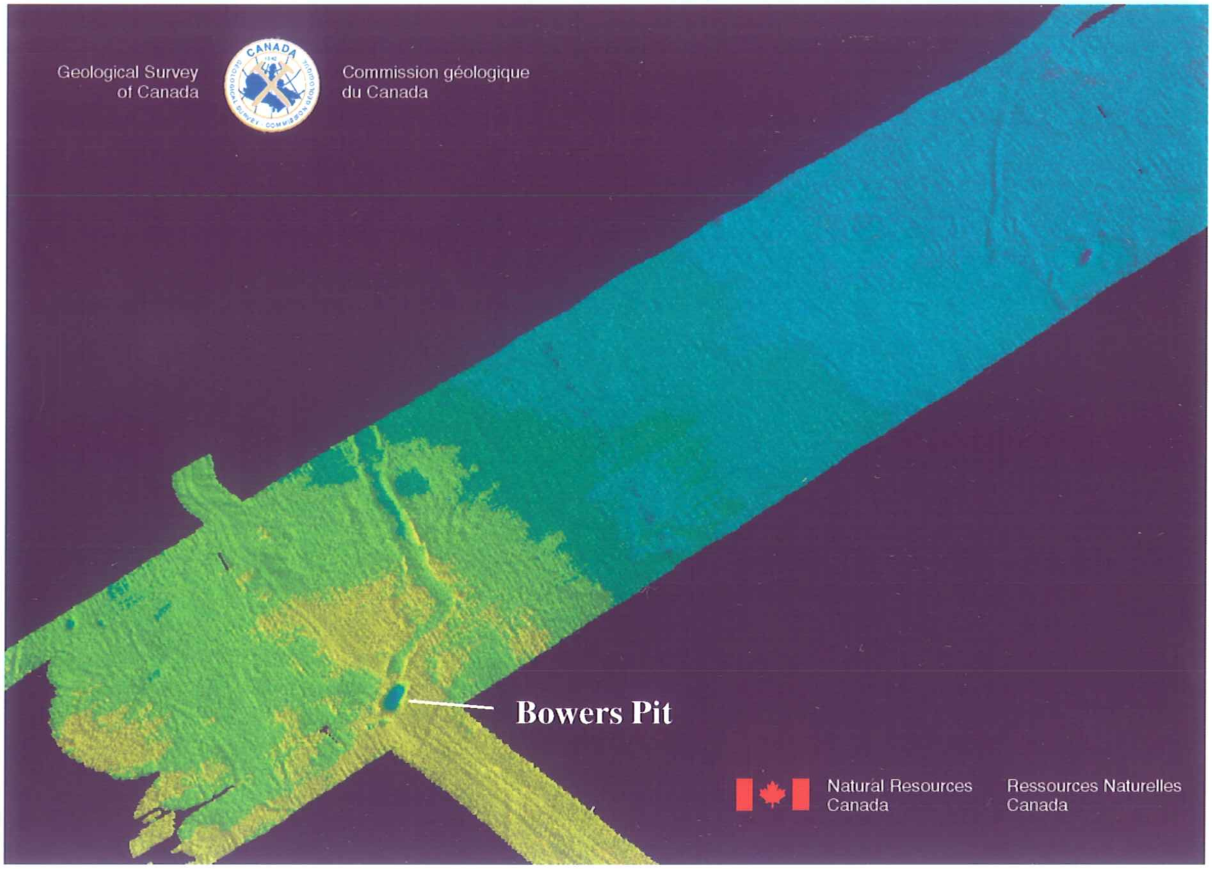

Swath bathymetric surveys on northeastern Grand Bank: CSS Matthew 96-011

by

G.V. Sonnichsen
and L. Lussier

Geological Survey of Canada Open File # 3392

November, 1996

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CSS Matthew 96-011**

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and L.M. Lussier[2]

GEOLOGICAL SURVEY OF CANADA OPEN FILE # 3392

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Engineering COOP program

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CRUISE SUMMARY

Vessel:	CSS Matthew
Commanding Officer:	Capt. R. Lockyer
Cruise dates:	June 10 -21 , 1996, (Julian Days 162-173) 5.5 days transit to and from BIO 5.5 days for survey
Survey area: **Area limits:**	Northeastern Grand Banks (46°25'N, 48°50'W to 47°N, 47°50'W)
Responsible Agency:	Geological Survey of Canada (Atlantic) Marine Environmental Geology (MEG)
Senior Scientist:	Gary Sonnichsen
Personnel:	G. Sonnichsen (Senior Scientist) R. Currie (EM100 Systems Operator) D. Beaver (Navigation/EM100 operation) B. Wile (Simrad sidescan,CHIRP) L. Lussier (University of Waterloo, Coop) G. Chapman (Saint Mary's University, Coop) J. MacDonald (Acadia University, Coop)

1.0 INTRODUCTION

The Geological Survey of Canada -Atlantic (GSC-A) conducted swath bathymetric and sidescan sonar surveys off northeastern Grand Bank from June 10 to June 21, 1996 aboard the DFO research vessel CSS Matthew (DFO Cruise 96-011). The purpose of the survey was to determine the EM100 swath bathymetric system's ability to measure relief, shape and depth characteristics of subtle seafloor ice scour features characteristic of the Grand Banks. Specifically, the swath bathymetric survey was intended to:

- determine whether depth, width and berm variations over an entire scour are measurable.
- confirm depth and width characteristics of seafloor scours (furrows and pits) which are signficant because they are large (extreme events), recent or well-documented.
- map topographic and scour depth variations along the length of a furrow.

The survey was carried out in support of GSC's long term research on the characteristics of the Grand Bank iceberg scour population and the processes and frequency of iceberg scouring. The survey was conducted with funding provided to GSC-Atlantic by the Program for Energy Research and Development (PERD), under project '6A4015 GRAND BANKS ICE SCOUR'. GSCA's research is focussed on developing a regional characterization of the distribution and severity of seabed iceberg scouring, undersatnding the controlling environmental parameters, and refining our estimated rates of occurrence. The research provides the knowledge base on seabed conditions and geohazards necessary for federal agencies and offshore regulators (Canada-Newfoundland Offshore Petroleum Board - CNOPB) who must approve development plans for new bottom-founded structures and pipelines off eastern Canada.

Targets chosen for the experimental EM100 survey reflect GSC efforts to collect regional data on the statisitcal properties of the Grand Banks scour population and to develop and build on existing repetitive mapping surveys. Repetitive mapping is considered the priority approach for determining the rates of scour recurrence on the Grand Banks. The low frequency of new scouring events demands a long time record of resurvey in order to have statistically meaningful results. By working closely with industry, maximum use can be made of older, existing seafloor data collected by industry thereby reducing costs and increasing the time interval between resurveys. In chronological order, the targets surveyed (FIGURE 1) during 96-011 were:

- a man-made seafloor excavation, the O-90 Glory Hole
- GSC's seafloor repetitive mapping site in the Terra Nova region
- 4000 Series 1994 repetitive mapping transects
- a resurvey of a 1988 scour survey in Husky's Whiterose area (incl. Berg 88-01's scour)
- confirmation survey of 2 recent scours (GSC-A's Grand Banks Scour Catalogue 95 (GBSC95) Scour_id's 1258 and 1260)
- confirmation survey of 4 recent craters (GBSC95 Scour_id's 1269, 1270, 1271 and 1272)
- a resurvey of the Springdale 89-01 scour and pit
- confirmation survey of GBSC95 Scour_id 2993 (6.0 m pit)
- GBSC95 Scour_id 565 (Bower's pit) and GBSC95 Scour_id 3030 (6.0 m crater) and GBSC95 Scour_id 575 (5.3 m pit)

Most targets selected were previously surveyed by GSC-A using sidescan sonar, a more conventional tool for ice scour measurements. Simrad 992 sidescan data were collected over some targets for which GSC-A did not have in-house sidescan data or to improve on existing sidescan coverage. Comparison of the sidescan and swath bathymetric data sets will determine their relative merits and determine the threshold of resolution for iceberg scours for the EM100.

