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Documentation of Recent  
Iceberg Grounding Events  
and a Comparison with Older  
Events of Known Age, Northern  
Grand Bank, Canada

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**DOCUMENTATION OF RECENT GRAND BANK ICEBERG GROUNDING  
EVENTS AND COMPARISON WITH OLDER EVENTS OF KNOWN AGE**

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## **EXECUTIVE SUMMARY:**

In 2001 and 2002, the Geological Survey of Canada (Atlantic) (NRCAN) conducted surveys over iceberg grounding sites produced during the 2000 iceberg season on Grand Bank. Three previously studied, older scours of known age (89-01, 88-01 and 83-95) were re-surveyed during the 2001 and 2002 field programs. Survey objectives were to:

1. record shape characteristics of scours of known age;
2. collect baseline data for subsequent monitoring of the processes and rates of biological colonization and physical degradation; and
3. develop methods of dating scours of unknown age.

Analysis of industry iceberg tracking data was found to be an effective method for identifying iceberg grounding events. In all, 10 scours were investigated, including the three previously surveyed scour features. The 2001 and 2002 surveys confirmed scours attributable to the 2000 season at six of the nine target sites. An additional scour of unknown age was surveyed while attempting to locate one of the 2000 scours.

High resolution seismic, side scan sonar and remotely operated vehicle (ROV) surveys were conducted in July, 2001. Multibeam bathymetric data were collected in the fall of 2002. The side scan and seismic data provided plan view and cross sectional profiles of the scours and seabed and subsurface sediment information. Detailed ROV video footage documented small scale scour features and proved valuable for studying biological colonization and physical degradation rates. Multibeam bathymetric data provided detailed elevation information and accurate measurements over the entire scour feature.

More pits (7) than furrows (3) were identified, reflecting an observational bias towards grounded (stationary for > 6 hours) rather than keel-dragging icebergs (not recognized by shipboard observers). Pit sizes varied considerably in both depth (0.5m to 7.5m) and size (25m to 50m), but furrow sizes remained similar regardless of changes in water depth, iceberg size or substrate type. Furrows produced during iceberg drift appear to be depth-limited by the resistance of the seabed sediments. This is evident where icebergs have scoured upslope with no appreciable increase in furrow depth. The iceberg appears to shed resistance load by tilting along its centre of buoyancy rather than gouging deeper into the sediment. This has been termed 'rise-up'. Multibeam bathymetry was used to calculate the amount of 'rise-up' for the three furrows. Pit depths are deeper than furrows and typically equal the maximum available iceberg keel depth suggesting that the bearing capacity of the seafloor sediments is surpassed once the iceberg becomes stationary.

Evidence for physical degradation of the scours was limited over the survey intervals (1 to 18 years) making it difficult to approximate scour age based on the degree of physical change. However, the physical stability of the features allows for a recognizable succession of biological colonization. This study documented the progressive biological change of scours over 18 years by increasingly diverse and mature infaunal and epifaunal species. Over the 18 years these populations reached levels similar to those of the surrounding seafloor. These results were applied to form an initial classification scheme to help identify recent scours of unknown age.



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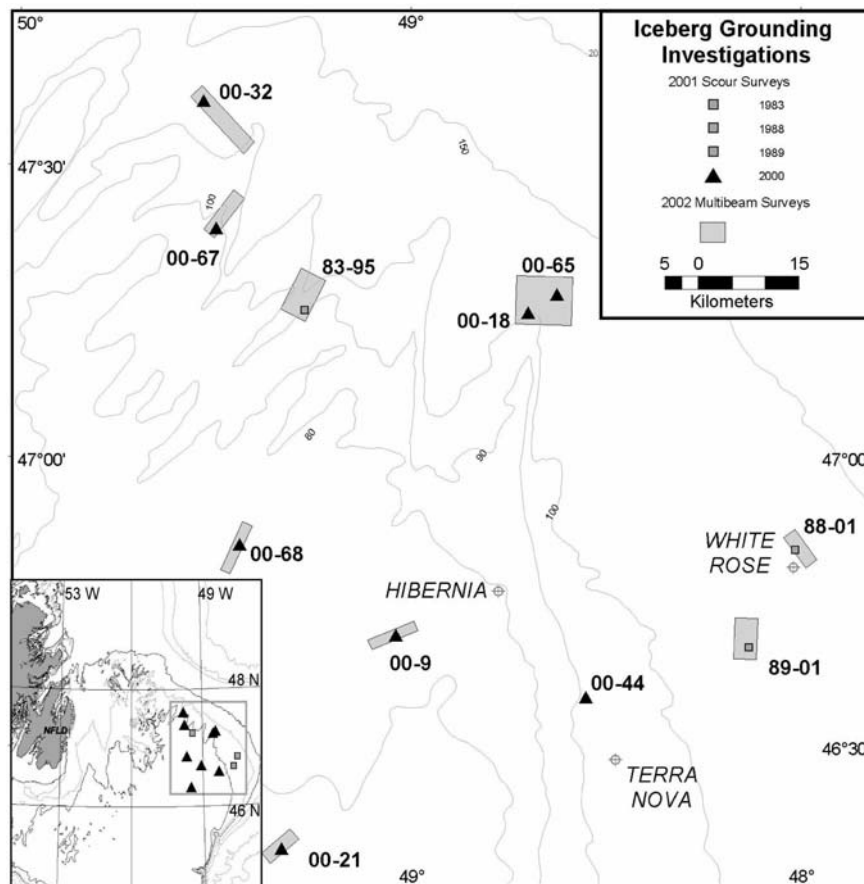
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# 1 INTRODUCTION:

The eastern Canadian continental shelf south to the Grand Bank of Newfoundland is transited by icebergs calved from the Greenland Ice Sheet and eastern Canadian arctic glaciers. An average of more than 4000 icebergs annually will drift south of Davis Strait (Lewis and Keen, 1990). The number of icebergs that will remain in the main axis of the Labrador Current and drift onto Grand Bank south of 48°N (Marko et al., 1994) varies significantly from year to year. In some years none survive the transit while in others up to 2000 have drifted onto the banks. Drifting icebergs with large drafts often impact the seabed (Lewis and Blasco, 1990), producing either linear furrows as they drag along the bottom or large semicircular pits when they roll and impact the seabed or remain aground in one location. Seventy-eight icebergs drifted onto the bank top between February and June 2000, nine of which were reported to have grounded (PAL, 2000) (Figure 1) based upon having remained stationary regardless of tidal and wind forcing.



**Figure 1:** Location map of iceberg groundings on the Grand Bank off Newfoundland and areas of detailed seabed investigation.

The 2000 iceberg season provided the first recent opportunity to develop case histories of known iceberg seabed groundings. Knowing how icebergs scour and damage the seabed is important for the design of safe and cost-effective sub-sea facilities. Studying recent scours created by icebergs of known size and under known environmental conditions enhances the understanding of the scouring process and improves our ability to calculate loads imposed on the seabed. Scour measurements to date on Grand Bank have only been made on three scours of known age versus hundreds of measurements from older, possibly degraded and in-filled scours (Campbell et al., in press). Comparison of scour morphology from recent scour events can help determine if the measurements from scours of unknown age are representative.

Another major uncertainty in scour risk calculations for petroleum operations is the frequency of iceberg scour occurrence. The seabed scour record can provide scour frequency estimates if the age of the seabed scour population and the length of time that scours remain visible on the seabed is known, e.g., residency time. Neither parameter is well constrained. This investigation attempts to address these issues by studying the recent 2000 groundings as well as investigating three previously studied groundings of known age in order to understand the rates and processes of scour deterioration. In addition to the data collected from the surveys over the scours, this report incorporates the results of several interpretation reports (Table 1) done under contract to the Geological Survey of Canada (Atlantic).

**Table 1:** Summary of internal reports that investigated the 2000 iceberg scours.

| <b>Report</b>                                                                                        | <b>Author (s)</b>                                                                   | <b>Date</b> |
|------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|-------------|
| Review of dating techniques and design recommendations for iceberg scour surveys on the Grand Banks. | Rob Myers                                                                           | March, 2001 |
| Documentation of iceberg grounding events from the 2000 season.                                      | Rob Brown<br>Richard McKenna<br>Mervin Marshall<br>John McClintock<br>Terry Bullock | June, 2001  |
| Report on the Biological Analysis of VHS Videos of 8 Iceberg Scours on the Grand Banks.              | Patricia Pocklington                                                                | 2003        |

## **2 BACKGROUND:**

### **2.1 Geologic Setting**

Large areas of the Grand Bank, with present day water depths of less than approximately 110 metres, were exposed during a low sea-level stand dated at about 15,000 years BP (Fader and King, 1981). Erosion and reworking of glacial deposits during the low-stand exposure and subsequent early Holocene marine transgression produced a relatively thin cover of surficial sand and gravel sediments across the bank tops that are commonly referred to as the Grand Bank Sand and Gravel Unit (Fader and Miller, 1986; Sonnichsen and King, 2001). In water depths greater than 110 metres surficial sediments are predominantly fine-grained sands of the Adolphus Sand unit (Fader and Miller, 1986; Sonnichsen and King, 2001). Surficial deposits unconformably overlie seaward-dipping silt and sand beds of the Tertiary Banquereau Formation over most of the Grand Bank. Locally, remnant patches of eroded glacial till deposits, lag boulder fields, and weakly cemented shelly material ('hardpan') related to glaciation, sub-aerial exposure, and subsequent marine transgression may be present at the base of the unconsolidated surficial sands and gravel sediments (King and Sonnichsen, 2000).

The Grand Bank Gravel sub-unit is a thin lag deposit (typically less than 2 metres thick) formed during the early Holocene marine transgression. The Grand Bank Sand sub-unit, which consists of relict and recent sand and gravelly sand bedforms, produces a discontinuous cover over the lag gravels on the bank tops. The larger bedforms, including sand ridges up to 10 metres thick and sand waves are interpreted to be relict features formed in the early to mid Holocene (Barrie et al., 1987). In water depths less than 110 metres, surface sands are occasionally reworked (Barrie and Collins, 1989) into bedforms including megaripples and symmetrical wave-formed ripples, during winter storms.

### **2.2 Grand Bank iceberg scour regime**

Research into iceberg scouring on the Grand Bank, primarily through the interpretation of side scan sonar and profiler data sets, was initiated in the late 1970's. Several scours have also been investigated directly using submersible or ROV observations (Mitten, 1988; Cameron and Sonnichsen, 1992). An early ice scour database, the East Coast Scour



Database, provided summary statistics recorded from regional geophysical data coverage but did not catalogue individual scour events (d'Apollonia and Lewis, 1981; Geonautics Limited, 1989). More recently, individual Grand Bank iceberg scours and iceberg pits were identified and mapped using geophysical records of industry and government. The Grand Bank Scour Catalogue (GBSC) is a digital database that includes information on scour metrics, position, water depth, source data type, and scour morphology (Myers et al., 1995; Sonnichsen, 1999; Campbell et al. in press). A review of the GBSC is included in a recent National Research Council sponsored study of scour risk in the Grand Bank region (Croasdale and Associates, 2000). The most recent update of the Grand Bank Scour Catalogue, (Campbell et al., in press), comprises measurements from more than 6000 recent iceberg scour features identified from industry and government side scan and sub-bottom profiles and more recently from multibeam bathymetry.

An iceberg scour is typically composed of a linear furrow with a trough and side berms. Occasionally, the furrow terminates in a semi-circular pit formed when the scouring iceberg stops drifting and remains stationary. Isolated pits are frequently seen, presumably the result of a change of iceberg profile that increases the drift (either a roll or shift of centre of gravity). The pits on the Grand bank are deeper and wider than furrows, and typically have higher berms. There may also be several sets of berms, and secondary pits may be generated from iceberg roll-over. Sonnichsen and King (2003) recently summarized scour metrics for northeastern Grand Bank, reporting scour densities of <1 to 3 scours/km<sup>2</sup>. Furrow lengths are quite variable but the average is 829 m with average widths of 22 m and depths of 0.4 m. Pits average 50 m across by 73 m in length and an average depth of 1.8 m. The maximum furrow depth is 1.5 m while pits as deep as 9 m have been recorded. However, on scours of unknown age measured depths may be less than original due to infilling or degradation over time. The maximum water depth to which modern icebergs can scour is not well constrained from either the seabed or iceberg record. Apparently fresh-looking isolated scour features are superimposed on a relict, degraded network of scours down to approximately 200 m water depth on northeastern Grand Bank. This is generally consistent with the deepest known Greenland fiords sill of 220 m (Wadhams, 2000). Iceberg draft measurements to date, while limited, also support this. Mobil Oil Canada cited a maximum observed draft of

200 m and a mean draft of 95 m based on 113 measurements (Mobil Oil Canada Ltd., 1985). The deepest recorded seafloor disturbance in the GBSC is at 257 m (Campbell et al., in press).

The recent application of high resolution multibeam bathymetry to the study of scour metrics reveal iceberg scours based on the elevation of the troughs and berms, even when their relief is less than 1 m. Shaded relief imagery produced from the dense depth soundings illustrates scour geometry, size and location, without the many geometric distortions inherent in side scan imagery. These attributes allow for more accurate scour measurements that included berm heights and trough depths.

### **3 PURPOSE:**

In 2001, a joint government and industry program was undertaken to:

- 1) Conduct seabed surveys to document the nine iceberg grounding sites reported to have occurred in 2000.
- 2) Re-survey older iceberg scours of a known age to document the sedimentological and biological evolution within these older seabed disturbances.

Collected data were used to:

- 1) Develop detailed case studies of the grounding events
- 2) Collect baseline data to allow subsequent monitoring of the processes and rates of scour degradation.
- 3) Test whether observations of scour evolution over time could provide a tool to estimate ages for scours of unknown ages.

Overall Objectives are to:

- 1) Refine understanding of ice scouring processes to help constrain scour force models.
- 2) To provide support in the development of safe, but cost effective sub-sea infrastructures.

## 4 METHODS:

### 4.1 Iceberg Monitoring

#### 4.1.2 Iceberg Drift and Grounding Data

To ensure safe oil and gas operations on Grand Bank, oceanographic conditions and iceberg activity in the northeastern Atlantic are constantly monitored by PAL (Provincial Airlines Limited) Environmental Services (PAL, 2000) and AMEC (AMEC, 2000). Offshore exploration rigs and production platforms at Hibernia and Terra Nova (Figure 1) continuously record the prevailing oceanographic conditions including winds, waves and currents. The Canadian Meteorological Centre (CMC) produces gridded wind conditions and the Canadian Ice Services (CIS) provides mean daily ocean currents. Iceberg tracking is performed by aircraft, oil platform radar and dedicated supply vessels deployed to monitor, measure, and if necessary, to tow the icebergs. Towing of icebergs typically is done to provide safety to marine infrastructures. Due to the mass and momentum of the icebergs ships try to direct the icebergs away by imposing pull at slight vectors to the route that the iceberg is already traveling. See appendix II for plots of ship vectors during tow procedures. Typically it is not the intention of the tow to ground the iceberg but to tow it into deeper water and away from equipment. However, for reasons such as the icebergs route or bathymetry the iceberg may become grounded. Iceberg dimensions are recorded and drift tracks are monitored in the PAL iceberg databases. Icebergs are recorded as grounded in the databases when they remained stationary for > 6 hours despite tidal and wind forcing. Based

**Table 2:** Details of reported grounding events (C-Core, 2001).

| ID     | Approx. Grounded Position |               | Grounding Times & Dates |             | Approximate Duration of Grounding Event (hours) |
|--------|---------------------------|---------------|-------------------------|-------------|-------------------------------------------------|
|        | Latitude (N)              | Longitude (W) | Start (UTC)             | End (UTC)   |                                                 |
| 00-009 | 46°-41.43'                | 49°-02.68'    | Mar 28-1630             | Apr 4-0330  | 155                                             |
| 00-011 | 46°-38.80'                | 47°-56.10'    | Mar 23-0300             | Mar 23-1030 | 9                                               |
| 00-018 | 47°-14.66'                | 48°-42.34'    | Mar 26-0750             | Mar 26-1404 | 6                                               |
| 00-021 | 46°-19.20'                | 49°-20.30'    | Mar 31-0130             | Apr 01-0730 | 30                                              |
| 00-032 | 47°-36.40'                | 49°-32.22'    | Apr 15-2001             | Apr 19-1925 | 96                                              |
| 00-044 | 46°-34.99'                | 48°-33.40'    | Apr 24-1820             | Apr 26-0030 | 30                                              |
| 00-065 | 47°-16.57'                | 48°-37.84'    | Apr 28-1027             | May 12-0500 | 330                                             |
| 00-067 | 47°-23.40'                | 49°-30.30'    | May 12-1640             | May 17-0005 | 104                                             |
| 00-068 | 46°-50.82'                | 49°-26.73'    | May 11-0700             | May 12-1900 | 36                                              |

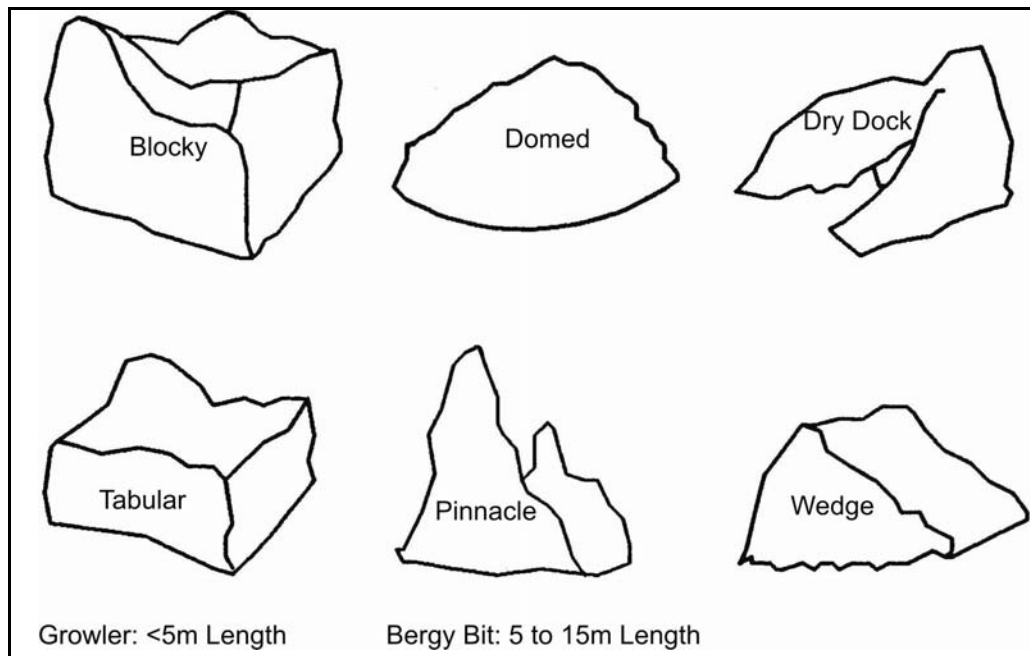
on these criteria nine groundings were identified from the monitoring databases for 2000 (Table 2). Available RADARSAT imagery for the region on dates close to groundings was examined and provided some confirmation for the iceberg positions reported by PAL. Plots of the RADARSAT positions along with PAL drift tracks are provided in Appendix II.

#### 4.1.3 Iceberg Characteristics

Above water iceberg shape was recorded based on standard shapes as shown in Figure 2. Waterline dimensions were estimated using a marine sextant. When possible, iceberg draft was measured using side scan sonar equipment. Otherwise, draft was estimated from the water depth at the time of reported grounding or from the equation (C-CORE, 2001).

$$Draft = 3.239Lwl^{0.68}$$

$Lwl$  represents the maximum waterline dimension of the iceberg. Details for the nine icebergs that grounded are given in Table 3 and Appendix II



**Figure 2:** Standard iceberg shapes used for calculation of iceberg mass (after C-Core 2001).

**Table 3:** Particulars of reported grounded icebergs of 2000 (C-Core, 2001)

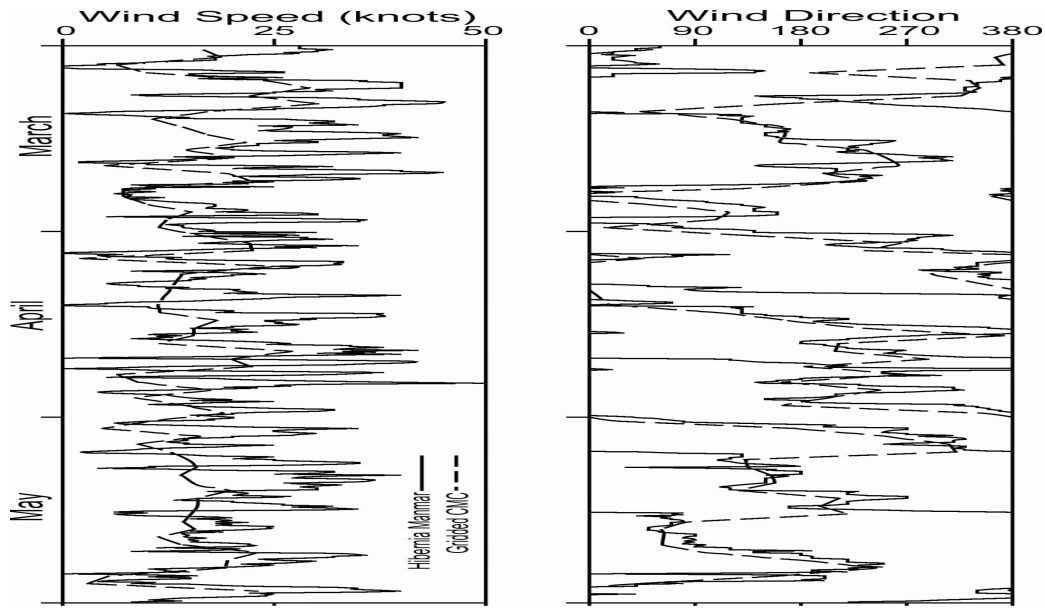
| ID     | Size   | Shape    | Length (m) | Width (m) | Height (m) | Est. Draft (m) |
|--------|--------|----------|------------|-----------|------------|----------------|
| 00-009 | Medium | Tabular  | 70         | 40        | 10         | 58             |
| 00-011 | Large  | Pinnacle | 120        | 82        | 40         | 84             |
| 00-018 | Medium | Pinnacle | 70         | 40        | 35         | 58             |
| 00-021 | Medium | Dome     | 63         | 49        | 18         | 75             |
| 00-032 | Large  | Pinnacle | 138        | 114       | 27         | 124            |
| 00-044 | Medium | Pinnacle | 100        | 60        | 30         | 74             |
| 00-065 | Large  | Pinnacle | 242        | 76        | 55         | 135            |
| 00-067 | Large  | Pinnacle | 110        | 76        | 40         | 102            |
| 00-068 | Medium | Dry Dock | 80         | 30        | 15         | 64             |

#### 4.1.4 Environmental Conditions

Current and wind velocity data were compiled for the dates of the reported iceberg groundings from the CMC and the Manmar wind observations at Hibernia. Gridded wind data from the CMC were presented as daily (valid 12 UTC) surface winds (~10 m elevation). A comparison was made (Figure 3) between daily gridded winds from CMC at the grid point closest to Hibernia to the 3 hourly Manmar winds observed at Hibernia (~70m elevation). The comparison shows good agreement for wind direction (Figure 3), though peak winds are usually under predicted. This could be related to the difference in the height at which the measurement is taken. Mean daily currents were obtained from CIS (valid 18 UTC). The CIS currents are based on historical drifter buoy data and modified locally with weekly buoy data. Drifter buoys are typically drogued at 50m. Wind and current data were interpolated from neighbouring grid points nearest to the iceberg location at each point along its track and are intended to give some representation of what the wind and current conditions may have been. Wind and current vector plots for each iceberg are given in Appendix II.

## 4.2 Seafloor investigations around grounding sites

In the summer of 2001 eight of the nine 2000 grounding sites were surveyed with side scan, high resolution seismic and ROV submersible (Hudson Expedition 2001038). Three older grounding sites from the 1980s (Scour 95, 88-01 and 89-01) were re-surveyed with the same tools. Survey priorities were assigned based on compilation and assessment of iceberg drift data (C-Core, 2001), design recommendations (Sonnichsen and Myers, 2001) and on proximity to other planned survey operations. The ninth site, 00-11, was not surveyed; it was



**Figure 3:** Comparison of daily CMC gridded winds to the 3 hourly Manmar winds observed at Hibernia. The gridded winds are surface elevation (~10m), while Manmar observations are platform elevation (~70m) (After C-Core 2001).

considered unlikely to have grounded as it had an estimated draft of 84 m and was reported to have grounded in 120 m water depth for 9 hours during light seas and winds.

Reconnaissance sidescan lines (400 m total swath coverage) were first conducted to identify the scour. Then more detailed (200 m total swath coverage) side scan lines were run over the scour feature. For most scours, orthogonal lines were also run to provide longitudinal transects across the scour profile with the Hunttec sub-bottom profiler. The final stage was to dive and record VHS video over the more prominent scour features. The ROV collected cobbles with biological growth from three of the scour features. Seabed sediment samples (IKU grab) were taken at five sites (Appendix I).

Initial plans were to use multibeam bathymetric data to locate the scours prior to the Hudson surveys, but there was insufficient time after project approval to contract a vessel in 2001. In 2002, SeaMap Surveys was awarded a contract to use the MV Anne S. Pierce and its hull-mounted Simrad EM1002 multibeam sonar system to collect detailed seabed elevation and scour profile data over the 10 scours targeted in 2000. Onboard and post cruise data processing optimized the data. Processed XYZ data were gridded in ArcGIS and saved as

individual site surveys. Appendix I provides a more detailed account of methods, instruments and settings.

## 5 RESULTS:

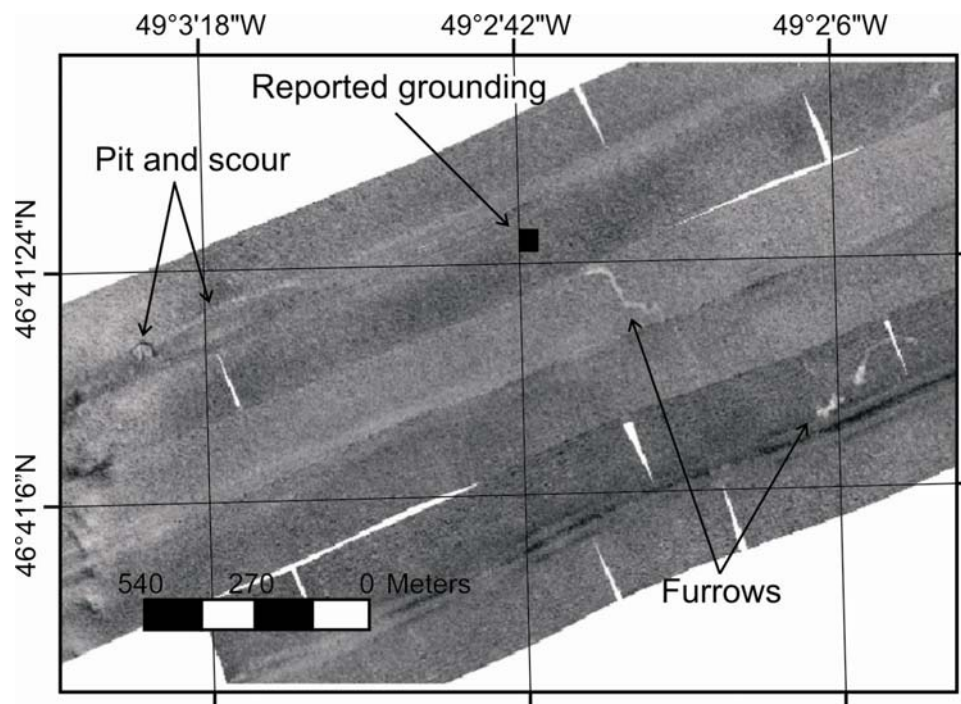
### 5.1 Individual Iceberg Cases

#### 5.1.1 Iceberg 00-09

##### Environmental conditions

Iceberg 00-09 was tracked from March 21<sup>st</sup> to April 19<sup>th</sup>, 2000 using Hibernia radar and visual observation from ships in the area (Appendix II). The iceberg was towed aground by the *Maersk Norseman* at approximately 16:30 on March 28<sup>th</sup> in 70m water depth. Half an hour later the iceberg rolled, exhibiting an “egg” shape above the water surface. The iceberg remained grounded for approximately 155 hours until becoming free on April 4<sup>th</sup>. It was then towed by the *Atlantic Eagle* for a day into deeper water.

Prior to the grounding, the wind was light to moderate northwesterlies March 21<sup>st</sup> to the 24<sup>th</sup>, increasing to moderately strong NW on the 25<sup>th</sup> until the 27<sup>th</sup> (Appendix II). Winds remained



**Figure 4:** Map of scour 00-09 view with side scan imagery.

strong but changed 180° to the SSE on March 28<sup>th</sup>. On April 4<sup>th</sup> the winds shifted to the NE, likely resulting in freeing the iceberg and pushing it towards deeper water. Ocean currents were generally light ~12 cm/s in March, ~25cm/s in April, increasing from ~4 cm/s on April 4<sup>th</sup>, to 20 cm/s by the 7<sup>th</sup>. Note that the winds and currents in late March were such that if the iceberg was not grounded they may have moved the iceberg off into deeper water sooner.

#### Scour and pit morphology

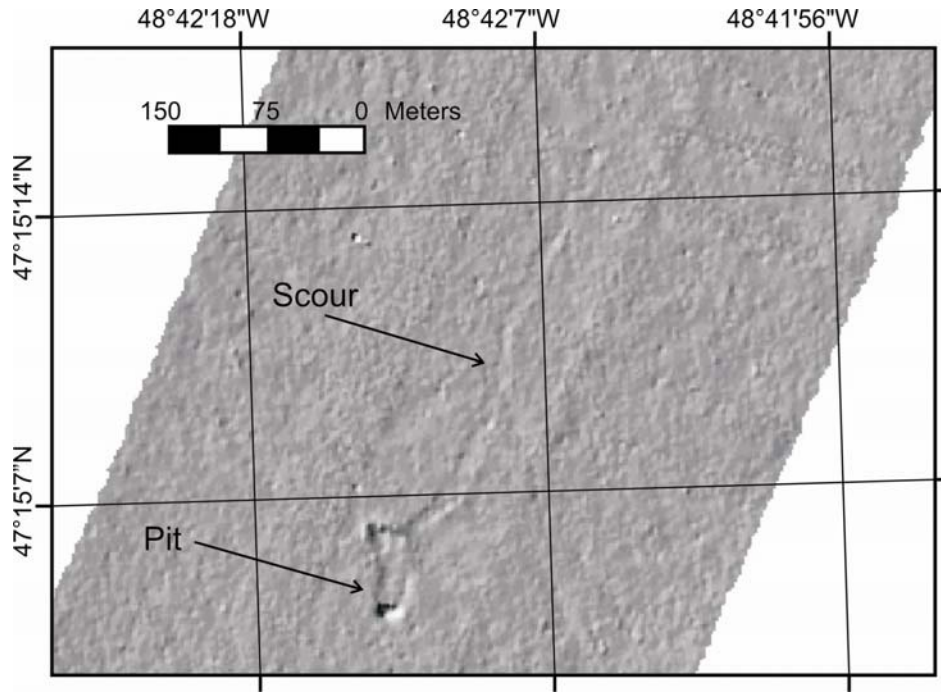
The reported grounding location for 00-09 was situated on a large sand ridge west of Hibernia (Figure 1). Initial side scan records were not very revealing with uniform moderate backscatter returns from the sandy seabed. A short furrow approximately 200 m long in 72 m of water was the only feature identified from the field records (Figure 4). More detailed side scan tracks at 200 m swath coverage were then run over the central target. The results were not particularly impressive and the scour was not considered a high priority. Multibeam bathymetry over the area only reveals a faint pit (Appendix III). Due to the lack of detail no further study was done on 00-09.

#### *5.1.2 Iceberg 00-18*

##### Environmental conditions

Iceberg 00-18 was tracked from March 25<sup>th</sup> to April 1<sup>st</sup>, 2000 using radar and visual observation from ships in the area (Appendix II). At 07:50, March 26<sup>th</sup> it was reported grounded by the Maersk Norseman in 103 m of water. The iceberg drifted free some time between 14:04, March 26<sup>th</sup> and 07:45 March 28<sup>th</sup>. It was monitored by the *Maersk Bonavista* until April 1<sup>st</sup> when it entered deeper water. Leading up to the grounding, winds were strong NW (12-14m/s) on March 25<sup>th</sup> and 26<sup>th</sup> and dropped slightly on the 27<sup>th</sup> (Appendix II). Winds then changed direction to blow strongly (16 m/s) from the SSW on the 28<sup>th</sup>, likely resulting in freeing the iceberg. On the 29<sup>th</sup> and 30<sup>th</sup> winds maintained direction but were light before shifting to the SSE as light-moderate on the 31<sup>st</sup> and 1<sup>st</sup>. Currents are fairly consistent to the ESE through NE at ~20-30cm/s March 25<sup>th</sup> to April 1<sup>st</sup>. Currents are consistent with an eastward track back out into deeper waters after drifting free.





**Figure 5:** Shaded relief image of Multibeam bathymetric data over scour 00-18.

#### Scour and pit morphology

The shape of the scour generated by iceberg 00-18 is a long furrow trending SSW terminating in a pit (Figure 5). The furrow is approximately 400 m in length (Table 4) and near the end it appears to track from east to west and back again with a pit at its southern end (Figure 5). The average furrow width is 19 m, berm heights average 0.1 m and the trough averages 0.3 m (Table 4). The pit has an average diameter of 37.5 m with average berm heights of 0.3 m and a maximum depth of 2.2 m (Table 4). The seafloor in the area of the grounding is relatively flat and composed of sand which in places appears to have formed low-amplitude sediment waves based on the reflectivity patterns in the sidescan records (Appendix III, Figure 2).

#### Biological and sedimentological observations

The sandy seafloor around the iceberg 00-18 grounding hosts a moderately abundant population of sand lance, sand dollars, the occasional large gastropods and other smaller molluscs (Appendix VI, Figure A1-A3). These taxa are characteristic for this type of seabed on the Grand Bank. However, they do display a patchy distribution in which areas are

dominated by one of these above taxa. Also noted was the occasional depressions created by or occupied by flounder (possibly *Hippoglossoides platessoides*). Snow crabs and anemones occurred infrequently. In some areas the presence of densely spaced low mounds, tracks, trails, tubes, and holes indicated sediment reworking by a significant infaunal community (Appendix VI, Figure A2). There was very little observed attached fauna, likely as a result of the mobile sandy surficial cover. The exception was an area of shelly cobbles that had numerous anemones on the cobbles (Appendix VI, Figure A5-A6).

On the outer berm wall a gradual decrease in the number of animals from the surrounding seabed onto the berm could be recognized. The pattern suggests the epifauna species had begun migrating up the sides of the outer berm. Sedimentologically the berm top varies from fine sand, to shelly patches, to large accumulations of rocks, cobbles and shells (Appendix VI, Figure A7-A9). In areas of fine sediment there was evidence of an infaunal community that had developed over the intervening year. However, boulders lacked any obvious attached benthic organisms. The inside walls of the berm varied; some places were smooth, and others were covered with shell debris. Inside the scour there were fewer organisms but there was some evidence of colonization. Of note were sand dollars plowing shallow furrows through the fine sediment towards the bottom of the pit (Appendix VI, Figure A10).

**Table 4:** Summary of furrow measurements made from the multibeam bathymetry. See Appendix IV, Table 1 for the measurements.

| Furrow        | Bathymetry (m) | Furrow length (m) | Statistics | Berm height (m) | Trough depth (m) | Berm width (m)* | Furrow width (m)** |
|---------------|----------------|-------------------|------------|-----------------|------------------|-----------------|--------------------|
| 00-18         | 102            | 400               | Mean       | 0.1             | -0.3             | 18.8            | 10.6               |
|               |                |                   | STDEV      | 0.1             | 0.1              | 4.2             | 2.5                |
| 00-65         | 127            | 1500              | Mean       | 0.3             | -0.4             | 25.7            | 13.6               |
|               |                |                   | STDEV      | 0.2             | 0.3              | 7.2             | 7.4                |
| 00-68         | 75             | 4500              | Mean       | 0.3             | -0.5             | 47.9            | 29.2               |
|               |                |                   | STDEV      | 0.2             | 0.2              | 7.4             | 6.6                |
| 88-01         | 124            | 1000              | Mean       | 0.2             | -0.7             | 25.8            | 20.6               |
|               |                |                   | STDEV      | 0.2             | 0.5              | 10.2            | 23.9               |
| 83-95         | 86             | 2000              | Mean       | 0.2             | -0.5             | 34.5            | 18.8               |
|               |                |                   | STDEV      | 0.1             | 0.3              | 8.2             | 7.1                |
| Overall mean  | 102.8          |                   |            | 0.2             | -0.5             | 30.5            | 17.8               |
| Overall STDEV | 22.6           |                   |            | 0.2             | 0.3              | 12.3            | 9.4                |

STDEV= standard deviation \*Berm width is crest to crest

\*\*Furrow width is the width at the seafloor

**Table 5:** Summary of pit measurements made from the multibeam bathymetry. See Appendix IV, Table 2 for the measurements.

| Pit           | Bathymetry (m) | Statistics | Berm height (m) | Pit depth (m) | Berm width (m)* | Pit width (m)** |
|---------------|----------------|------------|-----------------|---------------|-----------------|-----------------|
| 00-18         | 102            | Mean       | 0.3             | -1.1          | 37.5            | 26.4            |
|               |                | STDEV      | 0.3             | 0.9           | 28.0            | 29.6            |
| 00-21east     | 68             | Mean       | 0.0             | -0.6          | 30.8            | 22.7            |
|               |                | STDEV      | 0.1             | 0.0           | 11.8            | 8.7             |
| 00-21west     | 68             | Mean       | 0.1             | -0.5          | 27.5            | 18.7            |
|               |                | STDEV      | 0.1             | 0.0           | 1.2             | 3.2             |
| 00-32small    | 112            | Mean       | 0.2             | -1.6          | 45.6            | 30.1            |
|               |                | STDEV      | 0.1             | 0.0           | 9.1             | 4.5             |
| 00-32big      | 112            | Mean       | 1.1             | -2.5          | 42.1            | 27.9            |
|               |                | STDEV      | 0.6             | 0.2           | 9.5             | 11.7            |
| 00-65         | 127            | Mean       | 0.6             | -2.4          | 46.1            | 33.8            |
|               |                | STDEV      | 0.3             | 0.2           | 5.1             | 3.8             |
| 00-67         | 90             | Mean       | 0.7             | -4.0          | 49.7            | 30.6            |
|               |                | STDEV      | 0.3             | 0.1           | 6.9             | 2.4             |
| 89-01         | 110            | Mean       | 1.1             | -7.6          | 77.7            | 53.4            |
|               |                | STDEV      | 0.8             | 1.0           | 21.5            | 21.0            |
| 83-95         | 86             | Mean       | 1.2             | -3.7          | 93.2            | 65.2            |
|               |                | STDEV      | 0.8             | 0.1           | 6.1             | 10.6            |
| Overall mean  | 97.2           |            | 0.6             | -2.7          | 50.0            | 34.3            |
| Overall STDEV | 20.6           |            | 0.3             | 0.4           | 8.5             | 9.2             |

STDEV= standard deviation. \*Berm width is crest to crest

\*\*Pit width is the width at the seafloor

The pit formed by iceberg 00-18 is characterized by a very steep inner berm slope, a relatively smooth central area comprised of very fine sand and a ring of shell and pebble debris at the bottom. It is inhabited by low numbers of sand dollars, anemones, snow crabs but higher numbers of small bivalves and gastropods (Appendix VI, Figures A11-A12). The accumulation of shell debris and pebbles surrounding the center of the pit may have occurred as the iceberg rocked in the one location grinding against the edges causing the shells and pebbles within the sediment to work loose. Alternatively this is material that was on and in the iceberg and melted out while grounded. The dense reworking of the sediment through bioturbation seen in undisturbed seafloor was not observed in the pit. However, evidence of a few mounds and tracks suggests the start infauna colonization within the scour.

### 5.1.3 Iceberg 00-21

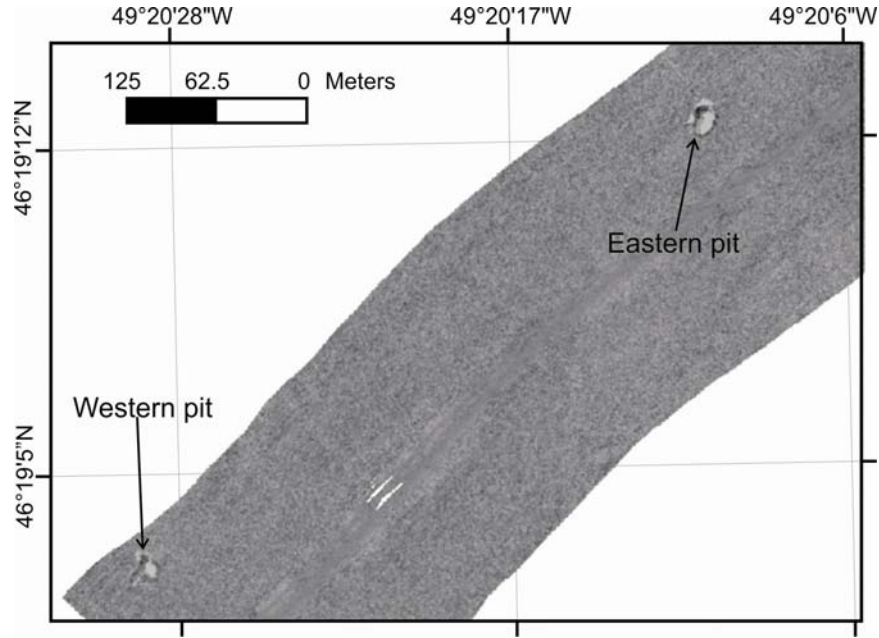
#### Environmental conditions

Iceberg 00-21 was tracked from March 28<sup>th</sup> to April 4<sup>th</sup>, 2000 using radar and visual observation from ships in the area (Appendix II). It was towed aground by the *Maersk Placentia* at approximately 01:30 on March 31<sup>st</sup> and remained grounded for about 30 hours in 68 m water depth. Iceberg 00-21 drifted free on April 1<sup>st</sup> and was towed again by the *Maersk Placentia* to southeast for approximately two days into deeper water.

Winds prior to the grounding were strong SSE (16m/s) on March 28<sup>th</sup>, becoming light to moderate from the NE and SE on March 29<sup>th</sup> and 30<sup>th</sup> (Appendix II). They remained light to moderate from the SSE through the grounding period of March 31<sup>st</sup> until April 2<sup>nd</sup> and then changed to SW for the 3<sup>rd</sup> and 4<sup>th</sup>. Ocean currents were generally light ~ 4-12cm/s throughout the period with directions to the west on March 28<sup>th</sup> and 30<sup>th</sup>, to the NE on the 29<sup>th</sup>, and to the NE through SE for the 31<sup>st</sup> to the 3<sup>rd</sup>.

#### Scour and pit morphology

The initial reconnaissance side scan survey for the iceberg 00-21 seabed scour identified a subtle circular feature that was almost missed. However, subsequent higher resolution lines identified two small fresh-looking pits (Figure 6). These features were also identified in the multibeam bathymetry (Appendix III, Figure 3). No ROV dives were conducted over the small pits; because of time constraints, it was felt that the ROV dives already conducted over other fresh pits in sandy terrain would suffice. Water depth over the two scour pits ranged from 72 to 73 m consistent with the approximate reported water depth (Table 4) (Appendix II). The two pits are similar in appearance with the more easterly of the two appearing slightly larger. The pits have an average diameter of approximately 30 m with an average berm height of 0.1 m and a maximum depth of 0.6 m (Table 4).



**Figure 6:** Map of scour 00-21 seen with side scan imagery.

#### 5.1.4 Iceberg 00-32

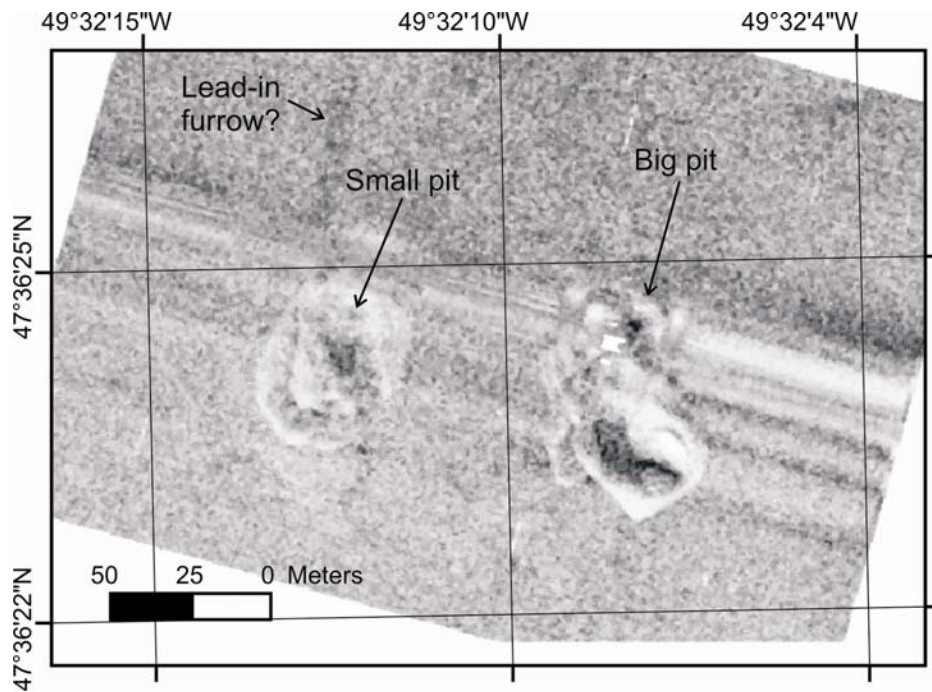
##### Environmental conditions

Iceberg 00-32 was tracked from April 15<sup>th</sup> to April 19<sup>th</sup>, 2000 using radar and visual observation from ships in the area (Appendix II). It was reported to have been grounded from 07:30 April 16<sup>th</sup> until 19:25 on April 19<sup>th</sup>. The estimated total time aground is 96 hours in approximately 112 m water depth. No towing operations were performed on this iceberg.

Winds were of moderate strength (10-12m/s) to the east and then NE on April 15<sup>th</sup> and 16<sup>th</sup> (Appendix II). They then became light from the east on the 17<sup>th</sup> followed by moderate winds from the NW over the 18<sup>th</sup> and 19<sup>th</sup>. Ocean currents were generally moderate (~46-55cm/s) to the NE from the 15<sup>th</sup> through 19<sup>th</sup>. However, the between the 15<sup>th</sup> and the 16<sup>th</sup> the winds and currents appear to have been of sufficient force and direction that if the iceberg had not been already grounded it would have likely traveled into deeper waters (Appendix II).

##### Scour and pit morphology

A draft measurement of 124 m was made for iceberg 00-32 from side scan sonar aboard the tracking vessel some time prior to the grounding. This is well in excess of the grounding water depth of 113 m, suggesting either errors in the measurement or a decrease in iceberg draft prior to grounding. Sidescan surveys for the 00-32 grounding site identified two prominent iceberg pits approximately 50 m apart and within 100 m of the reported grounding location (Figure 7). A very subtle furrow was identified leading into or out of the westerly pit (Figure 7 and Appendix III, Figure 4). Both pits are attributed to the Berg 00-32 grounding based on the lack of other fresh-looking features near the reported grounding location. However, the plotted iceberg positions are not detailed or accurate enough to confirm the order of events or the direction of scouring. The prominent elliptical eastern pit measured  $60 \times 35.5$  m, with an average berm height of 1.1m and a maximum depth of 2.7 m (Table 5). The western pit measured approximately  $56 \times 25$  m, with an average berm height of 0.2 m and a maximum depth of 1.6 m (Table 5). An IKU grab (Station 003) taken approximately 200 m north of the identified pits recovered well-sorted medium sand of the Adolphus Sand (Appendix V).



**Figure 7:** Map of scour 00-32 as seen with side scan imagery.

### Biological and sedimentological observations

The seabed surrounding scour site 00-32 was flat, sandy and inhabited by a dense population of sand dollars, some mollusks, and occasional basket stars, crabs and anemones (Appendix VI, figure B1 and B2). It also featured many depressions created by rays or flounders (Appendix VI, figure B3). In some places, the seabed had a mottled appearance, characteristic of accumulations of flocculent organic material seen elsewhere and reported by Schwinghamer et al. (1998). The mottled surface, the small mounds and hole, and the tracks and trails indicated presence of an active infaunal community in the area.

The outer berm rose up about 1-2 m from the seafloor in a gradual slope of sand. In some places sand dollars were making their way up the outside of the berm (Appendix VI, figure B4). Occasionally, sea anemones, crabs and basket stars were seen on the outer berm (Appendix VI, figure B5). The berm top was composed of sand and did not appear very wide. It was inhabited by moderate numbers of sand dollars. In some places, the berm was heavily marked by numerous large depressions likely generated by foraging fish. Also, observed on the berm top were some large anemones and basket stars (Appendix VI, figure B7 and B8). Large dropstones were rare and devoid of attached organisms (Appendix VI, figure B10). However, one was noted hosting a tall attached sea anemone covered in large gastropods (Appendix VI, figure B9).

The slope of the inner berm was steep and descended about 6 m to the pit base in 114 m water depth (Appendix VI, figure B11 and B12). The inner berm and pit bottom were composed of sand and characterized by numerous large depressions probably generated by fish (Appendix VI, figure B15). Overall the small biological community consisted of sea anemones, large carnivorous gastropods, a few sand dollars (Appendix VI, figure B13) and an occasional basket star. There were a few patches of shell debris, probably a result of the grinding of the iceberg. There was little evidence of infaunal or epifaunal communities as seen on the surrounding seabed. Moreover, the epifauna observed was a subset of that found on the surrounding seabed and was mostly comprised of the highly mobile forms of that fauna. The predominance of colonization through immigration of mobile organisms at this site rather than the settlement and growth of larvae is evidence of its recentness.

### 5.1.5 Iceberg 00-44

#### Environmental conditions

Iceberg 00-44 was tracked from April 23<sup>rd</sup> to April 29<sup>th</sup>, 2000 using Glomar radar and visual observation from ships in the area (Appendix II). It was reported to have been towed aground by the *Trinity Sea*. The tow was lost by this vessel at 23:42, April 23<sup>rd</sup> and at approximately 18:20 on April 24<sup>th</sup> deemed to be grounded in approximately 91 metres of water. It remained grounded for a total time of ~30 hours before drifting free on April 26<sup>th</sup>. The estimated grounding duration is uncertain as there is no recorded iceberg position from the morning of the 26<sup>th</sup> to midday of the 28<sup>th</sup>. However, during the estimated grounding time the winds were to the N-NW, which likely kept the iceberg grounded until switching to the south on the 27<sup>th</sup> (Appendix II). Once free, iceberg 00-44 was then towed by the *Maersk Placentia* for approximately 7 hours into safer waters.

The winds between April 23<sup>rd</sup> and 28<sup>th</sup> were light to moderate (6-10m/s) becoming strong (14m/s) by the 29<sup>th</sup> (Appendix II). Wind directions were from the north on the 23<sup>rd</sup>, from the SE on the 24<sup>th</sup>. For the remainder of the period winds were generally southerly but northerly on the 27<sup>th</sup>. Ocean currents were 10 to 14cm/s on the 23<sup>rd</sup>, slowing to about 5cm/s from the 24<sup>th</sup> to the 27<sup>th</sup> (Appendix II). On the 28<sup>th</sup> and 29<sup>th</sup> of April the currents returned to a speed of 10 to 14 cm/s. Currents directions were generally to the NE through to the SE, but for on the 24<sup>th</sup> on which it flowed to the NNW.

#### Scour and pit morphology

Efforts to locate the scour feature for scour 00-44 were unsuccessful. Three side scan lines were run at 100 m range over the reported grounding site, but no seabed scour features were identified. Additional surveying for the grounding site was done by Fugro-Jacques Geosurveys while conducting the fall 2000 Environmental Effects Monitoring (EEM) Program for the Terra Nova Project, with no success in identifying a scour. The fact that iceberg 00-44 was towed aground may explain why no observable seabed damage occurred. Due to the lack of an identifiable scour site no additional work has been done on this site including no multibeam swath bathymetry coverage in 2002.



### 5.1.6 Iceberg 00-65

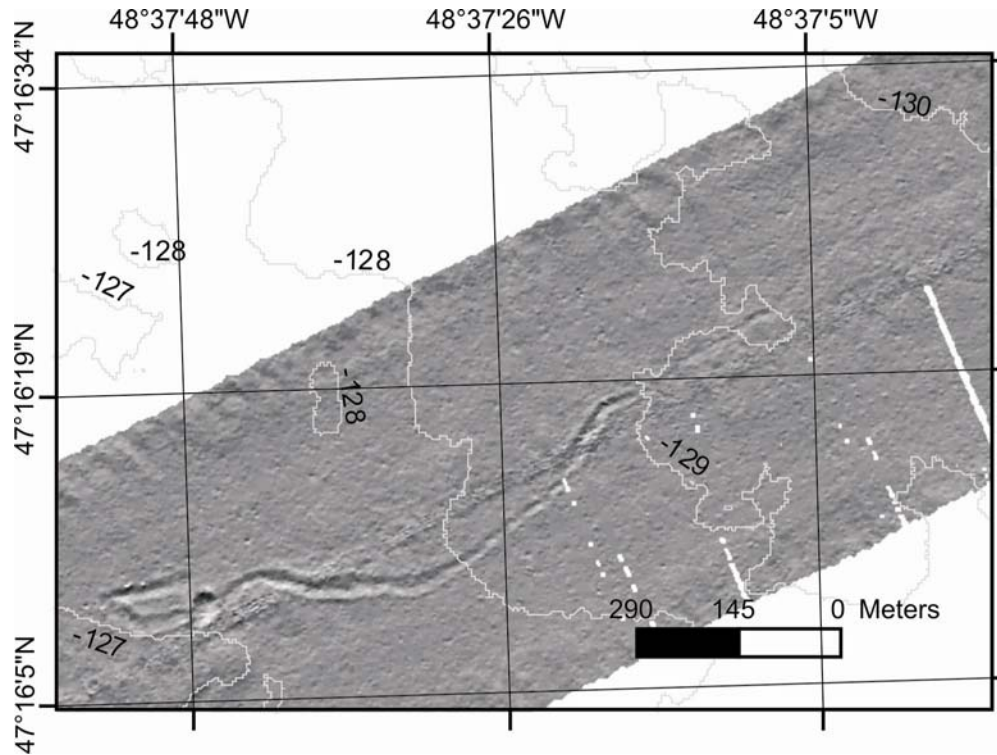
#### Environmental conditions

Iceberg 00-65 was tracked from April 28<sup>th</sup> to June 4<sup>th</sup>, 2000 using radar and visual observation from ships in the area (Appendix II). The draft of iceberg 00-65 was measured at 135 m using side scan sonar. It was reported grounded at 10:27 on April 28<sup>th</sup> in 127 m of water and remained grounded until 05:00, May 12<sup>th</sup>, after which it drifted into deeper waters before being towed by the *Maersk Gabarus* on the 19<sup>th</sup> of May for approximately two and a half days.

While grounded, the winds were generally light to moderate (3-10m/s) from April 28<sup>th</sup> to May 11<sup>th</sup>, with the exception of strong winds (15m/s) to the NE on April 29<sup>th</sup> (Appendix II). Wind directions were generally offshore and to the north over the grounding period. Ocean currents were moderate (~30-60cm/s) and to the E-NE. After floating free, winds and currents are reported to have been of moderate magnitude to the NW and NE for the 12<sup>th</sup> to the 19<sup>th</sup> of May as the iceberg moved to deeper waters. From April 28<sup>th</sup> to May 6<sup>th</sup> the winds and currents were of sufficient magnitude and direction that had it not been grounded it would have otherwise moved further offshore into deeper waters.

#### Scour and pit morphology

The 00-65 scour feature is located approximately 700 m south of the reported grounding location (C-Core, 2001). The observed initial touch down is in 129.5 m of water (Figure 8). It scoured upslope for approximately 1500 m to approximately 126.5 m, turned and scoured eastward 100 m before grounding and creating a terminal pit (Figure 8). In the eastern portion of the furrow a series of aligned circular indentations are visible before grounding and creating a terminal pit (Figure 8). In the eastern portion of the furrow a series of aligned circular indentations are visible only on the side scan records (Appendix II, Figure 5). These are suggestive of an oscillating or rocking motion against the seafloor by the scouring iceberg. The fact this is only notable on the side scan records implies that these features are at a scale below that of the multibeam resolution. There is a relatively steady upslope



**Figure 8:** Map of multibeam bathymetry over scour 00-65.

increase in furrow width from effectively zero at the start in approximately 129.5 m water depth at the start of the furrow to 25 m at the end (Figure 8). This is consistent with an iceberg of stable draft scouring upslope and gradually having to increasing the keel area in contact with the seabed. Scour depth increases only gradually and irregularly upslope. The furrow has a maximum depth 1.05 m, recorded just east of the pit. The overall average depth of the furrow is approximately 0.5 m (Table 4). The pit diameter is 45 m as measured from berm crest to crest; however, a measurement of the actual diameter at the seabed averages 34 m (Table 5). The maximum depth of the pit is 2.5 m below seabed a depth that is equivalent to the potential depth of the iceberg keel.

Biological and sedimentological observations

ROV imagery and bottom samples indicate the seabed surrounding scour 00-65 is fine to medium, olive-green sand of the Adolphus Sand with scattered pebbles and shells (Appendix VI, Figures C1-C4). It appears quite flat and featureless and devoid of large cobbles or boulders. No evidence of ripples or other bed forms was observed. There was considerable biological colonization and infaunal activity. The epifaunal organisms were principally sea

anemones, bivalves and gastropods (the dominant epibenthic species). An infaunal population was indicated by numerous mounds, holes and tubes generated by shrimps bivalves, annelids and sand lances (Appendix VI, Figures C1-C4). Depressions produced by fish foraging for infaunal animals were common and in some instances still occupied. No established attached fauna typical to some areas of the Grand Bank was observed (Lawrence et al. 1989). This is likely due to the lack of firm substrates for these organisms to colonize. However, the few rocks observed had no visible encrustation. Also in contrast to the seafloor surrounding other sites there were very few echinoderms, i.e. no sand dollars, no sea urchins, no brittle stars or basket stars.

The outer berm of scour 00-65 is recognized by an accumulation of shell debris and gravel at its base (Appendix VI, Figure C5). No species were noted on this substrate. The slope of the outer berm was gradual and was comprised of sand and shells. Apart from a few anemones, this area of the berm did not display abundant epifauna. The berm top varied, some places were sandy sediment and in others a shelly and pebble mixture. Although not abundant, the most conspicuous colonizers of the berm top were anemones and mollusks. Snow crabs, considered highly mobile scavengers, were seen occasionally. The sandy area of the berm tops contained some infaunal organisms and relatively large mobile gastropods (whelks) (Appendix VI, Figures C5-C10). The sediment on the inner berm was usually fine to medium grained sand and patches of shells and pebbles (Appendix VI, Figures C11 and C13). There was evidence of sediment reworking by invertebrates and fish (Appendix VI, Figures C11). Patchy clusters of anemones were seen but they were not as numerous as on the top of the berm, likely because being elevated improves their feeding opportunity from the water column. The scour trough had a similar sedimentary texture as that of the berm (Appendix VI, Figures C12 and C14). A random distribution of shells, mounds, anemones, gastropods, bivalves, and rarely snow crabs, or sand lances was observed. In places an internal furrow from where the keel made a deeper impression could be seen (Appendix VI, Figures C14). Overall, scour 00-65 is in an early phase of colonization and although it hosted a subset of the population on the surrounding seafloor it had not reached comparable numbers.

### 5.1.7 Iceberg 00-67

#### Environmental conditions

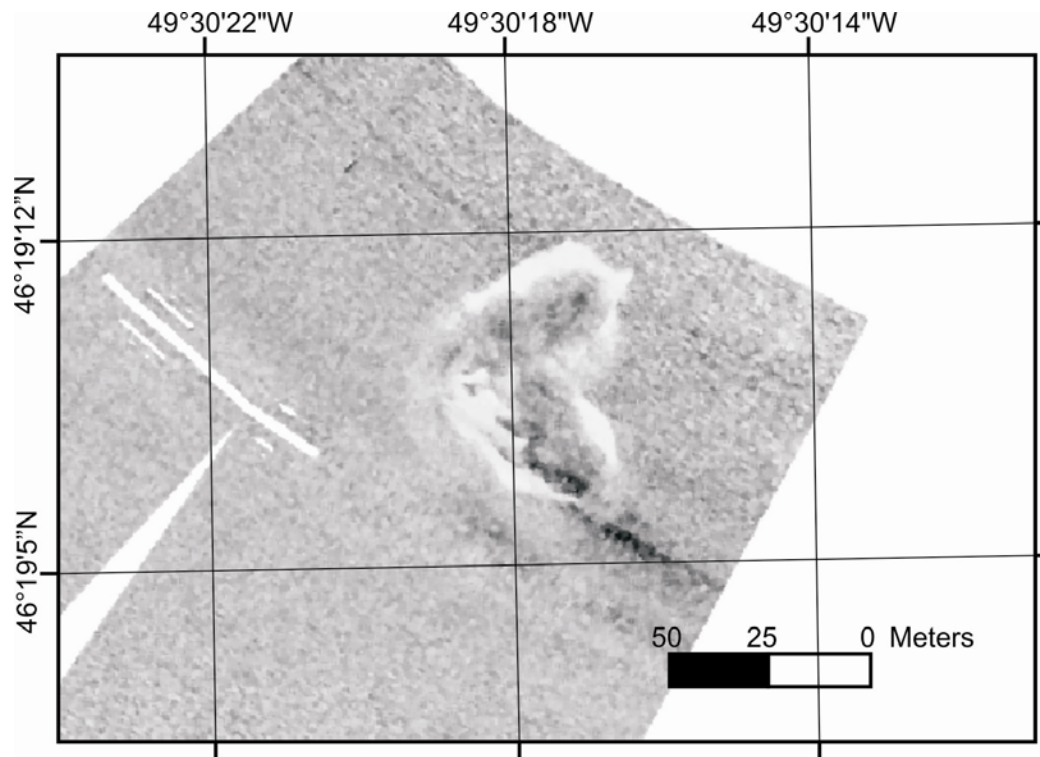
Iceberg 00-67 was tracked from May 5<sup>th</sup> to June 8<sup>th</sup>, 2000 using radar and visual observation from ships in the area (Appendix II). The *Tignish Sea* reported that the iceberg was to have broken in half at 01:20 on May 12<sup>th</sup>. At 16:40 on the same day it was reported to be grounded by the *Maersk Nascopie* in about 90 m of water and is expected to have remained grounded until 00:05 of May 17<sup>th</sup>, a total time of approximately 104 hours. This iceberg underwent no ice management towing operations. Although located further to the WNW than iceberg 00-65, it was subject to similar winds and currents. Winds were generally light-moderate (4-10m/s) from the 12<sup>th</sup> to the 17<sup>th</sup>. There was some fluctuation in wind directions over this period, ranging to the SE on the 12<sup>th</sup>, to the NW on the 13<sup>th</sup> to the 16<sup>th</sup>, and then to the NE on the 17<sup>th</sup> to the 20<sup>th</sup>. Ocean currents were consistently to the NE at approximately 20-40cm/s through May 5<sup>th</sup> to the 30<sup>th</sup>. Winds and currents also appear to be of sufficient magnitude and direction generally to the NE following the 17<sup>th</sup> to assist the iceberg's drift into deeper water.

#### Scour and pit morphology

The surveys over the reported grounding site of iceberg 00-67 revealed a 'V' shaped pit in a water depth of 87 m in both side scan (Figure 9) and multibeam bathymetry (Appendix III). Each arm was approximately 50 m long and had an average width of 42 m (Appendix IV) (Table 5). Berm heights average 0.7 m, and the pit was about 4 m deep (Appendix IV) (Table 5). Side scan imagery suggests a relative homogenous sandy seafloor. This was confirmed by ROV images which showed ripples and hummocks that are evidence for bottom current reworking (Appendix VI, Figures D1-D3). Grain size analysis from the IKU sample indicated that the sand is coarse grained with some fine gravel (Appendix V).

#### Biological and sedimentological observations

The biological community surrounding the 00-67 disturbance was diverse. A well established infaunal population was noted by the mounds and holes from which sand lances were frequently seen darting out of. The epifaunal population consisted of sand dollars,



**Figure 9:** Map showing side scan imagery over scour 00-67.

carnivorous gastropods and bivalves (Appendix VI, Figure D2). Large depressions, likely created by rays and flounder, were frequently seen on the seabed (Appendix VI, Figure D3). Crabs were seen only occasionally (Appendix VI, Figure D1) and one large cod was observed (Appendix VI, Figure D10). The outer berm is composed of sand similar to the surrounding seabed (Appendix VI, Figures D4-D6). The base of the outer berm featured patches of gravel, and large boulders. These were likely exhumed during scouring as they lack any attaching organisms, such as sponges, mollusks, polychaetes, or bryozoans that are typical of undisturbed boulders (Lawrence et al. 1989). The berm top varied from a smooth sandy substrate to large patches of shells and gravel and to occasional accumulations of poorly sorted boulders (Appendix VI, Figures D7-D11). With the exception of a few barnacles and rare anemones attached to some large boulders there appeared to be little colonization of the boulders. However, crabs were commonly observed in association with the rocks. In sandy substrates, the observed epifauna was similar to that on the surrounding seabed but in lower densities, i.e. few sand dollars, some mobile gastropods and occasional flounder.

Descending into the pit, the inner berm sides were steep and composed of sand, gravel, and shell mixture. The inner berm lacked any obvious colonization (Appendix VI, Figures D12-D15). The bottom of the pit was smooth, and composed of sand with shell and pebble debris (Appendix VI, Figures D16-D18). The hummocks, ripples observed on the outside sea floor were absent within the scour. However, there were some depressions typical of those created by flounder along with some slightly larger depressions of unknown origin (Appendix VI, Figures D16 and D18). Overall there was little evidence of infaunal or epifaunal organisms.

#### *5.1.8 Iceberg 00-68*

##### Environmental conditions

Iceberg 00-68 was tracked from May 5<sup>th</sup> to May 19<sup>th</sup>, 2000 using radar and visual observation from ships in the area (Appendix II). It was reported as grounded 07:00 on May 11<sup>th</sup>, then scouring the seabed from 02:00 to 09:00 on May 12<sup>th</sup> and free-floating by 19:00 on May 12<sup>th</sup>. The estimated grounded time was about 30 hours in ~ 75 m. The iceberg was towed into shallower water by the *Maersk Placentia* for approximately one and a half days on May 12<sup>th</sup> and 13<sup>th</sup> before having the tow slip. Winds were generally light up to May 12<sup>th</sup>, then near-moderate (9 m/s) on the 13<sup>th</sup>. Wind directions on May 12<sup>th</sup> were to the SE then changing to the NW on the 13<sup>th</sup>. Ocean currents were light (~10cm/or less) to the NW on the 12<sup>th</sup> and to the ENE on the 13<sup>th</sup>. The NW winds on the 12<sup>th</sup> were consistent with the iceberg's track to the SE and the grounding.

Interpretation of the side scan data showed no clear record of a “fresh-looking” scour in the vicinity of the grounding site, or along the nearby iceberg trajectory. However, a large older furrow was identified within several 100 metres of the area (section 5.3). Iceberg 00-68 was estimated to have a keel draft of 64 m (Appendix II). This is much shallower than the water depth at the reported grounding site (75 m). Thus, it is conceivable that iceberg 00-68 did not touch down on the seabed but likely became stationary due to the counter acting wind and current forces over the period.

## 5.2 Observations of re-surveyed older scour sites

### 5.2.1 Scour 89-01 (*Texaco or Springdale scour*)

Scour 89-01, also referred to as the Texaco or Springdale scour, is located near the Springdale M-29 well-site in approximately 112 m water depth (Figure 1). Iceberg 89-01 contacted the seafloor in approximately 117 m of water on March 9<sup>th</sup>, 1989, formed a 14 km long scour as it continued to drift southward into shallower water depths over the next 28 hours. It eventually grounded in 112 m water depth for 45 days before drifting free on April 24<sup>th</sup>. The iceberg was observed to shift position several times on April 21<sup>st</sup> to 24<sup>th</sup>.

Scour 89-01 is part of a repetitive mapping program by the GSC to document the evolution of these seabed scours on Grand Bank (Table 6). It was first studied during GSC cruise Dawson 89-006 in May of 1989, 11 days after it drifted free from the site (Fader, 1989) (Figure 10). Scour 89-01 site was re-surveyed with side scan sonar and ROV video in 1990 (Parrott et al., 1990; Cameron and Sonnichsen, 1992). A small side scan and multibeam survey was run over the site in 1996. The purpose of re-surveying the site in 2001, with side scan sonar and ROV video, and in 2002, with multibeam swath bathymetry, was to determine if observable changes had occurred to either the berm or the pit in terms of either sediment infill or biological re-colonization.

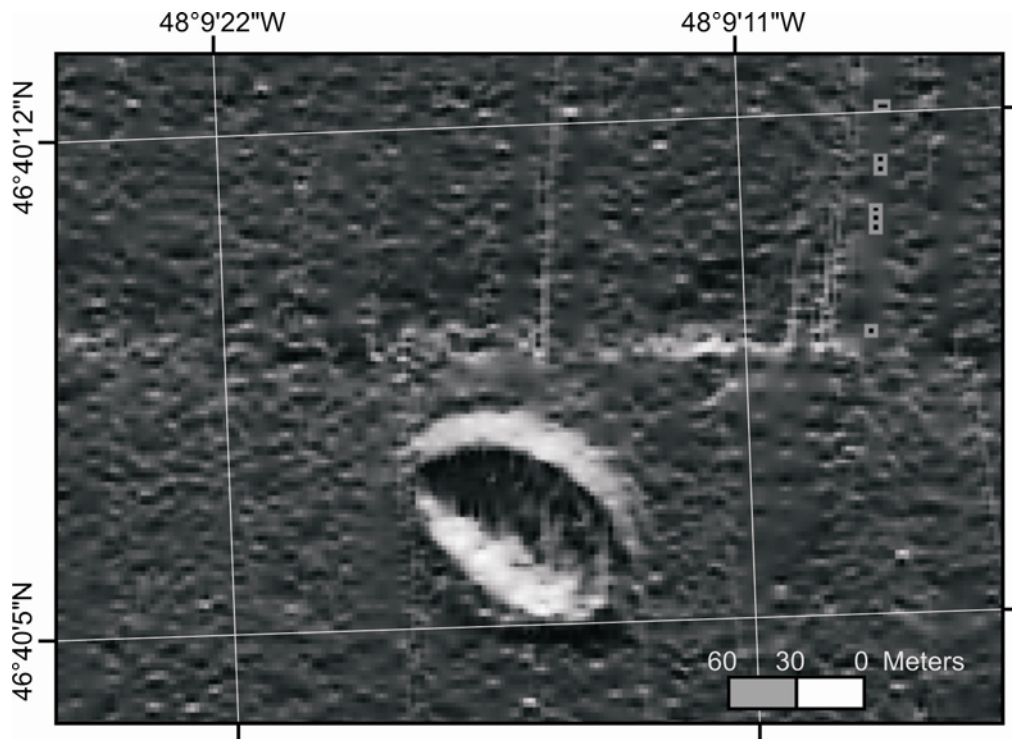
#### Scour and pit morphology

Scour 89-01 is comprised of a long and very shallow single-keel scour segment and a pronounced terminal pit (Appendix III, Figure 7) (Figures 10 and 11). Original measurements of the scour indicated that it was 14 km long trending north-south. It was approximately 20-30 metres wide and terminated in a well defined pit at the southern end. The pit was about 90 metres in diameter and 5 metres in depth, with the berm rising 1-3 metres above the seafloor (Geonautics, 1991; Cameron and Sonnichsen, 1992). The new measurements taken using the multibeam bathymetry data give an average width of 78 m with average berm heights of 1.1 and a maximum depth of 7.6 m (Appendix IV, Table 2) (Table 5).





**Figure 10:** Side scan image from cruise 89-006 of the terminal pit of scour 89-01. Image colours have been inverted to highlight the feature.



**Figure 11:** Shaded relief map of multibeam bathymetric data from the 2002 survey over scour 89-01



**Table 6:** Repetitive mapping history and associated survey instruments for three older scours of known age listed by year (and GSCA cruise number in parentheses).

| Scour | Side scan                                                                           | Huntec                          | Multibeam                       | ROV                             | Seafloor photos |
|-------|-------------------------------------------------------------------------------------|---------------------------------|---------------------------------|---------------------------------|-----------------|
| 89-01 | 1989 (89-006)<br>1990 (90-021)<br>1994 (94-081)<br>2001 (2001-038)                  | 1990 (90-021)<br>2001(2001-038) | 1998 (98-074)<br>2002(2002-012) | 1990 (90-021)<br>2001(2001-038) |                 |
| 88-01 | 1988 (Husky)<br>1990 (90-021)<br>2001 (2001-038)                                    | 1990 (90-021)<br>2001(2001-038) | 1996 (96-011)<br>2002(2002-012) | 1990 (90-021)<br>2001(2001-038) | 1988 (Husky)    |
| 83-95 | 1983 (Mobile)<br>1983 (83-033)<br>1986 (86-018)<br>1990 (90-021)<br>2001 (2001-038) | 1983 (83-033)<br>2001(2001-038) | 2002(2002-012)                  | 2001(2001-038)                  | 1983(83-033)    |

Note: All survey methods except seafloor photos were applied to the 2000 scours in 2001 or 2002.

