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# SEABED SURVEYS TO DOCUMENT GROUNDINGS FROM THE 2000 GRAND BANK ICEBERG SEASON

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## ABSTRACT

The 2000 iceberg season provided the first recent opportunity to investigate and develop case histories of reported iceberg groundings on Grand Bank. In 2001, the locations for eight of nine icebergs reported as grounded were investigated with sidescan sonar, Huntec sub-bottom profiler, a towed underwater camera and a light Work Class ROV. In addition to the new scours, re- surveys in 2001 extended the time series for three groundings from the 1980s. In 2002, swath bathymetric surveys were conducted to provide detailed scour depth and shape information. The 2001 and 2002 seabed surveys documented six seabed scour features attributable to year 2000 groundings. Three icebergs produced both a furrow and a terminal pit, and three produced isolated circular pits with little evidence of significant furrows leading into or out of the pit. One of the pitting icebergs produced one pit; the other two produced two pits each. Methods applied to measure scour depths from multibeam data are described for a pit and for a furrow.

## INTRODUCTION

Understanding how icebergs scour and damage the seabed is important for the design of safe and cost-effective sub-sea facilities off northeastern Canada. Studying recent scours created by icebergs of known size and under known environmental conditions enhances our 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, 2001). 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.

The year 2000 (Y2K) iceberg season provided the first recent opportunity to develop case histories of known iceberg seabed groundings. Seventy-eight icebergs drifted onto the bank top between February and June 2000, threatening both exploration and oil production platforms. The icebergs were tracked on oil platform radar and dedicated supply vessels were deployed to monitor, measure, and if necessary, to tow the icebergs. Offshore platforms at Hibernia and Terra Nova (Figure 1) recorded the prevailing oceanographic conditions including winds, waves and currents. The tracking vessels measured the track and speed of the icebergs and their physical characteristics. Nine icebergs were reported to have grounded (PAL, 2000) (Figure 1) based on the criteria of having remained stationary despite tidal and wind forcing.

In 2001, a joint government and industry program was undertaken to: 1) conduct seabed surveys to document the nine iceberg grounding sites recorded in 2000; 2) develop case studies of the grounding events to refine understanding of ice scouring processes and help constrain scour force models; and 3) collect base line data to allow subsequent monitoring of the processes and rates of scour degradation. This paper presents an overview of field surveys conducted in 2000 and 2001, some initial results, and a discussion of our evolving methods to derive scour metrics from a combined sidescan, multibeam, and video data set. Preliminary results for two of the recent scour features are presented.

## GRAND BANK ICEBERG SCOUR REGIME

The eastern Canadian continental shelf south to the Grand Banks of Newfoundland is transited by icebergs calved from the Greenland Ice Sheet and eastern Canadian arctic glaciers. 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 south of 48°. 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.

The Geological Survey of Canada developed a database to assess the constraint posed by seabed scouring Grand Bank icebergs (Canadian Seabed Research Ltd., 1992). The most recent update of the Grand Bank Scour Catalog, GBSC2000 (Campbell, 2001), comprises measurements from more than 6000 recent iceberg scour features identified from industry and government sidescan and sub-bottom profiles south of 49ºN. GBSC2000 scour measurements were derived from sidescan sonar, sub-bottom profilers, and more recently swath bathymetric sounding systems. Swath bathymetric data reveal iceberg scours based on the relief of the troughs and berms, even when their relief is less than 1 m. Shaded relief imagery produced from dense, digital seabed depth soundings illustrates scour geometry, size and location, without the many geometric distortions inherent in sidescan imagery.