This report provides a brief summary of survey operations and equipment, individual descriptions of the above-mentioned target surveys and color figures of the resulting seafloor imagery.

2.0 SYSTEMS OVERVIEW AND OPERATION

2.1 NAVIGATION

The primary navigation system for this survey was the Global Positioning System (GPS) with corrections (differential) being applied in real time to eliminate or minimize errors in the raw GPS signal generated by the Selective Availability policy of the US Dept. of Defence (Environmental Systems Research Institute, 1994). Raw GPS signals were received on a 12 channel Novatel GPS card installed in a 486 PC satellite receiver (Hydrostar PC (HPC) developed by Northech Surveys (Canada) Inc.). MOT-broadcast differential corrections were acquired from Cape Race over VHF radio to HPC. A differentially corrected GPS position in NMEA format was then transmitted to the Simrad EM100 and a PC running GSC-A's proprietary AGCNav software. AGCNav logs the navigation data and broadcasts real time positions, course, speed, and survey line information to the bridge and a slave PC in the aft lab for back-up storage. AGCNav logged the raw 'differentially corrected' navigation data at 5 second intervals for the entire survey.

Navigational difficulties were encountered three times during the cruise:

1) From the start of the survey (JD/GMT 165/0800) until 165/1750 HPC provided jumpy and irregular navigation data due to an incorrect configuration of accepted and rejected satellites. Once HPC was rebooted and default values were restored, the navigation became much more stable.
2) At approximately the start of JD 167, HPC began hanging and crashing on an improperly formatted serial message broadcast by MOT.After a great deal of trouble-shooting, the only way to clear up the problem was to bypass the HDC and transmit the 6 channel dGPS corrected position from the bridge's satellite receiver and send that to the EM100 and AGCNav. This resulted in a slightly degraded signal, but eliminated the constant HDC system crashes.
3) Monday morning (June 17, JD 169) we contacted MOT to inform them of the bad serial message being broadcast. Their response was to turn off the beacon while they figured out the problem. Thus we were without navigation and unable to work for approx. 4 hours.

2.1.1 Navigation processing

Raw differentially corrected navigation data were stored as part of the internal EM100 database format. The navigation data were imported into Universal Systems Ltd.'s (USL's) CARIS Hydrographic Information Processing System (HIPS) to be viewed and cleaned of obvious incorrect values or omissions. No cleaning of the AGCNAV data files was done onboard. It will be necessary to convert the cleaned HIPS navigation data from its internal binary format in order to import the navigation data into GSC-A navigational databases.

All data is fixed to the North American Datum of 1983 (NAD83). Figure 1 illustrates the track plot for the 96-011 CSS Matthew survey .

2.2 EM100 SWATH BATHYMETRIC SYSTEM

A multibeam swath bathymetric system is capable of providing highly accurate (± 5 m horizontal, ± 10's of cm vertical) high density bathymetric soundings over large seafloor areas. The size of the covered area is a function of the swath angle and water depth; it can be up to 7X water depth, depending on the system.

The EM100 is one of the first generation of swath systems purchased by the Canadian Hydrographic Service (CHS). It is somewhat limited in terms of its spatial resolution and in terms of its effective swath. It has 32 beams (16 on the port side and 16 on the starboard side), radiating from the centre of the transducer in either a NARROW or WIDE mode beam setting. The NARROW mode has a swath angle of 40° and the WIDE mode has a swath angle of 80°. The NARROW beam was used for a single pass over the O-90 Glory Hole, but was found to have too limited a swath coverage and was not used again. In WIDE mode, the EM100 still provides a quite limited swath, less than 1.5X water depth, with an approximate spatial resolution of ~5 to 8 m depending on the beam. Vertical resolution was roughly +/- 20 cm.

2.2.1 Swath Bathymetry Processing

The EM100 records raw,uncorrected two-way travel times for each received beam signal. This data must then undergo a series of corrections to compensate for changing sound velocities through the water column, the gyro, heave, pitch and roll of the ship, changing water depths due to tides and inaccurate navigation positions (as outlined earlier).

An **SVP (sound velocity profiler)** was deployed to measure the velocity of sound through the water column at successive depths to the seafloor. It was deployed each time a survey was conducted in a different water depth.The speed of sound in seawater will vary primarily with changes to temperature and salinity which occur as a result of solar heating at the surface and the varying properties of vertically changing water masses. On northeastern Grand Bank, the water mass is relatively homogenous through mixing as a result of wave, tide and current activity.

The **gyro** correction is measured in degrees and is the difference between the gyro sensor reading and the true heading of the vessel. During processing the Gyro Error value is subtracted from the gyro sensor readings.

The **pitch** of the ship refers to the angle of elevation from bow to stern as the ship passes over a wave. The Pitch Error value is the difference between the pitch sensor reading and the true pitch of the vessel.

The **roll** of the ship refers to the angle of elevation from port to starboard as the ship passes over a wave. The Roll Error value is the difference between the roll sensor and the true roll of the vessel.

The **heave** refers to the vertical displacement of the transducer as a result of wave action (pitch and roll combined).

Corrections for **tides** were obtained from a file of the predicted vertical displacements for June for the Hibernia .

All data and the above-mentioned corrections were imported into Universal Systems Ltd. (USL), CARIS Hydrographic Information Processing System (HIPS) for depth processing, direct visualization and editing. Here the differentially corrected navigation is viewed and corrected for obvious spurious or missing positions. Once the navigation data is cleaned and the corrections are available, the raw depth are corrected and merged with the cleaned navigation. The result is a collection of depths that are georeferenced to the seafloor. It is then possible to view and edit ("clean") these depths and reject any that are considered to be inaccurate by the operator. At this stage, the data are transferred to an HP work station where GSC-A proprietary grass4.1 routines are used to bin and grid the data values and convert them to georeferenced raster maps of seafloor topography.

2.2.2 GSC-A Ocean Mapping seafloor relief map production

Cleaned, georeferenced depth files were binned into 5x5m grid cells and an approximate average (note: at present, a running average of all values that fall in the cell is calculated rather than a true mean) depth of each cell is calculated using UNIX-based, USACERL grass4.1 Geographic Information System software. At GSC-A, a simplified Graphical User Interface (GUI) interface is used (AGCMENU), which is greatly enhanced with in-house swath bathymetric processing routines, additional menus and utility software.

Occasionally a 5x5 m cell would not contain any soundings and would show as a small gap in the data coverage. The data gaps were filled by calculating the average of the depth in each of 8 surrounding cells and applying it to the empty cell. This was repeated up to 4 times depending on the survey. Each survey region was colour-classified according to depth of the seafloor below sea level. A shaded relief image was created using a 45°sun elevation and a varied sun azimuth (to best enhance seafloor features in each surveyed area). The colour -classified rasters and shaded relief rasters were merged together to produce a final colour-shaded relief raster image and exported from Grass in a TIFF format. Final map production was done in Coreldraw 3.0 for Unix.

The figures included in this report are printed at a scale conveneient for inclusion and reproduction. They are intended to illustrate the size, location and general seafloor character at each target location. The amount of deatil evident in the figures will vary as a function of the size of the survey and the size of the feature. In some cases, it is diffiuclt to discewrn individual scour features (Figure 3, Figure 4, Figure 8). Future publications will include plots large enought to resolve the full seafloor detail.

2.3 SIDESCAN SONAR

The Simrad Mesotech 992 dual frequency (120 and 330 kHz) sidescan was used over a range of 300 m (600 m total swath). For this survey, the two 120 kHz channels (port and starboard) were used and digitized to Exabyte tape using AGC-DIG, a GSC-A developed 4 channel digital acquisition system. Hard copy records were collected using a 10 inch Alden 9315 thermal printer set to record the 120 kHz data in two channel print mode with auto-annotation.