Biological and sedimentological observations from 2001 ROV dives

The surrounding seabed at Scour 89-01 was flat and sandy with a uniform depth of about 110 m. Visible epifauna included brittle stars, gastropods, hermit crabs, and soft coral (anthozoan *Gersemia* sp.)(Appendix VI, Figures H1-H2). This soft coral occurs on the Grand Bank with bivalves, anemones and other soft-bodied attached organisms (Prena et al. 1999) (Appendix VI, Figure H1). Noted crabs were snow crabs (*Chionoecetes opilio*) and toad crabs (*Hyas* sp). A dead basket star was observed being consumed by numerous sea urchins (Appendix VI, Figure H2). Evidence of infaunal organisms included numerous small mounds, tubes, tracks and trails. Occasionally, dense populations of sand lance were encountered darting out of the seafloor. Overall these seafloor observations suggest the scour location is typical of this area of the Grand Bank and match the observations of Prena et al. (1997).

The base of the outer berm of scour 89-01 was distinguished by an increasing density in empty shells, gravel, and cobbles with sand rich patches. Only a few brittle stars and anemones could be discerned on this substrate, though there were probably other animals such as large carnivorous gastropods. Sandier areas hosted such organisms as sea urchins, sand dollars, brittle stars, snow crabs, and basket stars (Appendix VI, Figure H4). Dense populations of sand lance were also encountered in the sandy patches along the outer berm

(Appendix VI, Figure H3). The substrate of the berm top was similar to the outer berm (Appendix VI, Figures H7-H9). These areas of coarser material may be the result of the sands being winnowed away, however, there is little evidence of current rework or infilling of the scour. In the coarser areas the dominate organisms were anemones and basket stars which likely benefit from the firm substrate and being elevated from the seabed surface. The large boulders supported a variety of attached organisms including sponges, anemones and numerous mollusks (Appendix VI, Figure H17). Large snow crabs were also seen in association with the large boulders (Appendix VI, Figure H10). The inner wall of the berm consisted of a mixture of fine sand, shells, gravel, and boulders, with many areas dominated by a shelly gravel lag. A muddy diamicton outcropping from the upper part of the inner berm wall, and much of the large boulders associated with it, were colonized by numerous organisms (Appendix VI, Figures H12-H17). The pit base featured the largest variety and concentration of attached organisms such as sponges, and anemones, as well as others that were unidentifiable but probably included bryozoans, hydroids, tunicates, barnacles and soft corals. The most conspicuous was a cluster of tall narrow cylindrical sponges which provide a good reflection of the pit's stability and age (Appendix VI, Figures H18-H21). It was estimated that about 95% of the exposed surface of some of the rocks and boulders were covered by encrusting organisms. Close to the pit base (112.7 m) one of these boulders was sampled (Appendix VI, Figure H29). Some unexpected items at the base of the pit included a large log, refuse (pop cans and other debris) (Appendix VI, Figures H25-H27). This area showed the highest concentration of scavenging by carnivorous gastropods and sea urchins many of which were clustered around the decaying log. On the berm a partially buried cable was observed, presumably the one used to tow the iceberg in 1989 (also noted by Cameron and Sonnichsen, 1992) (Appendix VI, Figures H20 and H21). Overall this scour contrasted from the recent 2000 scours in that it exhibited dense colonization of the larger boulders by species which take sometime to establish, such as the cylindrical sponges, soft corals and other encrusting organisms, and the almost complete removal of the finer sedimentary material from the berms by seafloor currents.

### 5.2.1 Scour 88-01(Husky scour)

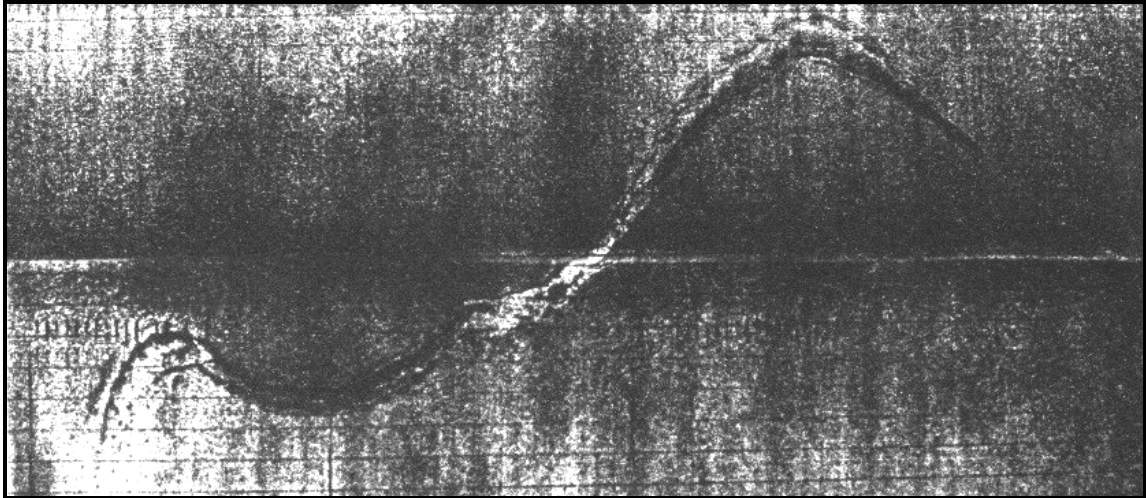
Iceberg 88-01, also referred to as the Husky scour, with a mass of  $\sim 1.9 \times 10^6$  tonnes, scoured and grounded between April 9<sup>th</sup> and 13<sup>th</sup>, 1988 in approximately 123 m water near the Husky White Rose E-09 well site (Figure 1) (Table 5) (Banke, 1988). A subsequent side scan survey conducted over the site shortly after the grounding (Banke, 1988; Woodworth-Lynas, 1989) attributed a 1 km furrow to the 88-01 iceberg (Figure 12). In 1990, GSC-A re-surveyed the scour with side scan sonar and a ROV submersible (Parrott et al., 1990; Cameron and Sonnichsen, 1992). In 1996, GSC-A used a Simrad EM100 swath bathymetric system to collect high resolution seafloor relief data over the 1988 side scan survey (Sonnichsen and Lussier, 1996). As part of the 1996 GSCA survey, Simrad M922 120 kHz side scan data were also collected. In 1997, TerraQuest Associates (1997) compared the data between 1988 and 1996 determining that there was no obvious change to the scour.

#### Scour and pit morphology

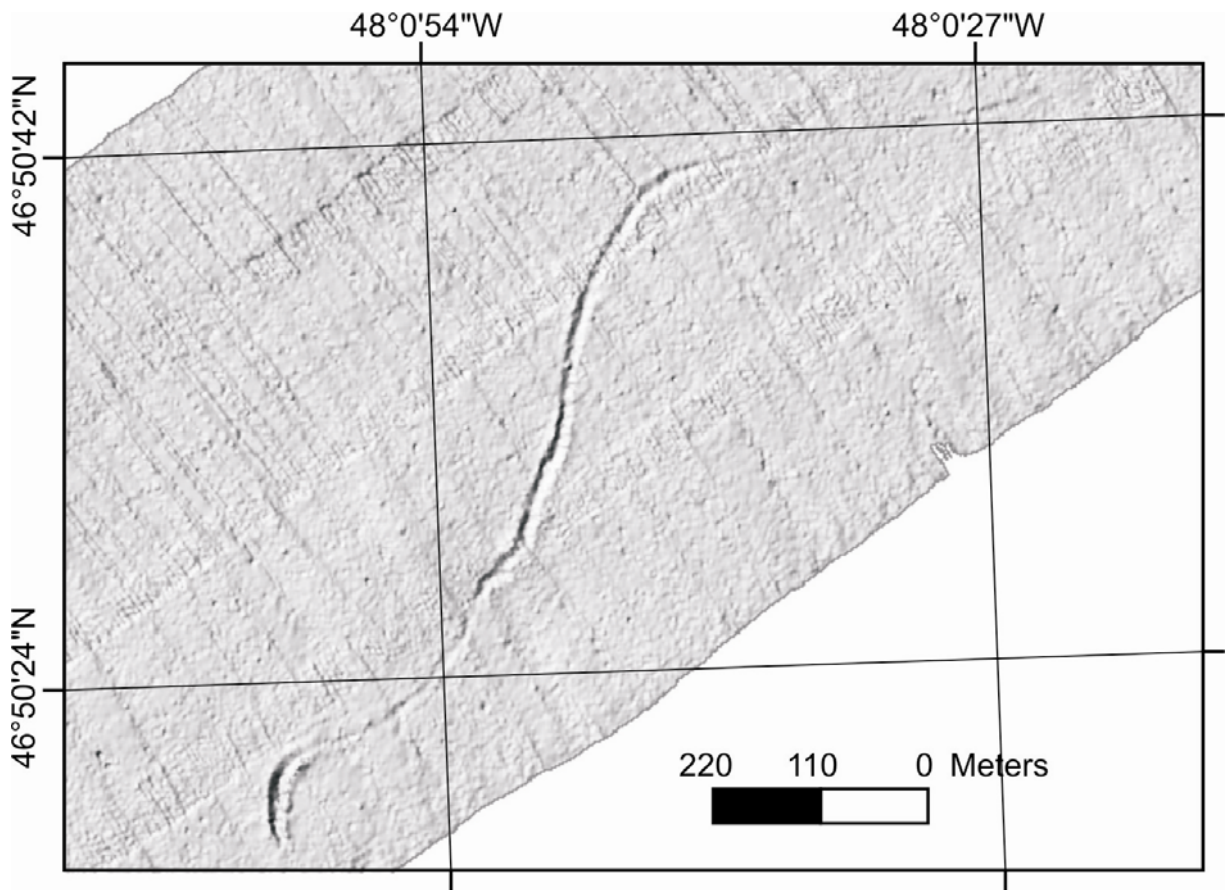
Side scan images from 2001 and multibeam bathymetry from 2002 depict a very similar looking scour to the previous surveys. It is a sinuous 1000 m long furrow initially running south-southwest, then curving to the southwest, and finally to the south for an additional 200 m for a total of 1200 m in length (Figure 13) (Table 4). The seafloor sediment in the area is the Adolphus sand (Sonnichsen and King, 2001). The grounding produced no terminal pit. The scour berms tended to be more or less continuous with areas exhibiting a scallop texture, likely wallow marks related to the effects of tidal- or storm-induced sea level fluctuations on the grounded iceberg (Woodworth-Lynas, 1989). Internal parallel scours are rare. Measurements made from the multibeam bathymetry data indicate an average berm height of 0.2 m with an average crest to crest width of 26 m (Table 4) (Appendix IV, Table 1). The furrow had an average depth of 0.7 m with an average incision width (furrow width excluding berms) of 21 m (Table 4) (Appendix IV, Table 1).

#### Biological and sedimentological observations

ROV video from 2001 shows the seabed at scour 88-01 to be flat, composed of a sandy substrate peppered with shell debris and occasional dropstones (Appendix V, Figures G1-



**Figure 12:** Side scan imagery from initial survey in 1988 of scour 88-01 (water column removed but uncorrected for slant-range and distorted aspect ratio)



**Figure 13:** Shaded relief map of multibeam bathymetry over scour 88-01.

G4). Visible epifauna in this area included brittle stars, gastropods, bivalves, anemones, crabs, sand lances, sand dollars and hermit crabs. Dropstones were heavily colonized by anemones. There was evidence of an abundant infauna population including small mounds, tubes, and holes. Larger fauna observed included flounder (possibly Yellowtail) and rays, both of which feed on infaunal invertebrates.

The transition from seabed to berm at 88-01 was characterized in some places by a large accumulation of shells, gravels and boulders, some hosting attached fauna, mainly anemones. The outer berm slope has a low inclination, and was inhabited by brittle stars, sand dollars, bivalves and an occasional crab (Appendix VI, Figures G5-G7). At the top the fauna comprised similar epifaunal species but perhaps in higher concentrations (Appendix VI, Figures G8 and G9). Within the areas of finer grained sediment there was an established infauna suggested by the characteristic small mounds, tracks and trails (Appendix VI, Figures G9-G10). Rays and flounder were also observed along the berm (Appendix VI, Figure G10).

As observed at other scours, the slope of inner berm was steep and composed of sand with numerous brittle stars, mollusks, and anemones (Appendix VI, Figures G11-G12). The trough was colonized by an established epifauna similar to that observed on the seabed outside. Numerous brittle stars, anemones, sand dollars, shrimps, sand lances, crabs and mollusks were observed on the fine sand (Appendix VI, Figures G13). In some places, there were large accumulations of shells and small rocks providing a firm substrate for attached fauna such as anemones. (Appendix VI, Figures G14-G15). Some of the species of anemones observed in the trough were larger than those observed at the one-year-old scours and perhaps were a different species, indicating a later stage of succession.

### 5.2.2 83-95 (*Scour 95*)

Iceberg 83-95 (*Scour95*), a 1.4 million tonne iceberg, was reported grounded in 95 m of water, approximately 40 km northwest of Hibernia (Figure 1), in March of 1983 (Schoenthaler, 1986). The resulting scour has been resurveyed several times (Table 6). Initially the scour was surveyed by Mobil Oil while the iceberg was still grounded and again in the fall after it had gone. Over the years the GSC-A has conducted a repetitive mapping

study to document changes to the scour. The initial survey was in the fall of 1983 (Vilks, 1984), with follow up surveys in the summer of 1986 (Parrott and Lewis, 1986) (Figure 14), and again in the summer of 1990 (Parrott and Sonnichsen, 1990).

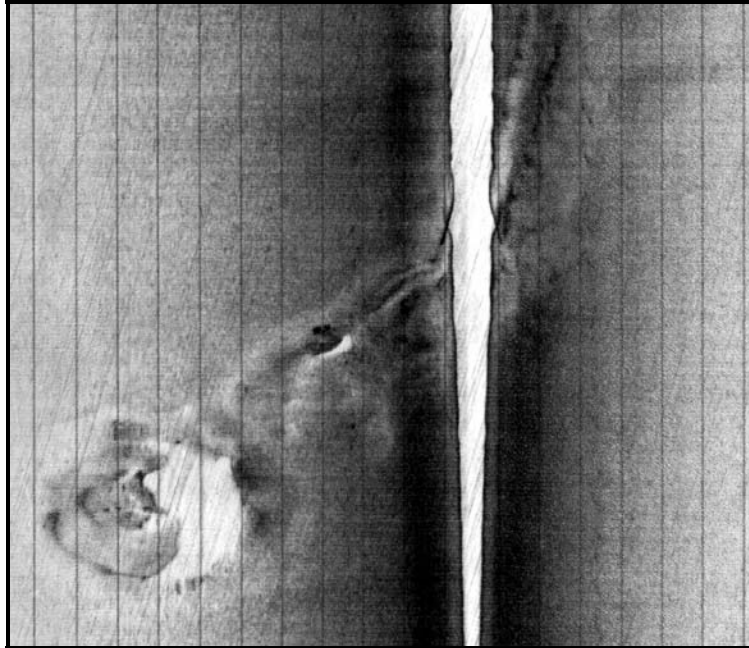
#### Scour and pit morphology

Scour 83-95 is a single-keel curvo-linear scour located within an area of mixed sand and gravel sediments with irregular sand bed forms (Mitton, 1988). It was originally measured as 6.8 km in length with a variable width ranging between 30-45 m along most of its length (Davidson et al, 1990). A 90 m diameter terminal pit with a depth of up to 1.2 m and surrounding berms up to 3 m high was identified on 1986 data at the southern end of Scour 83-95 (Parrot and Lewis, 1986). In the recent survey only the last 2 km of the scour including the terminal pit are clearly notable on the side scan and multibeam (Appendix III, Figure 9) (Figure 15). New measurements of the furrow give an average berm height of 0.2 m with an average width from crest to crest of 34.5 m (Table 4) (Appendix IV). The trough measures an average depth of 0.5 m with an average incision width of 19 m. The terminal pit is circular (Figure 15) with an average berm width from crest to crest of 93 m and a pit incision width of 65 m (Table 5) (Appendix IV). The pit had a depth of 3.7 m and an average berm height of 1.2 m (Table 5) (Appendix IV).

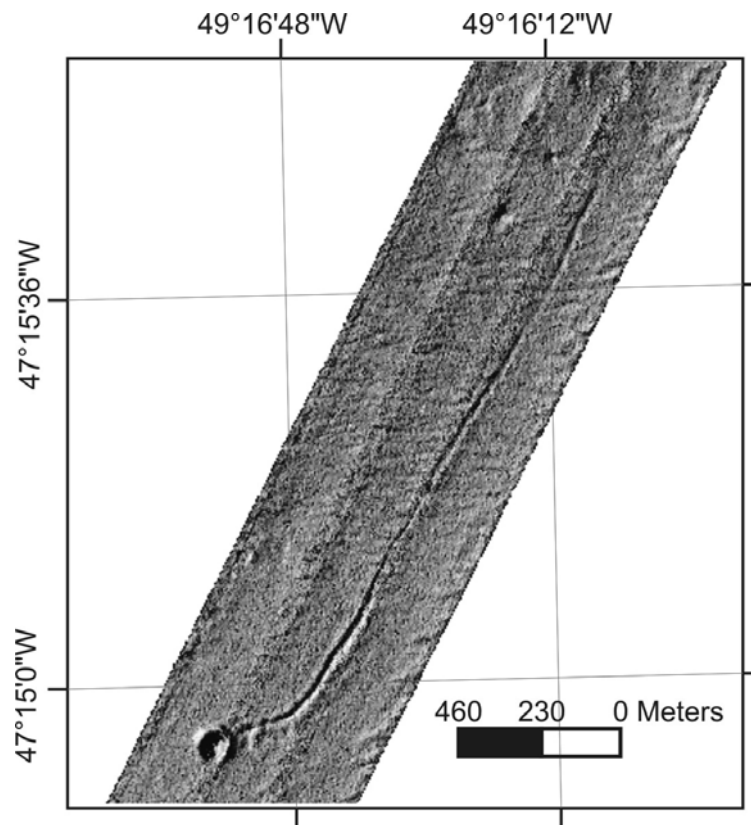
#### Biological and sedimentological observations

2001 ROV dives show the seabed around the scour as generally flat and sandy (Appendix VI, Figures F1-F3). A moderate numbers of sand dollars were observed as well as occasional areas with scattered bivalve shells, and tracks and trails created by epifauna and infaunal communities. In some places, the seabed was hummocky, and in these areas numerous sand lance were seen darting out of the seafloor. Crabs and occasional basket stars were also observed. The surrounding seabed also showed depressions created by flounder, several of which were observed either partially buried or swimming away.

Upon approaching the scour the bottom of the outer berm is observed as being sandy with few epibenthic organisms. There were some areas of cobbles and shelly debris (Appendix VI, Figure F4). The epifauna became moderately abundant towards the top of the outer berm



**Figure 14:** Side scan imagery from cruise 86-018 over scour 83-95 (much of the water column has been removed).



**Figure 15:** Shaded relief map of multibeam bathymetry over scour 83-95.

which varied from large sandy expanses to areas rich in shells, gravel and boulders. The sandy areas contained just a few sand dollars, the occasional anemones and depressions created by flounder (Appendix VI, Figures F7 & F8). In the coarser regions the epifauna is much richer. Boulders were heavily populated by a diverse degree of taxa, including sponges, anemones, small gastropods, crabs, starfish, and numerous small crustaceans and/or fish (Appendix VI, Figures F9-F14). Some of the finer sediment around these boulders has been winnowed away and replaced by small shells. These appear to be small carnivorous gastropods that likely originated from the community on the boulders.

The inner berm is observed as sandy with some shell debris and some evidence of reworking by organisms such as sand dollars and also by currents as there was some ripples noted along the edge (Appendix VI, Figures F5-F6). Near the bottom of the inner berm, the sediment appeared to be fine sand with sea anemones, sand dollars, and starfish present (Appendix VI, Figures F15-F16). The pit featured smooth fine-grained sand that occasionally was rippled (Appendix VI, Figures F17-F18). In some places, long rows of disarticulated bivalve shells were encountered usually colonized by anemones and starfish (Appendix VI, Figure F19). Other areas the seafloor comprised a mixture of rocks and shells (including sea urchin tests). Flounder were occasionally seen in the sandy areas. Dropstones within the pit were heavily populated with a variety of attached organisms similar to the dropstones on the surrounding seabed (Appendix VI, Figure F16). The degree and variety of colonization on boulders within the pit and on the berms indicates a later stage of community development.

### **5.3 Scour of unknown age**

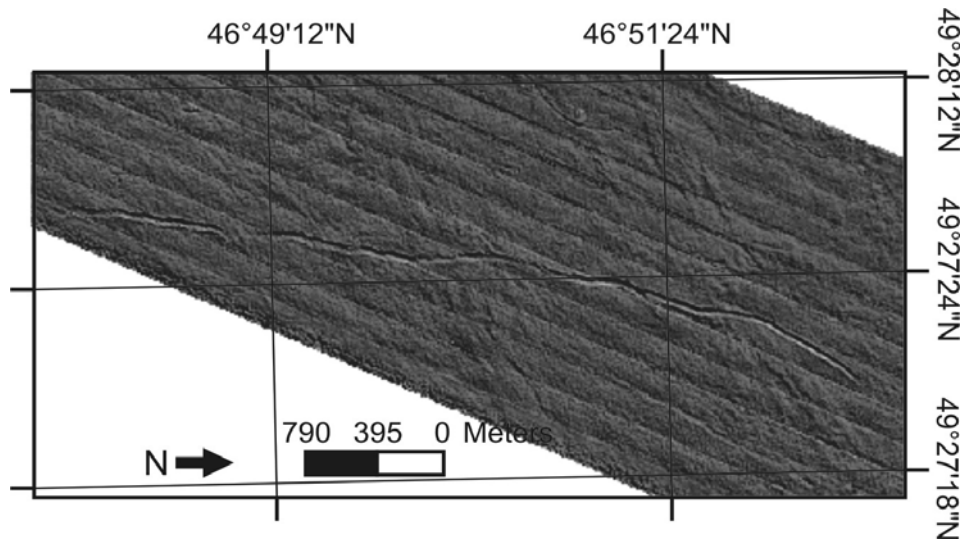
No clear record of a “fresh-looking” scour was identified in the vicinity of the 00-68 grounding site, nor along the nearby iceberg trajectory. However, a long, wide, relatively old-looking furrow was mapped parallel to and within a couple 100 m of the trajectory of iceberg 00-68 (Appendix III, Figure 10). This was considered coincidental, but when no other obvious target was identified, more detailed assessment of the furrow was undertaken to determine if it was an older furrow. This initial interpretation was quickly confirmed by the images from a ROV dive over a prominent section of the furrow. This scour of unknown



age provides a good opportunity test the ability to estimate the relative age of the scour based on our comparative study of new and old scours of known ages.

### Scour and pit morphology

Scour 00-68 is a linear furrow approximately 4.5 km in length (Figure 16) (Table 4). It traverses a relatively level area of the Grand Bank in 74 m of water approximately 75 km northwest of Hibernia (Figure 1, labelled 00-68). The furrow cuts into a coarse gravel seafloor (Sonnichsen and King, 2001) that likely overlies a coarser boulder bed as the berms contain frequent large boulders (Appendix VI). The side scan imagery of the scour portrays a poorly defined furrow with internal scalloping (Appendix III, p.128). The shaded relief imagery from the multibeam data show a clear scour that is quite regular in width and depth (Figure 19) (Appendix III, p. 128). The scalloping noted in the side scan records appears as faint cross-cutting ridges that likely represent changes in the iceberg contact with the seafloor (Appendix III, p. 128). A portion of the 00-68 furrow was investigated using the ROV (Appendix III, p. 128 and Appendix VI, Part E). Surface profiles were produced from the multibeam data in this area to measure widths and depths of the disturbance (Appendix IV). The furrow has an average berm height of 0.3 m and an average crest to crest width of 48 m (Table 4) (Appendix IV). The scour furrow has an average depth of 0.5 m and an average incision width of 30 m (Table 4) (Appendix IV).



**Figure 16:** Shaded relief map of multibeam bathymetry over the scour of unknown age.

### Biological and sedimentological observations

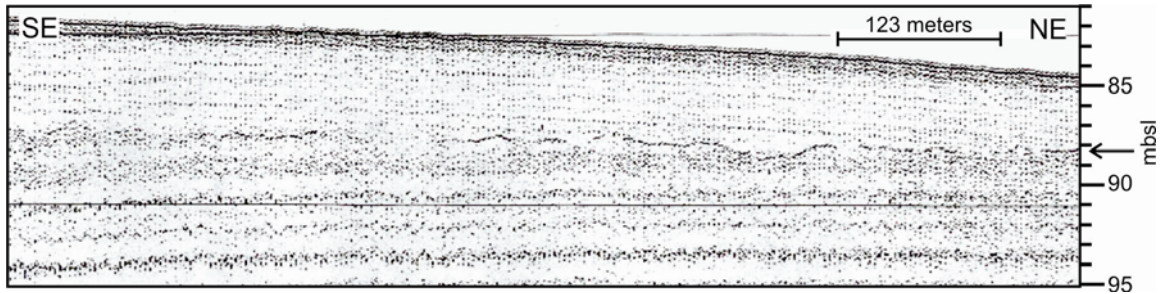
The seabed is composed of coarse-grained shelly gravel (Appendix VI, Figure E1). The trough also contains this substrate (Appendix VI, Figure E2) but also contains areas of coarse-grained sand with megaripples (Appendix VI, Figure E6). This finer surficial sand likely represents deposition in the low of the scour by sediment transport across the bank. The observed biological community supported a variety of motile scavengers including crustaceans, mollusks, and annelids. The most obvious attached organisms were the stalked tunicates which were not seen at the other iceberg scours (Appendix VI, Figure E1). The seabed in this area is similar to that found off Eastern Shoals of Newfoundland, where there is a widespread encrusting community that comprises hydroids, bryozoans, sponges, stalked tunicates (*Boltenia ovifera*), anemones and coralline encrusting algae –(*Lithothamnium* sp) (Lawrence et al. 1987).

The berm top was characterized by boulders mixed with gravel (Appendix VI, Figure E4-E5 & E7-E9). The boulders were densely colonized by the same biota as the surrounding seafloor, including the stalked tunicates (Appendix VI, Figure E4, and E7 to E9). Some of the boulders were so densely colonized it was impossible to tell if it was one large stone or a pile of small stones. Main identifiable colonizing organisms included more than one species of anemone, a variety of low growing sponges, starfish, crabs, barnacles, brittle stars, stalked tunicates, hydroids, bryozoans coralline algae *Lithothamniu*, and likely the motile scavenging fauna (e.g. shrimp, gastropods and annelids). The boulder piles in the trough were completely encrusted with similar organisms (Appendix VI, Figure E10-E12). Overall, the diversity and degree of colonization of this scour was generally not seen at any of the other sites (e.g. stalked tunicate).

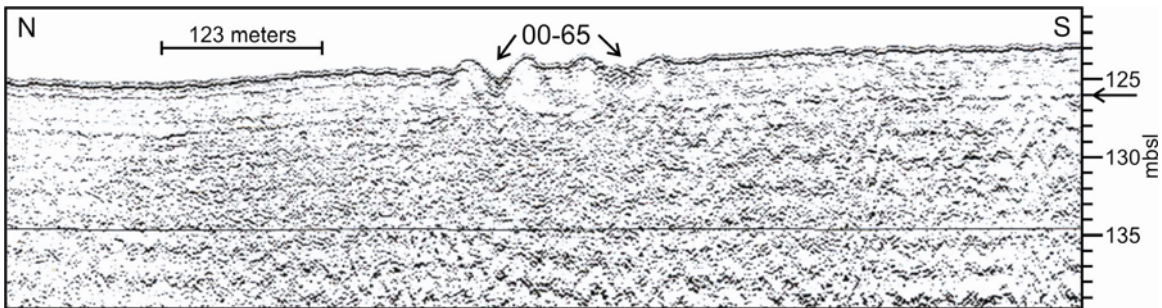
#### **5.4 Seabed morphology and subsurface geology**

Huntec profiles produced from the 2001 survey provide some insight into seabed morphology, cross sectional view of the scours and near-surface geology. In general, profiles showed a strong seabed reflection below which is an acoustic package characterized by weak discontinuous reflectors that are interpreted as sand. This package overlies a poorly

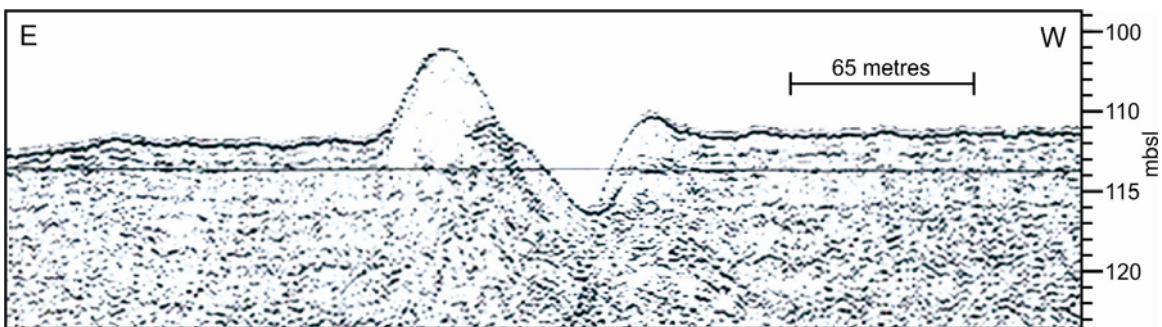
resolved acoustic package of stronger discontinuous reflectors with an irregular upper surface. Where the overlying sand drape is thin this irregularity may be expressed at the seafloor. The groundings of 2000 did not penetrate the irregular surface and scouring was confined to the overlying sand drape (Figures 17 and 18). Scour 89-01 appears to have scoured past the irregular surface (Figure 19) and in ROV images there appears to be outcrops of muddy diamicton in the walls of the inner berm (Appendix V, Figures 11-21).



**Figure 17:** Hunttec DTS profile near the 83-95 scour provides an example of the weak discontinuous reflectors of the sand drape that overlies an irregular surface, noted by the arrow at about 88 meters below sea level (mbsl).



**Figure 18:** Hunttec DTS profile over the terminal end of scour 00-65. There are two scours in this cross section as a result of the iceberg looping back east before grounding (Figure 8). The irregular surface is noted by the arrow at about 126 mbsl.



**Figure 19:** Hunttec DTS profile through scour 89-01. The irregular sub-surface is located at 116 mbsl.

## 5.5 Grain size

Grain size analyses were performed on sub-samples taken from the IKU grabs. IKU grabs were not collected in all grounding locations for either operational reasons or because of existing samples in the area. The results of the analyses show that the sediment is composed principally of medium to coarse sand with some minor components of fine to medium gravel and mud (silt and clay) (Table 7 and Figure 20) (Appendix V). Scour sites 00-32 and 00-67 were the coarsest areas, composed of a high proportion of coarse sand and fine gravel (Table 7 and Figure 20) (Appendix V), whereas, 00-18 and 89-01 are the finest grained samples, with 00-65 falling in between these two sets (Figure 20).

**Table 7:** Summary of grain size analyses.

|                     | 00-18 | 00-32 | 00-65 | 00-67 | 89-01 | 88-01 | 83-95 |
|---------------------|-------|-------|-------|-------|-------|-------|-------|
| % Gravel            | 0.06  | 4.27  | 2.82  | 4.38  | 0.46  | 3.12  | 7.59  |
| % Sand              | 98.33 | 94.36 | 96.44 | 95.32 | 98.21 | 95.88 | 92.19 |
| % Mud*              | 1.61  | 1.37  | 0.75  | 0.29  | 1.33  | 1     | 0.22  |
| Mean                | 1.82  | 1.69  | 1.33  | 0.62  | 2.06  | 1.68  | 0.75  |
| Dev.                | 0.80  | 1.31  | 1.03  | 0.86  | 0.89  | 1.17  | 1.2   |
| Kurt.               | 41.31 | 11.33 | 19.36 | 19.21 | 28.84 | 16.86 | 10.08 |
| Skew.               | 5.24  | 0.25  | 0.50  | 0.92  | 3.22  | -0.41 | -1.7  |
| * Mud = Silt + Clay |       |       |       |       |       |       |       |
| Lab no.             | 13151 | 13152 | 13153 | 13154 | 13155 | 5140  | 5138  |

## 6 DISCUSSION:

The use of industry iceberg tracking databases to locate iceberg groundings and the resulting seabed damage proved successful, although several shortcomings are worthy of noting:

1. Frequent observations and measurements of iceberg positions are required to confirm the direction of scouring or any changes in iceberg behaviour (i.e. rolling, tilting, turning, etc) especially when grounding has been reported.
2. A comparison of scour water depths to reported estimates of iceberg draft showed significant variability. Draft estimates based on water line length were off by as much as 70% in the case of Berg 00-18 (Table 3). There is also some concern regarding the accuracy of side scan measurements of berg draft. There was often a lag of several days between the measurement of draft and



**Figure 20:** Gravel, sand and mud diagram of grain size analyses from the IKU grab samples.

the subsequent grounding, so significant draft adjustments may have occurred due to iceberg calving or rolling. More should be done to confirm the accuracy of draft measurement techniques, particularly if they are part of the decision to manage an iceberg or not (i.e., draft considered insufficient to impact subsea facilities).

3. In the case of bergs 00-21, 00-32 and 00-67 (Table 3) the measured drafts, while conservative, differed from the grounding site water depth. Additionally, the investigated groundings had a higher proportion of pits to furrows than would be expected. If more and better draft measurements were made, the bias towards identifying pits would diminish.
4. Shipboard observations do not readily distinguish a keel-dragging iceberg (furrows) but can isolate groundings based on the lack of iceberg drift.

Notwithstanding the above, side scan sonar continues to be an effective reconnaissance tool, capable of resolving relatively small pits and shallow furrows (e.g. 00-09, Appendix III,

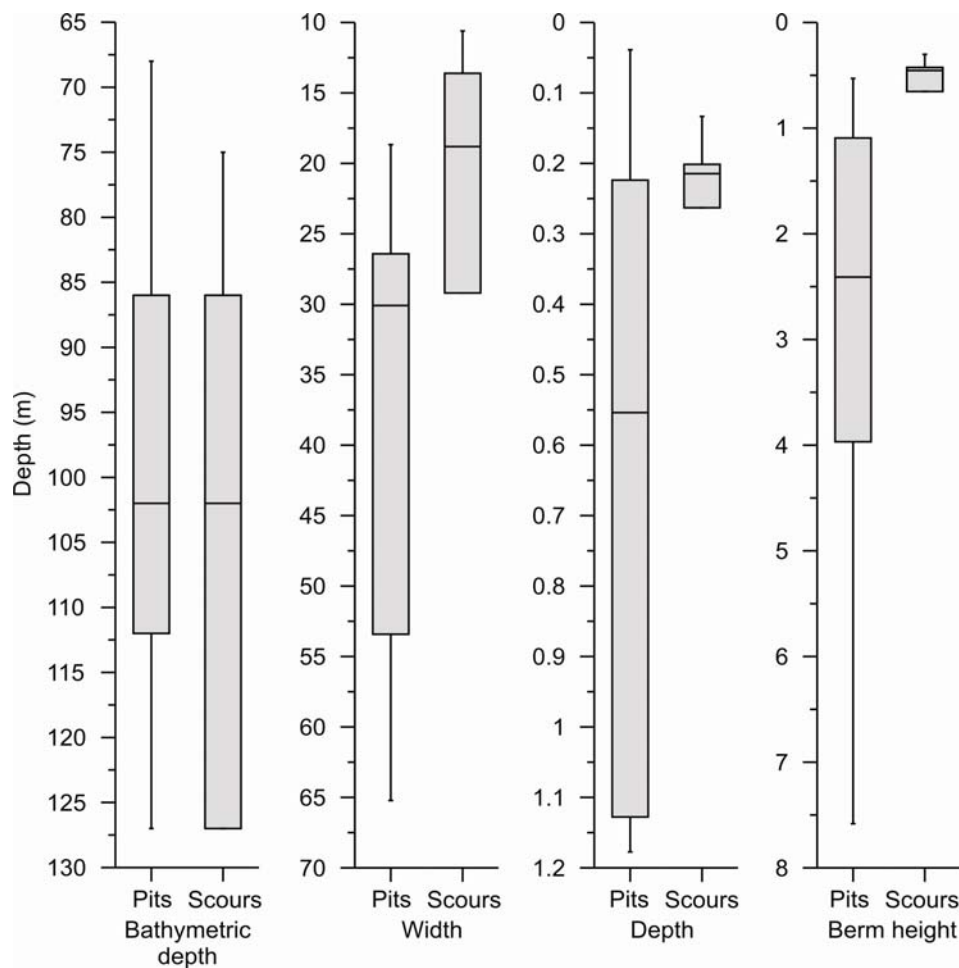
Figure 1). Multibeam bathymetry surveys are essential for detailed scour documentation and scour metrics. However, accuracy and repeatability must be better quantified. To accurately measure depths of Grand Bank furrows less than 1 m deep in shelf water depths requires careful data collection and rigorous post-processing. The industrial ROV allowed for precise manoeuvring around the disturbances and allowed for detailed filming and sampling. The visual record of the new and old seabed scours provides an excellent benchmark to study the rates and processes of scour degradation and biological re-colonization. In future, higher resolution videography and still photography should be specified.

Three of nine icebergs were reported as under tow when they grounded- icebergs 00-09, 00-21, and possibly 00-44. None remained under tow while aground. The seabed features resulting from 00-09 (a small pit and furrow with no discernable depth on multibeam; Figure 4) and 00-21 (2 small, isolated pits; Figure 6) were below average in size, despite some evidence iceberg velocities were increased during the tow. It is possible that the forces associated with towing the iceberg aground were reduced, but there is insufficient information in these data. Regardless, while many of the bergs were towed for portions of their monitored drift, none were towed while grounded so the seabed features are considered representative of icebergs under free drift.

## **6.1 Scour Characteristics**

Factors governing the severity of the seabed damage by iceberg keel impacts include iceberg size, water depth, momentum, grounding duration and surficial geology. Iceberg impacts on Grand Bank typically produce shallow furrows considering the size and momentum of the icebergs. This is likely largely a result of the hard overconsolidated seabed sediments and partly because of the ability of the iceberg to shed load by tilting on its centre of buoyancy and thus decreasing keel contact with the seabed. The new scours of 2000 are of no exception, with an overall furrow depth of 0.5 m and an average pit depth of 2.7 m (Tables 4 and 5). Furrow widths average 30.5 m with an average berm height of 0.2 m, whereas the pits have an average width of 50 m with an average berm height of 0.6 m. These scour metrics are compatible with those of the GBSC-2004 (Campbell et al., in press) (Appendix VII). There is a difference between the furrow and the pit dimensions. Firstly, pits are larger

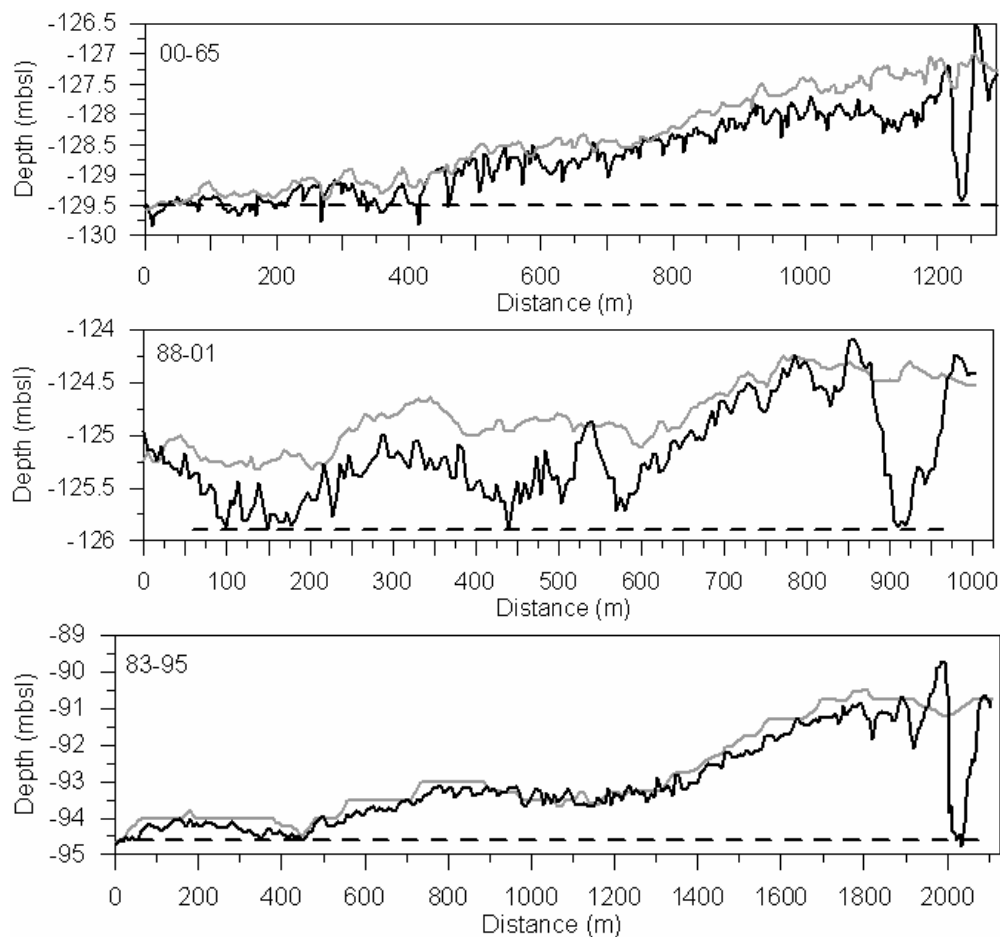
then the furrows (Tables 4 and 5; Figure 21). Secondly, the range of pit size is much broader than that of the furrows (Tables 4 and 5; Figure 21). Pits range from 0.5 – 7.6 m in depth, a range of 7 m, whereas, furrow depths are much shallower, ranging from 0.3 – 0.7 m, a difference of only 0.4 m (Tables 4 and 5; Figure 21). The same observation is made for widths and heights of the furrows and pits (Tables 4 and 5; Figure 21). The contrast between pit and furrow morphology results of the ability or inability of the seafloor sediments to fail during a keel dragging iceberg and a stationary iceberg.



**Figure 21:** Bar and whisker plots showing the concentration and extent of the pit and furrow metric for the 2000 grounding season.

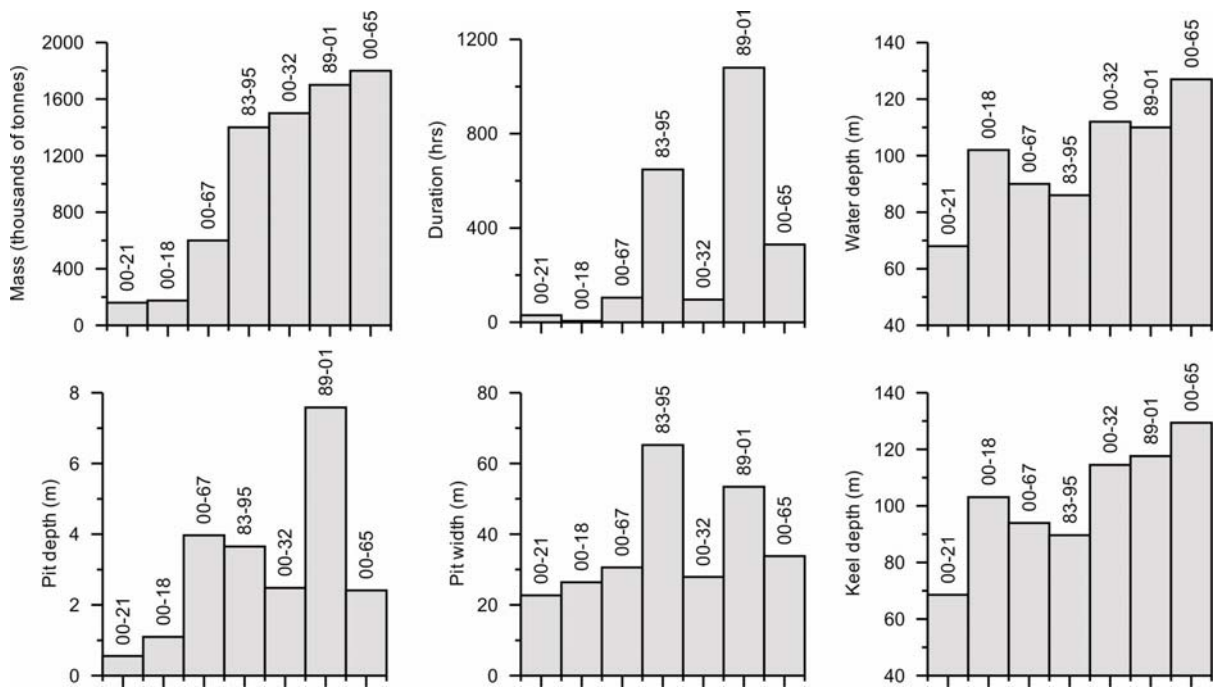
Pits are larger and vary more in their observed size and depths because the stationary iceberg increases the bearing capacity from the iceberg to the seafloor sediments allowing further sediment failure. As well pits are further excavated over the grounding duration due to tidal wave and oceanographic forces. These factors allow pit depths to reach that of the keel or greater (Figures 22). This also widens and heightens the pit features. The overall result is a broad range of pit sizes that reflect the size and depth of the iceberg and its grounding duration (Figure 23).

However, there are some exceptions; scours 00-18 and 00-67 have large disturbances that were produced by relatively small icebergs within a short duration of time (figures 5, 9 and 23). Additionally, 00-21 was towed parallel to the icebergs drift thereby increasing the



**Figure 22:** Plots comparing seafloor depth (grey) to scour depth (black) of three scours. Note that the pit (at the right) is the same depth as the start of the scour.

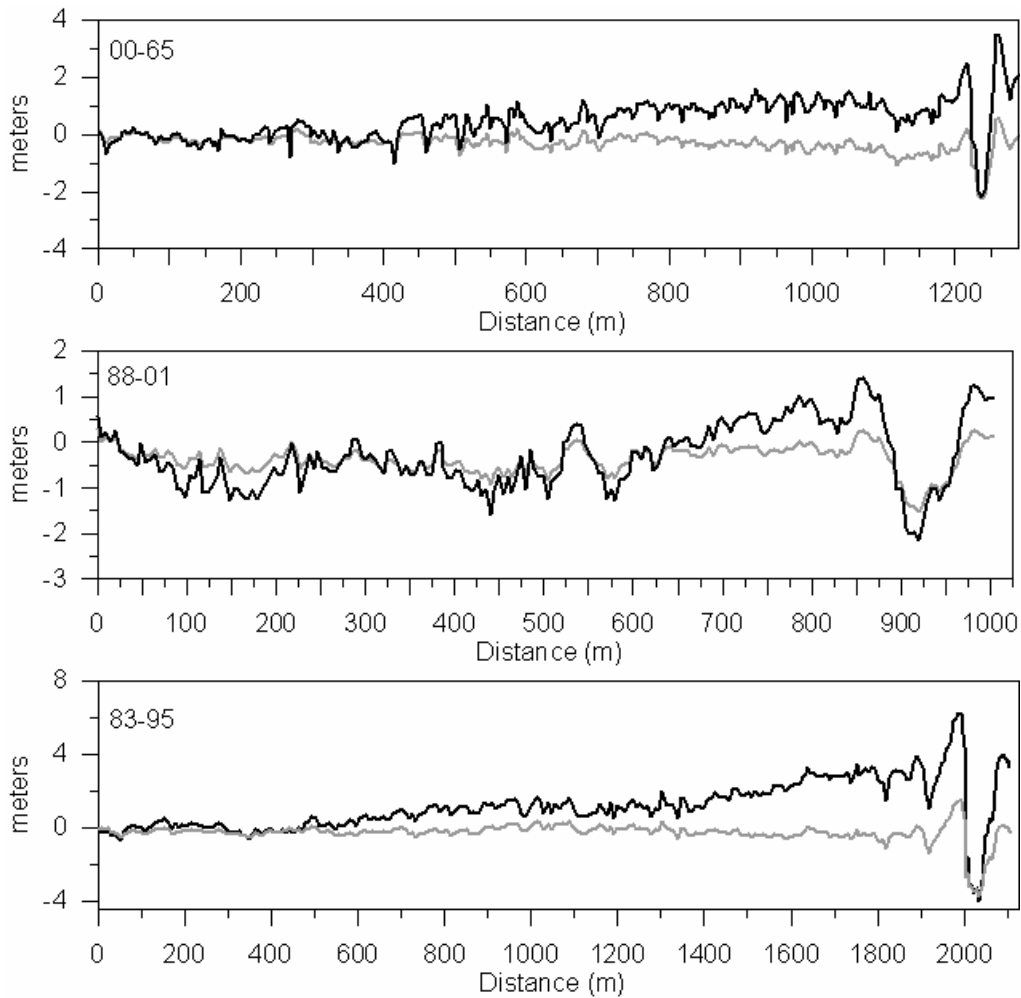




**Figure 23:** Bar plots comparing iceberg characteristics with that of the pit metrics. Note that due to limited information on iceberg drafts keel depth is the sum of water depth and pit depth.

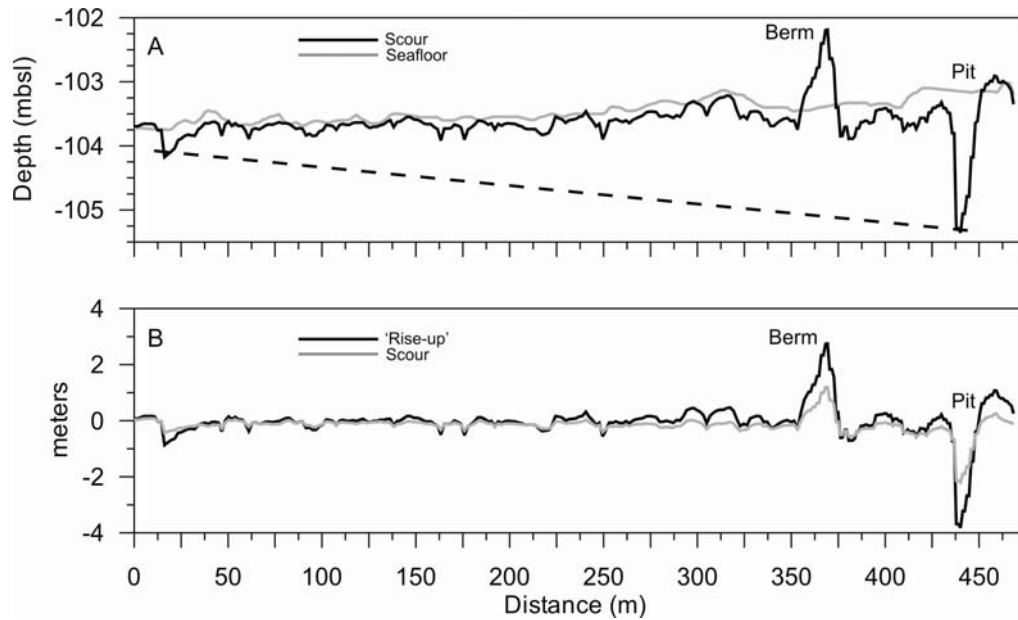
velocity of the iceberg just before impact (Appendix II). Although 00-21 was of similar size and had a longer grounding duration than 00-18 (Figure 23), the 00-21 seafloor disturbance was smaller than at 00-18 (Figure 6), suggesting the increased grounding velocity had little influence on the size of the scour.

Furrow widths and depths vary little because of the seafloor sediments resistance to fail beyond these depths while the iceberg is drifting. Once this threshold is reached any further bathymetric rise appears to be compensated for by the iceberg. This may be rolling, titling, rising up, ice failure, or ultimately grounding. The first three have generally been termed ‘rise-up’. ‘Rise-up’ can be calculated through analysis of the high density soundings from the multibeam data (Figure 24). Broadly, ‘rise-up’ is the compensation of the iceberg to a bathymetric rise rather than an associated increase in scour depth. It is believed the iceberg rotates on its center of buoyancy in order to shed load imposed by the seabed once a certain critical drag force with the seabed is achieved. Figure 24 shows the degree to which



**Figure 24:** Plots of three scours showing scour depth (grey) relative to seafloor (0 on the y-axis) and the ‘rise-up’ (black) effect from a bathymetric rise.

the 00-65, 88-01 and 83-95 icebergs had to ‘rise-up’ to accommodate the shoaling seafloor. The fourth, scour 00-18, shows little ‘rise-up’ or over-deepening of the furrow with bathymetric rise (Figure 25). This is puzzling because although it has a much smaller mass than the other three icebergs it has a fairly deep keel based on the size of the terminal pit (Figure 23). Clearly, more detailed observation of iceberg behaviour while scouring and of the keel dimensions is needed to make specific interpretations regarding ‘rise-up’ but it is clear that it has important implications for ice scour risk models and needs further investigation.



**Figure 25:** A) Comparative plot of scour to seafloor for scour 00-18. B) Comparative plot of scour depth to 'rise-up'.

## 6.2 Dating scours

The ability to date scours on the Grand Bank is key to a good understanding of the overall iceberg grounding regime and scour frequency and essential to determining past variations in iceberg density, iceberg drift and iceberg draft. Models of climate change and sea level variations can be used to constrain the onset of scouring activity on the Grand Bank and to estimate some broad changes in iceberg flux. Based on sea level rise in the early Holocene, Barrie et al. (1984) propose a maximum date of 12,000 years B.P. for the onset of scouring in less than 110 metres water. The intensification of the cold Labrador Current in the mid-Holocene would have allowed more icebergs to be delivered to Grand Bank. Climate studies results suggest that the intensification occurred between 5000 and 2500 B.P. (Scott et al., 1984; Lewis and Parrot, 1987). Furthermore, recent studies suggest a 500-1000 year climatic variations in the North Atlantic region may have occurred throughout much of the Holocene (Scott and Medioli, 1995, Chapman and Shackleton, 2000). The influence these variations had on the iceberg flux and hence ice scour impact rates on the Grand Bank is not known. To establish more detailed timelines for select scour populations or individual scours more precise dating is needed.

Establishing the age of individual scours is problematic. Most of the conventional dating methods have either not been adequately employed or are not appropriate. A literature review revealed very limited work in the field of absolute dating iceberg scours. Regional studies have been used to constrain the age of scour populations (Lewis et al., 1987) and palynology or radiocarbon dating methods have been used to constrain the age of older scours in depositional areas (Mudie, 1986; Lien, 1983). Other established Quaternary dating methods such as U-Series radiometric dating and luminescence dating have not been applied to dating ice scours on the Grand Bank or even on similar seabed disturbances in environments analogous to the Grand Bank. There has been some success in the Beaufort Sea and high arctic in dating recent scour ages to within several years. This has been done by observing cross-cutting and overlapping relationships of scours through repetitive mapping with side scan sonar (Myers et al., 1996, Blasco et al. 2000). However, results of repetitive mapping investigations on the Grand Bank have been not successful due to the relatively low scour impact rates in the region. Recent and ongoing work in the Canadian high arctic by the GSC and others show promising results in dating ice scours by documenting the rates of physical degradation and biological colonization (Conlan et al. 1998; Blasco et al. 2000). The theory states the ice scours are subject to physical, biological and, to a lesser extent, chemical degradation processes, and the rate of scour degradation is primarily dependant on the type of scoured substrate and the hydrodynamic environment. The degree of degradation is proportional to the scours age but will vary with differing substrates and hydrodynamic environments. For example scours formed in fine-grained non-cohesive sediments in a high-energy environment may be completely obliterated within a matter of years as physical degradation is very fast (Barnes et al., 1984; Myers et al., 1996). Conversely, scours formed in low energy environments may persist as recognizable features for thousands or tens of thousands of years (King 1976; Piper and Periera, 1992; Blasco et al. 1998). Likewise, rates of biological colonization differ with varying substrate and hydrodynamic conditions (Pocklington, 1987)

### **6.2.2** *Physical degradation*

The available repetitive side scan sonar data and submersible observations indicate that degradation rates on the Grand Bank are slow with little modification to scour morphology.

Yet overall side scan sonar records display a range of acoustic morphologies suggesting that the Grand Bank scour population is in various stages of degradation and represents a scour population that has accumulated over considerable time. There are well-defined morphologies typical of more recent scours and poorly defined morphologies characteristic of older severely degraded scours (Myers et al., 1995; Croasdale and Associates, 2000). Moreover, studies of scour densities show that densities are significantly higher (up to 30 times) in gravel substrates versus sandy ones (Lewis and Barrie, 1981). This suggests that a number of scours within the sandy areas have been degraded beyond recognition, and that the residency time for scours in sands is less than that for scours formed in gravels. Furthermore, long shelf transport of sand by oceanographic currents appears to be the principal influence of scour infilling. Sediment transport is highest in the winter months with major storms having the biggest impact. However, the rate of scour degradation (and corresponding residency time a scour remains a recognizable feature on sidescan or multibeam) is not known for the Grand Bank environment and likely highly variable.

The scours of 2000 were composed mostly of medium to coarse sand with minor amounts of gravel similar to the surrounding seafloor material (Appendix IV and V). There was no indication from the ROV video or from seismic profiles that the 2000 season icebergs penetrated through to the underlying till (Figure 18). However, it looks as though scour 89-01 did (Figure 19) and ROV footage shows a poorly sorted diamicton outcropping from the inner berm (Appendix VI; Part E). The pit depth supports the likelihood that the till was penetrated (Table 5).

From visual, sidescan and multibeam data, there is evidence for increasing degradation with time for the surveyed scours. The 2000 season scours appear fresh (sharp berm and trough boundaries, distinct shadows signifying berm and trough relief, lack of sediment infill, good continuity of feature) with no apparent physical modification to the berms and troughs. There is no visual evidence of significant winnowing of fines by currents or waves (Appendix VI; Part A and D). There are some concentrated patches of shell hash in the troughs but these are interpreted to have formed during the grounding event through keel interaction with the seabed (Appendix VI; Part A and D).

There is minor evidence of physical degradation in the three older but dated scours, notably winnowing of finer material from around the base of boulders on the berms (Appendix VI, Figures F13 and F16). Sizes of shell beds have increased, presumably through hydrodynamic sorting of the lighter shell material during significant storm events when waves interact with the seabed (Appendix VI; Part F-H).

The scour of unknown age (00-68) shows the highest degree of physical degradation. Physically the scour was difficult to separate from the surrounding seafloor. The low berms were composed of a boulder cobble with very little occurrence of gravels and sands similar to the surrounding seabed (e.g. Appendix VI; Figures E1 and E11). Within the trough there is scour infilling by coarse sand that form mega-ripples (Appendix VI; Figures E3, E5 and E6). While current features such as ripples or hummock were noted occasionally on the surrounding seafloor at other scour sites (Appendix VI; Part A and D), 00-68 was the only scour to have the bedforms within the scour (Appendix VI; Part E).

Overall, the low energy environment of the Grand Bank lends its self to slow physical degradation of these features. This makes it difficult to estimate scour age based on the degree of physical change and may only prove useful for very old scour features. However, because these features are relatively stable they provide little interruption to the biological colonization of the disturbance.

### **6.2.3** *The biological colonization*

Understanding the rate and processes of biological colonization of scours on the Grand Bank may make it possible to estimate the age of an individual scour. Biological colonization of the benthic community within scours takes time and eventually approaches a state of equilibrium in which the benthic community within the scoured area mirrors that of the surrounding seafloor. The rate at which this occurs is dependent on several factors including the pre-scour benthic community, the sediment or substrate type, and the hydrodynamic conditions at the scour site. In broad terms, efforts to date scours using biological methods can be broken down into two primary categories; the rate of infauna and epifauna community assemblage re-colonization and the growth rate of individual sessile, encrusting, and colonizing species.

The ROV video footage of the scour was very helpful in the investigation of the biological colonization of the scours. Pocklington (1987) investigated scours on the Labrador shelf and Grand Bank suggesting that colonization of the scour disturbance occurred as a series of successions similar to that which occurs at bait drops (Smith 1985). Recent studies of seafloor disturbances by trawls across the Grand Bank have similar findings (Prena et al. 1999). The succession indicates the first to arrive are the highly mobile scavengers, followed by less mobile organism and finally the establishment of more permanent benthic epifauna and infaunal forms. Thus, an early phase of colonization would be dominated by mobile organisms with very few attached or burrowing organisms. The phase would contrast to the surrounding undisturbed areas that would host a mature biological community. The later phase of colonization would see the establishment of the slowly colonizing epifauna and infauna species. This phase would start to match the surrounding seafloor. The ROV survey of the scours showed distinct differences from the scours of 2000 to the older scours. Likewise the 12 and 13 year-old scours (89-01 and 88-01 respectively) could also be distinguished from older scours (83-95 and scour of unknown age (00-68). These differences support succession of colonization.

The scours formed in 2000 had little biological colonization in comparison to the surrounding seafloor. The seafloor surrounding the scours typically had a large infaunal community. The surface hosts numerous sand dollars and starfish and some small sea anemones. Dropstones were covered with encrusting and attaching species. Within the scours the species were typically those of mobile scavengers and characterise an early phase succession. These mobile scavengers included crabs (snow and toad), echinoderms (sand dollars, brittle stars, sea urchins or basket stars) carnivorous gastropods, and rare detachable attached forms of sea anemones (Appendix VI).

There was some indication of the initiation of an infaunal community by the rare occurrence of small mounds, holes, and tubes but, not to the degree as observed on the surrounding seabed. Studies of recovery after trawler damage to the seafloor suggests that the infaunal community on the Grand Bank can re-establish itself within a year (Gordon et al. 2002). Observations of the 2000 scours suggest that these larger impacts with deeper incision depths

require longer than one year to return to pre-impact levels. In contrast to the dropstones on the seafloor, dropstones within the furrows and pits were absent of any benthic epifauna colonization, further, indication of the young age of these disturbances.

Observation on the scours of 12 and 13 years old (89-01 & 88-01 respectively) showed several differences suggestive of the establishment of a later secession. Although there still are mobile scavengers there is also an infaunal and epifaunal community that is starting to equal that of the surrounding seafloor population. The sandy areas of the furrows and pits showed evidence of burrows, mounds and sand lances darting out of the seafloor, suggesting an established infauna. Dropstone or boulder lags were covered with a number of attaching species. These commonly include encrusting sponges, tall soft sponges and large basket stars. The proportions and diversity species present in these scours indicate a more established phase of colonization.

Scours 88-01 and 89-01 were investigated by ROV in 1990 (Cameron and Sonnichsen, 1992). Their findings showed similar low bio-diversity for the 1- and 2-year old scours as seen on the recent 2000 season scours in the ROV dives performed during 2001. This comparison provides confirmation of the biological colonization over initial years and provides some baseline as to what is expected of these newer scours. Also noted at 89-01 was a cable from a failed attempt to tow the iceberg (Appendix VI, Figure H20 and H21). This cable was observed the in 1990 ROV dives (Cameron and Sonnichsen, 1992; Figure 3F). Comparison of 1990 footage to the 2000 video shows more concentrated growth in 2000 (Appendix VI, H20 and 21). Furthermore, the cable provided a good reference point to compare and overlap the two surveys and is recommended as a good feature to look for in future surveys.

A tall white organism was observed on boulders in some of the images by Cameron and Sonnichsen (1992) of scour 89-01 and in this study of scour 00-32 (Their figures 3A and 3E) (This report Appendix VI, Figure B6). This is odd as both of these scours are only one year old at the time and show no significant biological population apart from these organisms. The organisms are seemingly too large for such recent disturbances and therefore beg the question why are they there. These organisms may possibly be sponges (possibly *Haliclona*



*urceolus*) in which case they are too large to have grown in just one year (Kostylev, pers. comm. 2005) and they would have had to survive through the scouring. This is supported by one case in which a tall sponge was noted growing out of the side of a boulder on the inner berm of scour 89-01 suggesting that the boulder was displaced but the sponge continued to grow upwards by making a 90 degree turn (Appendix VI; Figures H13 and 14). Alternatively, and more likely, these are soft bodied sea anemones, likely *Alcyonium* that can grow quickly (Kostylev, pers. comm. 2005). The raised berms provide added height advantage for filter feeding and therefore these organisms likely quickly occupied this niche. However, it is still curious that there so few, so large.

Scour 83-95 is still clearly visible on the seafloor but it shows its 18 year age with a highly developed biological community which includes several species of anemones, sponges, bivalves, gastropods, bryozoans, and tunicates, as well as sea stars, basket stars, crabs and even large fish such as eel pout. In addition, smaller creatures such as annelids, crustaceans and hydroids were noted. This diverse and dynamic population matches the surrounding seafloor and would be considered a mature ecosystem that has fully colonized the disturbed area.

00-68 hosts a very mature ecological community, similar to 83-95. Both were a cobble rich substrate that was densely colonized by a mature benthic community. Although, the 83-95 scour site is well colonized and showed a much more diverse biological community than the younger scours, it did not have the degree of colonization as the scour of unknown age (00-68). At 00-68, recognizable organisms completely covered the cobbly seabed and scour included the highly conspicuous, purple *Lithothamnium* sp., a variety of different sponges, hydroids, anemones and stalked tunicate. Some of the largest boulders were completely covered with the encrusting coralline algae *Lithothamnium* sp. One of the larger patches was estimated to be approximately 60 cm in diameter. Based upon the estimate of Conlan et al. (1998) that *Lithothamnium* sp. grows at about 1mm per year, it would have taken 600 years to achieve this degree of coverage. This provides an estimated age that this boulder has at the seafloor surface for 600 years and could indicate that this scour may also be this old. Also noted were a range of bryozoans, some of which grow as a gelatinous layer over firm surfaces while others have upright, branching or arborescent aspects. Bryozoans have a very

short larval stage, it is thought that this functions merely to increase colonization through substrate selection, and is not useful as a means of dispersal. The dense colonies of bryozoans found on the scour are most likely a function of the substrate. In peaking communities of undisturbed environments bryozoan colonies can grow 10's of centimetres, and assume a wide variety of forms. The erect, arborescent forms visible on the large rocks indicate a very large colony (Appendix VI, Part E), and, as noted by Ryland (1965), colony size is proportional to colony age.

The comparison of scours in sandy substrates to 00-68 may not be appropriate. At the latter site, the presence of the boulder lag provides substrate for dense colonies of attached organisms, and thus an opportunity for colonizing propagules. This is not the case for the sandy seabed, as only glacial erratic dropstones encountered in undisturbed seabed or in the older scours were densely colonized. On the sandy seabed, the best indicator of community development is thought to be the infauna community. Although studies suggests that the infaunal community can achieve diversity of major faunal groups in short periods of time (Lee Hee et al. 2001), as well as little long term effects from trawling (Kenchington et al. 2001), the recent 2000 season scours host only a small infauna population with low diversity. In contrast the older scours exhibited a much larger infauna community reaching levels similar to that of the surrounding seafloor.

Despite differences in substrate between 83-95 and 00-68 the overall findings support a succession of biological development. The initial occupying species are the mobile opportunists. The more mobile of these such as crabs and fish would arrive very quickly and the slower echinoderms and gastropods would make their way into the scours over a longer period of time. This can take upwards of a year as is suggested by the drastic difference in the number of sand dollars on the seafloor surrounding the one year old scours to the number within (Appendix VI; Figures A1 and A10). Even the outer berms had higher numbers and appeared to pushing their way up the berm (e.g. Appendix VI, Figure D4). The later succession is colonization of infaunal and epifaunal species. This occurs over many years and begins to reach population levels that match the surrounding seafloor by 12 years (e.g. Appendix VI; Figure H3). The latest phase of colonization is noted in the 18 year old scour

83-95 by the higher numbers and overall diversity of species. Here time has allowed for the population to become well established as well as allowing for slower growing species to mature. This degree of colonization is only noted in this scour and in the scour of unknown age suggesting at least 18 years is needed to reach this population size and diversity.

Overall the range of scours shows a succession of biological development. This in turn may be used to generate a classification scheme that allows for the estimation ages for recent scours of unknown ages. The one year old scours host very low infaunal numbers and boulders are generally absent of any epifaunal species. These scours represent the start of colonization and would characterize scours of 0-2 years of age (Table 9). The scours of 12 and 13 years (89-01 and 88-01) are much more developed and show more bio-diversity with a number of varying benthic epifaunal and infaunal species beginning to match the surrounding seafloor in diversity but not necessarily in maturity. This degree of biological colonization represents scours of 10-15 years of age. Scours with development less than this

**Table 8:** Age classification for recent scours of unknown age.

| Scour   | Scour age | Biological development                                                                                         | Age class |
|---------|-----------|----------------------------------------------------------------------------------------------------------------|-----------|
| 00-18   | 1         | Little to no benthic development                                                                               | 0-2       |
| 00-32   | 1         |                                                                                                                |           |
| 00-65   | 1         |                                                                                                                |           |
| 00-67   | 1         |                                                                                                                |           |
| No data |           | For scours with slightly more development than age class 0-1                                                   | 2-5       |
| No data |           | For scours with slightly less development than age class 10-15                                                 | 5-10      |
| 89-01   | 12        | Diverse benthic population mostly of faster growing species with slower ones still to reach mature proportions | 10-15     |
| 88-01   | 13        |                                                                                                                |           |
| 83-95   | 18        | Diverse benthic population with most species reaching mature sizes.                                            | 15-20     |
| 00-68   | ?         | Very diverse population with all species reaching mature size.                                                 | 20+       |

would fall into two age categories; these with a slight more biological development than the 0-2 year olds would be considered between 2 and 5 years of age. Those with slightly less development than the 10-15 year old scours would have an approximate age of 5-10 years. The scour of 18 years old (83-95) had a slightly more diverse population than the 12 and 13 year old scours, yet was more established and matured. This scour represents biological

colonization characteristic of a scour 15-20 years of age. The scour of unknown age is very different sedimentologically and thus hosted some different species, possible the stalked tunicates which are not observed at any of the other sites. (Appendix VI, Part E). Despite this difference the scour clearly hosts a very diverse population that made it hard to determine when the ROV was in the scour or on the surrounding seafloor. The boulder collected at the site (Appendix VI, Figure E13) show a wide range of species many of which take some time reach these proportions. Based upon these observations this scour would be classified as older than 20 years. Although this classification is based on only a small number scours it provides the start to a useful tool in estimating recent scour ages (i.e. under 20 years old). Because scours older then 20 years appear to achieve the same biological diversity and maturity as the surrounding seafloor, age estimation will have to be based on known growth rates of early colonizers.

Past attempts to establish ages from species growth rates has been difficult due to lack of information on rates of growth in various regions. For example Pocklington (1987) noted visible sponge encrustation on a six-year-old scour on the Labrador Shelf but could not provide age estimates to scours of unknown ages in the area due to insufficient information on the growth rates of encrusting and colonial organisms. However, new research is starting to emerge that will allow age estimation for individual species that colonize soon after scour formation and leave a record of growth. For some species, the age of individual organisms can be determined directly by analyzing growth patterns in a manner analogous to counting the annual growth rings on trees. For species without annual growth patterns, the size of individual organisms or colonies can be used to estimate age. Growth rates and mature population ages are reported for several sessile organisms in various environments. For example:

- *Mya truncate*, a bivalve commonly called Blunt Gapper, in arctic reach maturity at approx. 50 years (Welch, 1992)
- *Arctica islandica* (ocean quahog) have annual growth rings and may reach ages in excess of 200 years (Kraus and Beal, 1989; Witbaard, 1997)
- Barnicales have annual growth rings (Kostylev, pers comm. 2005).
- *Lithothamnion* sp. (coralline algae) encrusting cobbles on scour berms have a growth rate of approximately 1mm per year (Conlan et al, 1998)

- Some deep-water coral species display growth lines, with radial and linear growth rates of <0.1 to 1mm/yr and 2 to 20mm/yr, respectively (Mortensen and Rapp, 1998; Risk et al., 2000; Davies et al., 2000).

The growth rate information is starting to be applied to understanding the life cycle of benthic communities. Studies off northeastern Greenland suggest that mature benthic communities would be established in approximately 50 years (Gutt et al. 1996). However, recent studies of colonization of scours in the Canadian high arctic suggest that the scours had achieved 65 to 84% colonization by 8 to 9 years of age (Conlan and Kvitek, 2005). To expand the dating of scours on the Grand Bank through rates of biological colonization more detailed studies specific to the region are needed.

## **7 CONCLUSIONS:**

The 2000 iceberg season provided an opportunity to study the effect of iceberg scouring on the Grand Bank. Surveys of the grounding sites in 2001 and 2002 successfully documented the shape and character of six iceberg scours from 2000 and re-surveyed three previously studied scours and an undocumented scour of unknown age. The outcome of the investigation concludes several important items.

1. The analysis of industry iceberg tracking data is a useful method of identifying icebergs that have grounded on the seabed. However, the seabed surveys identified inaccuracies in both estimates and actual measurements of iceberg draft. These measurements need better accuracy if the full understanding of the iceberg regime on the Grand Bank is to be understood. Additionally, more frequent observations of iceberg drift as well as measurements of position and behaviour could conceivably identify icebergs that drag their keel but remain in motion. Until then seabed surveys of future reported groundings may be the most cost-effective method of validating iceberg draft measurements.

2. With careful processing multibeam sonar provide a powerful high resolution digital bathymetric data set over an entire scour and allows great flexibility and accuracy in measuring scour dimensions compared to side scan and subbottom profiles. That said, measurements made from multibeam for these scours compare well with the Grand Banks Scour Catalogue (Campbell, in press) scour measurements from sidescan and subbottom profilers.
3. Measurements showed that furrow depths varied little, averaging 0.5 m with a standard deviation of 0.3. The consistency in similar furrow depths despite changes in bathymetry or differences in iceberg size suggests:
  - a. the physical properties of the seafloor sediments limit keel gouge depth at about this depth.
  - b. the iceberg must compensate for bathymetric changes, a phenomena that has been termed 'rise-up'.
4. Accurate measurements of 'rise-up' can be made using multibeam bathymetry data. These types of measurements are important for understanding the geotechnical constraints on scouring and ultimately our understanding of iceberg scouring processes.
5. The hydrodynamic environment of the Grand Bank dictates slow physical scour degradation due to low sediment transport loads. Scour age is thus difficult to estimate based on the degree of physical change. However, because these features are relatively stable they provide little interruption to the biological colonization of the disturbance.
6. Progressive biological changes were documented to scours over 18 years. These changes showed the gradual colonization of the disturbances by infaunal and epifaunal species to levels similar and maturity to that of the surrounding seafloor.