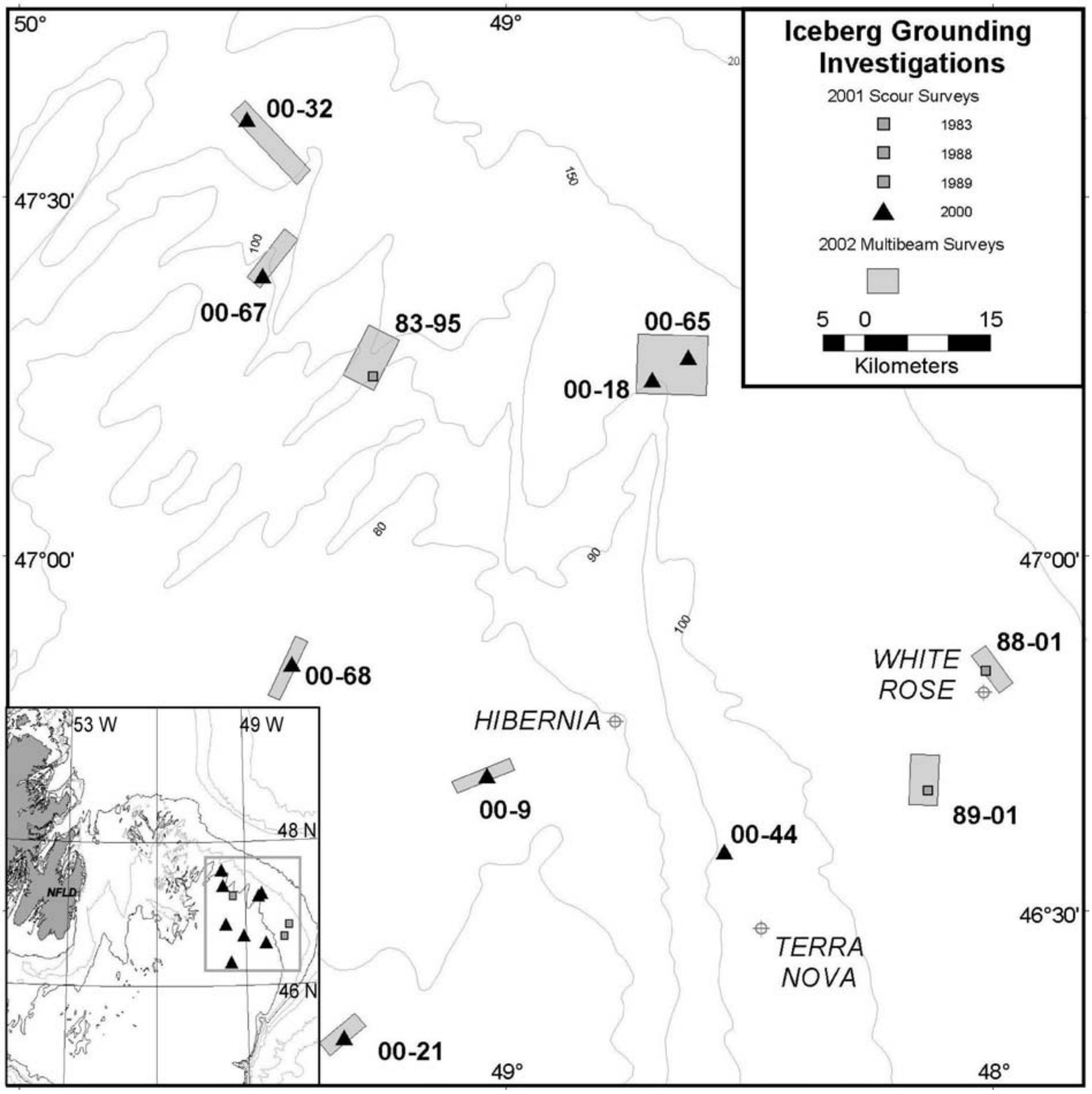


Figure 1: Location map showing the iceberg grounding sites investigated in 2001 using sidescan, subbottom profiler and ROV, and in 2002 using multibeam. Scours attributed to Bergs 00-65 and 00-32 are described in this paper.