2.4 CHIRP SUBBOTTOM PROFILER

This system was intended for use as a confirmation on the depth profile of the scour features. In typical geophysical investigations of ice scour features, the depth of the feature has ben extracted from the subbottom profiler.

Ultimately the CHIRP was only deployed once and for a limited time. This was primarily because of a shortage of available personnel to run 3 systems concurrently (swath, sidescan and CHIRP). No useful data was collected with the system. It was unable to penetrate the hard seafloor and was not operated across any scour features.

3.0 DESCRIPTION OF TARGET SURVEYS

3.1 O-90 Glory Hole

Background

In June of 1990, Petro-Canada attempted to drill and case a glory hole (the O-90 glory hole) for wellhead and BOP protection from iceberg scouring. The glory hole was partially excavated with a 7 m diameter Tornado drill, but it failed to achieve the targeted depth of 11 m. The 6m x 20m hole that was excavated has been the target of collaborative research by GSC-A and Petro-Canada in order to understand soil characteristics and their variability in the Terra Nova region (Sonnichsen and Zevenhuisen, 1996; Cameron and Sonnichsen, 1991). 'Hard pan' sediments described in past drilling operations have only been sampled and visually observed at this site (Coniglio, 1996). The glory hole has been monitored in 1990, 1994 and 1995 to look for evidence of sediment infill, transport and erosion to use as a quantitative analog for seafloor ice scour (pits and furrows), and the processes affecting their preservation on the seafloor.

The O-90 glory hole has been repetitively surveyed using sidescan sonar, subbottom profilers, ROV-mounted video and still photography.To date, no precise method was used for measuring the depth and size of the glory hole, therefore the EM100 survey was initiated to collect continuous depth measurements in and around the hole to determine its depth and shape. The hole also provided a small test target for use as a shake-down for the equipment and a chance to familiarize operators with the EM100.

Survey Summary

A series of ten lines, 3 km long and spaced 140 m apart were run at 9 knots over the glory hole. Two diagonal lines were run directly over the hole, the last of which was run in NARROW mode on the EM100. All other lines from 96-011 survey were run in WIDE mode as the swath coverage was too limiting in NARROW mode.

More than 600 000 soundings were collected in a 3x1 km^2 rectangle covering the O-90 glory hole and surrounding terrain. The soundings were imported into USL's CARIS Hydrographic Information Processing Software (HIPS) where they were corrected for predicted tides and depth-corrected water velocity variations. Ship's navigation were also reviewed and cleaned to remove obvious aberrant values. The corrected and cleaned soundings were then imported into GSC(Atlantic) Ocean Mapping Group's customized grass4.1 interface for further processing and display.

After experimenting with a variety of horizontal resolutions, the data were binned into 5x5 m cells and a running average of all soundings within that cell calculated. A maximum of all cells in a 3x3 m grid was also calculated but this did not change the dimensions or depth of the glory hole and introduced a lot of scatter and data gaps to the image. A raster image of the resulting mean depths per cell was created using GSC(Atlantic) Ocean Mapping software routines. The raster was then colour-classified in 1.0 m depth intervals. The classified image was then combined with a shaded relief map (45° sun elevation and 140° sun azimuth) to create a colour-shaded image of seafloor relief (Figure 2)

Observations

The glory hole is easily recognizable in the resulting shaded relief imagery (Figure 2). However, its dimensions become somewhat simplified when binned into a 5x5 m grid. The maximum depth (running average for each 5 m cell) recorded in the hole was 4.9 m deep. This is in good agreement with Sonnichsen and Zevenhuizen (1996) who reported a maximum depth of < 5 m from video observations. The surrounding seafloor is flat and largely featureless. One iceberg scour can vaguely be seen to the SE of the hole.

3.2 Terra Nova Seafloor Repetitive Mapping Area

Background

In 1988, GSCA and Petro-Canada established a series of 6 transects that were run with 70 kHz and 100 kHz sidescan to record seafloor sediments and features especially iceberg scours (Newfoundland Geosciences Ltd, 1988). In 1994 these lines were resurveyed, (as well as a series of E-W lines which covered the seafloor between the 1988 transects) in order to identify changes or additions to the existing ice scour population and to detect evidence for seafloor sediment mobility (Sonnichsen, 1994).

The 1988 and 1994 sidescan data were processed and analyzed jointly by GSCA and Canadian Seabed Research Ltd. (CSR, 1996) with funding provided by Petro-Canada. The result was a series of base maps detailing reflectivity boundaries of seafloor sediments, bedforms and seafloor features such as iceberg scour and anchor drags, and a database of measured parameters on 34 identified scours (width, length, shape, orientation). Sidescan data do not provide information on the depth of penetration of the scour below the seafloor, or changes in bathymetry over the length of the scour. All that was available from the 1988 and 1994 surveys were a few discrete passes over the iceberg scours with a Huntec Deep-Tow subbottom profiler, which had only recorded a measurable scour depth for a few of the 34 scours.

In an attempt to acquire the necessary depth information for the 34 identified ice scours, the sidescan mosaic area from 1994 was re-run with the EM100 system. The resulting seafloor relief imagery would also provide an opportunity to make a direct comparison to the information extracted from the sidescan mosaic in order to determine their relative abilities to identify scour features. The seafloor is not anticipated to have undegone significant erosion since 1994 based on the documented stability of the seafloor between 1988 and 1994.

Survey Summary

22 lines running WNW to ESE, 12.5 kilometres long, with a line spacing of 140 m were run at 9 knots. Then 2 diagonal lines were run NNE to SSW to survey a large scour that had been identified in the 1994 and 1988 sidescan imagery.

For the first 6 lines, the differentially corrected GPS positions provided by the HPC software were very jittery. This required considerable navigation editing and smoothing in the post-processing stage in HIPS. After rebooting the HDC computer, the navigation data became much more stable.

A 12x3 km rectangle covering the 1994 GSCA sidescan mosaic was surveyed with the EM100. Including the turn lines increased the coverage approximately 500 m east and west of the 1994 sidescan coverage. After removing spurious and mis-aligned depth values, sounding data were binned into a 5x5 m cells and a running average of all soundings within that cell calculated. A raster image of the resulting depth per cell was created using GSCA Ocean Mapping software routines. The raster was then colour-classified in 1.0 m depth intervals. The shaded raster image was created using a 45° sun elevation and a 140° sun azimuth (Figure 3).

Observations

The immediately striking feature is how flat the seafloor is in the Terra Nova region. There is a gradual overall increase of approximately 8 m in the seafloor depth, from 89 metres in the west to 97 m in the east. Small-scale relief on the order of 0.5 m is a correlatable with large-scale sand waves (CSR, 1996).

Figure 3 is too small-scale to identify all the seafloor features although four large pits and several large scour features are discernable at this resolution. At a lower scale, most of the scour features interpreted by CSR are identifiable, and measurements concerning the depth, width and length of features can be taken. However the scours have little appreciable depth (typically < 1m) and are only evident because of the colour-shaded enhancements and the linear coherence of the feature. Subtle mis-alignment of neighbouring soundings (1 or 2 decimetres) due to refraction errors in the processing are on the same scale as the depth of the scour features. Very precise measurements on width and depth of features may require more sophisticated processing to remove refraction errors in the soundings. Further work will determine the effectiveness in measuring features from the swath imagery and determine the need for further processing.

3.3 1994 4000 Series Repetitive Mapping Transects

Background

In 1994, GSCA developed a bench mark survey for future repetitive mapping surveys over the southeastern portion of the 1979 Mobil 4000 Series of sidescan transects (Geomarine, 1979). The area was chosen to take advantage of the 1979 sidescan data and a 1990 ESRF-sponsored resurvey of the original 4000 Series lines. In 1994, the original 10 lines were not resurveyed because of shiptime constraints. Instead, complete seabed coverage was attempted over a smaller subset of the lines to reduce the problem of remeasuring scours as separate features on individual lines. Three 4000 series lines (4007,4008,4009) were resurveyed for 35 km with a Simrad 992 dual frequency (120/330 kHz) sidescan and Huntec DTS. The resulting data were processed to create a continuous seafloor mosaic at 2m horizontal resolution. This was subsequently analyzed and interpreted using Arc/Info and grass4.1 software to create georeferenced databases of seafloor sediment distribution and seafloor character (SynMap, 1996). Based on that analysis a database of 192 unique scouring events were catalogued.

