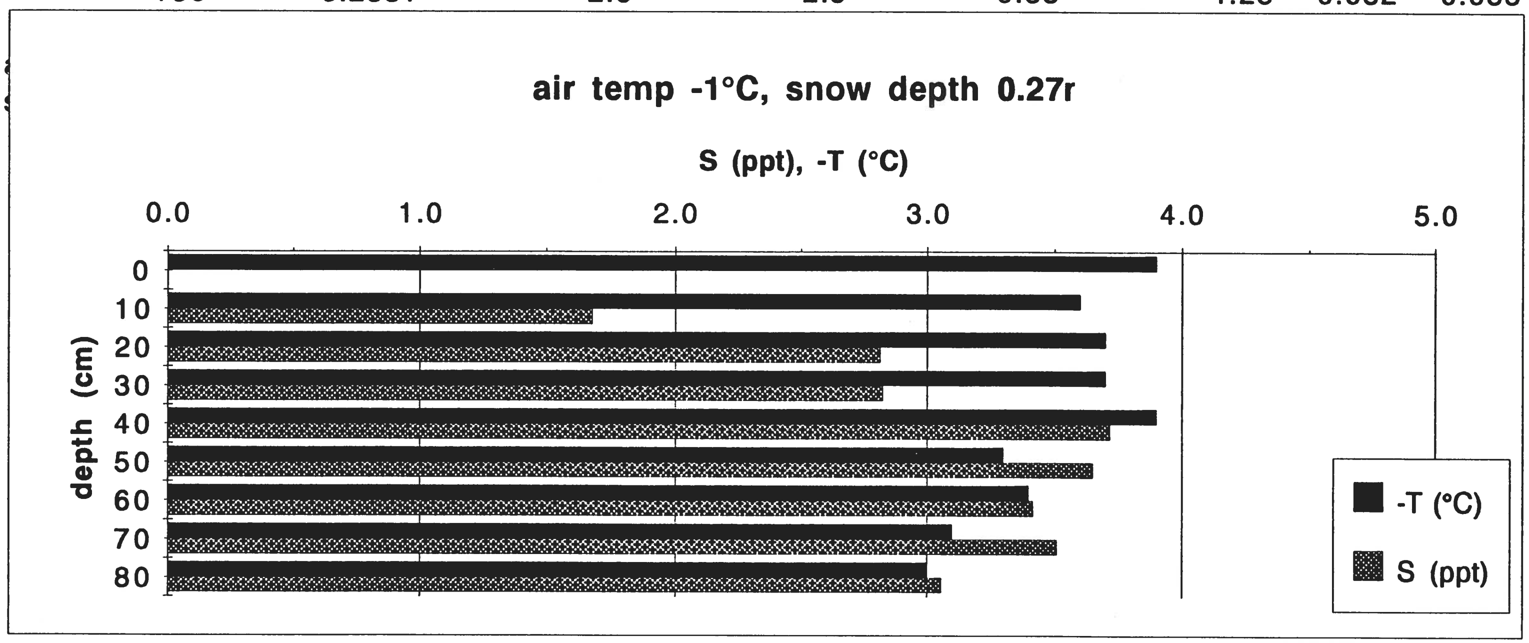
T-S site IE6

depth (cm)	*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	ν−2	ν−1	Str (kPa)
0	0.18456	1.9	-1.9	0.30	2.64	0.067	0.069	463
20	0.17193	2.1	-2.1	0.29	2.45	0.056	0.057	506
40	0.14835	2.3	-2.3	0.27	2.09	0.044	0.045	558
60	0.29703	2.7	-2.7	0.39	4.39	0.079	0.079	421
80	0.15698	2.7	-2.7	0.28	2.22	0.040	0.040	576
90	0.13500	2.7	-2.7	0.26	1.90	0.034	0.034	606
100	0.16606	3.3	-3.3	0.29	2.36	0.035	0.035	601
120	0.21966	3.7	-3.7	0.33	3.18	0.042	0.042	565
140	0.15484	3.7	-3.7	0.28	2.19	0.029	0.029	632
160	0.13728	3.7	-3.7	0.26	1.93	0.026	0.026	652
180	0.12803	3.7	-3.7	0.25	1.79	0.024	0.024	663
260	0.21755	4.0	-4.0	0.33	3.15	0.039	0.039	581
								569
								73.4