Sonnichsen and King (2003) recently summarized scour metrics for northeastern Grand Bank. The average furrow width is 22 m. Furrow lengths are quite variable but the average is 829 m. The average pit is 50 m across and 73 m in length. The average furrow depth in the general study region is 0.4 m and the average pit depth is 1.8 m. The maximum furrow depth is 1.5 m while pits as deep as 9 m have been recorded. Measured depths may be less than original due to infilling or degradation over time (up to thousands of years). On the bank top, reported densities of scour features range from less than 1 scours/km2 to 2.7 scours/km2. 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 ca. 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 (Mobil Oil Canada Ltd., 1985) cited a maximum observed draft of 200 m and a mean draft of 95 m based on 113 measurements. New un-validated iceberg draft measurements are now being made on some icebergs tracked by industry.

## FIELD SURVEYS OVER Y2K GROUNDING SITES

### *2001 Reconnaissance surveys*

Nine reported Y2K groundings and three older groundings of known age were to be surveyed in 2001 if time, weather and logistics allowed. Priorities were assigned based on a compilation and assessment of iceberg drift data (Brown et al., 2003), and proximity to other planned survey operations. The 2001 survey utilized sidescan sonar, subbottom profiler, towed underwater camera and ROV systems. Survey lines were run 200 m apart over the drift track at each reported iceberg-grounding site with a Simrad MS992 dual frequency sidescan at 200-m/channel range. Typically the Huntec Deep-Tow System (DTS$^{TM}$) boomer was operated concurrently. All data were printed in real-time and recorded digitally in SEGY format. The paper sidescan records were examined to locate the probable scour feature. Additional in-fill sidescan sonar lines were surveyed at 100 m range to provide a more detailed investigation of the scour. For most scours, orthogonal lines were surveyed to provide longitudinal transects across the scour profile with the Huntec profiler. The final stage was typically to dive and record VHS video over the more prominent scour features with the Benthos Open Frame Lightweight Class ROV. Berm heights and scour troughs were measured using the ROV depth transducer. The ROV collected cobbles with biological growth from three of the scour features. Ultimately, eight of the nine Y2K grounding sites were surveyed in 2001 (Figure 1). Additionally, all three grounding sites from the 1980s (Scour 95, 88-01 and 89-01) were re-surveyed with sidescan and Huntec and examined with the ROV video.

### *2002 swath bathymetric surveys*

The year 2000 scour-mapping program included a planned swath bathymetric survey of the identified scours immediately following reconnaissance sidescan surveys in 2001. However, because of logistical delays, swath surveys were not conducted until September 2002. The multibeam surveys were conducted with a Simrad EM1002 swath bathymetric system. A POS/MV Model 320 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.

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 sidescan in 2001 were re-surveyed with swath bathymetry in 2002.

## DATA PROCESSING

Digital sidescan data from 2001 were slant-range corrected, adjusted for beam pattern imbalances, gain equalized, and corrected for layback using methods described in Sonnichsen and Lussier (1996) and Sonnichsen, (1998). The resulting geometrically corrected and georeferenced sidescan TIFF imagery of the identified scour features were imported into ESRI ArcGIS ArcMap software for display and analysis.

The 2002 swath bathymetric data were cleaned and processed at sea. Soundings were examined in CARIS HIPS/SIPS 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 artifacts. Final field processing of the multi-beam data (data reduction, tidal correction, refraction editing, and surface cleaning) was then performed using CARIS HIPS/SIPS. 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 then produced with sun illumination and vertical exaggeration to display the scour features. The visible outline of the scour disturbance was then digitized as a polygon using both 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 ArcMap. All soundings within this perimeter were exported as the scour surface. A "pre-scour" surface was created by excluding depth values from within the digitized scour outline and then filling the void (ArcMap nearest neighbors 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.

## RESULTS

Six scour features attributed toY2K groundings were identified in the 2001 sidescan surveys (Table 1). A seventh scour identified as potentially caused by Berg 68 was determined to be older based on ROV evidence of mature biological growth on cobbles and boulders in and along the scour. Three Y2K icebergs produced both a furrow and a terminal pit, and three produced isolated circular pits with no pronounced evidence of furrows leading into or out of the pit. One of the pitting icebergs produced one pit; the other two produced two pits each. Details on the size and drift characteristics of the icebergs, and the prevailing environmental conditions are reported in Brown et al. (2003). This paper focuses on the ongoing analysis of scours from two icebergs, Berg 00-65 and Berg 00-32. An inherent difficulty in analyzing multibeam data from Grand Bank is that we can resolve linear features with depths at or below the vertical accuracy of the multibeam system. While still clearly visible on shaded relief imagery, the furrows have depths little greater than the effective resolution of the multibeam system. Individual depth measurements can vary by more than 20 cm due to positioning and motion compensation errors. Some caution should be given to values presented here, as more effort is required to normalize data and standardize measurement.