The site was chosen for EM100 surveys in order to

1) provide detailed seafloor topography data for the repetitive mapping site in order to determine changes in bedforms and sediment distribution over time
2) determine variations in morphology (width and depth variations, changes in orientation) over the length of individual scours
3) to compare the EM100's ability to resolve seafloor scour features to the Simrad 992 sidescan.

Survey Summary

Approximately 2/3 of the 1994 sidescan mosaic was successfully surveyed with the EM100 system. The survey was halted when repeated navigation system crashes made it impossible to collect data continuously along long lines.The survey recommenced near the end of the cruise but time ran out before all planned lines were completed. Ultimately, a series of 20 lines running WSW to ENE, 34 km long, with a line spacing of 140 m, were run at 9 knots.

Due to the size of the area surveyed, it was broken into 4 regions (ESRF1 to 4, west to east). The 4 resulting shaded raster image were created using a 45^{o} sun elevation and a 40^{o} sun azimuth and merged for final output (Figure 4).

Observations

At the scale illustrated in Figure 4, the detail necessary to identify small features is lacking (based on 5x5 m grid cells). Figure 4 is included to show the size, location and character of the seafloor over the 4000 lines; it is not intended for measurement or identification of features. However, a change in grade, and indications of some bedforms, furrows and pits are evident. There is an overall increase of approximately 45 m in the seafloor depth, from west to east. Abrupt, small changes in depth are associated with large-scale sandy bedforms. This is most evident in the western side of the survey region where well-developed sand ridges occur. The southern portion of the P-15 sand ridge on which the Hibernia GBS will be situated is evident in the SW portion of Figure 4.

Further work is required to compare the seabed features evident in the EM100 imagery to the features extracted from the sidescan mosaic (SynMap,1 996), but first indications are that the EM100 is a better tool for identifying pits. The EM100 also appears to be capable of resolving much smaller scours than anticipated.

3.4 Whiterose E-09 Scour Features

Background

An observed iceberg (Iceberg 88-01 with mass= ~ 1.9×10^6 tonnes; Husky Environmental Database) scouring and grounding event was interpreted to have occurred between April 9 and 13, 1988 near the Husky Whiterose E-09 well site based on rig supply boat reports (Banke, 1988). A subsequent sidescan survey (Banke, 1988; Woodworth-Lynas, 1989) attributed a 1 km scour to the 88-01 iceberg. This iceberg scour was resurveyed in 1990 to develop a case study observing changes over time: Any observed rate of degradation may then be applied to other scours in the same region to help determine the relative age of scour events.

During the 1988 survey of the Springdale E-09 wellsite area, three older larger scours (scours A,B, and C) were mapped and their depths were measured from the first return of the sidescan profile (Banke, 1988).

Survey Summary

21 lines running WSW to ENE, 11 km long, with a line spacing of 185 m, were run at 9 knots. The data were binned at a 5x5 m grid with a running mean of all depths recorded within the cell. A colour-classified raster (1.5 m intervals) and shaded relief raster (45° sun elevation and 315° sun azimuth) were combined to create a colour-shaded relief image (Figure 5).

Observations

The seafloor in the Whiterose region is relatively smooth and flat (Figure 5); it uniformly grades from 120 m in the west to 140 m in the east (grade is ~ 1 to 550 or 0.1°). The only apparent seafloor features are those generated by the effects of grounding icebergs.

The 88-01 iceberg mass is greater than 95 % of the icebergs predicted to drfit onto the Grand Banks shelf (Terra Nova Project, 1996). The 88-01 iceberg scoured the seafloor for approximately 900 m with a maximum depth (based on 5x5m averaged grid cells) of 2 - 2.5m. It is not as sinuous as previously portrayed but its length, width and depth are in fair accordance with Banke,1988. Also evident in the imagery (Figure 5) are Scours A and B and a portion of Scour C. Many other older scour features are present in the region surveyed. After a quick review of the raw 1988 sidescan data, it became apparent that not all of the scour features seen in the raw hardcopy sidescan records were mapped in the Banke report. Attempts are now being made to determine if any other interpretation of the sidescan data were made either by or for Husky, the sponsors of the initial 1988 survey. If not, a high priority should be placed on determining whether any observed features in the EM100 data were generated in the 8 years between the two surveys.

In this survey we see widely differing size populations of seabed ice scour features. Particularly striking is the narrow width and short length of the scour feature attributed to Berg 88-01 (a 1.9 million tonne iceberg) compared with Scour A,B,C and the other large furrows. At 120 m below seafloor, the Springdale wellsite is inferred to be below the effects of late Wisconsinan sea level which stood at -100 m below seafloor approximately 15 000 years before present. Thus the larger scours may be relict scours which were not created during the modern-day ice regime, but perhaps by larger icebergs that had calved from nearby ice sheets (Lewis et al, 1995). Alternatively, all the scour features may have been created during the modern iceberg regime which is inferred to have commenced ~2500 years ago, when the cold Labrador Current strengthened sufficiently to deliver icebergs to the Grand Banks (Lewis et al., 1995). If so, then widths,depths and lengths may depend as much on iceberg shape as on iceberg mass. Obviously for design purposes, it is important to distinguish the effects of relict icebergs from those of modern-day icebergs.

Also evident are a large number of broad shallow circular depressions which we interpret as degraded iceberg pits. The muted relief and absence of berms suggests they have been reworked and infilled although for how long is uncertain. Few if any of these are evident in previous sidescan imagery over the site. Again, initial impressions are that sidescan underestimates the number of pits, even relatively distinct features such as the pit located at 46° 51' N and 48° W in Figure 5.

3.5 Confirmation survey of 2 recent scours
(GBSC95 Scour_id's 1258, and 1260)

Background
Geonautics Ltd (1991), under funding provided by Environmental Studies Research Funds (ESRF), conducted an analysis of the 4000 Line Series repetitive mapping sidescan data collected in 1979 (Geomarine Ltd, 1980) and again in 1990 (Parrott and Sonnichsen, 1990). The primary objective was to identify any new scour events that had occurred in the intervening 11 years.

Only 2 potentially new scour events were identified over the ~700 line kilometres of repetitively surveyed seafloor. Scour_id 1258 was interpreted to be a crater-chain type scour with well-developed berms with crisp shadows on the sonograph record. It was classified as a new scour largely on its apparent clarity (or "freshness"): it was not evident on the original 1979 ORE data but difficulties in rerunning the line exactly may account for that. The scour is listed in the GBSC as having a depth of 4 m based on a seabed depression on the Huntec DTS which was aligned with the sidescan image of the new scour. This is considered an extreme depth for a recent feature on northeastern Grand Bank so it was considered important to confirm the geometry and depth of the new scour.

GBSC95 Scour_id 1260 is recorded as a new scour in the 1991 Geonautics database although there is no discussion of the feature in the report. In order to clarify whether the feature is in fact new, lines were oriented and extended somewhat to collect EM100 and sidescan data over Scour_id 1260 as part of the survey of scour_id 1258.

Survey Summary
EM100 data were collected at 9 knots along a series of 4 lines running WSW to ENE, 5 km long, with a line spacing of 205 m. The colour-shaded relief image was created using a 45° sun elevation, a 270° sun azimuth (Figure 6). 4 lines of sidescan and additional EM100 data were collected over this region in a subsequent survey.

Observations
The seafloor grades gently and uniformly from 132 m in the west to 142 m in the east (grade is 1 to 500 or ~ 0.11°). There is no obvious expression of any large-scale bedforms or other geomorphic features. As at Husky, the seafloor shows subtle shallow, circular depressions interpreted to be old, possibly relict scour pits. At least 4 other iceberg furrows are evident. None appear very clear or fresh; i.e there are no distinct shadows on the scour to suggest berms are sharp and blocky.