T-S profile site RM1

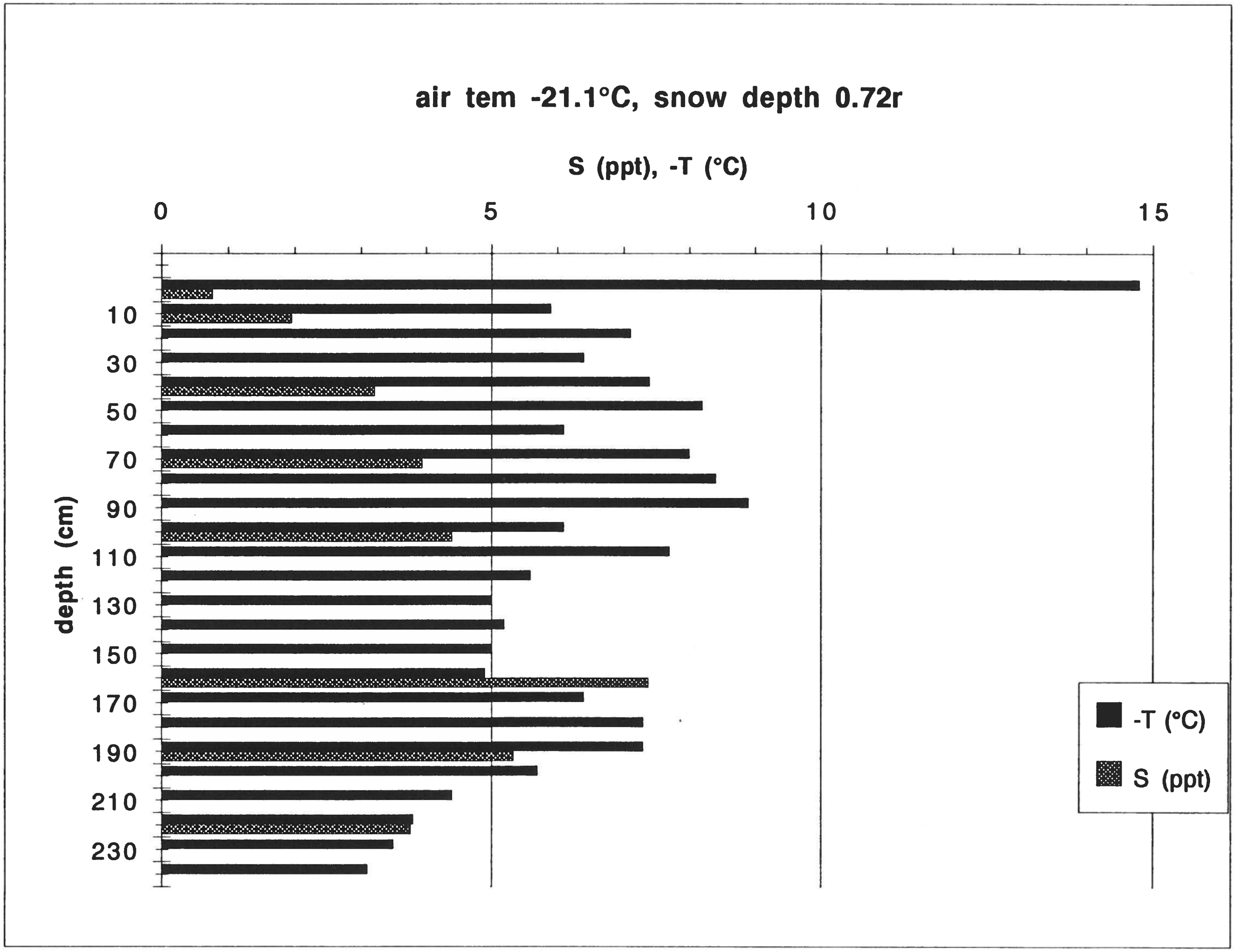
depth (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	v1	v2	Str (kPa)
0	0.0000	3.9	-3.9	0.00				
10	0.1206	3.6	-3.6	0.25	1.68	0.023	0.023	669
20	0.1959	3.7	-3.7	0.31	2.81	0.038	0.037	588
30	0.1967	3.7	-3.7	0.31	2.83	0.038	0.037	587
40	0.2545	3.9	-3.9	0.36	3.72	0.047	0.047	543
50	0.2501	3.3	-3.3	0.35	3.65	0.054	0.054	513
60	0.2351	3.4	-3.4	0.34	3.42	0.049	0.049	534
70	0.2410	3.1	-3.1	0.35	3.51	0.055	0.055	509
80	0.2119	3.0	-3.0	0.33	3.06	0.050	0.050	532
90	0.1910	2.9	-2.9	0.31	2.74	0.046	0.046	549
100	0.2139	3.1	-3.1	0.33	3.09	0.049	0.049	537
110	0.3064	2.8	-2.8	0.39	4.54	0.079	0.079	422
120	0.2533	2.6	-2.6	0.36	3.70	0.069	0.070	456
130	0.2881	2.5	-2.5	0.38	4.25	0.082	0.083	410
								527
								69.8



T-S profile site RM5

depth (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	v1	v2	Str (kPa)
0	0.06	14.8	-14.8	0.17	0.77	0.003	0.003	853
10	0.14	5.9	-5.9	0.26	1.96	0.017	0.017	709
20		7.1	-7.1					
30		6.4	-6.4					
40	0.22	7.4	-7.4	0.33	3.21	0.023	0.023	669
50		8.2	-8.2					
60		6.1	-6.1					
70	0.27	8.0	-8.0	0.37	3.95	0.026	0.026	649
80		8.4	-8.0					
90		8.9	-8.4					
100	0.30	6.1	-8.9	0.39	4.40	0.027	0.027	646
110		7.7	-6.1					
120		5.6	-7.7					
130		5.0	-5.6					
140		5.2	-5.0					
150		5.0	-5.2					
160	0.48	4.9	-5.0	0.49	7.38	0.075	0.074	435
170		6.4	-4.9					
180		7.3	-6.4					
190	0.36	7.3	-7.3	0.42	5.34	0.039	0.038	583
200		5.7	-7.3					
210		4.4	-5.7					
220	0.26	3.8	-4.4	0.36	3.76	0.043	0.042	563
230		3.5	-3.8					
240		3.1	-3.5					
250	0.29	4.4	-4.4	0.38	4.24	0.048	0.048	538
average			-6.596	average	3.890	0.033	0.033	627
st. dev			2.239	st. dev	1.890	0.021	0.020	117.726