Table 1: Summary of the iceberg scour case studies established or studied in 2001 and 2002

| Berg | Type | Length (m) | Width (m) | Height (m) | Mass (t) | Draft (m) | Depth (m) | Feature |
|---|---|---|---|---|---|---|---|---|
| 00-09 | Tabular | 70 | 40 | 10 | 99 680 | 58 | 75 | Furrows & Pit |
| 00-18 | Pinnacle | 70 | 40 | 35 | 174 440 | 58 | 98 | furrow |
| 00-21 | Dome | 63 | 49 | 18 | 162 208 | 75* | 68 | 2 pits |
| 00-32 | Pinnacle | 138 | 114 | 27 | 756 080 | 124* | 112 | 2 pits |
| 00-44 | Pinnacle | 100 | 60 | 30 | 320 400 | 74 | 91 | Not found |
| 00-65 | Pinnacle | 242 | 76 | 55 | 1 815 457 | 135 | 127 | Furrow & terminal pit |
| 00-67 | Pinnacle | 110 | 76 | 40 | 595 232 | 102* | 90 | Pit |
| 00-68 | Dry Dock | 80 | 30 | 15 | 38 448 | 64 | 75 | No discernable scour |
| 83-95 | Not reported | 100 | | 15 | 1 400 000 | 95 | 95 | Furrow & terminal pit |
| 88-01 | Dry dock | 287 | 114 | 40 | 1 900 000 | 123 | 123 | Furrow |
| 89-01 | Pinnacle | 217 | 119 | 46 | 2 100 000 | 112 | 110 | Furrow & terminal pit |

* measured draft (using sidescan sonar) versus calculated from waterline length.

**Berg 65**

The Berg 00-65 scour feature is located approximately 700 m south of the reported grounding location (Brown *et al.*, 2003). Berg 65 touched down in 130 m of water, scoured upslope for approximately 1400 m to 126.5 m wd, turned and scoured eastward 100m before grounding and creating a terminal pit (Figure 2). The eastern furrow portion (ca. 300 m) consists of a series of aligned circular indentations as if it was oscillating up and down or rocking against the bottom. These are evident on the sidescan records but not in the multibeam data, implying that scour depth is less than the resolution of the multibeam system.

There is a relatively steady upslope increase in furrow width from effectively zero on the NE start of the furrow to 23 m at its most shallow (Figure 3a). This is consistent with an iceberg of stable draft scouring up-slope and gradually having an increasing keel area in contact with the seabed. Widths in the GBSC were measured between berm centres (Figure 3b) as these are most readily recognized to the interpreter. Actual widths of the 00-65 furrow trough (Figure 3a and b) are approximately 70 % of the width measured between berm widths.