The results were applied to an initial classification scheme to help identify recent scours of unknown age.

## **8 SUGGESTIONS AND KEY ELEMENTS FOR FUTURE WORK**

The study of iceberg scouring processes in theory sounds simple enough. However, in practice the number of variables is great. This study provides new information in an attempt to provide a better understanding of these variables. Unfortunately, as with most studies it often generates new questions that require future work. Listed below are several suggestions for future consideration as well as a table outlining some of the key elements to keep in mind for future surveys.

- 1) More and better measurements of iceberg draft would benefit research and operations. As well, more frequent and greater detail of observations to iceberg behaviour while drifting would help identify icebergs that only drag their keels on the seabed rather than becoming grounded. Likewise, careful surveying of the grounding site to see if the towed iceberg is truly grounded.
- 2) Geotechnical studies of the surficial and near surface sediments on the Grand Bank would greatly improve the issues around 'rise-up' by allowing estimates of the resistance force imposed on the iceberg by the seabed. Ideally, an investigation around scour 00-65 using a cone penetrometer would be recommended.
- 3) A detailed re-survey by ROV of the scours in this report would expand the method of dating scours by biological colonization. This study lacked information on scours of 5 or 20+ years of age. At the time of this report the scours of 2000 are now 5 years old and scour 83-95 is now 23 years old.
- 4) At the very least a desktop study detailing the growth rates of individual benthic organisms on the Grand Bank is need for further application of biological colonization as a tool to estimate scour ages.

**Table 9:** Key elements of scours in this study.

| <b>Scour</b> | <b>Water depth (m)</b> | <b>Key elements</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|--------------|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 00-18        | 102                    | Linear 400 m scour trending SSW. Terminal pit is 2.2 m deep in a sandy seafloor.                                                                                                                                                                                                                                                                                                                                                                                                                               |
| 00-32        | 112                    | Two pits, a smaller one to the west (1.6 m) and the bigger to the east (2.5 m). There is a faint lead-in furrow into the smaller one.                                                                                                                                                                                                                                                                                                                                                                          |
| 00-65        | 127                    | Curvi-linear furrow 1500 m long that trends to the SSW, before making a small loop to the east and then south before grounding. The terminal pit is 2.4 m deep. Multibeam bathymetry was used to estimate 'rise-up'.                                                                                                                                                                                                                                                                                           |
| 00-67        | 90                     | L-shaped pit 4 m deep. Close to 83-95 with similar sedimentary properties and similar pit depths making it a good comparative case study.                                                                                                                                                                                                                                                                                                                                                                      |
| 00-68        | 75                     | 4.5 km long linear furrow of unknown age. Boulder cobble substrate with mature biological growth.                                                                                                                                                                                                                                                                                                                                                                                                              |
| 88-01        | 124                    | ~ 1 km long, curvilinear furrow. Also known as the Husky scour, it has been the focus of several re-repetitive mapping surveys. Very little physical degradation but well established biological growth beginning to match the surrounding seafloor.                                                                                                                                                                                                                                                           |
| 89-01        | 110                    | A long (9 km) very shallow furrow (depth undetermined) ending in a large terminal pit (7.6 m deep). Also known as the Texaco or Springdale scour, it has also been well studied. An outcropping of muddy diamicton in the inner berm with biological growth covering boulders exposed in the diamicton. A large cable on berm noted in 1990 and 2000 ROV dives with increasing growth on it. Large boulders on the berm covered in benthic organisms, some are tall white organisms noted in 1990 and in 2000. |
| 83-95        | 86                     | Also known as Scour95, about 60 km northwest of Hibernia, it has been studied extensively over the last 20 years. Biological growth is the most mature and provides good baseline information for a 20 year old scour.                                                                                                                                                                                                                                                                                         |



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## **APPENDIX I**

Details of methods, instruments  
and settings

### **Side scan Sonar**

GSCA Expedition 2001-038 employed the Simrad 992 Side scan Sonar with the GSCA Neutrally Buoyant Package added to the same Simrad 992 tow fish (tail removed). The pulse length of the 120 kHz transmitters was set to 0.1 milliseconds. Good data were achieved at all times and no problems occurred with the system. The sonar was operated from water depths of 70 to 140 metres. All reconnaissance lines were run at 200 m per channel range with the 120 kHz data recorded to hard-copy on the Alden Model 9315 thermal printer. For detailed lines, run once the scour target had been recognized, the side scan was operated at 100 m range and the 330 kHz channels were printed. The four channels of data were also tape recorded to an AGCDig digital acquisition system and Exabyte tape drive in four channel mode. 4000 to 4096 samples per trigger time were logged from four channels at a rate of 134 to 186 microseconds depending on sonar range.

### **Huntec DTS Subbottom Profiler**

The AGC #3 Deep Tow System (DTS) was used for 2001-038. It had a maximum power output of 1000 joules. It was configured with a multi-tip sparker, an external 7 metre 24 element streamer, and an internal Geoforce hydrophone. Firing rates were either 0.750 or 1.0 seconds. Up until DAY 210/0739 hr, the DTS shot trigger was masked (1 of 3) so as to reduce interference with the sleevegun data. Overall the DTS system worked well. The sparker needed to be re-tipped about every 24 hours or else it would overheat and stop the system. The sparker source coupled with the 24 element streamer provides the best possible penetration of the shallow (0 to 50 msec) strata on the Grand Banks. There was some reduction in resolution.

### **Sleeve Gun Seismic Reflection System**

One Haliburton, 10 cubic inch sleeve gun produced the seismic source signals throughout the entire cruise 2001-038. A single, one metre diameter float, attached with a four point bridle kept the gun approximately 1m below the surface. The float provided better buoyancy to the array, keeping a more consistent depth at different ship speeds and sea conditions. Air for the sleeve guns was supplied from the Price electric compressor.



The dual channel Benthos eel was used. The eel is configured similar to the SE eel array, the principal seismic receiver for the GSC (A) for many years. The data proved to be of similar quality, and no problems were experienced throughout the cruise. An NSRF eel was deployed in parallel with the dual channel Benthos eel. Data from the three eels was amplified, recorded on the AGCDig logger, and filtered and displayed on the EPC recorders. Timing control for firing the guns, triggering the data logger and other equipment was supplied by the MITS computer. It also supplied timing control for the Hunttec system and its logger.

The equipment supplied by GSC (A) for Cruise Hudson 99-031 worked well throughout the entire program. Approximately 180 hours of seismic data were collected with no loss of data due to equipment problems. The sleeve gun array showed little wear after approx. 180 hours of towing.

### **Digital 30 kHz sounder**

Continuous depth information as recorded by the ship's hull-mounted digital 30 kHz echo sounder were logged as part of the Regulus navigation (\*.01E format) data files. The \$SDDBK string in the E format files contains depths, in feet, metres, and fathoms, from the 30 kHz echo sounder. E format files are archive with GSCA Data Section. The depth information can be extracted using the GSC program ETOA.exe.

```
ETOA <filename>.99E -d $SDDBK 3.
```

Note the \$SDDBK string records the depth below the keel so 6 m must be added to the depth readings for a true water depth.

### **IKU Grab Sampler**

Five of the grounding sites had a predominately sand rich surficial cover that was conducive for sampling with GSC's large IKU grab. As samples were retrieved on deck, 35 mm print photos were taken. Then a visual description was logged of the sediment, grain size and composition. Sub-samples were taken grain size and biostratigraphy. As well as a bulk

bagged sample was also collected for archival purposes . Finally, in several cases as sample was collected for the possible future dating by optically stimulated luminescence (OSL).

## **ROV**

Scours were dived on with a benthos open frame lightweight class ROV. The ROV was equipped with a VHS video recorder and a single mechanical arm and storage bag. Video footage was taken detailing the scours and surrounding seafloor. Also several boulders were sampled from the older sites. Video and samples were taken to study the physical and biological evolution of the scours on the Grand Bank.

## **Multibeam data**

The 2002 survey objectives were to acquire multi-beam coverage over the target area, and as much of the 2001 reconnaissance surveys as time allowed. After each primary site survey, targeted lines were run directly over the scour to assess repeatability and accuracy, and the effect of line orientation. In several cases, the reconnaissance surveys had to be curtailed due to time and budget constraints. Excess ship motion due to heavy seas occasionally diminished data quality. However, all scour sites surveyed with side scan in 2001 were re-surveyed with swath bathymetry in 2002.

The multibeam surveys used a Simrad EM1002 swath bathymetric system. A POS/MV Model 320 (Version 3) motion sensing system measured position, roll, pitch, heading (true), and heave of the sonar transducer. An Applied Microsystems Limited sound velocity and pressure probe provided sound speed profiles of the water column. Two CARIS HIPS/SIPS 5.2 data processing workstations were used to store, process and clean the collected depth soundings and obvious errors (data spikes) were removed using quality flags to indicate whether the data had been rejected, or was outside deliverable survey specifications. The outer-most twenty beams were rejected to reduce or remove refraction artefacts. Final field processing of the multi-beam data (data reduction, tidal correction, refraction editing, and surface cleaning) was then performed using CARIS HIPS/SIPS. A further post cruise data cleaning by TEKmap consulting optimize the data. The resulting cleaned XYZ data points were loaded into the ArcMap module of ArcGIS as individual scour surveys. A continuous

surface was made using the ArcGIS triangulated irregular net (TIN) method. Shaded relief images were produced with sun illumination to display the scour features. The visible outline of the scour disturbance was then digitized as a polygon using both the sidescan and shaded relief imagery.

To measure scour metrics accurately from the multibeam data, scour relief and depth had to be distinguished from the surrounding terrain and undisturbed seabed slope. This was relatively straightforward for circular pits where there is no appreciable relief change across the scour disturbance site. Here the average water depth was subtracted from soundings within the scour disturbance polygon to produce a difference map showing positive values for berms protruding above the base seabed and negative values for the excavated pit. For a linear furrow, the area of scour disturbance was first digitized as a polygon feature within ArcGIS. All soundings within this perimeter were exported as the scour surface. A “pre-scour” seafloor was generated by excluding depth values from within the digitized scour outline and then filling the void (ArcGIS nearest neighbours TIN routine) using depth values within 10 m of, but outside, the scour perimeter. A simple subtraction of the two surfaces then provided the net scour depth along the feature. The results of the subtraction were gridded to produce another bathymetric map of the scour with seafloor as zero and any positive relief as positive values and any negative relief as negative values. From this map surface profiles were made to measure the scour metric.

### **Grain size**

A sub-sample was taken from each IKU grab for grain size analysis. Grain size analysis was done in the SedLab at the Bedford Institute of Oceanography. Samples were wet sieved in  $\frac{1}{4}$  phi intervals down to 1mm size fraction. The remaining fines were analysed through a settling tube at  $\frac{1}{10}$  phi intervals to  $63\mu\text{m}$ . Due to the small amount of material finer than  $63\mu\text{m}$  (less than 5% of the sample) the remaining material was grouped at 8 phi ( $4\mu\text{m}$ ).

**Table 1:** Parameters and settings used during the 2001-038 survey


| Parameter                           | Setting                                                                           |
|-------------------------------------|-----------------------------------------------------------------------------------|
| Fire rate                           | 0.50 - 0.75 second - shallow water<br>.75 - 1.5 seconds - deep water              |
| PCU power setting                   | 4 kilovolts (480 joules) - shallow water<br>5 kilovolts (750 joules) - deep water |
| ESU power setting                   | 60 microfarad (1000 joules max.)                                                  |
| BMC (motion compensation)           | Pressure Mode                                                                     |
| Display Gain                        | Seismic #1- Spreading Loss or +20 Db.<br>Seismic #2 - Fixed +20 Db.               |
| Filter Setting                      | Seismic #1 - 1000 - 5000 hertz<br>Seismic #2 - 700 - 3500 hertz                   |
| Processor Gain (System Console)     | 4 KV                                                                              |
| DTS source                          | sparker - 030A, 030B, 036, 042, 047<br>boomer - phase 030C and 030D               |
| AGC DIG delay                       | Nil                                                                               |
| AGC DIG sample rate                 | 60 microsecond - shallow water<br>120 microsecond - deep water                    |
| AGC DIG samples per channel / range | 4096 / 245 metres - shallow water<br>4096 / 490 metres - deep water               |
| EPC sweep speed                     | 125 or 250 msec. - shallow water<br>500 msec. - deep water                        |
| EPC print polarity                  | Positive                                                                          |

**Table 2:** Station details for the 2001-038 survey.

| STN | LOCATION   | TYPE       | DAY/TIME   | LATITUDE  | LONGITUDE  | DEPTH (m) | DIVE #  | Comments                                                                                                      |
|-----|------------|------------|------------|-----------|------------|-----------|---------|---------------------------------------------------------------------------------------------------------------|
| 1   | Berg 18    | IKU Grab   | 210 / 2120 | 47.252218 | -48.703451 | 106       |         | fine-med. sand 40 cm thick. Greyish-olive green. Lot of quartz. Scattered subang. pebbles of mixed lithology. |
| 2   | Berg 65    | IKU Grab   | 210 / 2204 | 47.272346 | -48.623868 | 133       |         | Fine olive-green sand with scattered pebbles. Core taken for OLS dating techniques                            |
| 3   | Berg 32    | IKU Grab   | 210 / 2027 | 47.608333 | -49.535000 | 112       |         | Push core taken for OLS dating technique.                                                                     |
| 4   | Berg 67    | IKU Grab   | 212 / 1910 | 47.390021 | -49.504970 | 90        |         | medium to coarse sand with granules and sand dollars                                                          |
| 5   | Berg 89-01 | IKU Grab   | 214 / 2103 | 46.670200 | -48.156100 | 109       |         | sand                                                                                                          |
| 6   | Berg 65    | ROV Camera | 209 / 1320 | 47.260666 | -48.607333 | 127       | Dive 2  |                                                                                                               |
| 7   | Berg 65    | ROV Camera | 209 / 1655 | 47.268833 | -48.632666 | 125       | Dive 3  |                                                                                                               |
| 8   | Berg 18    | ROV Camera | 210 / 1615 | 47.254666 | -48.700833 | 103       | Dive 5  |                                                                                                               |
| 9   | Berg 32    | ROV Camera | 211 / 1710 | 47.607166 | -49.536333 | 112       | Dive 6  |                                                                                                               |
| 10  | Berg 32    | ROV Camera | 211 / 1806 | 47.607500 | -49.537000 | 112       | Dive 7  |                                                                                                               |
| 11  | Berg 67    | ROV Camera | 212 / 1400 | 47.387833 | -49.504666 | 86        | Dive 8  |                                                                                                               |
| 12  | Berg 67    | ROV Camera | 212 / 1610 | 47.389166 | -49.505666 | 86        | Dive 9  |                                                                                                               |
| 13  | Berg 32    | ROV Camera | 212 / 2145 | 47.606333 | -49.536000 | 112       | Dive 10 |                                                                                                               |
| 14  | Berg 95    | ROV Camera | 213 / 1855 | 47.247833 | -49.283166 | 93        | Dive 11 |                                                                                                               |
| 15  | Berg 88-01 | ROV Camera | 214 / 1352 | 46.839833 | -48.015666 | 123       | Dive 12 |                                                                                                               |
| 16  | Berg 89-01 | ROV Camera | 214 / 1815 | 46.670333 | -48.156166 | 116       | Dive 13 |                                                                                                               |
| 17  | Berg 68    | ROV Camera | 216 / 2100 | 46.837500 | -49.454000 | 73        | Dive 14 |                                                                                                               |
| 18  | Berg 95    | ROV Grab   | 213 / 2029 | 47.248566 | -49.282966 | 93        | Dive 11 | Cobble recovered by ROV from Berg 95 berm.                                                                    |
| 19  | Berg 89-01 | ROV Grab   | 214 / 2026 | 46.668800 | -48.154100 | 115       | Dive 13 | Cobble recovered by ROV on berm of Berg 89-01 pit. End Tape 12.                                               |
| 20  | Berg 68    | ROV Grab   | 216 / 2204 | 46.836300 | -49.454800 | 72        | Dive 14 | Cobble recovered by ROV at Berg 68 berm. Tape 13.                                                             |

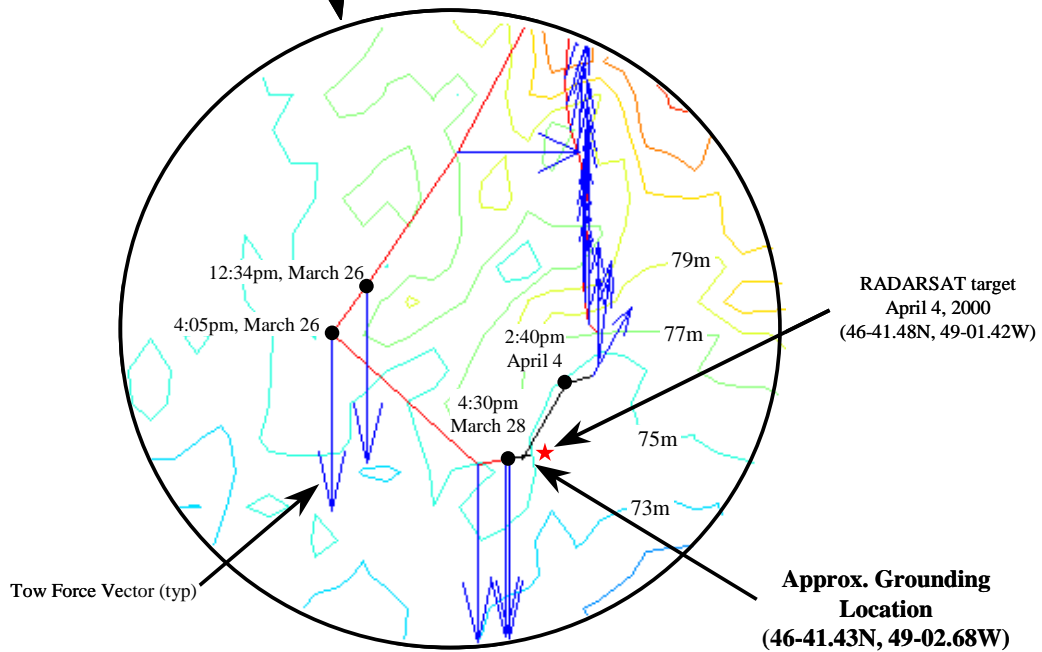
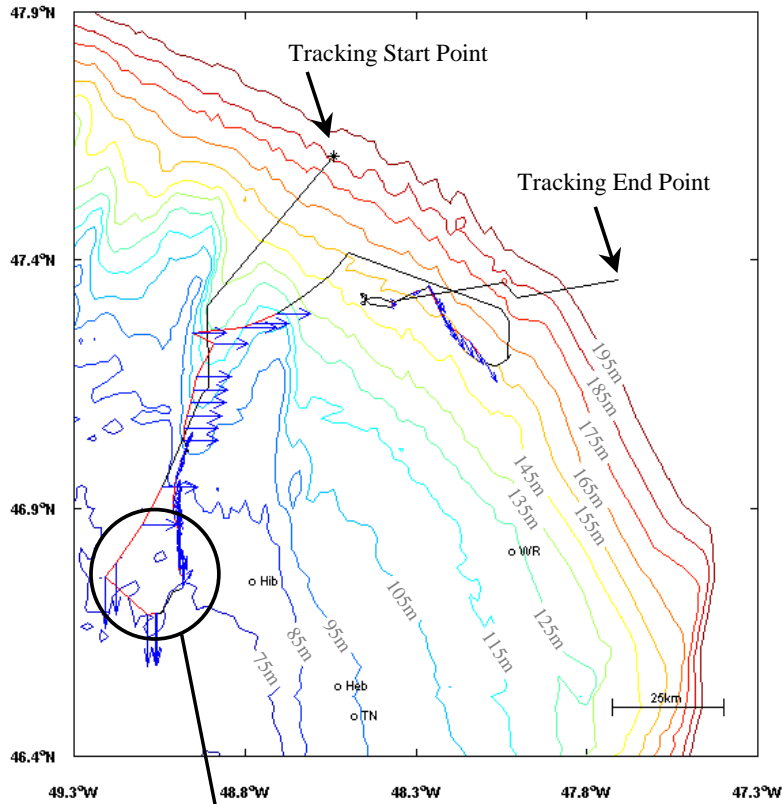
## **APPENDIX II**

Individual Iceberg Case Studies  
(C-Core 2001)

| Iceberg 00-009           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | General                                                                                                                                                                                                                                                                              |
|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Iceberg Particulars      |  <p>*Draft was estimated using the equation in Section 2.1.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | <p><b>Size:</b> Medium</p> <p><b>Length:</b> 70m</p> <p><b>Width:</b> 40m</p> <p><b>Height:</b> 10m</p> <p><b>Estimated Draft*:</b> 58m</p> <p><b>Reported Shape:</b> Tabular</p> <p><b>Approx. Grounded Location:</b> 46° 41.43' N, 49° 02.68' W</p> <p><b>Water Depth:</b> 75m</p> |
| Anecdotal Information    | <ul style="list-style-type: none"> <li>• Iceberg was tracked from March 21 to April 19, 2000 using Hibernia radar and visual observation from ships in the area.</li> <li>• Iceberg was reported to have been towed aground by the <i>Maersk Norseman</i> at approximately 16:30 on March 28. Half an hour later the iceberg rolled, exhibiting an “egg” shape above the water surface.</li> <li>• Iceberg was reported as grounded by <i>Hibernia</i> radar 06:30 on March 31.</li> <li>• Total time reported grounded: ~155 hours</li> <li>• Iceberg was reported ungrounded on April 4 and was towed by the <i>Atlantic Eagle</i> for approximately one day.</li> <li>• No other grounding incidents were reported as the iceberg was towed northward into deeper water.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                      |
| Environmental Conditions | <ul style="list-style-type: none"> <li>• Winds light-moderate March 21-24, then moderate-strong NW March 25-27. Remaining strong 15m/s on March 28 on day of grounding but changing 180° to SSE.</li> <li>• Winds generally light-moderate SW through SE March 29 to April 4 on day of ungrounding. On April 3 and 4, winds were more towards the NE likely encouraging the berg into deeper water.</li> <li>• Winds to end of track on April 19 generally light-moderate.</li> <li>• Currents generally light ~ 12cm/s in March, ~25cm/s in April. Currents tended to pick up from ~4cm/s on the 4<sup>th</sup>, increasing to 20cm/s on the 7<sup>th</sup> generally consistent with the ungrounding.</li> <li>• Note that the winds and currents are those that accompany the berg along its track and should give an indication of the driving forces in the area of the berg.</li> <li>• Winds and currents were such that after the grounding event they might have conceivably moved the berg off into deeper water had it not been grounded. Similarly, the eventual ungrounding is also generally consistent with the winds and currents at that time.</li> </ul> |                                                                                                                                                                                                                                                                                      |

# Iceberg 00-009

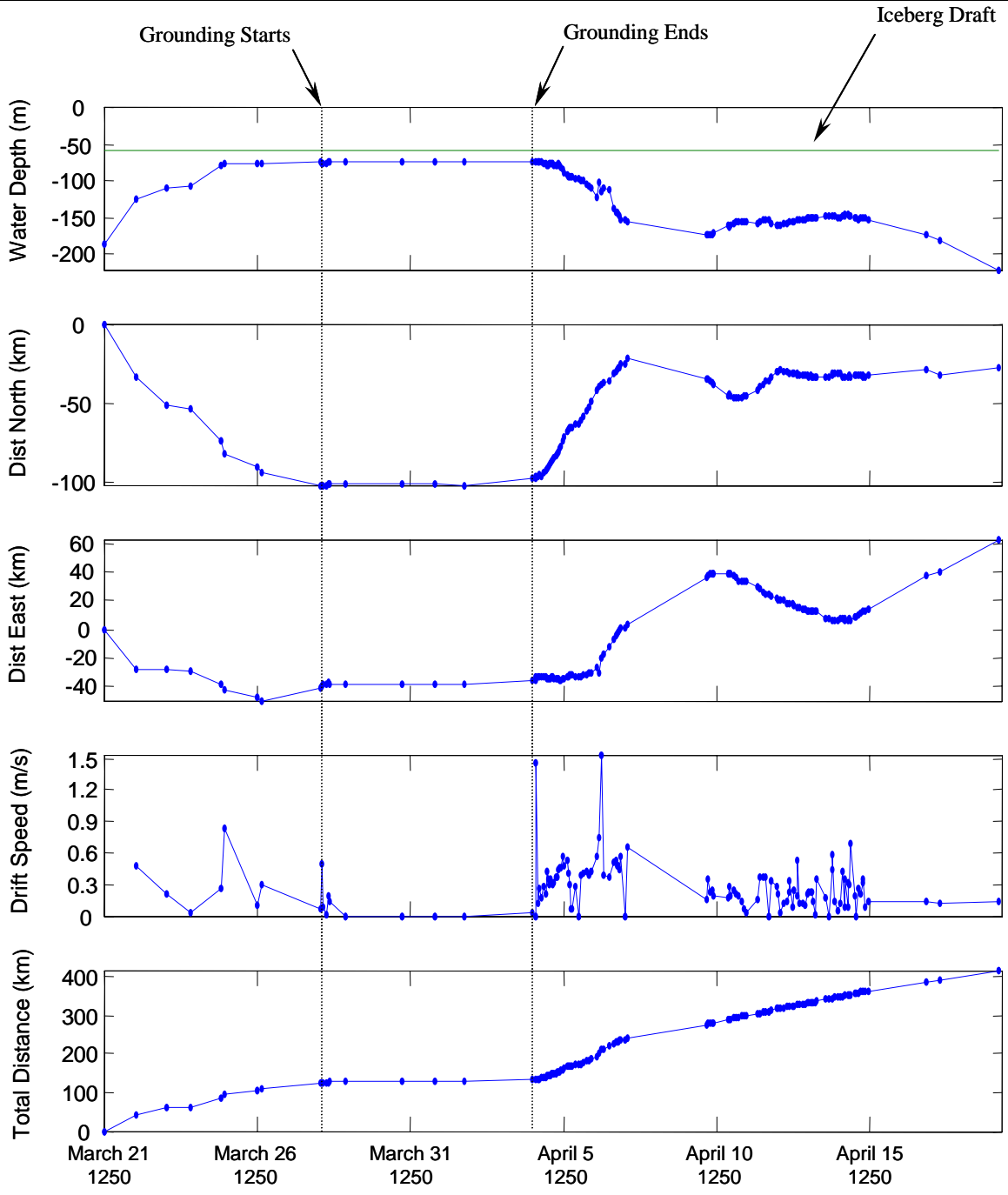
# Trackplot





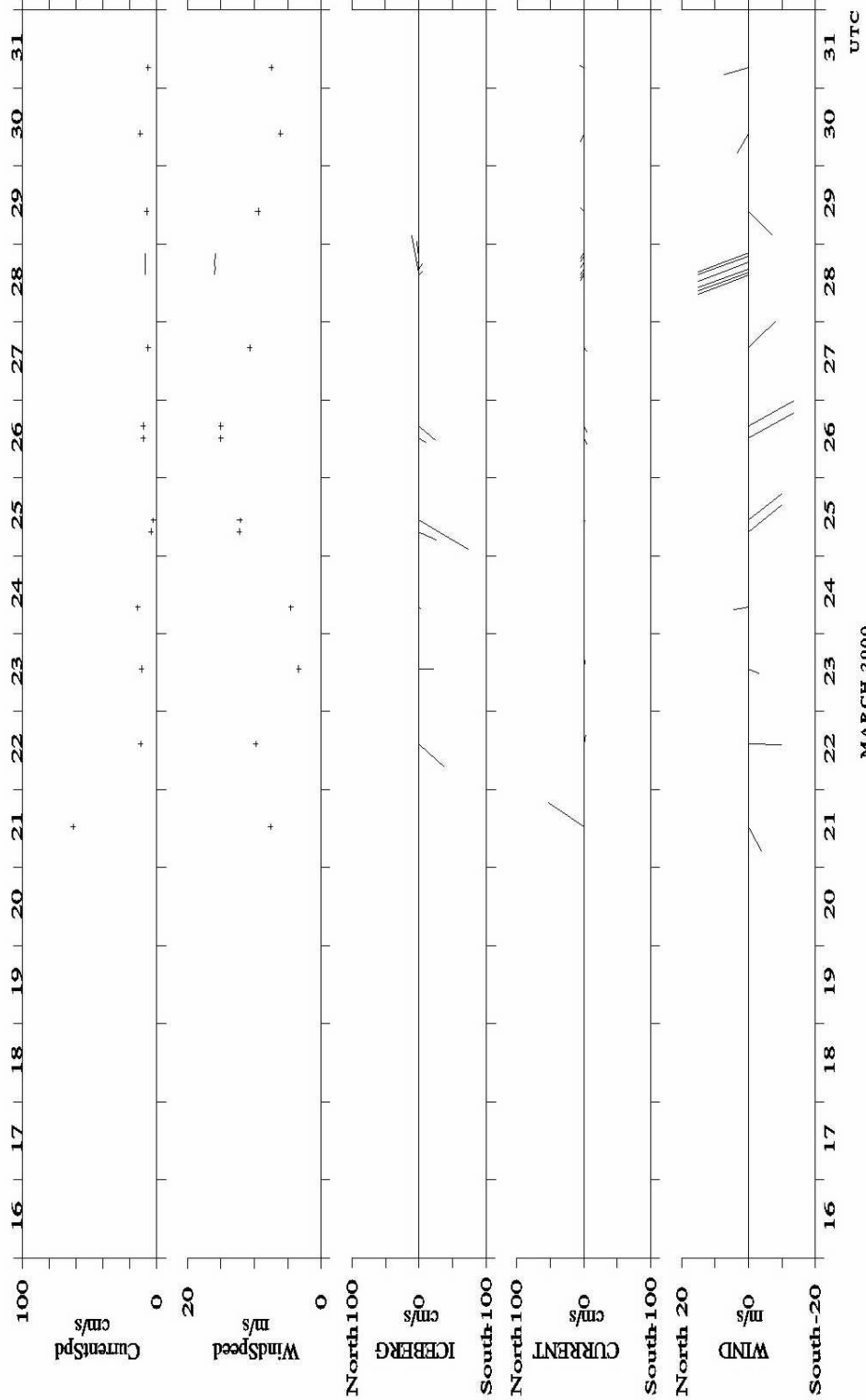
# Iceberg 00-009

# Drift Data



# Iceberg 00-009

# Environmental Data

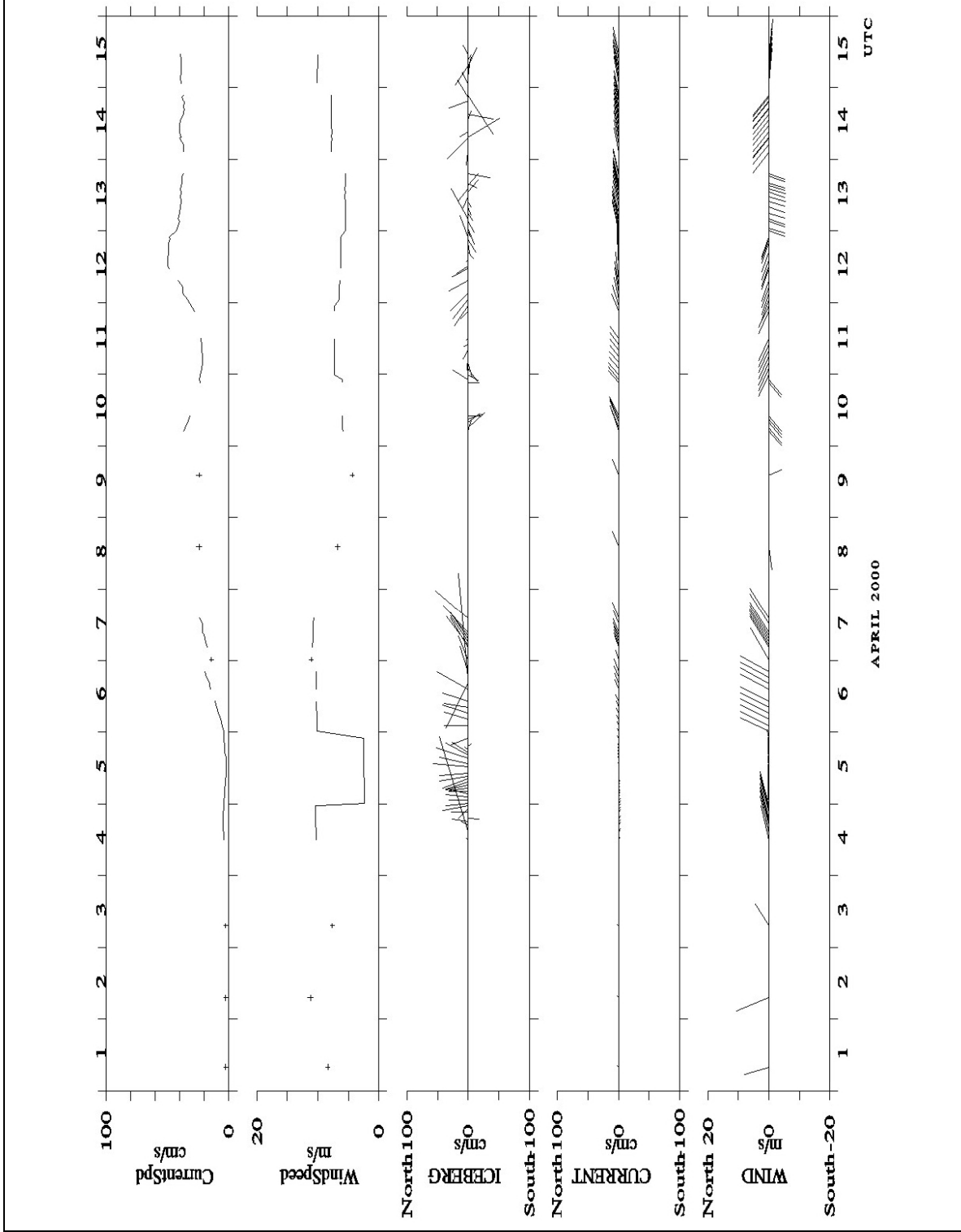


MARCH 2000

UTC

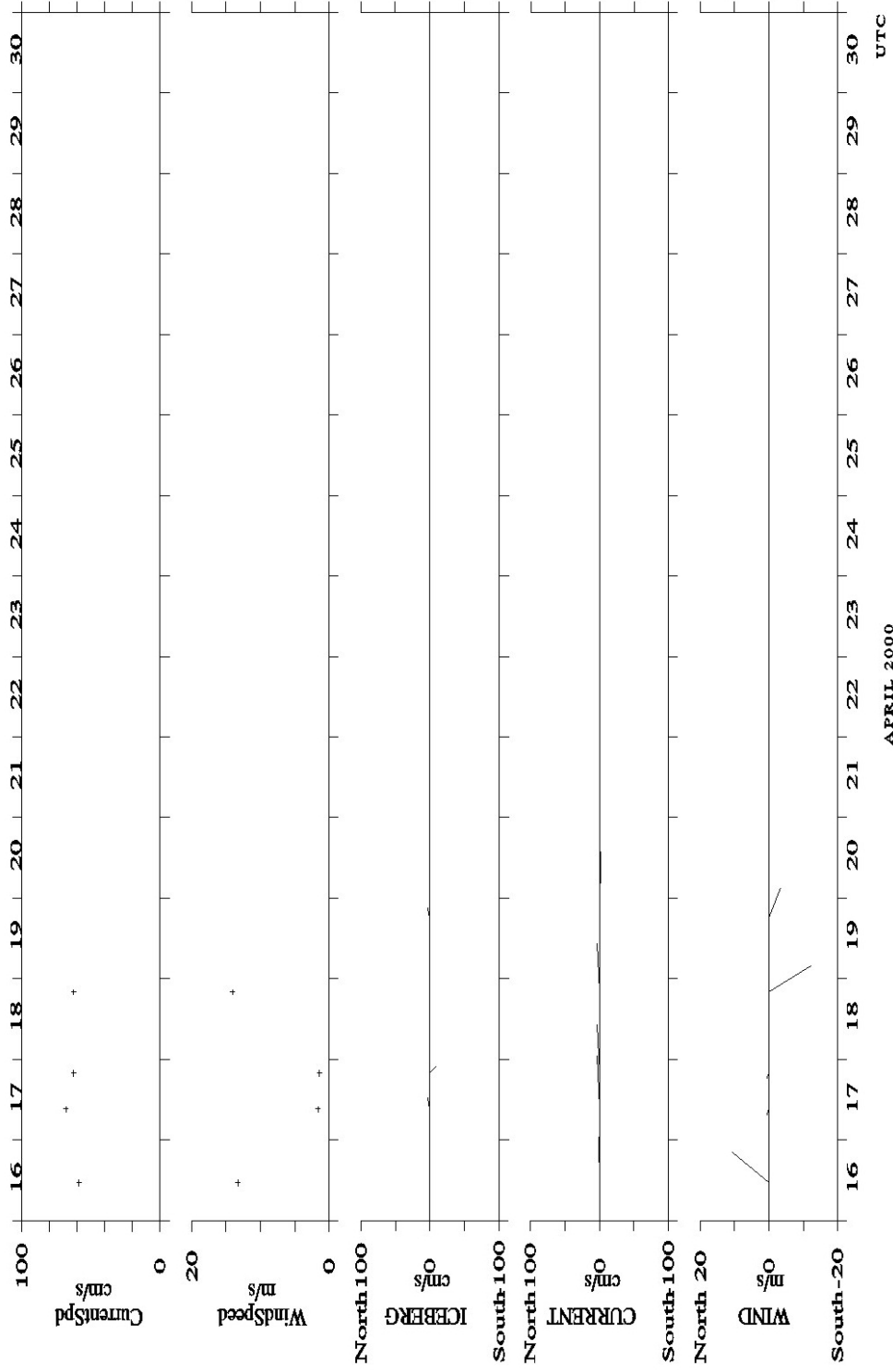
# Iceberg 00-009


# Environmental Data



# Iceberg 00-009

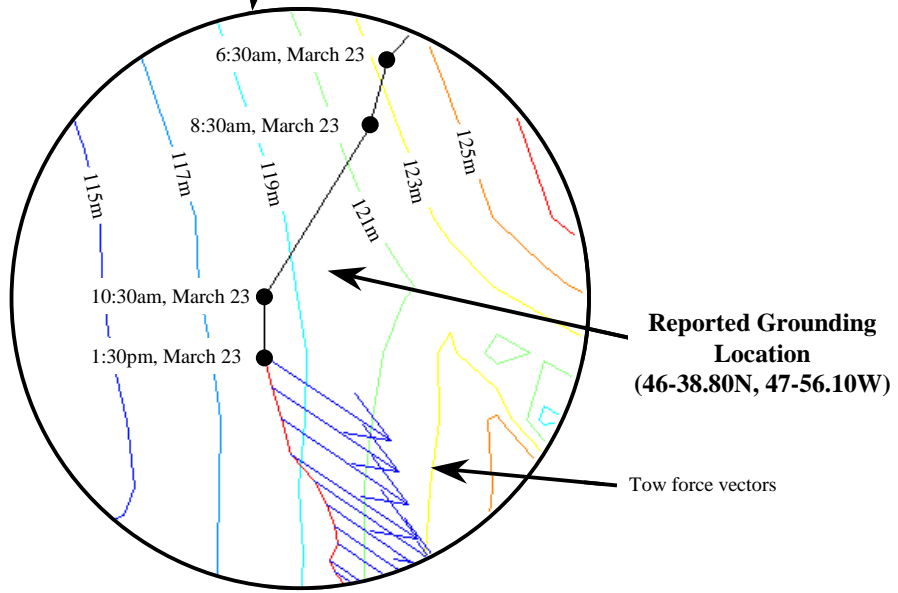
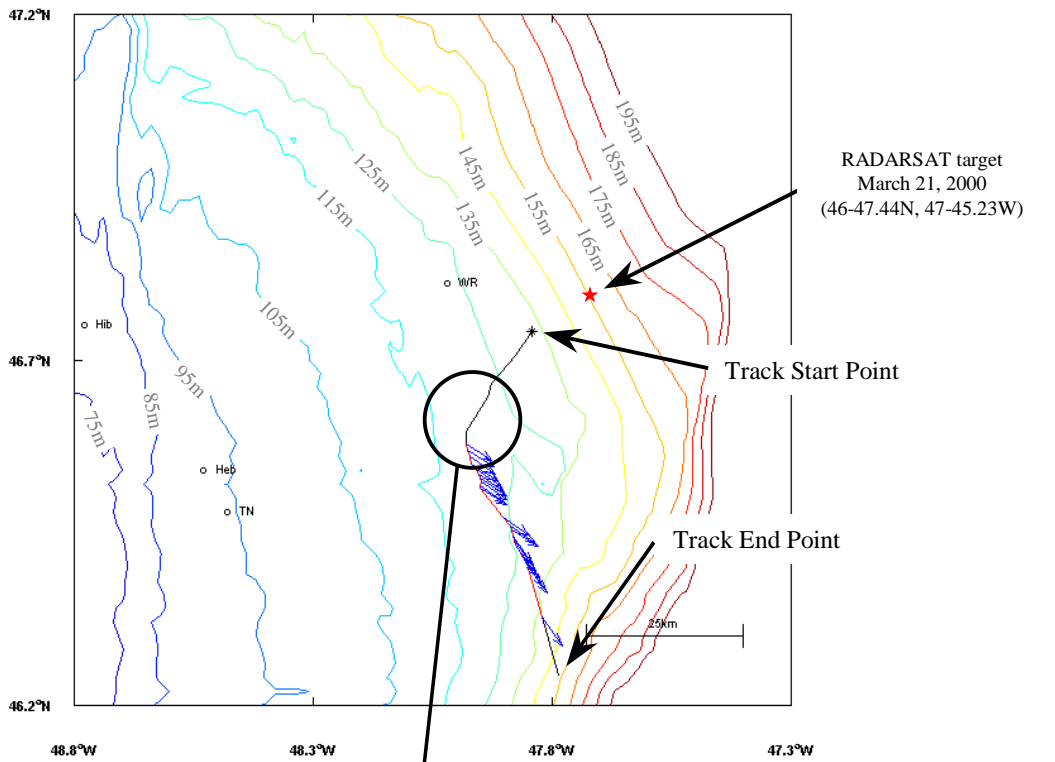
# Environmental Data



| Iceberg 00-011                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | General                                                                                                                                                                                                                                                                                           |
|----------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Iceberg Particulars                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <p> <b>Size:</b> Large<br/> <b>Length:</b> 120m<br/> <b>Width:</b> 82m<br/> <b>Height:</b> 40m<br/> <b>Estimated Draft*:</b> 84m<br/> <b>Reported Shape:</b> Pinnacle<br/> <b>Approx. Grounded Location:</b><br/>           46° 38.80' N, 47° 56.10' W<br/> <b>Water Depth:</b> 120n         </p> |
| * Draft was estimated using the equation in Section 2.1. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                   |
| Anecdotal Information                                    | <ul style="list-style-type: none"> <li>• Iceberg was tracked from March 22 to March 25, 2000 using radar and visual observation from ships in the area.</li> <li>• Iceberg was reported to have possibly grounded at 03:00, March 23 by the <i>Burin Sea</i>. Grounded water depth was reported as 121m at 06:30, March 23.</li> <li>• Total time reported grounded: ~9 hours</li> <li>• Iceberg ungrounded approximately 10:30, March 23 when it was towed by the <i>Burin Sea</i> for approximately one and one half days.</li> <li>• No other grounding incidents were reported as the iceberg was towed to the southeast into deeper water.</li> </ul>                                                                                                       |                                                                                                                                                                                                                                                                                                   |
| Environmental Conditions                                 | <ul style="list-style-type: none"> <li>• Winds NNW moderate 10m/s on March 22 then becoming light ~ 5m/s on March 23.</li> <li>• Currents NE 15-20cm/s on March 22, then dropping to NW 10cm/s or less on March 23.</li> <li>• Winds and currents, while light, were directed to the SE or NE into slightly deeper water during this two day period 22<sup>nd</sup> to 23<sup>rd</sup>. The berg was towed on to the SE by midday on the 23<sup>rd</sup>.</li> <li>• The 9 hour grounding period is short and it is possible that it might not in fact have been grounded at all. This hypothesis is supported by the light winds and currents which themselves are consistent with the berg exhibiting little motion during this 9 hour time period.</li> </ul> |                                                                                                                                                                                                                                                                                                   |

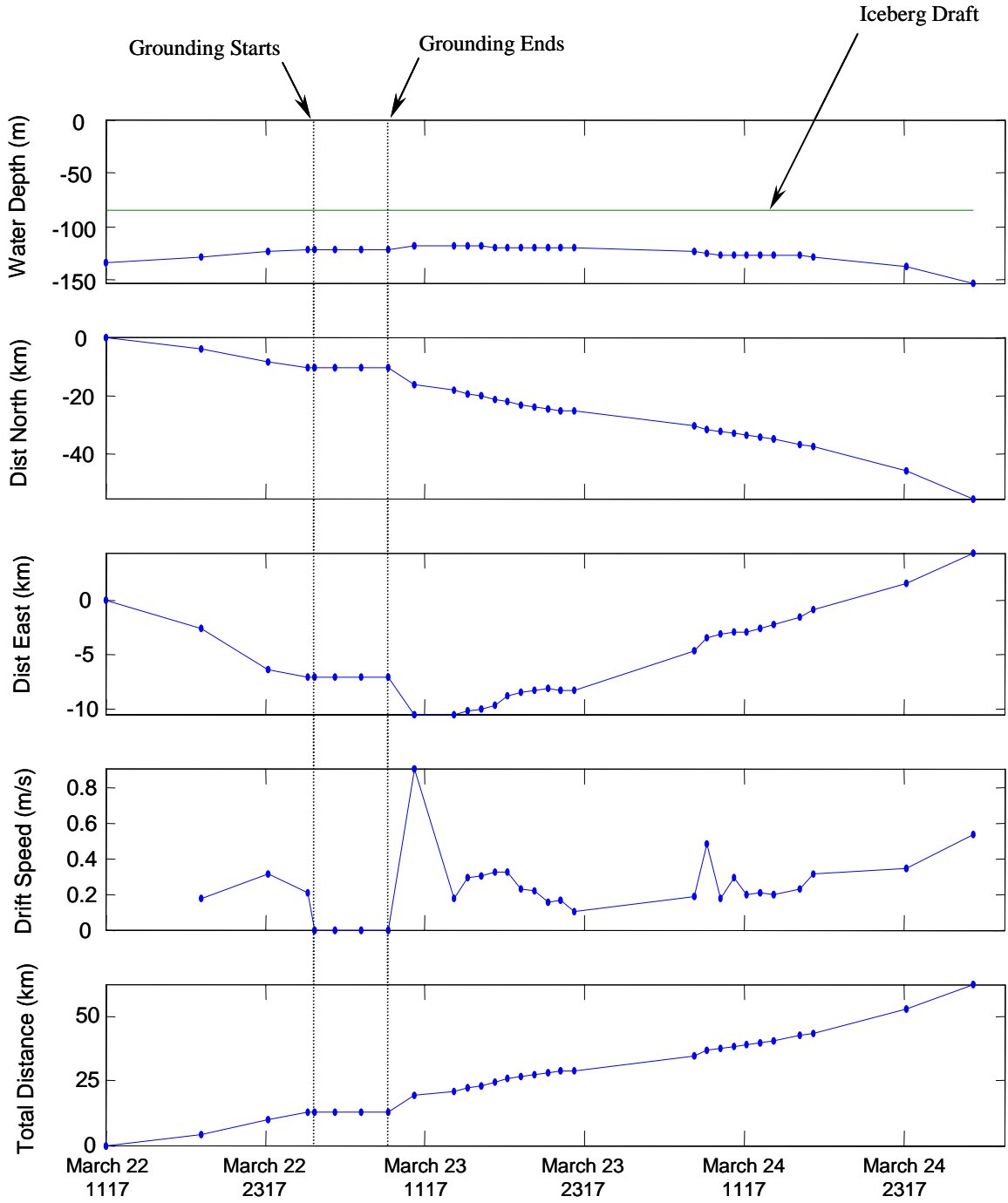
# Iceberg 00-011

# Trackplot



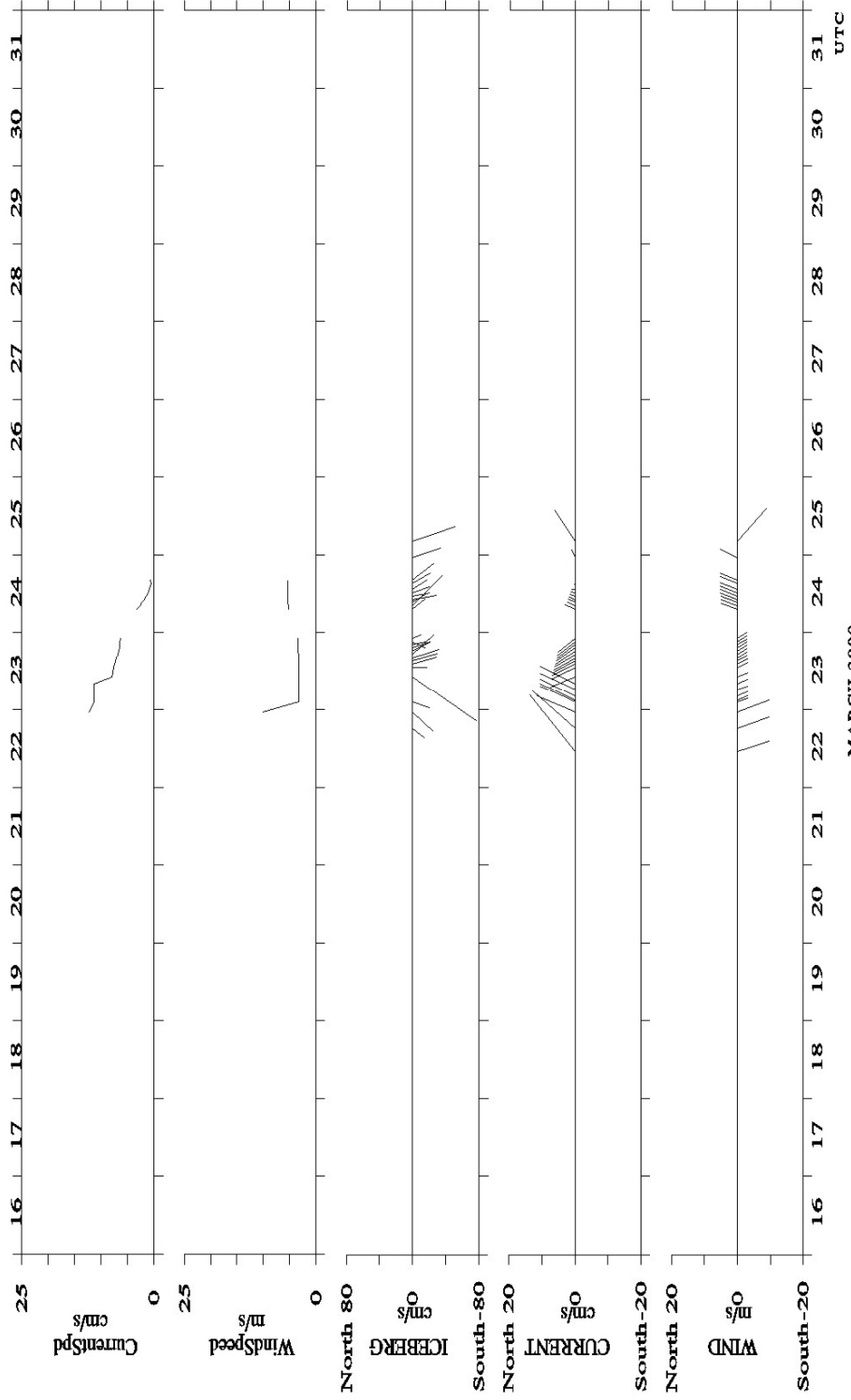
# Iceberg 00-011

# Drift Data



# Iceberg 00-011


# Environmental Data



MARCH 2000

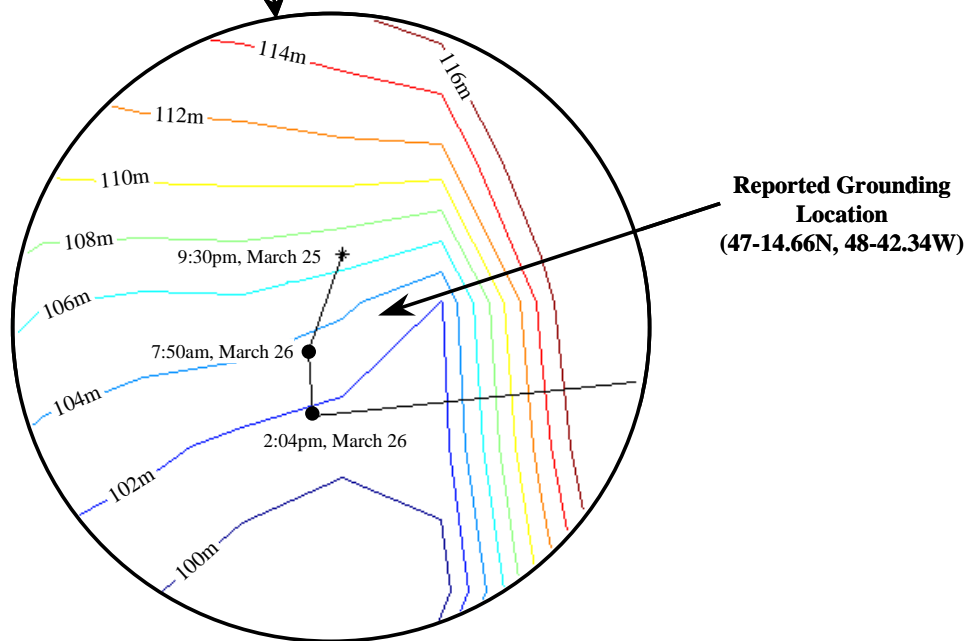
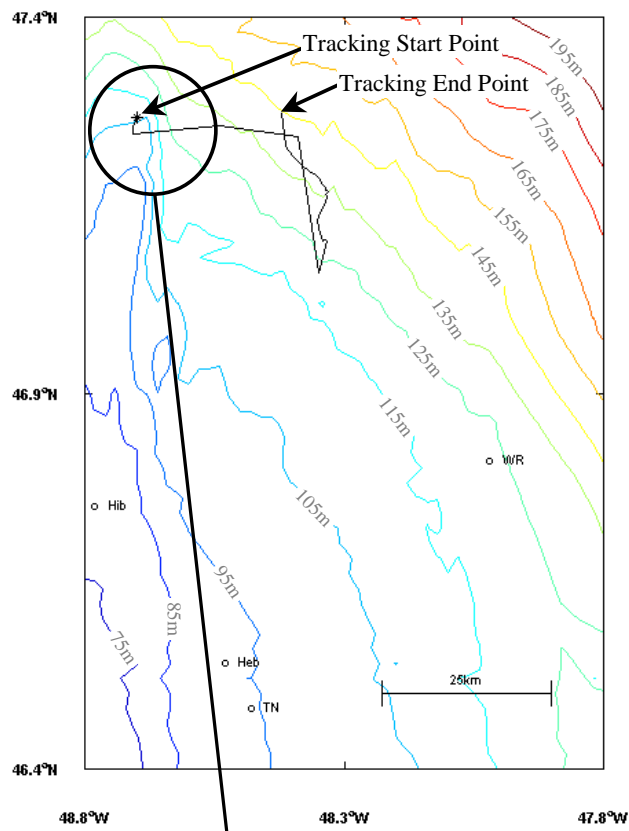
UTC



| Iceberg 00-018                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | General                                                                                                                                                                                                                                                                                    |
|----------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Iceberg Particulars</b>                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | <p><b>Size:</b> Medium</p> <p><b>Length:</b> 70m</p> <p><b>Width:</b> 40m</p> <p><b>Height:</b> 35m</p> <p><b>Estimated Draft*:</b> 58m</p> <p><b>Reported Shape:</b> Pinnacle</p> <p><b>Approx. Grounded Location:</b><br/>47° 14.66' N, 48° 42.34' W</p> <p><b>Water Depth:</b> 102m</p> |
| * Draft was estimated using the equation in Section 2.1. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                            |
| <b>Anecdotal Information</b>                             | <ul style="list-style-type: none"> <li>• Iceberg was tracked from March 25 to April 1, 2000 using radar and visual observation from ships in the area.</li> <li>• Iceberg was reported as grounded at 07:50, March 26 by the <i>Maersk Norseman</i>.</li> <li>• Total time reported grounded: ~6 hours</li> <li>• Iceberg ungrounded some time between 14:04, March 26 and 07:45, March 28 and was monitored by the <i>Maersk Bonavista</i> until April 1 where it had entered deeper water.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                            |
| <b>Environmental Conditions</b>                          | <ul style="list-style-type: none"> <li>• Winds NW strong 12-14m/s March 25-26. Winds drop slightly on the 27<sup>th</sup> then increase again to strong 16m/s on the 28<sup>th</sup> but this time changing direction 180° to blow from the SSE.</li> <li>• Light winds on the 29<sup>th</sup> and 30<sup>th</sup>, then SSE light-moderate for the 31<sup>st</sup> and 1<sup>st</sup>.</li> <li>• Currents fairly consistent to the ESE through NE at ~20-30cm/s March 25 to April 1. Currents consistent with an eastward track back out into deeper waters after the possible grounding on the 26<sup>th</sup>/27<sup>th</sup>.</li> <li>• The 6 hour grounding period is short and it is possible that it might not in fact have been grounded at all. This hypothesis may be supported by the light currents on the 26<sup>th</sup> and 27<sup>th</sup>. Wind shift of 180° on the 28<sup>th</sup> is coincident with the in between time period when the iceberg may have been grounded or, remained generally in the same location due to changing winds.</li> </ul> |                                                                                                                                                                                                                                                                                            |

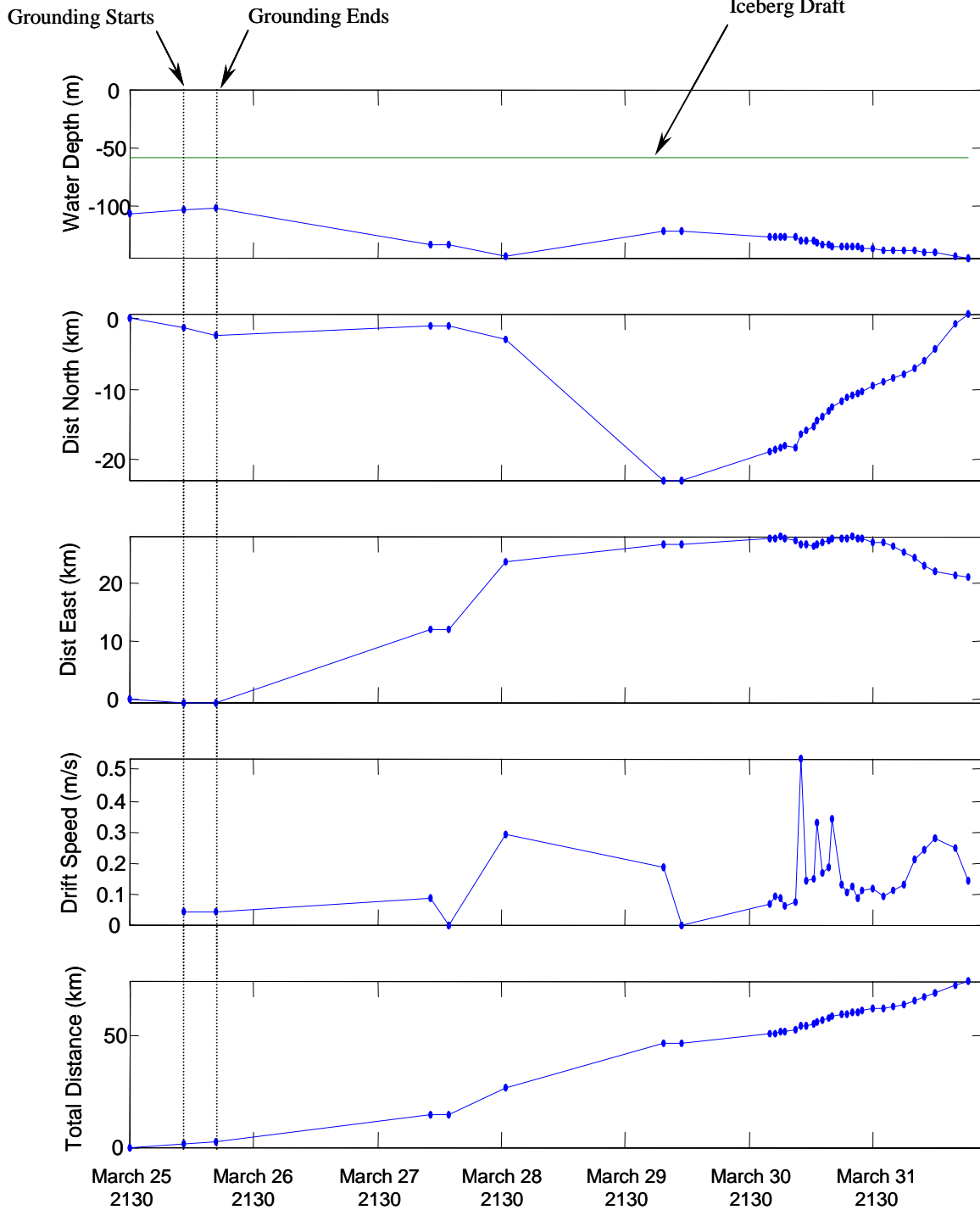
# Iceberg 00-018

# Trackplot



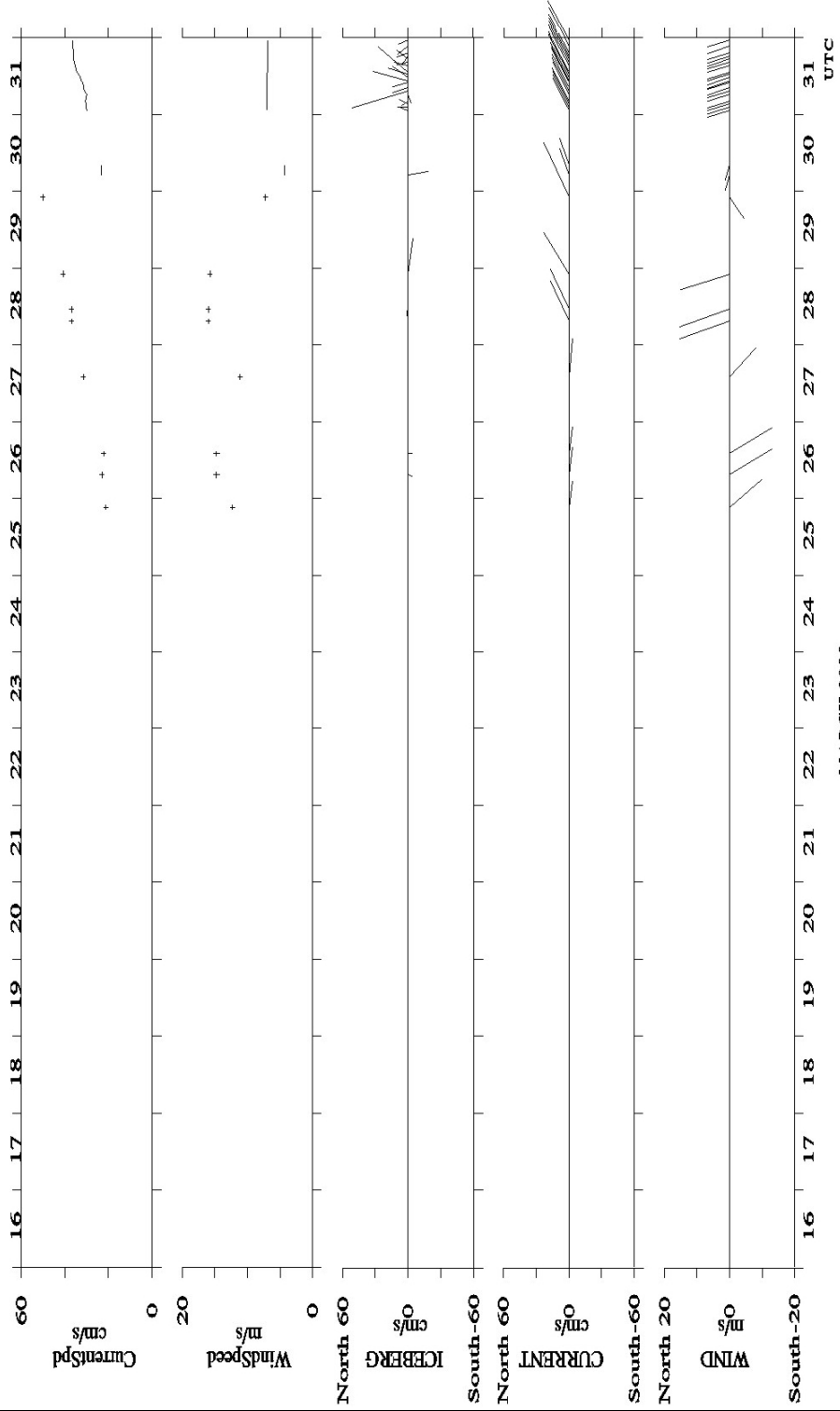
# Iceberg 00-018

# Drift Data



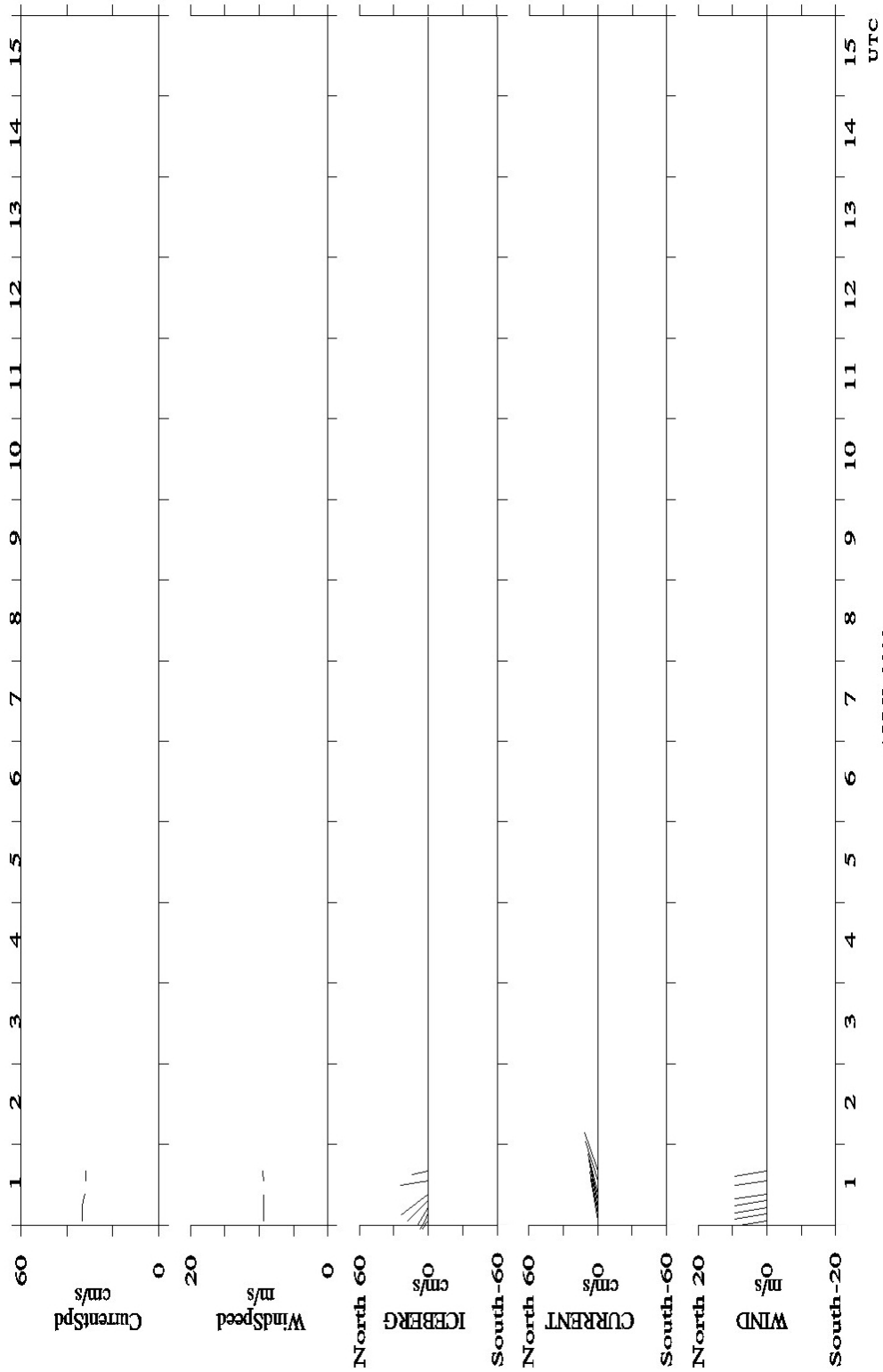
# Iceberg 00-018

# Environmental Data




# Iceberg 00-018

# Environmental Data

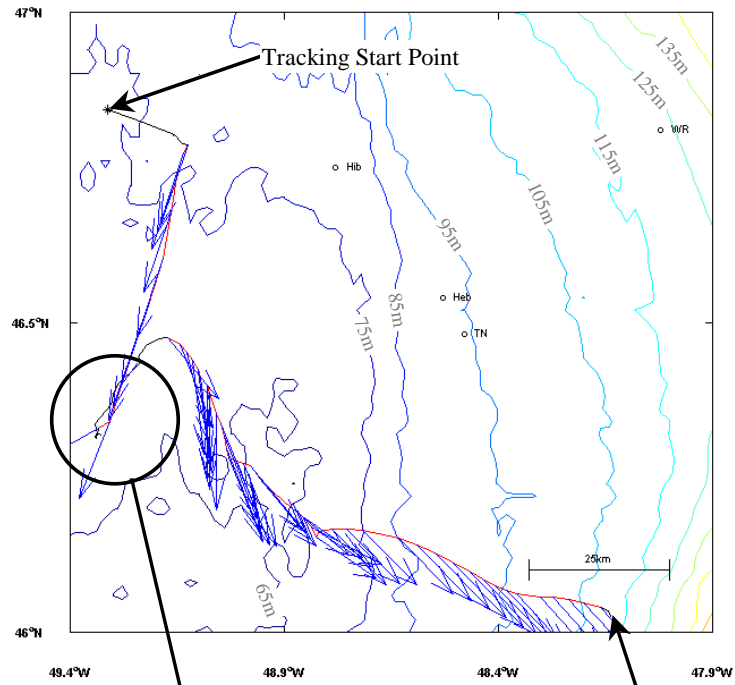


APRIL 2000

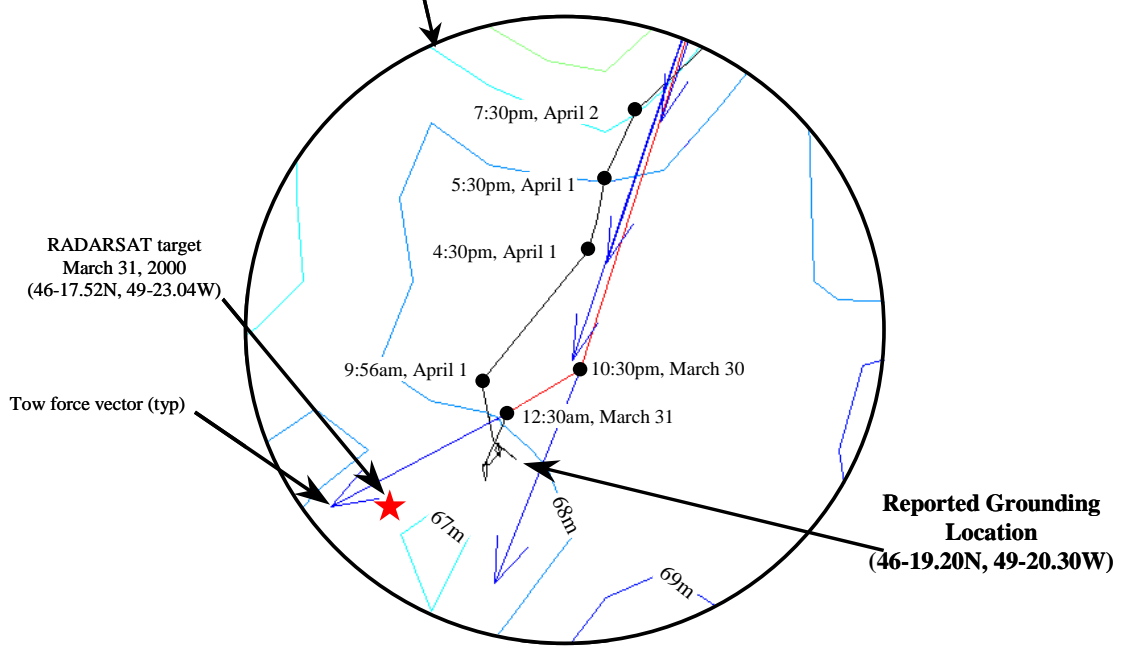
| Iceberg 00-021                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | General                                                                                                                                                                                                                                                                               |
|------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Iceberg Particulars</b>                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <p><b>Size:</b> Medium</p> <p><b>Length:</b> 63m</p> <p><b>Width:</b> 49m</p> <p><b>Height:</b> 18m</p> <p><b>Estimated Draft*:</b> 75m</p> <p><b>Reported Shape:</b> Dome</p> <p><b>Approx. Grounded Location:</b><br/>46° 19.20' N, 49° 20.30' W</p> <p><b>Water Depth:</b> 68m</p> |
| *Draft was measured using side-scan sonar equipment. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                       |
| <b>Anecdotal Information</b>                         | <ul style="list-style-type: none"> <li>• Iceberg was tracked from March 28 to April 4, 2000 using radar and visual observation from ships in the area.</li> <li>• Iceberg was likely towed aground by the <i>Maersk Placentia</i> at approximately 01:30 on March 31.</li> <li>• Total time reported grounded: ~30 hours</li> <li>• Iceberg ungrounded on April 1 and was towed by the <i>Maersk Placentia</i> for approximately two days.</li> <li>• No other grounding incidents were reported as the iceberg was towed southeast into deeper water.</li> </ul>                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                       |
| <b>Environmental Conditions</b>                      | <ul style="list-style-type: none"> <li>• Winds SSE strong 16m/s March 28, then NE through SE light-moderate March 29-30. Remained light-moderate through grounding on March 31 until the end of the track period on April 4. Winds remained from the SSE for the 31<sup>st</sup> through 2<sup>nd</sup> then changed to SW for the 3<sup>rd</sup> and 4<sup>th</sup>.</li> <li>• Currents generally light ~ 4-12cm/s through the period. Currents to the west on the 28<sup>th</sup> and 30<sup>th</sup>, to the NE on the 29<sup>th</sup>, and to the NE through SE for the 31<sup>st</sup> to 3<sup>rd</sup>.</li> <li>• Winds on the 31<sup>st</sup> and 1<sup>st</sup> were light-moderate and to the north, generally consistent with the track the berg did take back into slighter deeper water after the ungrounding.</li> </ul> |                                                                                                                                                                                                                                                                                       |