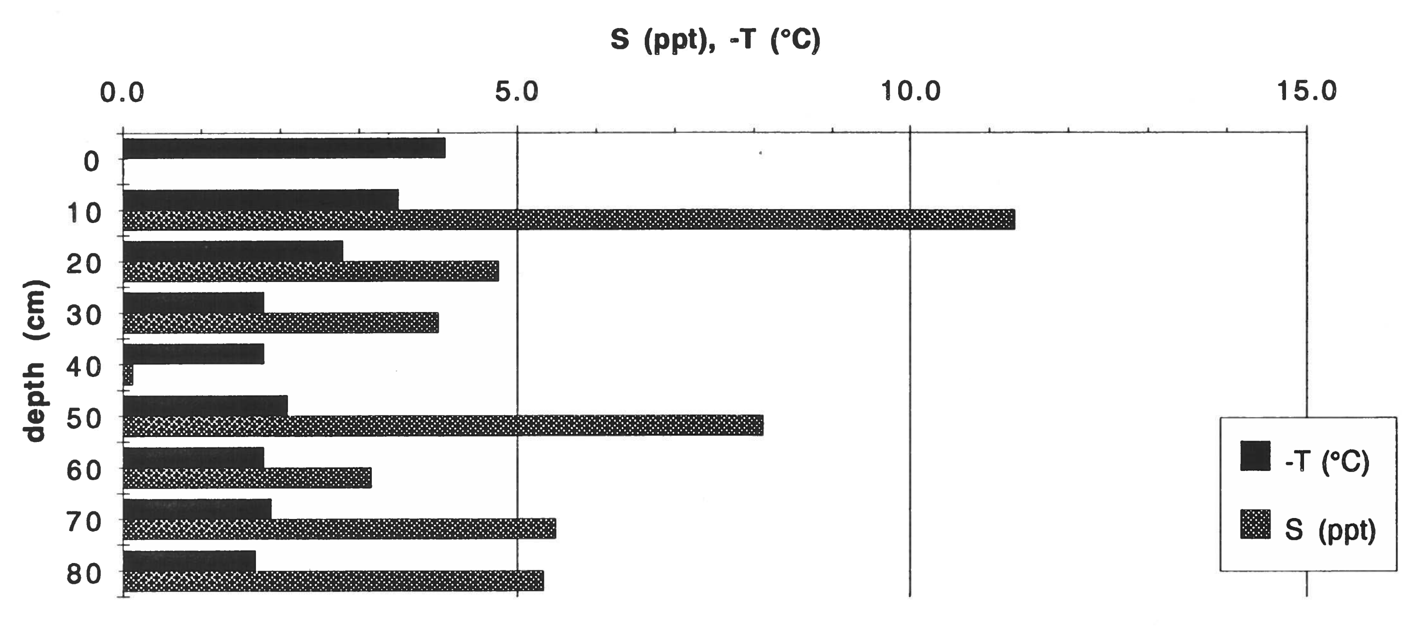
T-S profile site RM5



T-S profile site RM23

depth (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	v1	v2	Str (kPa)
0		11	-11.0	0.00	0.01	0.000	0.000	
10	0.72	4.1	-4.1	0.60	11.32	0.137	0.136	249
20	0.32	3.5	-3.5	0.40	4.77	0.067	0.067	463
30	0.27	2.8	-2.8	0.37	4.01	0.070	0.070	454
40	0.01	1.8	-1.8	0.07	0.13	0.004	0.004	845
50	0.53	1.8	-1.8	0.51	8.12	0.215	0.224	70
60	0.22	2.1	-2.1	0.33	3.16	0.072	0.074	445
70	0.37	1.8	-1.8	0.43	5.49	0.145	0.152	228
80	0.36	1.9	-1.9	0.42	5.34	0.134	0.139	257
90	0.24	1.7	-1.7	0.35	3.56	0.100	0.105	354
								373.956
								219.294