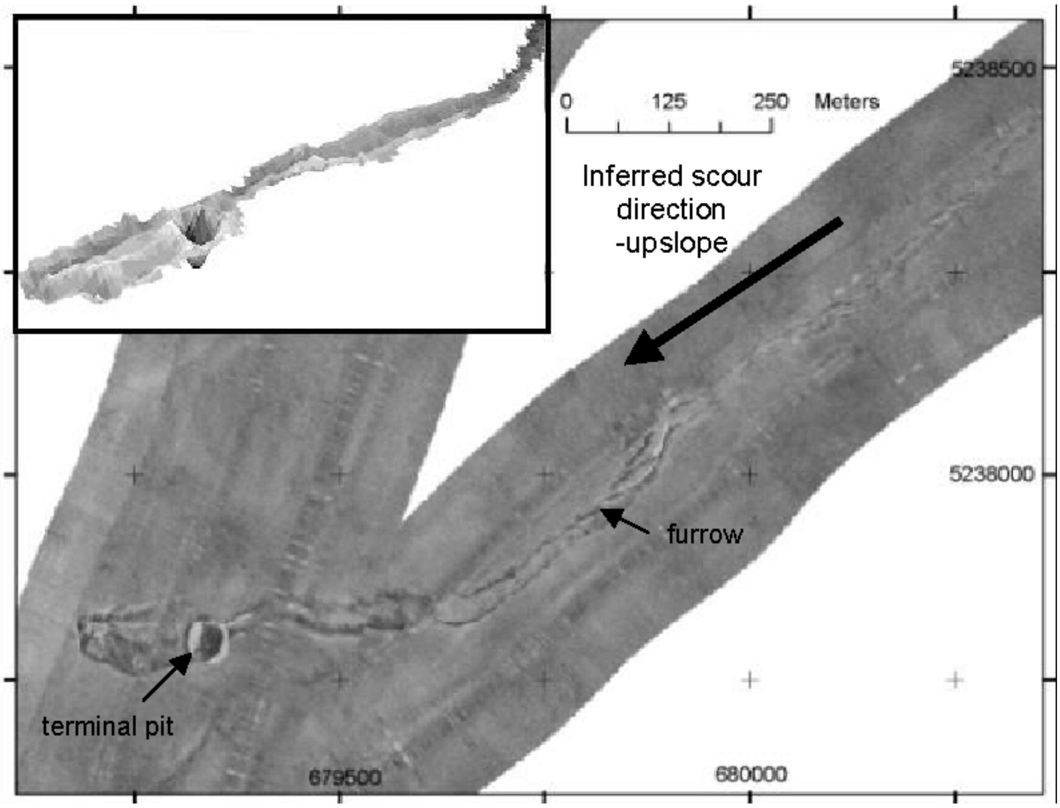


Figure 2: Sidescan sonar image showing the mapped extents of the seabed furrow and terminal pit produced by Berg 00-65. The inset is a shaded relief perspective from the 2002 swath bathymetry data shows the increased penetration depth of the pit versus the furrow.

Scour depth increases only gradually and irregularly up-slope (Figure 3c). The northeastern portion of the furrow is not discernable on shaded relief imagery produced from the multibeam data (Figure 2 (inset)). The average overall furrow depth is approx. 0.5 m. The maximum furrow depth is 1.3 m, recorded just east of the pit in a narrower portion of the furrow. The furrow depth is shallow in comparison to the potential depth of penetration of the berg keel (Figure 3d).

Berg 00-65 produced a terminal pit where it ultimately came to rest for a reported 330-hour interval. The pit has a diameter of 50 m as measured between the sharp berm crests evident in the sidescan imagery. The actual diameter of the below-seabed portion of the feature is 45 m. A subtle inner circular ridge can be seen in the sidescan imagery. In the multibeam soundings this coincides with a central ridge or pinnacle within the pit. The maximum-recorded depth of the pit is 2.5 m below seabed. It is only in the terminal pit that the depth of penetration is equivalent to the potential depth of iceberg keel penetration based on the observed rise-up (Figure 3d).

ROV imagery and bottom samples indicate the surrounding seabed is fine to medium, olive-green sand of the Adolphus Sand (Sonnichsen and King, 2003) with scattered pebbles and shells. It appears quite flat and featureless and devoid of large cobbles or boulders. No evidence for ripples or other bedforms were seen. The pit berm is flat and regular and consists of sand. There is more gravel and shell material on the berm top than on the berm slopes.

The pit base was also smooth, but some evidence was seen for sorting of gravel into a circular ring at the deepest part of the pit. Spot soundings recorded by the ROV indicated a 2.6 m range in depth from the berm top to the base of the pit.