# Iceberg 00-021

# Trackplot



Tracking End Point



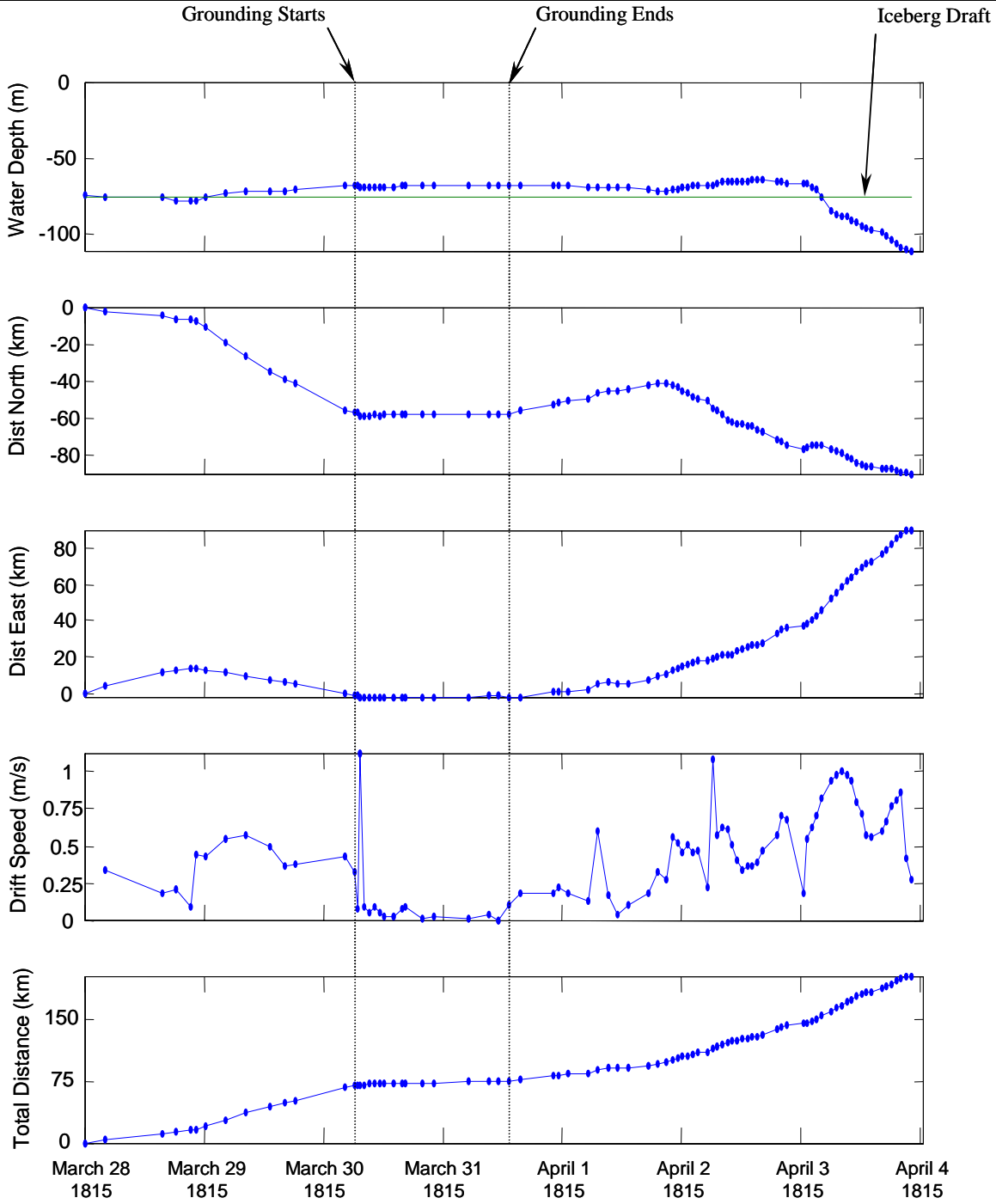
RADARSAT target  
March 31, 2000  
(46-17.52N, 49-23.04W)

Tow force vector (typ)

**Reported Grounding  
Location**  
(46-19.20N, 49-20.30W)

# Iceberg 00-021

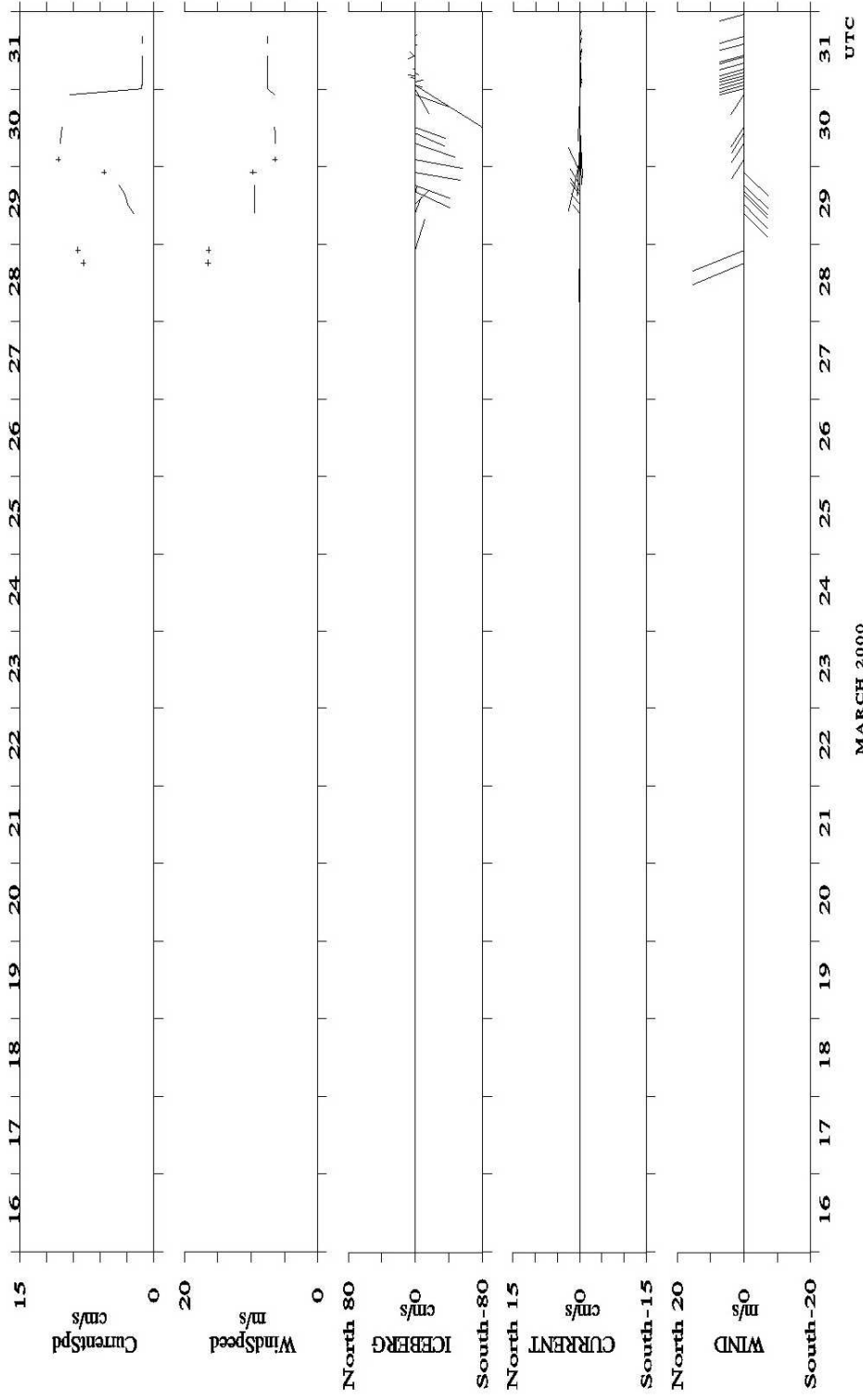
# Drift Data





# Iceberg 00-021

# Environmental Data

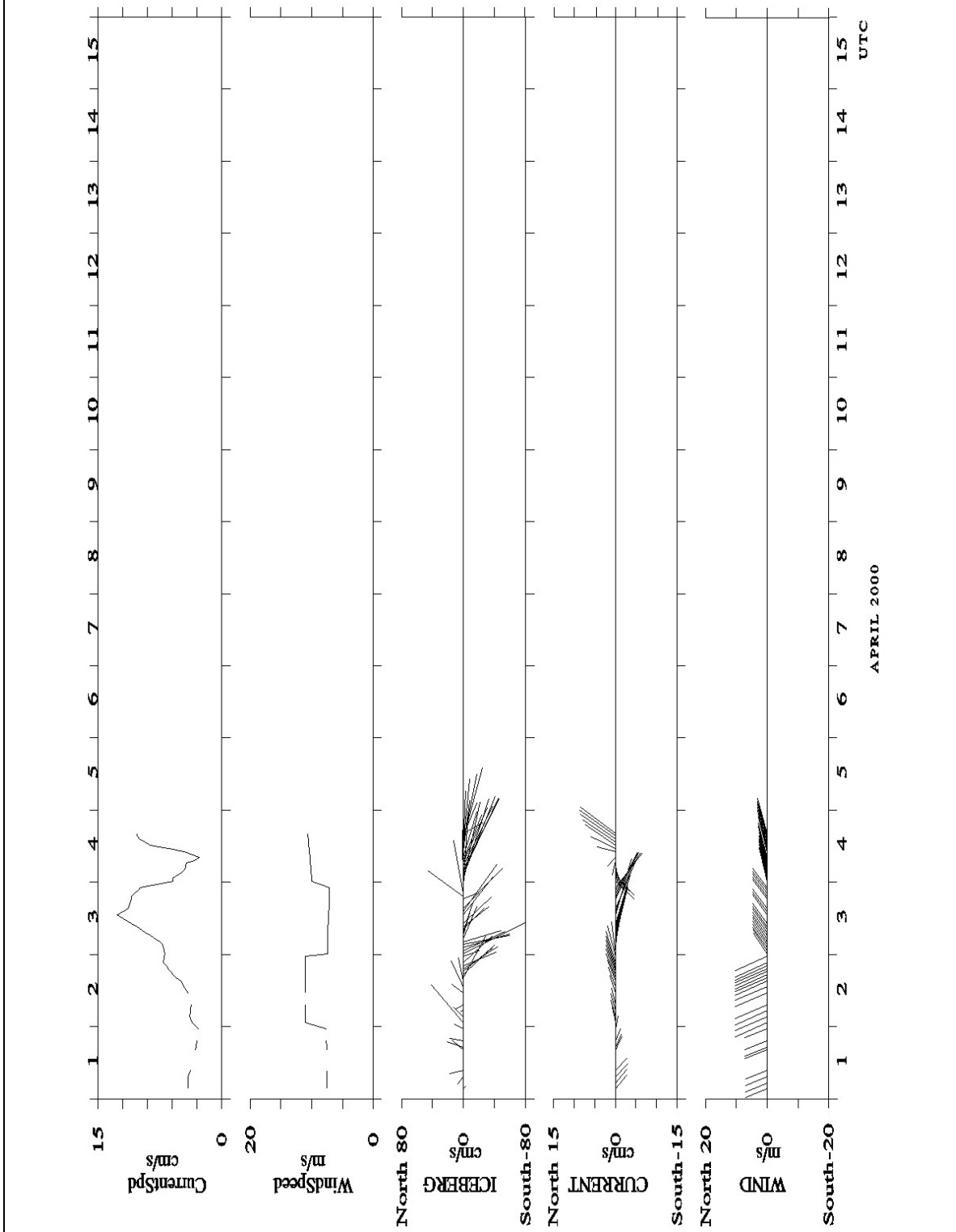



MARCH 2000

UTC

# Iceberg 00-021

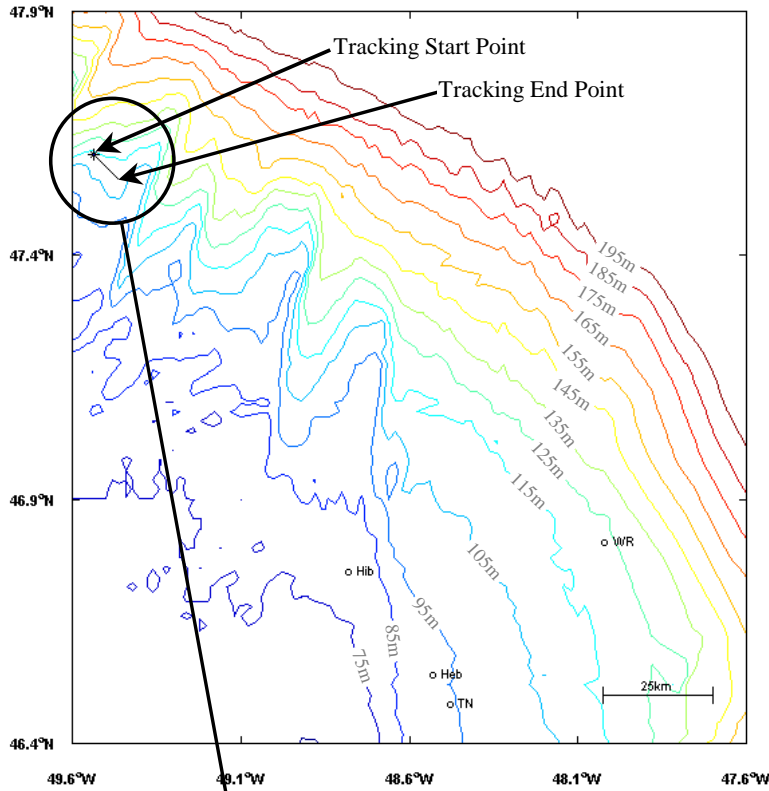
# Environmental Data



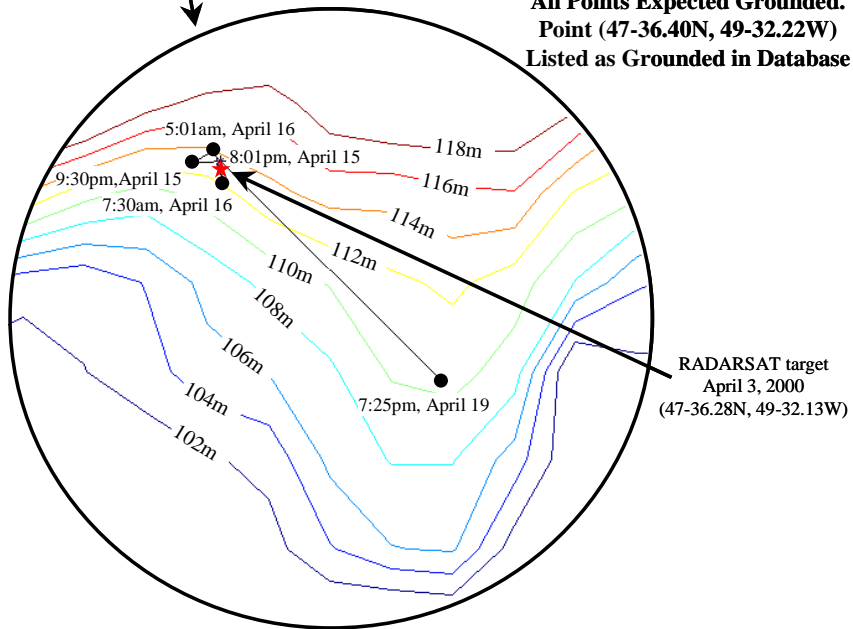
| Iceberg 00-032                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | General                                                                                                                                                                                                                                                                                  |
|---------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Iceberg Particulars</b>      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | <p><b>Size:</b> Large</p> <p><b>Length:</b> 138m</p> <p><b>Width:</b> 114m</p> <p><b>Height:</b> 27m</p> <p><b>Estimated Draft*:</b> 124m</p> <p><b>Reported Shape:</b> Pinnacle</p> <p><b>Approx. Grounded Location:</b> 47° 36.40' N, 49° 32.22' W</p> <p><b>Water Depth:</b> 112m</p> |
|                                 | *Draft was measured using side-scan sonar equipment.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                          |
| <b>Anecdotal Information</b>    | <ul style="list-style-type: none"> <li>• Iceberg was tracked from April 15 to April 19, 2000 using radar and visual observation from ships in the area.</li> <li>• Iceberg was reported to have been grounded 07:30 April 16 and 19:25 April 19 and is suspected to have been grounded the entire time it was tracked.</li> <li>• Total time reported grounded: ~96 hours</li> <li>• No towing operations were performed on this iceberg.</li> </ul>                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                          |
| <b>Environmental Conditions</b> | <ul style="list-style-type: none"> <li>• Winds moderate 10-12m/s to the east and then NE on April 15 and 16. Light winds to the west on the 17<sup>th</sup> followed by moderate winds to the SE on the 18<sup>th</sup> and 19<sup>th</sup>.</li> <li>• Currents generally moderate ~46-55cm/s to the NE for all days from the 15<sup>th</sup> through 19<sup>th</sup>.</li> <li>• Acknowledging it is a short period on the 15<sup>th</sup> and 16<sup>th</sup> when the berg appears to be grounded, the winds and currents appear to have been of sufficient magnitude and direction that they would have otherwise moved the berg further offshore into deeper waters had it not been grounded.</li> </ul> |                                                                                                                                                                                                                                                                                          |

# Iceberg 00-032

# Trackplot

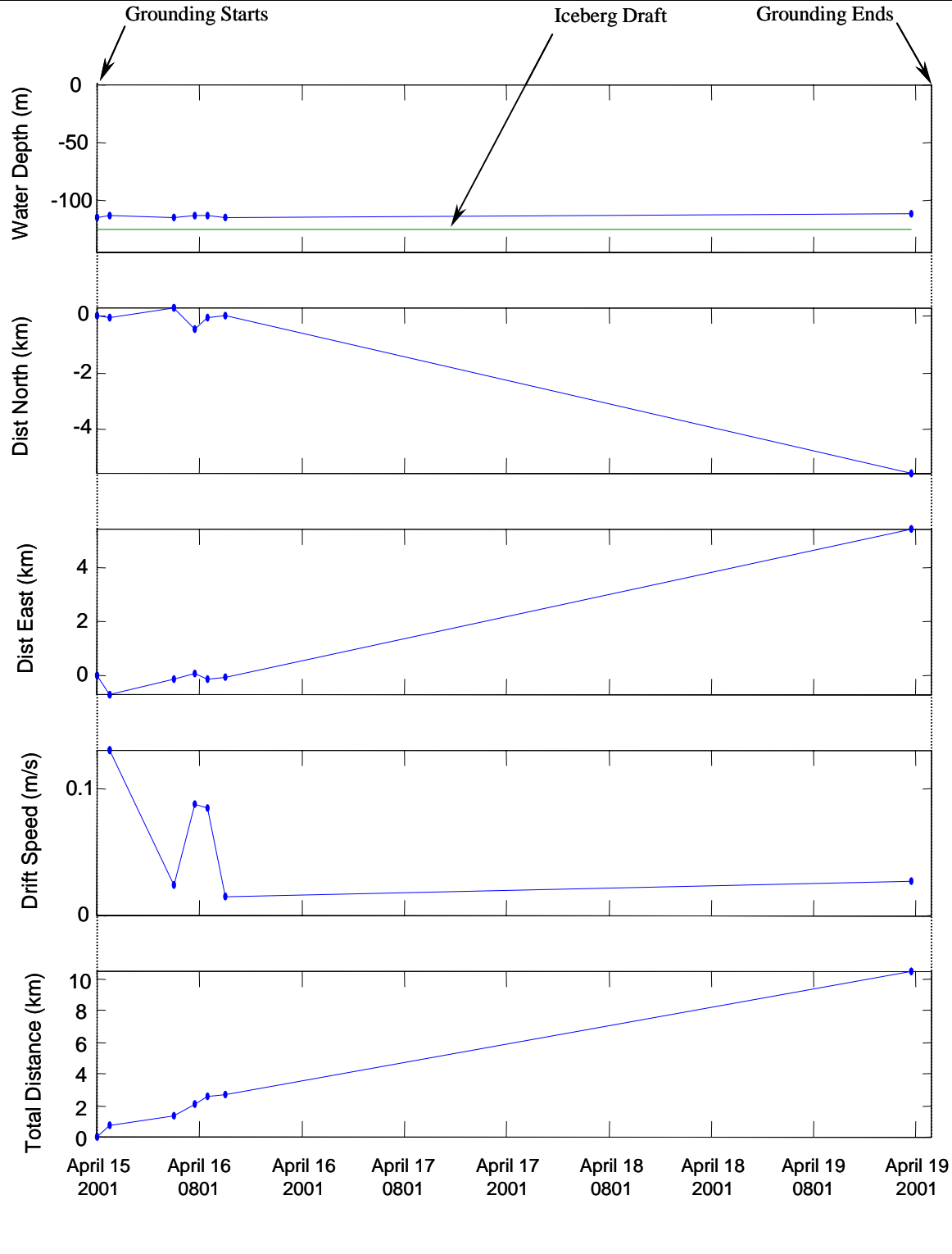


**All Points Expected Grounded.  
Point (47-36.40N, 49-32.22W)  
Listed as Grounded in Database**



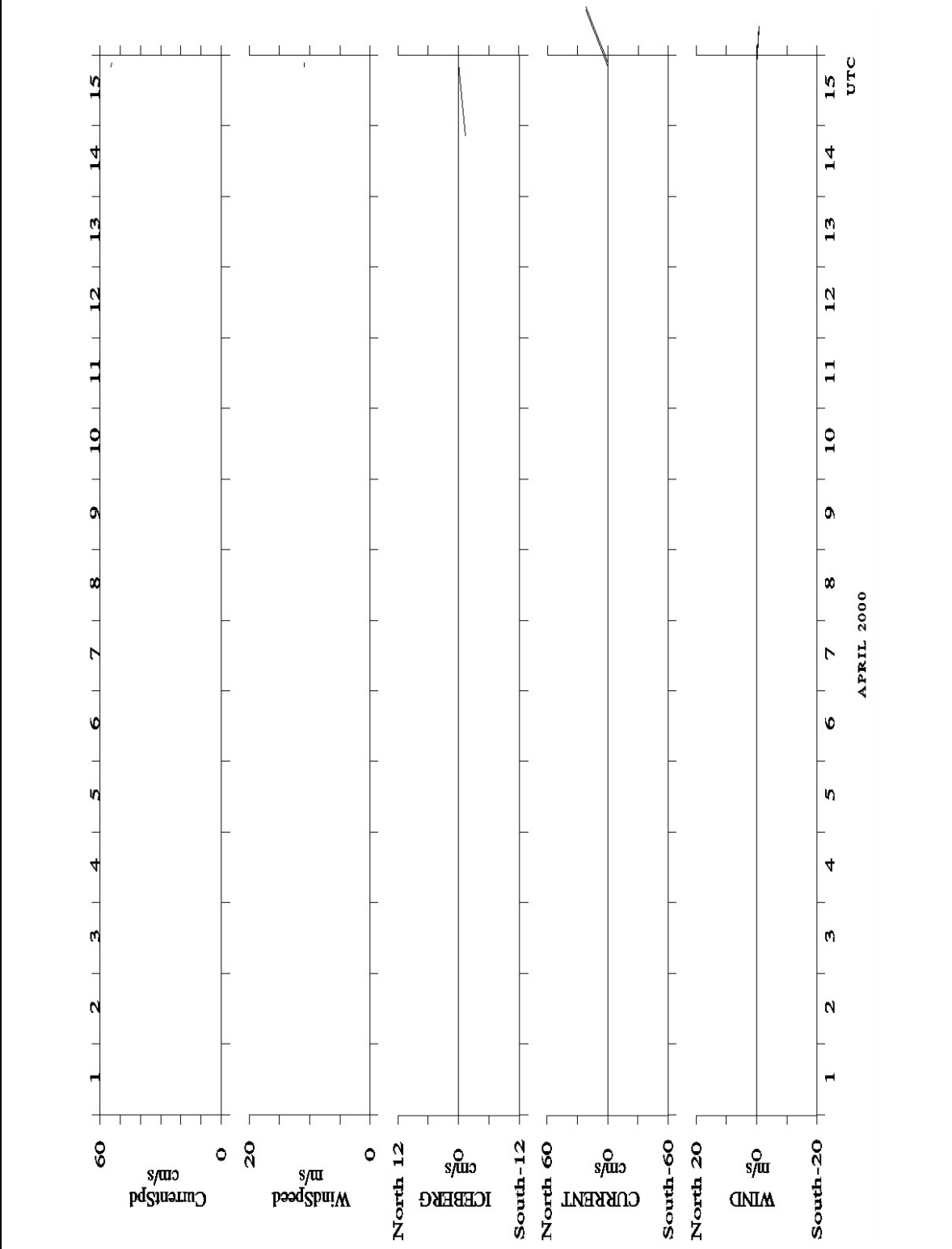
# Iceberg 00-032

# Drift Data



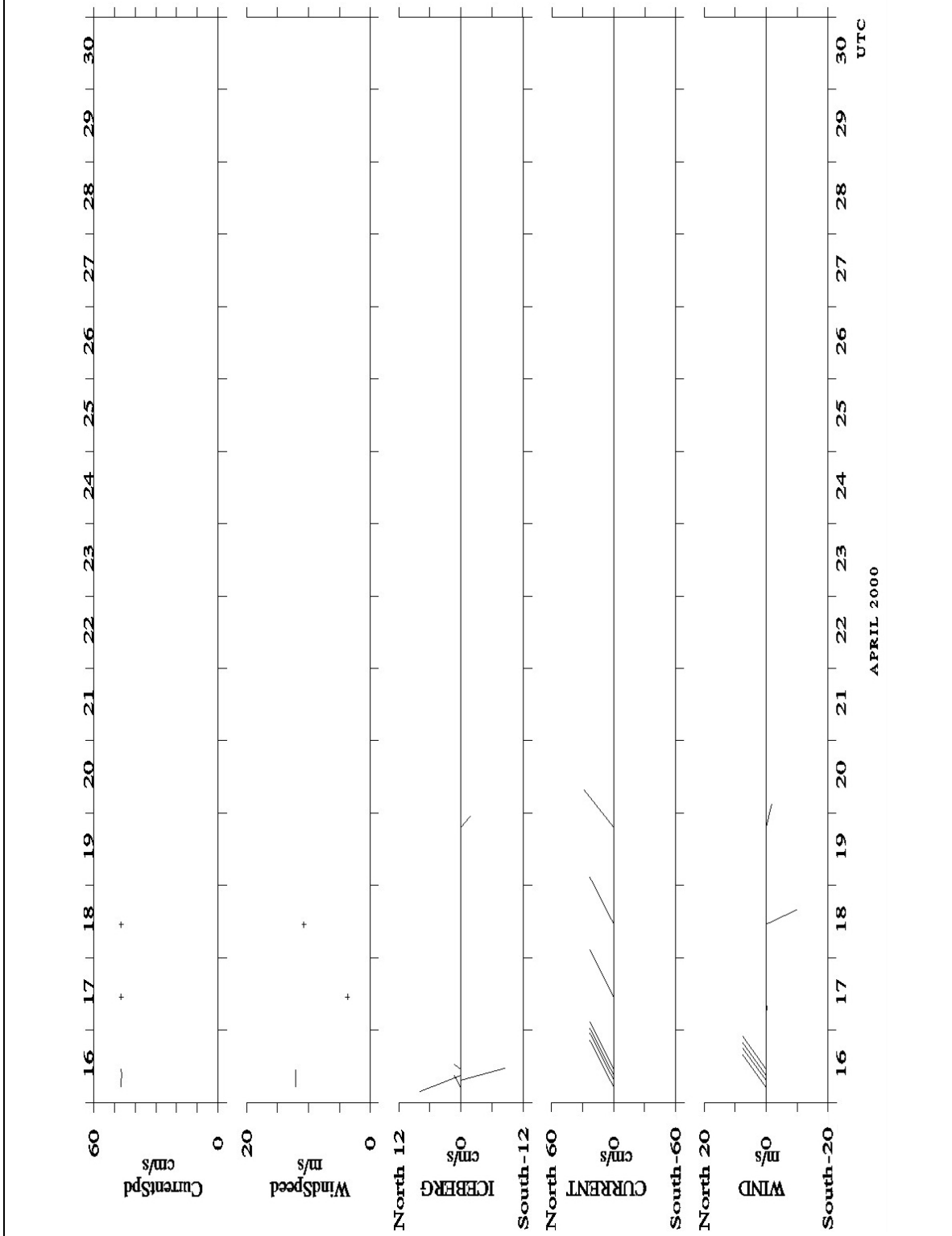
**Iceberg 00-032**

**Environmental Data**




# Iceberg 00-032

# Environmental Data



APRIL 2000

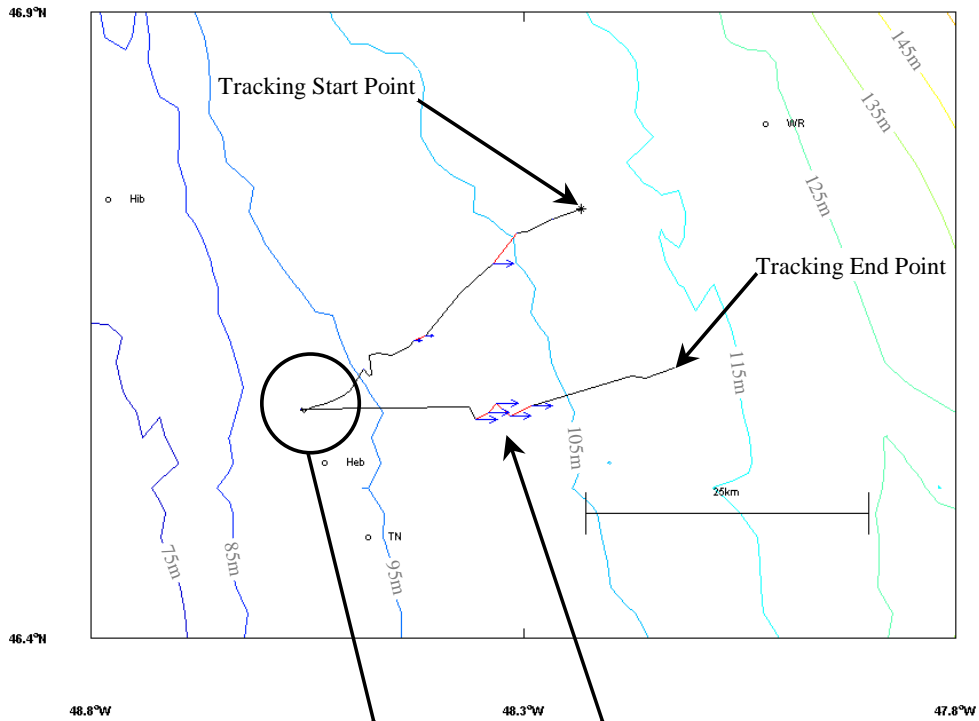
UTC

| Iceberg 00-044                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | General                                                                                                                                                                                                                                                                    |
|----------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Iceberg Particulars                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <p> <b>Size:</b> Medium<br/> <b>Length:</b> 100m<br/> <b>Width:</b> 60m<br/> <b>Height:</b> 30m<br/> <b>Estimated Draft*:</b> 74m<br/> <b>Reported Shape:</b> Pinnacle<br/> <b>Approx. Grounded Location:</b> 46° 34.99' N, 48° 33.40' W<br/> <b>Water Depth:</b> 91m </p> |
| * Draft was estimated using the equation in Section 2.1. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                            |
| Anecdotal Information                                    | <ul style="list-style-type: none"> <li>• Iceberg was tracked from April 23 to April 29, 2000 using Glomar Grand Banks radar and visual observation from ships in the area.</li> <li>• Iceberg was reported to have been towed aground by the <i>Trinity Sea</i>. The tow was lost by this vessel at 23:42, April 23 and was deemed grounded at approximately 18:20 on April 24.</li> <li>• Total time seemed grounded: ~30 hours</li> <li>• Iceberg was reported ungrounded by April 26 and was towed by the <i>Maersk Placentia</i> for approximately 7 hours.</li> <li>• No other grounding incidents were reported for this iceberg.</li> <li>• The <i>Maersk Placentia</i> towed a side scan sonar unit over the grounding location in Fall 2000 to obtain a two-dimensional view of the scour site; however, no analysis or reporting of the collected data has been performed yet. The data should be available. [Jim Dempsey, Cormorant Ltd., personal communication, April 2001]</li> </ul>                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                            |
| Environmental Conditions                                 | <ul style="list-style-type: none"> <li>• Winds light-moderate 6-10m/s April 23-28 becoming strong 14m/s April 29. Winds were from the north on the 23<sup>rd</sup>, from the SE on the 24<sup>th</sup> and then generally from the south for the remainder of the period except from the north on the 27<sup>th</sup>.</li> <li>• Currents ~10-14cm/s on the 23<sup>rd</sup>, 28<sup>th</sup> and 29<sup>th</sup> but low at ~5cm/s for the 24<sup>th</sup> through 27<sup>th</sup>. Currents generally to the NE (or NNW on the 24<sup>th</sup>) through SE.</li> <li>• There is some uncertainty with the estimated grounding duration since there are no berg positions from early morning on the 26<sup>th</sup> to midday on the 28<sup>th</sup>; however, from the evening of the 24<sup>th</sup> leading up to that time on the 26<sup>th</sup>, the winds were to the NW or north perhaps keeping the berg in alongside the shallower bathymetry. The currents, small in magnitude, were to the north on the 24<sup>th</sup> then changing to the SE on the 25<sup>th</sup>. Both winds and currents on the subsequent days, the 28<sup>th</sup> and 29<sup>th</sup> are offshore towards the NE through SE consistent with the berg's track.</li> </ul> |                                                                                                                                                                                                                                                                            |



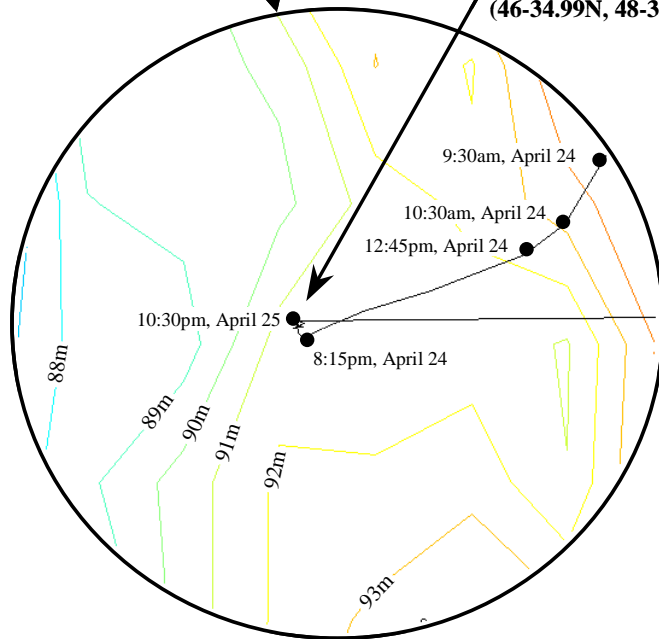
# Iceberg 00-044

# Trackplot



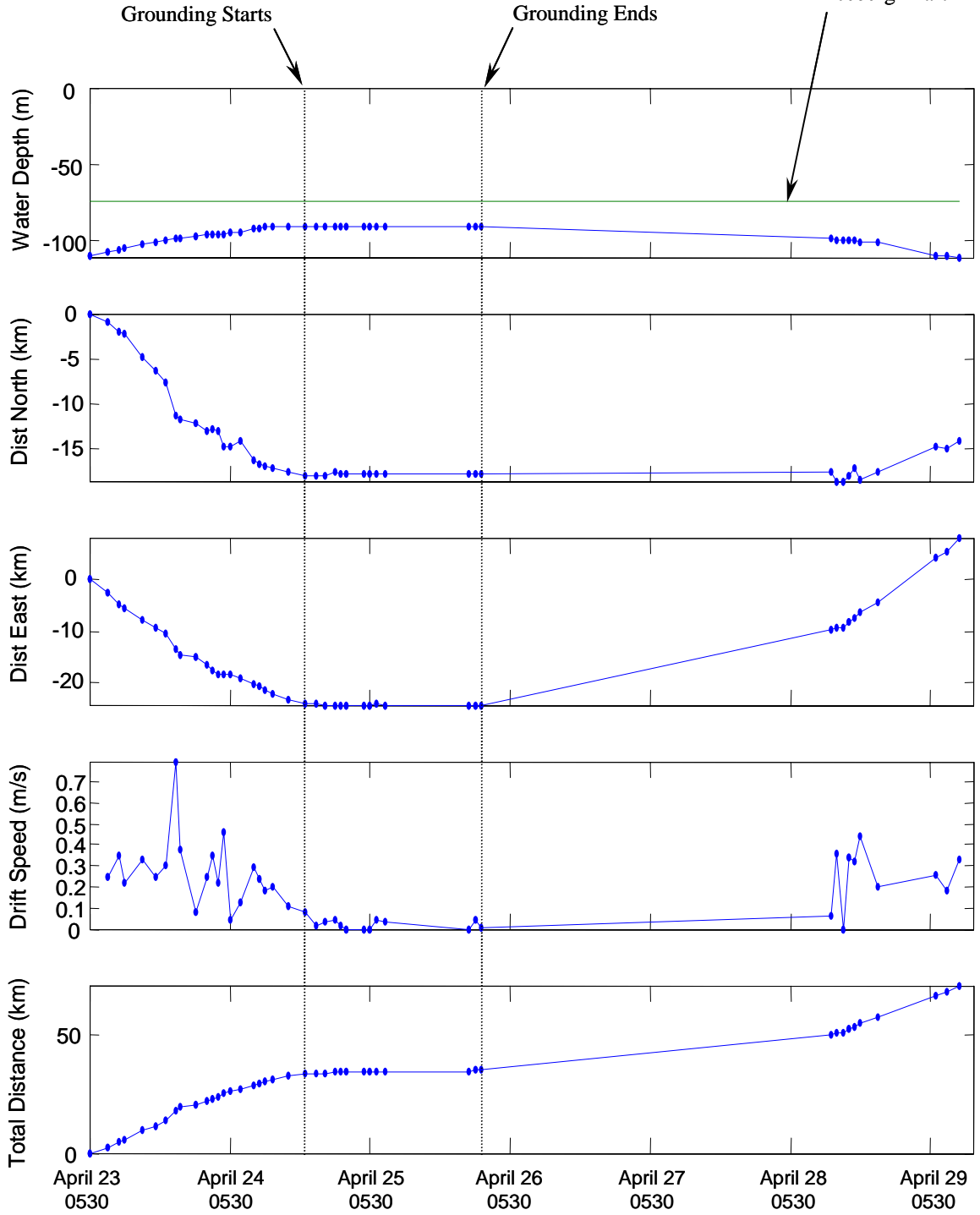
Tow force vectors

**Reported Grounding Location  
(46-34.99N, 48-33.40W)**



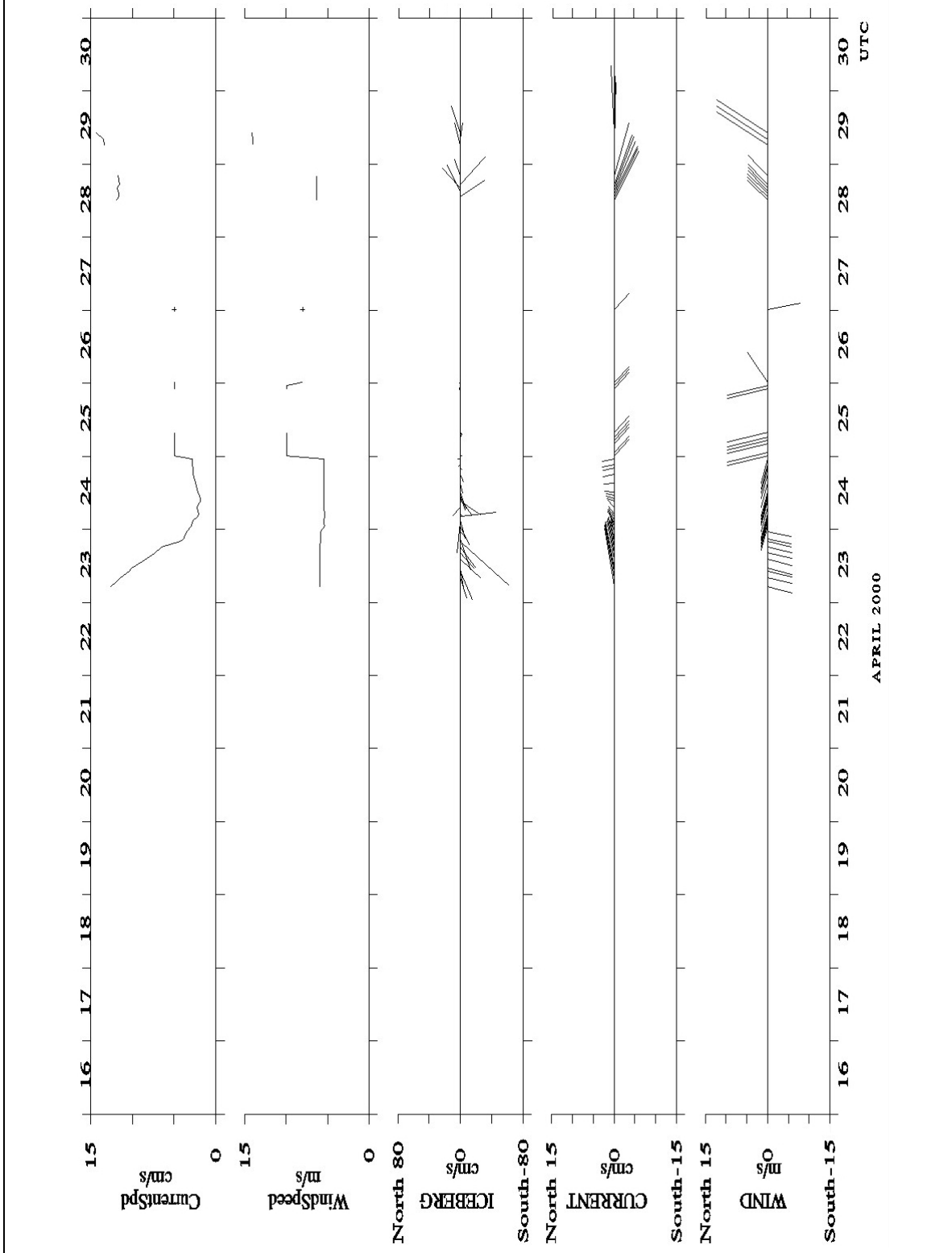
# Iceberg 00-044


# Drift Data



# Iceberg 00-044

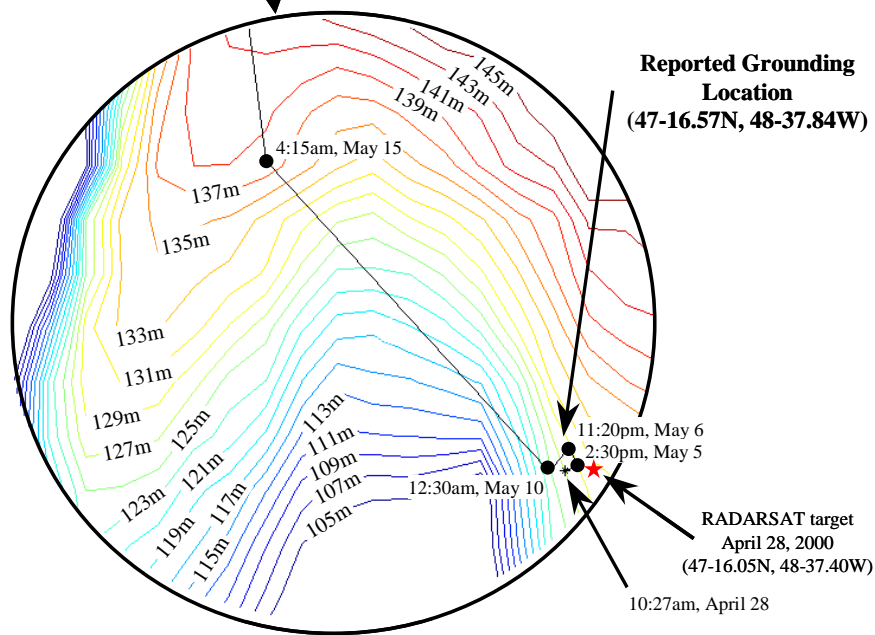
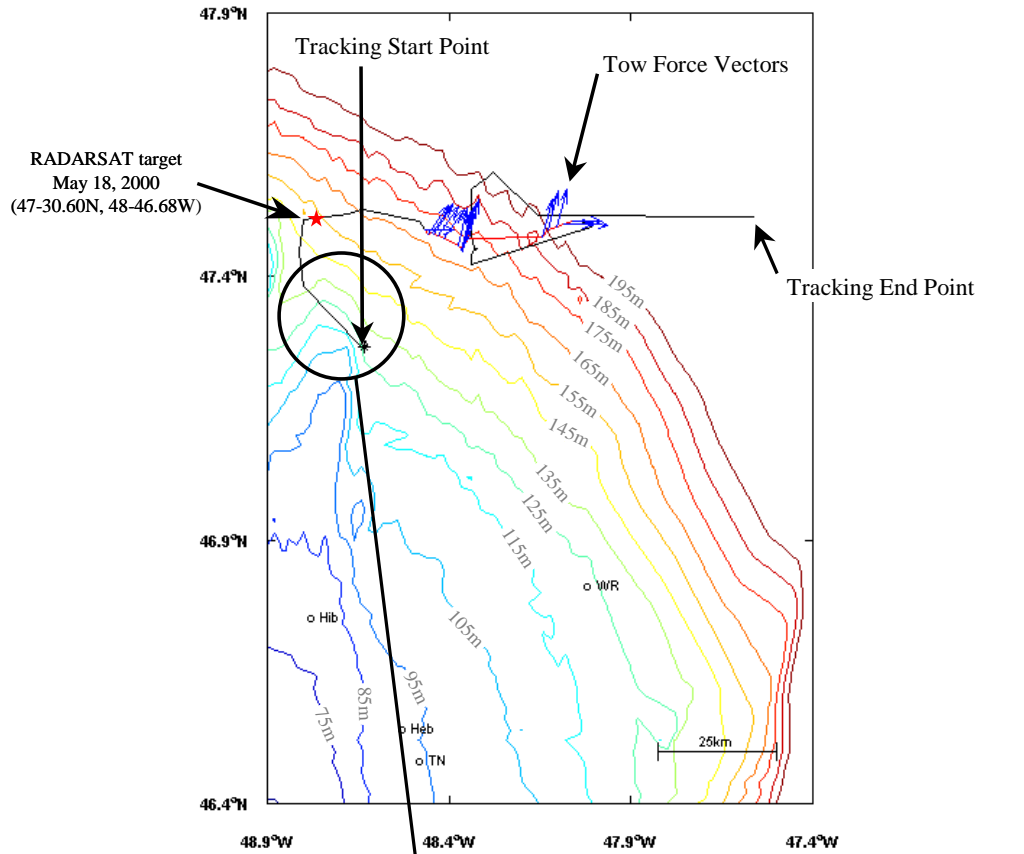
# Environmental Data



| Iceberg 00-065                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | General                                                                                                                                                                                                                                                                                     |
|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Iceberg Particulars</b>                               |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <p><b>Size:</b> Large</p> <p><b>Length:</b> 242m</p> <p><b>Width:</b> 76m</p> <p><b>Height:</b> 55m</p> <p><b>Estimated Draft*:</b> 135m</p> <p><b>Reported Shape:</b> Pinnacle</p> <p><b>Approx. Grounded Location:</b><br/>47° 16.57' N, 48° 37.84' W</p> <p><b>Water Depth:</b> 127m</p> |
| * Draft was estimated using the equation in Section 2.1. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                             |
| <b>Anecdotal Information</b>                             | <ul style="list-style-type: none"> <li>• Iceberg was tracked from April 28 to June 4, 2000 using radar and visual observation from ships in the area.</li> <li>• Iceberg was expected to be grounded 10:27, April 28 when tracking first began.</li> <li>• Total time expected grounded: ~330 hours</li> <li>• Iceberg was reported as ungrounded by 05:00 on May 12 and was later towed by the <i>Maersk Gabarus</i> for approximately two and a half days.</li> <li>• No other grounding incidents were reported as the iceberg entered deeper water.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                             |
| <b>Environmental Conditions</b>                          | <ul style="list-style-type: none"> <li>• Winds generally light-moderate 3-10m/s from April 28 through May 11, except for strong 15m/s winds to the NE April 29. A fair degree of fluctuation in wind directions during this period, but generally blowing offshore to the north through SE.</li> <li>• Currents generally moderate ~30-60cm/s to the east and NE through this same April 18 to May 11 period of interest.</li> <li>• Winds and currents also appear to be of moderate magnitude and direction generally to the NW through NE for the 12<sup>th</sup> through the 19<sup>th</sup> when the berg drifted up to the NW and N into deeper waters until having towing commence on the 19<sup>th</sup>.</li> <li>• Through the period at least from the 28<sup>th</sup> through 6<sup>th</sup> the winds and currents appear to have been of sufficient magnitude and direction that they would have otherwise moved the berg further offshore into deeper waters had it not been grounded, particularly the near gale force winds to the NE on the 29<sup>th</sup>.</li> </ul> |                                                                                                                                                                                                                                                                                             |

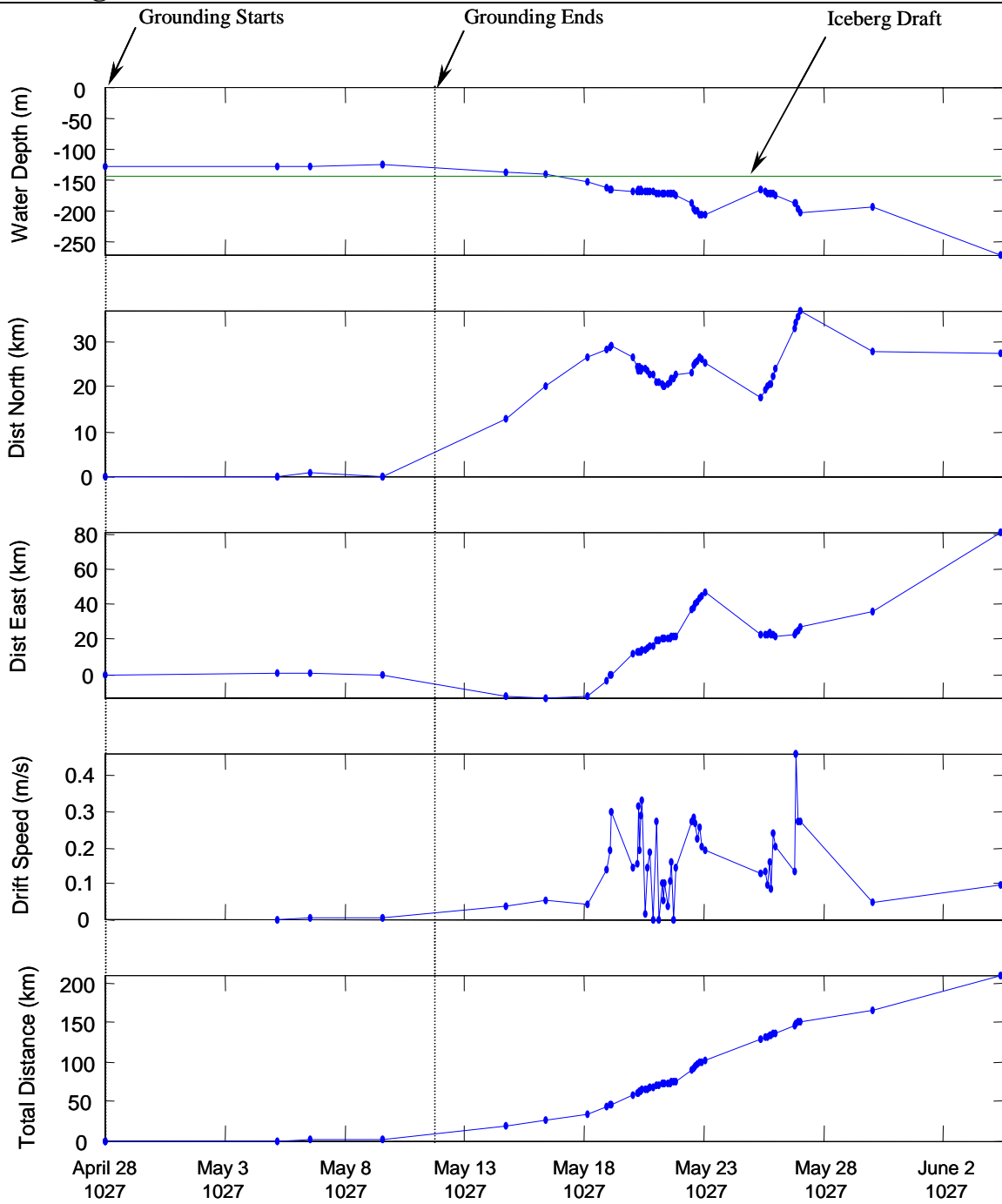
# Iceberg 00-065

# Trackplot



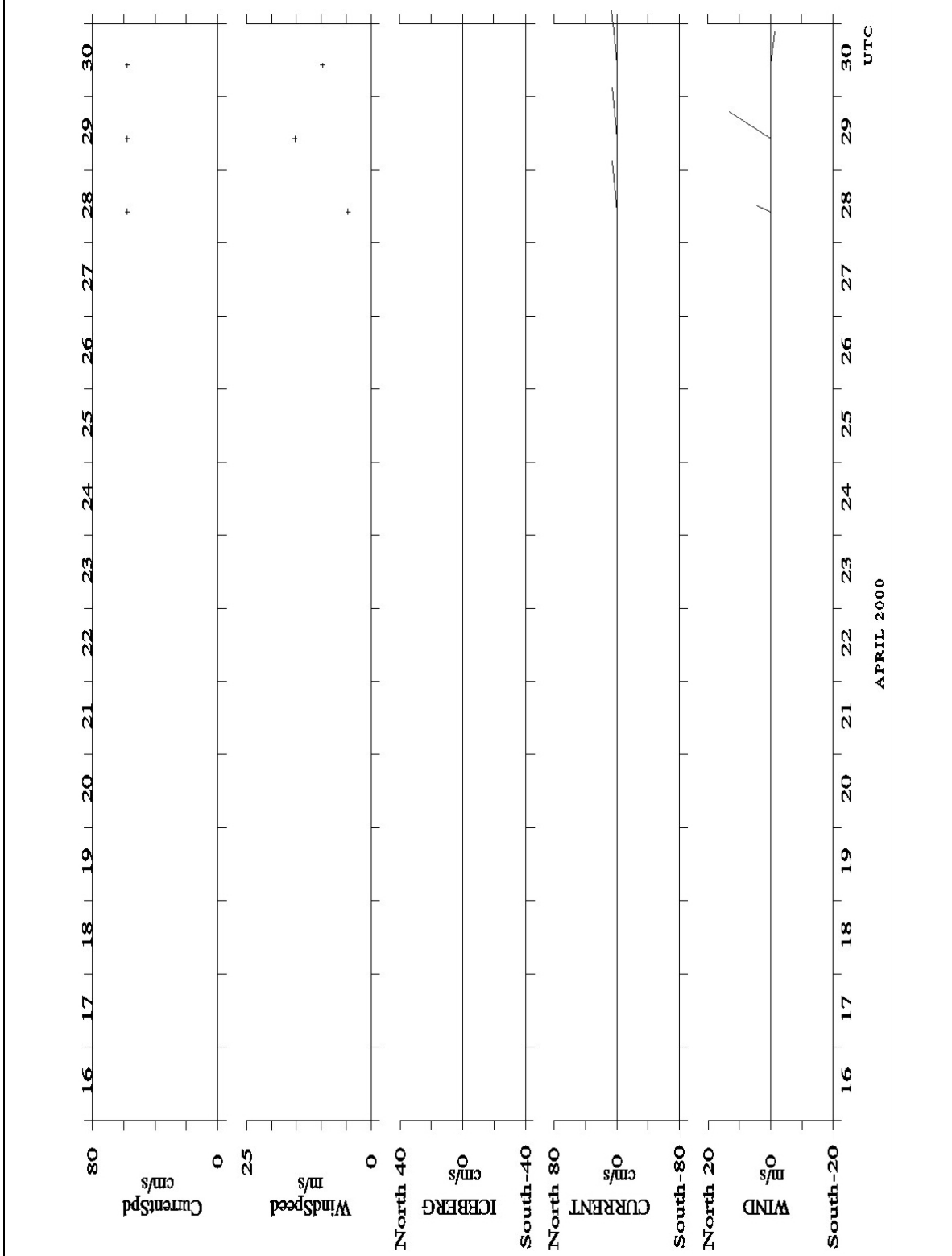
# Iceberg 00-065

# Drift Data



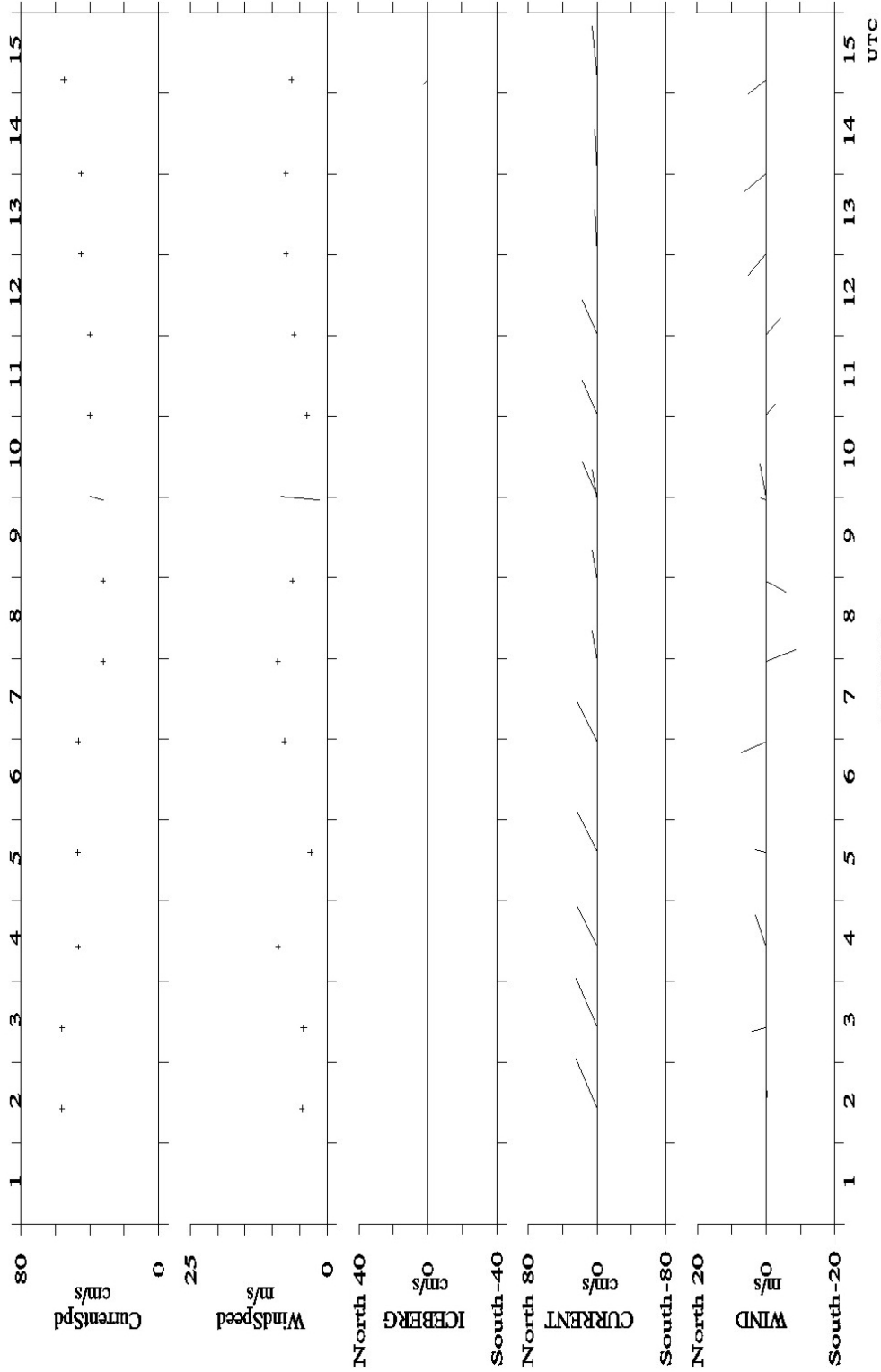
# Iceberg 00-065

# Environmental Data



# Iceberg 00-065

# Environmental Data



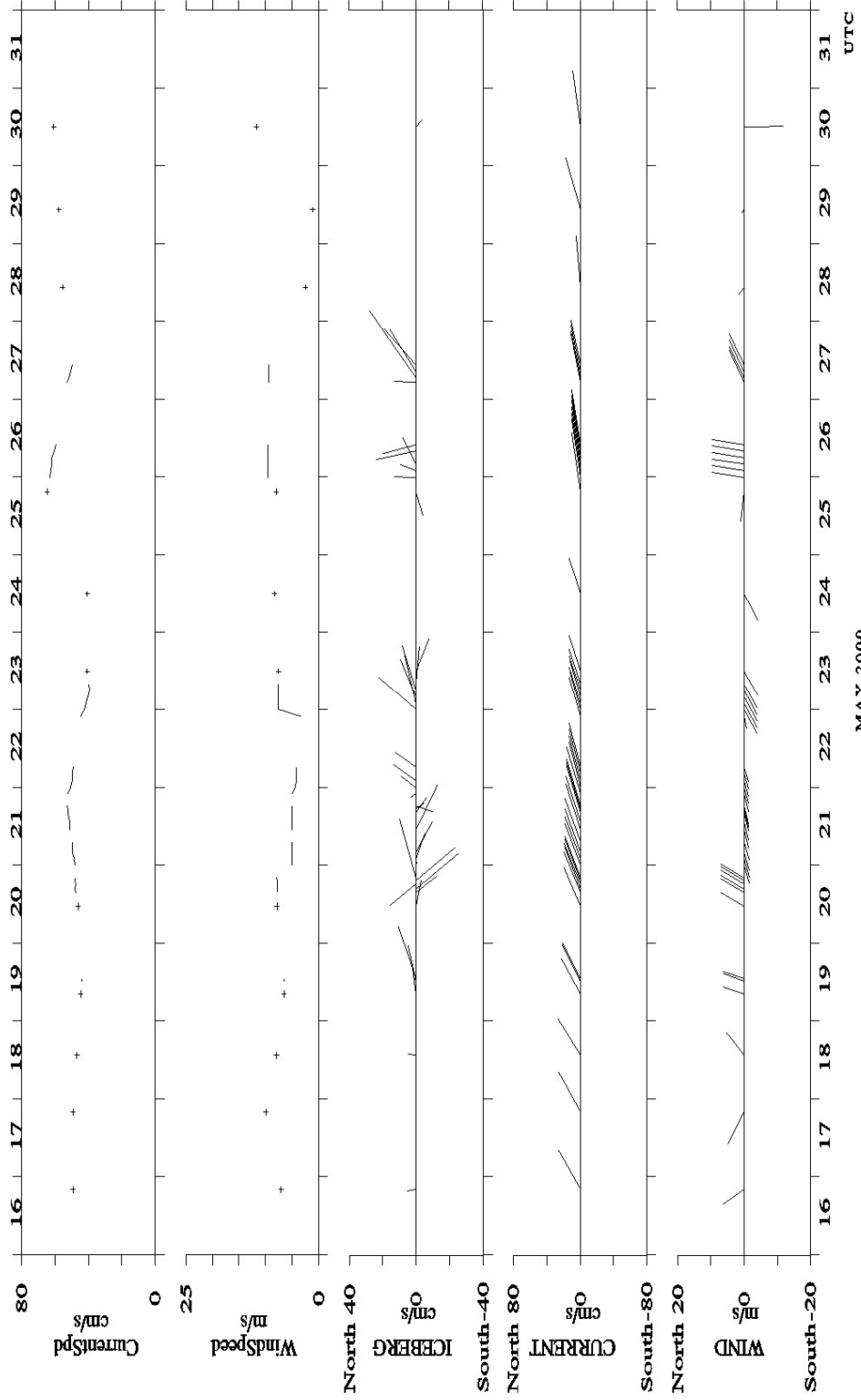
MAY 2000

UTC




# Iceberg 00-065

# Environmental Data

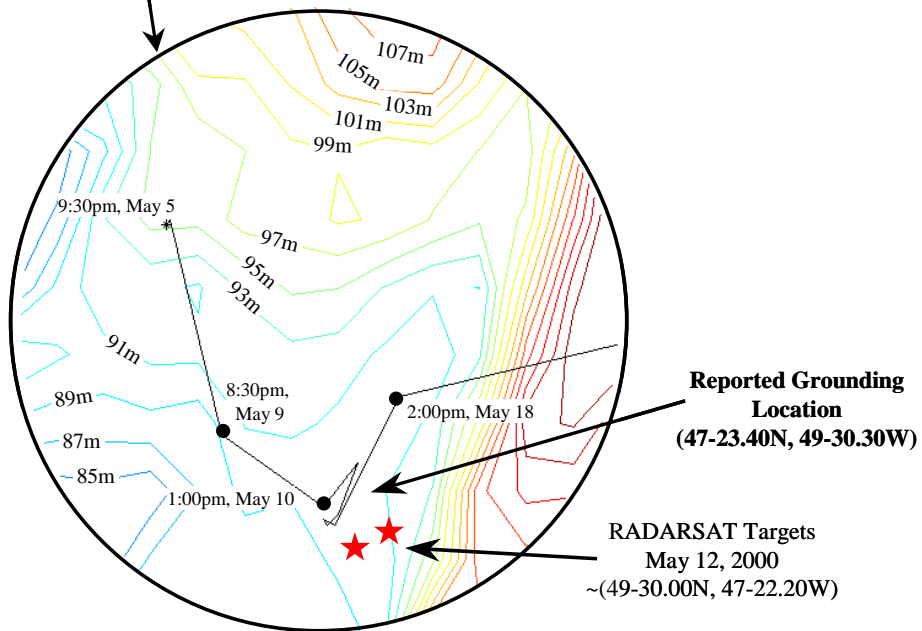
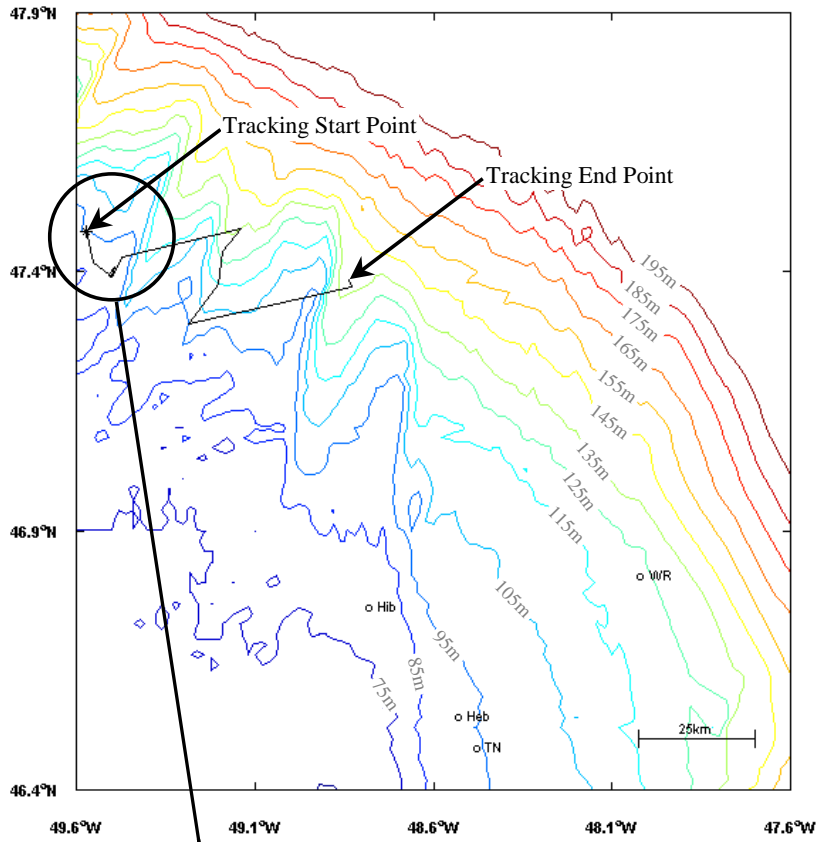


MAY 2000

| Iceberg 00-067                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | General                                                                                                                                                                                                                                                                                |
|-----------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Iceberg Particulars</b>                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <p><b>Size:</b> Large</p> <p><b>Length:</b> 110m</p> <p><b>Width:</b> 76m</p> <p><b>Height:</b> 40m</p> <p><b>Estimated Draft*:</b> 102m</p> <p><b>Reported Shape:</b> Pinnacle</p> <p><b>Approx. Grounded Location:</b> 47° 23.40' N, 49° 30.30' W</p> <p><b>Water Depth:</b> 90m</p> |
| *Draft was measured using side-scan sonar equipment 8½ days after the start of the grounding event. |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                        |
| <b>Anecdotal Information</b>                                                                        | <ul style="list-style-type: none"> <li>• Iceberg was tracked from May 5 to June 8, 2000 using radar and visual observation from ships in the area.</li> <li>• Iceberg was reported by the <i>Tignish Sea</i> to have broken in half 01:20 on May 12. It was reported to be grounded by the <i>Maersk Nascopie</i> 16:40 on May 12 and is expected to have ungrounded by 00:05 on May 17.</li> <li>• Total time expected grounded: ~104 hours</li> <li>• No ice management towing operations were performed on this iceberg.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                        |
| <b>Environmental Conditions</b>                                                                     | <ul style="list-style-type: none"> <li>• While further to the WNW than iceberg 65, iceberg 67 seemed to be subject to similar winds and currents over the similar time period of early to mid-May. The focus with 67 is the assumed grounding period of May 12-17.</li> <li>• Winds generally light-moderate 4-10m/s from the 12<sup>th</sup> through the 17<sup>th</sup>. Some degree of fluctuation in wind directions during this period, to the SE on the 12<sup>th</sup>, then to the NW for the 13<sup>th</sup> through 17<sup>th</sup>, then to the NE for the 18<sup>th</sup> to 20<sup>th</sup>.</li> <li>• Currents ~20-30cm/s consistently to the NE through this same May 12-17 period. Currents for the other days in the tracking period May 5-30 are similar ~20-40cm/s.</li> <li>• Winds and currents also appear to be of sufficient magnitude and direction generally to the NE following the 17<sup>th</sup> to assist the berg's drift out into deeper waters.</li> <li>• As for berg 65, it appears that through the period from the 12<sup>th</sup> through 17<sup>th</sup> the winds and currents were of sufficient magnitude and direction that they would have otherwise moved the berg NE or north further offshore into deeper waters had it not been grounded.</li> </ul> |                                                                                                                                                                                                                                                                                        |