The feature interpreted to be GBSC95 Scour_id 1258 is visible at the northeast end of the imagery (~5208800 N, 726500 E)(Figure 6). It is unfortunate that data were not collected further to the south as it does not appear that the entire feature has been surveyed.This location is almost 500 metres offset from the GBSC95 coordinates for that feature but there are no other features that would be obvious candidates for Scour_id 1258. This can be partially explained by the lack of a layback correction in the GBSC95 database.

Scour 1258 does appear to be a crater-chain type scour as described in the GSBC95 database. In Figure 6, at that location there are three aligned features. The large pit-like depression at the northern end is not considered to be associated with scour 1258 because it appears smoother, more degraded and therefore older. Just to the south is a large circular pit 5.9 m deep with a distinct berm almost 2 m high, giving a total relief for the feature of almost 8 metres.Immediately south is a more elongated depression which extends off the imagery. It is 4.6 m deep with a 1 m berm. Both would be considered to have been created by the same iceberg because of their similar dimensions, orientation and character.

While more work will be needed to attempt to confirm its apparent young age, the very sharp clarity of its features suggest it has not been reworked or infilled, and it is obviously much younger than other features surrounding it.

3.6 Confirmation survey of 4 new craters
(GBSC95 Scour_id's 1269, 1270, 1271, 1272)

Background

In the course of the 1991 analysis of the 4000 Line Series repetitive mapping sidescan data (Geonautics, 1991), 4 circular pits were also interpreted as new scour features. The craters were catalogued separately, but may have been created by the same iceberg. Again, slight misalignment of the 1979 and 1990 survey lines resulted in a somewhat "uncertain interpretation of the craters as new" (Geonautics, 1991) but the very sharp, fresh character of the pits supported the classification of the craters as new. In the GBSC95 database, Scour_id's 1269, 1270, 1271 and 1272 do not have scour depths (Canadian Seabed Research Ltd., 1995) as they were not crossed with the subbottom profiler.

The EM100 swath bathy system and Simrad 992 sidescan were used to confirm the geometry and character of the 4 craters largely because the craters appear to be new events.

Survey Summary

EM100 data were collected at 9 knots along a series of 4 lines running SW to NE, 2.5 km long, with a line spacing of 175 m. 4 lines of sidescan data and additional EM100 data were then collected over the targets. The shaded raster image was created using a 45° sun elevation and a 45° sun azimuth (Figure 7).

Observations

The 4 pits show up very clearly in the EM100 data as four roughly circular depressions with well-pronounced berms (Figure 7, Table 1). 1272 appears to be associated with a short furrow on the southern edge of the pit. 1272 also has a small secondary pit on its eastern edge which may be related to the scour feature. 1269 is the largest and the deepest. It has smaller depressions on the north side of the crater which may be related to the furrow heading towards 1272. Scours 1270 and 1271 appear as isolated singular pits. To the east of the pits there is an apparently older scour which was measured to be 125 m wide and ~0.6 m deep. It has rounded, ill-defined berms, although the downslope berm is somewhat better defined.

The crater features are enigmatic; it is difficult to visualize the process that would cause 1 iceberg to create 4 such deep pits so close to each other without any connecting scour marks. However, it seems highly improbable that 4 separate icebergs would create such fresh-looking (i.e recently-formed) pits so close to each other.

GBSC95 scour_id	Depth avg,max	Width 1	Width 2	Upslope berm_ht	Downslope berm_ht
1269	4.5, 6	75	55	0.6	0.9
1270	1.5, 2.5	40		0.9, merged with 1269	0.35
1271	3,3.4	70		0	0.45
1272	2.8,3.5	60		0.2	??
Degraded furrow	0.6	125			

Table 1: Measured depths, widths and berm for 5 features identified on Figure 7

3.7 Texaco Springdale Scour 89-01

Background

Early in 1989, observations associated with drilling activities at the Texaco Springdale M-29 wellsite documented the grounding of a large 1.3 million tonne iceberg. Berg 001 drifted south out of the edge of the pack ice on March 9 and grounded in 112 m of water on March 10, 1989. It remained grounded for 45 days before drifting free on April 10 (Banke, 1989). The environmental conditions during the period of free drift,scouring and subsequent grounding have been compiled by Banke (1989), and include:

wind and currents measured at a nearby drill rig.
Pack ice extent from aerial reconnaissance
drift track of all bergs logged by the rig and supply boats
iceberg photographs and measurements
several 2D underwater profiles of Berg 001
towing records from the supply boats.

Approximately 15 kilometres of the inferred 20 km scour were surveyed by the Geological Survey of Canada only 11 days after the berg drifted free (Fader, 1989). At the northern end the scour is 20 m wide and its depth was not measurable on the Huntec DTS. The scour ends in a terminal pit at its southern end. The pit is estimated to be 90 m wide, with a depth of 5 m below the seafloor, and a berm rising 1 to 3 m above the seafloor A smaller pit-like feature (30 - 40 m was seen approximately 75 m northeast of the larger pit (Parrott et al, 1990).

The combination of the environmental data and the detailed seafloor surveys data for Berg 001 and the scours it created on the seafloor provide a significant case study in our understanding of the scour process and the mechanisms under which scours degraded or obliterated. The opportunity to collect EM 100 data over the scour provides valuable depth and relief information on the entire scour and any variations along its length.

Survey Summary

The Springdale 89-01 scour presented some difficulties in designing a suitable survey because of its long length and narrow width. A series of 3 lines running N to S, 25 km long, with a line spacing of 150 m, were run at 9 knots. Five passes were also run crossing the N S lines for confirmation of the presence of the scour. The shaded raster image was created using a 45° sun elevation and a 215° sun azimuth (Figure 8). Figure 8 illustrates the size of the survey and the general relief and depth of the seafloor but is not of sufficient scale to reveal much information on the 89-01 scour

Observations

The 89-01 survey was hampered by poor weather conditions and repeated navigation system breakdowns. Ultimately, there was insufficient time to conduct a large enough survey to ensure complete coverage of the 89-01 scour. That aside, the EM100 data did resolve the terminal pit (at 5174000 N in Figure 8) and confirmed that the furrow leading into the pit left little if any depression in the seafloor. An older scour first identified in 1989 is seen clearly but there is no visible relief evidence for the 89-01 furrow. Aside from the terminal pit, 4 other pits are seen in the relief imagery. Further work is require to say anything conclusive about how much of the 89-01 furrow was surveyed and whether there sit has any measurable depth.

3.8 Confirmation survey of GBSC95 Scour_id 2993

Background

The GBSC is comprised of many scours incorporated from pre-existing databases, the majority from the Mobil Scour Catalogue. The raw sidescan data that were the source of these scour measurements were often not accessible to the GSC. For some of the scour features with large reported depths, it was considered important to confirm the reported measurements and to augment the database with new information on their geometry and character. One of the targeted features in the GBSC was Scour_id 2993, incorporated from the Mobil Scour Catalogue from a 1980 survey by C-CORE on behalf of Mobil, entitled the 8000 Series survey. The feature is a pit in 106 m of water, 20 km from the Terra Nova field and 35 km from Hibernia with a reported depth of 6m.
A small EM 100 survey was targeted over the reported position of Scour_id 2993

Survey Summary

A series of 4 lines running W to E, 4 km long, with a line spacing of 150 m, were run at 9 knots. A diagonal pass was also run from NE to SW over the pit. The shaded raster image was created using a 45° sun elevation and a 40° sun azimuth (Figure 9)

Observations

EM100 data reveal 3 pits in the reported vicinity of Scour_id 2993. The deepest is considered to be 2993. It is measured to be 6 m deep, and 94 m across E-W and 100 m across N-S. There is a distinct berm 0.8 m in height on the eastern edge. The EM100 depth is in exact agreement (6m) with the GBSC95 depth which was recorded from Huntec.