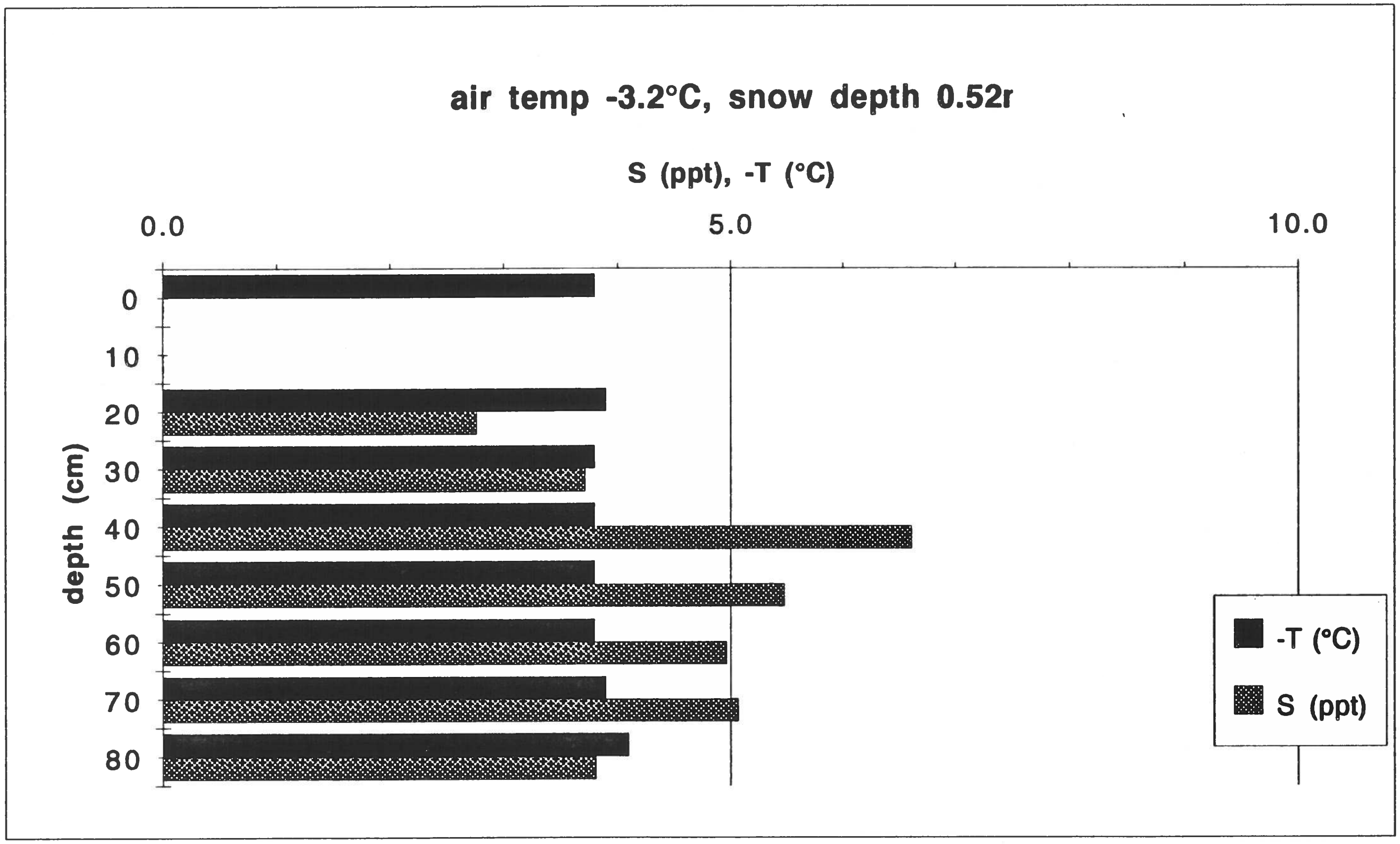
air temp -14.4°C, snow depth 0.36r



T-S profile site RM26

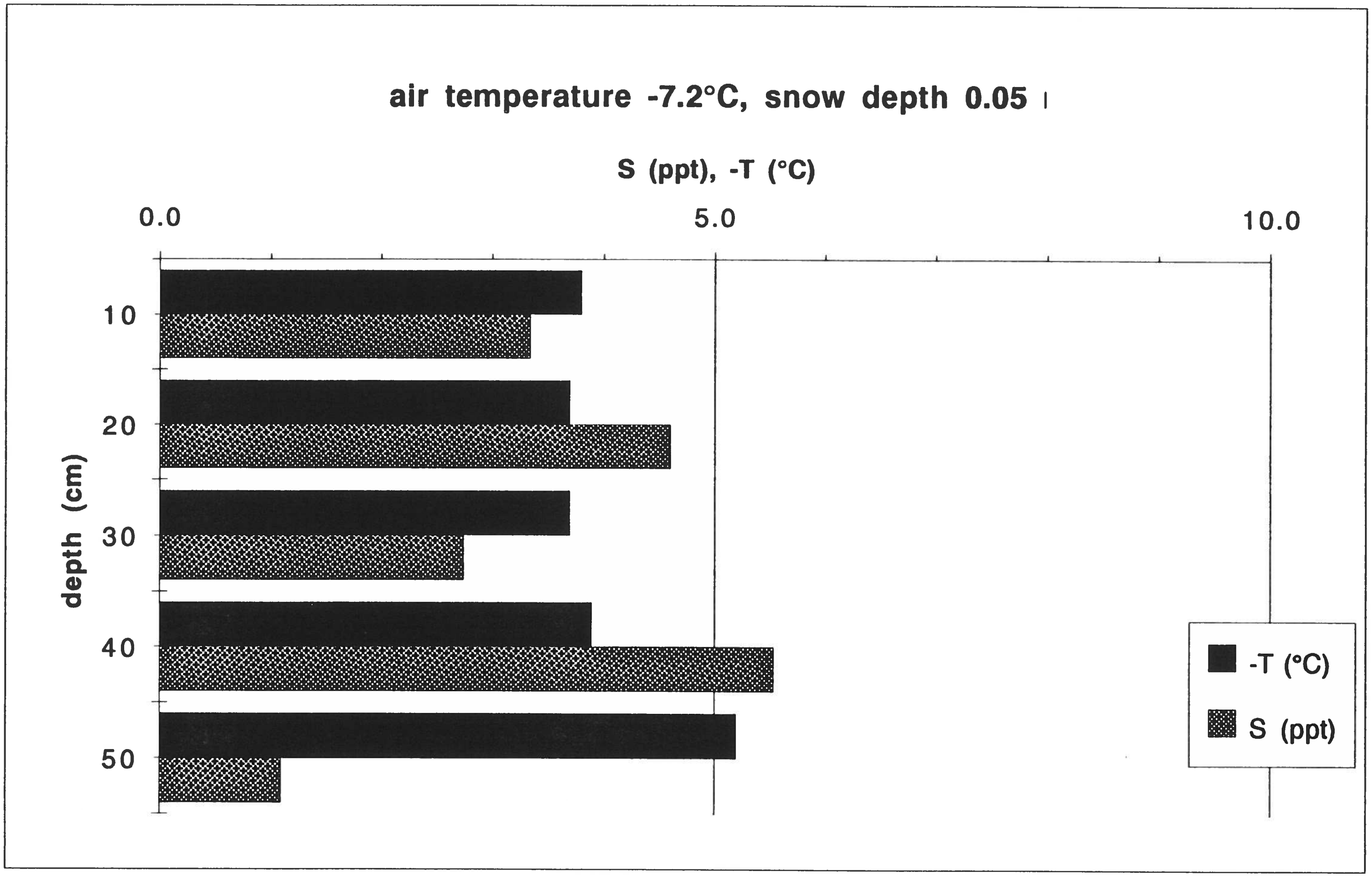
depth (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	ν1	ν2	Str (kPa)
0		3.8	-3.8	0.00	0.01			
10			0.0	0.00	0.01			
20	0.19	3.9	-3.9	0.31	2.77	0.035	0.035	600
30	0.25	3.8	-3.8	0.36	3.72	0.048	0.048	538
40	0.44	3.8	-3.8	0.47	6.62	0.086	0.086	397
50	0.37	3.8	-3.8	0.43	5.48	0.071	0.071	447
60	0.33	3.8	-3.8	0.41	4.97	0.065	0.064	472
70	0.34	3.9	-3.9	0.41	5.07	0.064	0.064	473
80	0.26	4.1	-4.1	0.36	3.81	0.046	0.046	547
90	0.31	4.1	-4.1	0.39	4.56	0.055	0.055	509
100	0.21	3.9	-3.9	0.32	2.96	0.038	0.037	587
110	0.21	4.0	-4.0	0.32	3.00	0.037	0.037	589
120		3.8	-3.8					
130	0.16	3.8	-3.8	0.29	2.32	0.030	0.030	626
140	0.13	3.8	-3.8	0.26	1.86	0.024	0.024	661
150	0.16	3.6	-3.6	0.28	2.29	0.031	0.031	620
160	0.26	3.6	-3.6	0.36	3.76	0.051	0.051	525
average			-3.6	average	3.33	0.049	0.049	542
st. dev			0.942	st. dev	1.827	0.017	0.017	68.951