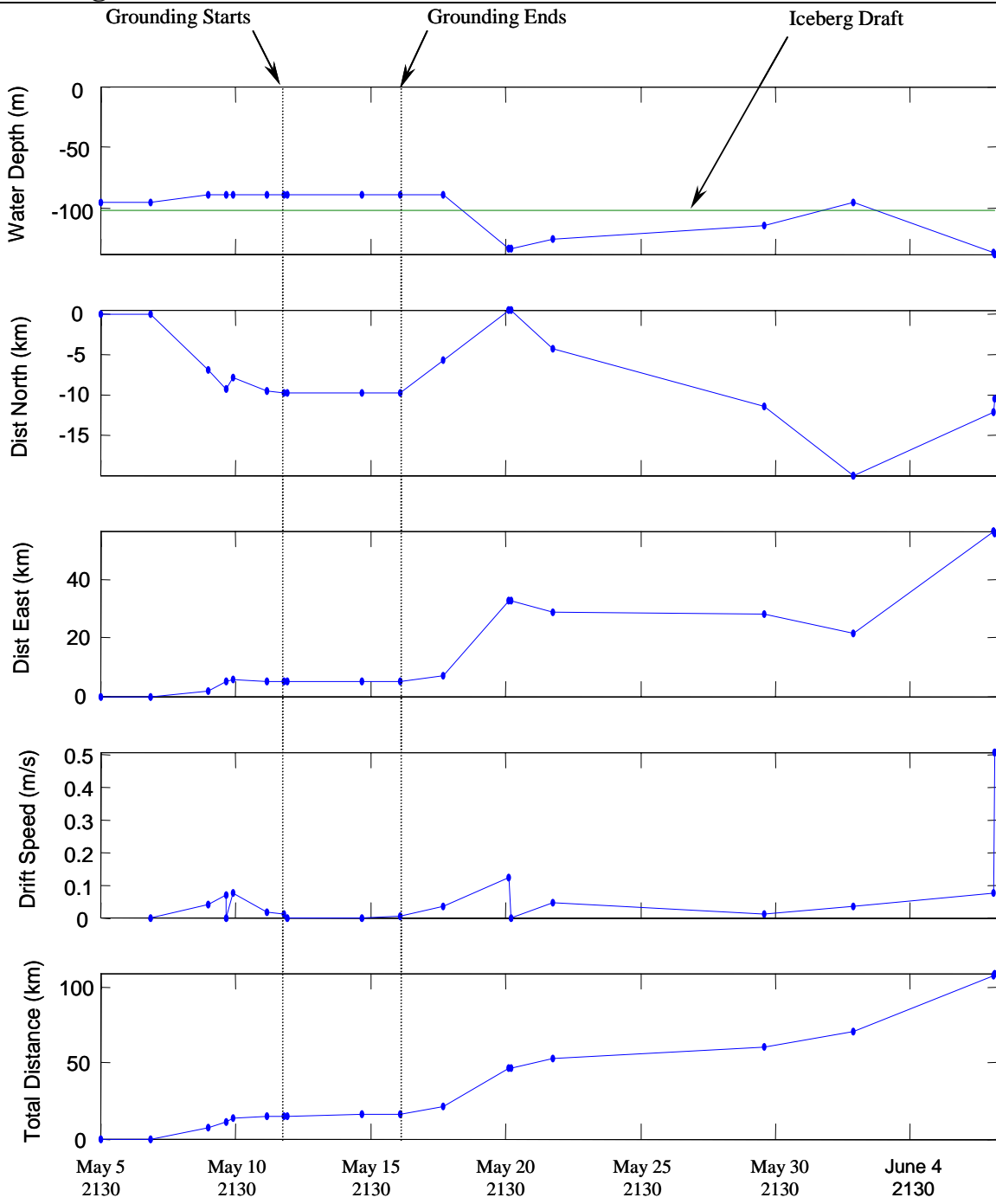
# Iceberg 00-067

# Trackplot



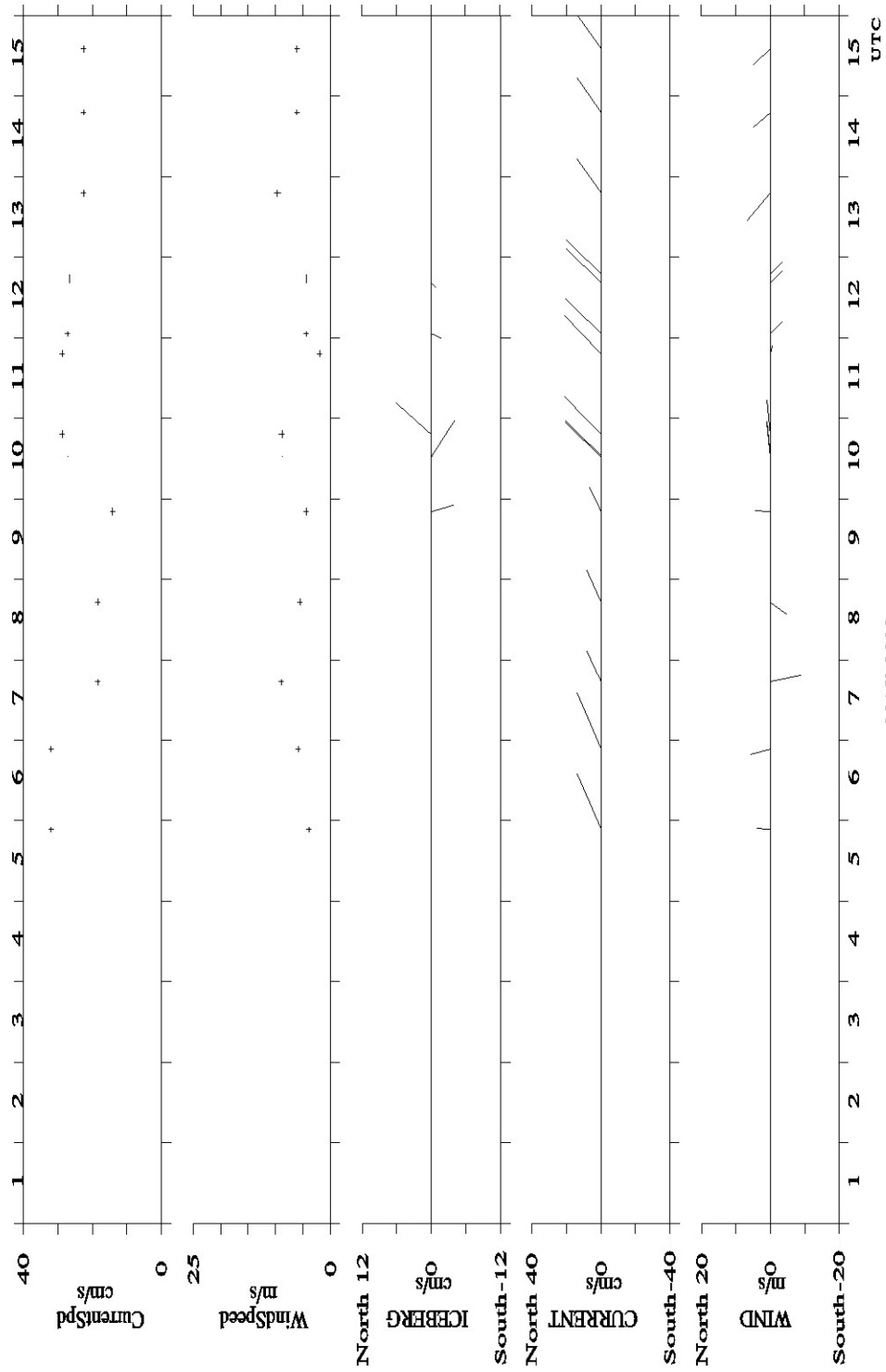
# Iceberg 00-067

# Drift Data



**Iceberg 00-067**

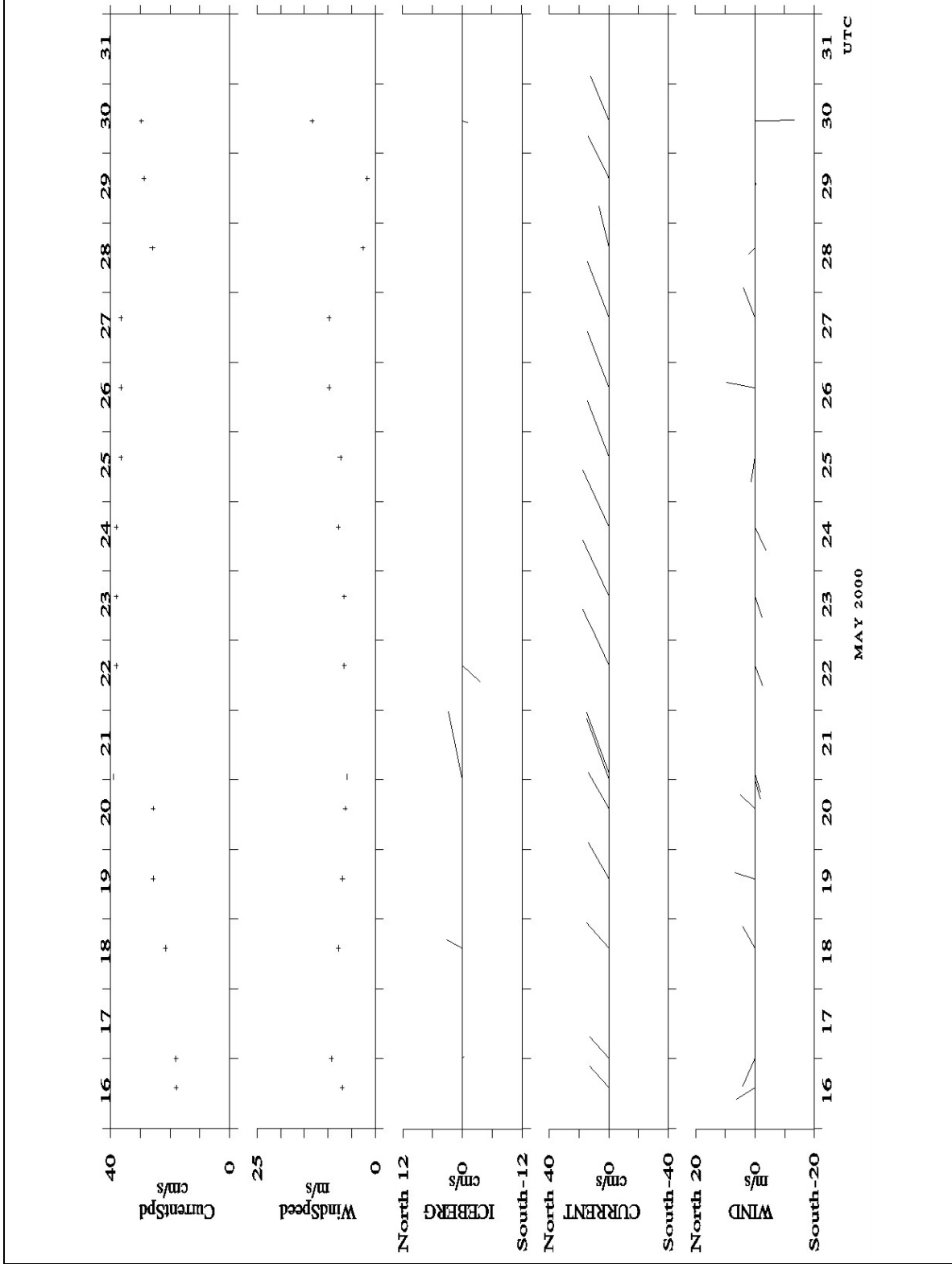
**Environmental Data**




MAY 2000

# Iceberg 00-067

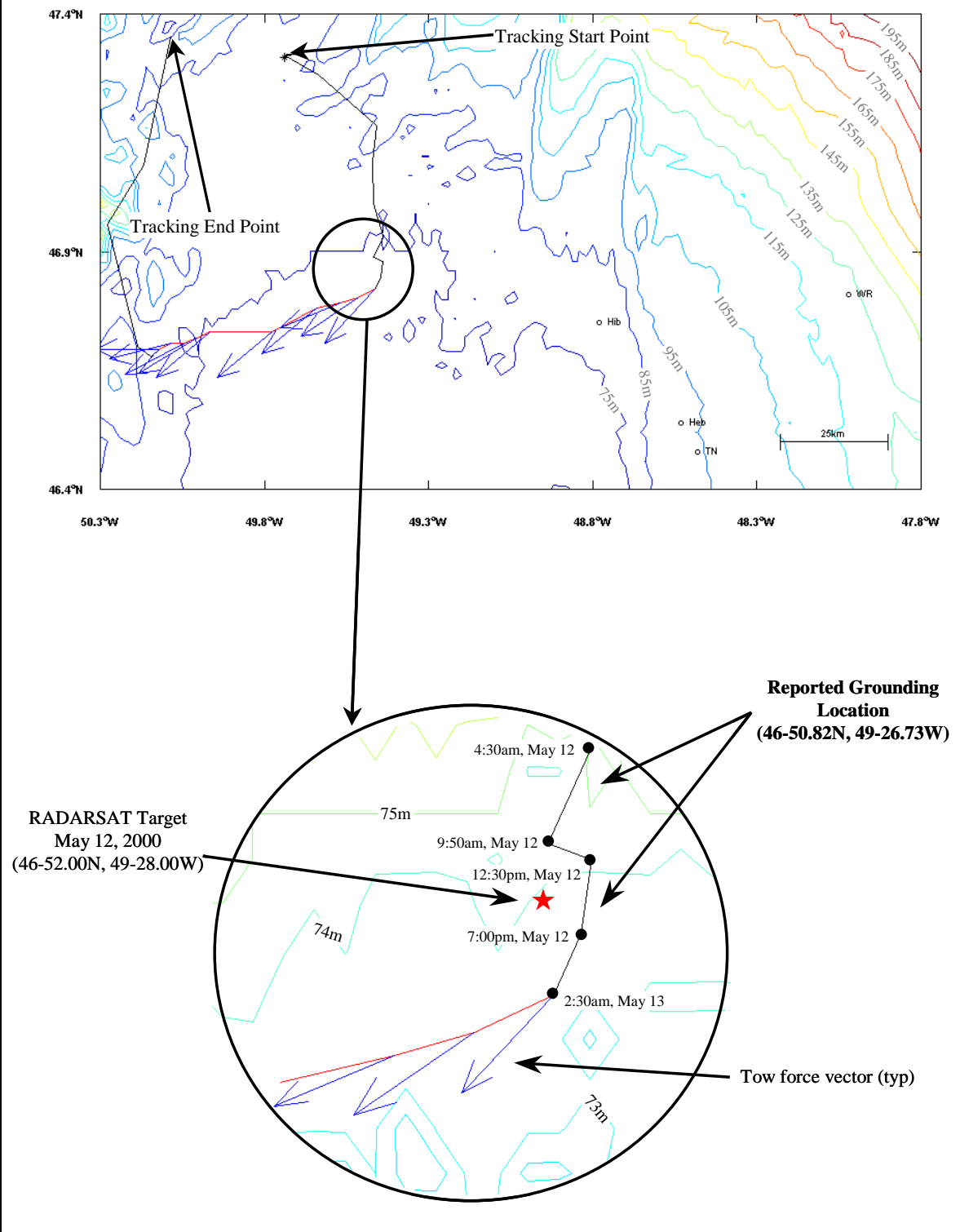
# Environmental Data



| Iceberg 00-068                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | General                                                                                                                                                                                                                                                                         |
|---------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Iceberg Particulars</b>      |                                                                                                                                                                                                                                                                                                                                                                                                                                                     | <b>Size:</b> Medium<br><b>Shape:</b> Dry Dock<br><b>Length:</b> 80m<br><b>Width:</b> 30m<br><b>Height:</b> 15m<br><b>Estimated Draft*:</b> 64m<br><b>Reported Shape:</b> Dry Dock<br><b>Approx. Grounded Location:</b><br>46° 50.82' N, 49° 26.73' W<br><b>Water Depth:</b> 75m |
| <b>Anecdotal Information</b>    | <ul style="list-style-type: none"> <li>• Iceberg was tracked from May 5 to May 19, 2000 using radar and visual observation from ships in the area.</li> <li>• Iceberg was reported as grounded 07:00 on May 11, scouring the seabed from 02:00 to 09:00 on May 12 and still grounded 19:00 May 12.</li> <li>• Total time expected grounded: ~36 hours</li> <li>• Iceberg was towed into shallower water by the <i>Maersk Placentia</i> for approximately one and a half days on May 12 and 13 before having the tow slip.</li> </ul> |                                                                                                                                                                                                                                                                                 |
| <b>Environmental Conditions</b> | <ul style="list-style-type: none"> <li>• Winds generally light up to May 12, then near-moderate 9 m/s on the 13<sup>th</sup>. Winds were to the SE on the 12<sup>th</sup> changing to the NW on the 13<sup>th</sup>.</li> <li>• Currents light ~10cm/or less, to the NW on the 12<sup>th</sup> and to the east and NE on the 13<sup>th</sup>.</li> <li>• The NW winds on the 12<sup>th</sup> were consistent with the iceberg's track to the SE and the grounding. The iceberg's subsequent track was while under tow.</li> </ul>    |                                                                                                                                                                                                                                                                                 |

**Iceberg 00-068**

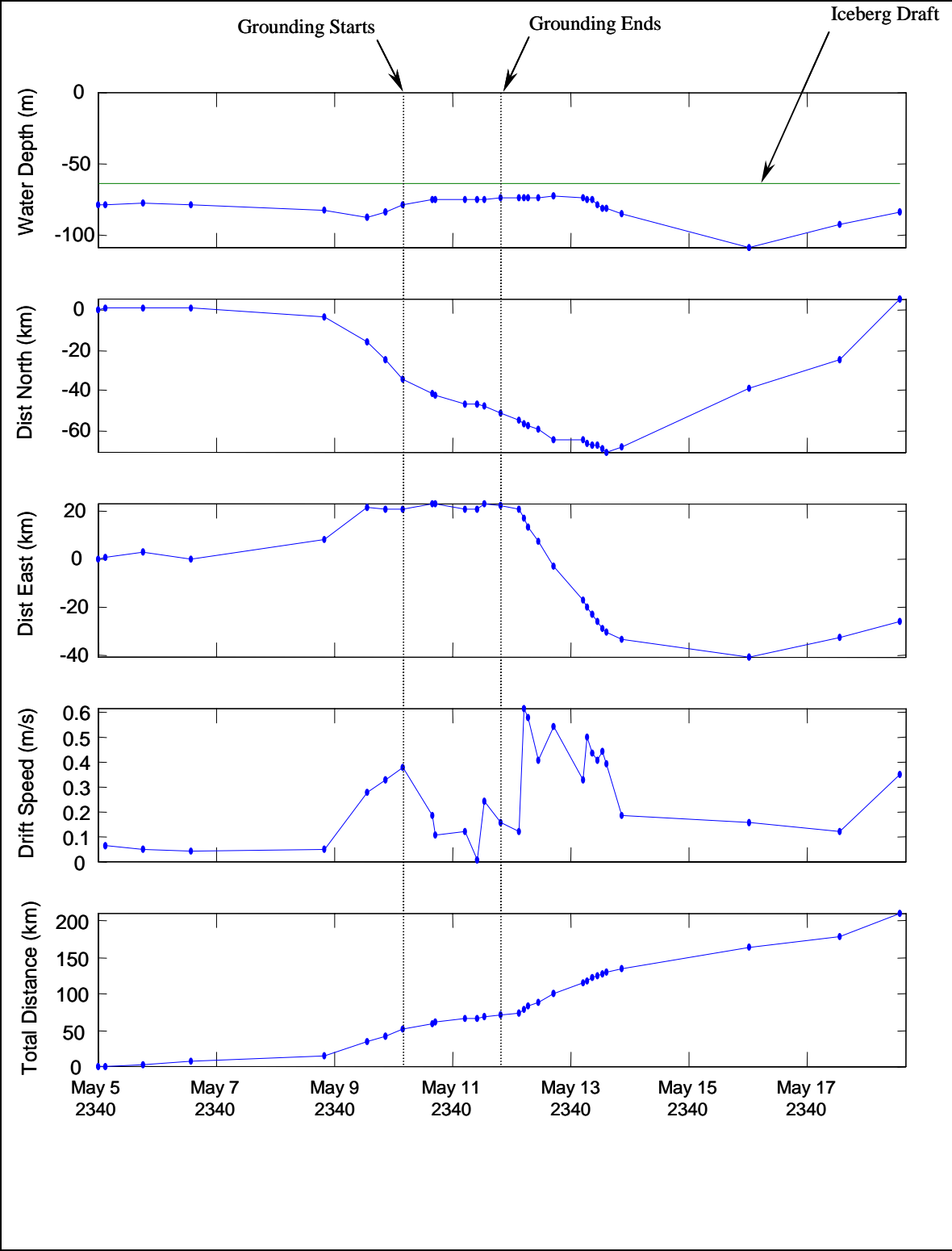
**Trackplot**



**Iceberg 00-068**

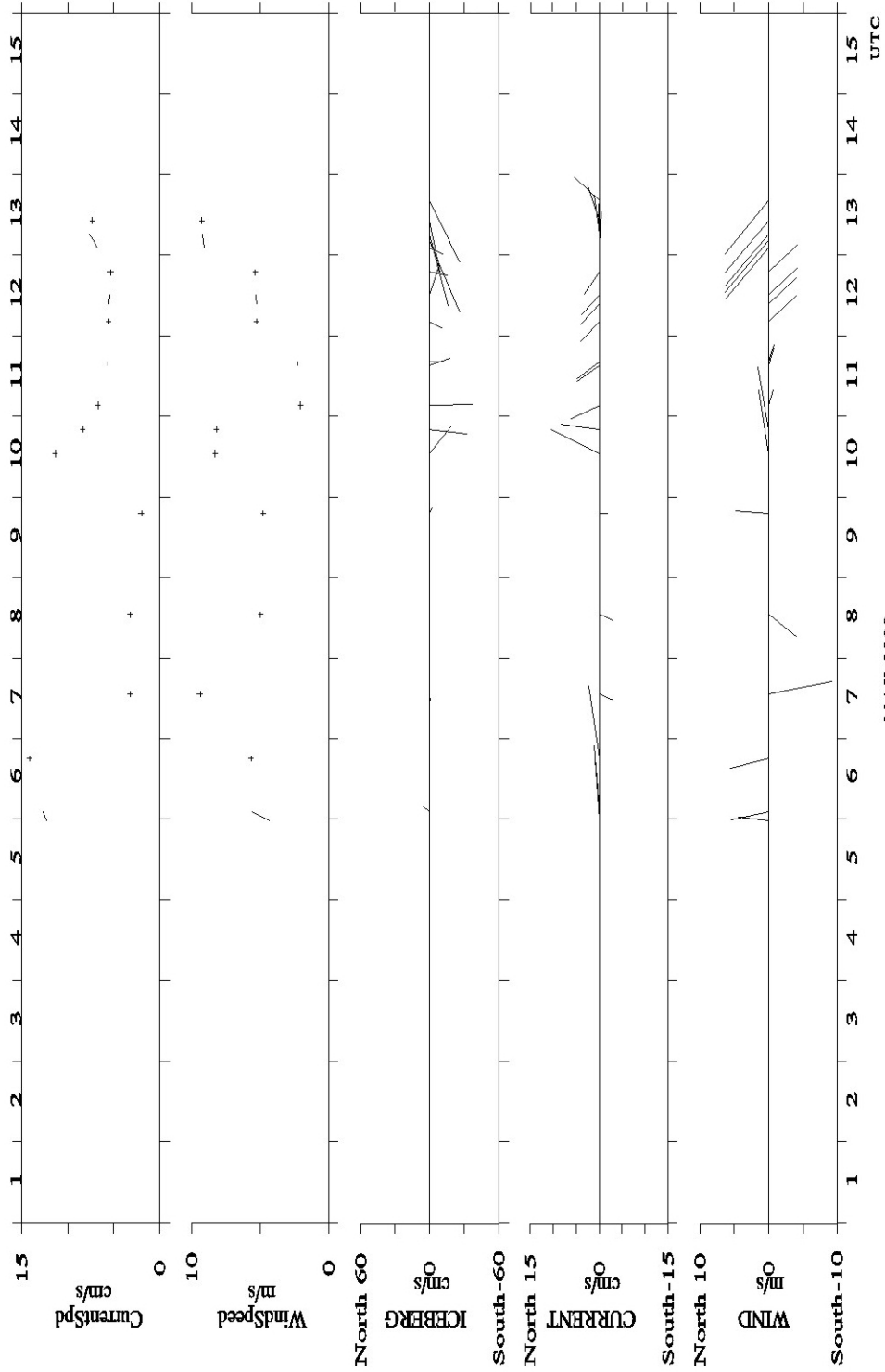
**Drift Data**





# Iceberg 00-068

# Environmental Data

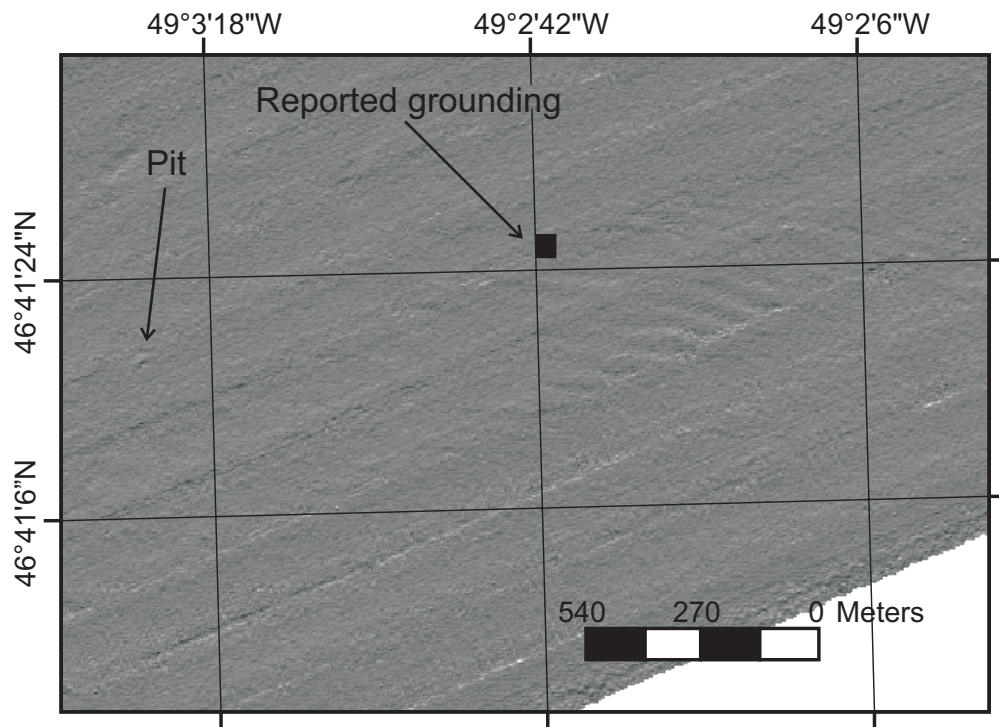
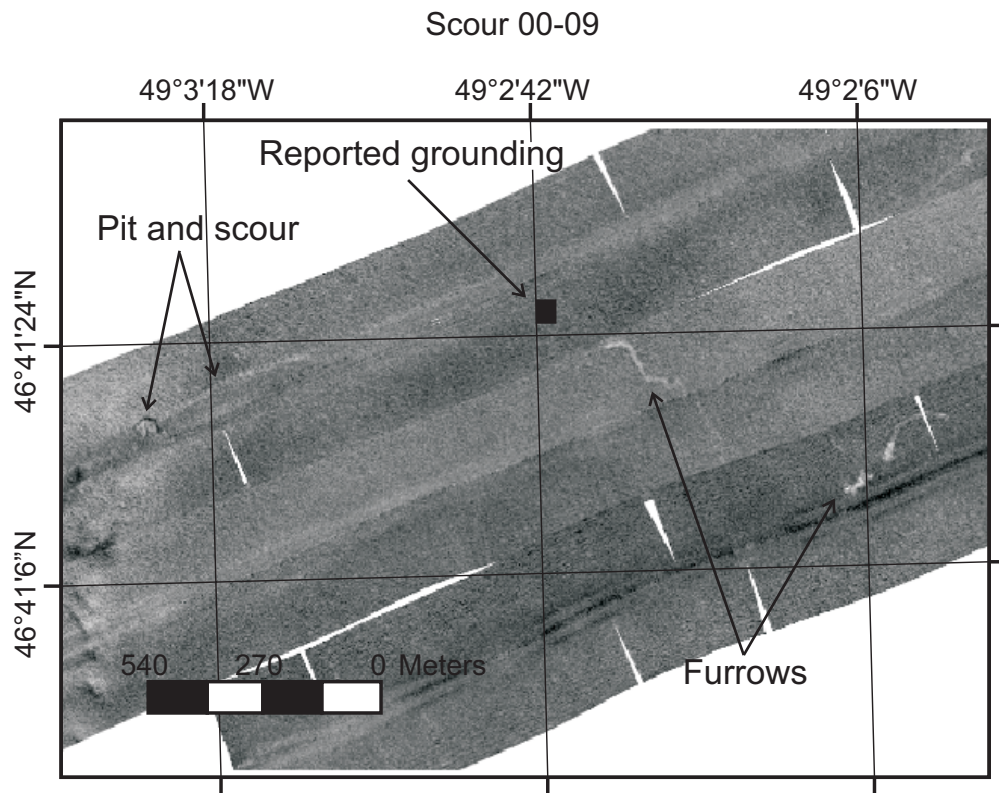


MAY 2000

UTC

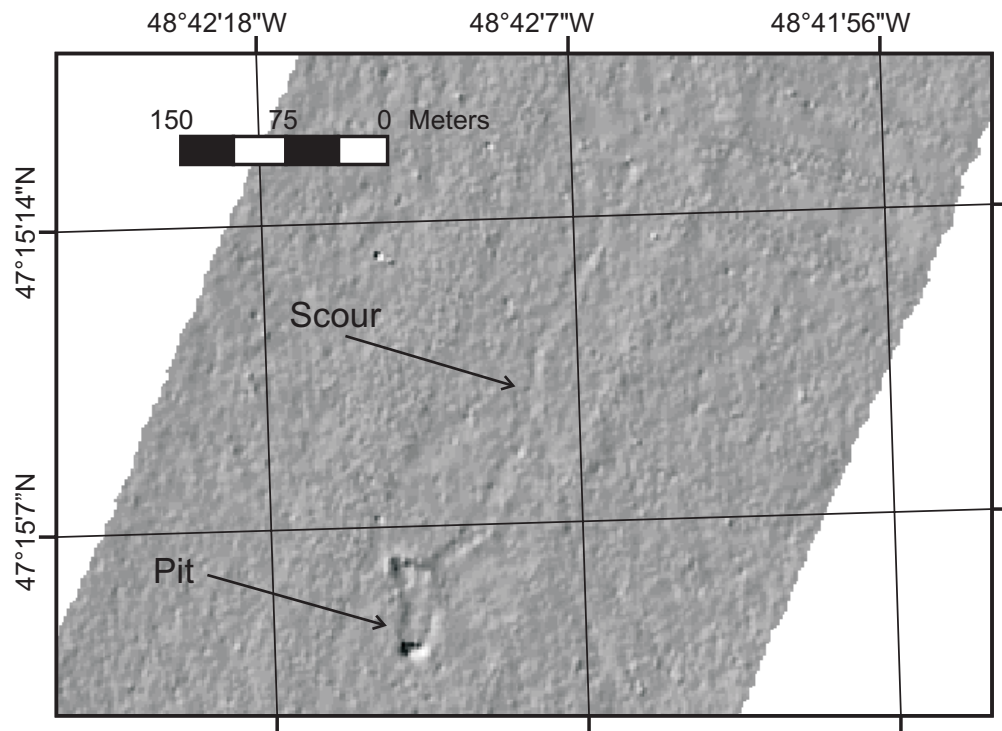
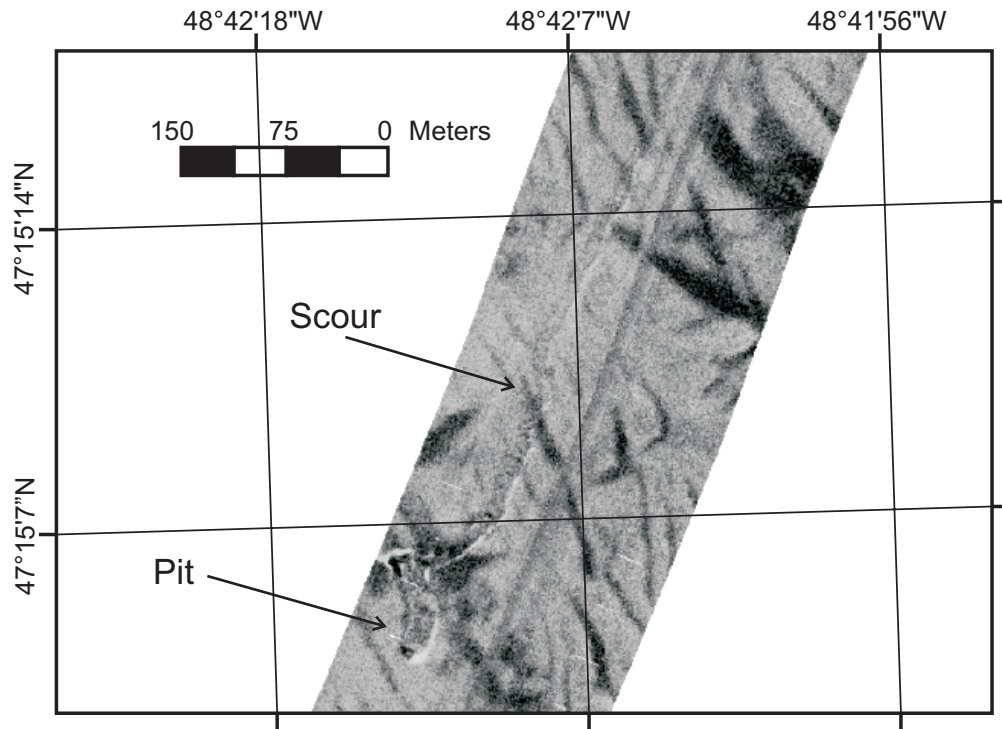
### **APPENDIX III**

Side scan imagery and multibeam  
bathymetry of the groundings



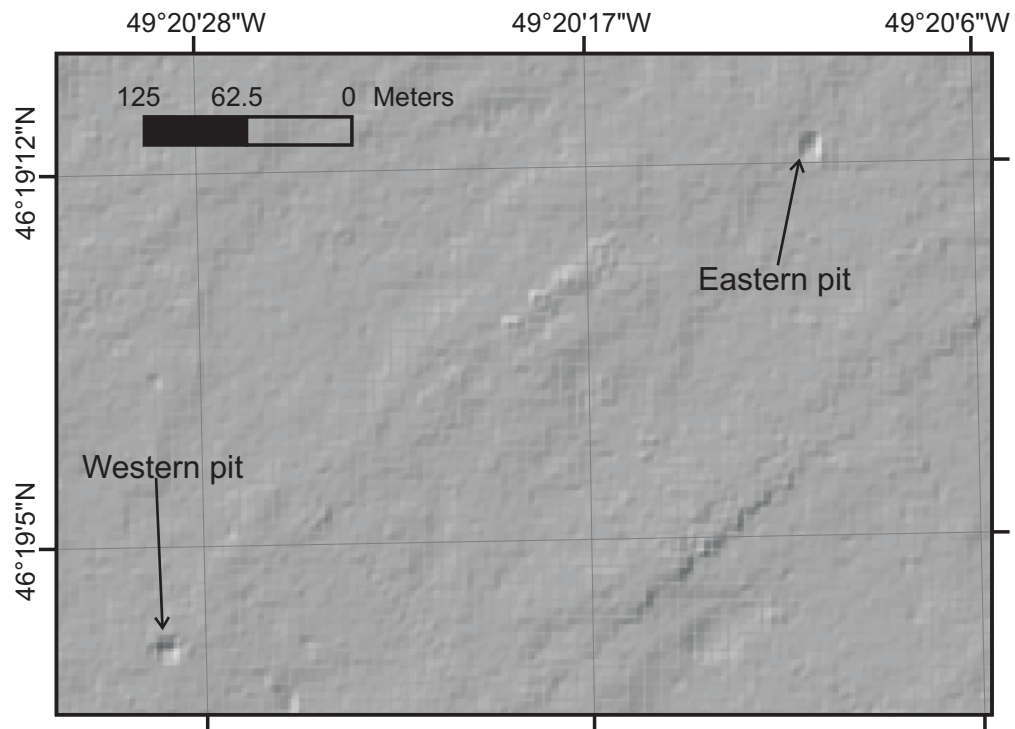
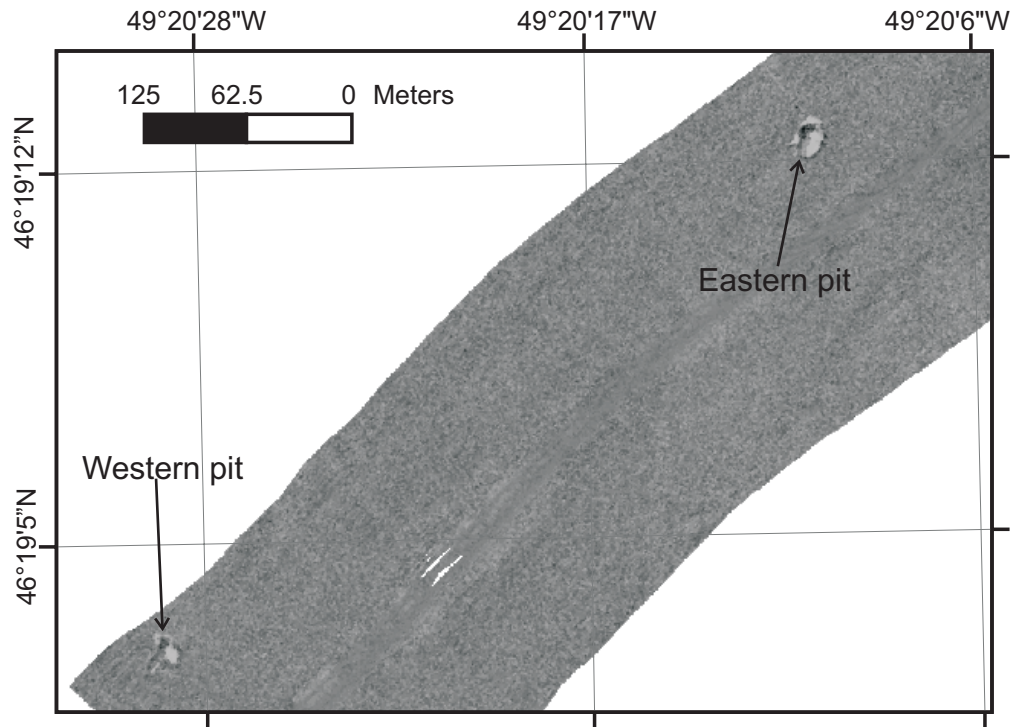
Maps showing the grounding of iceberg 00-09, the upper map is of sidescan imagery of the seafloor and the lower map is a shaded relief map of the multibeam bathymetry data.

### Scour 00-18



Maps showing the grounding of iceberg 00-18, the upper map is of sidescan imagery of the seafloor and the lower map is a shaded relief map of the multibeam bathymetry data.

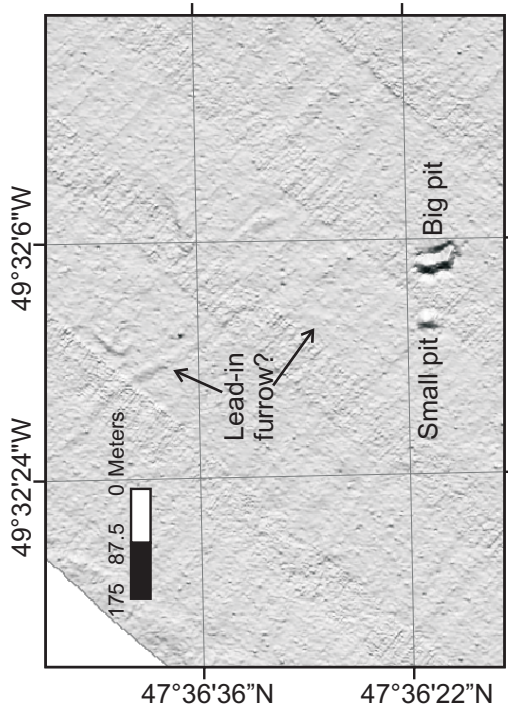
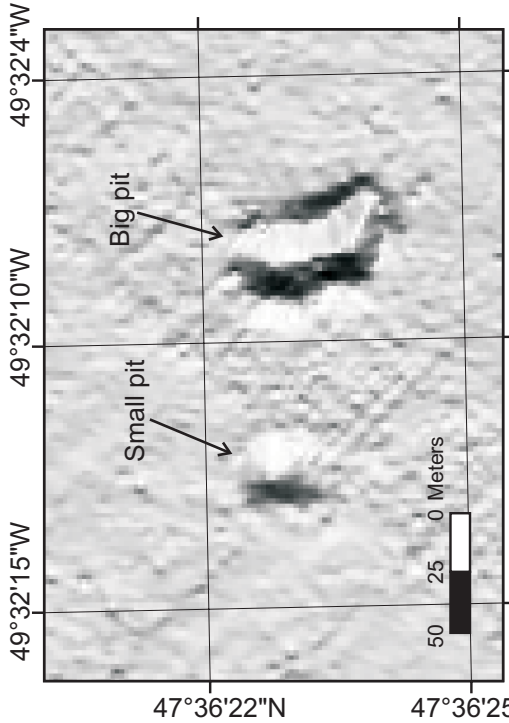
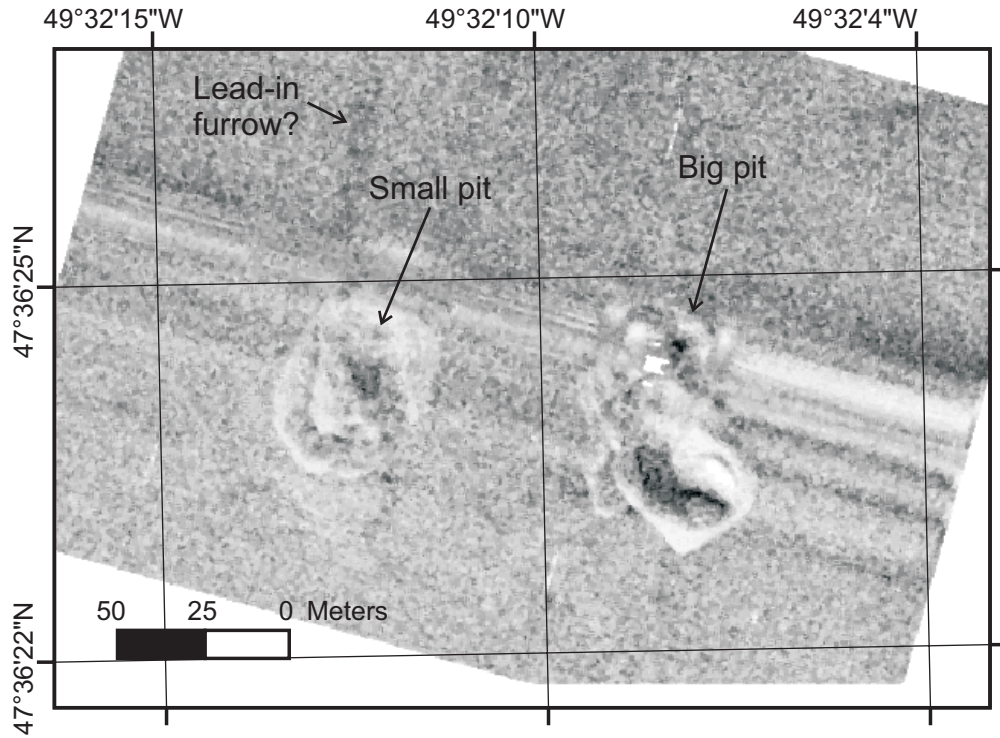
### Scour 00-21



Maps showing the grounding of iceberg 00-21, the upper map is of sidescan imagery of the seafloor and the lower map is a shaded relief map of the multibeam bathymetry data.

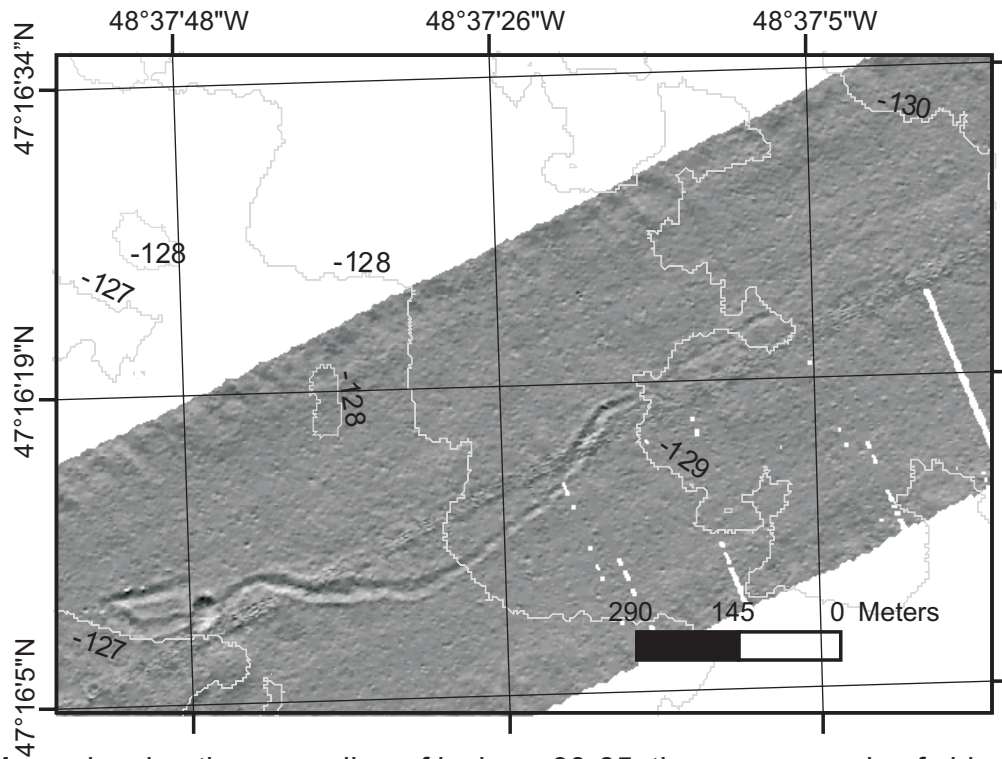
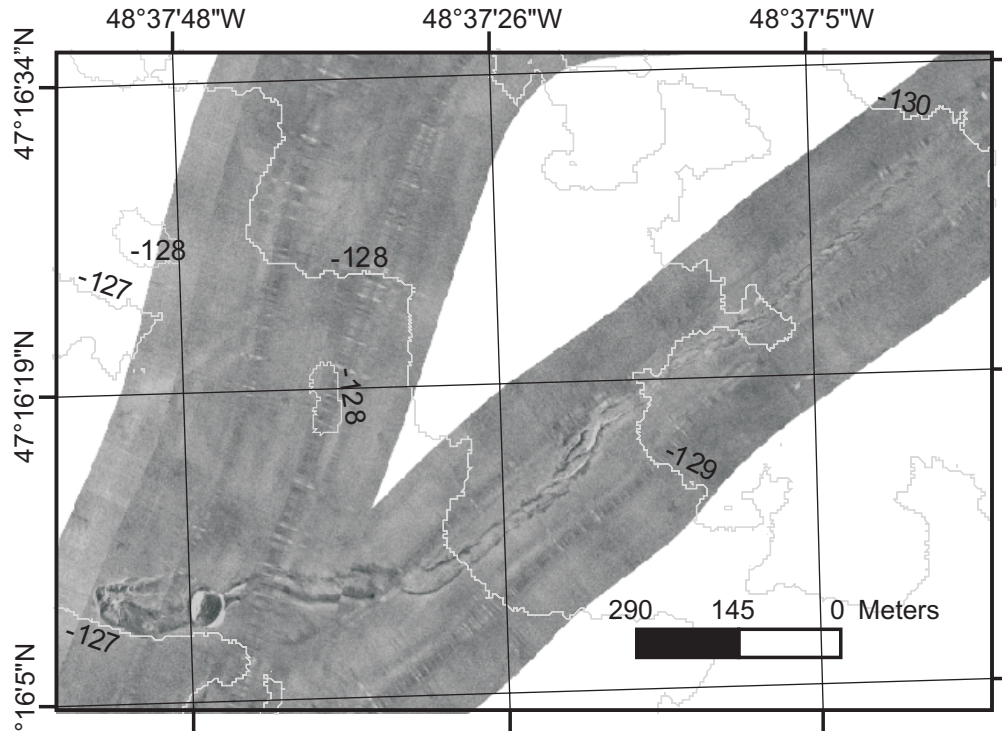


Scour 00-32



Maps showing the grounding of iceberg 00-32, the upper map is of sidescan imagery of the seafloor and the lower maps are shaded relief maps of the multibeam bathymetry data. At this resolution the possible lead-in furrow is not clear in the multibeam bathymetry, however when panned out there appears a faint scour to the northwest of the small pit.

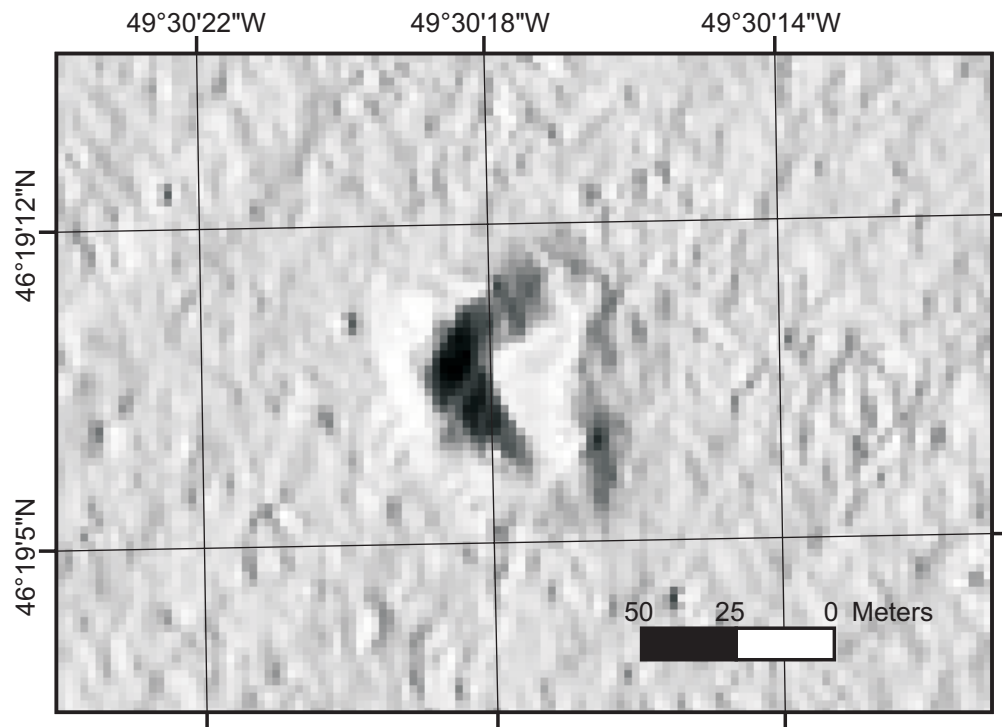
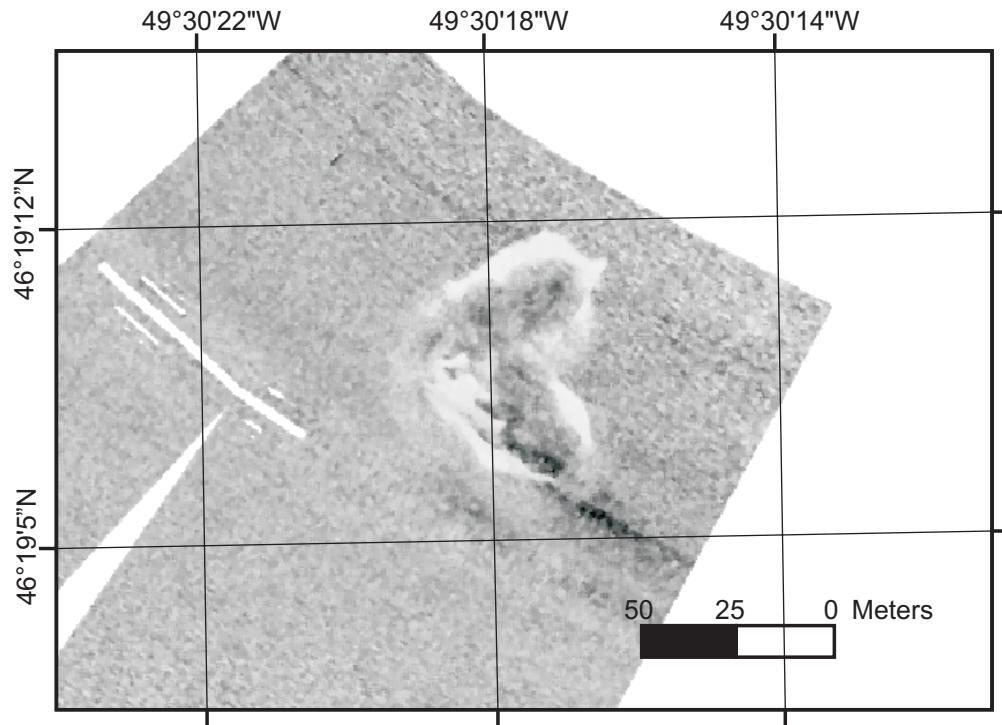
### Scour 00-65



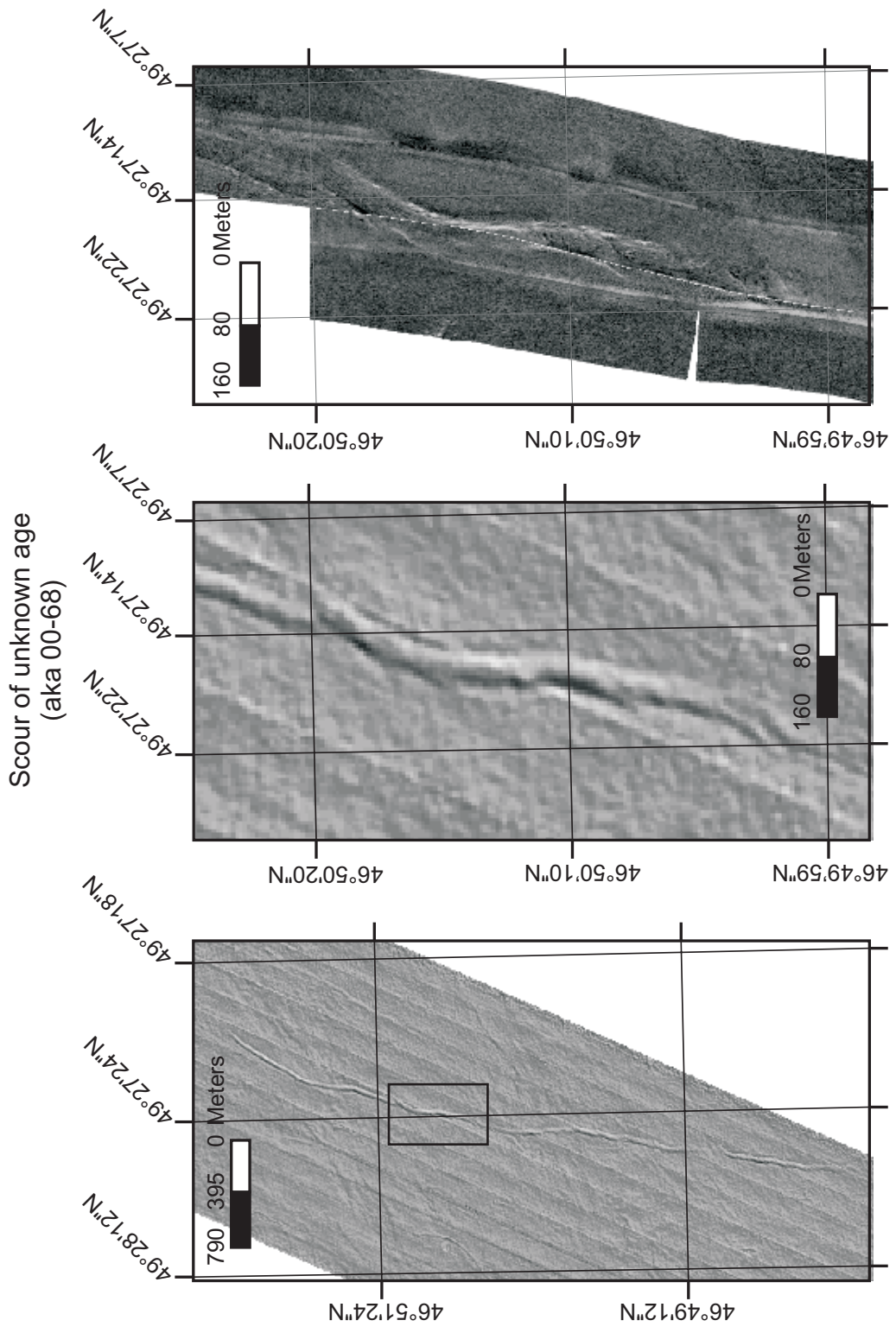
Maps showing the grounding of iceberg 00-65, the upper map is of sidescan imagery of the seafloor and the lower map is a shaded relief map of the multibeam bathymetry data.



### Scour 00-67



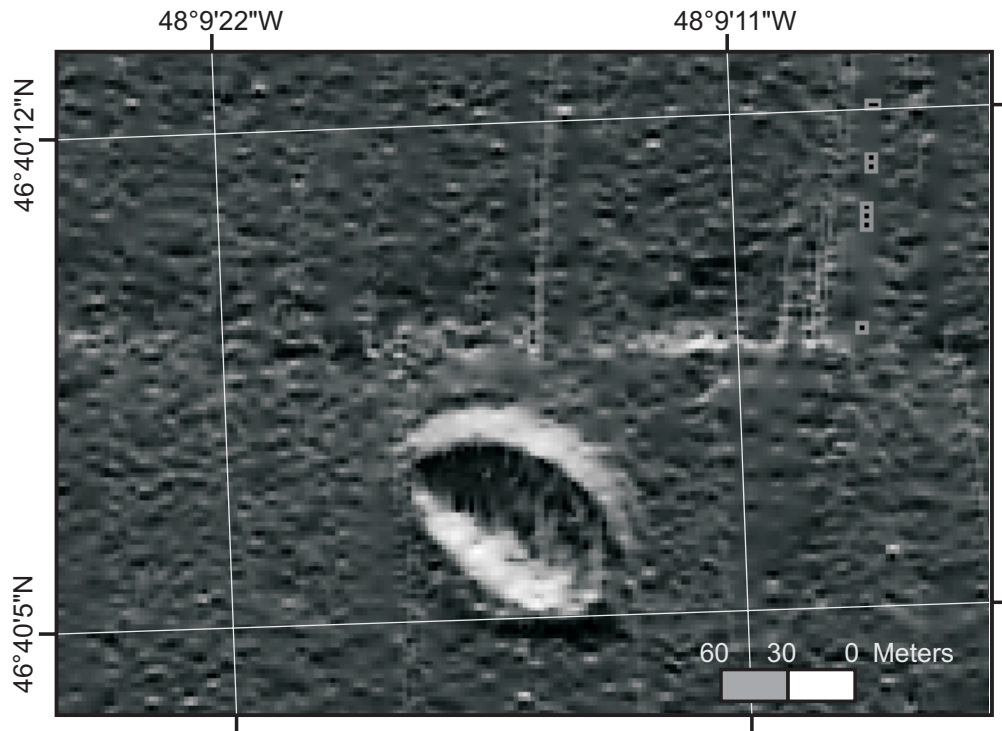
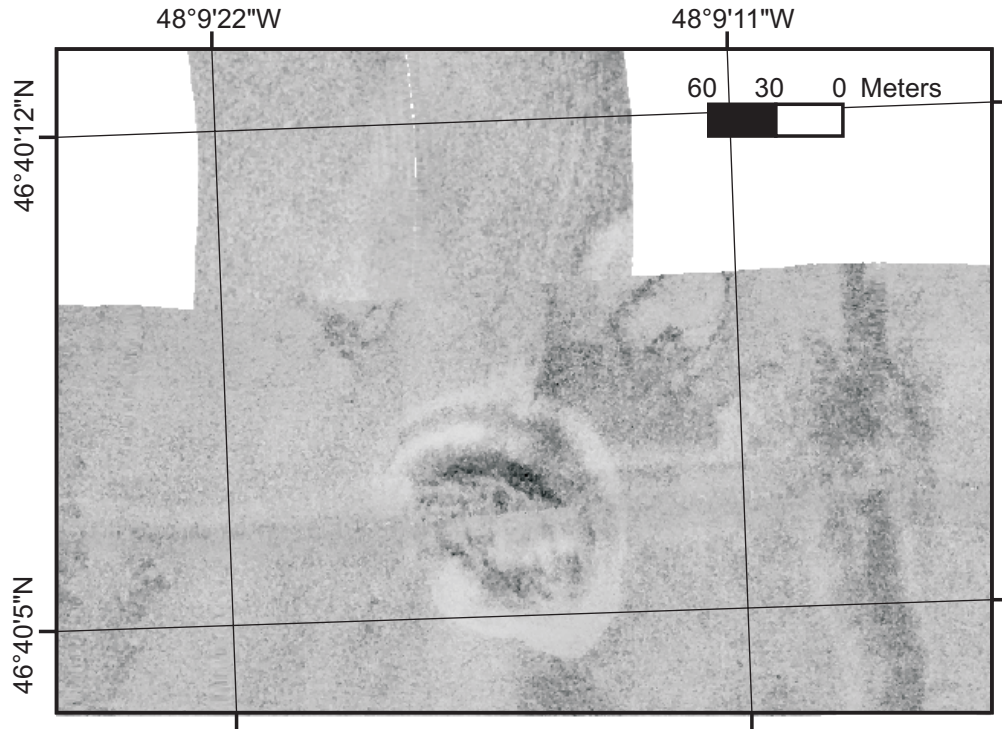
Maps showing the grounding of iceberg 00-67, the upper map is of sidescan imagery of the seafloor and the lower map is a shaded relief map of the multibeam bathymetry data.



Scour of unknown age  
(aka 00-68)

Map showing the older scour of unknown age that was surveyed while looking for the grounding site of scour 00-68. The map to the left is a shaded relief map produced from the multibeam bathymetry of the overall scour. The other two represent the area that was studied. The first is of multibeam bathymetry and the second is of sidescan imagery.

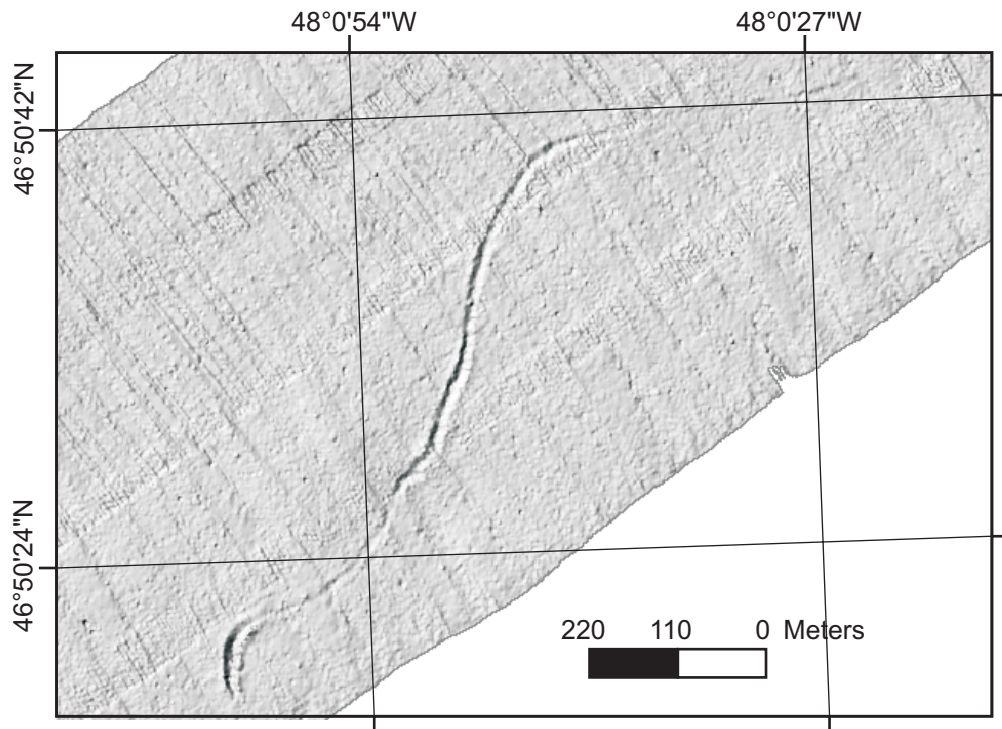
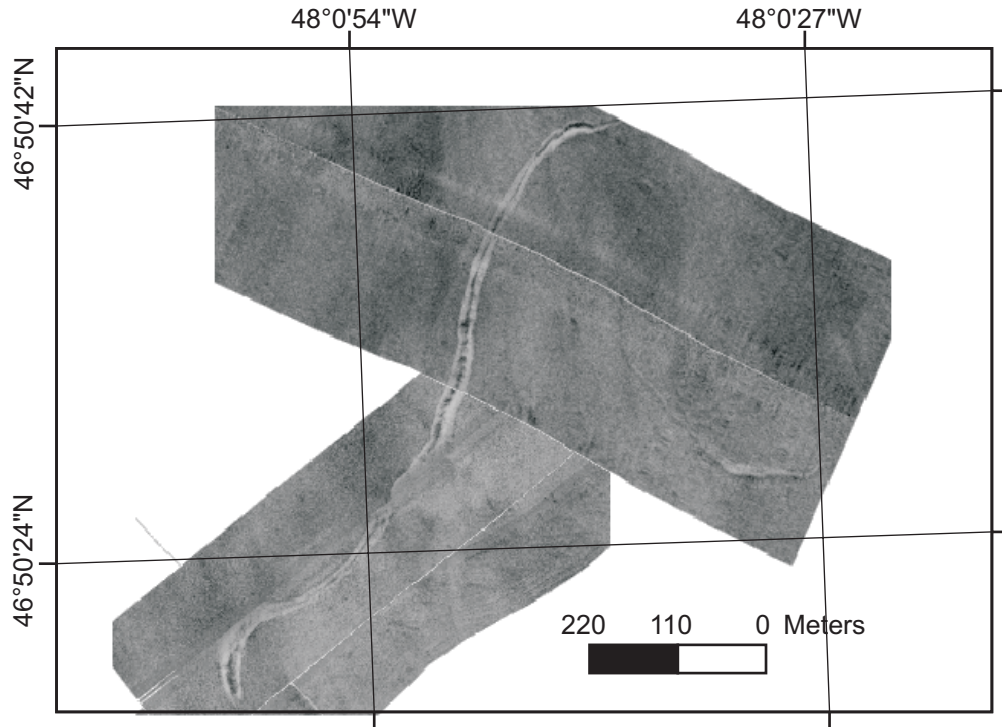
# Scour 89-01



Maps showing the grounding of iceberg 89-01, the upper map is of sidescan imagery of the seafloor and the lower map is a shaded relief map of the multibeam bathymetry data.

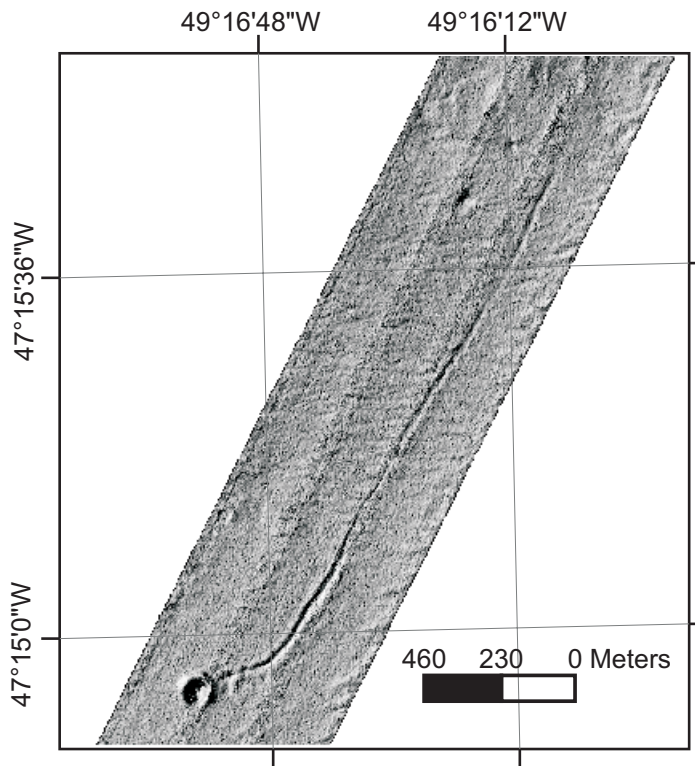
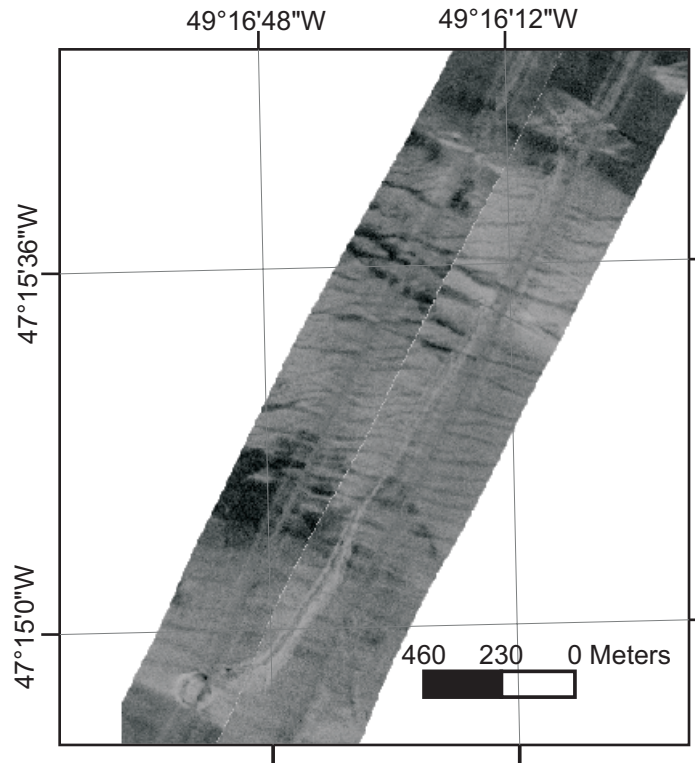


### Scour 88-01



Maps showing the grounding of iceberg 88-01, the upper map is of sidescan imagery of the seafloor and the lower map is a shaded relief map of the multibeam bathymetry data.