A shallower pit of approximately the same dimensions is visible about 150 m north of 2993, and a smaller pit is seen approximately 70 m NE of 2993. Older sidescan will be examined to see whether the features were missed or not interpreted as pits. All three appear as isolated pits with no lead-in furrows observed.

3.9 GBSC95 Scour_id's 565 (Bowers Pit),3030 and 575

Background

In October, 1980, a circular seabed depression 5.4 m deep and 100 m wide was identified from Huntec DTS sub-bottom profiler data, approximately 11 km east of the Hibernia P-15 well location. The location subsequently became the target of research into the origin and significance of seabed iceberg pits. In 1984 and 1985, HMCS Cormorant returned with the SDL_1 manned submersible to investigate the pit. It was informally named Bowers Pit after the Captain R. Bowers of HMCS

Cormorant. Davidson et al., 1991 provides a detailed description of the many geophysical, geological and geotechnical investigations centred on Bowers Pit. Barrie (1986) from direct submersible measurements describes the pit as an amphitheatre-like depression, 125 m long, 45 m wide and up to 10 m below the seafloor at its deepest. The scour furrow leading into Bowers Pit is recorded as 100 m wide, 3 km long and its depth averages about 1.5 m below seafloor. It is reported to be degraded in the sandier sediments and with well-developed berms in the more gravelly portions of the seafloor. The EM100 survey was intended to confirm the depth and geometry measurements for both the pit and lead-in scour recorded by submersible and Huntec DTS and sidescan.

At the same time, a confirmation survey was carried out on GBSC scour_id 3030, a 6 m crater only identified in the Mara well site survey 4 km due east of Bowers Pit. As the Mara site survey data is unavailable to GSC, it was worthwhile to confirm the pits existence and the reported depth in GBSC95 which was imported from the Mobil Ice Scour Catalogue (Nordco Ltd, 1984). Sidescan data were collected at 300 m range over select lines in order to mosaic the seafloor over Bowers Pit and Scour_id 3030.

The final survey during 96-011 was conducted over a 5.3 m pit approximately 6 km south of Bowers Pit. In the GBSC95 database, it was reported as an iceberg scour or furrow rather than a crater. In response to a query from Petro-Canada, the original 1988 GSCA sidescan data were reviewed. It was somewhat ambiguous because of poor sidescan imagery, but was re-interpreted as a crater rather than a furrow. It was decided to take the opportunity during 96-011 to collect EM100 data and Simrad 992 sidescan in order to confirm the type of scour feature and its depth.

Survey Summary

A series of 11 lines running W to E, 5.5 km long with a line spacing of 140 m were run at 9 knots over Bower's pit and scour_id 3030. A transit line was run to the south for 5 km and then 6 passes were run from NNE to SSW over scour_id 575. The resulting shaded raster image was created using a 45° sun elevation and a 135° sun azimuth (Figure 10)

Observations

Based on EM100 imagery, Bowers Pit is 150 m long, 80 m wide, and up to 9 m deep. It is by far the largest feature identified on top of the Grand Bank. It is a terminal pit for a very wide, distinct lead-in furrow. The lead-in furrow was measured in two transects, each 40 m wide. On the southern transect, the scour was 90 m wide, 1 m deep, with asymmetric berms (0.3 m on the upslope (west) side, 0.8 m on the downslope (east). On the northern transect, the scour was 80 m wide, 0.7 m deep, with symmetric berms 0.3 m high on either side.

The terrain around Bowers Pit is surprisingly quite heavily scoured. Future comparison to the recorded scours within GBSC95 and review of existing sidescan data will determine whether the features were previously identified. Much of the survey falls within the bounds of the Mara wellsite survey conducted by Geonautics for Mobil Oil in 1980. It would be interesting to compare existing seabed data to that collected in 1980.

Scour_id 3030 is evident in Figure 10 as an isolated pit 5.9 m deep and 100 m N-S and 120 m across E-W. It has a 1 metre berm on the east and west flanks and approximately a 0.5 m berm on the southern flank. It is located in 106 m water depth. A prominent furrow is seen just to the north of Scour_id 3030 in Figure 10.

Scour _id 575 is located in 90 metres of water (Figure 10). It is an elliptical pit 130 m long (NNW-SSE) , 65 m across (ENE-WSW) and a maximum of 6.3 metres deep. A berm approximately 0.8 m high is evident on the eastern side of the pit.

4.0 SUMMARY AND CONCLUSIONS

Many of the described observations are preliminary and need further study. However, based on the first GSC swath bathymetric survey on the Grand Banks, we can say the following:

1) Swath bathymetry is an effective tool for measuring the relief, shape and depth characteristics of subtle seafloor ice scour features characteristic of Grand Bank. Depth, width and berm variations over an entire scour or pit are measurable to within a couple decimetres.

2) The major constraint to data quality appears to be minor variations in positional accuracy, and limits on the ability of the shipboard electronics to correct for the motion of the vessel. Principally, it is the aesthetics of the seabed relief imagery that suffer rather than the systems's ability to resolve features.

3) Advantages to swath bathymetry in comparison to sidescan as an ice scour mapping tool are 1) The data is absolutely positioned in relation to the ship's antenna which removes the difficulty and uncertainty of layback corrections and towfish positioning; 2) The data is motion-compensated which greatly reduces beam positioning errors; 3) The data does not have to be corrected for geometric distortions; 4) The data provides high vertical resolution depth and relief information on the scours, the most critical parameter necessary for design considerations; 5) The data results in simple x,y,z soundings which are relatively easy to manipulate and query quantitatively.

   The above features must be weighed against certain advantages of the sidescan data, namely 1) the sidescan backscatter data gives a semi-quantitative measure on seabed texture (grain size) and micro-relief; 2) the sidescan data can resolve features on the scale of a few metres; whereas the EM100 will only resolve features with dimensions greater than ~ 10 m by 10 metres; 3) sidescan is a much more readily available and inexpensive tool with plenty of historical data for comparison while EM100 is still expensive and totally new to northeastern Grand Bank.

4) Somewhat surprisingly, depths on extreme pits measured from the swath data are in fair agreement with GBSC depth estimates based on subbottom profiler data. Scour_id 2993 (6.0 in GBSC, 6 m from swath); Scour_id 575 (6.0 in GBSC, 6.3 m from swath)Scour_id 3030 (6.0 in GBSC, 5.9 m from swath)

5) A preliminary comparison of the scour features identified from the swath data versus the features previously identified from sidescan data suggests that the sidescan underestimates the number of pits.

6) There is good potential for future use of swath bathymetric surveys to determine whether 2 populations of scour exist on Grand Bank; and also to characterize recent features from older degraded features based on slope and relief measurements.

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APPENDIX 1 SUMMARY OF SURVEY LINES

APPENDIX 2 LINE NUMBER START/ STOPS

LINE NUMBER	START DAY/TIME	STOP DAY/TIME	EM100 DATA	SIDESCAN DATA	CHIRP DATA
100	165/0844	165/0848	X		
101	165/0855	165/0908	X		
102	165/0915	165/0925	X		
103	165/0932	165/0944	X		
104	165/0950	165/1000	X		
105	165/1007	165/1019	X		
106	165/1026	165/1037	X		
107	165/1044	165/1057	X		
108	165/1058	165/1113	X		
109	165/1113	165/1117	X		
110	165/1117	165/1121	X		
111	165/1121	165/1127	X		
112	165/1128	165/1131	X		
113	165/1131	165/1134	X		
114	165/1135	165/1203	X		
115	165/1204	165/1210	X		
116	165/1211	165/1254	X		
117	165/1254	165/1301	X		
118	165/1301	165/1341	X		
119	165/1341	165/1350	X		
120	165/1350	165/1433	X		
121	165/1433	165/1440	X		
122	165/1440	165/1520	X		
123	165/1520	165/1526	X		
124	165/1526	165/1558	X		
125	165/1712	165/1737	X		
126	165/1737	165/1804	X		
127	165/1804	165/1812	X		
128	165/1812	165/1854	X		
129	165/1854	165/1900	X		
130	165/1900	165/1945	X		
131	165/1945	165/1951	X		
132	165/1951	165/2031	X		
133	165/2031	165/2037	X		
134	165/2037	165/2119	X		
135	165/2119	165/2125	X		
136	165/2125	165/2208	X		
137	165/2208	165/2214	X		
138	165/2214	165/2255	X		
139	165/2255	165/2302	X		
140	165/2302	165/2344	X		
141	165/2344	165/2350	X		
142	165/2350	166/0029	X		
143	166/0029	166/0034	X		
144	166/0034	166/0116	X		
145	166/0116	166/0122	X		