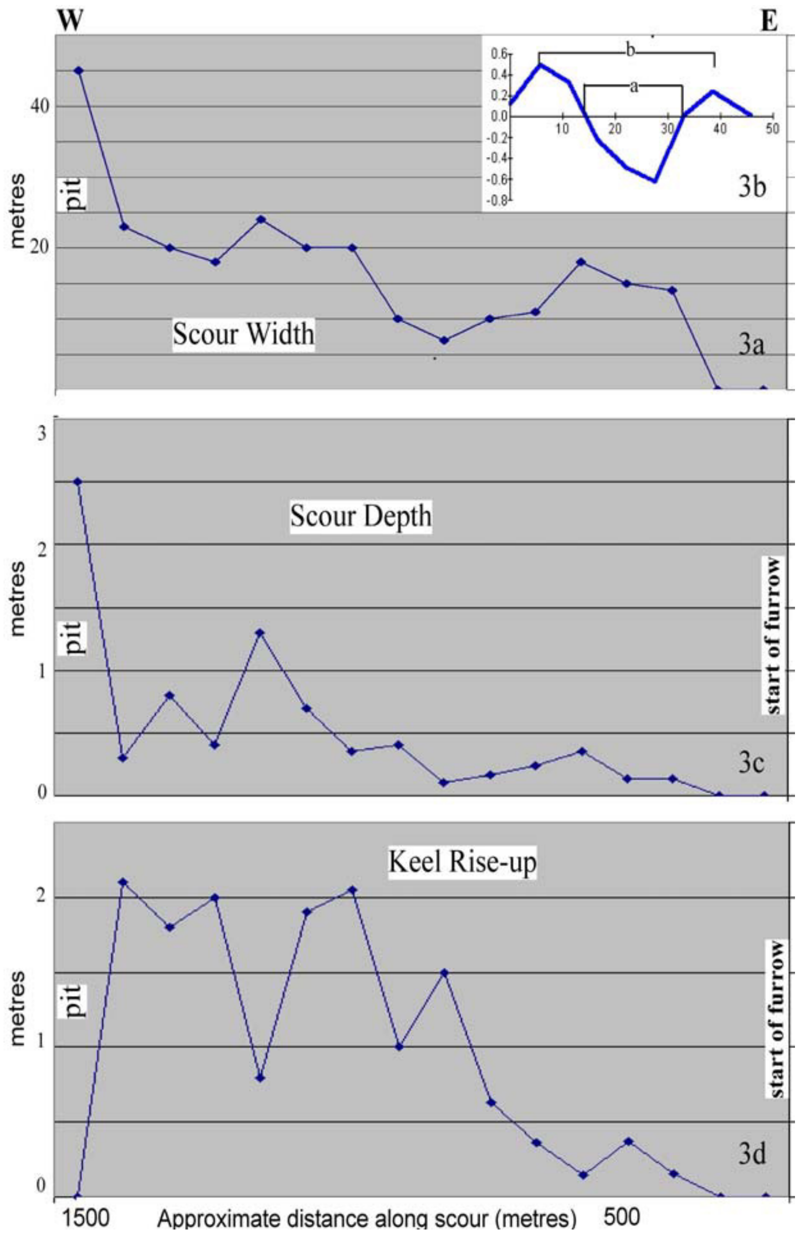


Figure 3: Representative scour width and depth measurements along the furrow and terminal pit of Berg 00-65. Profiles were measured from the swath bathymetric data using ArcMap 3D Analyst module.

**Berg 00-32**

Berg 00-32 was reported grounded for approximately 96 hours in 112 m of water (Brown et al., 2003). Based on a recorded draft measurement of 124 m (well in excess of local water depth), Berg 00-32 reportedly dragged its keel through much of the area. The iceberg draft was measured using sidescan sonar equipment aboard the tracking vessel. Subsequently, sidescan surveys for the 00-32 seabed scour identified two prominent iceberg pits approximately 50 m apart within 100 m of the reported grounding site. A very subtle furrow only 10s of metres long was identified leading into or out of the westerly pit. No other scour features were recognized. The subtle furrow is well aligned with the drift track for Berg 32 as it left the area so it can be interpreted as the lead-out furrow. 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, plotted iceberg positions are not detailed or accurate enough to confirm the order of events or the direction of scouring. All features attributed to berg 00-32 were in 113 m of water based on the 2002 multibeam data.