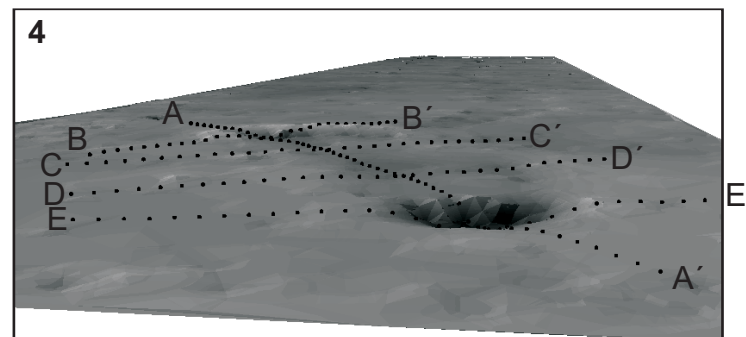
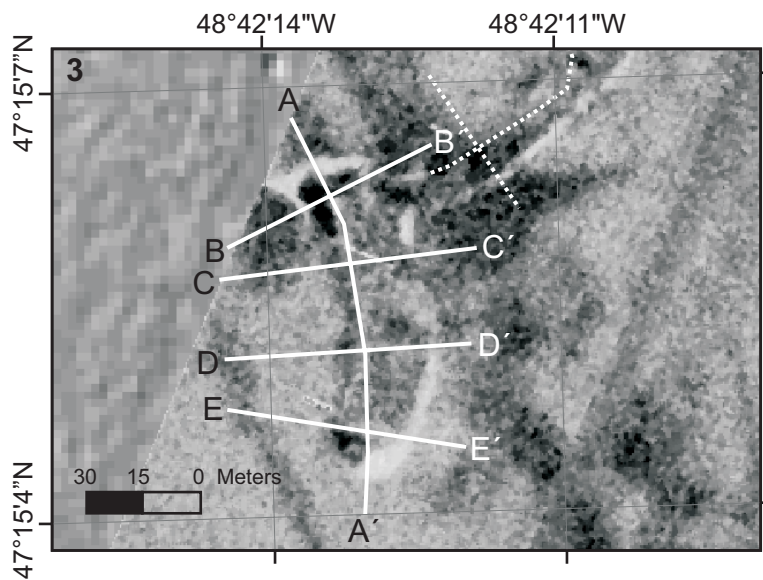
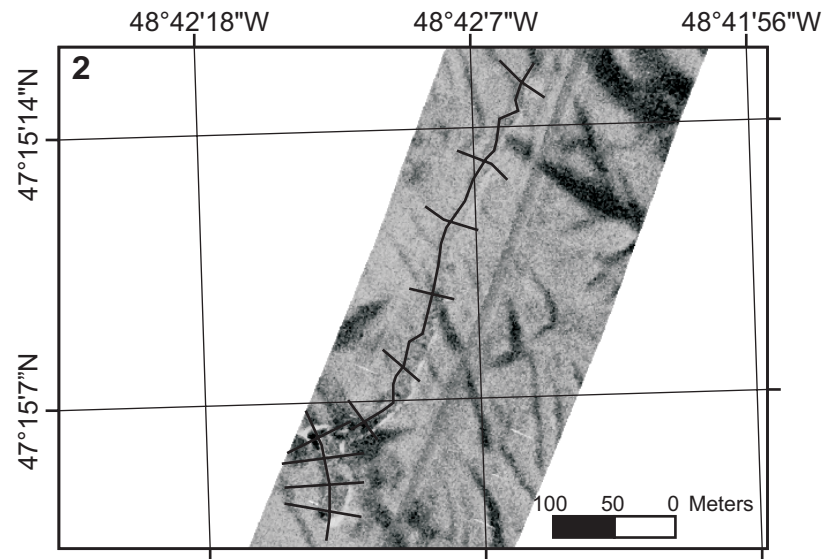
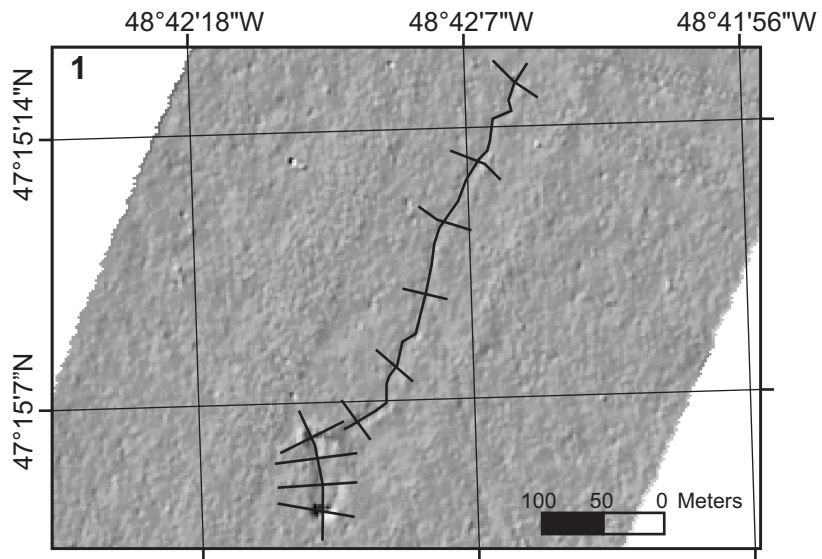
### Scour 83-95



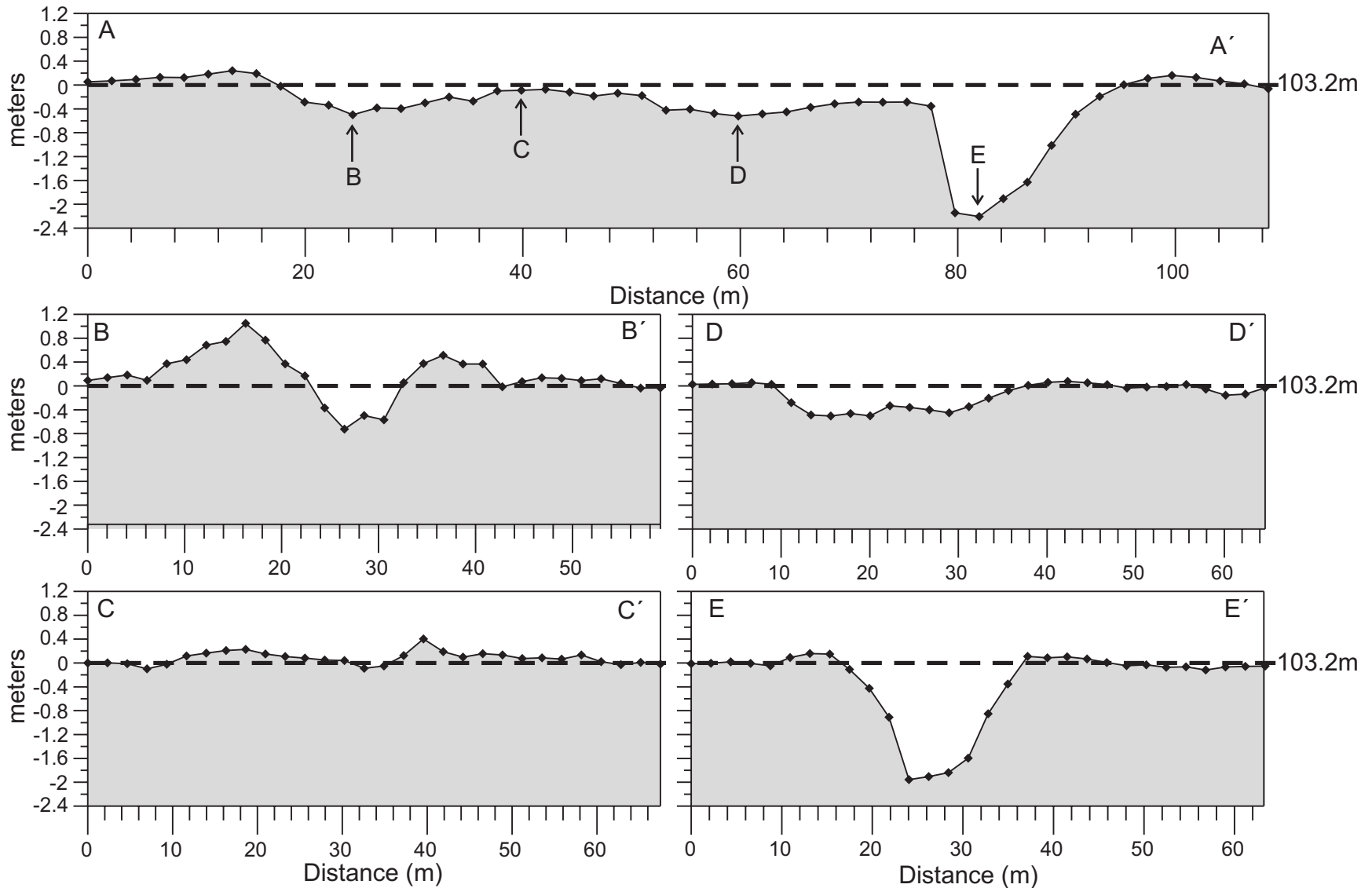
Maps showing the grounding of iceberg 83-95, the upper map is of sidescan imagery of the seafloor and the lower map is a shaded relief map of the multibeam bathymetry data.

## **APPENDIX IV**

Surface profiles of the 2000 furrows and pits



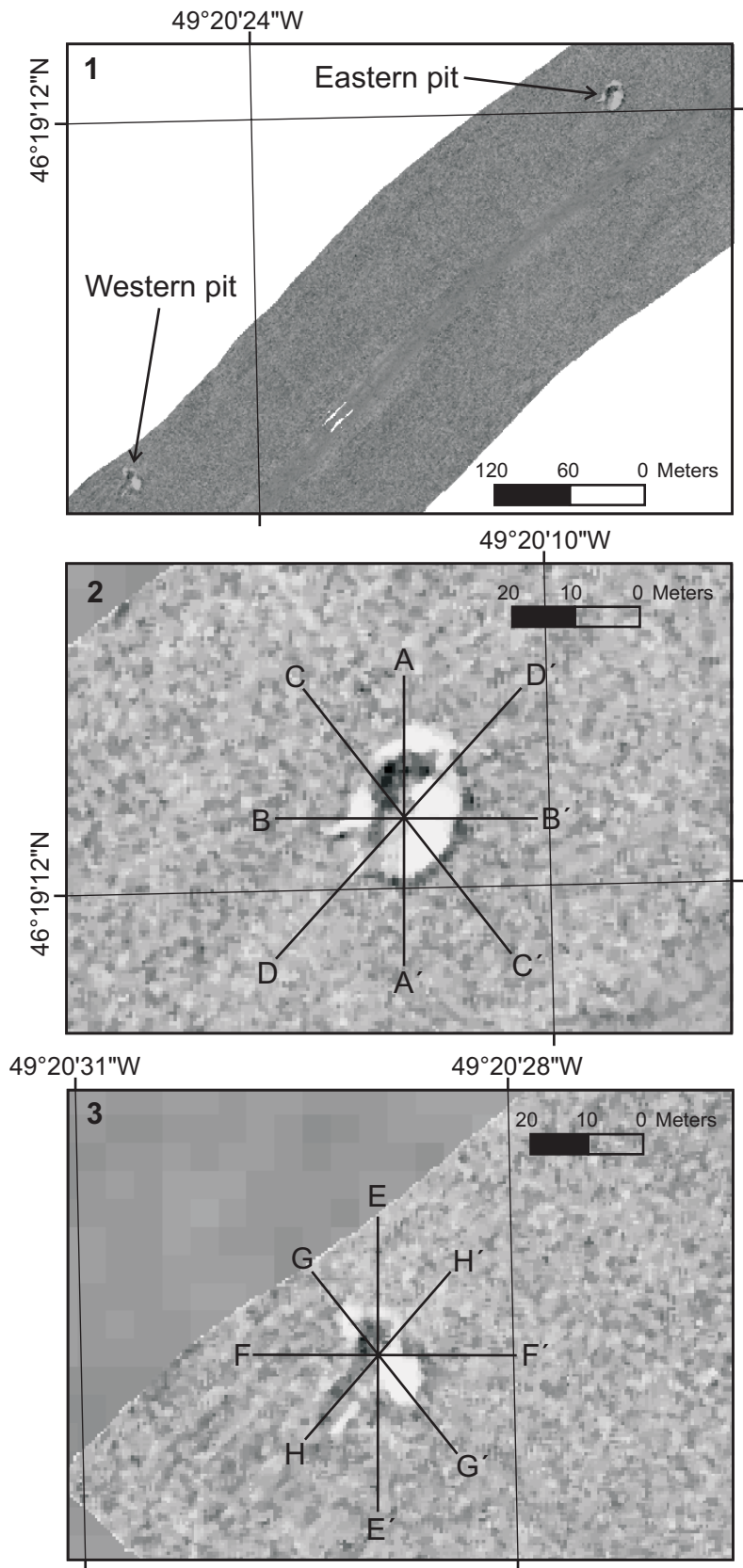
Maps showing the locations of surface profiles made of scour 00-18. (1) and (2) are of the whole scour seen by multibeam (1) and by sidescan (2). (3) is a close-up of the terminal end of the scour viewed by sidescan. (4) is a 3-D view generated with multibeam bathymetry.



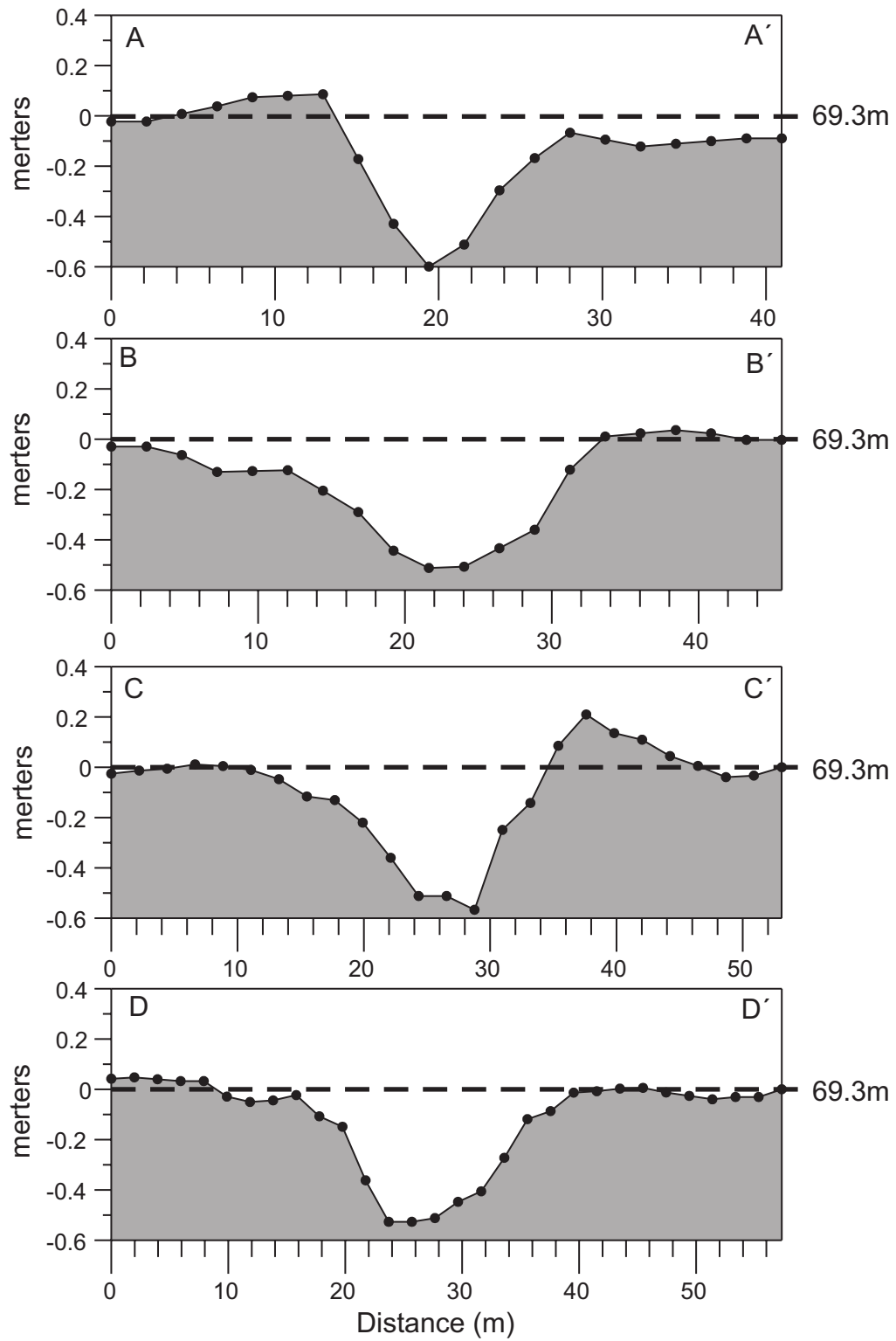
Surface profiles of the terminal end of scour 00-18.



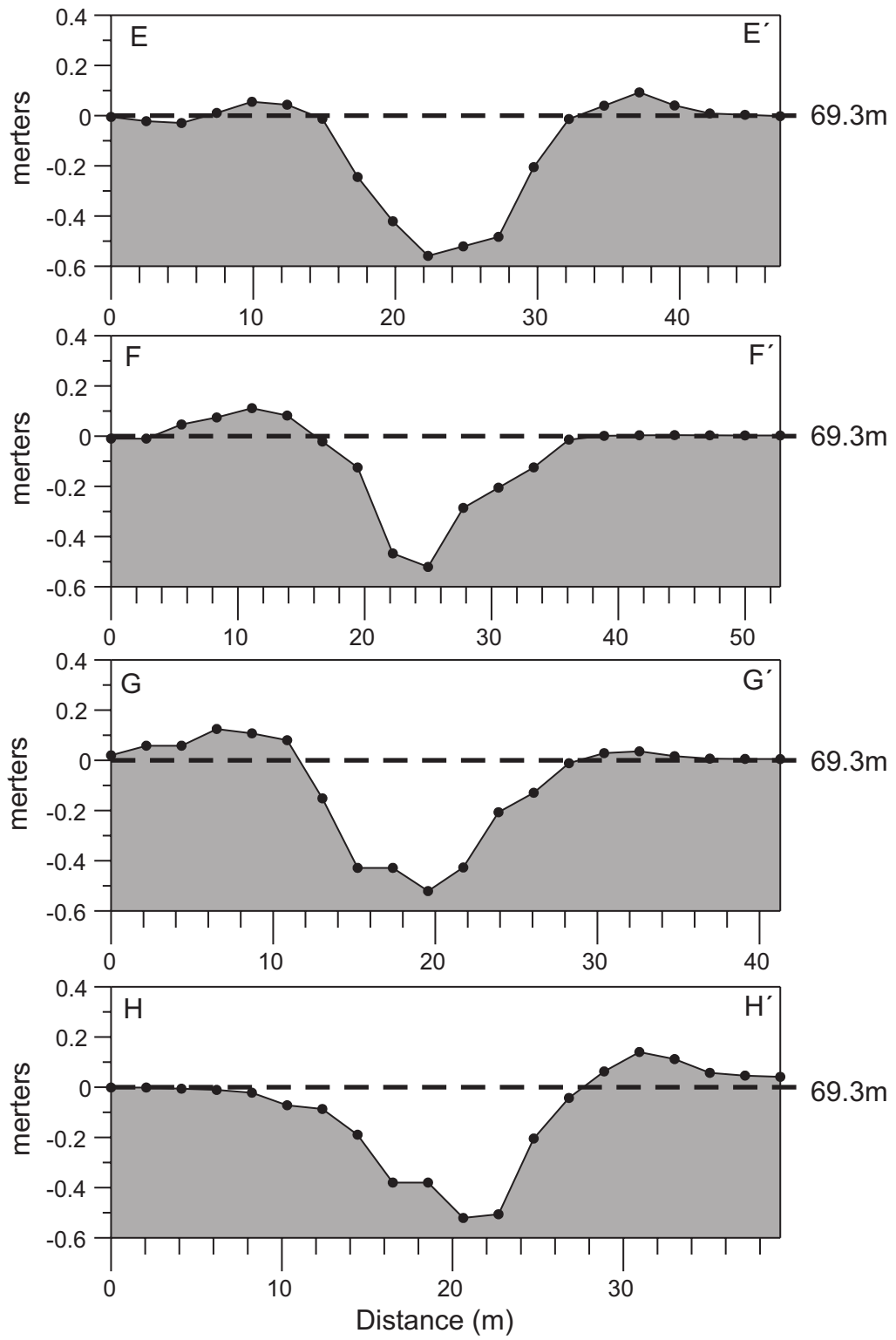
# Scour 00-21



Map showing the location of surface profiles of scour 00-21. (1) shows the location of the two pit as seen in sidescan. (2) is a close up of the eastern pit and (3) is a close up of the western pit.

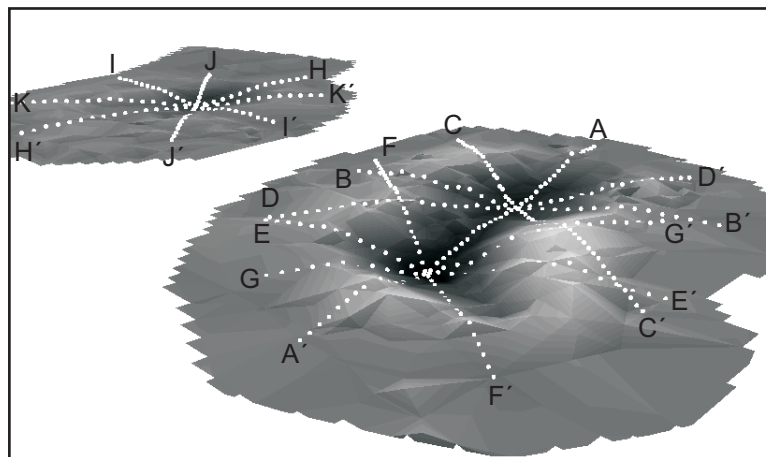
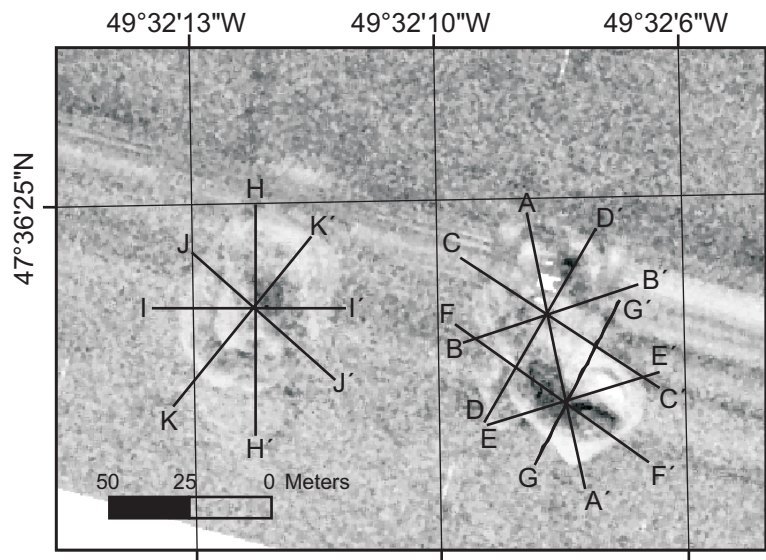
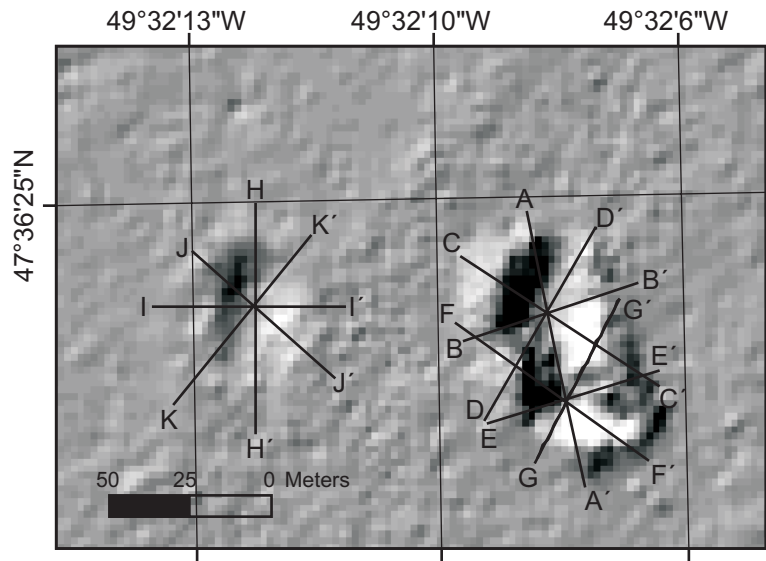


Surface profiles through the eastern pit of scour 00-21.

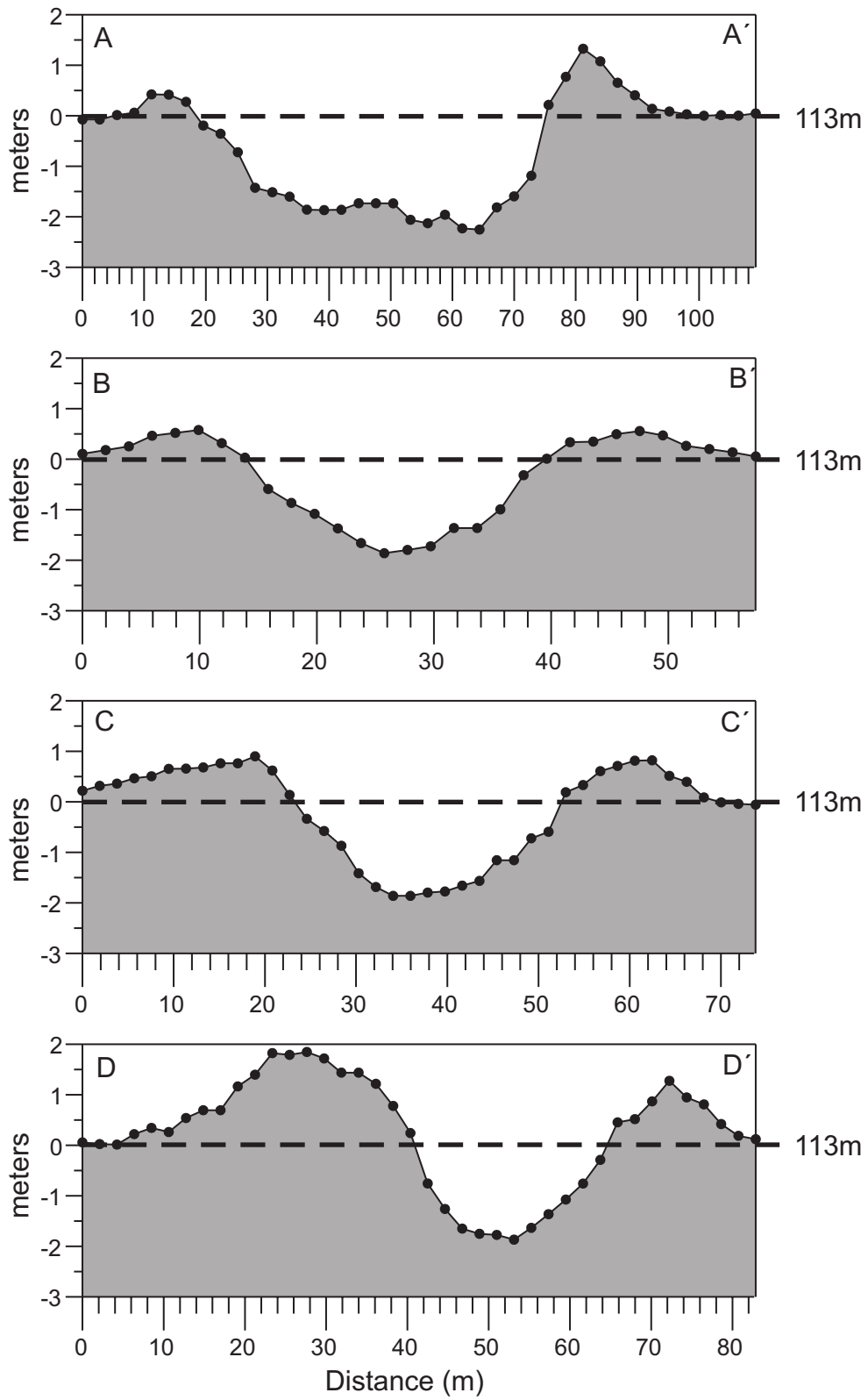


Surface profiles through the western pit of scour 00-21.

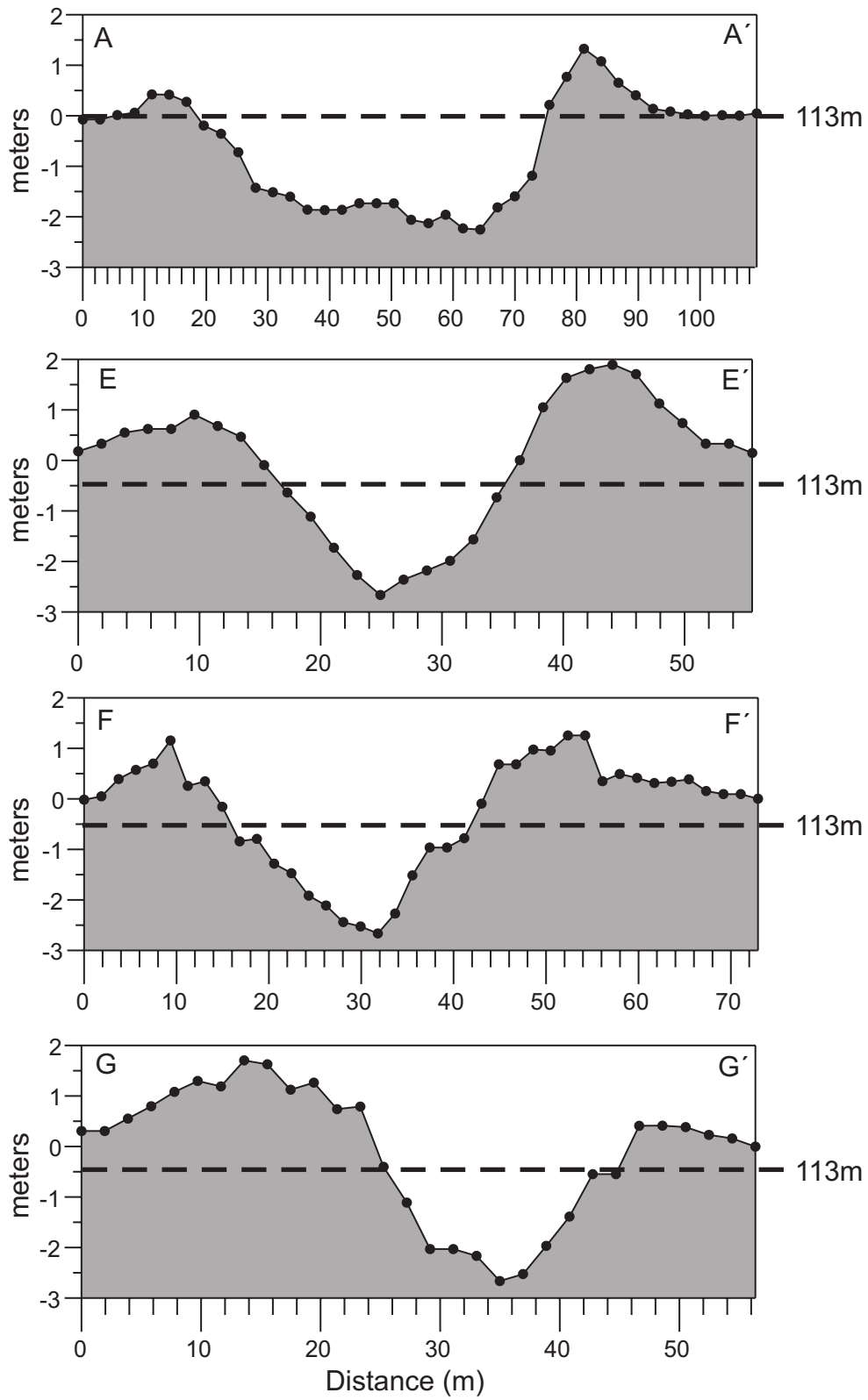
### Scour 00-32



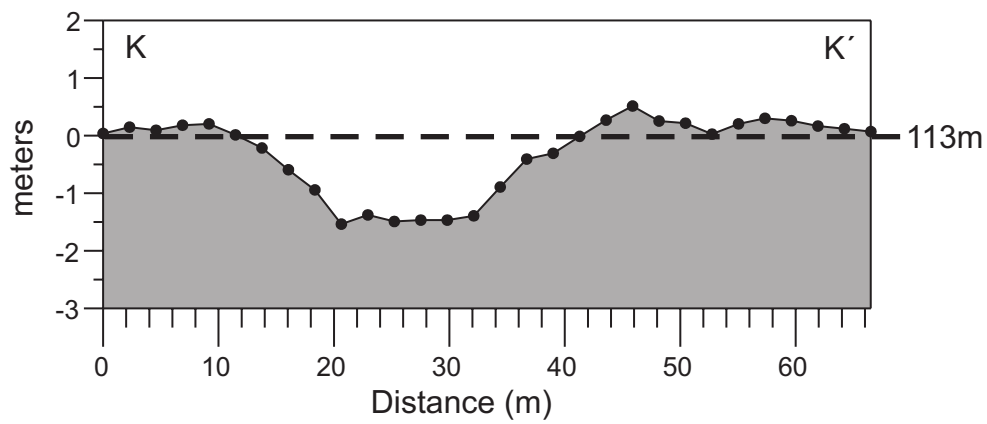
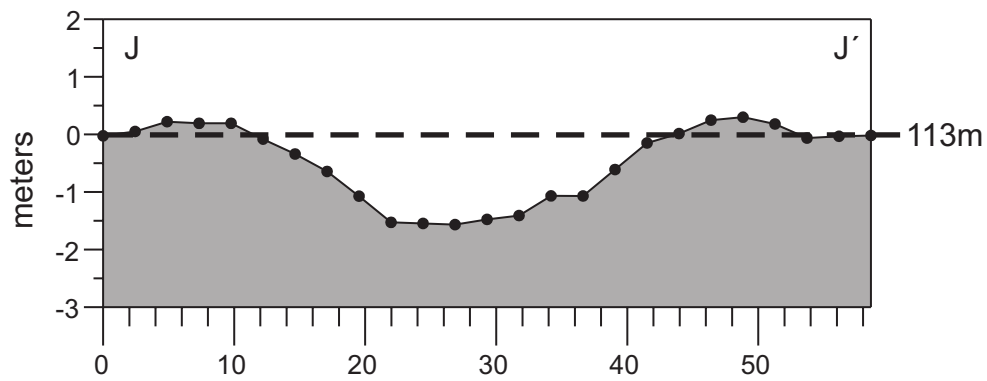
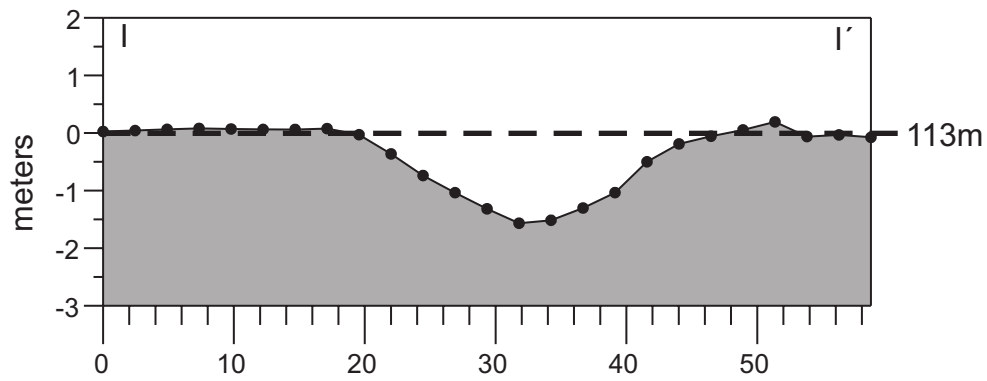
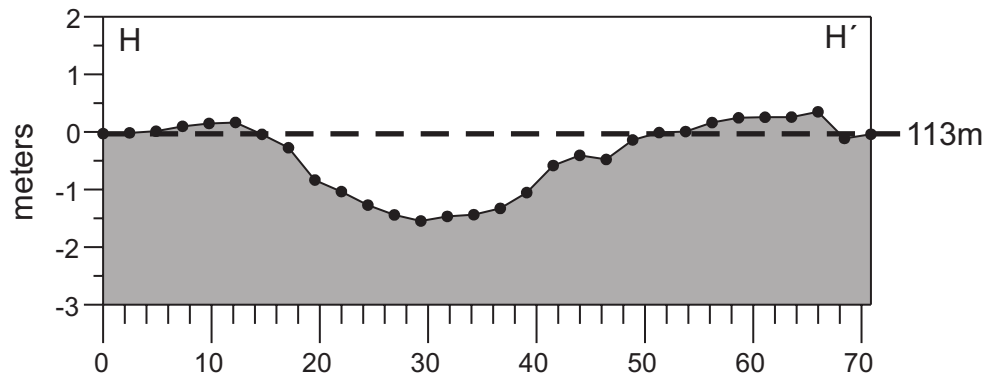
Maps showing the location of surface profiles of scour 00-32. (A) is of the multibeam bathymetry, (B) is of sidescan and (C) is a 3-D view generated from the multibeam bathymetry data.



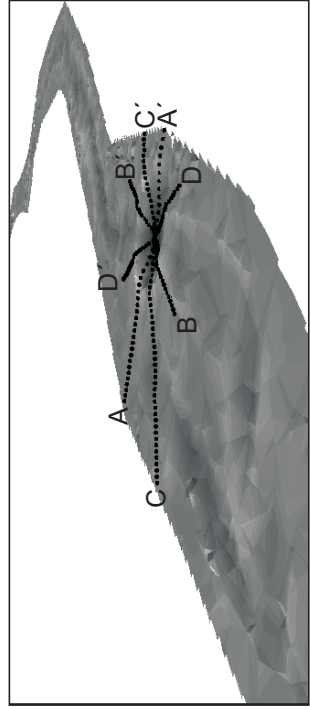
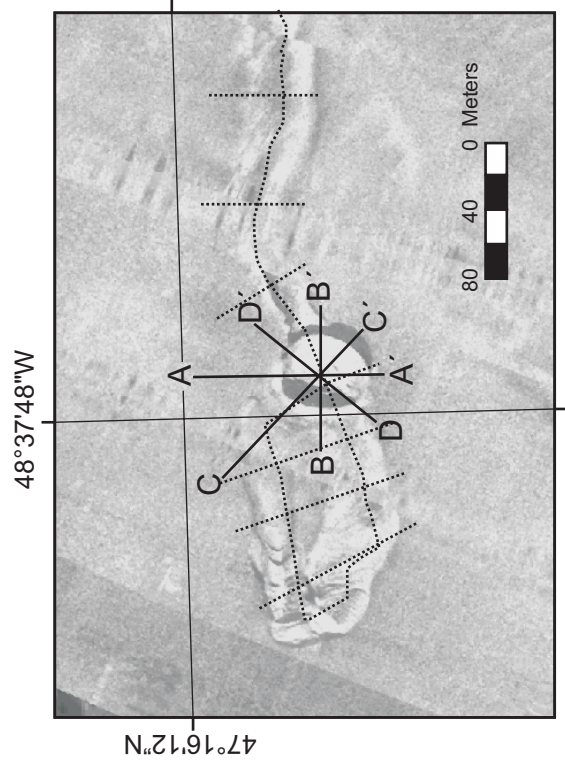
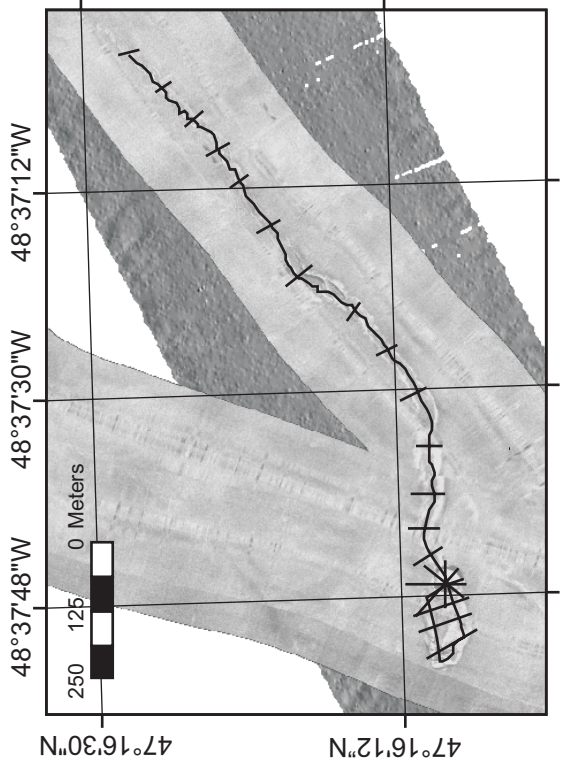
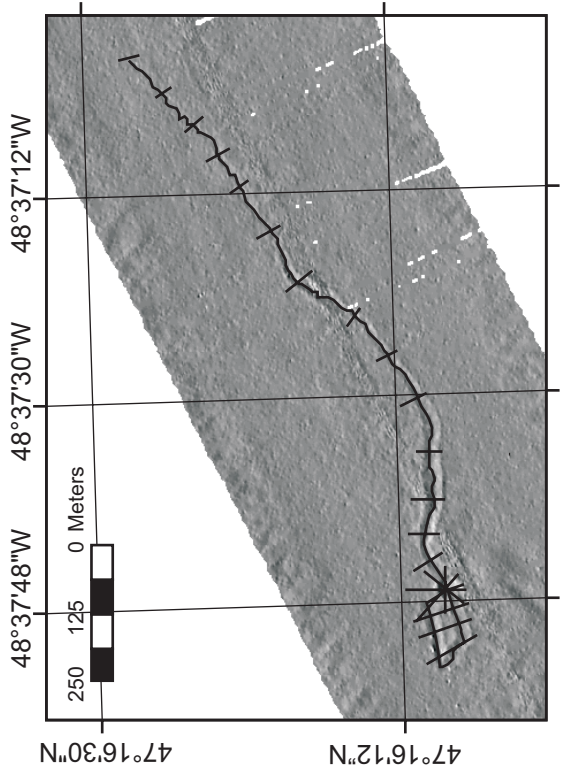
Surface profiles of through the northern part of the larger of pit.



Surface profiles of through the southern part of the larger of pit.

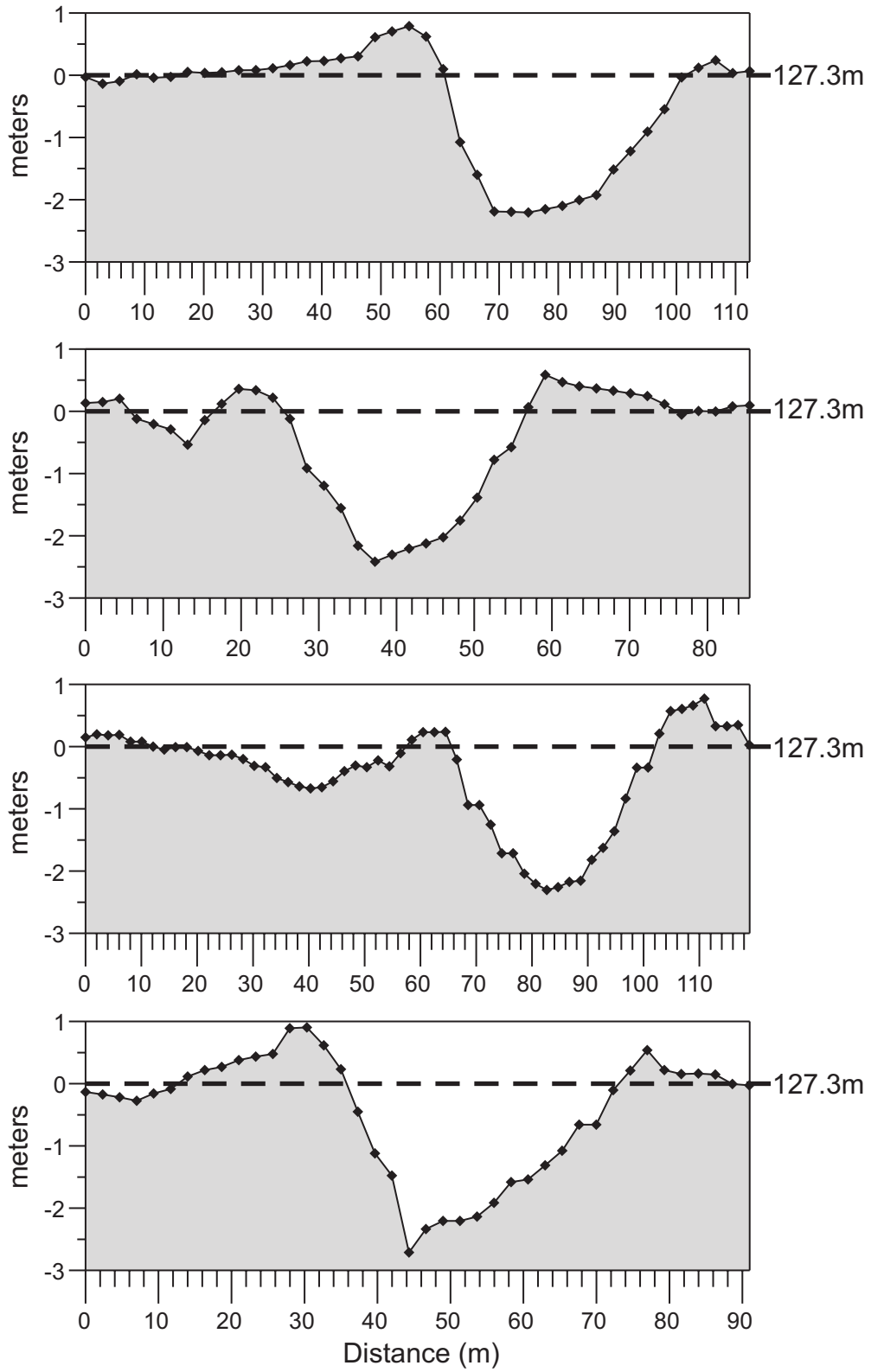


Surface profiles of through the smaller of pit.

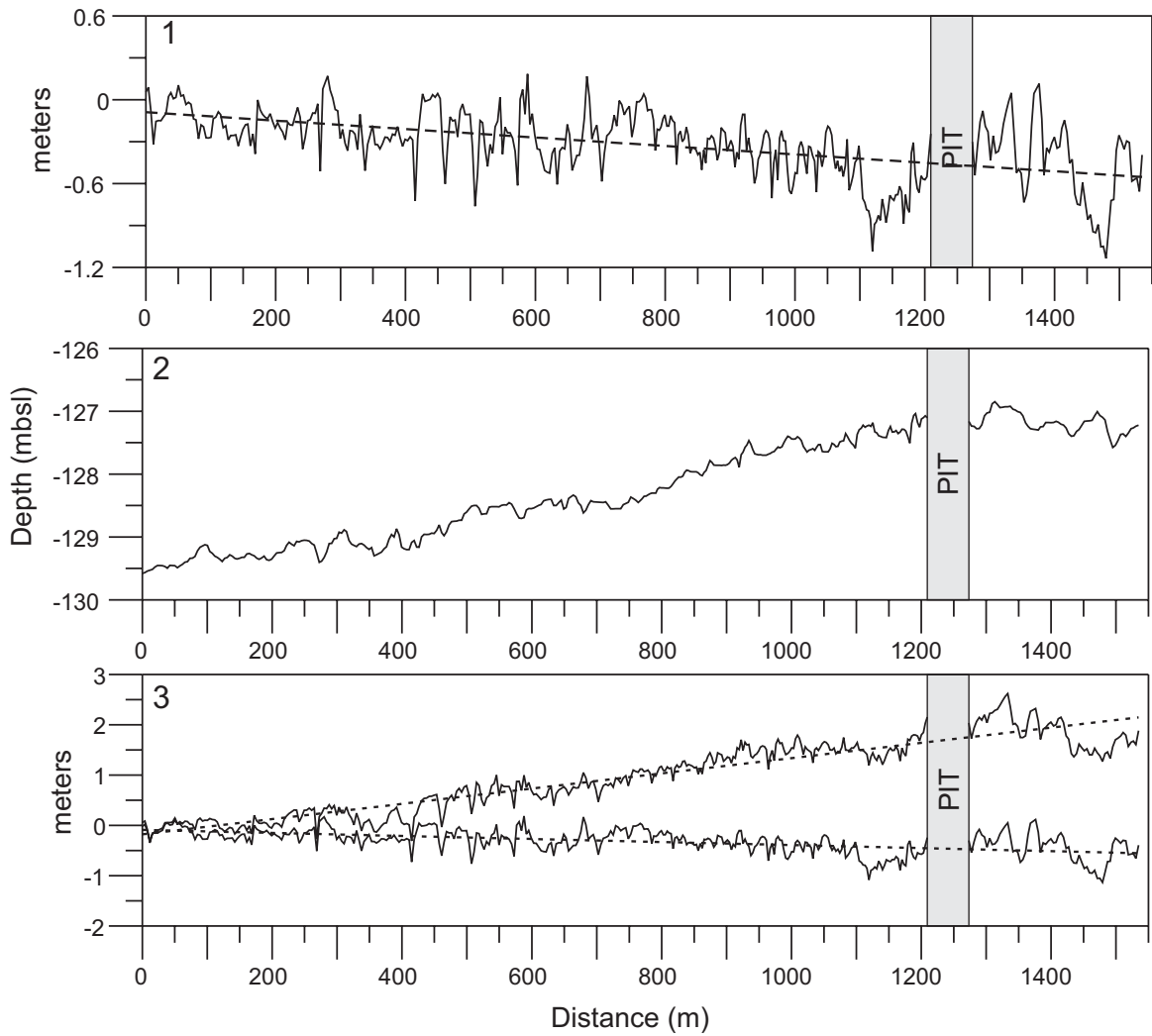


Maps showing the locations of surface profiles made of scour 00-65. (1) and (2) are of the whole scour seen by multibeam (1) and by sidescan (2). (3) is a close-up of the terminal end of the scour viewed by sidescan. (4) is a 3-D view generated with multibeam bathymetry.



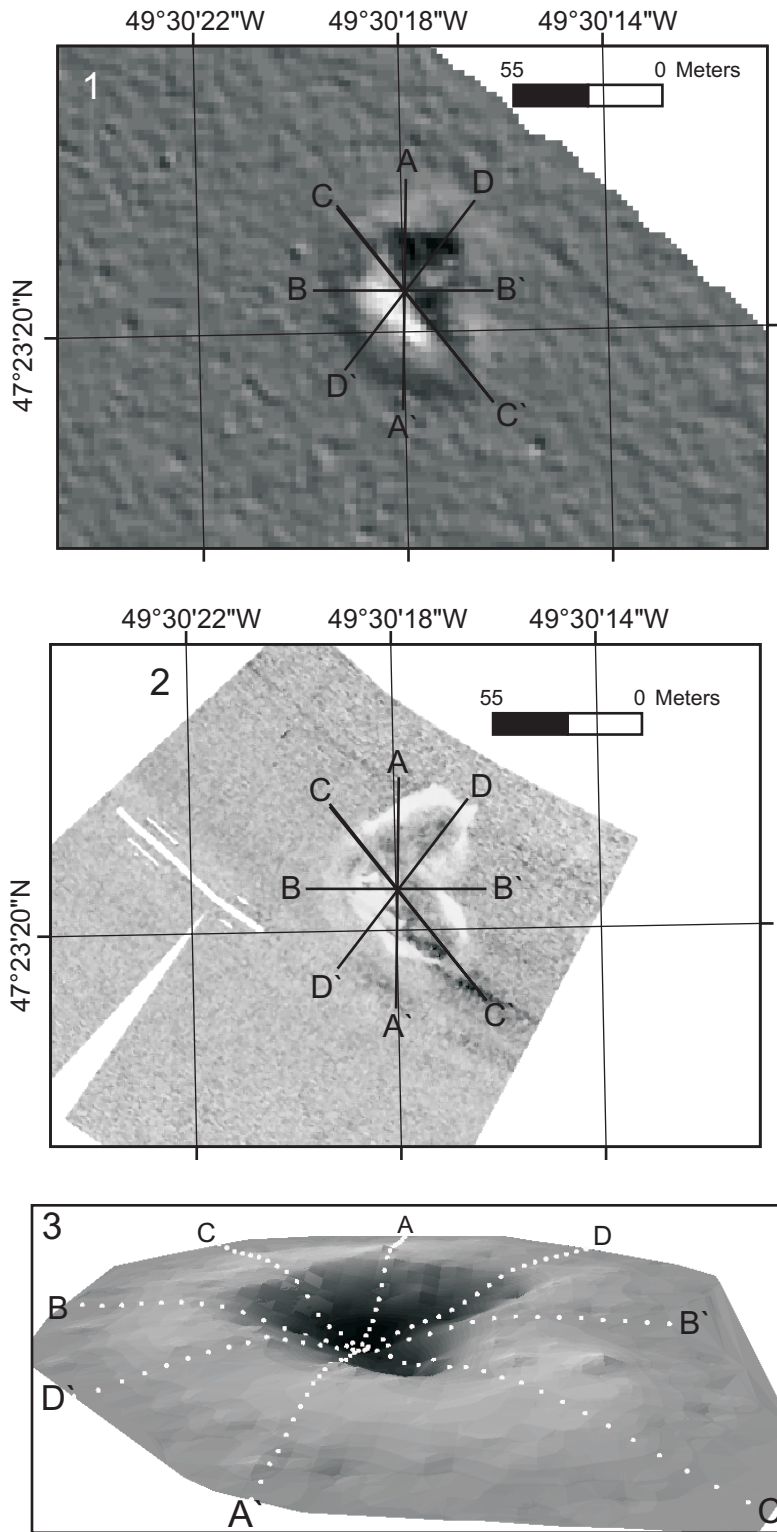


Surface profiles through the terminal pit of scour 00-65.

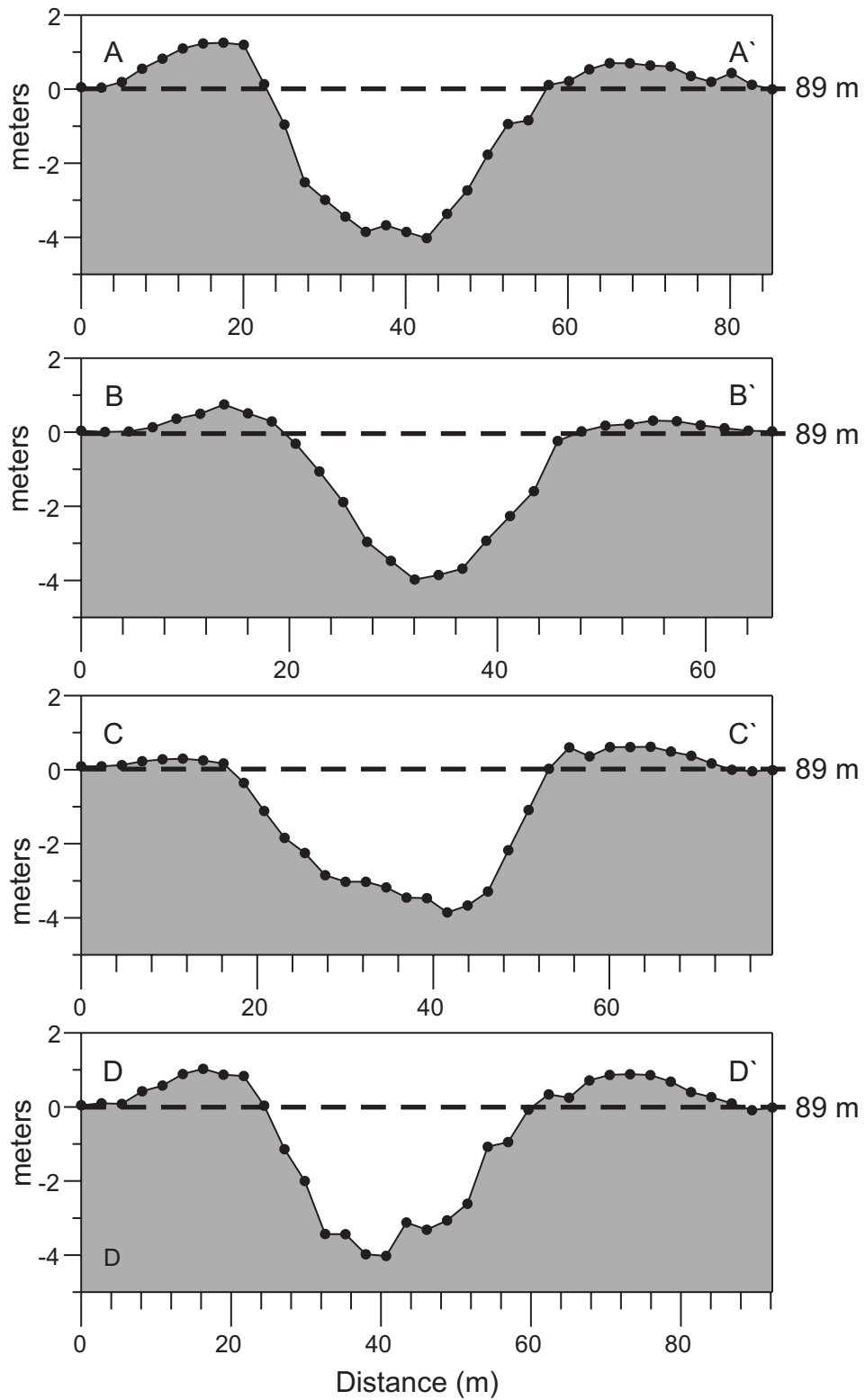


(1) Measured variations in the depth of the scour. (2) A synthetic 'pre-scour' seafloor. (3) A plot showing the degree of keel rise-up for scour 00-65.

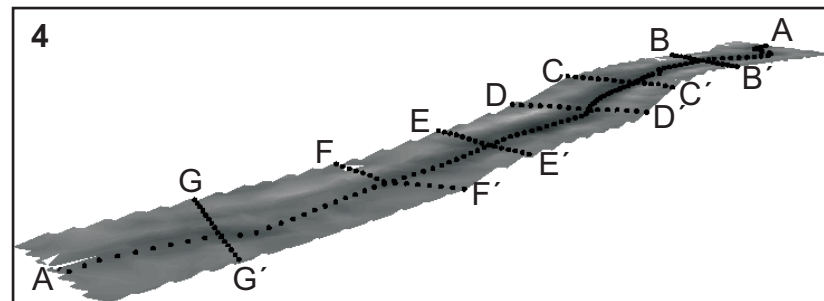
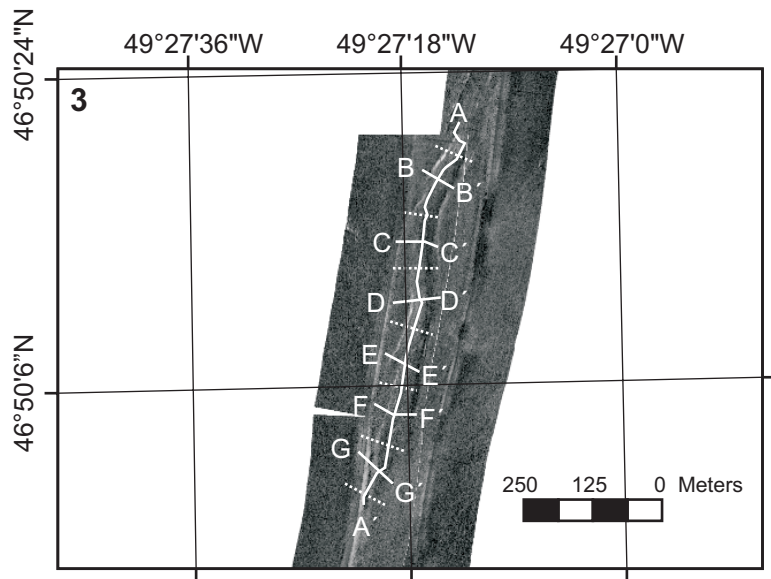
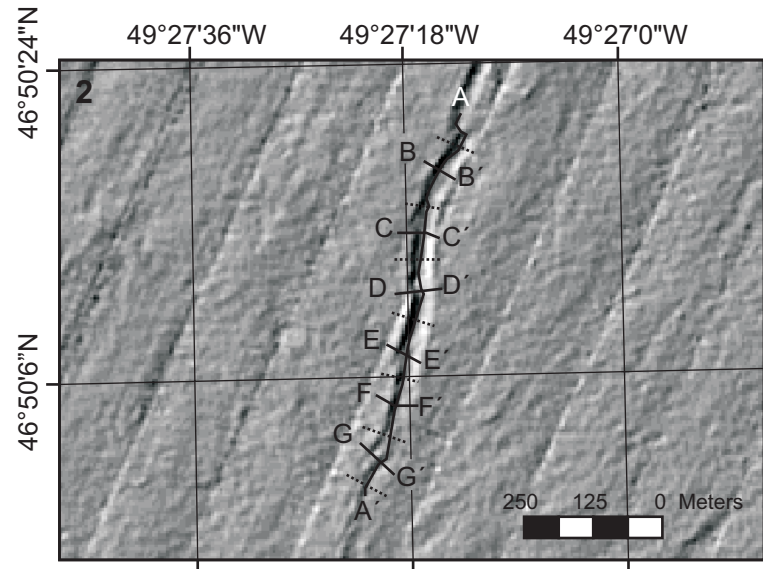
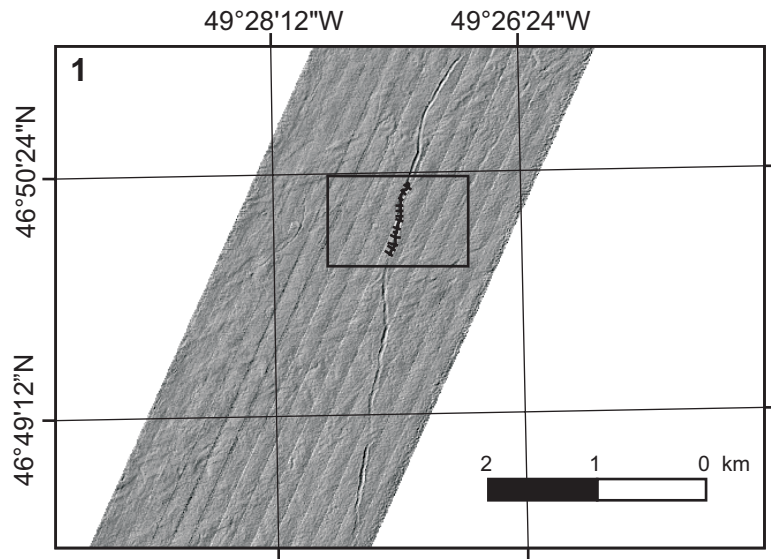
### Scour 00-67



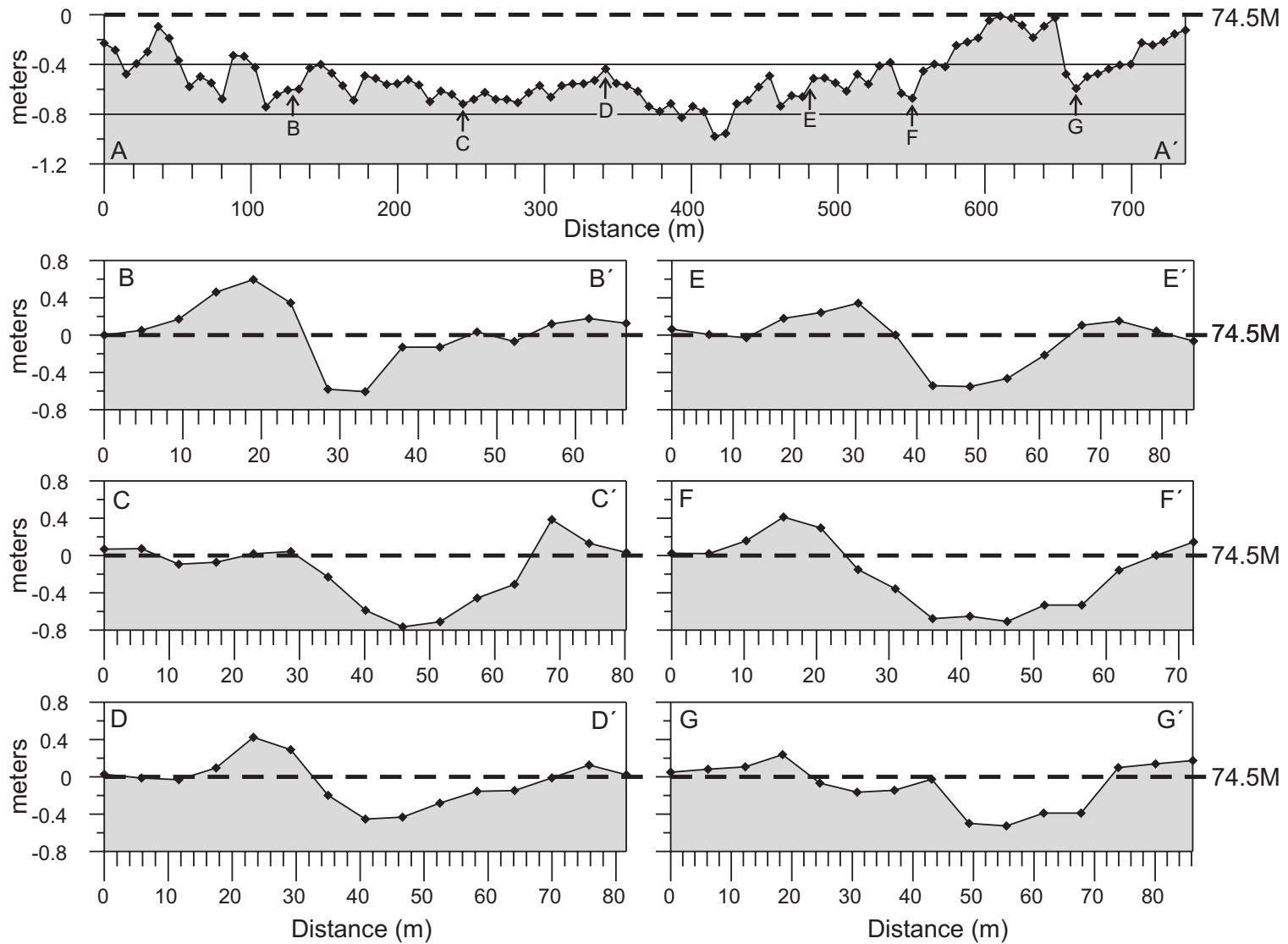
Maps showing the location of surface profiles of scour 00-67. (1) is of the multibeam bathymetry, (2) is the sidescan and (3) is a 3-D view generated from the multibeam bathymetry data.



Surface profiles of scour 00-67.

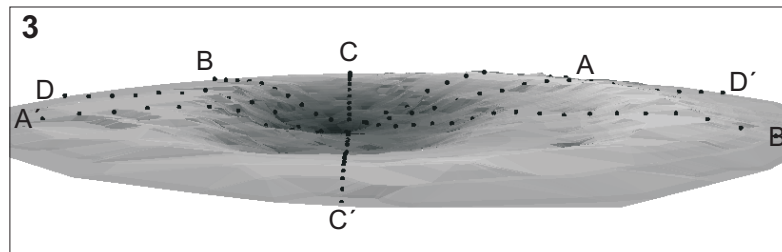
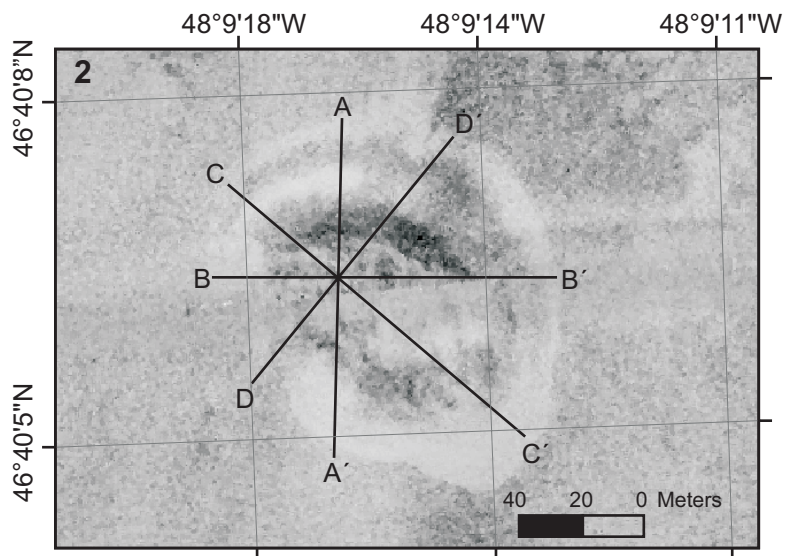
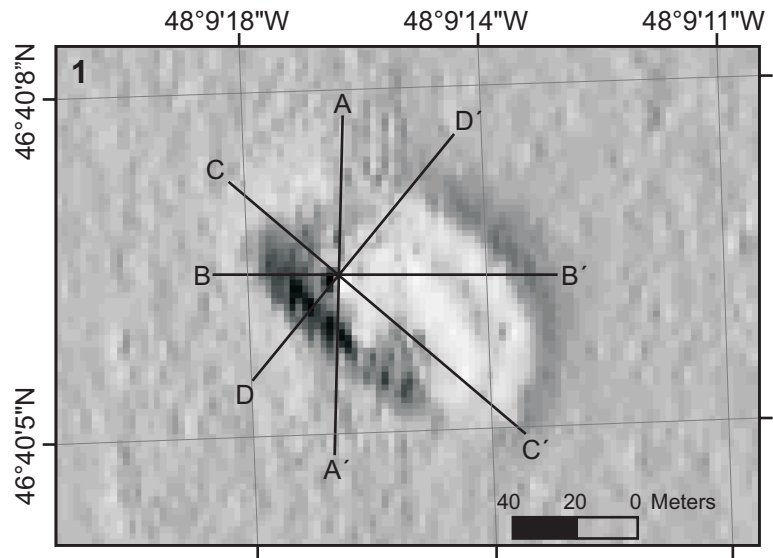


Maps showing the locations of surface profiles made of scour 00-68. (1) is of the whole scour seen by multibeam. (2) and (3) are a close-ups of the investigated part of the scour viewed by both multibeam (2) and sidescan (3). (4) is a 3-D view generated with multibeam bathymetry.

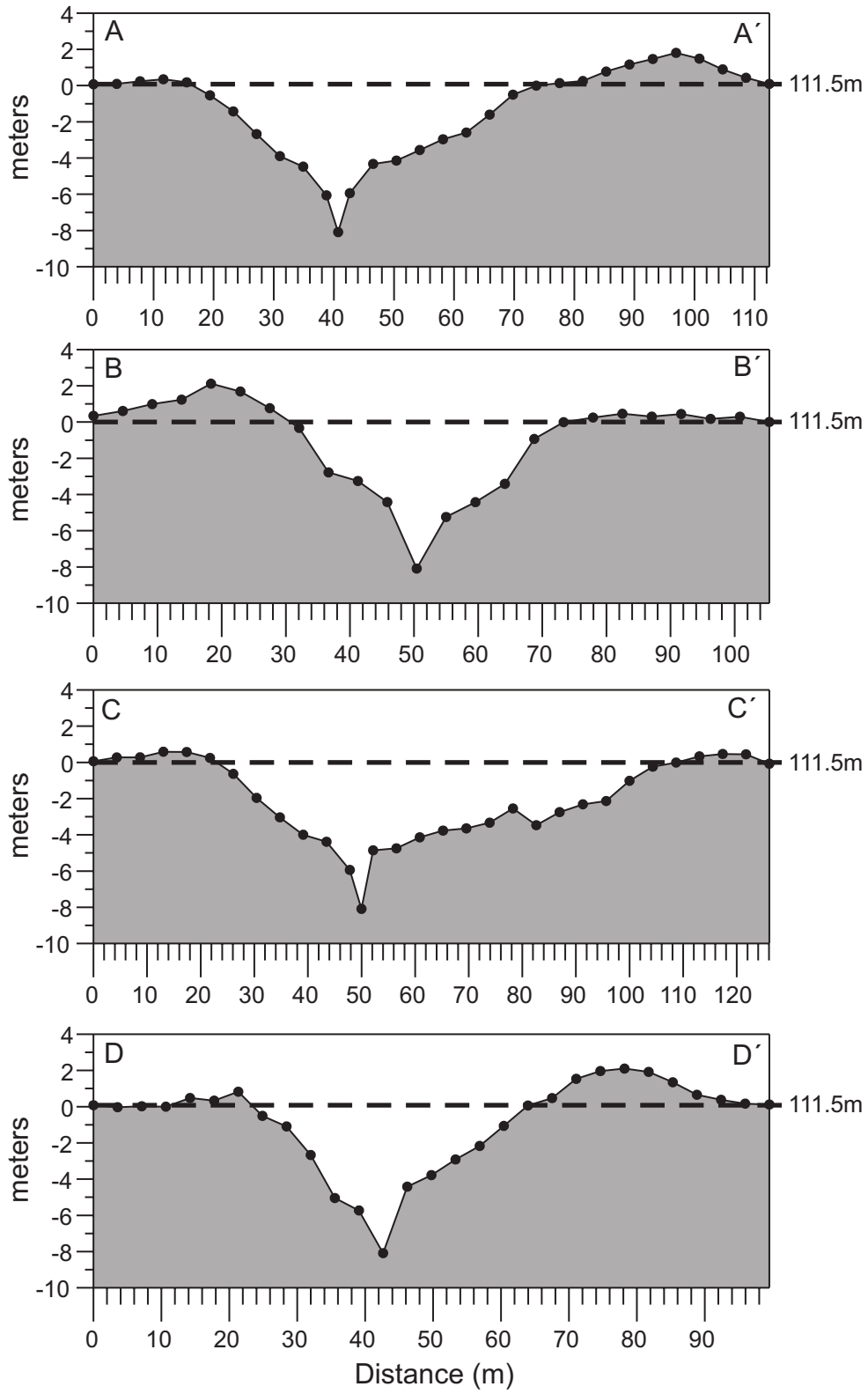


Surface profiles of scour ---=68 in the area of study.

### Scour 89-01

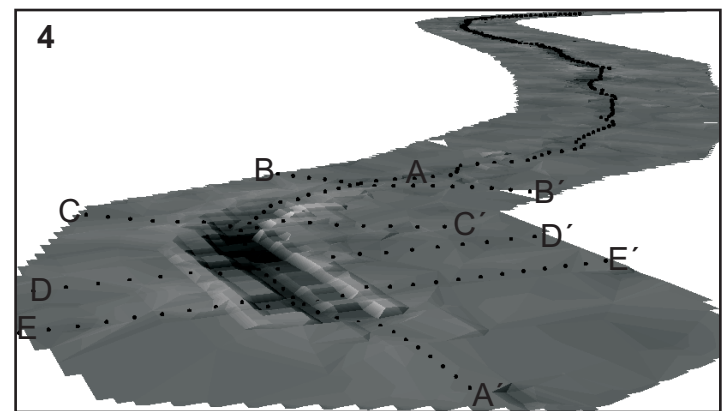
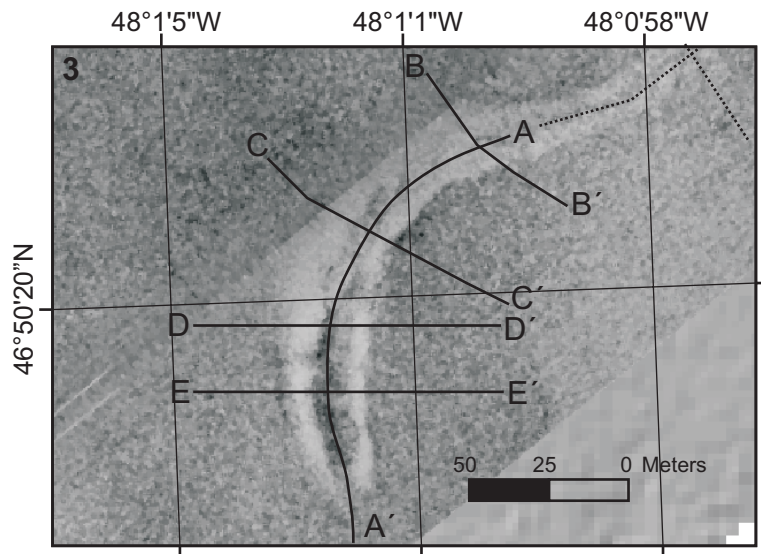
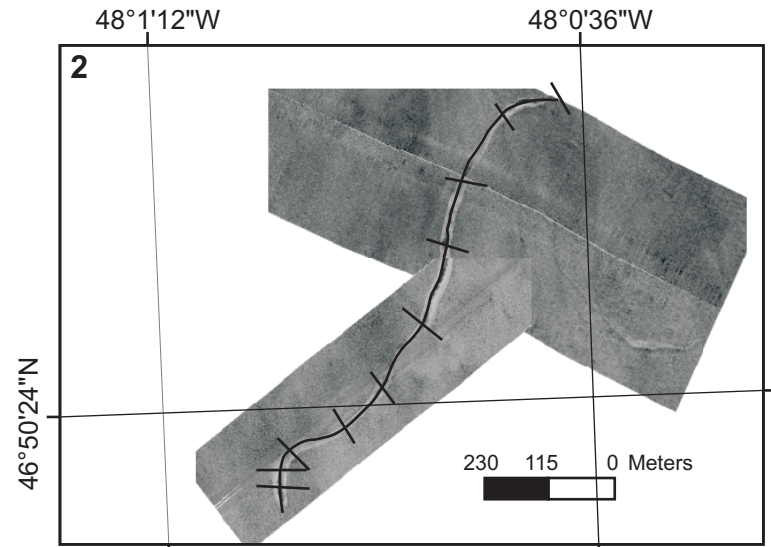
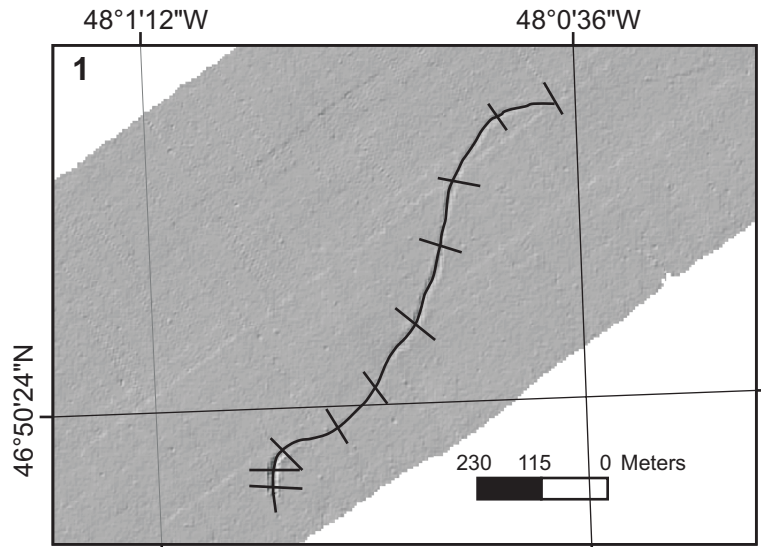


Maps showing the location of surface profiles of scour 89-01. (1) is of multibeam bathymetry, (2) is of sidescan and (3) is a 3-D view generated from the multibeam bathymetry data.