LINE NUMBER	START DAY/TIME	STOP DAY/TIME	EM100 DATA	SIDESCAN DATA	CHIRP DATA
147	166/0202	166/0208	X		
148	166/0208	166/0252	X		
149	166/0252	166/0300	X		
150	166/0300	166/0343	X		
151	166/0343	166/0350	X		
152	166/0350	166/0434	X		
153	166/0434	166/0441	X		
154	166/0441	166/0523	X		
155	166/0523	166/0532	X		
156	166/0532	166/0614	X		
157	166/0614	166/0622	X		
158	166/0622	166/0706	X		
159	166/0706	166/0755	X		
160	166/0755	166/0816	X		
161	166/0816	166/0822	X		
162	166/0822	166/0840	X		
163	166/0840	166/0854	X		
164	166/0854	166/1014	X		
165	166/1014	166/1037	X		
166	166/1037	166/1210	X		
167	166/1210	166/1359	X		
168	166/1359	166/1404	X		
169	166/1404	166/1440	X		
170	166/1440	166/1630	X		
171	166/1630	166/1638	X		
172	166/1638	166/1834	X		
173	166/1834	166/1841	X		
174	166/1841	166/2041	X		
175	166/2041	166/2046	X		
176	166/2046	166/2238	X		
177	166/2238	166/2314	X		
178	166/2314	166/2320	X		
179	166/2320	167/0126	X		
180	167/0126	167/0133	X		
181	167/0133	167/0319	X		
182	167/0319	167/0326	X		
183	167/0326	167/0510	X		
184	167/0525	167/0545	X		
185	167/0545	167/0550	X		
186	167/0550	167/0551	X		
187	167/0603	167/0641	X		
188	167/0641	167/0648	X		
189	167/0648	167/0840	X		
190	167/0840	167/0847	X		
191	167/0847	167/1100	X		
192	167/1100	167/1105	X		
193	167/1105	167/1253	X		
194	167/1253	167/1259	X		
195	167/1259	167/1512	X		
196	167/1512	167/1519	X		

LINE NUMBER	START DAY/TIME	STOP DAY/TIME	EM100 DATA	SIDESCAN DATA	CHIRP DATA
249	169/0123	169/0127	X		
250	169/0127	169/0133	X		
251	169/0133	169/0138	X		
252	169/0138	169/0144	X		
253	169/0144	169/0148	X		
254	169/0210	169/0216		X	
255	169/0229	169/0241		X	
256	169/0253	169/0304		X	
257	169/0318	169/0327		X	
258	169/0330	169/0401		X	
259	169/0443	169/0513		X	
260	169/0533	169/0603		X	
261	169/0619	169/0649		X	
262	169/0848	169/1035	X		
263	169/1035	169/1046	X		
264	169/1046	169/1125	X		
265	169/1124	169/1139	X		
266	169/1335	169/1351	X		
267	169/1351	169/1400	X		
268	169/1400	169/1409	X		
269	169/1409	169/1417	X		
270	169/1417	169/1428	X		
271	169/1428	169/1435	X		
272	169/1435	169/1443	X		
273	169/1558	169/1748	X		
274	169/1801	169/1924	X		
275	169/1924	169/1928	X		
276	169/2030	169/2056	X		
277	169/2056	169/2205	X		
278	169/2205	169/2224	X		
279	169/2224	169/2237	X		
280	169/2237	169/2243	X		
281	169/2243	169/2255	X		
282	169/2255	169/2302	X		
283	169/2302	169/2314	X		
284	169/2314	169/2321	X		
285	169/2321	169/2333	X		
286	169/2333	170/0007	X		
287	170/0007	170/0116	X		
288	170/0116	170/0122	X		
289	170/0122	170/0138	X		
290	170/0138	170/0145	X		
291	170/0145	170/0204	X		
292	170/0204	170/0211	X		
293	170/0211	170/0227	X		
294	170/0227	170/0234	X		
295	170/0234	170/0254	X		
296	170/0254	170/0300	X		
297	170/0300	170/0316	X		
298	170/0316	170/0337	X		

LINE NUMBER	START DAY/TIME	STOP DAY/TIME	EM100 DATA	SIDESCAN DATA	CHIRP DATA
300	170/0343	170/0351	X		
301	170/0351	170/0407	X		
303	170/0415	170/0434	X		
304	170/0434	170/0441	X		
305	170/0441	170/0456	X		
306	170/0456	170/0505	X		
307	170/0505	170/0525	X		
308	170/0525	170/0615	X		
309	170/0615	170/0814	X		
310	170/0814	170/0820	X		
311	170/0820	170/1024	X		
312	170/1024	170/1030	X		
313	170/1030	170/1124	X		
314	170/1124	170/1207	X	X	
315	170/1207	170/1233	X	X	
316	170/1233	170/1243	X	X	
317	170/1243	170/1311	X	X	
318	170/1311	170/1322	X	X	
319	170/1322	170/1351	X	X	
320	170/1351	170/1403	X	X	
321	170/1403	170/1441	X	X	X
322	170/1441	170/1452	X	X	X
323	170/1452	170/1500	X	X	X
324	170/1500	170/1509	X	X	X
325	170/1509	170/1515	X	X	X
326	170/1515	170/1528	X	X	X
327	170/1528	170/1534	X	X	X
328	170/1534	170/1558	X	X	X
329	170/1558	170/1601	X	X	X
330	170/1601	170/1609	X		X
331	170/1609	170/1610	X		
332	170/1610	170/1634	X		

APPENDIX 3 DIGITAL SIDESCAN AND CHIRP DATA

AGCDig Digital Tapes (Exabyte)

SIMRAD 992 SIDESCAN

Note:
SIMRAD 992 SSS, Ch 0-120-L, Ch 1-120-R (300 metre range)

TAPE	START Day/Time	STOP Day/Time	Scour Target	Line #'s
1	168/1856	168/2146	Husky Scour	235 - 237
2	169/0210	169/0651	Craters and Pnewsc	254 - 261
3	170/1124	170/1601	565, 3030, 575	314 - 329

CHIRP SUBBOTTOM PROFILER

TAPE	START Day/Time	STOP Day/Time	Scour Target	Line #'s
1	170/1412	170/1450	Pit 575	322-323