T-S profile site RM26



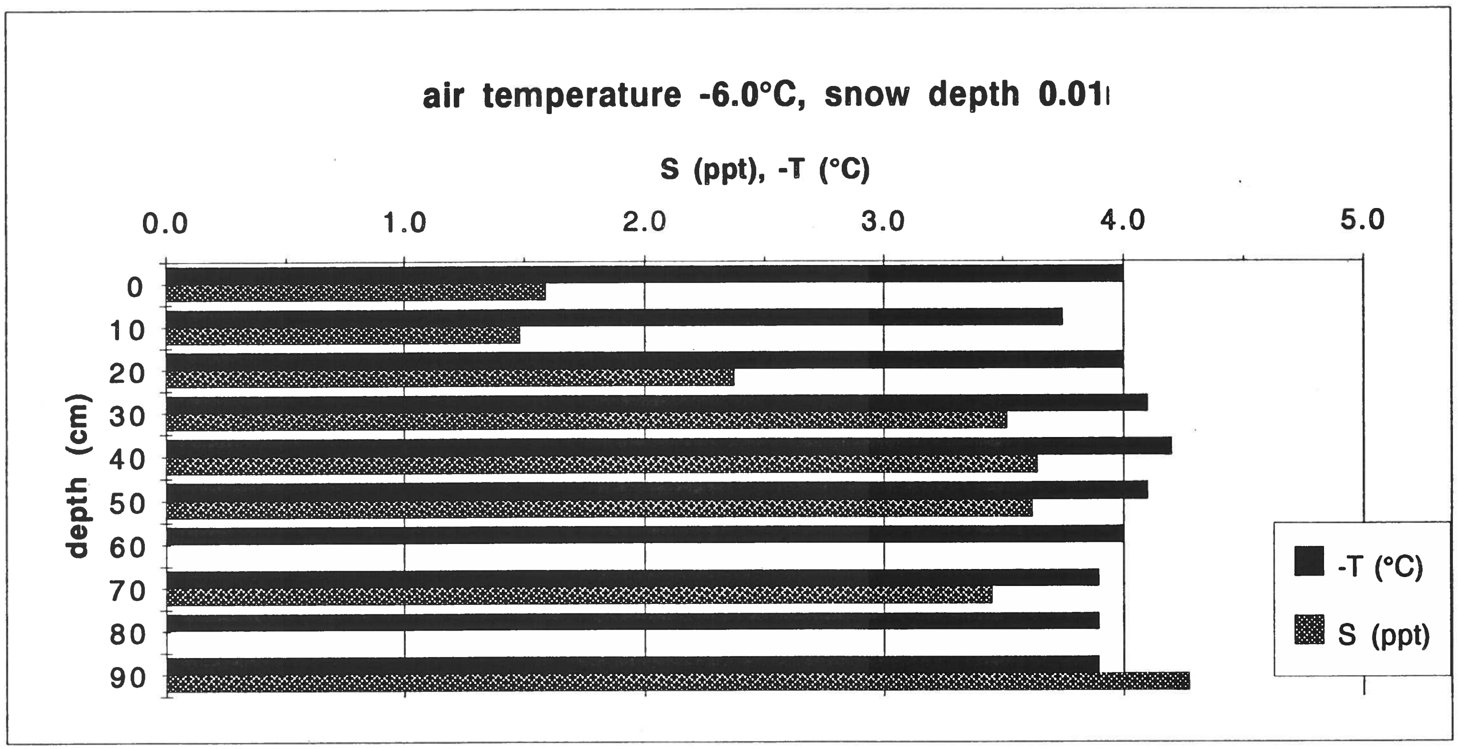
T-S profile site LR5

depth (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	v1	v2	Str (kPa)
10	0.23	3.8	-3.8	0.34	3.35	0.044	0.043	559
20	0.31	3.7	-3.7	0.39	4.60	0.061	0.061	484
30	0.19	3.7	-3.7	0.31	2.75	0.037	0.036	592
40	0.37	3.9	-3.9	0.43	5.54	0.070	0.070	451
50	0.08	5.2	-5.2	0.20	1.10	0.011	0.011	761
								570
								121.243