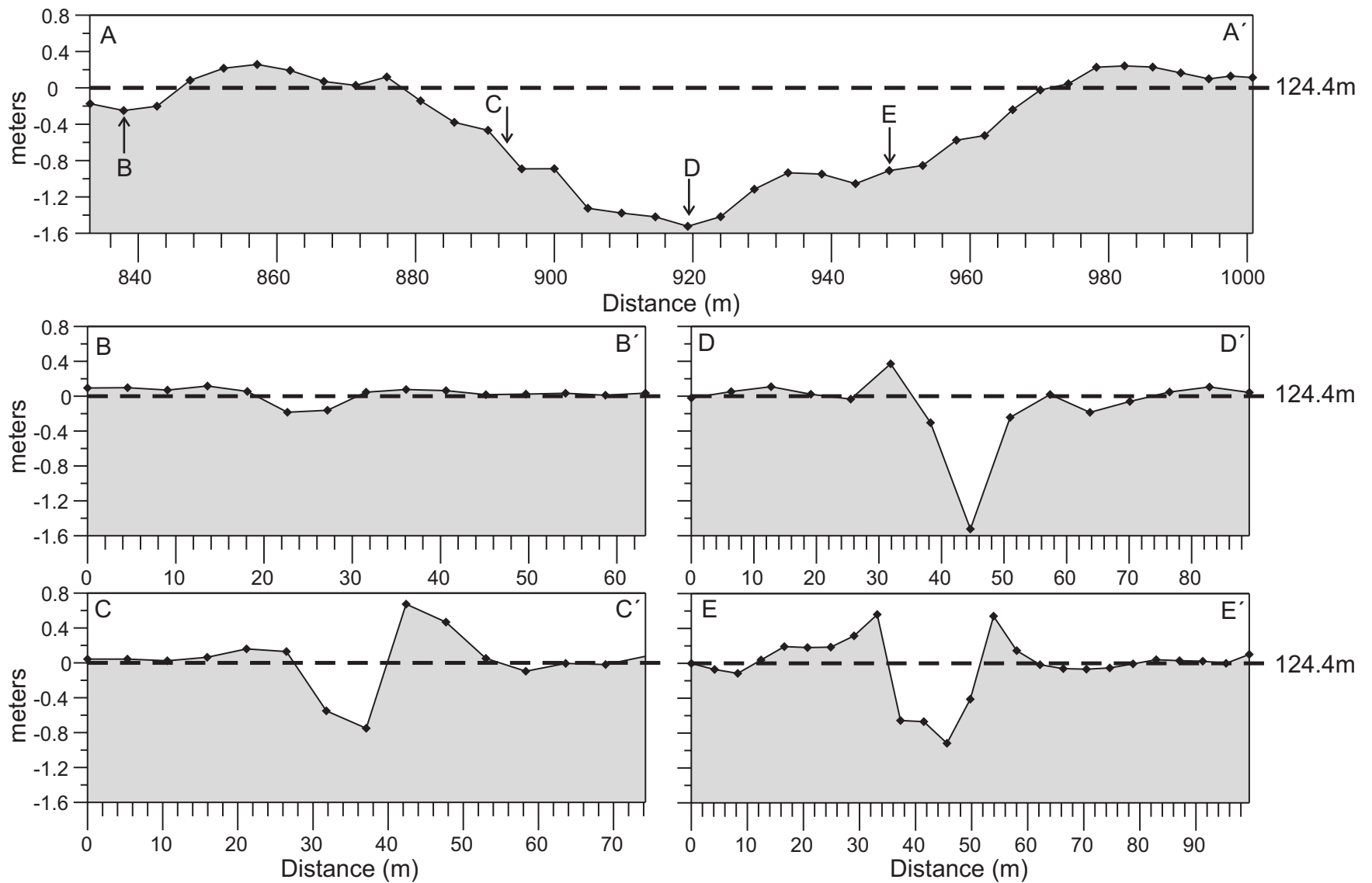


Surface profiles through scour 89-01.

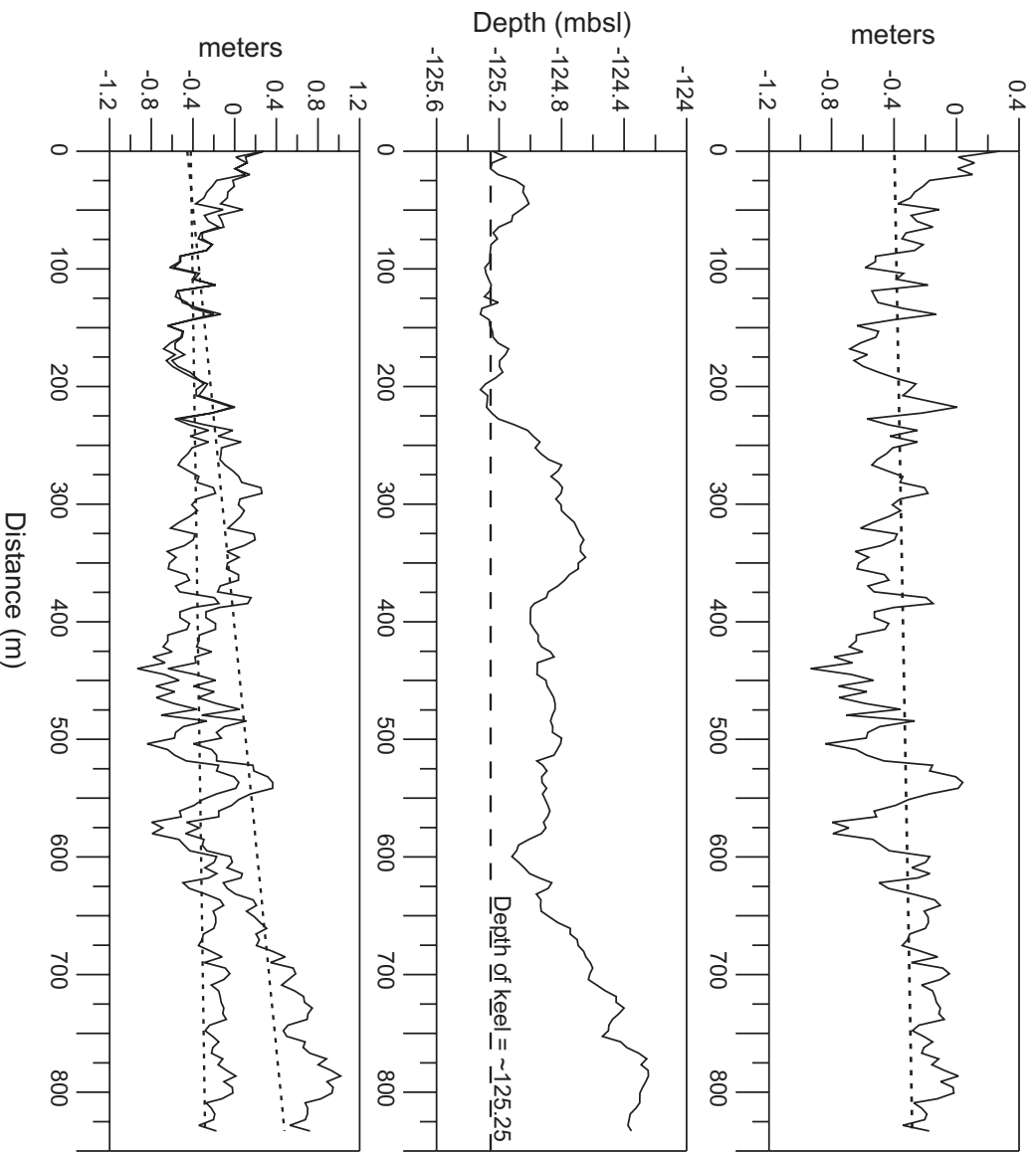




Maps showing the locations of surface profiles of scour 88-01. (1) and (2) are of the whole scour seen by multibeam bathymetry and sidescan. (3) is a close-ups of the terminal end of the scour viewed by sidescan. (4) is a 3-D view generated with the multibeam bathymetry.

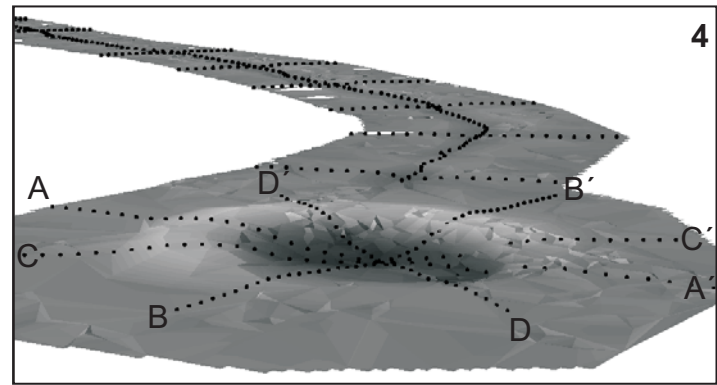
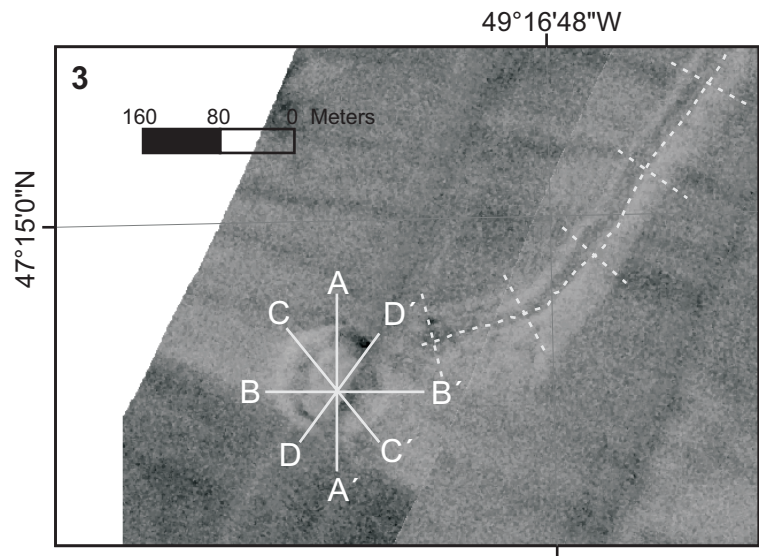
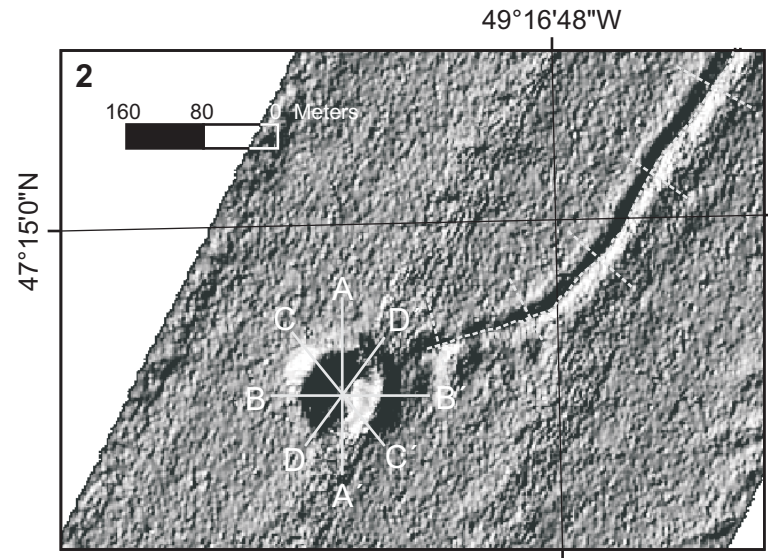
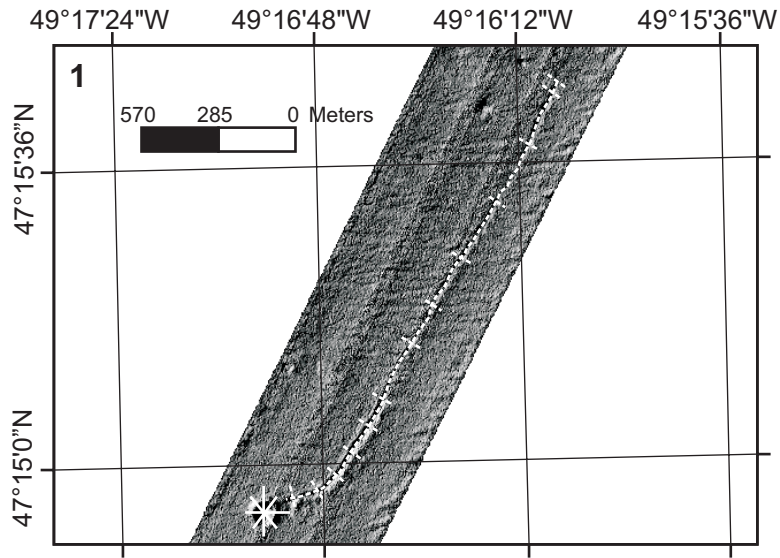


Surface profiles through the terminal end of scour 88-01.

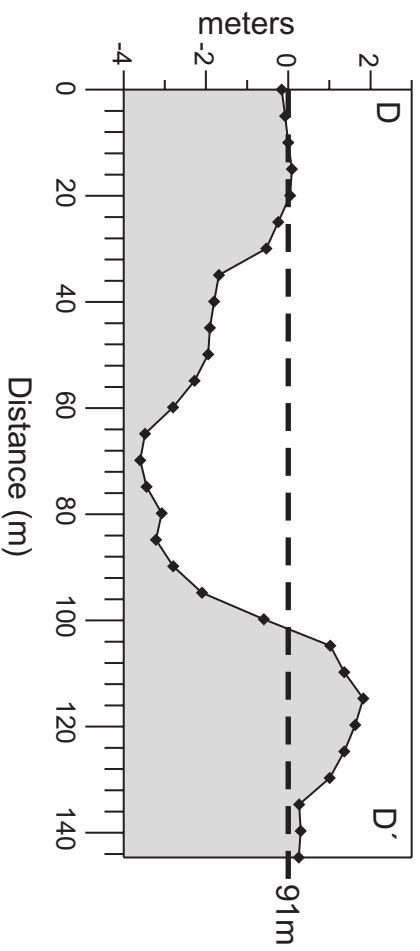
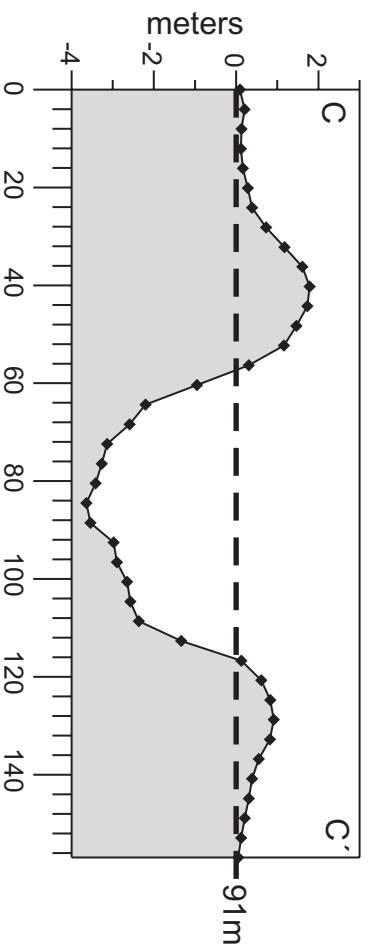
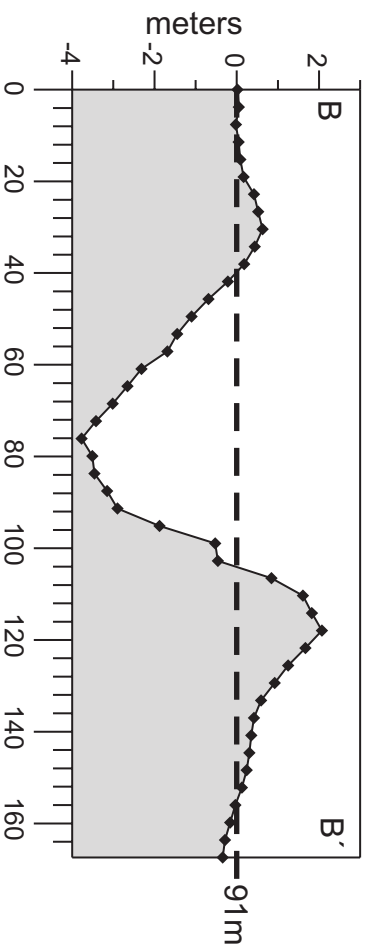
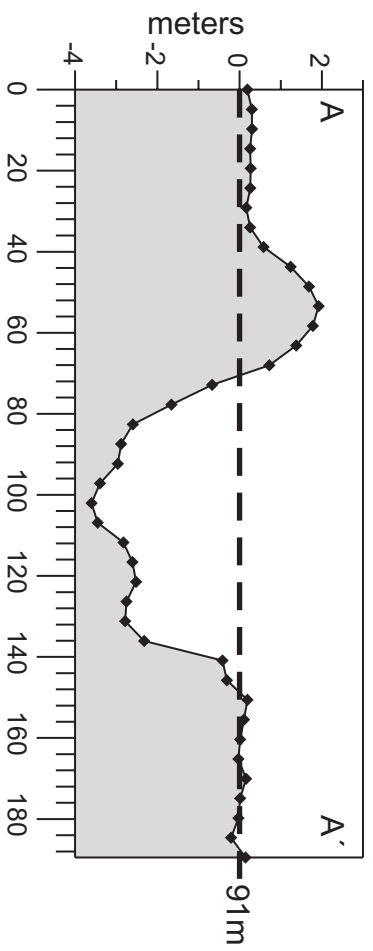


(1) Measured variations in the depth of the scour. (2) 'Pre-scour' seafloor measured over the trough of the scour. (3) A plot showing the degree of keel rise-up for scour 83-95.

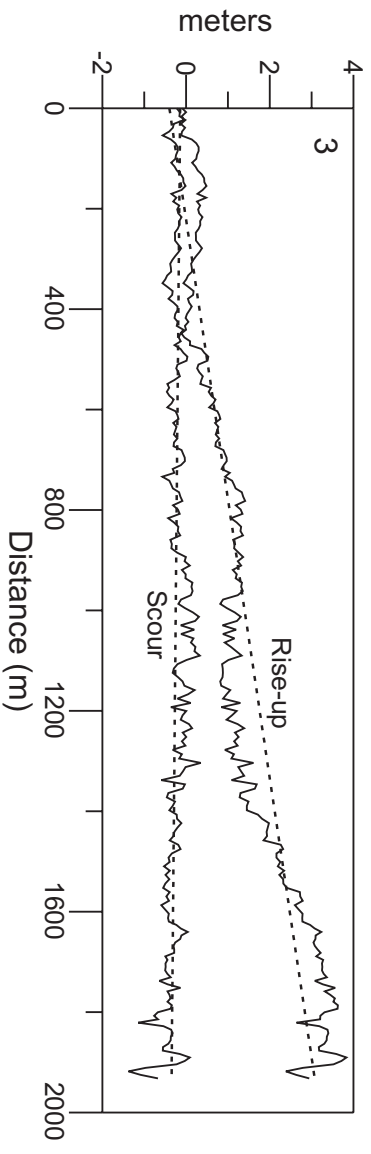
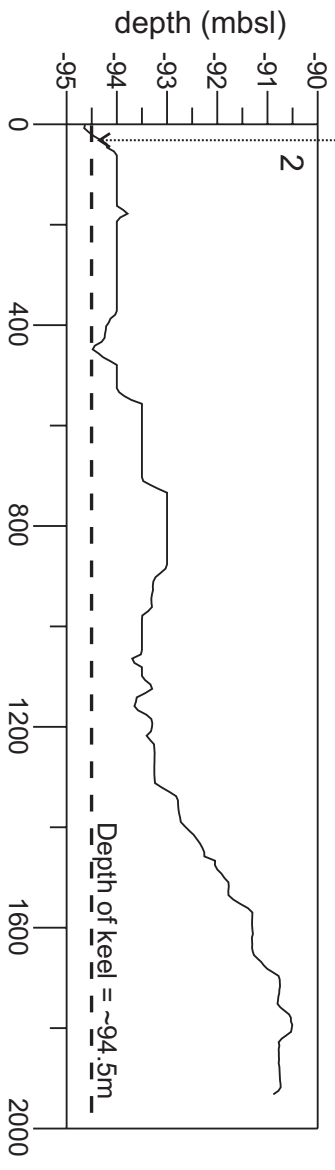
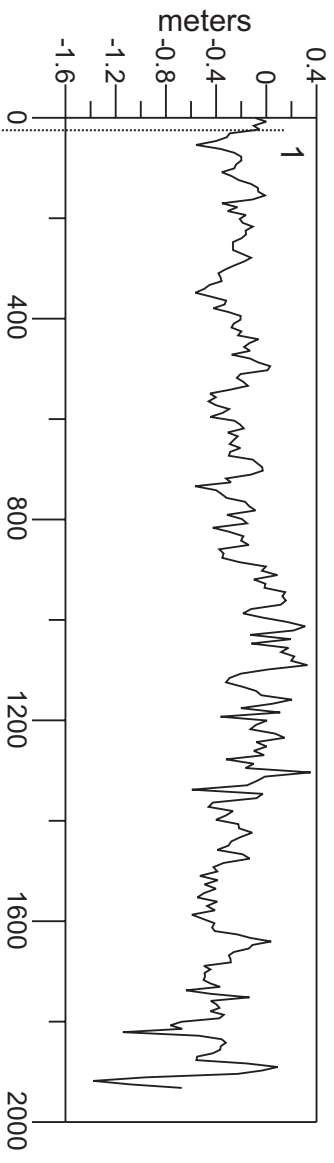
# Scour 83-95



Maps showing the locations of surface profiles of scour 83-95. (1) is of the whole scour captured with multibeam bathymetry, (2) and (3) are close-ups of the terminal end of the scour, in multibeam bathymetry and sidescan. (4) is a 3-D view generated with the multibeam bathymetry.



Surface profiles through pit 83-95.



(1) Measured variations in the depth of the scour. (2) 'Pre-scour' seafloor measured over the trough of the scour. (3) A plot showing the degree of keel rise-up for scour 83-95.

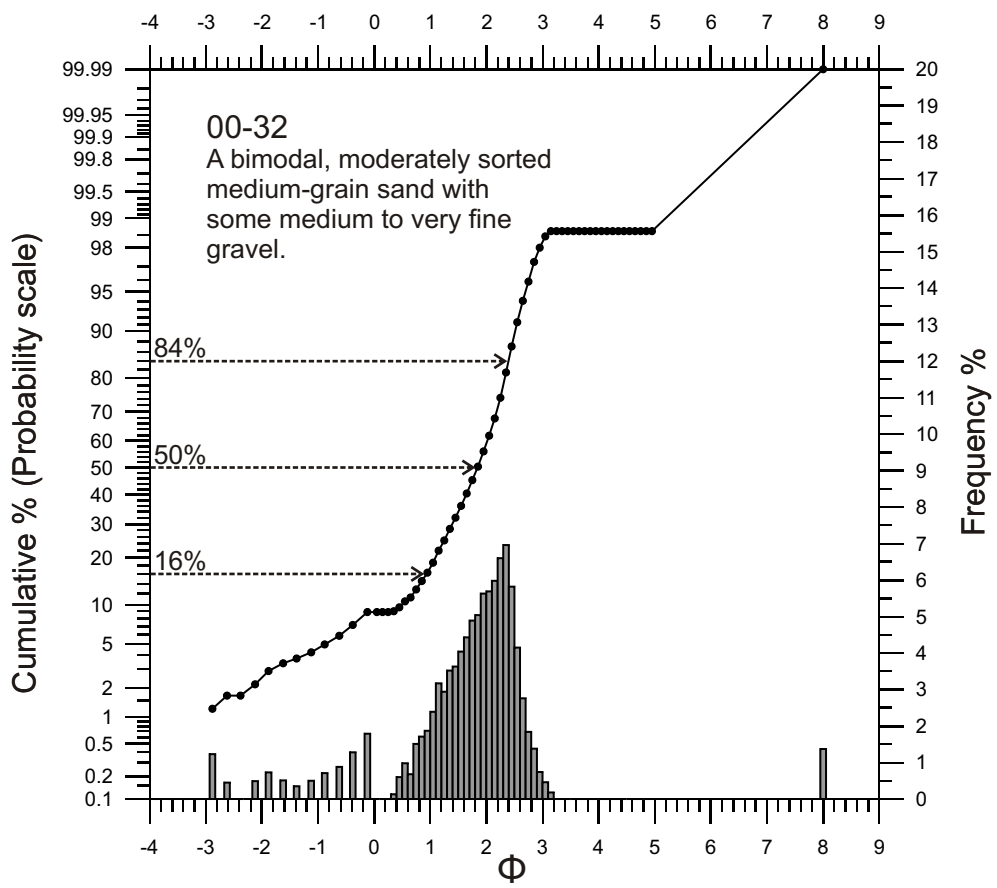
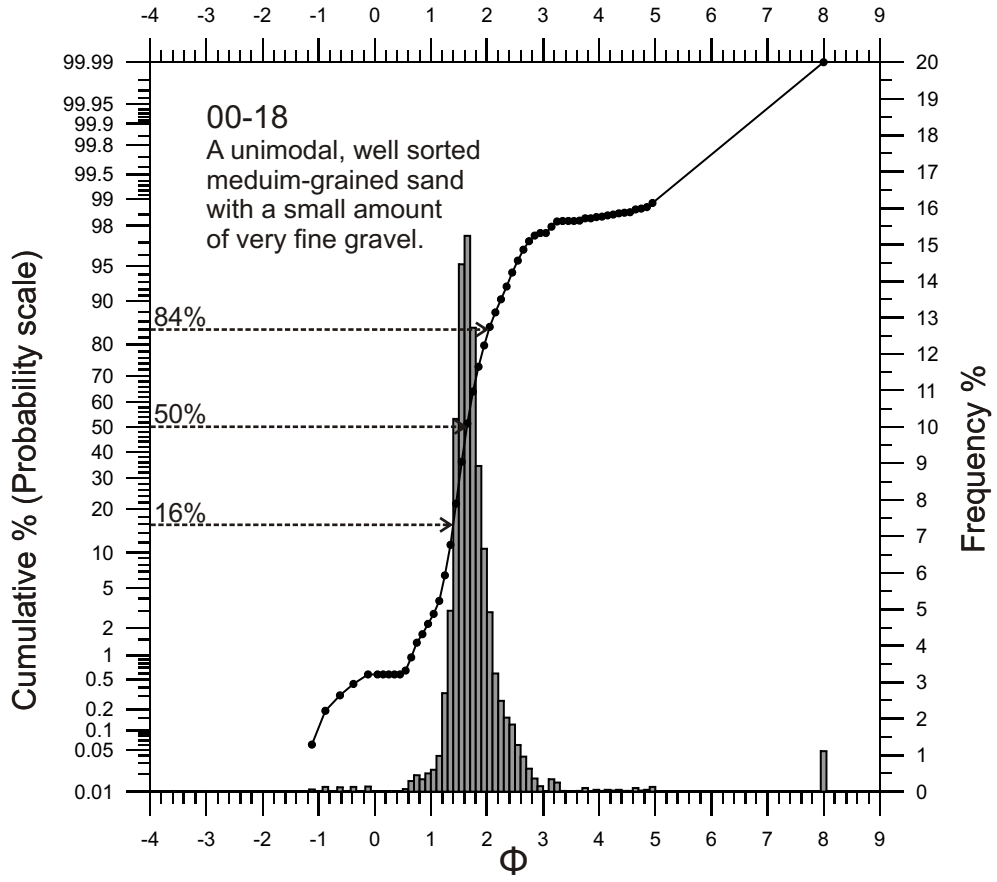
## **APPENDIX V**

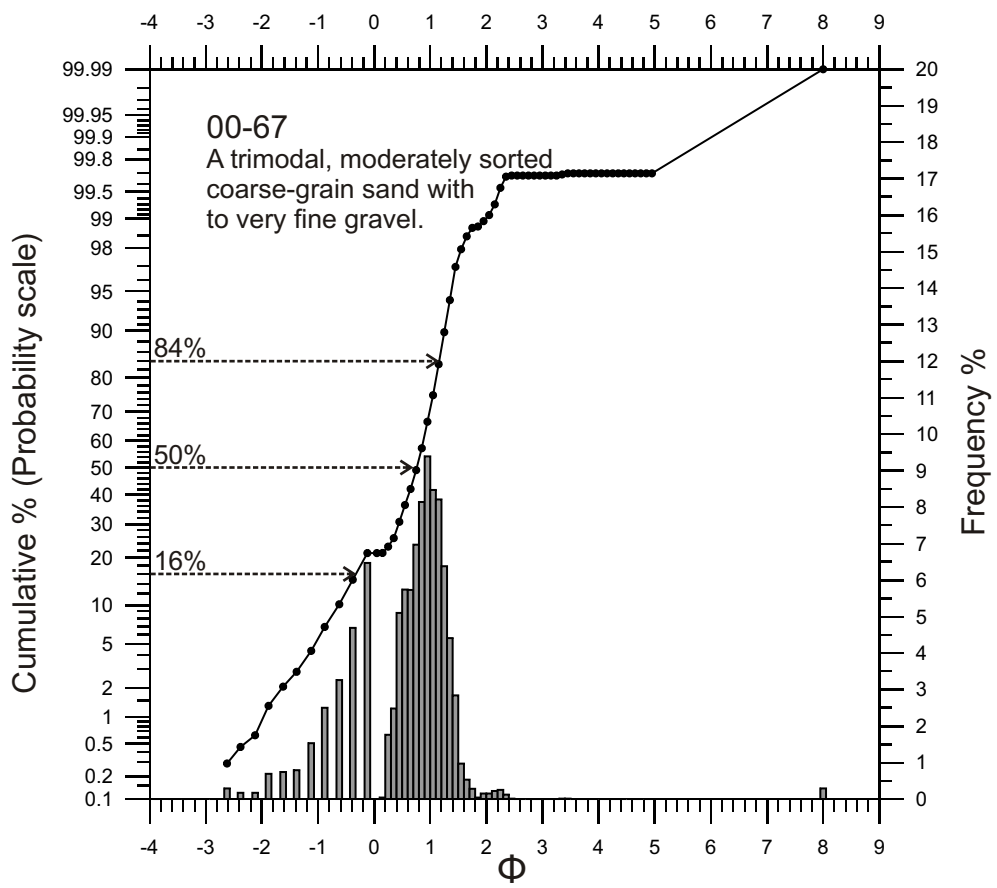
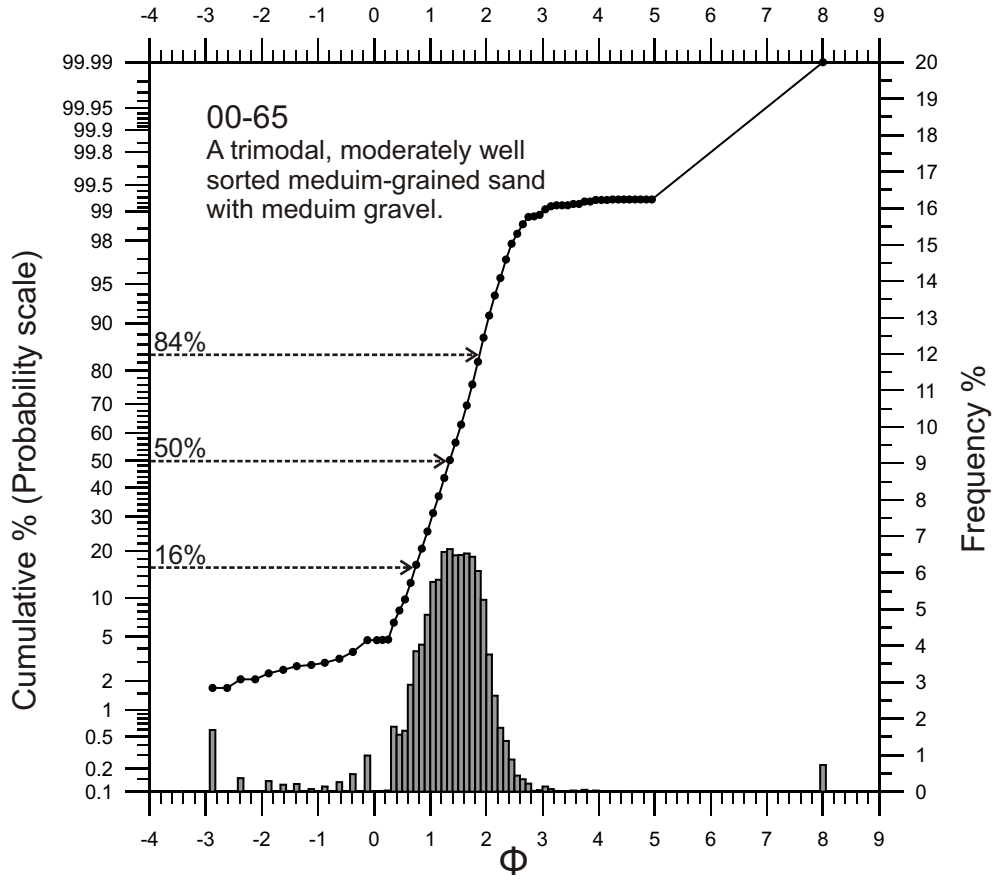
Grain size data and plots

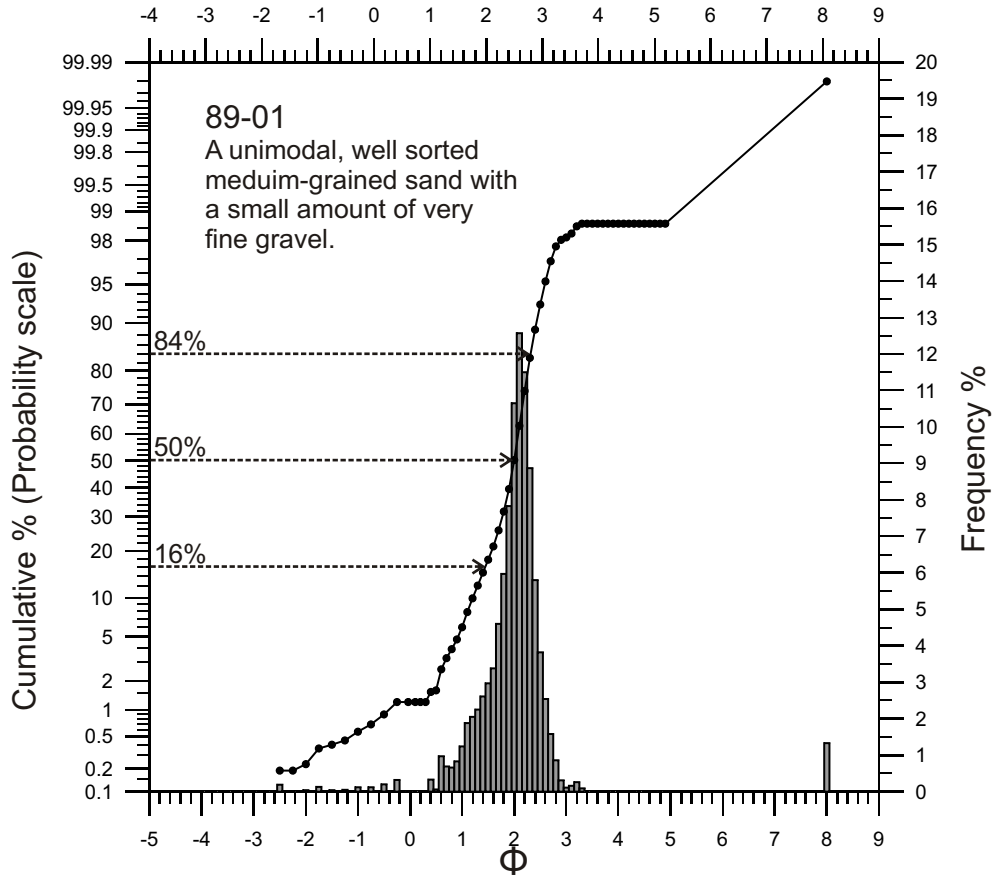
Grain size from IKU grabs at five of the surveyed scours

| Aperture      |        | 00-18       |              | 00-32       |              | 00-65       |              | 00-67       |              | 89-01       |              |
|---------------|--------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|-------------|--------------|
| $\mu\text{m}$ | $\Phi$ | Frequency % | Cumulative % | Frequency % | Cumulative % | Frequency % | Cumulative % | Frequency % | Cumulative % | Frequency % | Cumulative % |
| 16000         | -4     | 0           | 0            | 0           | 0            | 0           | 0            | 0           | 0            | 0           | 0            |
| 13454         | -3.75  | 0           | 0            | 0           | 0            | 0           | 0            | 0           | 0            | 0           | 0            |
| 11314         | -3.5   | 0           | 0            | 0           | 0            | 0           | 0            | 0           | 0            | 0           | 0            |
| 9514          | -3.25  | 0           | 0            | 0           | 0            | 0           | 0            | 0           | 0            | 0           | 0            |
| 8000          | -3     | 0           | 0            | 1.23        | 1.23         | 1.69        | 1.69         | 0           | 0            | 0           | 0            |
| 6727          | -2.75  | 0           | 0            | 0.45        | 1.68         | 0           | 1.69         | 0.29        | 0.29         | 0           | 0            |
| 5657          | -2.5   | 0           | 0            | 0           | 1.68         | 0.37        | 2.06         | 0.17        | 0.46         | 0.19        | 0.19         |
| 4757          | -2.25  | 0           | 0            | 0.49        | 2.17         | 0           | 2.06         | 0.17        | 0.63         | 0           | 0.19         |
| 4000          | -2     | 0           | 0            | 0.73        | 2.9          | 0.29        | 2.35         | 0.69        | 1.32         | 0.04        | 0.23         |
| 3364          | -1.75  | 0           | 0            | 0.51        | 3.41         | 0.19        | 2.54         | 0.74        | 2.06         | 0.13        | 0.36         |
| 2828          | -1.5   | 0           | 0            | 0.35        | 3.76         | 0.21        | 2.75         | 0.79        | 2.85         | 0.04        | 0.4          |
| 2378          | -1.25  | 0.06        | 0.06         | 0.5         | 4.26         | 0.07        | 2.82         | 1.53        | 4.38         | 0.05        | 0.45         |
| 2000          | -1     | 0.13        | 0.19         | 0.71        | 4.97         | 0.14        | 2.96         | 2.5         | 6.88         | 0.12        | 0.57         |
| 1682          | -0.75  | 0.12        | 0.31         | 0.88        | 5.85         | 0.26        | 3.22         | 3.26        | 10.14        | 0.12        | 0.69         |
| 1414          | -0.5   | 0.13        | 0.44         | 1.28        | 7.13         | 0.48        | 3.7          | 4.69        | 14.83        | 0.2         | 0.89         |
| 1189          | -0.25  | 0.14        | 0.58         | 1.79        | 8.92         | 0.99        | 4.69         | 6.47        | 21.3         | 0.32        | 1.21         |
| 1025          | -0.035 | 0           | 0.58         | 0           | 8.92         | 0           | 4.69         | 0           | 21.3         | 0           | 1.21         |
| 933           | 0.1    | 0           | 0.58         | 0           | 8.92         | 0.02        | 4.71         | 0.04        | 21.34        | 0           | 1.21         |
| 871           | 0.2    | 0           | 0.58         | 0           | 8.92         | 0.03        | 4.74         | 1.76        | 23.1         | 0           | 1.21         |
| 812           | 0.3    | 0           | 0.58         | 0.13        | 9.05         | 1.78        | 6.52         | 2.48        | 25.58        | 0           | 1.21         |
| 758           | 0.4    | 0           | 0.58         | 0.6         | 9.65         | 1.56        | 8.08         | 5.1         | 30.68        | 0.33        | 1.54         |
| 707           | 0.5    | 0.07        | 0.65         | 0.98        | 10.63        | 1.67        | 9.75         | 5.74        | 36.42        | 0.06        | 1.6          |
| 660           | 0.6    | 0.29        | 0.94         | 0.68        | 11.31        | 2.93        | 12.68        | 5.73        | 42.15        | 0.97        | 2.57         |
| 616           | 0.7    | 0.45        | 1.39         | 1.51        | 12.82        | 3.85        | 16.53        | 6.97        | 49.12        | 0.69        | 3.26         |
| 574           | 0.8    | 0.34        | 1.73         | 1.71        | 14.53        | 4.03        | 20.56        | 8.14        | 57.26        | 0.66        | 3.92         |
| 536           | 0.9    | 0.5         | 2.23         | 1.87        | 16.4         | 4.85        | 25.41        | 9.39        | 66.65        | 0.83        | 4.75         |
| 500           | 1      | 0.6         | 2.83         | 2.39        | 18.79        | 5.75        | 31.16        | 8.47        | 75.12        | 1.24        | 5.99         |
| 467           | 1.1    | 0.98        | 3.81         | 3.17        | 21.96        | 5.81        | 36.97        | 8.21        | 83.33        | 1.88        | 7.87         |
| 435           | 1.2    | 2.7         | 6.51         | 2.94        | 24.9         | 6.57        | 43.54        | 6.38        | 89.71        | 2.05        | 9.92         |
| 406           | 1.3    | 4.96        | 11.47        | 3.52        | 28.42        | 6.65        | 50.19        | 4.41        | 94.12        | 2.25        | 12.17        |
| 379           | 1.4    | 10.22       | 21.69        | 3.63        | 32.05        | 6.48        | 56.67        | 2.84        | 96.96        | 2.61        | 14.78        |
| 354           | 1.5    | 14.46       | 36.15        | 4.04        | 36.09        | 6.49        | 63.16        | 0.97        | 97.93        | 2.97        | 17.75        |
| 330           | 1.6    | 15.24       | 51.39        | 4.43        | 40.52        | 6.53        | 69.69        | 0.53        | 98.46        | 3.38        | 21.13        |
| 308           | 1.7    | 12.72       | 64.11        | 4.89        | 45.41        | 6.44        | 76.13        | 0.28        | 98.74        | 4.6         | 25.73        |
| 287           | 1.8    | 8.93        | 73.04        | 5.04        | 50.45        | 6.05        | 82.18        | 0.04        | 98.78        | 5.97        | 31.7         |
| 268           | 1.9    | 6.66        | 79.7         | 5.63        | 56.08        | 5.26        | 87.44        | 0.15        | 98.93        | 7.83        | 39.53        |
| 250           | 2      | 4.92        | 84.62        | 5.69        | 61.77        | 3.76        | 91.2         | 0.15        | 99.08        | 10.65       | 50.18        |
| 233           | 2.1    | 3.24        | 87.86        | 5.98        | 67.75        | 2.63        | 93.83        | 0.22        | 99.3         | 12.57       | 62.75        |
| 218           | 2.2    | 2.49        | 90.35        | 6.6         | 74.35        | 1.75        | 95.58        | 0.25        | 99.55        | 11.5        | 74.25        |
| 203           | 2.3    | 2.03        | 92.38        | 6.96        | 81.31        | 1.39        | 96.97        | 0.12        | 99.67        | 8.87        | 83.12        |
| 189           | 2.4    | 1.84        | 94.22        | 5.82        | 87.13        | 0.88        | 97.85        | 0.01        | 99.68        | 5.8         | 88.92        |
| 177           | 2.5    | 1.28        | 95.5         | 4.15        | 91.28        | 0.44        | 98.29        | 0           | 99.68        | 3.82        | 92.74        |
| 165           | 2.6    | 0.96        | 96.46        | 2.76        | 94.04        | 0.34        | 98.63        | 0           | 99.68        | 2.54        | 95.28        |
| 154           | 2.7    | 0.63        | 97.09        | 1.84        | 95.88        | 0.22        | 98.85        | 0           | 99.68        | 1.58        | 96.86        |
| 144           | 2.8    | 0.36        | 97.45        | 1.38        | 97.26        | 0.02        | 98.87        | 0           | 99.68        | 0.86        | 97.72        |
| 134           | 2.9    | 0.15        | 97.6         | 0.74        | 98           | 0.04        | 98.91        | 0           | 99.68        | 0.31        | 98.03        |
| 125           | 3      | 0           | 97.6         | 0.46        | 98.46        | 0.14        | 99.05        | 0           | 99.68        | 0.11        | 98.14        |
| 117           | 3.1    | 0.34        | 97.94        | 0.18        | 98.64        | 0.07        | 99.12        | 0           | 99.68        | 0.16        | 98.3         |
| 109           | 3.2    | 0.25        | 98.19        | 0           | 98.64        | 0.02        | 99.14        | 0           | 99.68        | 0.26        | 98.56        |
| 102           | 3.3    | 0.02        | 98.21        | 0           | 98.64        | 0           | 99.14        | 0.01        | 99.69        | 0.09        | 98.65        |
| 95            | 3.4    | 0           | 98.21        | 0           | 98.64        | 0           | 99.14        | 0.01        | 99.7         | 0           | 98.65        |
| 88            | 3.5    | 0           | 98.21        | 0           | 98.64        | 0.03        | 99.17        | 0           | 99.7         | 0           | 98.65        |
| 82            | 3.6    | 0.02        | 98.23        | 0           | 98.64        | 0           | 99.17        | 0           | 99.7         | 0           | 98.65        |
| 77            | 3.7    | 0.1         | 98.33        | 0           | 98.64        | 0.05        | 99.22        | 0           | 99.7         | 0           | 98.65        |
| 72            | 3.8    | 0           | 98.33        | 0           | 98.64        | 0           | 99.22        | 0           | 99.7         | 0           | 98.65        |
| 67            | 3.9    | 0.05        | 98.38        | 0           | 98.64        | 0.03        | 99.25        | 0           | 99.7         | 0           | 98.65        |
| 63            | 4      | 0.02        | 98.4         | 0           | 98.64        | 0           | 99.25        | 0           | 99.7         | 0           | 98.65        |
| 58            | 4.1    | 0.05        | 98.45        | 0           | 98.64        | 0           | 99.25        | 0           | 99.7         | 0           | 98.65        |
| 54            | 4.2    | 0.03        | 98.48        | 0           | 98.64        | 0.01        | 99.26        | 0           | 99.7         | 0           | 98.65        |
| 51            | 4.3    | 0.05        | 98.53        | 0           | 98.64        | 0           | 99.26        | 0           | 99.7         | 0           | 98.65        |
| 47            | 4.4    | 0.02        | 98.55        | 0           | 98.64        | 0           | 99.26        | 0           | 99.7         | 0           | 98.65        |
| 44            | 4.5    | 0.02        | 98.57        | 0           | 98.64        | 0           | 99.26        | 0           | 99.7         | 0           | 98.65        |
| 41            | 4.6    | 0.1         | 98.67        | 0           | 98.64        | 0           | 99.26        | 0           | 99.7         | 0           | 98.65        |
| 38            | 4.7    | 0.03        | 98.7         | 0           | 98.64        | 0           | 99.26        | 0           | 99.7         | 0           | 98.65        |
| 36            | 4.8    | 0.05        | 98.75        | 0           | 98.64        | 0           | 99.26        | 0           | 99.7         | 0           | 98.65        |
| 33            | 4.9    | 0.13        | 98.88        | 0           | 98.64        | 0           | 99.26        | 0           | 99.7         | 0           | 98.65        |
| 4             | 8      | 1.11        | 99.99        | 1.37        | 99.99        | 0.73        | 99.99        | 0.29        | 99.99        | 1.33        | 99.98        |





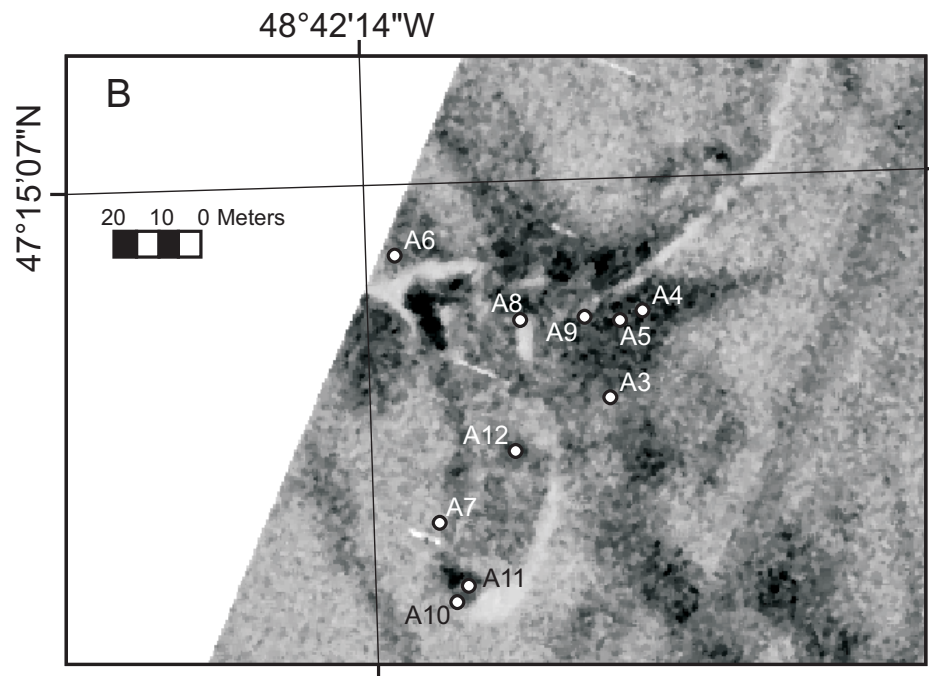
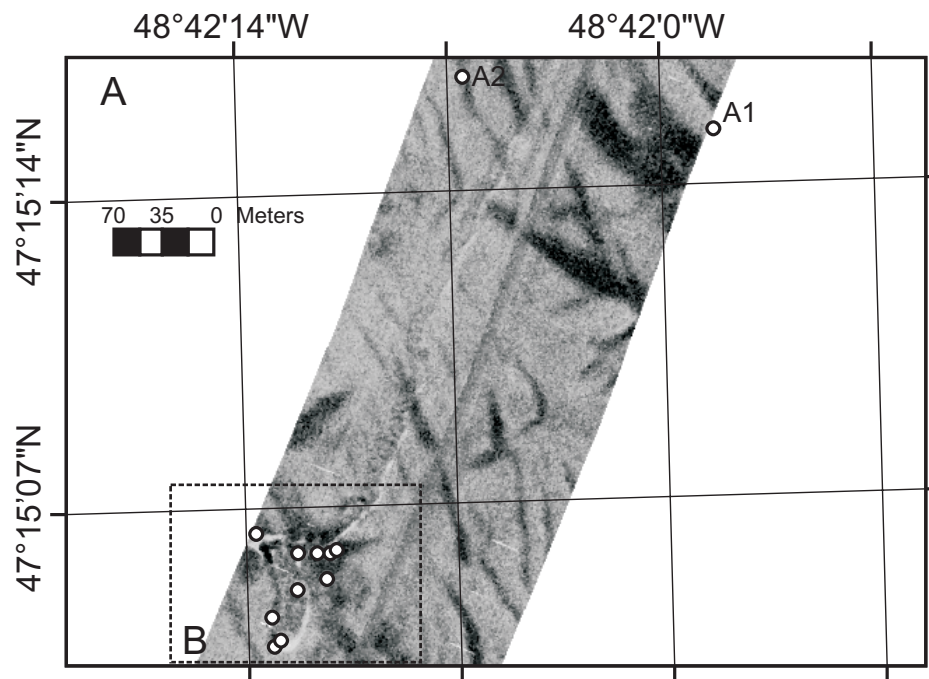




Appendix VI  
Image grabs from  
ROV video footage of the seabed  
around the grounding sites



Part A  
Scour 00-18



Location of image grabs from the ROV video footage over the 00-18 scour as seen here through side scan imagery. (B) is a closeup of the terminal part of the scour.



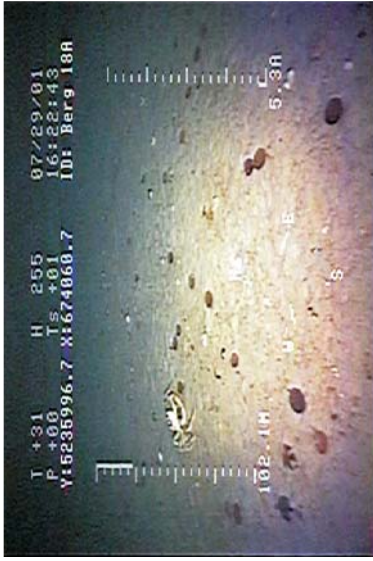


Figure A1: Sand dollars and crab on seafloor.



Figure A2: Bioturbation shown by the exiting sand lances and the mounded texture on the seafloor.



Figure A3: Pebbles and shells covering the sandy seafloor.



Figure A4: Hummocky seafloor, highlighted by the concentrations of pebbles in the troughs and sand on the crests.



Figure A5: Base of outer berm with megaripples showing deformation induced by the scouring iceberg 00-18. Substrate is sandy with coarser shelly gravel in the troughs of the megaripples and at the base of the berm. A boulder in the centre of the image is covered by a soft coral.



Figure A6: Outer berm showing the sandy substrate with biological growth on the boulders.





Figure A7: Top of outerberm.

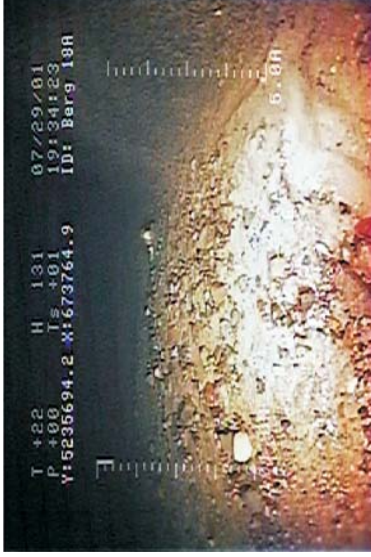


Figure A8: Berm top showing a bouldery sand substrate.

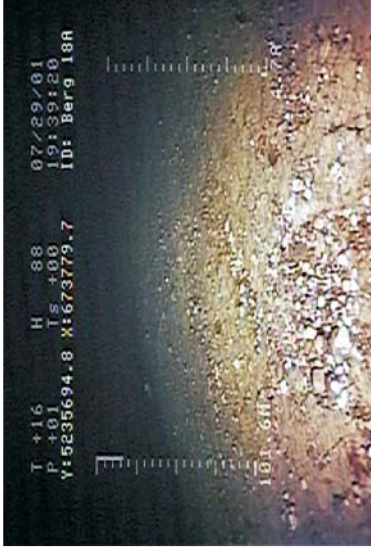


Figure A9: Berm top exhibiting a poorly sorted substrate of sand, gravel and shells.



Figure A10: Inner berm of the pit showing a sandy substrate with rare benthic organisms. There is some evidence of mounding suggesting some infaunal activity.

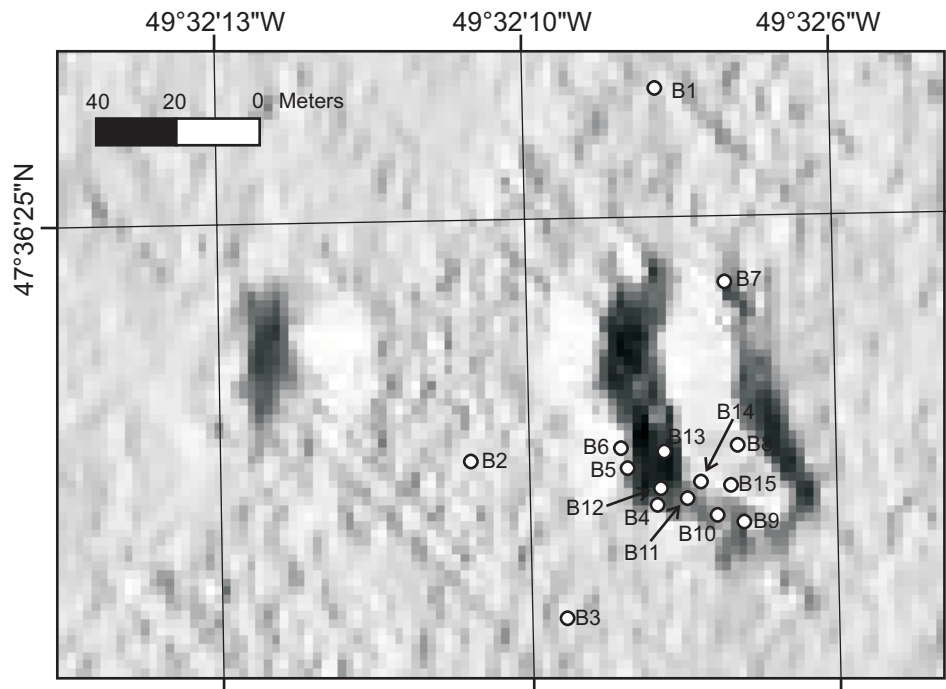
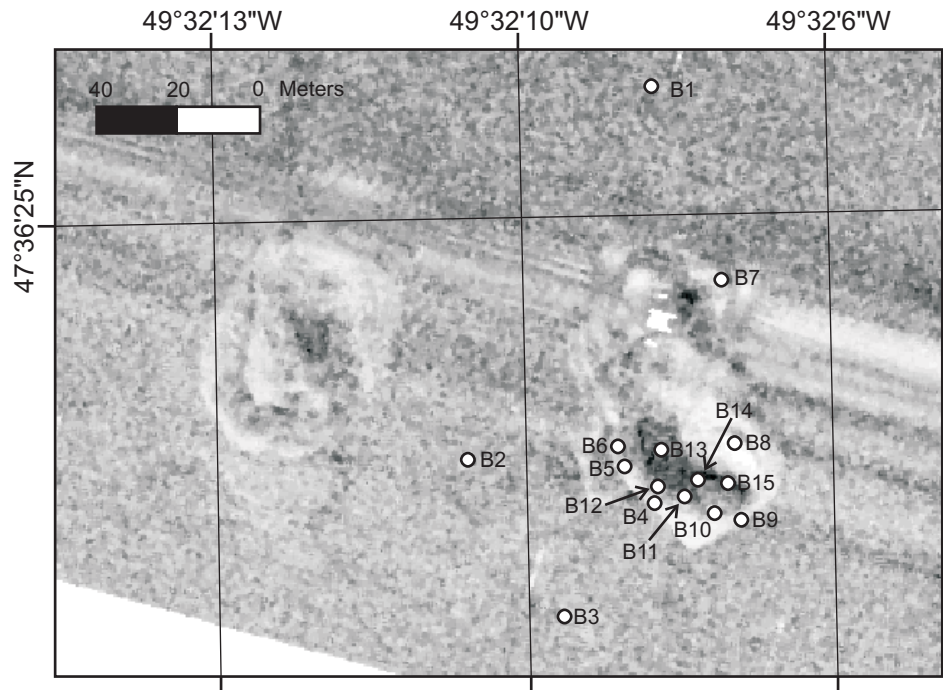


Figure A11: Pit base with inner berm in the background. Pit composed of sand with some shells and pebbles. Very little active biological colonization. Depth shown by the ROV is approximately 104 metres



Figure A12: Closeup of shell hash in the bottom of the pit.

Part B  
Scour 00-32



Map showing the locations of the image grabs taken from the ROV video footage around scour 00-32. The top map uses side scan and the bottom uses multibeam.





Figure B1: Seafloor near the 00-32 groundline showing a sandy substrate with empty shells, and pebbles, as well as crabs and sand dollars. Water depth is approximately 112 metres.



Figure B2: Another shot of the seafloor showing a similar substrate as B1. Again with sand dollars but also a sea anemone.



Figure B3: The seafloor with sand dollars, crabs and a ray.



Figure B4: A boulder on the berm top with no attached organisms.



Figure B5: The berm top the substrate remains sandy but there is little colonization by the organisms noted on the surrounding seafloor.



Figure B6: A large boulder set into the berm top hosts a tall sponge and numerous gastropods. Interestingly, the size of the sponge is larger than one years growth, thus, the boulder likely under went little rotational movement as the berm was pushed up.



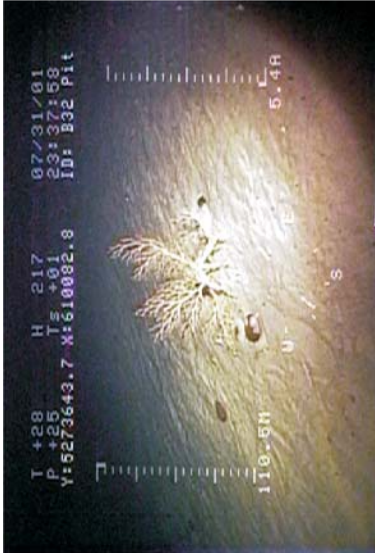


Figure B7: The outer berm showing mobile organisms, a basket star and some sand dollars, on a sandy substrate.

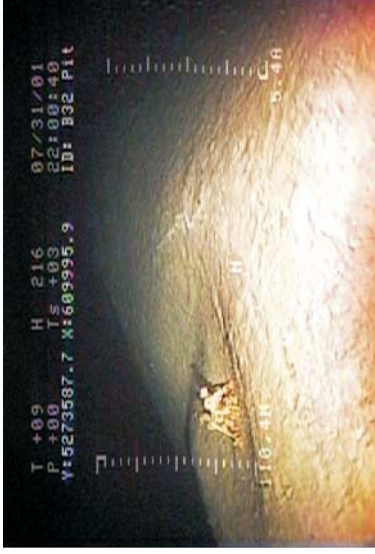


Figure B8: Sandy berm top at 110.5 metres. To the left there is a basket star.



Figure B9: Here the berm top is slightly more populated with sand dollars, crabs and a basket star.

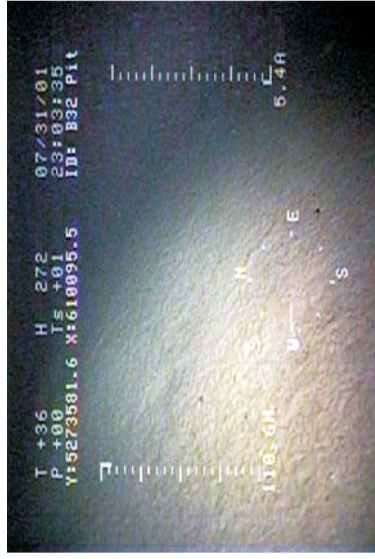


Figure B10: Upper part of the inner berm wall, steep, sandy, and lacks any significant biological community.



Figure B11: Lower part of the inner berm, also steep, sandy and lacks any significant biological community.

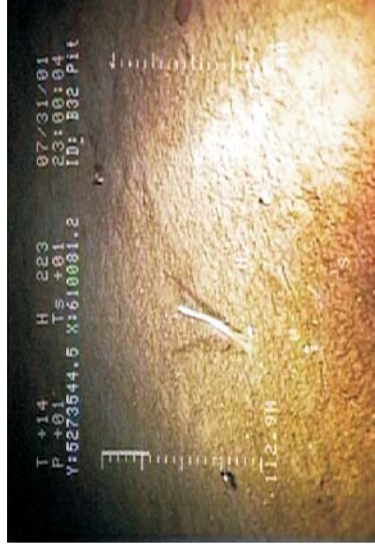


Figure B12: Here the inner berm shows some life, a few sand dollars and sand lances.



Figure B13: This shot shows the initial phases of colonization of the pit indicated by the presence of tracks and trails, sea anemones and sand lances exiting the floor.



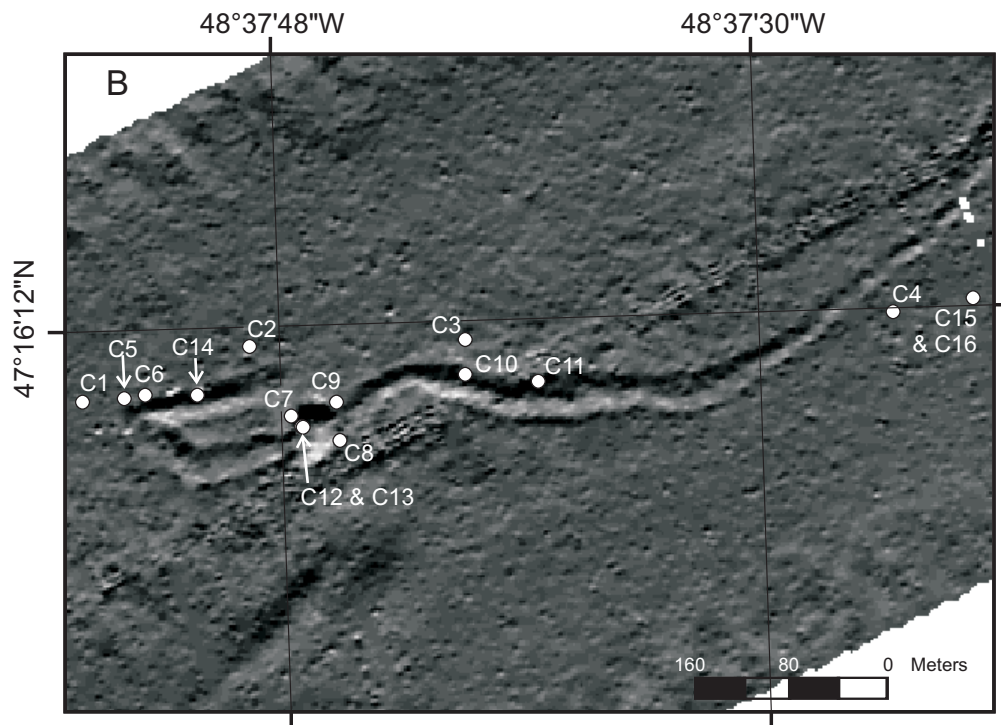
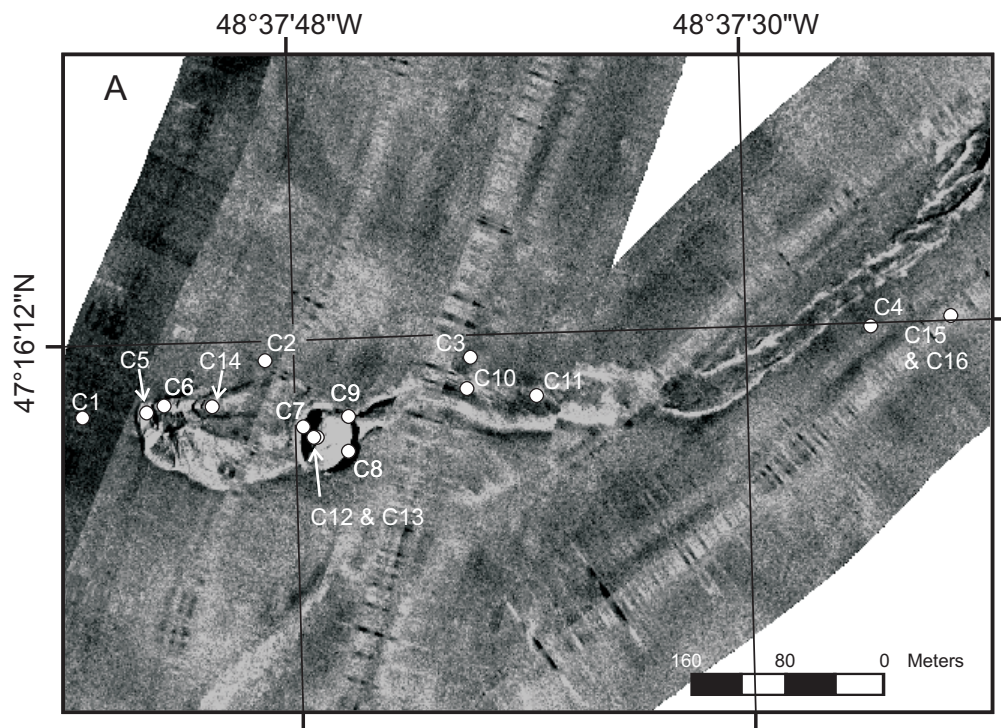
Figure B14: Base of the pit, although the floor of the pit is a similar sediment as the surrounding seafloor it lacks the biological community.



Figure B15: Another shot of the pit showing small depressions likely made by fish.



Part C  
Scour 00-65



Maps showing the location of image grabs ROV footage, (A) is sidescan and (B) is multibeam bathymetry.



Figure C1: Seafloor characterized by bioturbated sand with sea anemones and sponges. Water depth is around 127 metres.



Figure C2: Seafloor characterized by bioturbated sand with sea anemones and sponges.

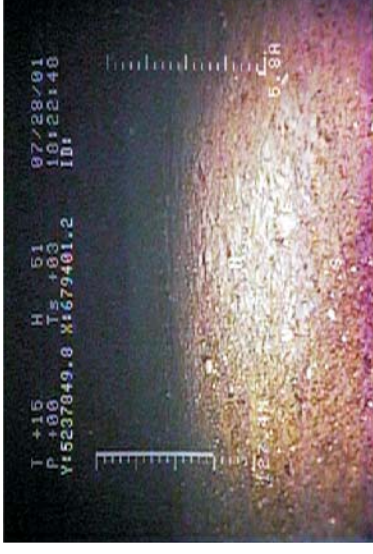


Figure C3: Seafloor characterized by bioturbated gravelly sand with some sea anemones. The scour's berm can be faintly seen in the background.



Figure C4: Seafloor characterized by bioturbated sand with sea anemones and sponges.



Figure C5: The outer berm is a poorly sorted gravelly sand hosting limited life.



Figure C6: Berm crest showing an increase in sea anemones along with a crab.





Figure C7: The crest of the berm is generally similar to the outer berm composed of a poorly sorted gravelly sand.



Figure C8: This area of the berm crest has a higher gravel content.



Figure C9: A boulder on the berm providing shelter for a crab, but no evidence of colonization by slow growing attached species.



Figure C10: The berm crest showing the lack of biological colonization on the small boulders.



Figure C11: Inner berm showing a gravel substrate hosting no attached species; but, as on the outer and crest evidence of mobile species.

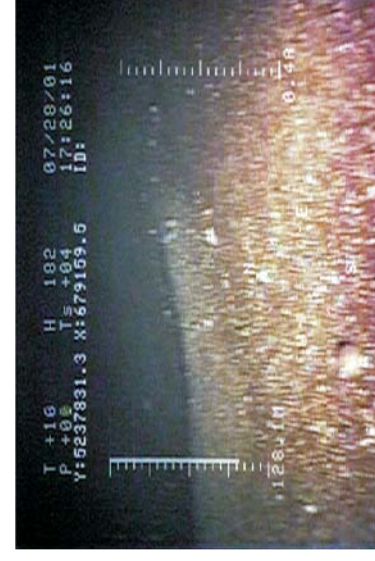


Figure C12: Scour trough, as with the inner berm is a poorly sorted gravel with little life.



Figure C13: Closeup of the coarser inner berm wall.



Figure C14: Scour trough showing a smaller furrow within the scour.