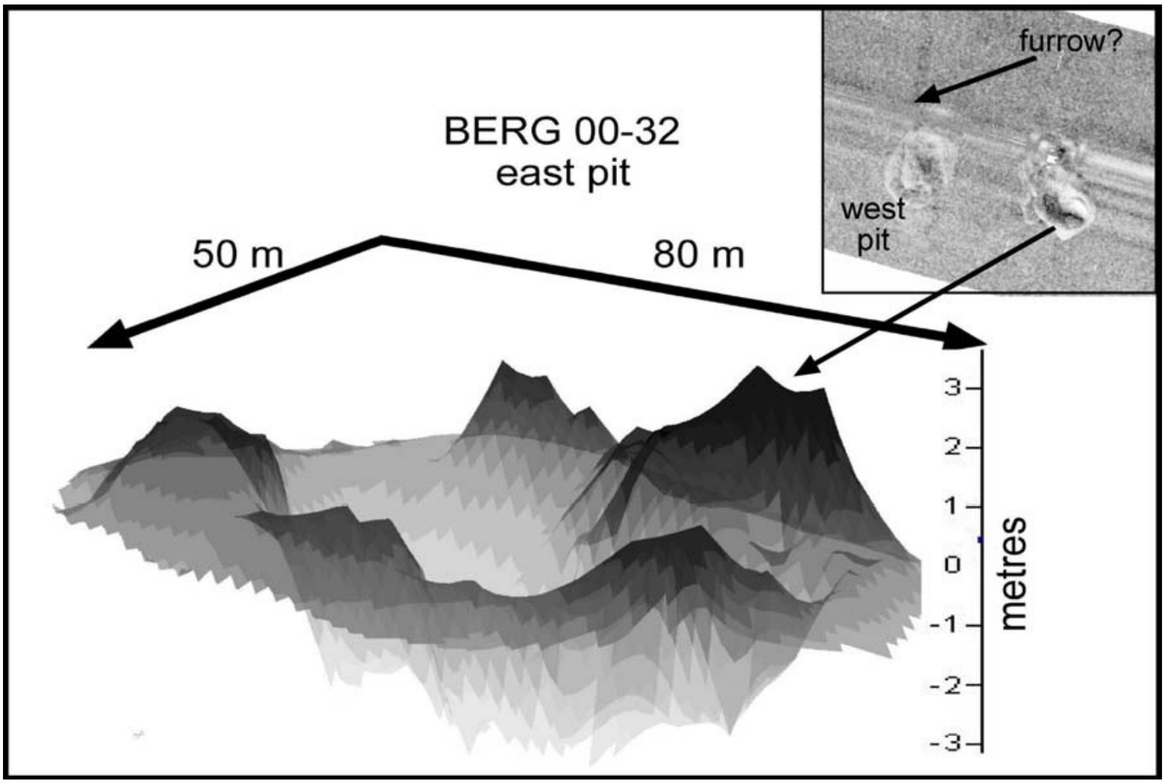


Figure 4: Two pits and a subtle furrow were identified in 2001 sidescan sonar data (inset) collected near the reported grounding of Berg 00-32. It is unclear whether the furrow was created on the way in or out of the pit. The shaded relief perspective of the larger, deeper eastern pit illustrates the relief and variability of the one-year old feature.

The prominent elliptical eastern pit excavated a seabed area 28 m wide and 58 m long. Including the raised berms, the total disturbed area was approximately 50 m x 80 m (Figure 4). The maximum berm height recorded from multibeam soundings was +3 m and the maximum pit depth was -3 m. The excavated volume is ca.1800 $m^3$ while the sediment volume accounted for in the surrounding berms is 1200 $m^3$. The subtler western pit excavated ca. 600 $m^3$ from a pit 23 m across and 42 m wide. Only 200 $m^3$ can be accounted for in the surrounding berms.