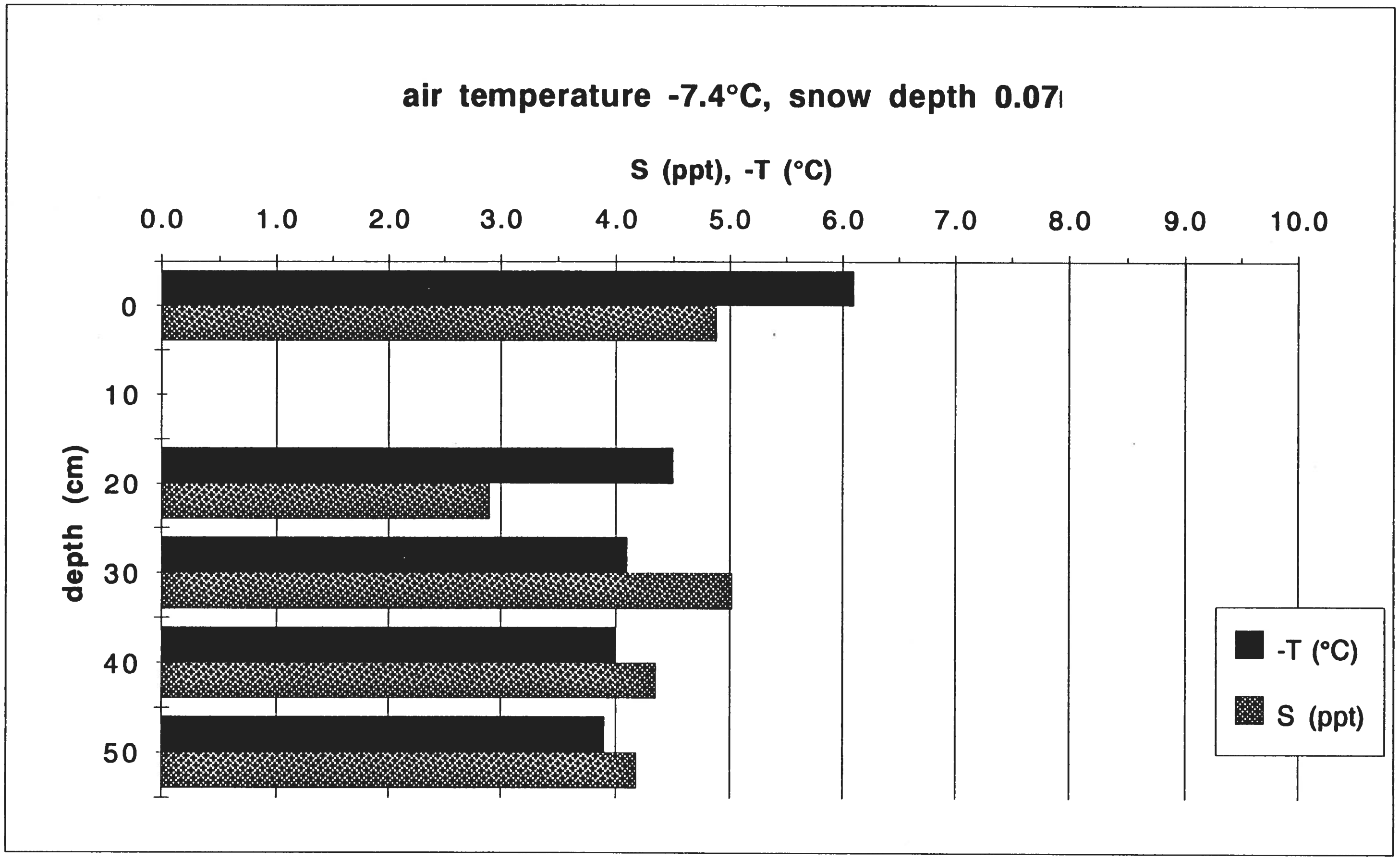
T-S profile site LR9

depth (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	v1	v2	Str (kPa)
0	0.11	4.0	-4.0	0.24	1.59	0.020	0.020	690
10	0.11	3.8	-3.8	0.23	1.48	0.020	0.019	692
20	0.17	4.0	-4.0	0.29	2.37	0.029	0.029	630
30	0.24	4.1	-4.1	0.35	3.52	0.043	0.042	563
40	0.25	4.2	-4.2	0.35	3.64	0.043	0.043	561
50	0.25	4.1	-4.1	0.35	3.63	0.044	0.044	557
60		4.0	-4.0					
70	0.24	3.9	-3.9	0.34	3.46	0.044	0.044	558
80		3.9	-3.9					
90	0.29	3.9	-3.9	0.38	4.27	0.054	0.054	513
								595.6
								66.956