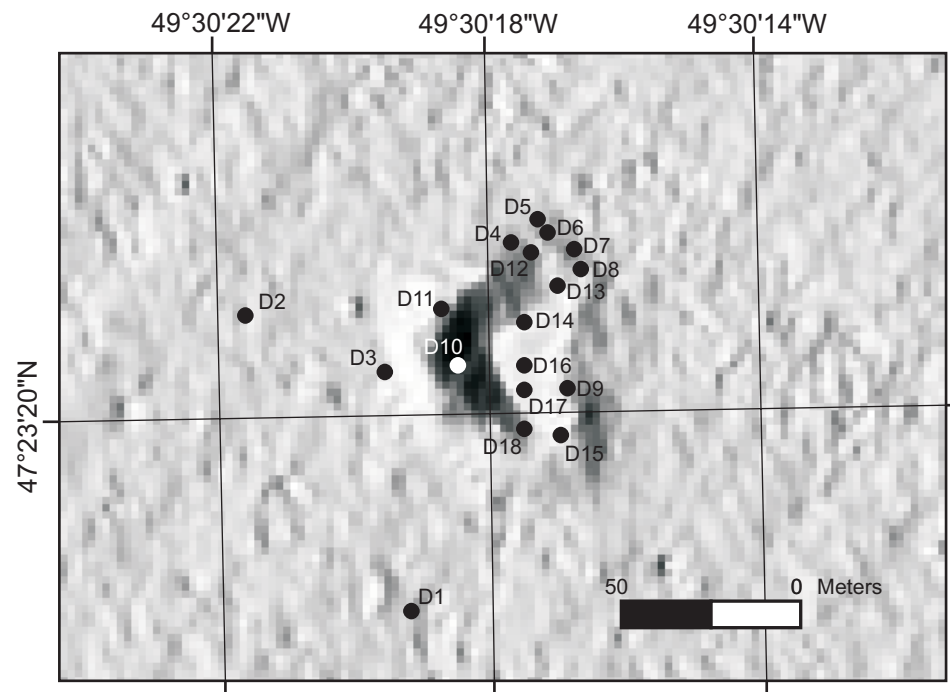
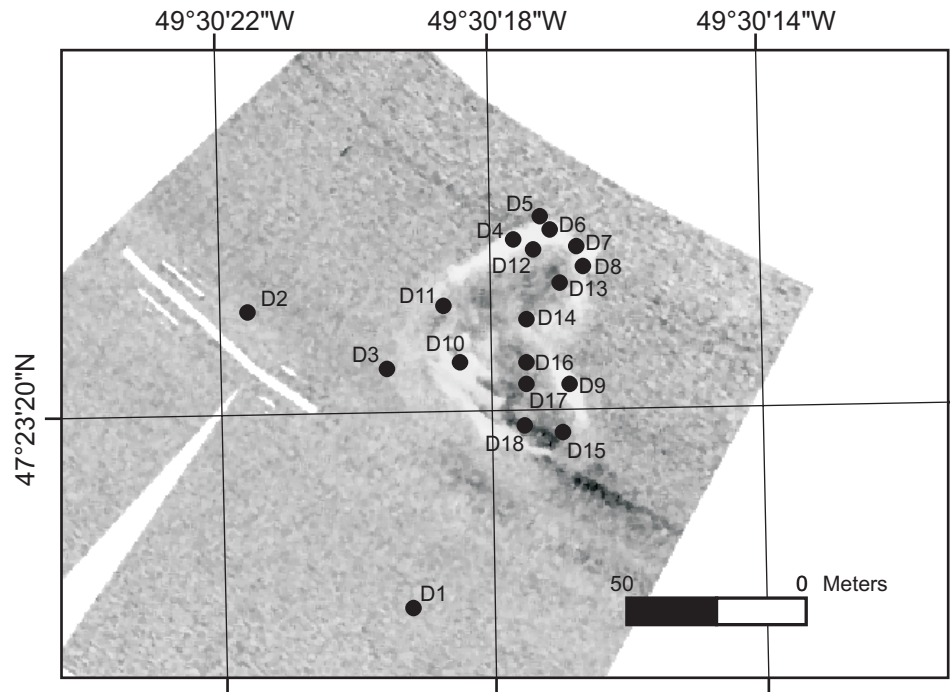
Figure C15: What looks like a whale vertebrae within the scour providing shelter for crabs.



Figure C16: Another shot of the bone, note the ring of coarser material suggesting current winnowing.



Part D  
Scour 00-67



Maps showing the locations of image grabs from ROV video footage taken around scour 00-67. The top one is side scan and the bottom one is multibeam





Figure D1: In general the seafloor surrounding scour 00-67 is sand with hummocks. Seen here with a crab and a flounder.



Figure D2: Sandy hummocky relief on the seafloor with common sand dollars.



Figure D3: Sandy seafloor with sand dollars and small depressions likely made by foraging fish. The outer berm of the scour may be seen in the background. Water depth is about 87 metres.



Figure D4: The outer berm is composed of sand with little coarser material. This shot shows the amount of sand dollars decrease towards the top of the berm.



Figure D5: Sand substrate on the upper outer berm with a few sand dollars.

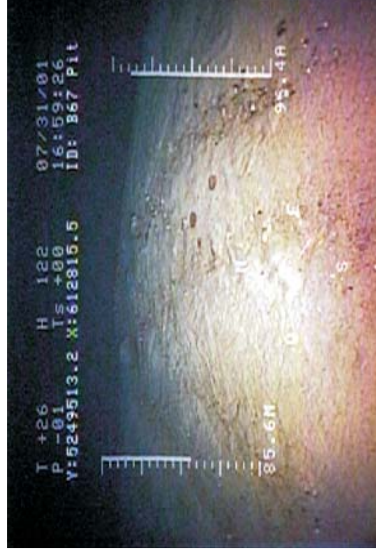


Figure D6: The outer berm showing mega-ripples and rare sand dollars.





Figure D7: The berm crest showing a small sand dune and poorly sorted gravel with very little life. The crest is in about 85.5 metres.



Figure D8: The berm crest here shows the two principal the substrates found on the crest. Gravelly sand to the left and poorly sorted cobbles to the right.



Figure D9: Sand and gravel on the berm crest, no biological activity.



Figure D10: Sand coarse gravel and boulders on the berm crest and cod.



Figure D11: Very coarse gravel and boulders on the berm crest with no biological colonization of the boulders.



Figure D12: Closeup of the inner berm showing a mixture of sand, gravel and small boulders but little biological activity.





Figure D13: A shot of large boulders on the lower inner berm, again with no biological colonization.



Figure D14: Large boulders on the lower inner berm with no biological growth.



Figure D15: Poorly sorted boulders on the lower inner



Figure D16: Pit, a sandy gravel with very little life. Pit depth is about 90 metres.

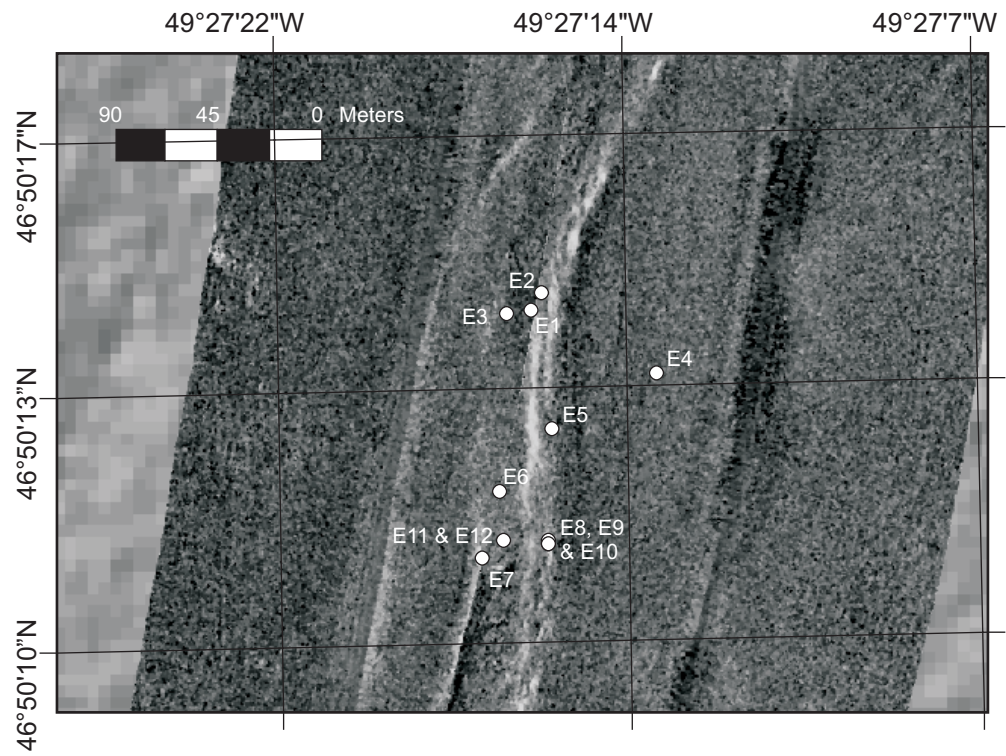
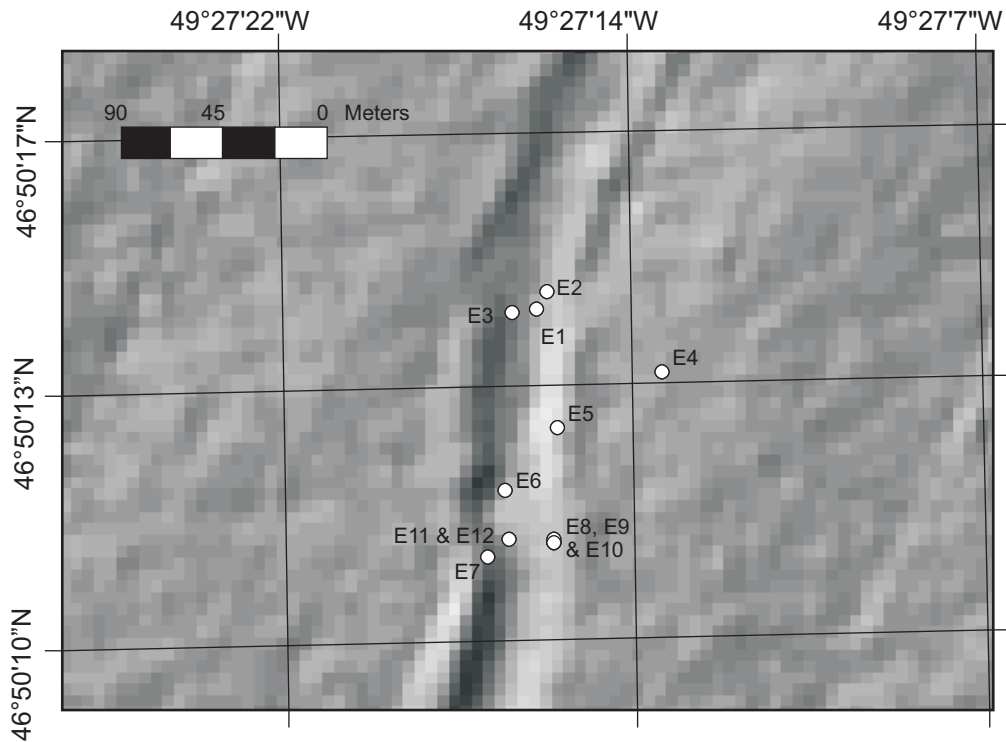


Figure D17: Closeup of the sandy gravel in the pit. Note also the unbroken shells.



Figure D18: Another shot of the pit looking south. Small pits are likely from fish.

Part E  
Scour of unknown age (00-68)



Map showing the locations of image grabs from taken from the ROV video footage around scour 00-68.





Figure E1: Coarse gravel on the seafloor populated with hydroids



Figure E2: Similar coarse gravel within the scour floor.

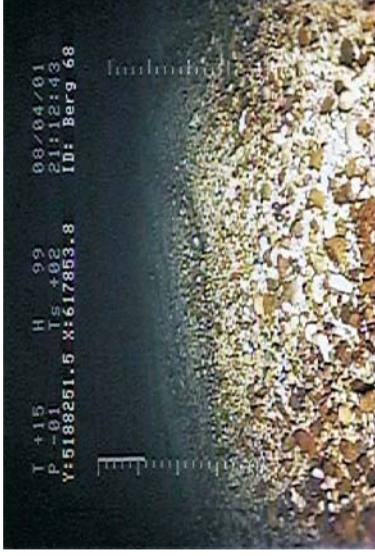


Figure E3: Megaripples on coarse gravel on the inner berm.



Figure E4: Boulders on the berm.



Figure E5: Displaced boulders on the berm



Figure E6: Hummocky surface with hummocks composed of a coarse sand and gravel with a gravel trough within the scour.



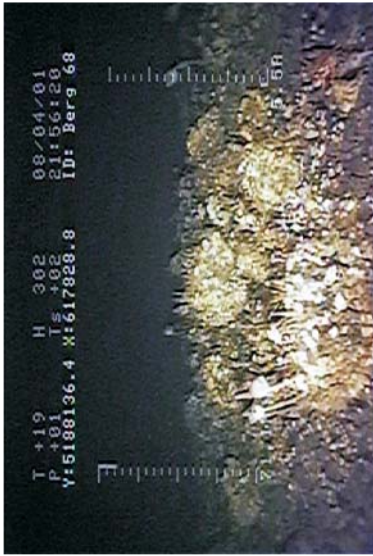


Figure E7: Boulders on the berm.

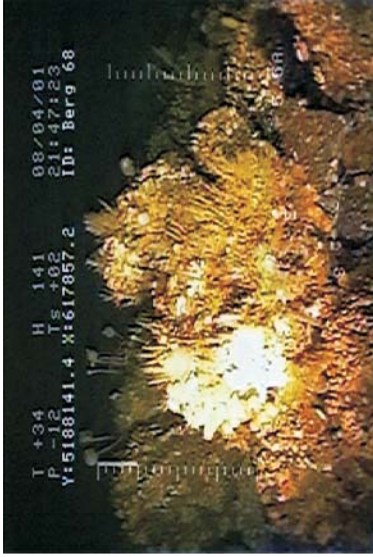


Figure E8: Boulders on the berm.

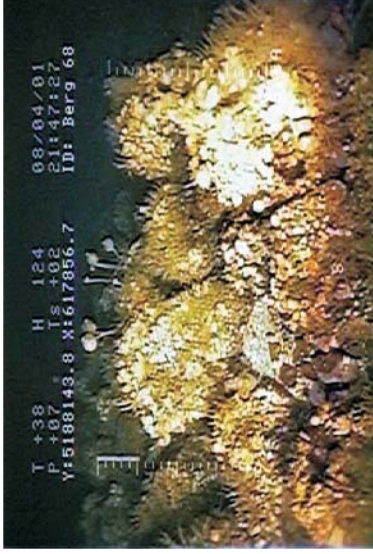


Figure E9: Boulders on the berm.



Figure E10: Coarse material on the scour floor.



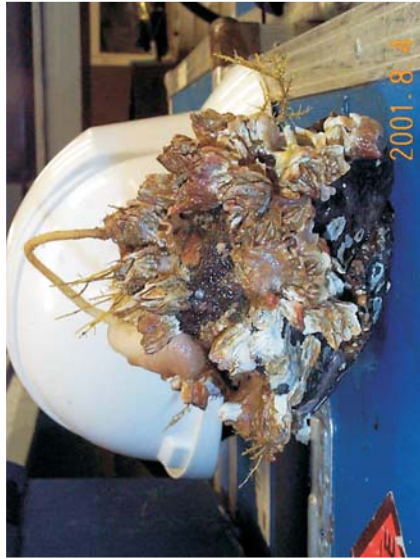
Figure E11: Sample location from the scour.



Figure E12: Sample location again.

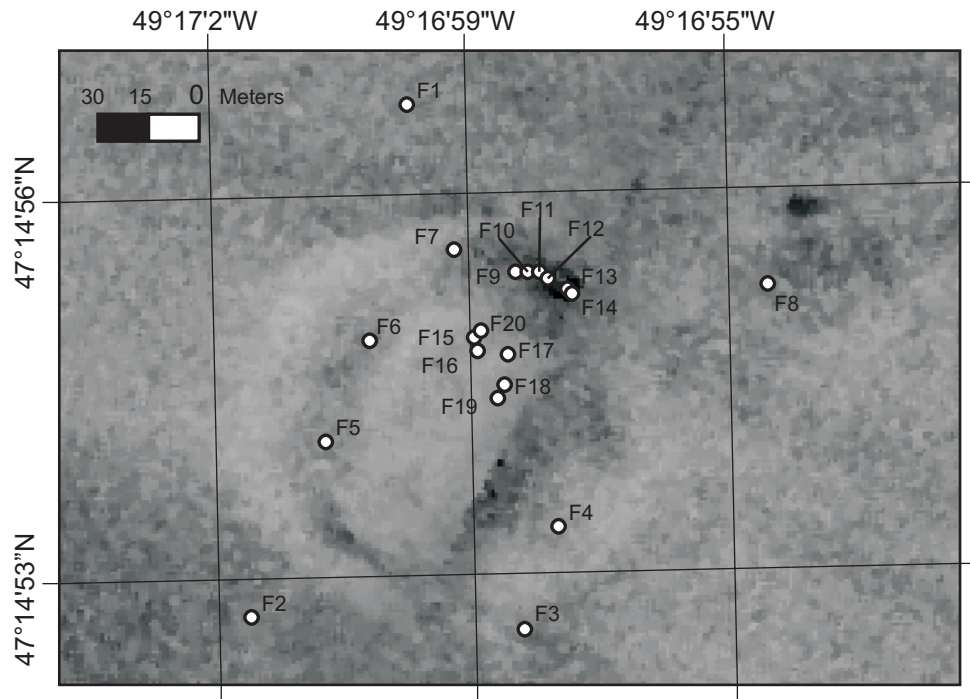
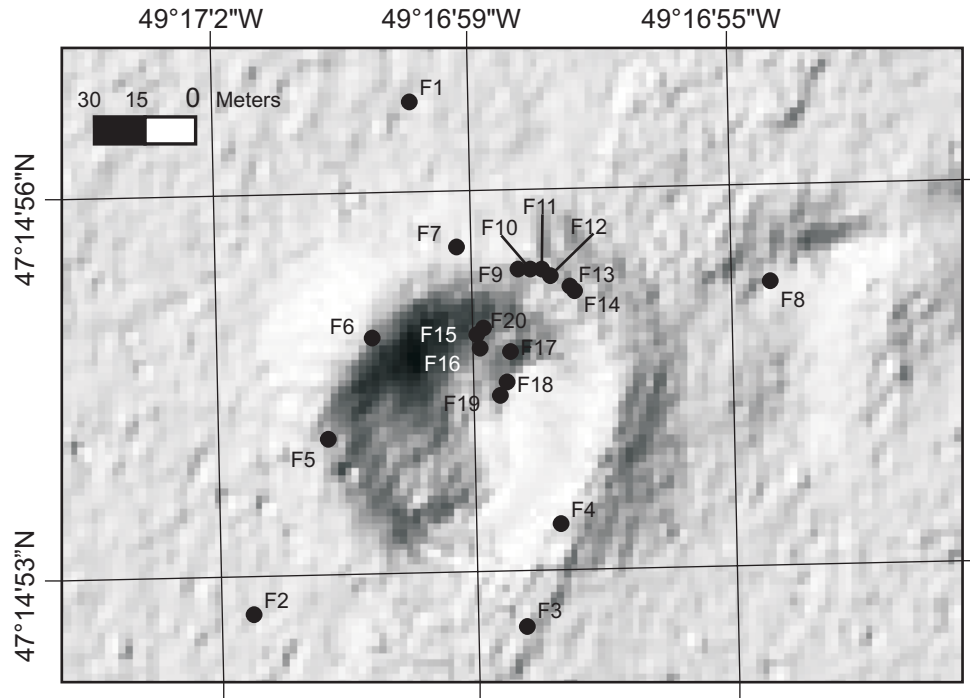


Figure E13: Shots of the sampled boulder from the scour.





Part F  
83-95



Maps showing the locations of image grabs from ROV video footage taken around scour 83-95. The top one is multibeam and the bottom one is sidescan.





Figure F1: Sandy seafloor with sand dollars and empty shells.



Figure F2: Hummocky seafloor.

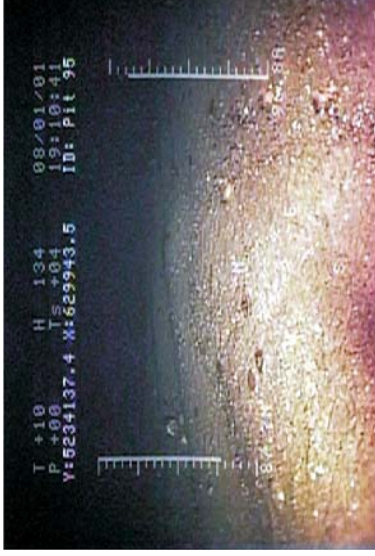


Figure F3: Gravelly sand seafloor with some sand dollars and sea anemones near the outer berm.



Figure F4: The outer berm showing a sandy substrate mixed with shells and gravel.



Figure F5: A sandier area of the upper inner berm with a few sand dollars.



Figure F6: Sandy upper inner berm with abundant sand dollars and a crab.





Figure F7: The sandy berm top showing a drop stone covered in biological growth.



Figure F8: Abundant sand lances exiting the scour floor near the pit.



Figure F9: Berm top, showing growth on coarse substrate.



Figure F10: Closeup of a boulder on the berm top.



Figure F11: Berm top, showing growth on coarse substrate.



Figure F12: Berm top, showing growth on coarse substrate, including a pout fish.





Figure F13: Another image of the biological community on the top of the berm.



Figure F14: On top of the berm looking into the pit and the transition from coarse to fine substrate.



Figure F15: A moderately coarse area of the inner berm.



Figure F16: The inner berm showing a coarse sand and gravel substrate with boulders covered in biological growth.



Figure F17: Hummocky morphology near the floor of the pit.



Figure F18: The pit floor is composed of poorly sorted sand and gravel.



Figure F19: A patch of the pit floor with a concentration of gravel and empty shells.

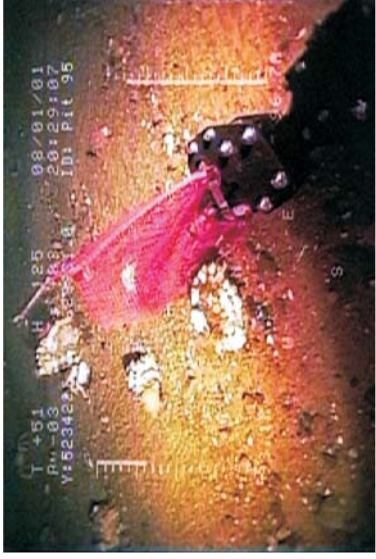


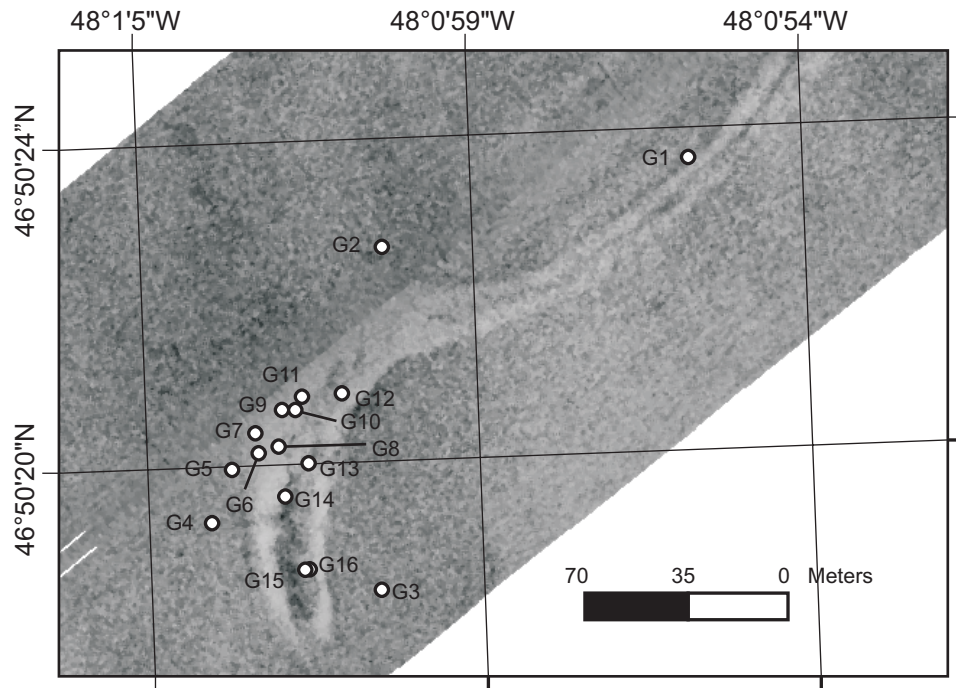
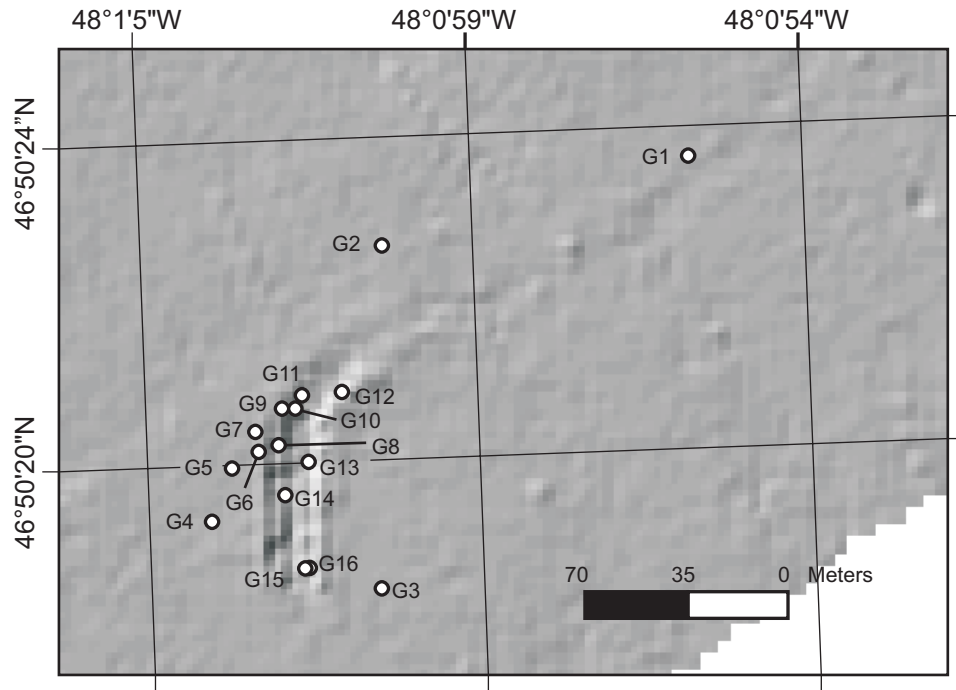
Figure F20: Sample location within the pit.



Figure 21: A-E are shots of the recovered boulder from the pit.



Part G  
88-01



Maps showing the locations of image grabs from ROV video footage taken around scour 88-01. The top one is multibeam and the bottom one is sidescan.



Figure G1: Sandy berm covered with brittle stars, sand dollars and sea anemones.



Figure G2: Sandy berm appearing very similar to the berm in G1.

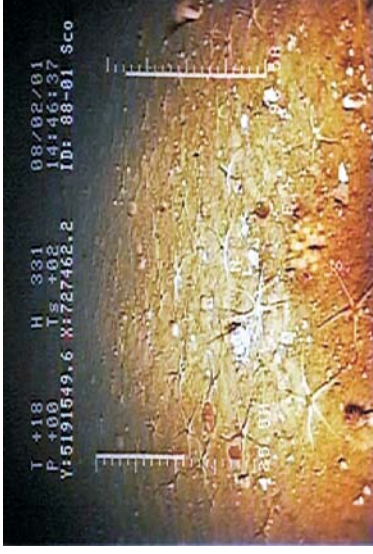


Figure G3: Seafloor.



Figure G4: Seafloor.



Figure G5: Sandy berm with similar organisms as the seafloor.

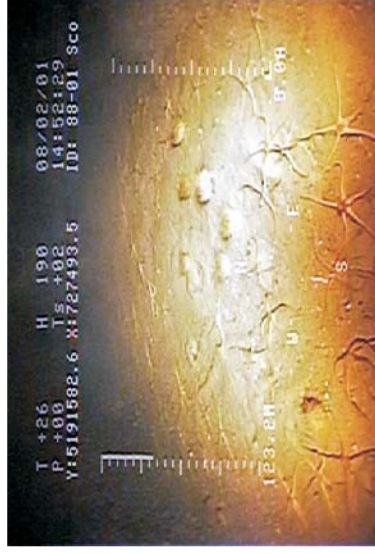


Figure G6: Close-up of the outer berm.





Figure G7: Outer berm showing similar organisms as elsewhere including a ray.



Figure G8: Sandy berm top with brittle stars sand dollars, sea anemones and crabs.



Figure G9: Berm top very similar to seafloor.



Figure G10: Berm top.



Figure G11: Upper inner berm.



Figure G12: Upper inner berm.



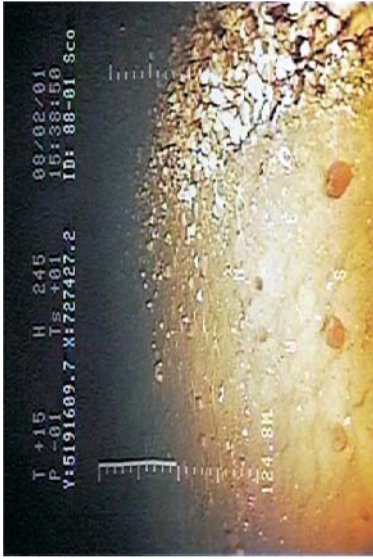


Figure G13: Scour trough showing the boundary between the dominate sand and the patches of gravelly shell hash. The dominate sand areas shown here hosting similar organisms as the sandy seafloor; sand dollars and brittle stars.



Figure G14: Shell hash in the scour trough.

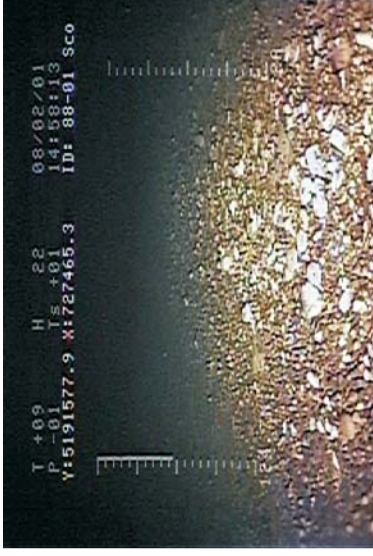
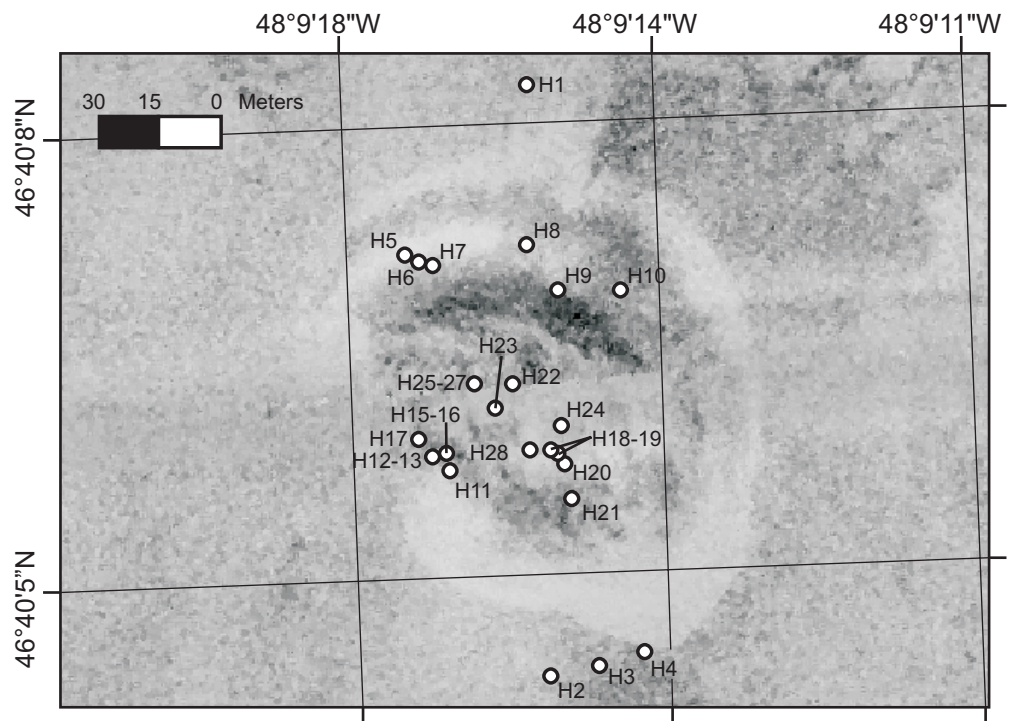
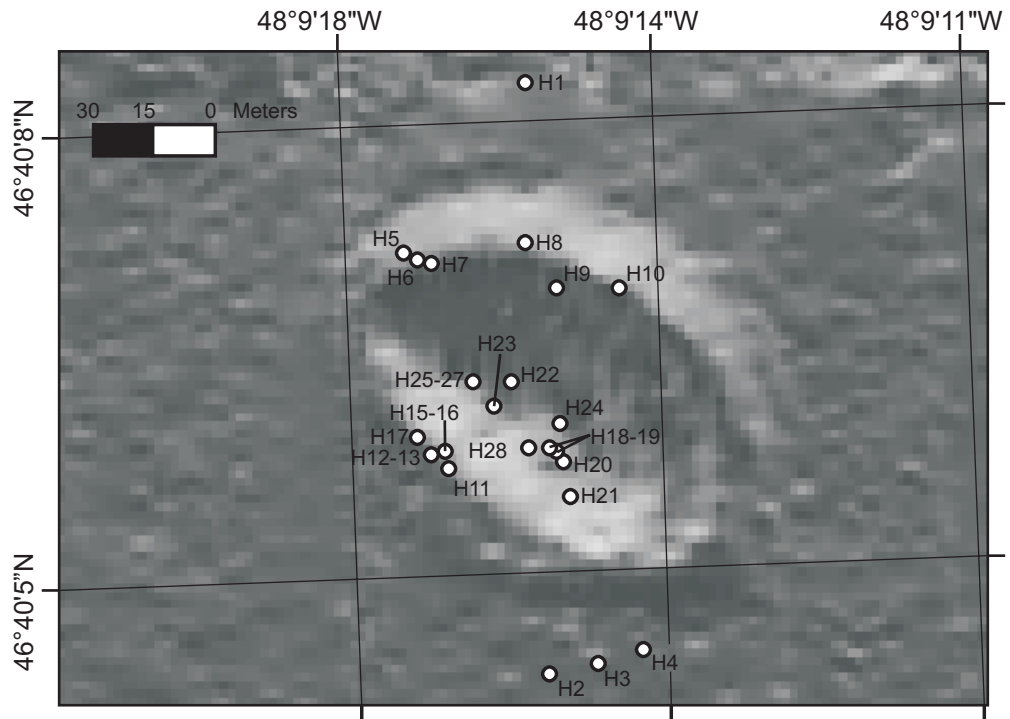


Figure G15: Gravel and shell hash in the scour trough.



Figure G16: Shell hash in the scour trough along with crabs and a large stick.

Part H  
89-01



Maps showing the locations of image grabs from ROV video footage taken around scour 89-01. The top one is multibeam and the bottom one is sidescan.





Figure H1: Sandy seafloor covered with brittle stars, sand dollars and sea anemones.



Figure H2: Gravelly sand seafloor with sea urchins eating a large starfish.



Figure H3: Gravelly sandy lower outer berm with abundant sand lances.



Figure H4: Basket star on a drop stone located on the lower outer berm.



Figure H5: Sandy gravel on the outer berm.



Figure H6: Gravel berm top with some sea anemones.





Figure H7: Gravel berm top with some sea anemones.

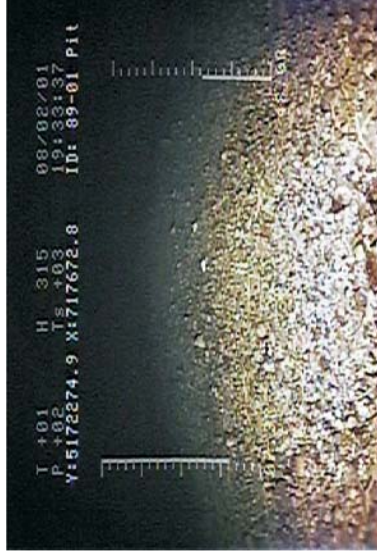


Figure H8: Gravel and small cobbles on the berm top.



Figure H9: Gravel and larger cobbles on the berm top.

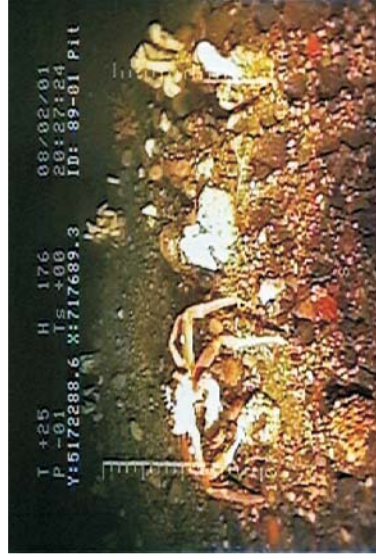


Figure H10: Boulder cobble on the berm top with diverse biological colonization.



Figure H11: Inner berm diamicton outcrop and boulders. In the centre a tall sponge is growing on a boulder. The large boulder in the background is shown in figure H17.

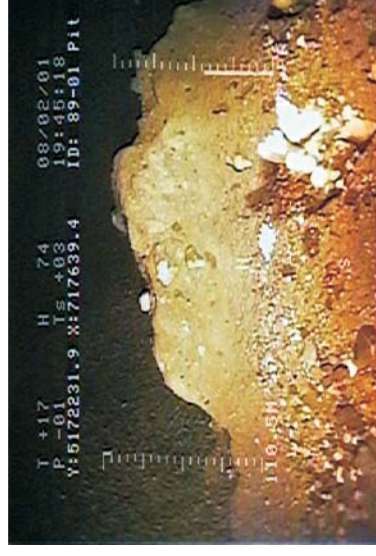


Figure H12: Muddy diamicton outcrop on the inner berm.





Figure H13: Looking into the pit along side of the muddy diamicton out crop.



Figure H14: Another shot of the tall sponge, note that its growth is from the side of the boulder.

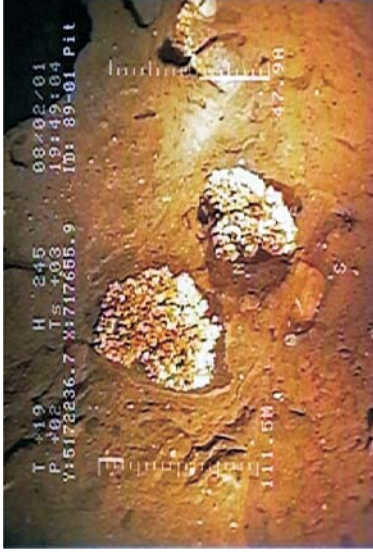


Figure H15: Barnacle covered boulders on the inner wall of the outcrop.

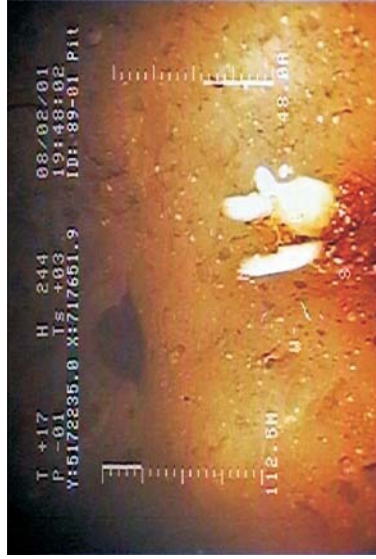


Figure H16: Growth on a boulder on the inner wall outcrop. Also, a small hole in the wall of the out crop.

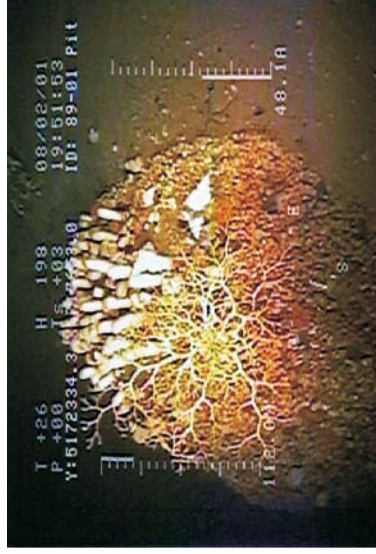


Figure H17: A large boulder near the diamicton out crop with a diverse biological community.



Figure H18: Boulders along the inner pit edge with diverse colonization.





Figure H19: Another shot of boulders in H19.



Figure H20: Large boulders and muddy diamicton out crop. Note large cable in background. This was also observed in 1990 and thought to have been used to tow the iceberg (Cameron and Sonnichsen, 1992)



Figure H21: Another shot of the cable and boulders further up the inner berm. Note that there is some biological growth on the cable too.



Figure H22: A sandy gravel inner berm with boulders covered in biological growth.

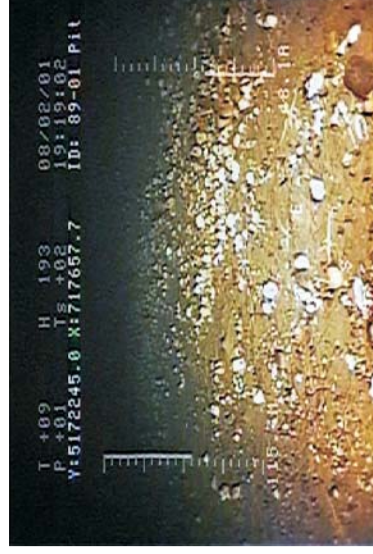


Figure H23: Pit floor a gravelly sand with empty shells brittle stars, sea anemones and sand dollars.



Figure H24: Pit floor composed of a pebbly sand with brittle stars, sea anemones and sand dollars.



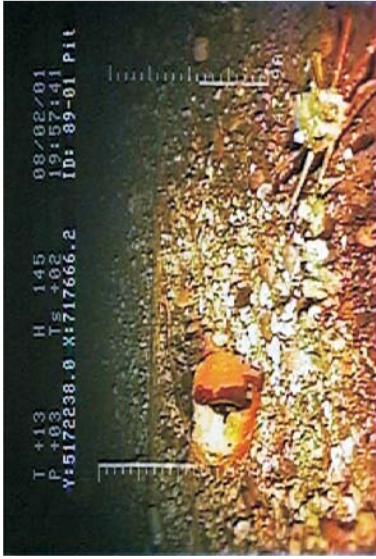


Figure H25: Shell hash and gravel along with tin cans, crabs and a log.

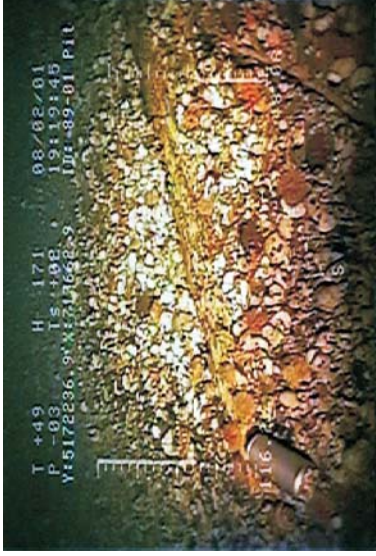


Figure H26: More of garbage and shell hash at the pit base. Note the large number of sea urchins around the log.

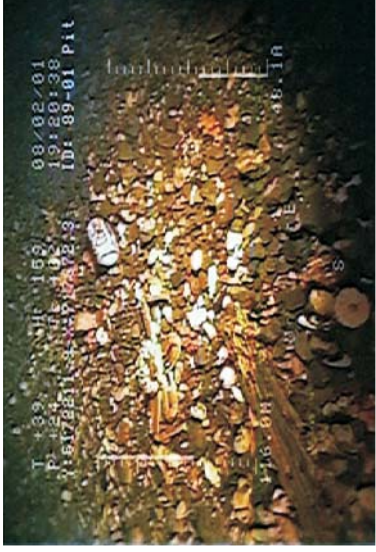


Figure H27: Another shot at the other end of the log showing another can, as well as another crab.



Figure H28: Sample location.

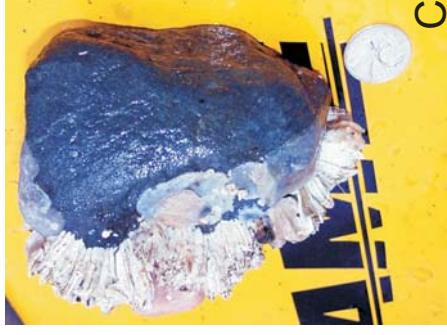
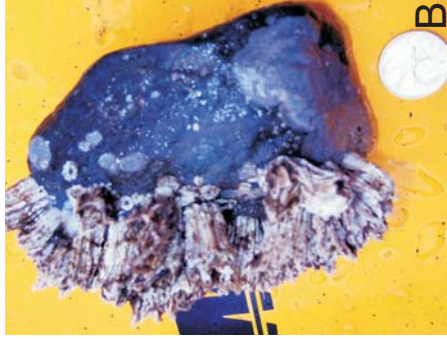
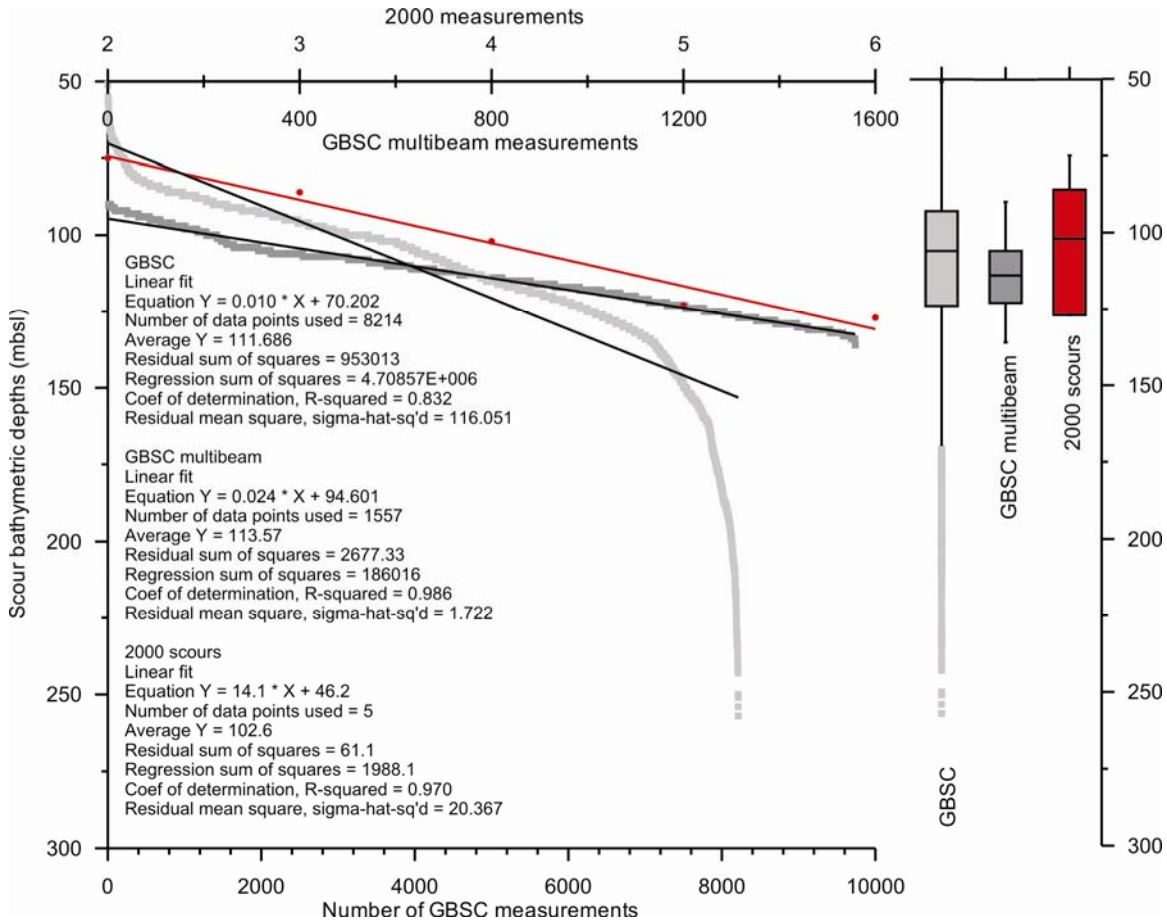


Figure H29: A-C are shots of the sampled boulder from pit 89-01.

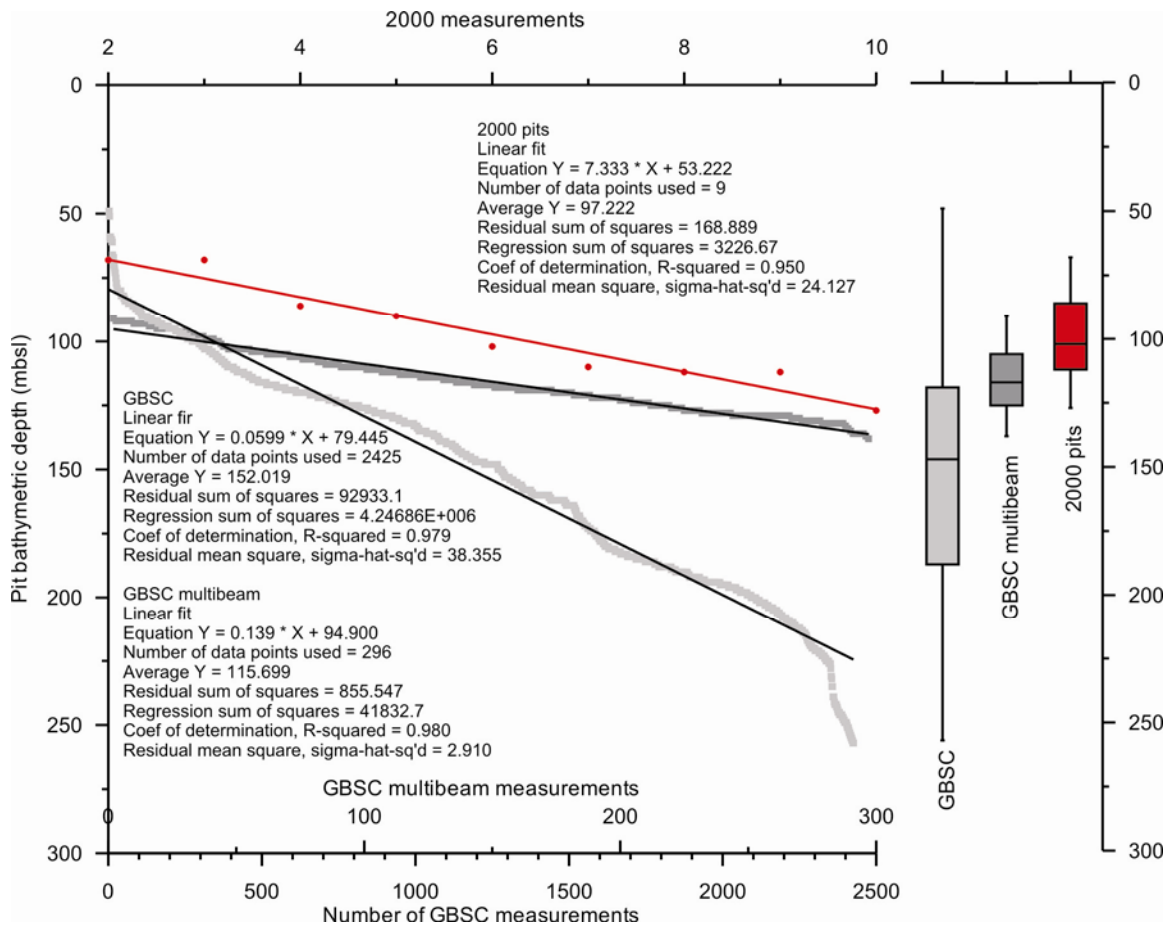


## **Appendix VII**

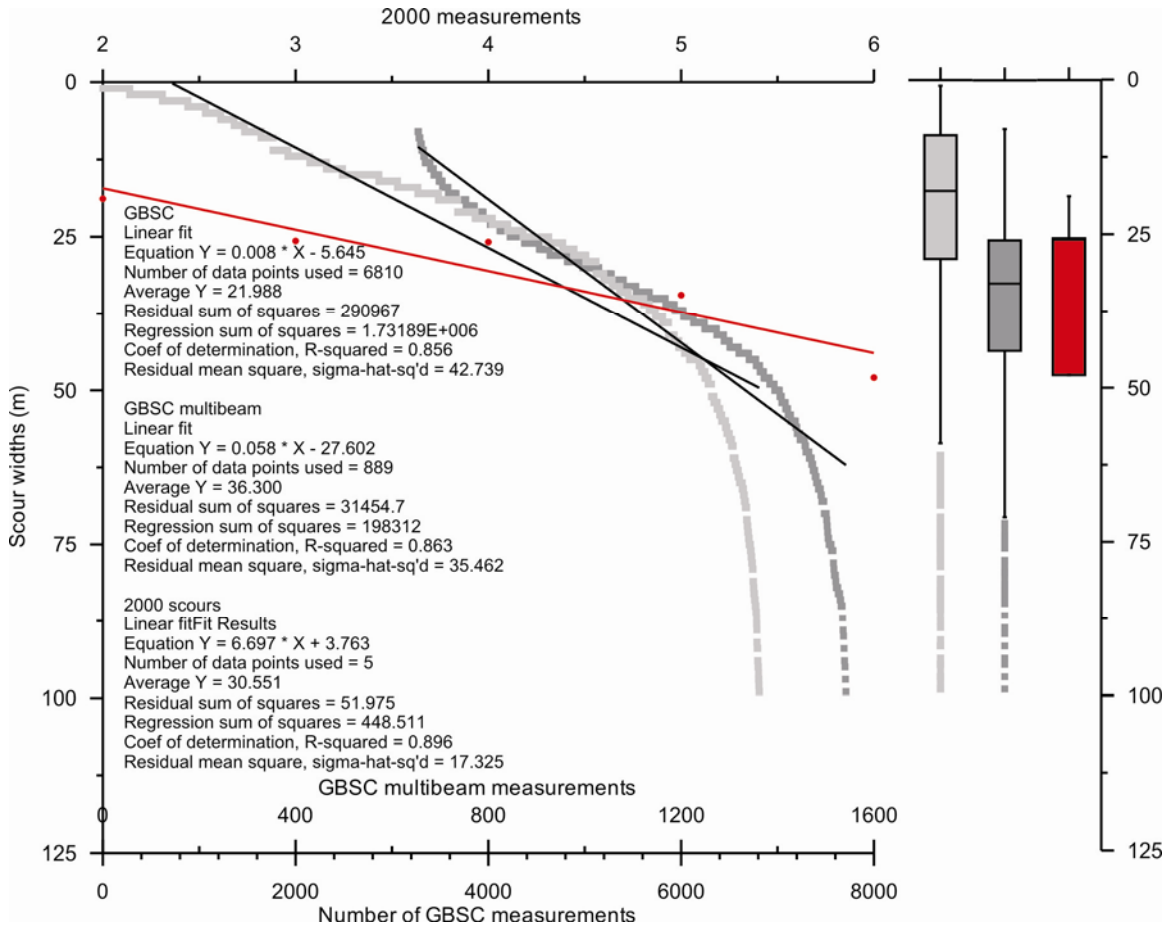
Comparison plots of the 2000 scour metric  
to those of the GBSC-2004



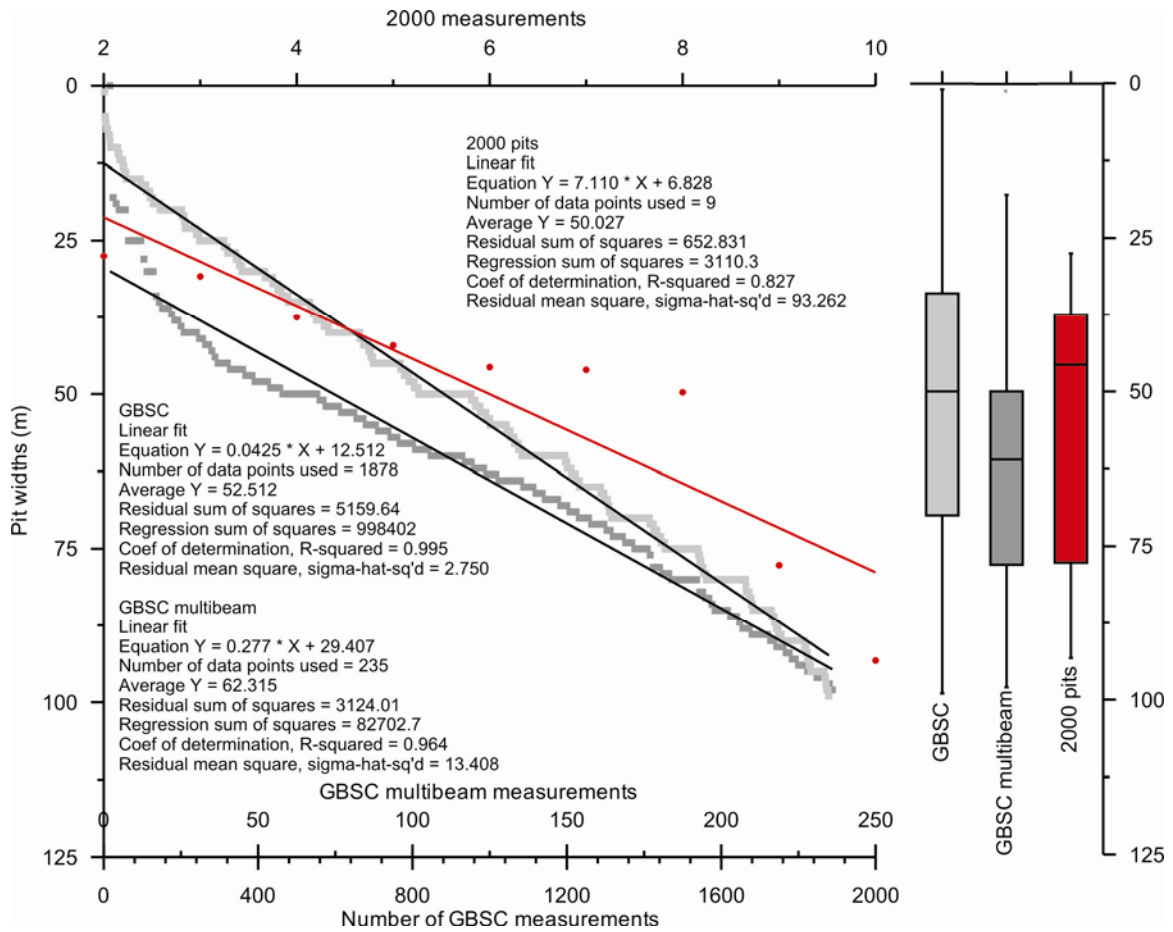
**Figure 1:** Plots of the bathymetric depth of measured pits from the GBSC2004 (■), GBSC multibeam (■) (Campbell et al. 2005) and those investigated in this report (●). Also, to the right, is box - whisker plots showing the weighted range of the data.



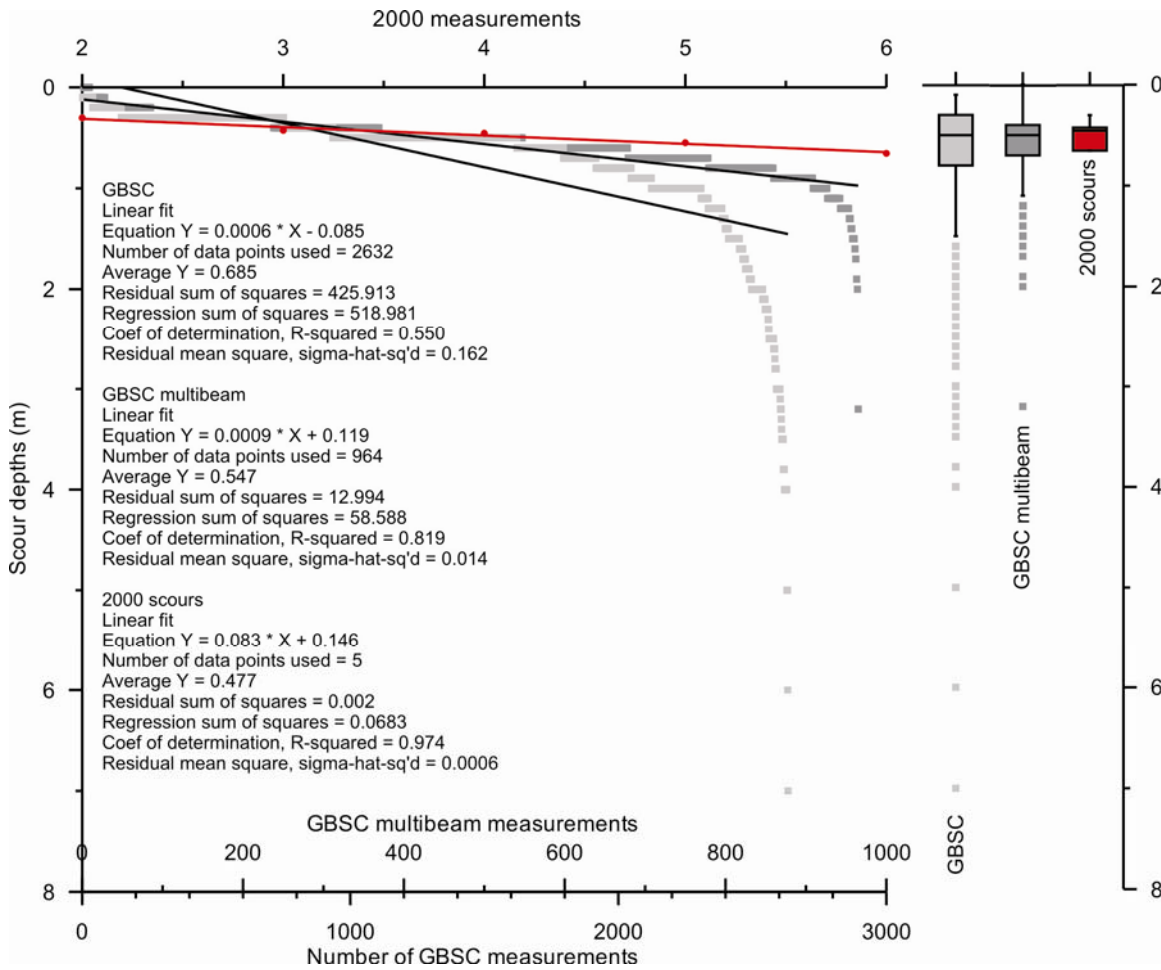
**Figure 2:** Plots of measured bathymetric depths of measured pits from the GBSC (■) GBSC multibeam (■) (Campbell et al. 2005) and the scours of this investigation (●).



**Figure 3:** Plots of measured scour widths (berm crest to crest) from the GBSC (■) GBSC multibeam (■) (Campbell et al. 2005) and the scours of this investigation (●).

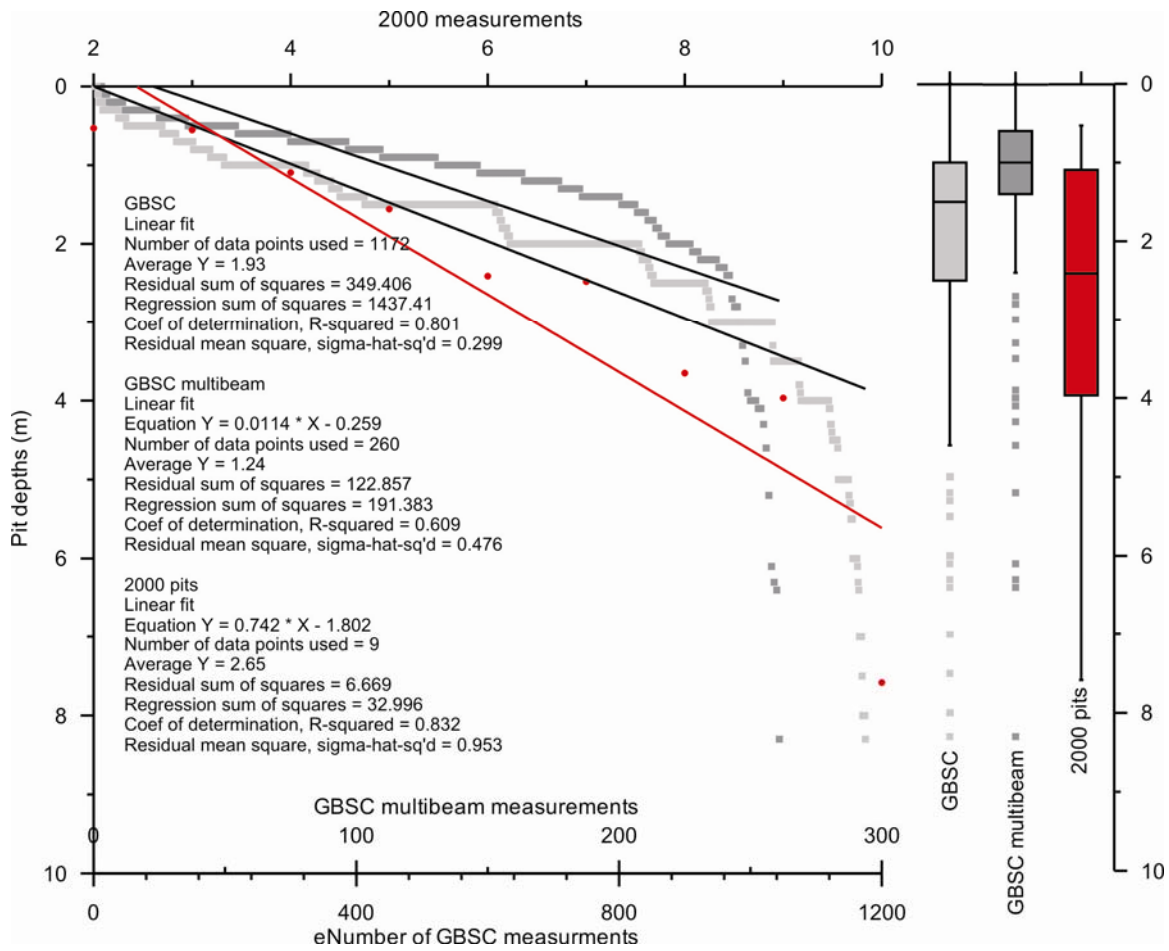


**Figure 4:** Plots of measured pit widths (berm crest to crest) from the GBSC (■) GBSC multibeam (■) (Campbell et al. 2005) and the scours of this investigation (●).

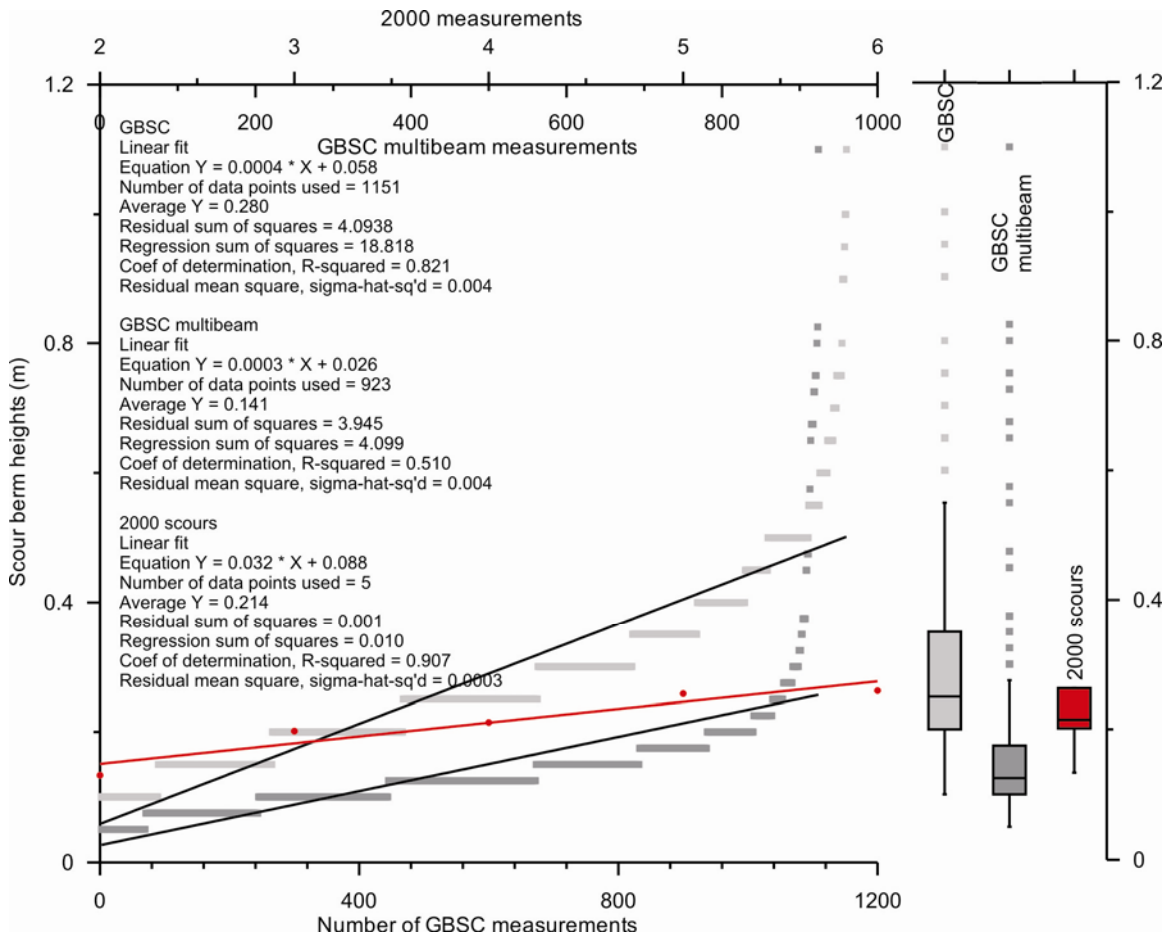


**Figure 5:** Plots of measured pit depths from the GBSC (■) GBSC multibeam (■) (Campbell et al. 2005) and the scours of this investigation (●).

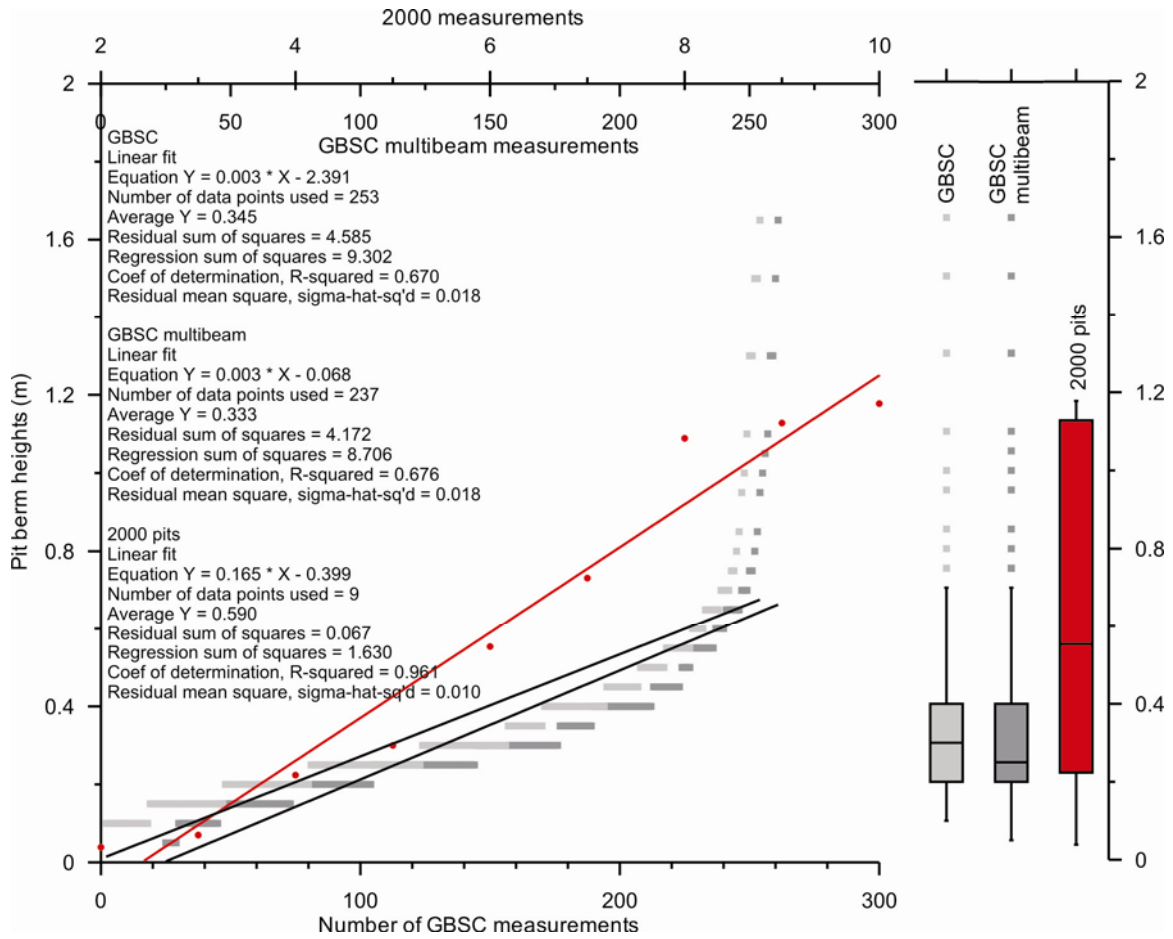




**Figure 6:** Plots of measured pit depths from the GBSC (■) GBSC multibeam (■) (Campbell et al. 2005) and the scours of this investigation (●).



**Figure 7:** Plots of measured scour berm heights from the GBSC (■) GBSC multibeam (■) (Campbell et al. 2005) and the scours of this investigation (●).



**Figure 8:** Plots of measured pit berm heights from the GBSC (■) GBSC multibeam (■) (Campbell et al. 2005) and the scours of this investigation (●).