ROV observations indicate the seabed surrounding the Berg 00-32 scour pit consists of flat, relatively featureless sand with sand dollars. A sediment sample taken 200 m north of the identified pits recovered well-sorted medium sand of the Adolphus Sand (Sonnichsen and King, 2003). Shells are common on the seabed surrounding the scour and on the berm itself. Within the pit, shell occurrence is less common. The eastern pit berm and surrounding seabed is dimpled with many small circular depressions that are likely created by fish rather than any process related to the iceberg. Spot ROV soundings at the eastern pit recorded berm heights of approximately 3 m above the seabed and a pit depth of 2.5 below seabed.

## SUMMARY AND DISCUSSION

The use of industry iceberg tracking databases to identify iceberg groundings and the resulting seabed damage proved successful. However, more frequent observations and measurement of position are required to confirm the direction of scouring or any changes in iceberg behaviour (rolling, tilting, turning, etc) especially when grounding has been reported. Comparison of grounding location water depths to reported estimates of iceberg draft showed significant variability (Table 1). Draft estimates based on water line length were off by as much as 70 % in the case of Berg 00-18. There is also some concern regarding the accuracy of sidescan measurements of berg draft. In the case of bergs 00-21, 00-32 and 00-67 (Table 1) the measured drafts, while conservative, were off by more than 10 %. The year 2000 icebergs produced a higher proportion of pits to furrows than expected. This is likely because shipboard observations cannot readily distinguish a keel-dragging iceberg (furrows) but can isolate groundings based on the lack of iceberg drift. If more and better draft measurements were made, the bias towards identifying pits would diminish.

As expected, the sidescan proved an effective reconnaissance tool, capable of resolving relatively small pits and shallow furrows. Multibeam sonar surveys are an essential tool for scour documentation but 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. Data processing for the 2000 scours is still ongoing. The use of an industrial ROV allowed precise maneuvering and sampling. The visual record of the new seabed scours provides an excellent benchmark to study the rates and processes of scour degradation and biological re-colonization.

Berg 00-65 provided an excellent case study for a berg that produced both a linear furrow and a terminal pit. The furrow is very shallow and remains relatively so, even as the berg scoured upslope. As Berg 00-65 moved upslope, one would expect scour depth to have increased as the keel dug into the slope. The fact that it doesn’t shows that the iceberg either floated higher or tilted farther backwards as it moved along. The maximum depth of 1.3 m at the upslope end of the furrow is still less than the berg keel was capable of cutting. There was more than 2.3 m of excess iceberg draft at the far west portion of the furrow. This is the first clear documentation of the rise-up phenomena on Grand Bank and has implications for ice scour risk models. It is believed the iceberg rotated on its center of buoyancy in order to shed load imposed by the seabed. It is only in the terminal pit that the depth of penetration is equivalent to the potential depth of iceberg keel. No rolling mechanism was required to produce the 2.5 m deep pit. This supports Clark and Landva, (1988) who reported that > 95 % of the observed pits, with depths less than 3 m, could form simply under indentation forces during a rolling or punching iceberg impact.

## CONCLUSIONS

A multi-component approach using industry iceberg tracking data, remotely-sensed geophysical data, and direct observation through remotely operated vehicle is an effective method for understanding seabed modification processes associated with grounded ice. This approach has allowed for the detailed investigation of eight reported grounding events from the year 2000 ice season. The results show that the metrics of new furrows and pits are comparable to the dimensions of features of indeterminate age. Additionally, for the first time, clear evidence of rise-up phenomenon has been identified on Grand Bank.

With improvements, there is great potential for this approach in future:

- More frequent observations of iceberg drift and measurements of iceberg position would refine the ability to identify icebergs that drag their keel but remain in motion.
- Continued seabed bathymetric surveys of reported groundings would be a cost-effective way to validate iceberg draft measurements.
- The full potential for multibeam data to provide detailed geometry and depth information on Grand Bank seabed scour will only be realized after sophisticated processing to isolate subtle depth measurement errors.

Future follow-up surveys of scours of known age will provide valuable new insights on the rates and processes of scour degradation or infill. Time-series observations on the progressive biological colonization of the scours should also lead to more quantitative methods of dating scours of unknown age.

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