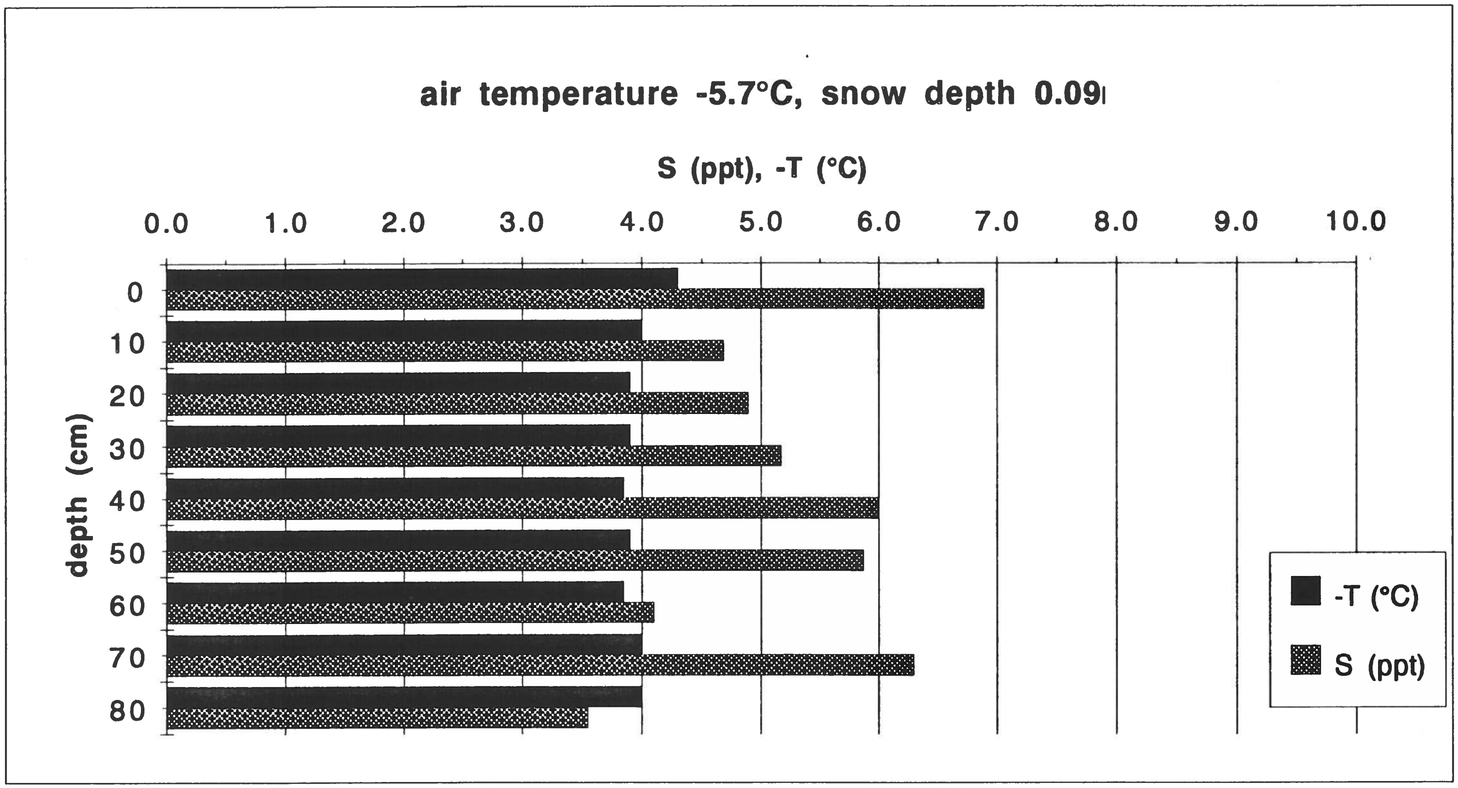
T-S profile site LR16

depth (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	ν1	ν2	Str (kPa)
0	0.33	6.1	-6.1	0.41	4.88	0.041	0.041	570
10								
20	0.20	4.5	-4.5	0.32	2.90	0.032	0.032	615
30	0.34	4.1	-4.1	0.41	5.02	0.061	0.060	486
40	0.29	4.0	-4.0	0.38	4.35	0.054	0.054	514
50	0.28	3.9	-3.9	0.38	4.18	0.053	0.053	518
								540
								51.482



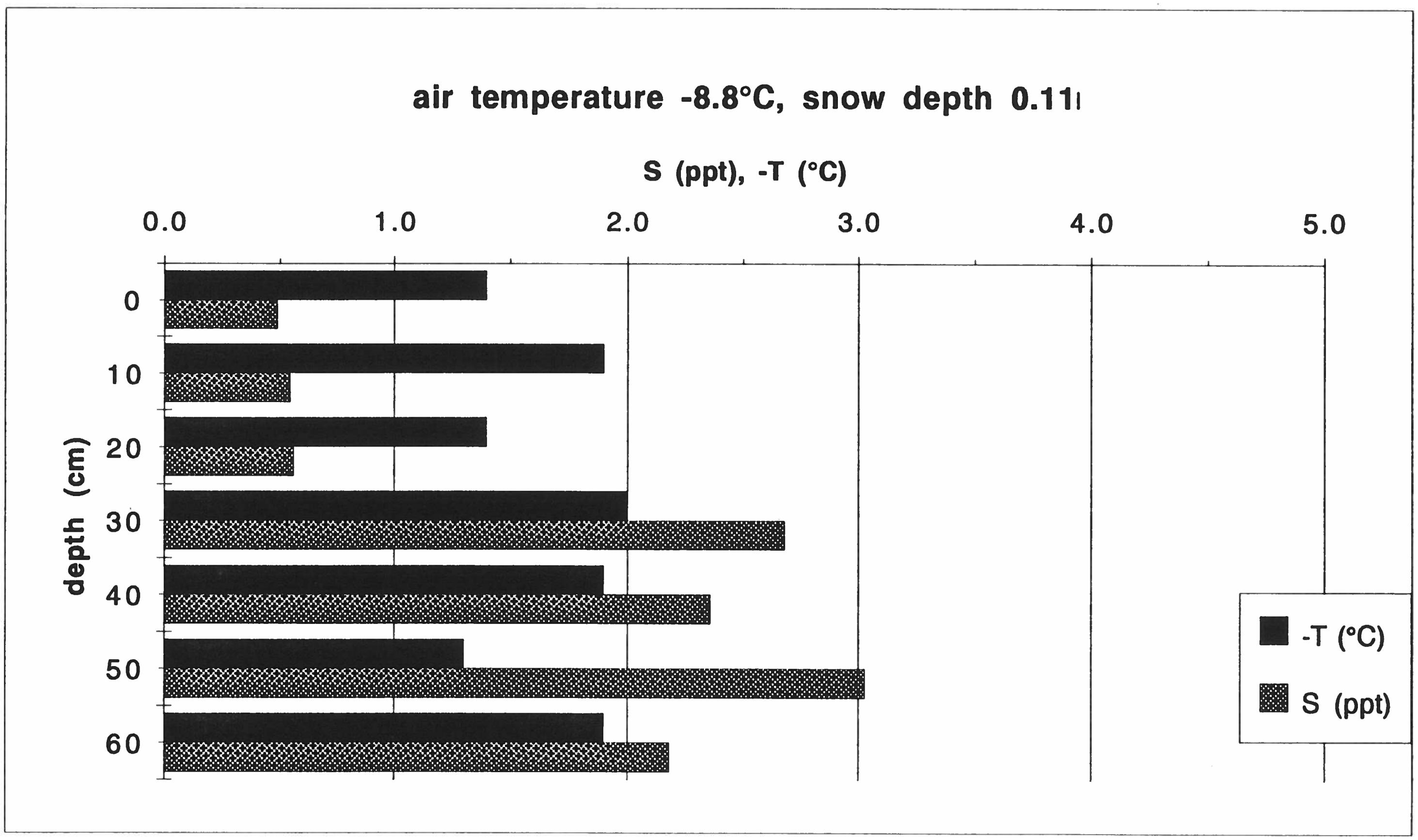
T-S profile site LR23

depth (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	v1	v2	Str (kPa)
0	0.45	4.3	-4.3	0.48	6.90	0.080	0.079	417
10	0.32	4.0	-4.0	0.40	4.68	0.058	0.058	497
20	0.33	3.9	-3.9	0.41	4.89	0.062	0.062	481
30	0.35	3.9	-3.9	0.42	5.17	0.066	0.065	468
40	0.40	3.9	-3.9	0.45	5.99	0.077	0.077	427
50	0.39	3.9	-3.9	0.44	5.87	0.075	0.074	436
60	0.28	3.9	-3.9	0.37	4.10	0.053	0.052	519
70	0.42	4.0	-4.0	0.46	6.30	0.078	0.078	423
80	0.24	4.0	-4.0	0.35	3.55	0.044	0.044	557
								469.5
								48.606