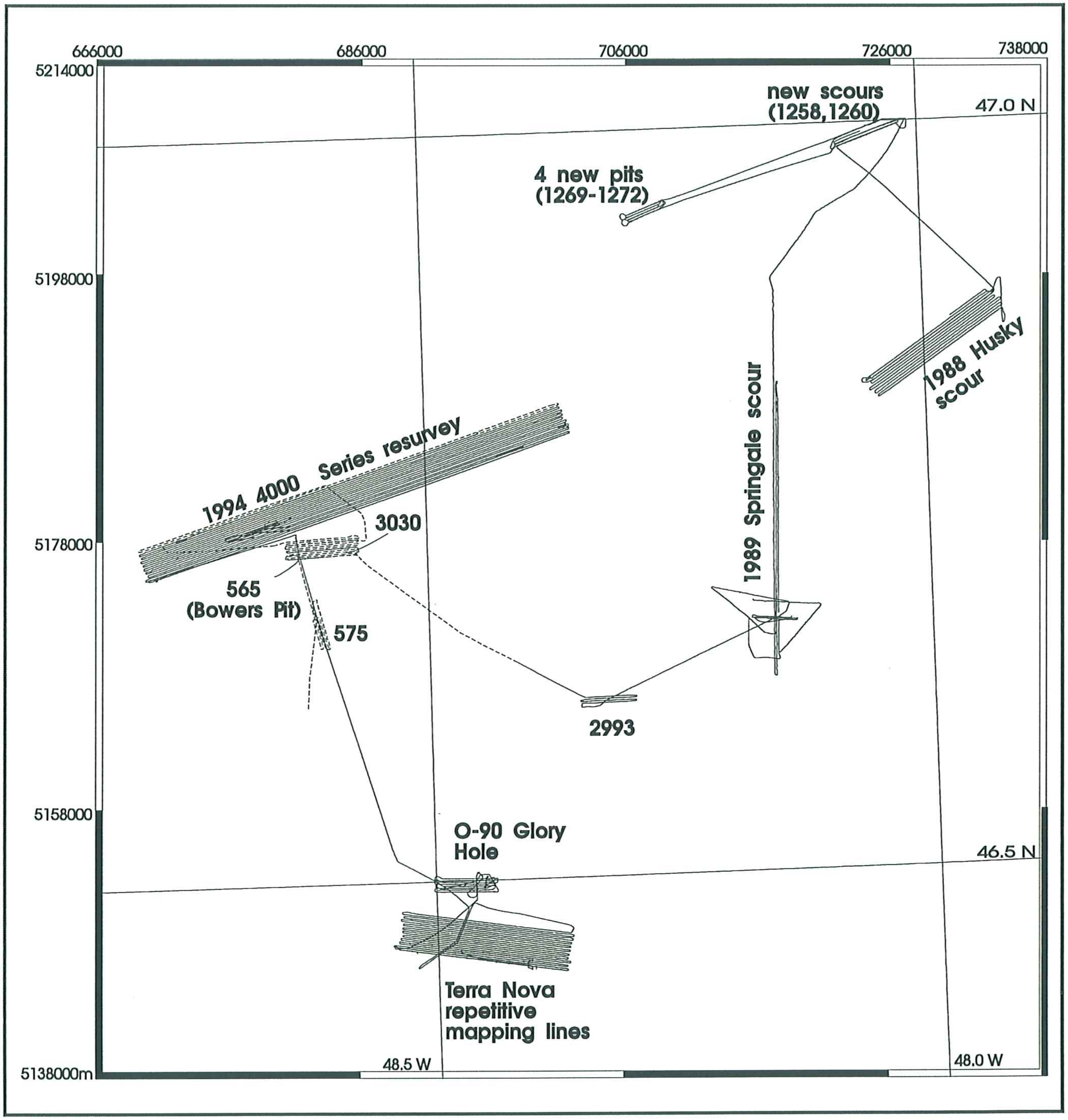
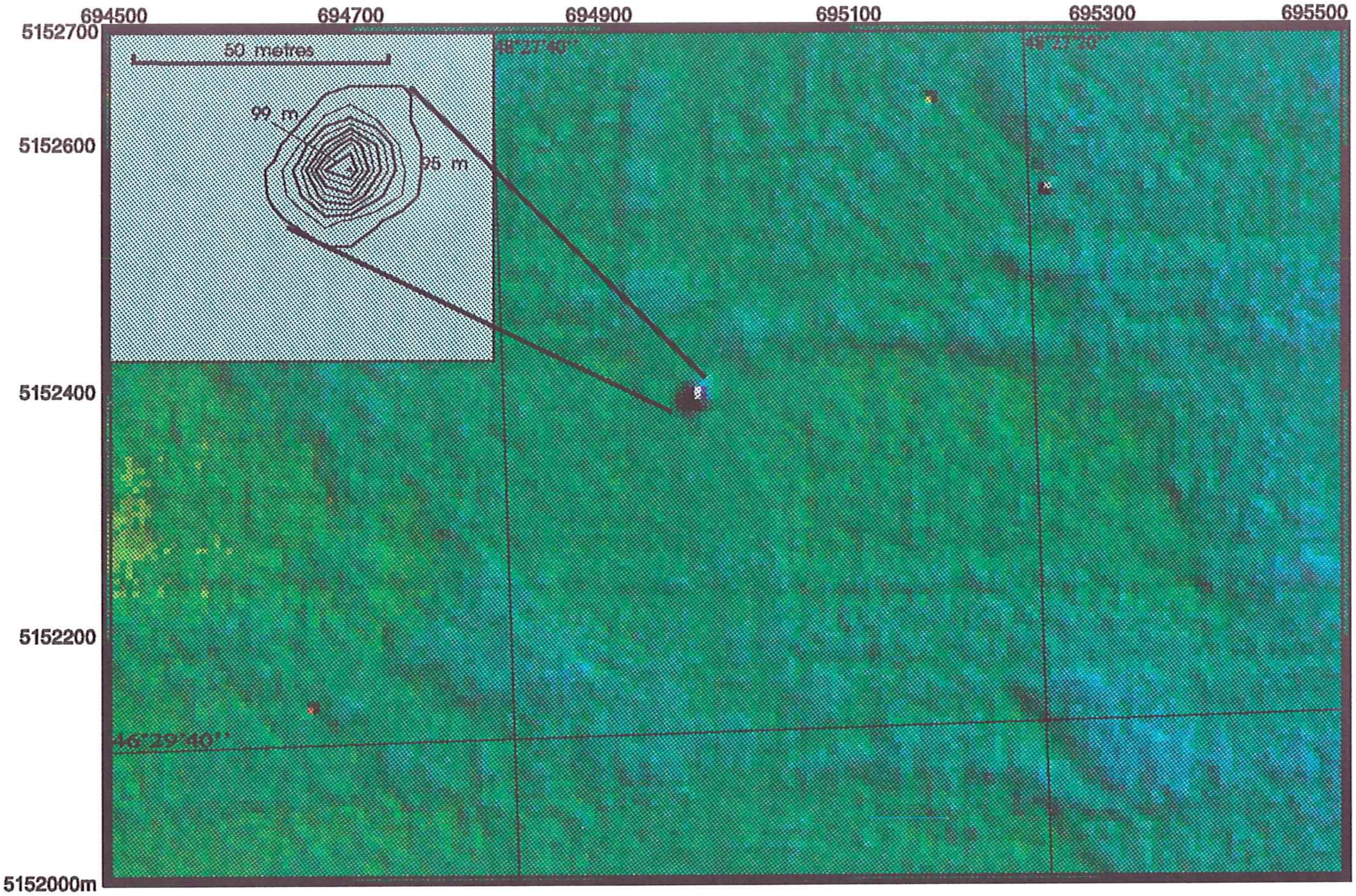


Figure 1: 96-011 CSS Matthew Track Plot
Numbers refer to Grand Banks Scour Catalogue (GBSC92) Scour_id



Matthew 96-011 Swath Bathymetric Surveys - northeastern Grand Bank

O-90 Glory Hole

The depth values are corrected for predicted tides and sound velocity variations through the water column. The average depth is calculated (as a running mean) per 5x5 m grid cell.

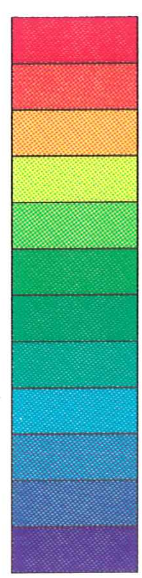
Colour-shaded raster image created using GSC-Atlantic Ocean Mapping Grass 4.1 software.

Colours represent the depth of the sea floor below sea level in 0.5 m increments.

Shading created usingt a 45° sun elevation and a 225° sun azimuth.

UTM Zone 22
C.M. 51° W
NAD 83

Legend:



Scale:

Geological Survey of Canada - Atlantic

Figure 2