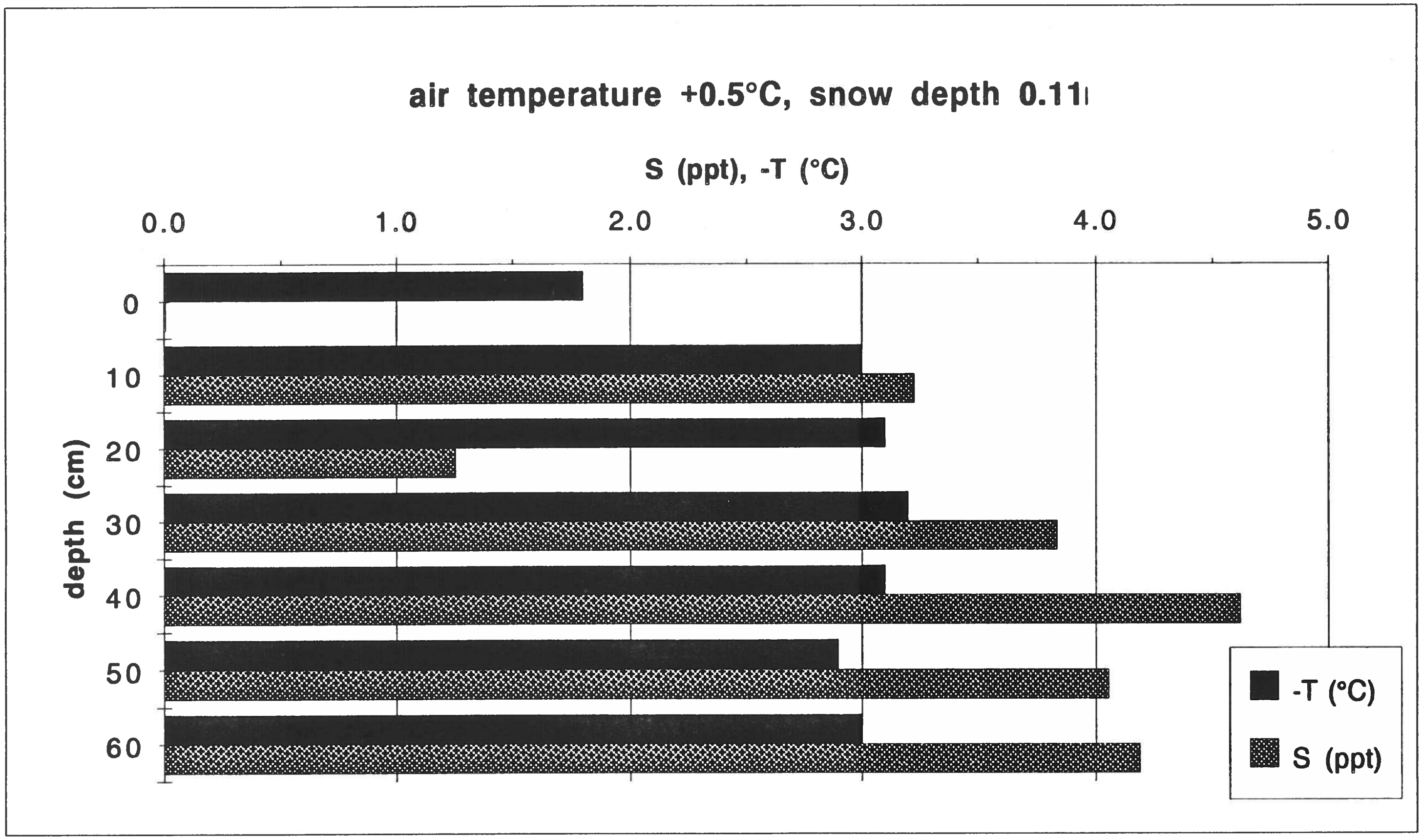
T-S profile site LR32

depth (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	v1	v2	Str (kPa)
0	0.0372	1.4	-1.4	0.14	0.49	0.017	0.018	713
10	0.0412	1.9	-1.9	0.14	0.55	0.014	0.014	735
20	0.0424	1.4	-1.4	0.15	0.56	0.019	0.021	696
30	0.1872	2.0	-2.0	0.31	2.68	0.064	0.066	474
40	0.1658	1.9	-1.9	0.29	2.36	0.059	0.061	493
50	0.2100	1.3	-1.3	0.32	3.03	0.110	0.120	324
60	0.1541	1.9	-1.9	0.28	2.18	0.055	0.057	511
								564
								154.164



T-S profile site LR40

depth (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	v1	v2	Str (kPa)
0		1.8	-1.8	0.00	0.01	0.000	0.000	
10	0.2227	3.0	-3.0	0.33	3.23	0.052	0.052	521
20	0.0916	3.1	-3.1	0.21	1.26	0.020	0.020	690
30	0.2620	3.2	-3.2	0.36	3.84	0.059	0.059	495
40	0.3119	3.1	-3.1	0.39	4.62	0.073	0.073	442
50	0.2762	2.9	-2.9	0.37	4.06	0.068	0.068	459
60	0.2846	3.0	-3.0	0.38	4.19	0.068	0.068	459
								511
								92.123



T-S data icing samples

height (cm)	2*C(m-mhos)	-T (°C)	T (°C)	Rt^.5	S (ppt)	v1	v2	Str (kPa)
80	0.88	3	-3.0	0.66	14.13	0.229	0.230	40
150	0.77	3	-3.0	0.62	12.33	0.200	0.201	101
seawater	1.99397			1.00	34.88			
average			-3.0 average		13.23	0.215	0.215	71
st. dev			0.000 st. dev		1.275	0.021	0.021	42.914